Grade 11 Physics (30S)

A Course for
Independent Study

Manitoba

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A Course for Independent Study

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Introduction

INTRODUCTION

Overview

Welcome to Grade 11 Physics: A Course for Independent Study.

Grade 11 Physics deals with basic concepts that will form the foundation concepts necessary for you to study physics in the future. You have already studied many concepts in physics. For example, in Grade 9 Science you studied electricity. In Grade 10 Science you studied motion of vehicles and passengers, specifically how and why they move. We will be referring to concepts that you have studied in the past as the new concepts that you will be studying are introduced. In turn, the concepts that you learn in Grade 11 Physics will prepare you for Grade 12 Physics.

As a student enrolled in an independent study course, you have taken on a dual role—that of a student and a teacher. As a student, you are responsible for mastering the lessons and completing the learning activities and assignments. As a teacher, you are responsible for checking your work carefully, noting areas in which you need to improve and motivating yourself to succeed.

What Will You Learn in This Course?

In this course, you will use scientific and technology-related knowledge to understand and interpret their environment. You will develop your mathematical, and analytical skills and demonstrate the application of the scientific method through viewing laboratory videos. Laboratory activities have an important role to play in any science course which reflects the nature of the discipline.

How Is This Course Organized?

The Grade 11 Physics course consists of four major topics. The four major topics are broken down into modules for a total of ten modules. The breakdown of topics and modules is shown below:

Topic 1: Mechanics

- Module 1: Kinematics
- Module 2: Vectors
- Module 3: Dynamics

Topic 2: Fields

- Module 4: Gravitational Fields
- Module 5: Electric Fields
- Module 6: Magnetic Fields and Electromagnetism

Topic 3: Waves

- Module 7: Waves in One Dimension
- Module 8: Waves in Two Dimensions

Topic 4: Sound and Light

- Module 9: Sound
- Module 10: Models, Laws, and Theories, and the Nature of Light

Each module in this course consists of several lessons, which contain the following components:

- **Lesson Focus:** The Lesson Focus at the beginning of each lesson identifies one or more specific learning outcomes (SLOs) that are addressed in the lesson. The SLOs identify the knowledge and skills you should have achieved by the end of the lesson. (For a complete list of the SLOs identified for Grade 12 Physics refer to Appendix D at the end of this course.)
- **Key Words:** This list identifies the important words that are used in the lesson. The key words are highlighted in bold within the text and identified by key word icons. They are defined in the Glossary at the end of the course in Appendix B.
- **Introduction:** The introduction sets the stage for the lesson. It may draw upon prior knowledge or briefly describe the organization of the lesson.
- **Lesson:** The main body of the lesson is made up of the content that you need to learn. It contains explanations, diagrams, and fully completed examples.
- **Learning Activities:** Most lessons include one or more learning activities that will help you learn about the lesson topics and prepare you for the assignments, the midterm examination, and the final examination. Once you complete a learning activity, check your responses against those provided in the Learning Activity Answer Key found at the end of the module. Do not send your learning activities to the Distance Learning Unit for assessment.
- **Assignments:** Assignments are found throughout each module within this course. At the end of each module, you will mail or electronically submit all your completed assignments from that module to the Distance Learning Unit for assessment. All assignments combined will be worth a total of 50 percent of your final mark in this course.

- **Video Files:** Some lessons refer to the *Grade 12 Physics (30S) Laboratory Activities* video files, which you are required to view for this course.
- **Summary:** Each lesson ends with a brief review of what you just learned.

This course also includes the following section:

- **Appendices:** At the end of the course, you will find four appendices, which contain information that is required for the course or that could be useful in helping you to complete the course. Here is a list of the appendices found at the end of the course:
  - **Appendix A: Equation Sheet** contains a list of equations grouped according to the topics addressed in this course. This list of equations will be provided with the exams that you will be writing. It is imperative that you learn which concept each equation refers to, the quantity associated with each symbol, and its unit of measurement.
  - **Appendix B: Glossary** defines terms used within this course.
  - **Appendix C: Kinematics Graphs Transformation Organizer**
  - **Appendix D: List of Specific Learning Outcomes** contains the complete list of SLOs to be achieved in Grade 11 Physics. You will not be using this appendix. It has been placed here to help classroom teachers who are using this course as a resource.

What Resources Will You Need for This Course?

You do not need a textbook for this course. All the content is provided directly within the course. You will, however, need access to a variety of resources.

The required resources for this course are identified below.

Required Resources

For this course, you will need access to the following resources. If you do not have access to one or more of these resources, contact your tutor/marker.

- **A calculator:** Use a graphing or scientific calculator as you work through this course. You will also need the calculator for the examination(s).
- **Equipment to view video files:** You will need equipment to view the *Grade 11 Physics (30S) Laboratory Activities* video files.

Electronic Resources

For this course, you will need the following electronic resource. If you do not have access to the Internet, or if you need a copy of the resource, contact the Distance Learning Unit at 1-800-465-9915.

- **Video(s):** You will have an opportunity to view the *Grade 11 Physics (30S) Laboratory Activities* video files, available in the learning management system (LMS). If you do not have access to the Internet or if you need a copy of the video, contact the Distance Learning Unit at 1-800-465-9915.

Optional Resources

It would be helpful if you had access to the following resources:

- **Photocopier/scanner:** With access to a photocopier/scanner, you could make a copy of your assignments before submitting them so that if your tutor/marker wants to discuss an assignment with you over the phone, each of you will have a copy. It would also allow you to continue studying or to complete further lessons while your original work is with the tutor/marker. Photocopying or scanning your assignments will also ensure that you keep a copy in case the originals are lost.
- **Resource people:** Access to local resource people, such as teachers, school counsellors, and librarians, would help you complete the course.
- **A computer with spreadsheet software:** Access to spreadsheet software (e.g., Microsoft Excel) would help you to present and analyze data graphically.
- **A computer with Graphical Analysis software:** This software will help you to produce and analyze graphs. If you do not have access to this software and you are attending school, ask your ISO school facilitator how you can obtain access. If you are not attending school, you will have received the software with the course.

- **A computer with Internet access:** Some lessons suggest website links as sources of information or for supplementary reference and reading. If you do not have Internet access, you will still be able to complete the course, but you will need to find different ways of accessing information.

Who Can Help You with This Course?

Taking an independent study course is different from taking a course in a classroom. Instead of relying on the teacher to tell you to complete a learning activity or an assignment, you must tell yourself to be responsible for your learning and for meeting deadlines. There are, however, two people who can help you be successful in this course: your tutor/marker and your learning partner.

Your Tutor/Marker

Tutor/markers are experienced educators who tutor Independent Study Option (ISO) students and mark assignments and examinations. When you are having difficulty with something in this course, contact your tutor/marker, who is there to help you. Your tutor/marker's name and contact information were sent to you with this course. You can also obtain this information in the learning management system (LMS).

Your Learning Partner

A learning partner is someone **you choose** who will help you learn. It may be someone who knows something about physics, but it doesn't have to be. A learning partner could be someone else who is taking this course, a teacher, a parent or guardian, a sibling, a friend, or anybody else who can help you. Most importantly, a learning partner should be someone with whom you feel comfortable and who will support you as you work through this course.

Your learning partner can help you keep on schedule with your coursework, read the course with you, check your work, look at and respond to your learning activities, or help you make sense of assignments. You may even study for your examination(s) with your learning partner. If you and your learning partner are taking the same course, however, your assignment work should not be identical.

How Will You Know How Well You Are Learning?

You will know how well you are learning in this course by how well you complete the learning activities, assignments, and examinations.

Learning Activities

The learning activities in this course will help you to review and practise what you have learned in the lessons. You will not submit the completed learning activities to the Distance Learning Unit. Instead, you will complete the learning activities and compare your responses to those provided in the Learning Activity Answer Key found at the end of each module.

Make sure you complete the learning activities. Doing so will not only help you to practise what you have learned, but will also prepare you to complete your assignments and the examinations successfully. Many of the questions on the examinations will be similar to the questions in the learning activities. **Remember that you will not submit learning activities to the Distance Learning Unit.**

Assignments

Lesson assignments are located throughout the modules and include questions similar to the questions in the learning activities of previous lessons. The assignments have space provided for you to write your answers on the question sheets. You need to show all your steps as you work out your solutions, and make sure your answers are clear (include units, where appropriate).

Once you have completed all the assignments in a module, you will submit them to the Distance Learning Unit for assessment. The assignments are worth a total of 50 percent of your final course mark. You must complete each assignment in order to receive a final mark in this course. You will mail or electronically submit these assignments to the Distance Learning Unit along with the appropriate cover page once you complete each module.

For some assignments, you will need to view the video *Grade 11 Physics (30S) Laboratory Activities*, gather data from the video, and write a laboratory report.

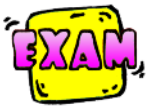
The video contains the following laboratory activities:

- *Kinematics*
- *Dynamics*
- *The Tangent Galvanometer*
- *The Magnetic Field of a Solenoid (Current Balance)*
- *Snell's Law*
- *Resonance and the Speed of Sound*
- *The Particle Model of Light*

You will submit the laboratory reports, along with the other assignments, to the Distance Learning Unit for assessment.

The tutor/marker will mark your assignments and return them to you. Remember to keep all marked assignments until you have finished the course so that you can use them to study for your examinations.

Midterm and Final Examinations



The course contains a midterm examination and a final examination.

- The **midterm examination** is based on Modules 1 to 6 and is worth 20 percent of the final mark for the course. You will write the midterm examination when you have completed Module 6.
- The **final examination** is based on Modules 1 to 10, and is worth 30 percent of your final mark in this course. Most of the final exam (25% of your final mark) is based on Modules 7 to 10. A small portion of it (5% or your final mark) is based on Modules 1 to 6. You will write the final examination when you have completed Module 10.

The two examinations are worth a total of 50 percent of your final course mark. You will write both examinations under supervision.

To do well on each examination, you should review all the work you have completed from the modules, including all learning activities and assignments.

Practice Examinations and Answer Keys

To help you succeed in your examinations, you will have an opportunity to complete a Midterm Practice Examination and a Final Practice Examination. These examinations, along with the answer keys, are found in the learning management system (LMS). If you do not have access to the Internet, contact the Distance Learning Unit at 1-800-465-9915 to obtain a copy of the practice examinations.

These practice examinations are similar to the actual examinations you will be writing. The answer keys enable you to check your answers. This will give you the confidence you need to do well on your examinations.

Requesting Your Examinations

You are responsible for making arrangements to have the examinations sent to your proctor from the Distance Learning Unit. Please make arrangements before you finish Module 5 to write the midterm examination. Likewise, you should begin arranging for your final examination before you finish Module 10.

To write your examinations, you need to make the following arrangements:

- **If you are attending school,** your examination will be sent to your school as soon as all the applicable assignments have been submitted. You should make arrangements with your school's ISO school facilitator to determine a date, time, and location to write the examination.
- **If you are not attending school,** check the Examination Request Form for options available to you. Examination Request Forms can be found on the Distance Learning Unit's website, or look for information in the learning management system (LMS). Two weeks before you are ready to write the examination, fill in the Examination Request Form and mail, fax, or email it to

  Distance Learning Unit
  500–555 Main Street
  PO Box 2020
  Winkler MB R6W 4B8
  Fax: 204-325-1719
  Toll-Free Telephone: 1-800-465-9915
  Email: distance.learning@gov.mb.ca

How Much Time Will You Need to Complete This Course?

Learning through independent study has several advantages over learning in the classroom. You are in charge of how you learn and you can choose how quickly you will complete the course. You can read as many lessons as you wish in a single session. You do not have to wait for your teacher or classmates.

From the date of your registration, you have a maximum of **12 months** to complete this course, but the pace at which you proceed is up to you. Read the following suggestions on how to pace yourself.

Chart A: Semester 1

If you want to start this course in September and complete it in January, you can follow the timeline suggested below.

Module	Completion Date
Module 1	Middle of September
Module 2	End of September
Modules 3 and 4	Middle of October
Modules 5 and 6	Middle of November
Midterm Examination	End of November
Modules 7 and 8	Middle of December
Modules 9 and 10	Beginning of January
Final Examination	End of January

Chart B: Semester 2

If you want to start this course in February and complete it in May, you can follow the timeline suggested below.

Module	Completion Date
Module 1	Middle of February
Module 2	End of February
Modules 3 and 4	Beginning of March
Modules 5 and 6	Middle of March
Midterm Examination	Beginning of April
Modules 7 and 8	Middle of April
Modules 9 and 10	Beginning of May
Final Examination	Middle of May

Chart C: Full School Year (Not Semestered)

If you want to start this course in September and complete it in May, you can follow the timeline suggested below.

Module	Completion Date
Module 1	End of September
Module 2	End of October
Modules 3 and 4	Middle of December
Modules 5 and 6	Middle of January
Midterm Examination	End of February
Modules 7 and 8	End of March
Modules 9 and 10	End of April
Final Examination	Middle of May

Timelines

Do not wait until the last minute to complete your work, since your tutor/marker may not be available to mark it immediately. It may take a few weeks for your tutor/marker to assess your work and return it to you or your school.

> If you need this course to graduate this school year, all coursework must be received by the Distance Learning Unit on or before the first Friday in May, and all examinations must be received by the Distance Learning Unit on or before the last Friday in May. Any coursework or examinations received after these deadlines may not be processed in time for a June graduation. Assignments or examinations submitted after these recommended deadlines will be processed and marked as they are received.

Why Is the Course so Large?

This course package includes all the things you would find in a regular face-to-face physics course taught in a classroom, such as the following:

- all the information that is normally found in a textbook
- all the notes that a teacher would hand out in class
- all the assignments that a teacher would hand out in class
- all the learning activities that a teacher would hand out in class, along with their answer keys
- all the explanations and instructions that a teacher would either say or write on a blackboard or whiteboard

This course also contains many diagrams and graphs, which tend to take up more room than straight text. This makes the course seem larger than it actually is.

When and How Will You Submit Completed Assignments?

When to Submit Assignments

While working on this course, you will submit completed assignments to the Distance Learning Unit six times. The following chart shows you exactly what assignment you will be submitting at the end of each module.

Submission of Assignments	
Submission	Assignments You Will Submit
1	**Module 1: Kinematics** Module 1 Cover Sheet Assignment 1.1: Part A: Symbolic Mode Part B: Significant Digits Part C: Scalars and Vectors Part D: Position-Time Graph 1 Assignment 1.2: Video Laboratory Activity: Kinematics Assignment 1.3: Part A: Acceleration-Time Graph Part B: Position-Time Graph 2 Part C: Constant Velocity and Acceleration
2	**Module 2: Vectors** Module 2 Cover Sheet Assignment 2.1: Part A: Drawing Vectors Part B: Sketching Vectors Part C: Adding Vectors Assignment 2.2: Vector Journey
3	**Module 3: Dynamics / Module 4: Gravitational Fields** Module 3/Module 4 Cover Sheet Assignment 3.1: Video Laboratory: Dynamics Part A: Free-Body Diagrams Part B: Dynamics and Kinematics Part C: The Vector Nature of Newton's Second Law Assignment 4.1: Part A: Gravitational Fields Part B: Mass, Weight, and Weightlessness Assignment 4.2: Laboratory Activity: Determining Acceleration Due to Gravity Assignment 4.3: Part A: Free Fall Part B: Friction

Submission of Assignments (continued)	
Submission	Assignments You Will Submit
4	**Module 5: Electric Fields / Module 6: Magnetic Fields and Electromagnetism** Module 5/Module 6 Cover Sheet Assignment 5.1: Electric Fields Assignment 5.2: Part A: Calculating Electric Field and Electric Force Part B: The Parallel Plate Apparatus Part C: The Millikan Drop Experiment Assignment 6.1: Part A: Magnetic Fields Part B: The Earth's Magnetic Field Part C: Electromagnetism Assignment 6.2: Video Laboratory Activity: The Tangent Galvanometer Assignment 6.3: Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance) Assignment 6.4: Forces on Currents in a Magnetic Field
5	**Module 7: Waves in One Dimension / Module 8: Waves in Two Dimensions** Module 7/Module 8 Cover Sheet Assignment 7.1: Part A: Transverse Waves and Longitudinal Waves Part B: Reflection and Transmission of Waves in One Dimension Part C: Wave Interference and Standing Waves in One Dimension Part D: Resonant Frequency and Harmonics Assignment 8.1: Waves in Two Dimensions—Reflection Assignment 8.2: Video Laboratory Activity: Snell's Law Assignment 8.3: Part A: Waves in Two Dimensions—Refraction Part B: Waves in Two Dimensions—Diffraction Part C: Waves in Two Dimensions—Interference
6	**Module 9: Sound / Module 10: Models, Laws, and Theories, and the Nature of Light** Module 9/Module 10 Cover Sheet Assignment 9.1: Part A: The Nature of Sound Part B: Beats and Resonance Part C: The Doppler Effect Assignment 9.2: Video Laboratory Activity: Resonance and the Speed of Sound Assignment 9.3: Music and Noise Assignment 10.1: The Scientific Method, Laws, Theories, and Models Assignment 10.2: Video Laboratory Activity: The Particle Model of Light Assignment 10.3: Part A: The Nature of Light and Newton's Corpuscular Theory Part B: Determining the Speed of Light Part C: Wave Theory of Light Part D: Young's Experiment Assignment 10.4: The Photoelectric Effect and Wave-Particle Duality

How to Submit Assignments

In this course, you have the choice of submitting your assignments either by mail or electronically.

- **Mail:** Each time you **mail** something, you must include the print version of the applicable Cover Sheet (found at the end of this Introduction). Complete the information at the top of each Cover Sheet before submitting it along with your assignments.
- **Electronic submission:** You do not need to include a cover sheet when submitting assignments electronically.

Submitting Your Assignments by Mail

If you choose to mail your completed assignments, please photocopy/scan all the materials first so that you will have a copy of your work in case your package goes missing. You will need to place the applicable module Cover Sheet and assignment(s) in an envelope, and address it to

Distance Learning Unit
500–555 Main Street
PO Box 2020
Winkler MB R6W 4B8

Your tutor/marker will mark your work and return it to you by mail.

Submitting Your Assignments Electronically

Assignment submission options vary by course. Sometimes assignments can be submitted electronically and sometimes they must be submitted by mail. Specific instructions on how to submit assignments were sent to you with this course. In addition, this information is available in the learning management system (LMS).

If you are submitting assignments electronically, make sure you have saved copies of them before you send them. That way, you can refer to your assignments when you discuss them with your tutor/marker. Also, if the original hand-in assignments are lost, you are able to resubmit them.

Your tutor/marker will mark your work and return it to you electronically.

Note

The Distance Learning Unit does not provide technical support for hardware-related issues. If troubleshooting is required, consult a professional computer technician.

What Are the Guide Graphics For?

Guide graphics appear in the margins of the course to identify specific tasks. Each graphic has a specific purpose, as described below:

Lesson Focus/Specific Learning Outcomes SLOs): Note that these SLOs will be addressed within the lesson. (A complete list of the Grade 12 Physics SLOs can be found in the Appendix at the end of this course.)

Internet: Use the Internet, if you have access to it, to obtain more information. Internet access is optional for this course.

Learning Partner: Ask your learning partner to help you with this task.

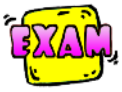
Phone Your Tutor/Marker: Telephone your tutor/marker.

Learning Activity: Complete a learning activity. This will help you to review or practise what you have learned and to prepare for an assignment or an examination. You will not submit learning activities to the Distance Learning Unit. Instead, you will compare your responses to those provided in the Learning Activity Answer Key found at the end of the applicable module.

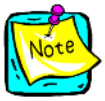
Assignment: Complete an assignment. You will submit your completed assignments to the Distance Learning Unit for assessment at the specified times.

Video: View a video.

Mail or Electronic Submission: Mail or electronically submit your completed assignments to the Distance Learning Unit.



Examination: Write your midterm or final examination at this time.



Note: Take note of and remember this important information or reminder.

Remember: If you have questions or need help at any point during this course, contact your tutor/marker or ask your learning partner for help.

Good luck with this course!

NOTES

Grade 11 Physics (30S)

Module 1 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

Drop-off/Courier Address

Distance Learning Unit
555 Main Street
Winkler MB R6W 1C4

Mailing Address

Distance Learning Unit
500–555 Main Street
PO Box 2020
Winkler MB R6W 4B8

Contact Information

Legal Name: _____ Preferred Name: _____

Phone: _____ Email: _____

Mailing Address: _____

City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 1 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 1.1: Part A: Symbolic Mode	_____ /5	_____ /5
Part B: Significant Digits	_____ /5	_____ /5
Part C: Scalars and Vectors	_____ /5	_____ /5
Part D: Position-Time Graph 1	_____ /5	_____ /5
❑ Assignment 1.2: Video Laboratory Activity: Kinematics	_____ /20	_____ /20

continued

Grade 11 Physics (30S)

Module 1 Cover Sheet *(continued)*

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 1 Assignments *(continued)*	**Attempt 1**	**Attempt 2**
Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	_____ Date Received	_____ Date Received
❑ Assignment 1.3: Part A: Acceleration-Time Graph	_____ /6	_____ /6
Part B: Position-Time Graph 2	_____ /6	_____ /6
Part C: Constant Velocity and Acceleration	_____ /6	_____ /6
	Total: ____ **/58**	**Total:** ____ **/58**

For Tutor/Marker Use
Remarks:

Grade 11 Physics (30S)

Module 2 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Module 2 Assignments	**Attempt 1**	**Attempt 2**
Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	_____ Date Received	_____ Date Received
❑ Assignment 2.1: Part A: Drawing Vectors	_____ /5	_____ /5
Part B: Sketching Vectors	_____ /5	_____ /5
Part C: Adding Vectors	_____ /10	_____ /10
❑ Assignment 2.2: Vector Journey	_____ /16	_____ /16
	Total: ____ **/36**	**Total:** ____ **/36**

For Tutor/Marker Use
Remarks:

Grade 11 Physics (30S)

Modules 3 and 4 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Modules 3 and 4 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 3.1: Video Laboratory: Dynamics	_____ /20	_____ /20
❑ Assignment 3.2: Part A: Free-Body Diagrams	_____ /5	_____ /5
Part B: Dynamics and Kinematics	_____ /5	_____ /5
Part C: The Vector Nature of Newton's Second Law	_____ /8	_____ /8
❑ Assignment 4.1: Part A: Gravitational Fields	_____ /4	_____ /4
Part B: Mass, Weight, and Weightlessness	_____ /5	_____ /5

continued

Grade 11 Physics (30S)

Modules 3 and 4 Cover Sheet *(continued)*

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Modules 3 and 4 Assignments *(continued)*	**Attempt 1**	**Attempt 2**
Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	_____ Date Received	_____ Date Received
❑ Assignment 4.2: Laboratory Activity: Determining Acceleration Due to Gravity	_____ /20	_____ /20
❑ Assignment 4.3: Part A: Free Fall	_____ /5	_____ /5
Part B: Friction	_____ /5	_____ /5
	Total: ____ **/77**	**Total:** ____ **/77**

For Tutor/Marker Use
Remarks:

Grade 11 Physics (30S)

Modules 5 and 6 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Modules 5 and 6 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 5.1: Electric Fields	_____ /5	_____ /5
❑ Assignment 5.2: Part A: Calculating Electric Field and Electric Force	_____ /5	_____ /5
Part B: The Parallel Plate Apparatus	_____ /5	_____ /5
Part C: The Millikan Drop Experiment	_____ /6	_____ /6
❑ Assignment 6.1: Part A: Magnetic Fields	_____ /5	_____ /5
Part B: The Earth's Magnetic Field	_____ /5	_____ /5
Part C: Electromagnetism	_____ /5	_____ /5

continued

Grade 11 Physics (30S)

Modules 5 and 6 Cover Sheet *(continued)*

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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City/Town: _____ Postal Code: _____

Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Modules 5 and 6 Assignments *(continued)*	**Attempt 1**	**Attempt 2**
Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	_____ Date Received	_____ Date Received
❑ Assignment 6.2: Video Laboratory Activity: The Tangent Galvanometer	_____ /20	_____ /20
❑ Assignment 6.3: Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance)	_____ /20	_____ /20
❑ Assignment 6.4: Forces on Currents in a Magnetic Field	_____ /5	_____ /5
	Total: ____ **/81**	**Total:** ____ **/81**

For Tutor/Marker Use
Remarks:

Grade 11 Physics (30S)

Modules 7 and 8 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use		For Office Use Only	
Modules 7 and 8 Assignments Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.		**Attempt 1** _____ Date Received	**Attempt 2** _____ Date Received
❑ Assignment 7.1:	Part A: Transverse Waves and Longitudinal Waves	_____ /5	_____ /5
	Part B: Reflection and Transmission of Waves in One Dimension	_____ /10	_____ /10
	Part C: Wave Interference and Standing Waves in One Dimension	_____ /5	_____ /5
	Part D: Resonant Frequency and Harmonics	_____ /5	_____ /5
❑ Assignment 8.1:	Waves in Two Dimensions—Reflection	_____ /5	_____ /5
❑ Assignment 8.2:	Video Laboratory Activity: Snell's Law	_____ /20	_____ /20

continued

Grade 11 Physics (30S)

Modules 7 and 8 Cover Sheet *(continued)*

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Modules 7 and 8 Assignments *(continued)*	**Attempt 1**	**Attempt 2**
Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	_____ Date Received	_____ Date Received
❑ Assignment 8.3: Part A: Waves in Two Dimensions—Refraction	_____ /7	_____ /7
Part B: Waves in Two Dimensions—Diffraction	_____ /5	_____ /5
Part C: Waves in Two Dimensions—Interference	_____ /5	_____ /5
	Total: ____ **/67**	**Total:** ____ **/67**

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Remarks:

Grade 11 Physics (30S)

Modules 9 and 10 Cover Sheet

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use		For Office Use Only	
Modules 9 and 10 Assignments		**Attempt 1**	**Attempt 2**
Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.		_____ Date Received	_____ Date Received
❑ Assignment 9.1:	Part A: The Nature of Sound	_____ /4	_____ /4
	Part B: Beats and Resonance	_____ /6	_____ /6
	Part C: The Doppler Effect	_____ /5	_____ /5
❑ Assignment 9.2:	Video Laboratory Activity: Resonance and the Speed of Sound	_____ /20	_____ /20
❑ Assignment 9.3:	Music and Noise	_____ /5	_____ /5
❑ Assignment 10.1:	The Scientific Method, Laws, Theories, and Models	_____ /5	_____ /5
❑ Assignment 10.2:	Video Laboratory Activity: The Particle Model of Light	_____ /20	_____ /20

continued

Grade 11 Physics (30S)

Modules 9 and 10 Cover Sheet *(continued)*

Please complete this sheet and place it on top of your assignments to assist in proper recording of your work. Submit the package to:

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Mailing Address: _____

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Attending School: ❑ No ❑ Yes

School Name: _____

Has your contact information changed since you registered for this course? ❑ No ❑ Yes

Note: Please keep a copy of your assignments so that you can refer to them when you discuss them with your tutor/marker.

For Student Use	For Office Use Only	
Modules 9 and 10 Assignments *(continued)*	**Attempt 1**	**Attempt 2**
Which of the following are completed and enclosed? Please check (✓) all applicable boxes below.	_____ Date Received	_____ Date Received
❑ Assignment 10.3: Part A: The Nature of Light and Newton's Corpuscular Theory	_____ /5	_____ /5
Part B: Determining the Speed of Light	_____ /5	_____ /5
Part C: Wave Theory of Light	_____ /5	_____ /5
Part D: Young's Experiment	_____ /7	_____ /7
❑ Assignment 10.4: The Photoelectric Effect and Wave-Particle Duality	_____ /5	_____ /5
	Total: ____ **/92**	**Total:** ____ **/92**

For Tutor/Marker Use
Remarks:

Released 2019

Printed in Canada
Imprimé au Canada

Grade 11 Physics (30S)

Topic 1: Mechanics

Topic 1: Mechanics

Introduction to Topic 1

The first topic in this course is mechanics which deals with the relationships between matter, force, and energy, especially as they affect the motion of objects. Mechanics is broken up into two parts—kinematics and dynamics.

In Module 1, you learn the principles of kinematics—a description of motion itself. Module 2 deals with vectors. Although vectors does not fall into either kinematics or dynamics, you need to understand vectors in order to study dynamics. Vectors are types of number that indicate not only magnitude (like all other numbers), but also direction. Module 3, the study of dynamics, explains why motion occurs the way it does. This involves an understanding of the forces that act on objects.

NOTES

Grade 11 Physics (30S)

Module 1: Kinematics

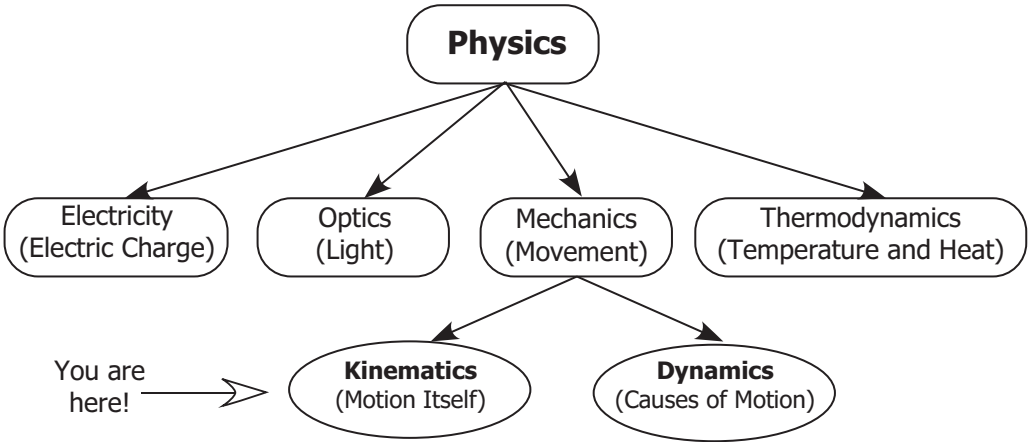
This module contains the following

- Introduction to Module 1
- Lesson 1: Introduction to Physics
- Lesson 2: Working with Vectors, Scalars, and Significant Figures
- Lesson 3: Terms for Describing Motion
- Lesson 4: The Position-Time Graph and Velocity
- Lesson 5: Analyzing Velocity-Time Graphs using Slope
- Lesson 6: Analyzing Motion Graphs using Area
- Lesson 7: Deriving Equations for Motion Involving Uniformly Accelerated Motion
- Lesson 8: Constant Velocity and Acceleration: Problem Solving
- Module 1 Summary

Module 1: Kinematics

Introduction to Module 1

Welcome to the first module of Grade 11 Physics. The first lesson of this module is an introduction to physics. In Lesson 2, you will be working with vectors, scalars, and significant figures. In the third lesson, you will learn about terms for describing motion. Lesson 4 deals with the position-time graph and velocity. In Lesson 5, you will analyze velocity-time graphs using slope. In Lesson 6, you will analyze motion graphs using area. In Lesson 7, you will derive equations for motion involving uniformly accelerated motion. The final lesson deals with solving problems dealing with constant velocity and acceleration.



Assignments in Module 1

When you have completed the assignments for Module 1, submit your completed assignments to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 1.1, Part A	Symbolic Mode
2	Assignment 1.1, Part B	Significant Digits
3	Assignment 1.1, Part C	Scalars and Vectors
4	Assignment 1.1, Part D	Position-Time Graph 1
5	Assignment 1.2	Video Laboratory Activity: Kinematics
5	Assignment 1.3, Part A	Acceleration-Time Graph
6	Assignment 1.3, Part B	Position-Time Graph 2
7	There are no assignments in Lesson 7.	
8	Assignment 1.3, Part C	Constant Velocity and Acceleration

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Lesson 1: Introduction to Physics (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe what physics is
- list and describe the four modes of representation
- describe a relationship among variables using the four modes of representation

Key Words

physics	visual mode	numerical mode
graphical mode	symbolic mode	variables
independent variable	dependent variable	constant
line of best fit	slope	

Introduction

This first lesson will provide you with a description of the meaning of physics, which is not as easy as it might seem. This lesson will also examine the different ways that we look at things in physics. One way of describing things in physics is to use equations. Your understanding of the concepts of physics will come from analyzing a situation using a variety of methods that we call **modes of representation**. It is only through the process of looking at a situation from a variety of angles (or "modes") that a full understanding can be achieved. This course will employ a variety of these modes of representation.

What is Physics?

This question does not have a simple answer, or, rather, it has a simple answer but that answer by itself is not very helpful. If you look up physics in a dictionary or even in the back of a physics textbook, you will usually find an unhelpful statement, such as: "physics is the study of the properties and relationships between matter and energy." While this is not wrong, it doesn't really help you understand what it is. So to help understand what physics is, let's take a backwards approach.

In school, science is often divided into three main parts, or **disciplines**. They are physics, chemistry, and biology. Of the three, most people have at least a beginning understanding of biology—it is the "study of living things." Most people also know that chemistry concerns itself with "chemicals"—what they are made up of and how they interact with each other. While these descriptions of biology and chemistry are not very complete, they are at least a beginning. It is rare that people are able to provide even such a rudimentary definition of physics. So here is the *first* way that you can think of physics: physics is the *rest of science* after chemistry and biology have been accounted for.

You probably already know at least approximately what "science" is all about. For example, you are likely aware that the following things can be learned about in science and are therefore a part of science:

- The production of lightning and thunder
- The inner workings of the heart
- How rainbows are produced
- The rusting of certain metals
- Gravity
- How plants produce food
- The burning of gasoline

In this list, the item "inner workings of the heart" clearly involves life and is therefore best considered to be a part of biology, as is the item on "how plants produce food." The "rusting of certain metals" and the "burning of gasoline" involve the behaviours and interactions of different kinds of substances, and so are considered to be part of chemistry. All of the other items are physics!

It might seem silly identifying physics as "the rest of science," but historically this is pretty much how what we now call physics came to be.

The following points are summarized from the section "From Philosophy to Physics" in the book *The Search for Knowledge* by Isaac Asimov:

- In ancient times, there was no such thing as science, and certainly no physics, chemistry, or biology. Instead there were "philosophers" who were literally "lovers of wisdom."
- Some philosophers studied natural phenomena and were referred to as "natural philosophers," which is essentially what we would now think of as "scientists."
- The Greek word for "natural" is "physikos"—so physics was initially considered to be the same as "science."
- When people eventually specialized into specific areas of study, these areas were given their own names (mathematics, astronomy, geology, chemistry, and biology) and were removed from the topic of "physics."
- What we now call physics is what remains after the above have been removed.
- Splitting up science into separate areas is artificial, and in fact these areas tend to blend into each other.

Why Study Physics?

People are likely to give you different answers to this question because each might value different things. So here are several answers to this question in no particular order. Note that these are not necessarily *all* the answers!

1. Asking why one would study physics is like asking why one would learn how to draw, to play an instrument, or to play a sport. Sure, there *might* be a life-changing benefit (maybe you will get fabulously rich by becoming a famous artist/musician/athlete), but it is also perfectly acceptable to pursue these activities just for interest and fun. Many people actively doubt this about physics, preferring instead to think of physics as being very dull and certainly not something that could ever be "fun." Of course, some of these same people are fascinated to learn about such things as electricity, black holes, curve balls, and holograms—all of which involve physics. In other words, knowledge of physics helps to satisfy our natural curiosity about the world around us—everything from tsunamis to forensics.
2. Studying physics is necessary or, at least, strongly recommended for certain careers, such as engineers, medical doctors, dentists, pilots, meteorologists, and, of course, physicists.

3. Understanding physics can also be very practical, often when you least expect it. For example, understanding basic physics concepts can help you make more informed choices when buying many things (such as stereos, computers, and even cars), or how to get better mileage from your car.
4. A good foundation in physics can go a long way toward helping you understand other topics you may find interesting, such as chemistry, biology, computers, astronomy, geology, and music.

The Four Modes of Representation

If you consider the various branches of physics and the underlying principles, a common theme exists:

> Physics is the study of relationships in the world we perceive around us.

However, those relationships are embedded in a social and historical context—a set of lenses through which the relationships are perceived and acted upon. For example, we contemplate "something interesting," and then build models to identify fundamental characteristics to determine how they interact and influence each other. From these relationships, we are able to predict the behaviour of other "interesting things" that have the same or similar parameters. A major component of physics, then, is the study of relationships in a variety of different forms.

These different modes of representation are the different ways we look at a situation and the different ways we can represent the relationships within that situation. The more modes of representation we use, the better we will understand those relationships—that is, the physics that underlines that situation.

Mode Number 1: Visual

Have you ever been bored and played with an elastic band? You likely noticed that the more you pull, the more the band stretches. This is a simple experiment whose results can be expressed in words so that you get a picture in your mind of what is happening.

> Because it gives you a picture in your mind, it is an example of the **visual mode** of representation.

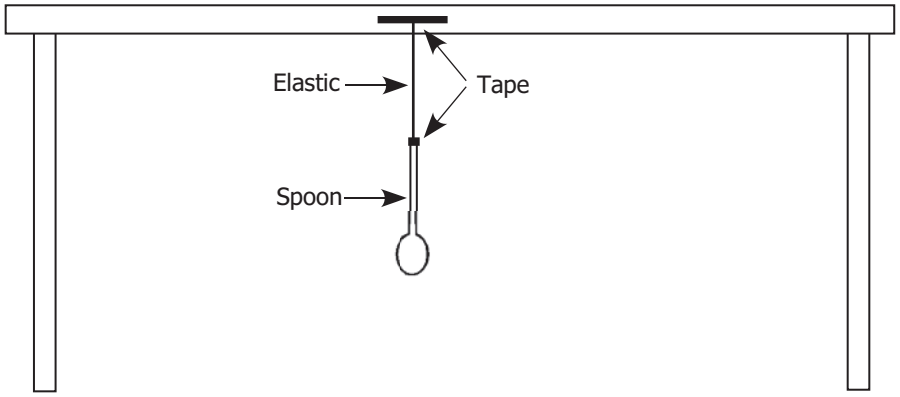
Sometimes this is also called a **qualitative** description because it describes the quality of the event. Qualities include things like pull and stretch.

For the remainder of this lesson, you will need the following things:

1. a thin elastic band cut once to make an elastic "string"
2. tape (transparent, masking, or duct will do)
3. a 30-cm ruler
4. five metal tablespoons.

Test your elastic string to be sure you can stretch it a bit and it will not break. Then tape one end to the edge of a table or counter so that the other end will hang over the edge and be a fair bit above the ground.

Visual Mode of Representation



Now we are ready to move on to the next mode.

Mode Number 2: Numerical

To get a more exact relationship between pull and stretch, we must collect data or numbers. This is called a quantitative description. In the **numerical** mode of representation, we must define the measurements and use equipment to collect the data.

> The **numerical mode** describes the relationship using numbers.

The data can then be examined to determine an exact relationship. There are basically three kinds of data:

1. **constants**—values that are the same during the experiment
2. **independent variables**—values that are set by the experimenter
3. **dependent variables**—values that are measured during the experiment

In our case, the elastic string is a constant. The number of tablespoons is the independent variable. The amount the elastic stretches will be the dependent variable.

Now that the string is taped to the edge of a table or countertop:

1. Place a piece of tape on the string about 10 cm down from the edge of the table.
2. Measure the exact length with the ruler and record it in the table below in the space with a (*).
3. Tape one spoon to the string so that the end of the handle is on the top edge of the piece of tape.
4. Let the spoon hang freely and measure the string length from the table edge to the tape mark (spoon handle top), and record this information in the table.
5. Tape another spoon on top of the first, just as they rest together inside a drawer.
6. Measure the length, record information in the table, and repeat until you have used all four spoons. Hopefully, the whole thing will not pull off the table before you are finished!

Number of Spoons	String Length (cm)	Stretch (cm)
0	(*)	0
1		
2		
3		
4		

Now calculate the amount the string stretched for each spoon added. You will do this by subtracting the original length, (*) amount, from each length. Consider the example below:

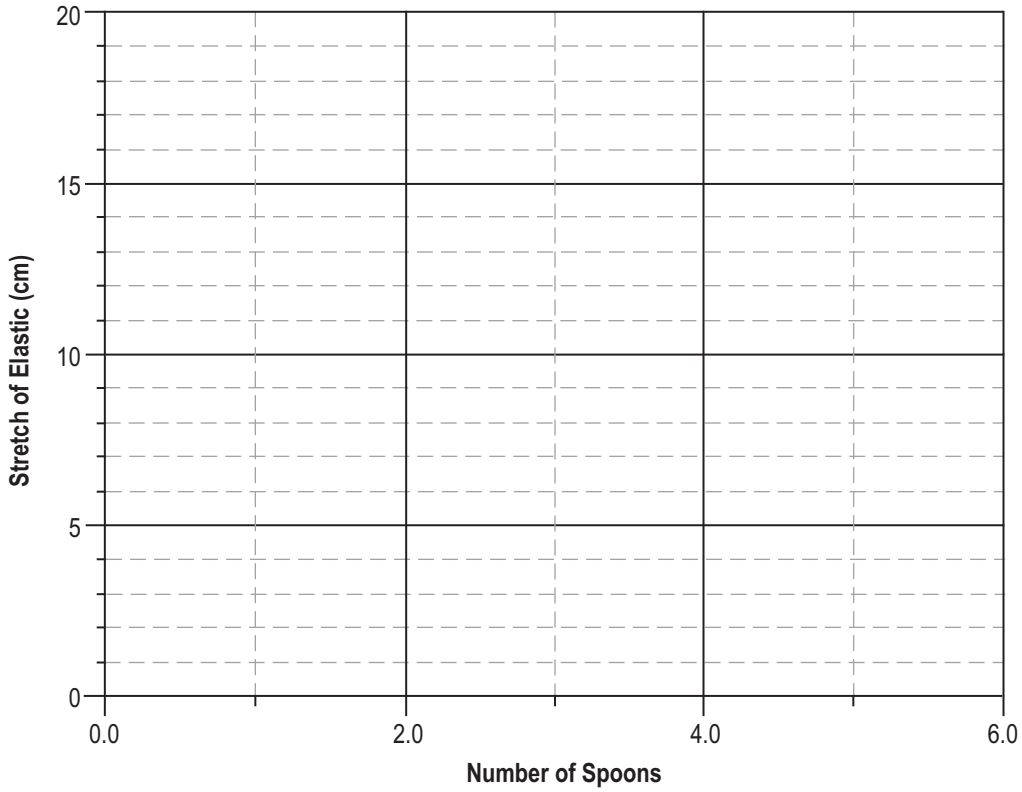
Number of Spoons	String Length (cm)	Stretch (cm)
0	(*) 9.7	0
1	12.0	2.3
2	14.2	4.5
3	16.6	6.9
4	18.9	9.2

Mode Number 3: Graphical

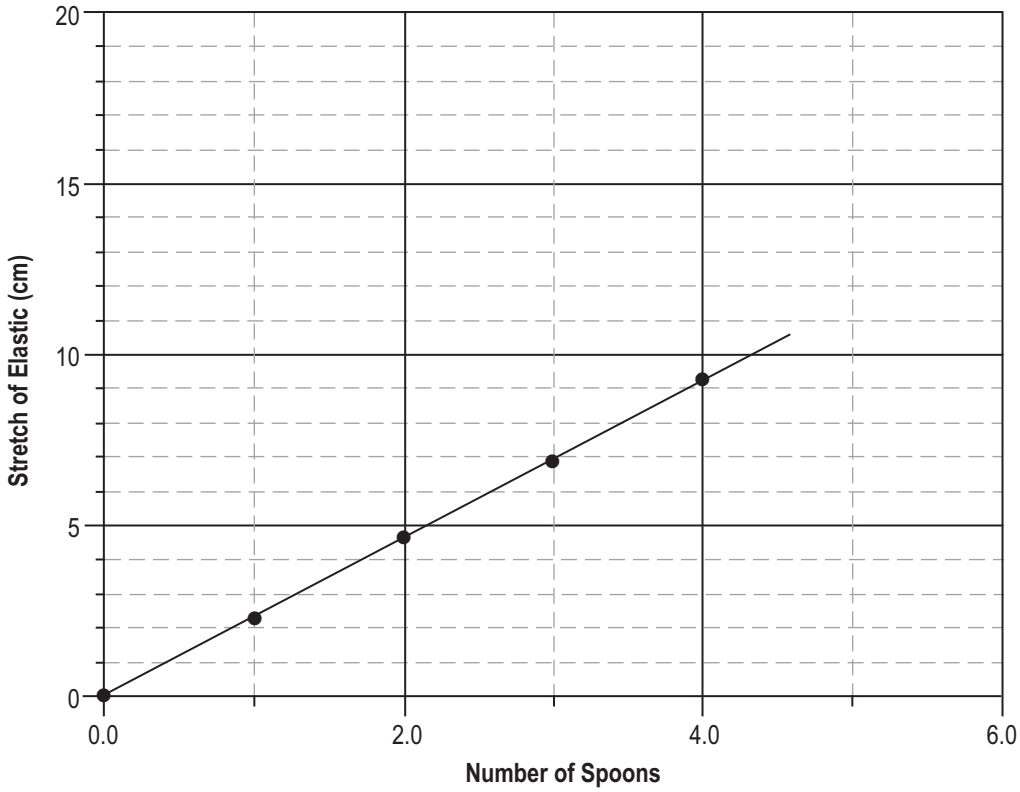
The **graphical mode** is a mathematical picture of the data.

For this graph, place the amount of stretch on the vertical axis and the number of spoons on the horizontal axis. When placing the numbers along the axes, start at zero and distribute the numbers evenly. After placing the data points on the graph, join them with a line of best fit. A **line of best fit** is a straight line through the data points so that it touches as many points as possible and has as many points above as below the line. Do not draw a line from one data point to the next. You may want to add a title to the graph.

Plot your data on the graph below.



Using the example data the graph would look like:



You learned in mathematics that the equation of a straight line can be written as $y = mx + b$ where m represents the slope of the line and b represents the y-intercept. In this case the y-intercept is zero since the graph begins at the origin. For this course, the y-intercept will remain at zero for the data we collect.

For the graph above, the y-values are the values of the stretch of the string. The x-values represent the number of spoons. In this case we could determine the value of the slope. The slope is determined by dividing the difference in the y-coordinates by the difference in x-coordinates for two points. Choose two data points that are on your line of best fit. If we use the coordinates (0,0) as (x_1, y_1) and (3,6.9) as (x_2, y_2), then the slope is

$$m = k = \frac{y_2 - y_1}{x_2 - x_1} = \frac{6.9 \text{ cm} - 0.0 \text{ cm}}{3.0 \text{ spoons} - 0.0 \text{ spoons}} = 2.3 \text{ cm/spoon}$$

Determine the slope of your graph.

$$m = k = \frac{y_2 - y_1}{x_2 - x_1} =$$

Mode Number 4: Symbolic

The **symbolic mode** represents the relationship as an algebraic equation/formula.

Generally, an algebraic equation is determined by using the graph. The purpose of the algebraic equation is to predict new situations that were not recorded in the experiment. For example, "How much will the string stretch with five spoons?" We can start by writing a word equation as:

Stretch of string = (slope of line) x (number of spoons)

Then we can introduce some algebraic symbols, such as:

S = stretch of string
n = number of spoons

Using the data from the example, the algebraic equation will then be:

$$S = 2.3n$$

If we had placed five spoons on the string, then we would predict the stretch to be:

$$\begin{aligned} S &= 2.3n \\ &= 2.3(5) \\ &= 11.5 \text{ cm} \end{aligned}$$

Determine the stretch of your string with five spoons and then test it by adding another spoon to your apparatus.

Note: The algebraic equations we will develop in this course have accepted symbols and are written in a traditional way. For the purpose of explaining the modes of representation, we have used arbitrary symbols and format for a well accepted law of nature. The law is called Hooke's Law and predicts how all elastic materials will behave when a force (push or pull) is applied to them. The accepted format for Hooke's Law is:

$$F = kx$$

Where F = the force applied, measure in Newtons
k = the spring constant (how stiff the spring is), measure in Newtons/metre
x = the stretch or compression of the spring, measured in metres

You do not need to understand Hooke's Law at this point. What you have to understand are two things:

1. There are four ways (modes) to express an event. All of the modes are important when dealing with physics. We do not want you to think of physics as simply plugging numbers into formulas and calculating an answer. You should be able to explain an event in any or all of the modes.
2. There are accepted ways of representing the algebraic equations we will come across in this course. Sometimes it may not seem to make sense why certain symbols are being used. Just remember that physics is an old science and tradition is important. Also, there are only so many symbols to choose from and many are used more than once in different contexts.

Learning Activity 1.1

Recording Data

Now you will get the chance to review and practice what you have learned by completing this learning activity. Remember, you do not submit learning activities for assessment. Instead, you complete them in order to prepare yourself to complete the assignments (which are submitted for assessment). Once you have completed this learning activity, check your answers in the answer key at the end of this module.

1. A person is moving slowly at a constant speed to the right. Every second, the distance travelled from the origin is recorded. The diagram below is one way to **visually** record the data. In this situation, the independent variable is the time.

   • At t = 0.0 s, the distance travelled d = 0.0 m.

   •⟶ At t = 2.0 s, d = 1.0 m

   •⟶ At t = 4.0 s, d = 2.0 m

   •⟶ At t = 6.0 s, d = 3.0 m

   •⟶ At t = 8.0 s, d = 4.0 m

   •⟶ At t = 10.0 s, d = 5.0 m

   a) Express the data above numerically in the form of a data table. Construct the data table horizontally. Be sure to label the rows correctly.

   b) Now construct a graph of the data above.

(continued)

Learning Activity 1.1: Recording Data (continued)

c) To illustrate the symbolic mode, determine the mathematical equation that relates the distance and the time. Include the magnitude of the slope in your answer.

2. If you were asked by another student "What is physics?", what would you say?

Lesson Summary

Physics is not easy to define. Isaac Asimov, in tracing the development of the study of science from ancient times, made the following statements:

- In ancient times, there was no such thing as science, and certainly no physics, chemistry, or biology; instead there were "philosophers" who were literally "lovers of wisdom."
- Some philosophers studied natural phenomena and were referred to as "natural philosophers," which is pretty nearly what we would now think of as "scientists."
- The Greek word for "natural" is "physikos"—so physics was initially the same as "science" in general.
- When people eventually specialized into specific areas of study, these areas were given their own names (mathematics, astronomy, geology, chemistry, and biology) and were removed from "physics."
- What we now call physics is what remains after the above have been removed.
- Splitting up these areas of study was an artificial, somewhat arbitrary construct, and in fact these areas tend to blend into each other

The aspect of physics that we will be investigating is the study of relationships in the world we perceive around us.

In order to learn and fully understand the concepts of physics, you must look at the situation in a variety of methods called modes of representation.

For our investigation into the effect on an elastic's amount of stretch from the pull of different numbers of spoons attached to it, the following are the four modes of representation.

1. Visual Mode

   The **visual mode** gives you a picture of the phenomenon in your mind.

2. Numerical Mode

   The **numerical mode** describes the relationship using numbers.

3. Graphical Mode

   The **graphical mode** is a mathematical picture of the data.

4. Symbolic Mode

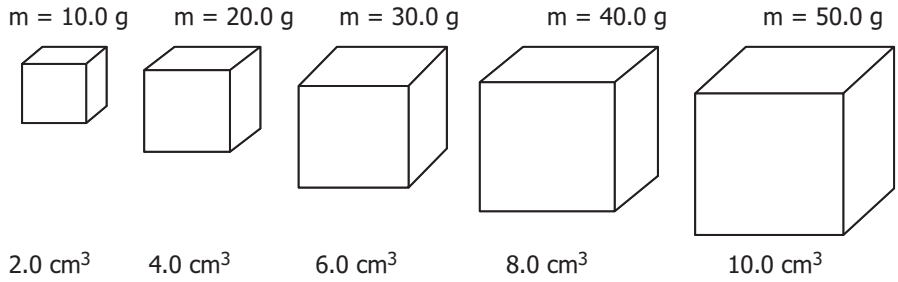
   The **symbolic mode** represents the relationship as an algebraic equation/formula.

Assignment 1.1, Part A

Symbolic Mode (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 1, after you have completed Module 1.

A student wants to determine the mathematical relationship between the mass of an object and the volume of the object. In the experiment, it is important to ensure that the material that the object is made of remains constant. The visual representation of this situation is shown below. The volume is the independent variable. As the volume is changed, the mass is recorded.

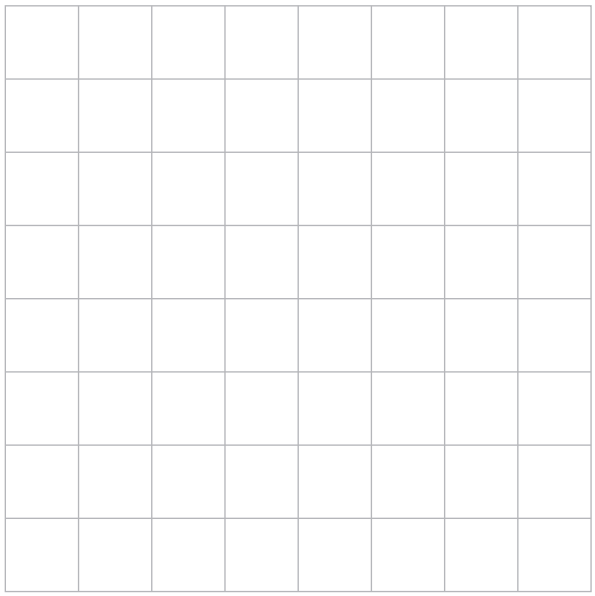


a) Express the data above numerically in the form of a data table. Construct the data table horizontally. Be sure to label the rows correctly.

(continued)

Assignment 1.1, Part A: Symbolic Mode (continued)

b) Now construct a graph of the data above.



c) To illustrate the symbolic mode, determine the mathematical equation that relates the volume and the mass. Include the magnitude of the slope in your answer.

Equation:

Substitution:

Solving:

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for setting up the data table correctly in part (a)
- 1 mark for correctly labelling the axes, distributing the numbers evenly along the axis, and writing a reasonable title
- 1 mark for plotting the points and drawing the straight line
- 1 mark for determining the slope in part (c)
- 1 mark for writing the correct mathematical equation in part (c)

Lesson 2: Working with Vectors, Scalars, and Significant Figures (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ differentiate between quantities that are scalars and those that are vectors
- ❑ understand the importance of expressing calculation answers to the correct number of significant figures
- ❑ perform calculations that result in the correct number of significant figures

Key Words

vector quantities
quantity
scalar quantities
magnitude
significant figures

Introduction

In making measurements, we are trying to determine "how much" we have of "something." The "something" we are trying to measure is called the **quantity**. We know which quantity we are measuring by checking out the unit of measurement. A unit of metres indicates a distance, and a unit of seconds indicates a time or time interval.

Sometimes it is important for us to specify a direction when we give the value for a quantity. This is where we need to subdivide quantities further into two categories: those with direction and those without direction.

If we do calculations on our calculator using numbers representing quantities we have measured, how do we know where to round off our answer? Should we keep all the digits in the calculator display? If not, where should we round off the answer?

Quantities

When we count, we use **exact numbers**. If we count people, we have exactly four. There is no uncertainty about this number. The quantity here is the number of people.

Measurements using an **interval scale**, like that found on a ruler, involve some uncertainty or estimation. Measurements on an interval scale require an instrument to determine the amount or size or magnitude of the quantity. You know that you use a ruler (the instrument) to measure length (the quantity). To measure length, you could also use a micrometer or an electronic device that sends out infrared radiation. To measure temperature (the quantity), you use a thermometer (the instrument).

How do you tell if the quantity is a length or a temperature? You inspect the unit that accompanies the magnitude of the measurement. A complete measurement consists of the magnitude and the unit.

Therefore, 5 m and 5°C are not the same quantities, as 5 m represents the quantity of length since the unit is metres, and 5°C represents the quantity temperature since the unit is degrees Celsius.

Vectors and Scalars

Most quantities we measure are **scalars**. These are measured with a size or magnitude without regard to direction. For example, temperature is a scalar. While it can be positive or negative, it does not have a direction associated with it, such as right or left, or east or west.

> A **scalar** is a physical quantity that has only a magnitude or size.

When measuring quantities in science, it is necessary to specify the direction for some quantities. **Vectors** require that a direction be given along with the size or magnitude.

> A **vector** is a physical quantity that has a magnitude and a direction.

Force is a vector. You can pull on a door handle with a force of 25 Newtons (25 N) [east], or you can push on the door handle with a force of 25 Newtons (25 N) [west]. While these two forces have the same magnitude, they act in different directions. One force will open the door; the other force will not.

To specify a vector, you must include three pieces of information: a size, a unit, and a direction.

In the study of motion, two similar quantities—speed and velocity—are often confused. **Speed** describes how fast an object is moving, regardless of direction. The speedometer of a car measures speed. It indicates how fast the car is moving, but does not include the direction. For example, 100 km/h is a typical speed for a car on the highway.

Velocity, though, is a **vector quantity**. If we start at a point and travel at 100 km/h east for one hour, we will end up 100 km east of our starting point. If we travel at 100 km/h west, starting from the same point, we will end up 100 km west of the starting point. These two velocities, 100 km/h east and 100 km/h west, are definitely different velocities. It is the direction that makes them different.

Learning Activity 1.2

Quantities

In your previous studies of science, you have been introduced to many quantities and many instruments used to measure these quantities. Fill in the missing parts in the table below. Once you have completed this learning activity, check your answers in the key at the end of this module.

Quantity	Symbol of the Quantity	Unit	Vector or Scalar
time instant			
time interval			
distance travelled			
displacement			
mass			
length			
speed			
acceleration			
velocity			
force			
energy			

The Purpose of Significant Digits

Systems of measurement were invented in order to compare quantities. Only the size of the object used to define a unit of measure is known exactly. The metre was once defined as the distance between two scratches on a bar of platinum-iridium alloy at 0°C. All other measurements of distance are estimated. Not all measurements, however, are known to the same accuracy, which refers to how close the measurement is to the true value. A micrometer, for example, will yield a more accurate measurement of the diameter of a hair than will a metre stick.

Significant digits tell us something about how the measurement was made. A better instrument allows us to make better measurements and we record a greater number of significant digits in reporting this value. A metre stick would only allow us to record the thickness of a hair as 0.1 mm, while a micrometer—a much better measuring instrument—allows us to record the thickness as 0.137 mm. This second measurement is closer to the true value and is a more accurate measurement.

Recording a Measurement Using Significant Digits

When recording a measurement, include every digit that is absolutely certain plus the first digit that must be estimated. This is the definition of a **significant digit**.

> **Significant digits** are those digits in a measurement that are known for certain plus one uncertain digit.

Significant digits are part of the measurement. For example, suppose the length of a table is measured with a ruler calibrated to 10 centimetres. A proper measurement would be recorded as 2.64 metres. This indicates the table has a length of two metres plus 60 centimetres plus a little bit more. The table is definitely less than 2.7 metres but greater than 2.6 metres. The first two digits are known exactly and the third digit is estimated by a GUESS (Module 1, Lesson 8 will provide a detailed description of the GUESS method). The measurement has three significant digits.

A measurement of the same table with a ruler calibrated to centimetres could yield 2.642 metres. A better instrument yields a greater number of significant digits when measuring the same object.

The final significant digit will always be one unit smaller than the calibration of the measuring instrument. For example, the first measurement was recorded to the nearest centimetre while the ruler was calibrated only to the nearest 10 centimetres. The second measurement was recorded to the nearest tenth of a centimetre while the rule was calibrated to the nearest centimetre.

Zeroes are to be recorded if they are significant. For instance, if a table is measured and the end of the table coincides with a mark on the ruler (for example, 2.6 metres), a zero must be recorded. If the ruler is calibrated in 10 centimetres, record zeroes until the next smaller unit, one centimetre, is recorded. In this case, the measurement would be 2.60 metres. If the metre stick was calibrated in centimetre units, then zeroes are recorded until one millimetre is recorded. Here, the measurement would be 2.600 metres.

Rules for Significant Digits

The following rules are used to determine the number of significant digits in a given measurement:

1. All non-zero digits are significant.
   e.g., 374 (3 sig digs) 8.1 (2 sig digs)
2. All zeroes between non-zero digits are significant.
   e.g., 50407 (5 sig digs) 8.001 (4 sig digs)
3. Leading zeroes in a decimal are not significant.
   e.g., 0.54 (2 sig digs) 0.0098 (2 sig digs)
4. Trailing zeroes are significant if they are to the right of a decimal point.
   e.g., 2370 (3 sig digs) 16000 (2 sig digs) 160.0 (4 sig digs)
5. In numbers greater than 1, trailing zeroes are not significant unless stated so.
   e.g., 37000 (2 sig digs)

The last three zeroes may or may not be part of the measurement. To show that they are, we use scientific notation. All the zeroes written in the number in scientific notation are significant.

37000 with 3 significant digits would be 3.70×10^4

37000 with 4 significant digits would be 3.700×10^4

37000 with 5 significant digits would be 3.7000×10^4

37000.0 has 6 significant digits

An Alternative Rule for Significant Digits

Here is an alternative rule for determining significant digits. The rule is really a mnemonic device. You, the student, are easily confused about the number of significant digits, especially if zeroes are present. This rule will allow you to achieve success in working with significant digits, which should, in turn, encourage you to keep using them. This method is called the "**Atlantic-Pacific" method**.

If the number in question does not contain a decimal, think "A" for Absent. If the number in question does contain a decimal, think "P" for Present.

Next, imagine a map of North America with north pointing to the top of the page. The "A" now stands for Atlantic and the "P" now stands for Pacific oceans.

Now, imagine an arrow starting from the correct coast being drawn towards the number. Once the arrow hits a non-zero digit, that digit and all digits after it are significant.

Example 1

How many significant digits are shown in the number 37 500?

There is no decimal, so we think of "A" for "Absent." Therefore, an arrow must come in from the Atlantic Ocean (i.e., the right side), as shown below.

37 500←

The first non-zero digit that the arrow hits would be the 5. The 5 and all digits after it—in this case, to the left of the 5—are significant.

Answer: There are three significant digits in the number 37 500, (the 3, 7, and 5.)

Example 2

How many significant digits are shown in the number 0.040500?

There is a decimal, so we think of "P" for "Present." Therefore, an arrow must come in from the Pacific Ocean (that is, the left side), as shown below.

→ 0.040500

The first non-zero digit that the arrow hits would be the 4. The 4 and all digits after it (in this case, to the right of the 4) are significant.

Answer: There are five significant digits in the number 0.040500, (the 4, 0, 5, 0, and 0). Example 2 employs three separate rules for significant digits and zeroes.

Learning Activity 1.3

Significant Digits: Part 1

Write the answer to each question in the space provided in the table. Then check your answers with the answer key found at the end of the module.

1. Determine the number of significant digits in each of the following numbers.

5.897		8.000		10001	
0.333		8.001		0.008000	
7		0.009		947.000	
10000		12000		10000.0	
10321		55040		375000	

2. State the number of significant digits in each measurement.

a) 2509 m		g) 7.62 km	
b) 0.00055 m		h) 0.0670 m	
c) 5.060×10^5 m		i) 9.0000×10^{-5} m	
d) 240 m		j) 2.4 m	
e) 2400 m		k) 2400.0 m	
f) 0.005050 m		l) 50 m	

Rounding Off Numbers

Before you proceed any further, check Appendix A at the end of this module for rules about rounding off numbers.

In physics it will be necessary to round off your answers. You will need to round off a particular digit in the number. This is the **digit to be rounded off**. The digit after the number to be rounded off is called the **trailing digit**.

Example

In 52<u>7</u>93, the underlined digit is the number to be rounded off. This makes the 9 the **trailing digit**.

The value of the trailing digit determines if the digit to be rounded off remains the same or is increased by 1.

We will use the following rules.

1. If the trailing digit is less than 5, the digit to be rounded off remains unchanged. Digits after the number to be rounded off are replaced by zeros until the decimal point is reached. This is done to ensure the digit rounded off maintains its place value. If the digit to be rounded is in the decimal part of the number, then digits after the number to be rounded off are simply dropped.

   Example

   Round off each number to the place value of the digit underlined.

   53<u>**8**</u>092 = 538000

   0.53<u>**8**</u>092 = 0.538

2. If the trailing digit is greater than 5, the digit to be rounded off is increased by 1.

   Example

   Round off each number to the place value of the digit underlined.

   538<u>**0**</u>92 = 538100

   0.538<u>**0**</u>92 = 0.5381

3. If the digit to be rounded off is trailed by a 5, we use the **odd-even rule**.

   If the digit to be rounded off is trailed by a 5 and the trailing digit is

   a) **even**, then the digit to be rounded remains **unchanged**

   b) **odd**, then the digit to be rounded is **increased by 1**

   Examples

   8<u>**8**</u>526 = 88000 (Even number trailed by a 5 remains unchanged.)

   8<u>**7**</u>526 = 88000 (Odd number trailed by a 5 is increased by 1.)

Calculations and Significant Digits

We have all done calculations using a calculator. If the numbers that we start with are measurements, then the number of significant digits we are allowed to retain in our answer is affected by how many significant digits there were in each of the measurements involved in the calculation. So we cannot just copy all the digits that are in the display of a calculator and say that this is the answer.

In the work that you will be doing in Grade 11 Physics, most of the calculations will involve the four basic operations of addition, subtraction, multiplication, and division. The rules for significant digits and calculations fall into two categories: those for addition and subtraction, and those for multiplication and division.

Addition and Subtraction and Significant Digits

Let us consider an example. In order to make the ideas more obvious, we will arrange the numbers in columns.

5.6**2** m	The bold **2** is the last significant digit.
+3.27**6** m	The bold **6** is the last significant digit.
8.8**96** m	

In the sum, there are now two digits (the **9** and the **6**) that involve an uncertain digit. You will recall that significant digits are those digits that we know for certain plus one uncertain digit. Our answer in this case does not express the correct number of significant digits as determined by the measurements in the question.

What we must do now is round the answer so that there is only one uncertain digit in the answer. The digit that we round is the first uncertain digit (largest place value) we come to as we read the answer from left to right.

In this case, we must round the **9**. Since the **9** is trailed by a **6**, we must increase the **9** by one.

Our final answer is then 8.9**0** m. The **0** must be written in the answer since it occupies the place value where the largest uncertainty lies.

> In addition and subtraction, round the answer off the digit in the place value that represents the **largest uncertain place value** in the question.

Multiplication and Division and Significant Digits

The rule for multiplication and division is different than for addition and subtraction.

Again, we use the idea that there should be only one uncertain digit in the answer. Let's consider the following example:

If we multiply 4**3** and 12.2**5**, we do the following work.

12.2**5**	
x 4**3**	
36.75	Each digit in this line is obtained using an uncertain digit.
490 **0**	In this line, only the last 0 is obtained using an uncertain digit.
5**26.75**	In this line, only the 5 was obtained without using an uncertain digit.

Again, in the answer, we are allowed to keep only one uncertain digit. Therefore, we must round off the 2.

Our answer will be 530. The 3 will be the only uncertain digit.

To make it even clearer that there are only two significant digits in our answer, we can write the answer in scientific notation. Only those digits that are significant will be included in the first part of the number written in scientific notation.

$$53\mathbf{0} = 5.\mathbf{3} \times 10^2$$

Significant digits and multiplication or division

1. Determine the number of significant digits in each part of the question.
2. Perform the multiplication or division using the calculator.
3. Round off the answer to the **fewest number** of significant digits given in the numbers in the question

You must be very diligent in using these rules for calculations and significant digits, and then correctly rounding off your answer will become as automatic as using punctuation when you write.

Other Mathematics Skills

We do not have the time or the space to address all the mathematical skills you will need to do the calculations involved in physics. Mathematical concepts will be introduced as the need for them arises. The appendix of this course includes information on some necessary mathematical skills, such as orders of operations, working with integers, fractions, basic algebra, basic geometry, scientific notation, calculator usage, graphing lines, and working with measurement units.

Learning Activity 1.4

Significant Digits: Part 2

When performing the following calculations, round off your answer to the correct number of significant digits, and then check your answers in the answer key at the end of the module.

1. A bowl contains 12 oranges. In this case, what type of number is 12?

2. How many significant digits are in each of the following numbers?

a) 18		f) 125 000 000	
b) 0.018		g) 125 000 000.0	
c) 250		h) 1.0×10^{8}	
d) 12000		i) 5.92×10^{-6}	
e) 1008		j) 4.30450×10^{3}	

3. Complete the following calculations on your calculator and write the preliminary answer (whatever the calculator displays). Round off the final answer to the correct number of significant digits.

   a) 2.8234 x 6.1 = _____
   b) 0.03940 x 0.0090400 = _____
   c) 820 ÷ 2.050 = _____
   d) 9000.0 ÷ 5820 = _____
   e) 738 + 25.92 = _____
   f) 87000 – 640.0 = _____
   g) 0.002050 – 0.0003892 = _____
   h) 90.25 + 4.984 – 6.3080 = _____
   i) 3.0625 x 8.0920 ÷ 140 = _____

Lesson Summary

In summary, **scalars are quantities with size or magnitude only**. We give the value of such a quantity with a number for its size and a unit to tell us the type of quantity. A **vector is a quantity with both magnitude and direction**. We give the value of a vector using a number for its size, a unit to tell us the type of quantity, and a direction.

Significant digits are used when we make measurements or do calculations with measured quantities. Counting does not involve any guesswork or estimation, so such numbers are said to be **exact**. When we measure using an interval scale, we record the digits we know for sure plus one digit that we estimate. This is our definition of **significant digits**.

When we want to identify which digits are significant in a given number, we can use the Atlantic-Pacific rule to help us determine which zeros are significant in the number.

When using a calculator to perform mathematical operations, you must round off the answer according to the following rules:

- In **addition and subtraction**, round the answer off the digit in the **place value** that represents the l**argest uncertain place value** in the question.
- In **multiplication and division**, round off the answer to the **fewest number** of significant digits given in the numbers in the question.

Assignment 1.1, Part B

Significant Digits (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 1, after you have completed Module 1.

Calculate and record the preliminary answers to the following questions. Then, provide the final answer to the correct number of significant digits.

1. 5.070 + 6.9 = _____

2. 0.0024050 – 0.00026980 = _____

3. 89000 x 0.01450 = _____

4. 198.02 ÷ 90850 = _____

5. 0.0023601 x 620 ÷ 38.000 = _____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for each question (one-half a mark is given for the correct preliminary answer and one-half a mark is given for correctly rounding off the answer)

NOTES

Lesson 3: Terms for Describing Motion (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the following: reference point, frame of reference, position, distance
- ❑ calculate the position and distance of an object from a reference point
- ❑ differentiate between quantities that are scalars and those that are vectors
- ❑ determine the instantaneous time, the instantaneous position, the displacement, and the time interval for a given motion
- ❑ determine the average speed and velocity of an object

Key Words

reference point	frame of reference	position
distance	instantaneous time	instantaneous position
displacement	time interval	speed
velocity	delta (Δ)	

Introduction

In Grade 10 Science, you were asked to describe motion in words, using numbers from measurements in a data table, using a graph of the measurements, and finally by using equations. You will recall that the graphs were particularly useful. The graphs that you drew—that is, position-time graphs, velocity-time graphs, and acceleration-time graphs—were all just different versions of the same story of the motion of an object. They not only described a motion, but they also allowed you to calculate some other quantities useful in describing motion.

So let's begin by describing motion in words. Again, think of describing motion as telling a story. A good vocabulary is required so that you can use the correct terms to describe what is happening. This lesson will bring these terms back to mind.

Time

You have already seen that there are many terms that can be associated with describing motion: time instant, time interval, position, displacement, speed, velocity, and acceleration. Before we begin to talk about **kinematics**, which is the study of motion, it would be wise to review all of these terms.

A **time instant** is just a clock reading, such as 3:14 PM.

A **time interval** is simply the time that elapses between two clock readings or two instants in time. For example, the time interval between 3:14:25 PM and 3:14:39 PM is 14 seconds.

Time is a scalar quantity meaning we can specify time using only magnitude. In SI, the unit we use for time is the second or s.

To calculate a **time interval**, we find the time that has elapsed between two intervals by subtracting: final time – the initial time.

$$\Delta t = t_2 - t_1$$

Quantity	Symbol	Unit
Time interval	Δt	seconds (s)
Initial time	t_1	seconds (s)
Final time	t_2	seconds (s)

To signify a "change in" some quantity, we use the symbol "delta" (Δ).

The symbol **delta** or Δ **signifies** a change in a quantity and is always calculated using:

$$\Delta = \text{final value} - \text{initial value}$$

Example:

On Tuesday, you have \$352.18 in your savings account. In that same account on Thursday, there is \$328.75. What is the change in the amount of money in your bank account?
On Tuesday, the initial value is \$352.18.
On Thursday, the final value is \$328.75.

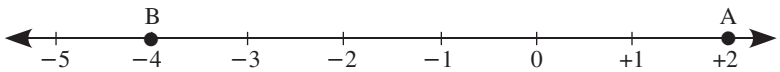
Change in value = final value – initial value
Δ value = \$328.75 – \$352.18 = –\$23.43
In this case, the value of the bank account decreased by \$23.43.

Position, Distance, and Speed

In order to talk about motion, we must be able to indicate where an object is located. An object moves when it changes its location.

> The **reference point** is the zero location in a coordinate system or frame of reference.
>
> **Position** is the location of an object in relation to the location of a specific point called the reference point.

Since in this section we are dealing only with motion along a straight line or straight-line kinematics, you can think of positions as falling along a straight line. A classic example would be the number line. The position of each number is marked on the line relative to the position of 0, the **reference point**. Numbers to the right of zero are considered to be positive numbers, and numbers to left the zero are considered to be negative numbers. In the same way, we can mark positions along a line.



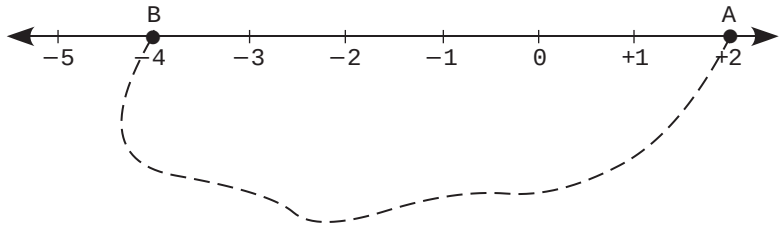
The reference point is zero, which we mark as 0 m.

The point **A** is located at a position of +2 m—that is, 2 m to the right of the reference point. Normally, we consider motion to the right or up to be positive. In a given question, you should specify the directions for the motions.

The point **B** is located at a position of –4 m—that is, 4 m to the left of the reference point. Again, we consider motion to the left or down to be negative.

The points A and B represent two positions: **A** represents position 1 (pos_1) and **B** represents position 2 (pos_2). If the object moved from position **A** to position **B**, then position **A** is called the initial position (pos_1) and position **B** is called the final position (pos_2).

Let's say a ladybug was to walk from position **A** to position **B**. The ladybug is not likely to walk in a straight line, but rather is likely to wander. A possible path is indicated below with the dashed line.



The location of the ladybug at a particular instant in time is called the **instantaneous position**.

As the ladybug travels along the path indicated by the dashed line, it will have an instantaneous position at each reading of a clock (e.g., at each second).

Along the path indicated by the dashed line, the ladybug travels a distance of 11 m during a time of 45 seconds.

Distance (d) is the length of the path travelled by an object. It has no direction and is therefore a scalar quantity.

Distance is a scalar—it measures only magnitude (the size, or length, of the motion's path). Distance is symbolized by the letter "d."

Note: When shown a symbol letter in physics, the "case" (i.e., whether the letter is capitalized or not) matters, so do not change it. In this case, distance must be a "d" and not "D."

In this case, the distance travelled is 11 m, d = 11 m.

The time interval, Δt, is 45 s.

From these data, we can calculate how fast the ladybug was travelling. How fast an object travels is called its speed. Average speed is calculated by taking the total distance travelled over the total time interval.

Speed is a measure of how fast an object is travelling. Speed is calculated by the distance travelled over the time interval.

$$v = \frac{d}{\Delta t}$$

Quantity	Symbol	Unit
Speed	v	metres/second (m/s)
Distance	d	metres (m)
Time interval	Δt	seconds (s)

Average speed = total distance travelled ÷ total time interval

$$v_{avg} = \frac{d_{total}}{\Delta t_{total}}$$

The speed of the ladybug would be:

$$v_{avg} = \frac{d_{total}}{\Delta t_{total}}$$
$$v_{avg} = 11 \text{ m}/45 \text{ s}$$
$$v_{avg} = 0.24 \text{ m/s}$$

Since speed has no direction associated with it, it is a scalar.

Learning Activity 1.5

Average Speed

Test your understanding of these ideas that you are reviewing by trying the questions below. Check your answers with the answer key at the end of the module.

1. Your school is rectangular in shape. Around the school is a sidewalk that also forms a rectangle. Along the length of the school, the sidewalk is 75.8 m; along the width of the school, the sidewalk is 25.6 m. It takes 65.3 seconds to walk on the sidewalk around the school and return to the starting point.
   a) What is the distance travelled?
   b) What was your average speed during this trip?
2. You are travelling in a car from Winnipeg to Regina. It takes you 2.50 hours to travel from your home to Brandon, which is a distance of 236 km. You stop in Brandon to have lunch and do some shopping, spending a total of 1.25 hours. The remaining 489 km of the trip to Regina requires 5.00 hours.
   a) What is the average speed for the part of the trip from your home to Brandon?
   b) What is the average speed for the whole trip from Winnipeg to Regina?

Displacement

When we want to include direction for motion, we don't (in physics) call it a distance anymore. **Displacement** is two things at the same time: how far an object ended up from its starting point, *and* the direction that it moved from its starting point. Displacement is a vector—it includes both a magnitude and a direction. Displacement is symbolized by the letter "d," but since it is a vector we must add a small "vector arrow" on top of it so that the full symbol for displacement is "$\vec{d}$." The small arrow on top avoids confusion between distance (d) and displacement ($\vec{d}$).

At this point, many people make the mistake of assuming that displacement is merely distance with a direction added onto it. This is not true, but is best shown with an example. Consider a person going for a walk. The person begins by walking 200 metres to the east. She then turns around and walks another 300 metres to the west. For this person's motion, we can describe the distance as 500 metres (this is the length of the path travelled). Notice that there is no indication of direction in this distance, and the change of direction during the motion doesn't affect the distance travelled. For this same motion, the displacement of the person would be 100 metres west (this is where the person ended up—both how far and in which direction). This can be symbolized as d = 500 m and $\vec{d}$ = 100 m [W]. Notice that square brackets ("[" and "]") are used to surround the direction (which may be abbreviated as shown) when it is a main direction such as north, south, east, west, up, or down.

Displacement represents the change in position of an object. Displacement is calculated by subtracting as follows: final position – initial position.

$$\vec{d} = \overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1$$

Quantity	Symbol	Unit
Initial position	$\overrightarrow{\text{pos}}_1$	metres (m)
Final position	$\overrightarrow{\text{pos}}_2$	metres (m)
Displacement	$\vec{d}$	metres (m)

Displacement is a *vector* quantity.

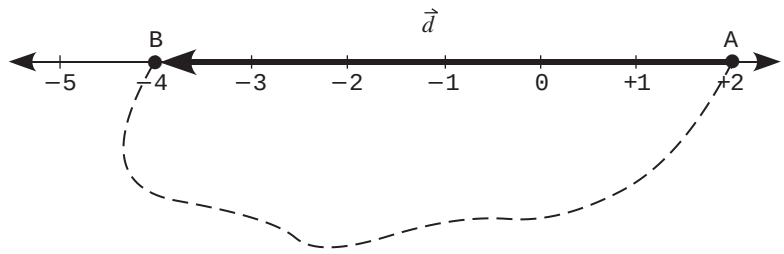
The ladybug's initial position was +2 m and its final position was –4 m.

$$\overrightarrow{\text{pos}}_1 = +2 \text{ m}$$
$$\overrightarrow{\text{pos}}_2 = -4 \text{ m}$$

$$\text{displacement} = \overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1$$

$$\vec{d}_{\text{tot}} = \overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1$$
$$\vec{d}_{\text{tot}} = -4 \text{ m} - (2 \text{ m}) = -6 \text{ m}$$

The displacement of the ladybug is –6 m or 6 metres to the left.



To represent a vector, we use a directed line segment (an arrow). The **tail** of the arrow (the end without a head) is placed at the initial position (point A). The **head** (the end of the arrow with the arrowhead) is placed at the final position (point B).

The displacement vector $\vec{d}$ is drawn in the diagram above.

Once you understand displacement and are able to determine displacement, you can move on to finding velocity. **Velocity** is defined as the rate of change of position. It is calculated by taking the displacement over the time interval.

Velocity is the rate of change of position. Velocity is calculated by the displacement over the time interval.

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{\overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1}{\Delta t}$$

Quantity	**Symbol**	**Unit**
Initial position	$\overrightarrow{\text{pos}}_1$	metres (m)
Final position	$\overrightarrow{\text{pos}}_2$	metres (m)
Displacement	$\vec{d}$	metres (m)
Velocity	$\vec{v}$	metres/second (m/s)
Time interval	Δt	seconds (s)

Velocity is a *vector* quantity.

Average velocity = total displacement ÷ total time interval

$$\vec{v}_{avg} = \frac{\vec{d}_{tot}}{\Delta t_{tot}}$$

Velocity is a vector quantity. Its direction will be the same as the direction of the displacement.

Velocity will have units of metres over seconds (m/s) in SI units. You may be familiar with other velocity units like kilometres per hour (km/h). Units like these should be converted to m/s before doing calculations.

You can think of velocity as speed plus direction.

Getting back to the ladybug, you can see that the displacement was –6 m during a time of 45 s.

Using, $\vec{v}_{avg} = \frac{\vec{d}_{tot}}{\Delta t_{tot}}$,

$$\vec{v}_{avg} = \frac{-6\text{ m}}{45\text{ s}} = -0.13\text{ m/s} = -0.1\text{ m/s}.$$

The velocity of –0.1 m/s indicates that the ladybug would have travelled from A to B and during 45 seconds if it had maintained a constant speed of 0.1 m/s in the negative direction or to the left. Since the ladybug had wandered from the straight-line path, this velocity represents the average velocity for this journey.

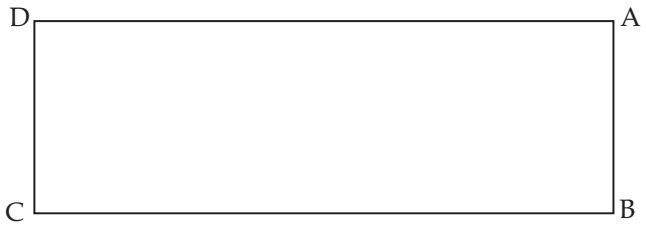
Learning Activity 1.6

Velocity

Test your understanding of these ideas by trying the following questions. Check your answers with the answer key at the end of the module.

To answer questions #1–3, use the following information.

A city block is laid out in a grid running north-south and east-west. The blocks measure 135 m in length in the east-west direction, and 45.0 m in width in the north-south direction. A city block is drawn below.



1. On your bicycle, you travel from A to B during 9.00 s.
   a) What is your average speed?
   b) What is your average velocity?
2. If you travel from A to B to C to D, what is your
   a) distance travelled?
   b) displacement?
3. If the journey in #2 took 55.0 s, calculate
   a) your average speed.
   b) your average velocity.
4. Write down which one of the following statements is incorrect and why.
   a) The car travelled around the track at a constant velocity.
   b) The car travelled around the track at a constant speed.

(continued)

Learning Activity 1.6: Velocity (continued)

5. Sound travels at a constant speed of 343 m/s in air.
   a) How much time does it take the sound of thunder to travel at distance of 5005 m?
   b) If the sound reflects back to the place where it originated, what is the average velocity of the sound?
6. Andy Green in the car *ThrustSSC* established a world record in 1997. The speed of the car was 341.1 m/s (1228 km/h). The car was powered by two jet engines. It was also the first car to officially exceed the speed of sound. To establish such a record, the driver made two runs through the course, one in each direction to nullify wind effects. First the car travelled from left to right a distance of 1609 m in a time of 4.740 s. Then the car travelled the same distance in the reverse direction in a time of 4.695 s. Determine the average velocity in each run.

Lesson Summary

Kinematics is the branch of physics that describes how objects move without referring to the forces that cause that motion.

The **reference point** is the zero location in a coordinate system or frame of reference. The **frame of reference** is the coordinate system used to define motion.

The **position** of an object is the separation between the object and the reference point. Both the distance and the direction are necessary to describe position.

Distance is simply the separation between two points. It does not require a direction.

A quantity that has both magnitude (size) and direction is called a **vector**. A quantity that has only a magnitude, or size, is called a **scalar**.

Instantaneous time is the time a timepiece such as a clock reads at any particular instant and that lasts zero seconds. **Instantaneous position** can be defined as the position of an object at a specific or instantaneous time.

The change in position of an object is called the **displacement** of the object.

The **time interval** can be defined as the difference between two clock readings or, in other words, two instantaneous times: $\Delta t = t_2 - t_1$.

We can define the average speed of an object as the distance travelled divided by the time required to cover the distance.

$$\text{average speed} = \frac{\text{distance}}{\text{time interval}} \text{ or } v = \frac{d}{\Delta t}$$

We can define the **average velocity** of an object as the displacement divided by the elapsed time.

$$\text{average speed} = \frac{\text{displacement}}{\text{time interval}} \text{ or } \vec{v} = \frac{\vec{d}}{\Delta t} = \frac{\overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1}{t_2 - t_1}$$

NOTES

Assignment 1.1, Part C

Scalars and Vectors (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 1, after you have completed Module 1.

The maximum grade for this solution is five points. You will receive one point for correctly answering each part of the question.

A whale swims due east for a distance of 8.0 km in a time of 2.50 h. It then turns around and moves west for 2.0 km in a time of 0.50 h. It turns around again and heads 4.0 km due east in a time of 1.00 h.

a) What is the total distance travelled by the whale?

Equation:

Substitution:

Solving:

b) What is the total displacement? Be sure to include direction with your answer.

Equation:

Substitution:

Solving:

(continued)

Assignment 1.1, Part C: Scalars and Vectors (continued)

c) What is the average speed for the entire trip?

Equation:

Substitution:

Solving:

d) What is the average velocity for the entire trip? Be sure to include direction with your answer.

Equation:

Substitution:

Solving:

e) There are five quantities discussed in this question: distance, displacement, time, speed, and velocity. Which of these are scalars and which are vectors?

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for the correct answer in each of parts (a) to (e)

Lesson 4: The Position-Time Graph and Velocity (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ draw a position-time graph from a data table of time and position
- ❑ describe how the slope of a position-time graph varies depending on the speed of the object
- ❑ analyze a position-time graph for velocity and draw an accompanying velocity-time graph
- ❑ determine the average velocity of an object by finding the slope of a position-time graph
- ❑ determine the instantaneous velocity of an object by finding the slope of the tangent line drawn on a position-time curve

Key Words

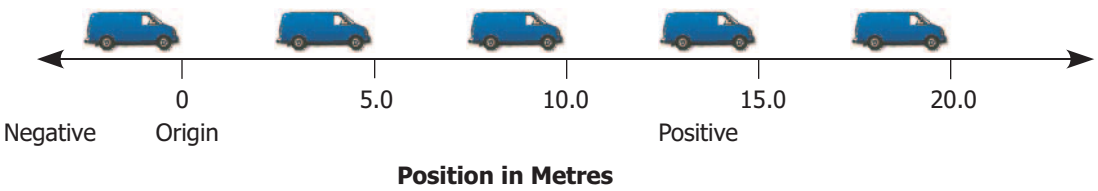
position	position-time graph	velocity
slope	average velocity	chord
tangent	instantaneous velocity	

Introduction

In this lesson, we extend our knowledge of distance, displacement, speed, and velocity to a graphical representation of these quantities. We will first discuss how to draw a position-time graph given a data table showing time and position data. We will then be able to determine the speed or velocity of an object from a position-time graph. The average velocity and the instantaneous velocity of an object are determined in similar ways when a position-time graph is given.

The Position-Time Graph

Describing motion simply involves telling a story about how an object is moving. There are different versions of this story. The version you tell depends on the type of information you want to include with the description. The first version we will investigate is the version involving where the object is (its position) at various instants in time.



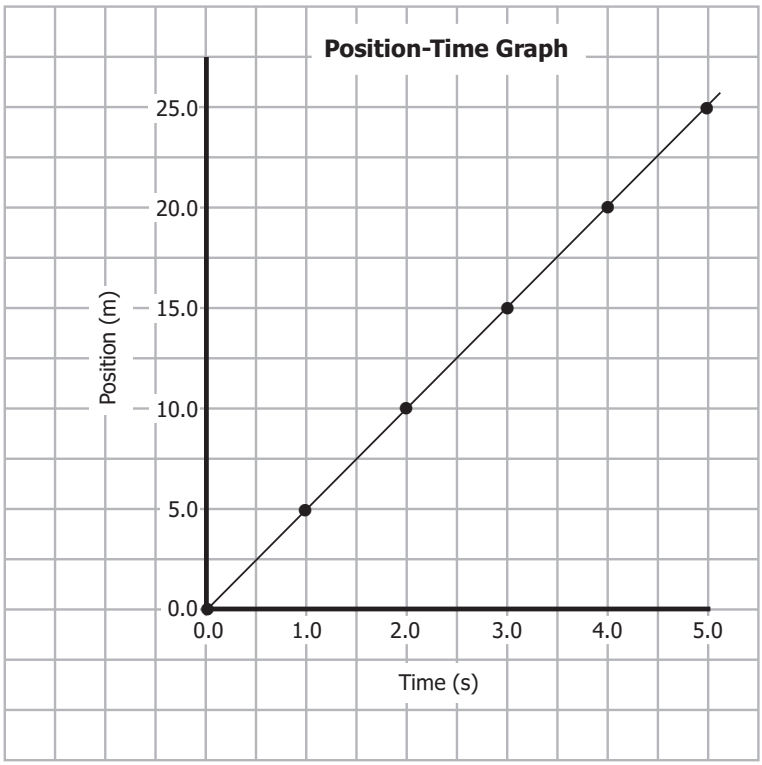
Suppose that an object—a van—is moving at a constant velocity. In the diagram above, snapshots of the motion of the van are taken at equal intervals of time—that is, at 0 s, 1.0 s, 2.0 s, and so on. This information represents the visual mode of representation.

We can create a data table as shown below. The instantaneous position of the van is recorded. This, you will recall, is the numerical mode of representation.

Time(s)	Position (m)
0	0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0

A graph that shows how the position depends on the clock reading, or time, is called a **position-time graph**. The graph below represents the data from the table. This is in the **graphical** representation of the motion.

This graph of position-time gives us some information that we can read **directly** from the graph. By examining the graph, you can determine the position of an object—in this case, the van—at a given time. You can also determine for a given position the time the object was at that location.



From the graph, we can also determine some information **indirectly**—that is, by doing some calculations.

For example, we can determine the time interval between two instants of time. Using two positions, you can also determine the displacement from the initial position to the final position.

For example, consider the time of 2.0 s and its position of 10.0 m. Let's call these the initial time (t_1) and the initial position $\left(\overrightarrow{\text{pos}}_1\right)$, respectively.

Also consider the time of 5.0 s and the position of the van at 25.0 m. Let's call these the final time (t_2) and the final position $\left(\overrightarrow{\text{pos}}_2\right)$, respectively.

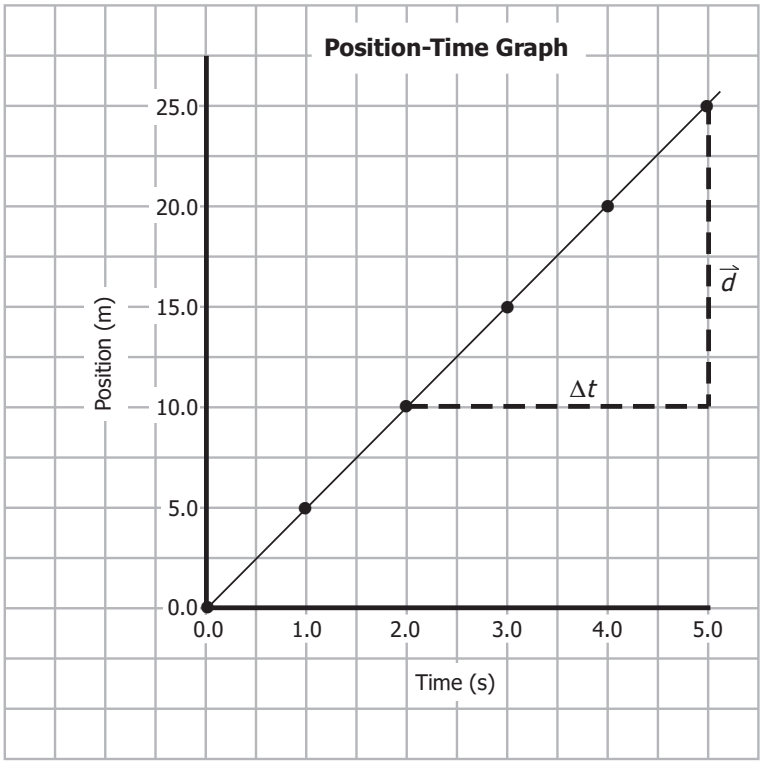
From these values, we can determine a time interval:

$$\Delta t = t_2 - t_1 = 5.0 \text{ s} - 2.0 \text{ s} = 3.0 \text{ s}$$

We can also determine the displacement:

$$\vec{d} = \overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1 = 25.0 \text{ m} - 10.0 \text{ m} = +15.0 \text{ m}$$

These quantities are sketched on the graph below.



You can see that the time interval is the horizontal distance between the two points on the graph. You should recognize this from mathematics as the **run**.

You can also see that the displacement represents the vertical distance from the first point to the second point. Again, you should recognize this from mathematics as the **rise**.

Finally, we can determine a third bit of information indirectly from the position-time graph, and that is the slope of the line. You'll recall that slope is calculated using:

$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

In this case, the rise represents the displacement and the run represents the time interval.

Once more, substituting for the run and the rise gives $\frac{\vec{d}}{\Delta t}$.

You should recognize that this ratio is what we earlier called "the quantity of velocity."

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{+15.0\,\text{m}}{3.0\ \text{s}} = +5.0\ \text{m/s}$$

The velocity of the van is 5.0 m/s in the positive direction (to the right).

So we have arrived at the final mode of representing concepts in physics, which is the **symbolic mode**.

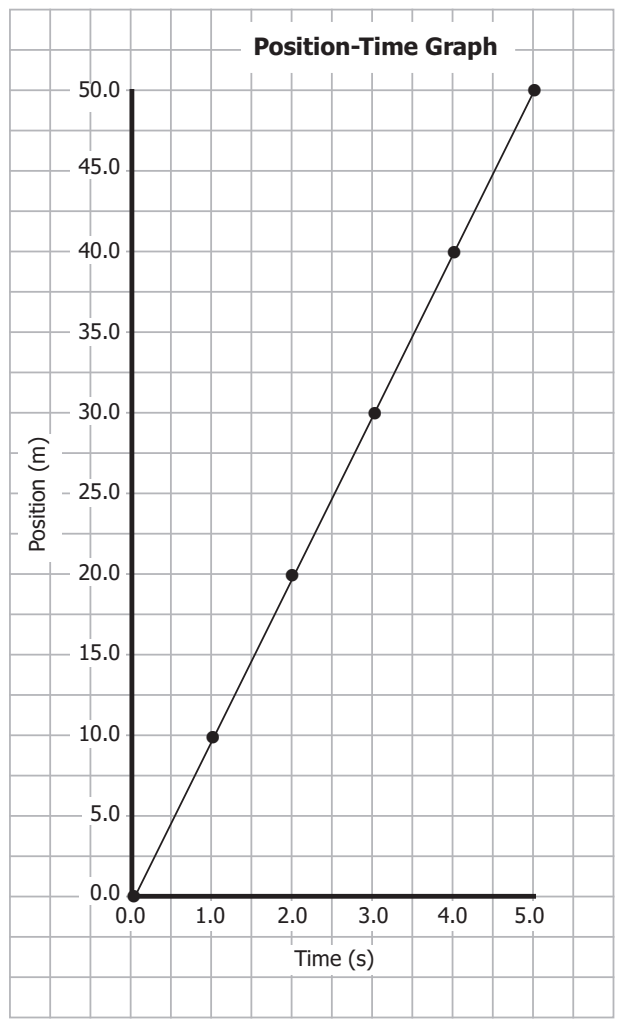
We can use the symbolic mode (commonly called an equation) to make predictions about the motion under consideration.

For example, let's consider a situation where the van is travelling at +10.0 m/s. Assume that at time t = 0 s, the van is at 0.0 m. Your task is to start with the symbolic mode and work backwards to the visual representation.

The equation can be used to predict the position of the van at a given time.

If the velocity is +10.0 m/s and the time is 1.0 s, the van will have a displacement during that 1.0 s of +10 m.

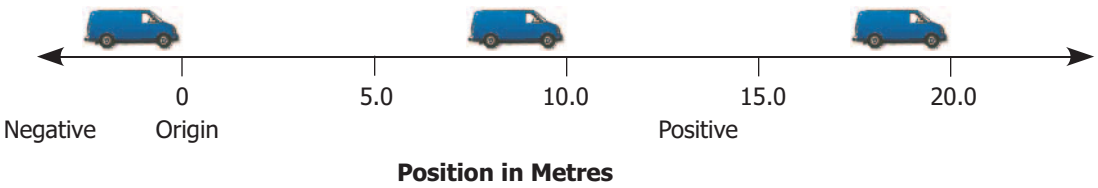
You can plot these two points on a position-time graph. Similarly, knowing the van moves +10 m every second, you can successively plot the position of the van for 3.0 s, 4.0 s, and 5.0 s.



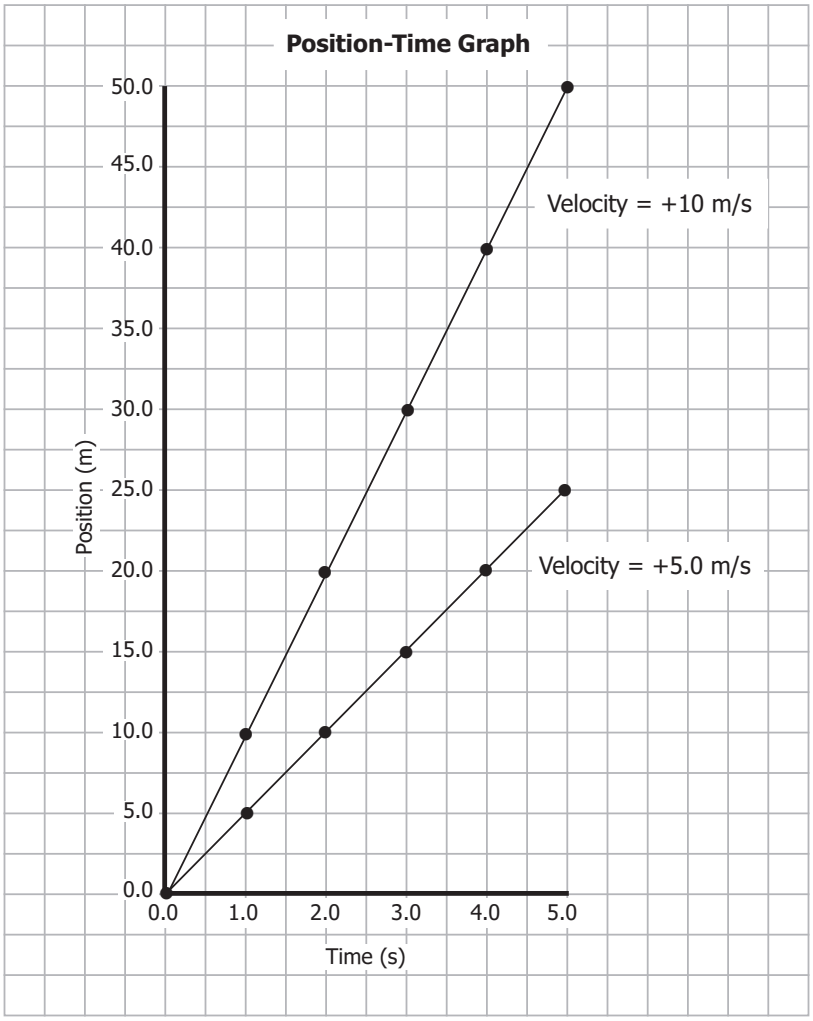
From the graph, you can construct a table of time and position for the van.

Time(s)	Position (m)
0	0
1.0	10.0
2.0	20.0
3.0	30.0
4.0	40.0
5.0	50.0

From the data table, you can reconstruct the visual representation of the motion of the van. To keep the same scale, we can only show three positions for the van.



Let's go back to the graph and compare the two lines.



The larger the velocity of the van, the steeper is the slope of the line on the position-time graph of the motion.

Velocity and the Position-Time Graph

The velocity of an object can be found from a position-time graph.

On a position-time graph, the displacement is the vertical separation of the two points: $\vec{d} = \overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1$.

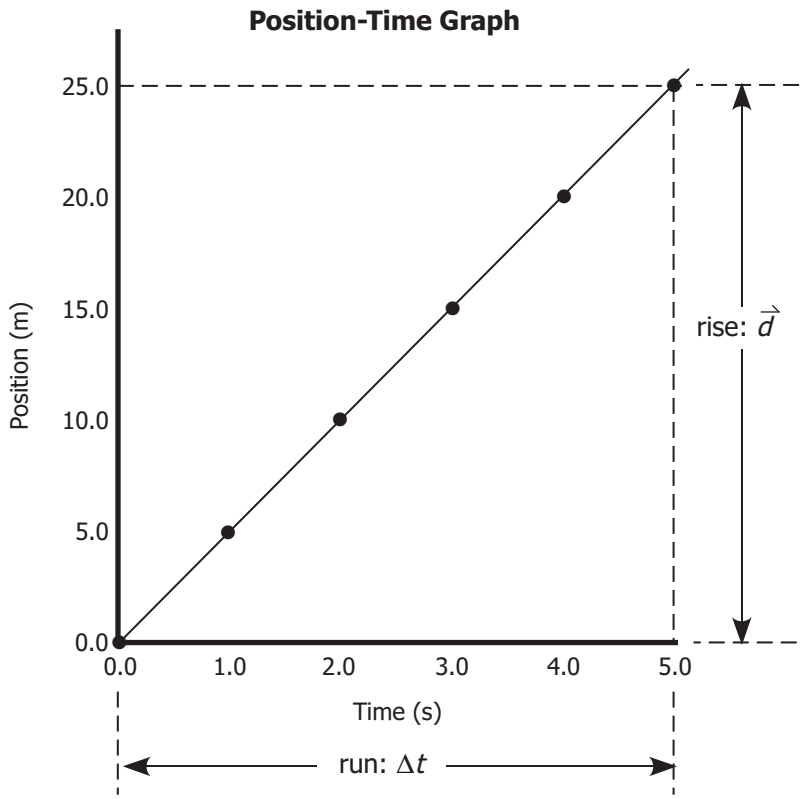
A time interval is the horizontal separation: $\Delta t = t_2 - t_1$.

By definition, the ratio of displacement to the time interval is the average velocity: $\vec{v} = \frac{\vec{d}}{\Delta t}$.

From mathematics, the ratio of the vertical separation of two points on a curve, or rise, to the horizontal separation of the points, or run, is the slope of a graph. That is,

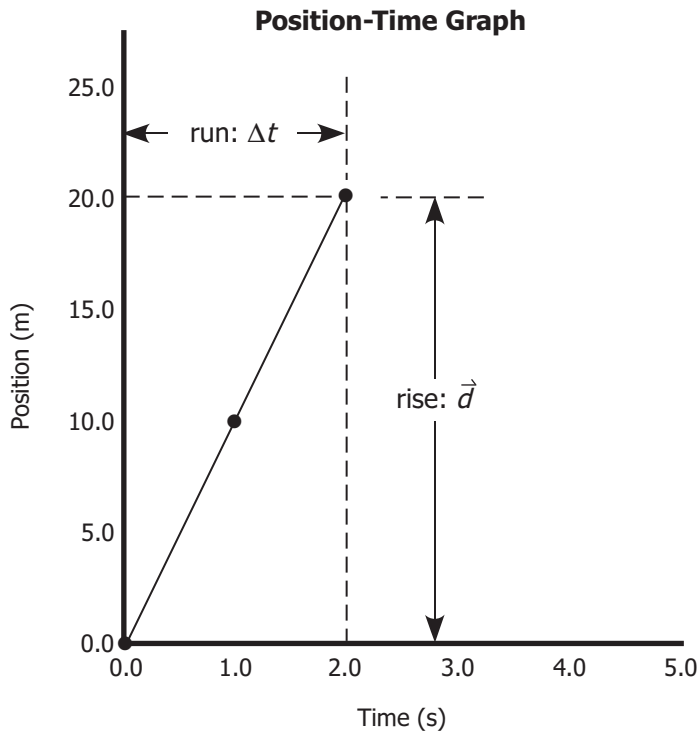
$$\text{slope} = \frac{\text{rise}}{\text{run}} \text{ or}$$

$$v = \frac{d}{\Delta t} = \frac{+4 \text{ m}}{10 \text{ s}} = +0.4 \text{ m/s}$$



In the graph above, the rise is 25.0 m and the run is 5.0 s. Therefore, the velocity is:

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{25.0 \text{ m}}{5.0 \text{ s}} = 5.0 \text{ m/s}$$



For this graph, the rise is 20.0 m and the run is 2.0 s. The velocity is:

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{20.0 \text{ m}}{2.0 \text{ s}} = 10 \text{ m/s}$$

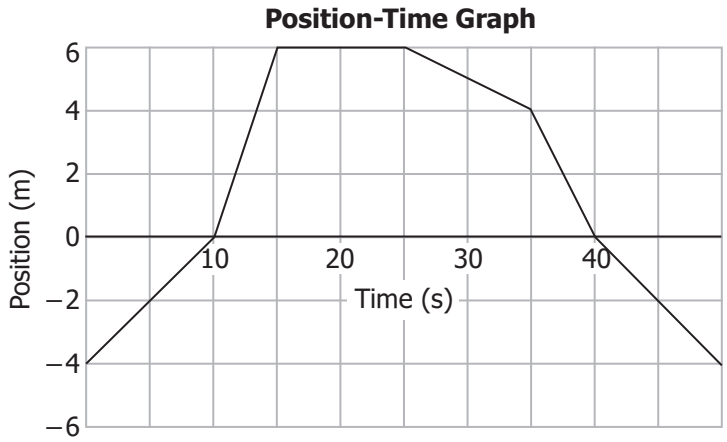
In general, **velocity** is given by the slope of a **position-time graph**.

$$\text{slope} = \frac{\text{rise}}{\text{run}} \text{ or } \vec{v} = \frac{\vec{d}}{\Delta t}$$

Learning Activity 1.7

Position-Time Graph: Part 1

Answer these questions, and then check your answers in the answer key at the end of the module.



The position-time graph above represents the motion of a remote-controlled toy truck as it moves back and forth along a straight-line path. The origin marks the position of the boy who controls the truck. The boy has not yet learned how to make the truck change its direction of motion.

A positive position marks positions to the right of the boy, and a negative position marks positions to the left of the boy.

1. During which time intervals is the truck to the right of the boy? …to the left of the boy?
2. During which time intervals is the truck moving in the positive direction? …in the negative direction? …not moving?
3. What is the position of the of the truck at 0 seconds? _____ 15 seconds?_____ 30 seconds? _____ 45 seconds? _____
4. When is the truck in front of the boy?

(continued)

Learning Activity 1.7: Position-Time Graph: Part 1

The graph of position-time **directly** gives some information about the motion. This tells the position-time version of the story of this motion—that is, where the truck is at a particular instant in time.

The graph of position-time also gives **indirect** information about the motion of the truck.

The following questions deal with obtaining this indirect information, such as distance travelled, displacement, average speed, and average velocity.

5. How far did the truck travel during the following time intervals?

   0–10 s _____ 10–15 s_____ 15–25 s_____ 25–35 s_____

   35–40 s _____ 40–50 s_____

6. What was the displacement of the truck during the following intervals?

   0–10 s _____ 10–15 s_____ 15–25 s_____ 25–35 s_____

   35–40 s _____ 40–50 s_____

7. Average speed is given by the distance travelled divided by the time interval. Calculate the average speed for each interval.

   0–10 s _____

   10–15 s_____

   15–25 s_____

   25–35 s_____

   35–40 s _____

   40–50 s_____

8. The following relationship is used to calculate average velocity:

   average velocity = displacement/time interval or $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

   This relationship also represents the slope of the line on a position-time graph.

(continued)

Learning Activity 1.7: Position-Time Graph: Part 1

Calculate the average velocity for each time interval by calculating the slope of the line segment. Show your work.

Run = Δt **Time Interval**	**Rise = $\vec{d}$** **Displacement**	**Slope = $\vec{v} = \frac{\vec{d}}{\Delta t}$**

9. How do the signs of the velocities in #8 compare with the direction of motion in #2?

10. In terms of the truck's motion, what does a negative velocity mean?

    A positive velocity?

    A velocity of 0 m/s?

Average Velocity

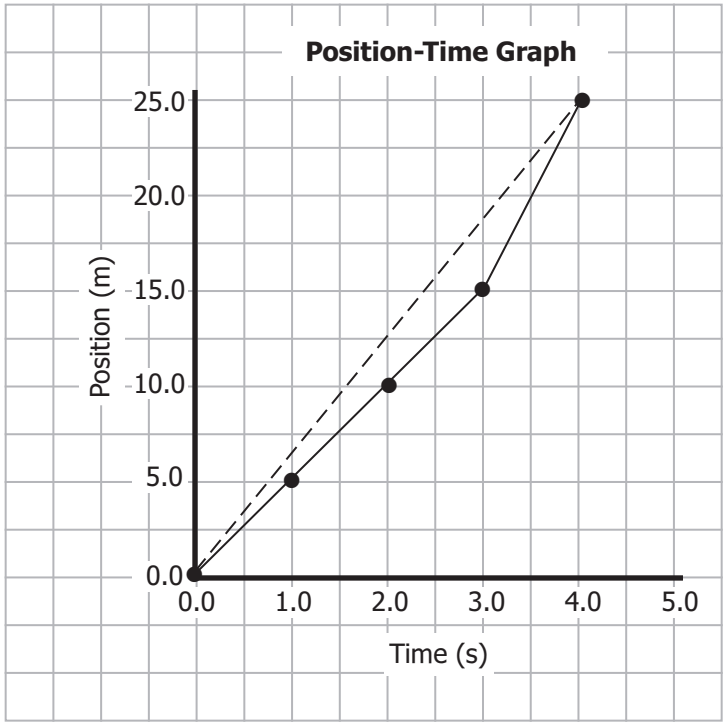
In the graphs of the van, the velocity of the van was constant over the time periods indicated.

> The motion of an object with constant velocity is called **uniform motion**.

Constant velocity is indicated by an object moving at a steady pace, not speeding up or slowing down or changing the direction of motion.

The first graph of the first case showed a constant velocity of 5.0 m/s for 5.0 s, and the second graph of the second case showed a constant velocity of 10.0 m/s for 5.0 s. For these graphs, the average velocity and the velocity over a short time interval will have the same value because the velocity is constant.

Now let us look at a situation where the velocity may vary over a time interval. The graph below shows two different constant velocities over a time interval.



In the first three seconds, the velocity is constant. During this time the velocity is:

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{15.0 \text{ m}}{3.0 \text{ s}} = 5.0 \text{ m/s}$$

Between the time of 4.0 s and 5.0 s, the velocity is also constant but different from the first three seconds. This second velocity is:

$$\vec{v} = \frac{25.0 \text{ m} - 15.0 \text{ m}}{4.0 \text{ s} - 3.0 \text{ s}} = 10.0 \text{ m/s}$$

To determine the average velocity over the full 4.0 s, we first draw a line called a chord that joins the initial position to the final position.

> The slope of the chord joining two points on a position-time graph yields the **average velocity** for that time interval.

This line has a rise of 25.0 m over a run of 4.0 s. Therefore, the average velocity is:

$$\vec{v}_{\text{avg}} = \frac{25.0 \text{ m}}{4.0 \text{ s}} = 6.25 \text{ m/s or } 6.2 \text{ m/s}$$

Note that the answer *is not* the average of the velocities—that is,

$$\frac{5.0\ \text{m/s} + 10.0\ \text{m/s}}{2} = 7.5\ \text{m/s}.$$

In general, we can say that the average velocity is given by the slope of the line joining two points on a position-time graph.

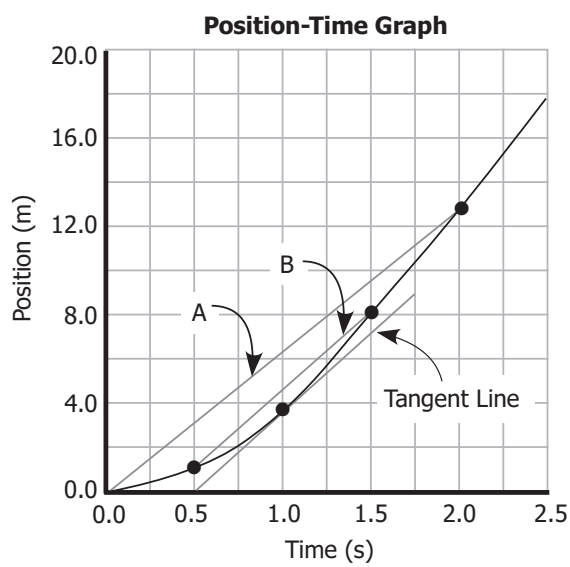
To confirm this, we can find the average velocity another way. We determine the total displacement for the trip and divide by the total time. In this case, the total displacement over the two intervals is $\vec{d}$ = 15.0 m + 10.0 m = 25.0 m. The total time over the two intervals is Δt = 3.0 s + 1.0 s = 4.0 s. Therefore, the average velocity is:

$$\vec{v}_{\text{avg}} = \frac{25.0\ \text{m}}{4.0\ \text{s}} = 6.25\ \text{m/s or } 6.4\ \text{m/s}$$

Instantaneous Velocity

When a person is driving a car, the speedometer will show the speed of the car. If the speedometer swings from 40 km/h to 60 km/h, the car is speeding up. If the driver glances at the speedometer and the needle reads 50 km/h, it means that, at that instant, the speed was 50 km/h. In other words, the instantaneous velocity was 50 km/h. That is, if its velocity had been constant, the car would have driven 50 km in 1 h.

We can use a position-time graph to find instantaneous velocity. When a runner does a 100 m dash, the first two seconds (or so) are used to speed up. The position is changing so that the curve is a smooth line.



Suppose we wanted to find the velocity of the person at 1.00 s.

We can start by finding the average velocity over 2.0 s (using line A above). After 2.0 s, the displacement is 12.5 m. The slope of the line from 0.00 s to 2.0 s is $\vec{v}_{avg} = \frac{12.5\text{ m}}{2.0\text{ s}} = 6.25\text{ m/s}$.

Now we choose a smaller time interval—the one between 0.5 s and 1.5 s (using line B above). The displacement interval is 6.8 m (8.0 m – 1.2 m) and the time interval is 1.0 s. The slope of the connecting line is, therefore, 6.8 m/s.

This process could be continued, choosing the time interval to be smaller and smaller until the two clock readings are almost the same. When this happens, we can no longer draw a line connecting the two points. We draw a straight line that is tangent to the curve at this point.

A **tangent** to a curved line touches the curved line at one point only. At that point, the tangent has the same slope as the curved line.

The slope of the line that is tangent to the curved line on a position-time graph is called the **instantaneous velocity** at that instant.

A tangent line is shown above. The slope of this line is $\vec{v} = \frac{8.8\text{ m} - 0.0\text{ m}}{1.75\text{ s} - 0.50\text{ s}} =$ 7.0 m/s, and this is the instantaneous velocity of the runner at 1.0 s.

You can see then that we have three types of velocities. We can calculate each velocity from a position-time graph.

In all cases, we take the slope of a line on the position-time graph to determine the velocity.

1. If the line on the position-time graph is a straight line, the velocity is uniform. The **slope of this straight line** gives the **constant average velocity** over that **time interval**.
2. If the line on the position-time graph is not straight but curved or it consists of line segments of different slopes, then we can calculate an **average velocity** for a given time interval. First, draw a chord from the initial position to the final position. The **slope** of this **chord** gives the **average velocity** over this **time interval**.
3. If the line on the position-time graph is a curve, then the slope is always changing. To determine the **instantaneous velocity** at an instant in time (not a time interval), draw a **tangent** to the curve at that time instant.

The **tangent** is drawn so that it runs in the same direction as the curve at that point in time.

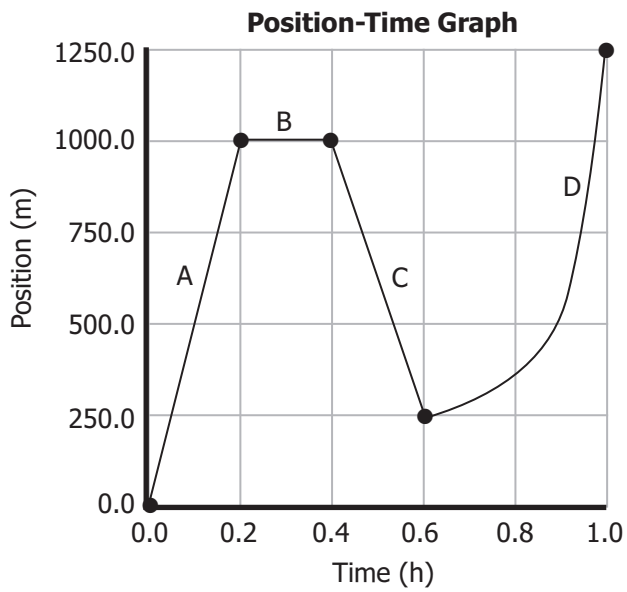
The **slope** of the **tangent** gives the **instantaneous velocity** (the velocity at that **instant**).

Learning Activity 1.8

Position-Time Graph: Part 2

Answer this question, and then check your answers with the answer key at the end of this module.

The graph below shows a possible situation for a person who is exercising.



a) For the segments A to C above, calculate the velocity. (Note: Convert each of the time intervals into seconds so that the units of velocity are recorded in m/s. 1 h has 3600 s.)

b) During which of the time intervals, A to C, was the runner moving the fastest?

(continued)

Learning Activity 1.8: Position-Time Graph: Part 2 (continued)

c) During which of the time intervals was the runner returning towards the starting point?

d) During which of the time intervals was the runner most likely resting?

e) What was the average velocity over the whole run?

f) For the time interval corresponding to D, determine the instantaneous velocity at a position of 500.0 m.

Lesson Summary

A **position-time graph** is a graph that shows how the position depends on the clock reading, or time. Some information on a position-time graph is found **directly** from the graph. Just by looking at the graph, you can determine the position of an object at a certain time or the time at which an object is at a certain position.

Other information on a position-time graph is found **indirectly** from the graph. This type of information involves some sort of calculation.

Knowing two clock readings on the graph, you can calculate a **time interval**: $\Delta t = t_2 - t_1$.

The time interval corresponds to the **run** between two points.

Knowing two positions on the graph, you can calculate a **displacement**: $\vec{d} = \overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1$.

The displacement corresponds to the **rise** between two points.

For an object that is moving faster, the slope of the graph is greater.

The ratio of the vertical separation of two points on a curve, a displacement or rise, to the horizontal separation of the points, the time interval or run, is the **slope** of a graph. That is, $\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\vec{d}}{\Delta t}$.

The **slope** of a line on position-time graph over a **time interval** is the **average velocity** of the mass. If the line on the position-time graph is a **straight line**, the velocity is **constant** over that time interval. The **average velocity** is the same as this **constant velocity** for the time interval.

If during the time interval there are several lines with different slopes on the position-time graph, it is necessary to first draw a **chord** joining the initial position to the final position. The **slope** of this **chord** represents **the average velocity** during this time interval.

If the line on the position-time graph is a **curve**, it is necessary to draw a **tangent** to this curve at the instant in time for which we want to determine the velocity. The **slope** of the **tangent** to the line on a position-time graph is called the **instantaneous velocity** at that instant in time.

The larger the slope of the line on a position-time graph, the larger the velocity.

Website: Motion Graphs

The following website includes an applet that simulates the motion of a car: www.walter-fendt.de/ph14e/acceleration.htm.

Graphs of position-time, velocity-time, and acceleration-time are drawn in real time with the motion.

To simulate uniform motion (constant velocity), press Reset, and set the velocity to 2.00 m/s and the acceleration to 0 m/s/s. Press Enter and run the simulation.

To simulate accelerated motion, press Reset, and set the velocity to 0 m/s and the acceleration to 1.00 m/s/s. Press Enter and run the simulation.

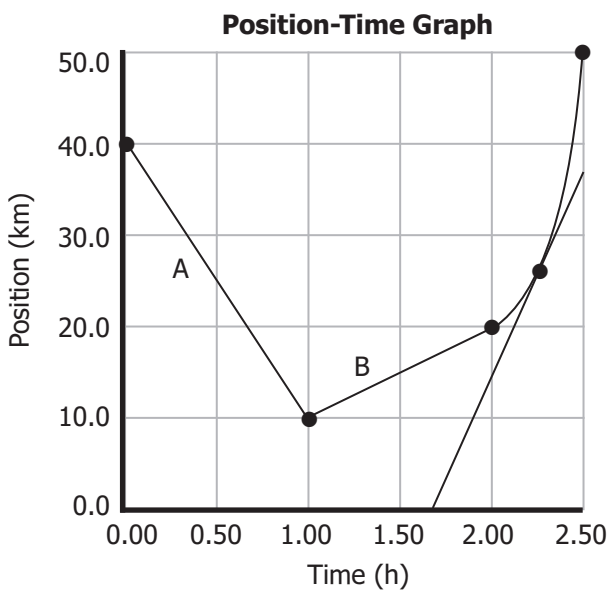
Observe the effect of changing the initial velocity and the acceleration.

Assignment 1.1, Part D

Position-Time Graph 1 (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 1, after you have completed Module 1.

The physics of a position-time graph and a moving bus
The following graph shows the motion of a bus. When calculating the velocities in the questions below, do so in units of km/h.



a) Determine the velocity of the bus from 0.00 h to 1.00 h.

Equation

Substitution:

Solving:

(continued)

Assignment 1.1, Part D: Position-Time Graph 1 (continued)

b) What was the average velocity of the bus over the whole 2.50 h?

Equation:

Substitution:

Solving:

c) Compare the motion of the bus in Parts A and B. In your answer, discuss the direction in which the buses are moving, and compare the magnitudes of their velocities.

d) What was the instantaneous velocity at 2.25 h?

Equation:

Substitution:

Solving:

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining the correct velocity for part (a)
- 1 mark for determining the correct average velocity for part (b)
- 1 mark for comparing the direction of velocity for part (c)
- 1 mark for comparing the correct magnitude of velocity for part (b)
- 1 mark for determining the correct instantaneous velocity for part (d)

Lesson 5: Analyzing Velocity-Time Graphs Using Slope (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ calculate the acceleration of an object given a velocity-time graph
- ❑ draw an acceleration-time graph from a given velocity-time graph
- ❑ determine the average acceleration from a velocity-time graph

Key Words

acceleration
slope
change in velocity

Introduction

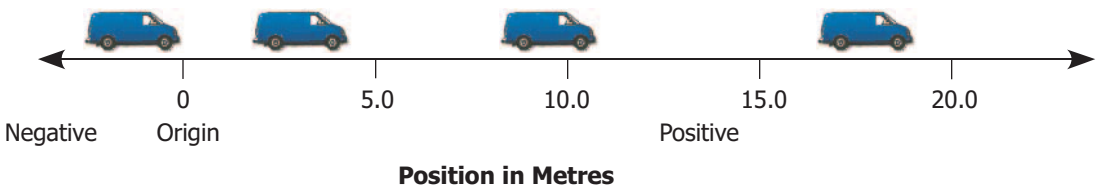
So far we have studied the position-time version of the story of the motion and determined velocity. In this lesson, we expand our discussion of graphing in kinematics. We begin with another version of the story of the motion, a graph of velocity versus time. This version describes how the object is moving (which way, how fast). We then define the term "acceleration," and discover how to determine acceleration from a velocity-time graph. You should then be able to plot an acceleration-time graph.

The idea is that in describing motion we can use three different versions of the same story: a position-time version, a velocity-time version, and an acceleration-time version. With any story, you should be able to take one version and construct the other versions of the story. Your task in this lesson will involve taking one version of the story of a motion (velocity-time) and constructing another version (acceleration-time).

For the purposes of this course, graphing these graphs will occur only for the case of constant acceleration.

Average Acceleration

Below is a graphic showing the van we mentioned earlier. This time you can see that in successive equal time intervals (between snapshots of the van) the van is travelling a greater distance. This is an indication that the van is not moving with a constant velocity, but the velocity is increasing. This is an example of **acceleration**.



When the velocity changes, we say the object is accelerating.

We can define the **average acceleration** as the rate of change of velocity:

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}}$$

Acceleration is defined as the rate of change of velocity. Acceleration is calculated by taking the change in velocity and dividing it by the time interval.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$

Quantity	Symbol	Unit
Acceleration	$\vec{a}$	metres/second squared (m/s^2)
Change in velocity	$\Delta\vec{v}$	metres/second (m/s)
Time interval	Δt	seconds(s)
Initial velocity	$\vec{v}_1$	metres/second (m/s)
Final velocity	$\vec{v}_2$	metres/second (m/s)

The SI unit of velocity is the metres per second (m/s), and the unit of time is the second (s). The SI unit of average acceleration is the metre per second squared (m/s^2).

Example: Calculating Acceleration

A person is running. The runner changes velocity going from +5.0 m/s to +7.0 m/s in a time of 1.0 s. What is the acceleration?

Given: Let right be the positive direction.

Initial velocity $\vec{v}_1 = +5.0 \text{ m/s}$

Final velocity $\vec{v}_2 = +7.0 \text{ m/s}$

Time interval $\Delta t = 1.0 \text{ s}$

Unknown: acceleration $\vec{a} = ?$

Equation: $$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$

Substitute and solve: $$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{(+7.0 \text{ m/s}) - (+5.0 \text{ m/s})}{1.0 \text{ s}}$$

$$= \frac{+2.0 \text{ m/s}}{1.0 \text{ s}} = +2.0 \text{ m/s}^2$$

The runner accelerates at 2.0 m/s^2 to the right. In other words, he increases his velocity by 2.0 m/s every second.

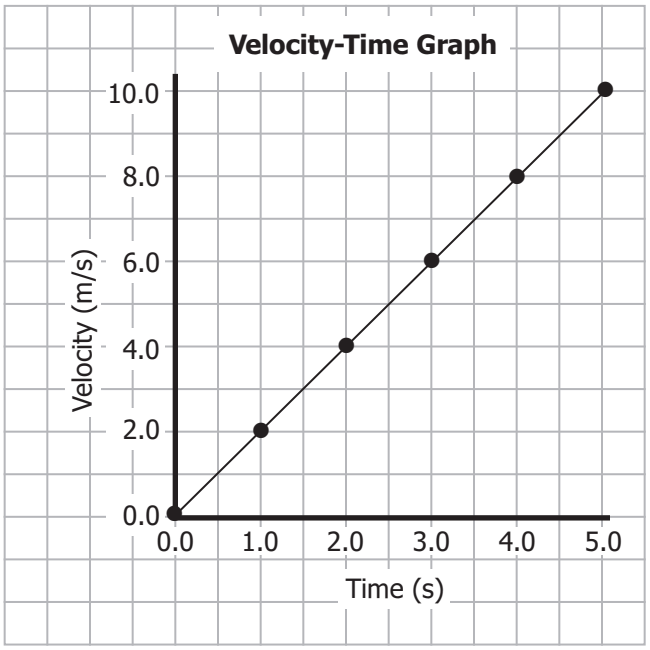
Velocity-Time Graph for Accelerated Motion

Let's take this information about the runner and produce a velocity-time graph.

Let's assume that the runner begins with a velocity of 0.0 m/s at a time of 0.0 seconds. From the acceleration of +2.0 m/s^2, you know that the runner increases his velocity by 2.0 m/s every second. This information is listed in the data table below.

Time(s)	Velocity (m/s)
0.0	0.0
1.0	2.0
2.0	4.0
3.0	6.0
4.0	8.0
5.0	10.0

These data are plotted in the graph below. You can see that the velocity is changing uniformly from 0.0 m/s to 10.0 m/s over a time period of 5.0 s.



Earlier we saw that the slope of a position-time graph gives the rate of change of the displacement, which is the velocity.

> Now we see that **the slope of a velocity-time graph gives the rate of change of velocity— that is, the acceleration**.

Information on a Velocity-Time Graph

In the lesson on position-time graphs, you saw that there is certain information that can be obtained **directly** from the graph and **indirectly** from the graph.

Just by looking at a velocity-time graph, you can read the velocity at a given instant in time or the time for a given velocity. This is the **direct** information we obtain from a velocity-time graph.

The **indirect information**, you will remember, requires that you do a calculation. On a velocity-time graph, you can calculate the following using two points on the line:

- a time interval, Δt
- a change in velocity, $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$

and by calculating the slope, the acceleration, $\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$.

Average Acceleration

On a position-time graph, you found the average velocity by drawing a chord joining two points on the position-time graph and determining the slope of this chord. The average velocity was equal to the slope of the chord.

Using the identical technique, you can determine the average acceleration on a velocity-time graph.

On that velocity-time graph, select two points on the line and draw a chord joining those two points.

> The **slope** of the chord on a **velocity-time** graph yields the **average acceleration**.

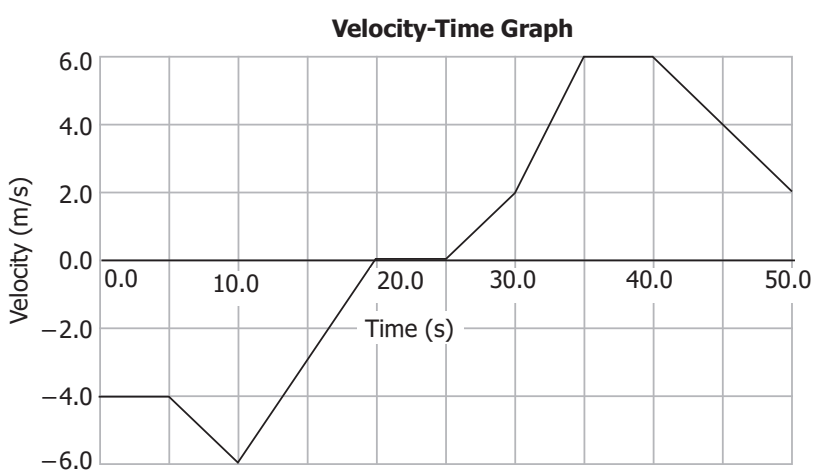
On a position-time graph, you determined the instantaneous velocity at a given point in time by drawing the tangent to the line. The slope of the tangent to the line on a position-time graph yielded an average velocity.

Again, using the identical technique, you can determine the instantaneous acceleration on a velocity-time graph.

> To determine the **instantaneous acceleration**, draw a **tangent** to the line on the **velocity-time graph** at the time in question. The **instantaneous acceleration** is given by the **slope** of this **tangent**.

In Grade 11 Physics, we will consider motion only with a constant acceleration. Therefore, the lines on a velocity-time graph will be straight lines. The instantaneous acceleration at any point in time along the straight line will just be given by the slope of that straight line.

Example: Analyzing a Velocity-Time Graph



1. During which interval(s) is the
   a) velocity uniform?

      A uniform velocity means the velocity is constant. This occurs during these intervals: 0 – 5 s, 20 –25 s, and 35 to 40 s.

   b) average acceleration positive?

      Slope on the velocity-time graph represents acceleration and a line with a positive slope represents a positive acceleration. This occurs during the intervals from 10 to 20 seconds, 25 to 30 seconds, and 30 to 35 seconds

   c) average acceleration negative?

      Lines with a negative slope will have a negative acceleration. This occurs during the intervals from five to 10 seconds and 40 to 50 seconds.

   d) average acceleration zero?

      An acceleration of zero is given by a line with the slope of zero. The acceleration of zero and during the intervals from zero to five seconds, 20 to 25 seconds, and 35 to 40 seconds.

   e) average acceleration uniform?

      A uniform or constant acceleration is illustrated by a straight line on a velocity-time graph. Since all of the lines are straight, the acceleration during each interval is uniform or constant.

2. During which interval(s) is the instantaneous velocity
   a) zero?

      This is direct information. You're being asked during which time intervals is the velocity zero. The velocity is zero from 20 to 25 seconds.

   b) positive?

      The velocity is positive for all times from 25 to 50 seconds.

   c) negative?

      The velocity is negative for all times from zero to 20 seconds.

3. What is the average acceleration between
   a) 0 and 10 s?

      Draw a chord from (0.0 s, –4.0 m/s) and (10.0 s, –6.0 m/s). The slope of this chord gives the average acceleration.

$$\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{(-6.0\ \text{m/s}) - (-4.0\ \text{m/s})}{10.0\ \text{s}} = -0.20\ \text{m/s}^2$$

b) 10 and 20 s

$$\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{(0.0\ \text{m/s}) - (-6.0\ \text{m/s})}{10.0\ \text{s}} = +0.60\ \text{m/s}^2$$

c) 25 and 40 s

$$\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{(+6.0\ \text{m/s}) - (0.0\ \text{m/s})}{15.0\ \text{s}} = +0.40\ \text{m/s}^2$$

d) for the whole trip

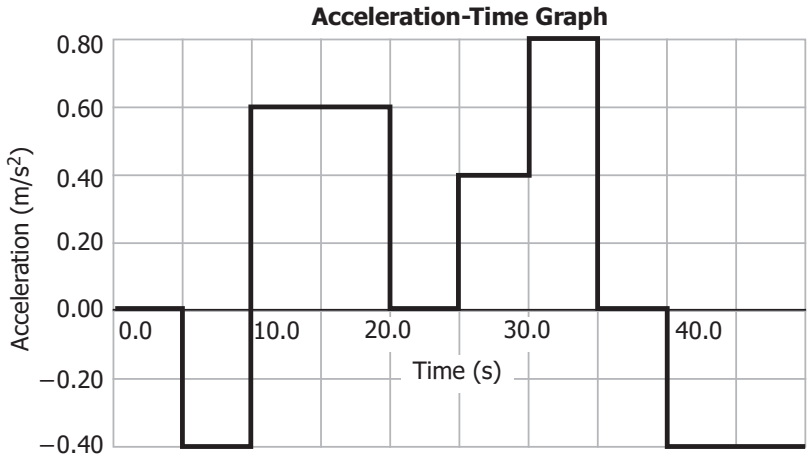
$$\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{(+2.0\ \text{m/s}) - (-4.0\ \text{m/s})}{50.0\ \text{s}} = +0.12\ \text{m/s}^2$$

4. Using the appropriate chart, draw the acceleration-time graph that accompanies this velocity-time graph.

Determining acceleration from a velocity-time graph requires that you take slope. A chart then should contain a column for the run (time interval), a column for the rise (change in velocity), and a column for the slope (acceleration).

Run	**Rise**	**Slope**
Time Interval (s)	Change in velocity (m/s) $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$	Acceleration (m/s^2) $\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$
0.0–5.0	(–4.0 m/s) – (–4.0 m/s) = 0.0	0.0 m/s ÷ 5.0 s = 0.0 m/s^2
5.0–10.0	(–6.0 m/s) – (–4.0 m/s) = –2.0	–2.0 m/s ÷ 5.0 s = –0.40 m/s^2
10.0–20.0	(0.0 m/s) – (–6.0 m/s) = +6.0	+6.0 m/s ÷ 10.0 s = +0.60 m/s^2
20.0–25.0	(0.0 m/s) – (0.0 m/s) = 0.0	0.0 m/s ÷ 5.0 s = 0.0 m/s^2
25.0–30.0	(+2.0 m/s) – (0.0 m/s) = +2.0	+2.0 m/s ÷ 5.0 s = + 0.40 m/s^2
30.0–35.0	(+6.0 m/s) – (+2.0 m/s) = +4.0	+4.0 m/s ÷ 5.0 s = +0.80 m/s^2
35.0–40.0	(+6.0 m/s) – (+6.0 m/s) = 0.0	0.0 m/s ÷ 5.0 s = 0.0 m/s^2
40.0–50.0	(+2.0 m/s) – (+6.0 m/s) = –4.0	–4.0 m/s ÷ 10.0 s = –0.40 m/s^2

Since the slope is constant over each interval, the graph of the acceleration-time will be a series of horizontal lines. The resulting acceleration-time graph will consist of what looks like a series of bars.



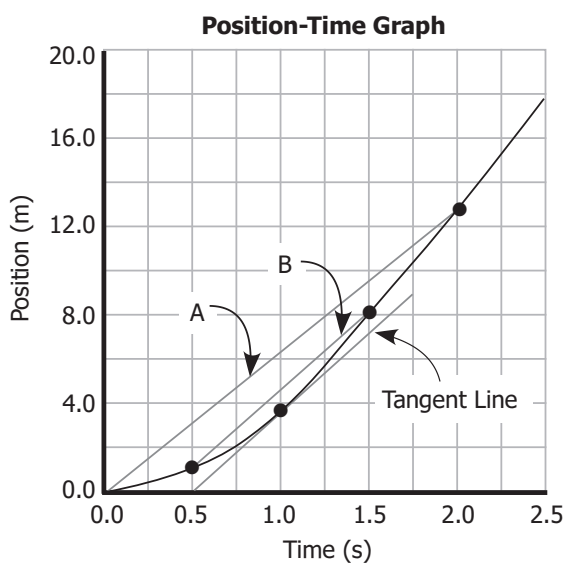
Video Laboratory Activity: Kinematics

In this lab activity, you will view *Kinematics*, a short video laboratory activity found in the learning management system (LMS). You will collect some data from the video, so begin by reading the introduction and answering the pre-lab questions.

When you have finished the lab, you will complete a laboratory report, which is included at the end of this (and every other) laboratory assignment. The laboratory report is the only part of this assignment that you will submit for assessment. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

Introduction

The slope of the line that is tangent to the curved line on a position-time graph is called the **instantaneous velocity** at that instant. In this assignment, we will make use of an approximation of the instantaneous velocity at the midpoint of an interval. If our interval is small enough, then the slope of the tangent at the midpoint is very nearly the slope of the line joining the endpoints. In this position-time graph, the slope of the tangent line at time = 1 second is nearly the same as the slope of line B joining the endpoints $t = 0.5$ s and $t = 1.5$ s. Using this approximation, we can easily calculate the instantaneous velocity from our data tables without drawing tangent lines on our graphs.

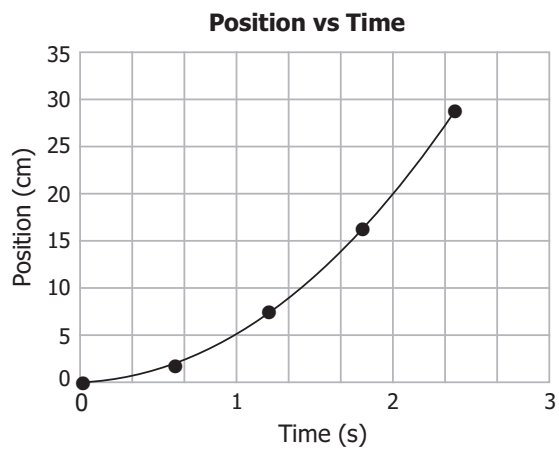


Sample Problem

Consider the following data table for a moving object:

Position (cm)	Time (s)
0	0
1.8	0.6
7.2	1.2
16.2	1.8
28.8	2.4

The graph of position versus time would be:



To find the average velocity for the first interval from $t = 0$ s to $t = 0.6$ sec, we use the following:

Approximates the instantaneous velocity at 0.3 s (the midpoint between $t = 0$ s and $t = 0.6$ s).

$$\vec{v}_{avg} = \frac{\vec{d}}{\Delta t}$$

$$\vec{v}_{avg} = \frac{1.8 - 0}{0.6 - 0}$$

$$\vec{v}_{avg} = 3.0 \text{ cm/s}$$

This value also approximates the instantaneous velocity at the midpoint of the interval. (Remember that this approximation just saves us the effort of drawing a tangent on the graph and calculating the slope of the tangent.) Now we can use these calculations to complete a table for instantaneous velocity and time.

Velocity (cm/s)	Time (s)
3.0	0.3
9.0	0.9
15.0	1.5
21.0	2.1

Sample Calculations

Approximates the instantaneous velocity at 0.9 s (the midpoint between t = 0.6 s and t = 1.2 s).

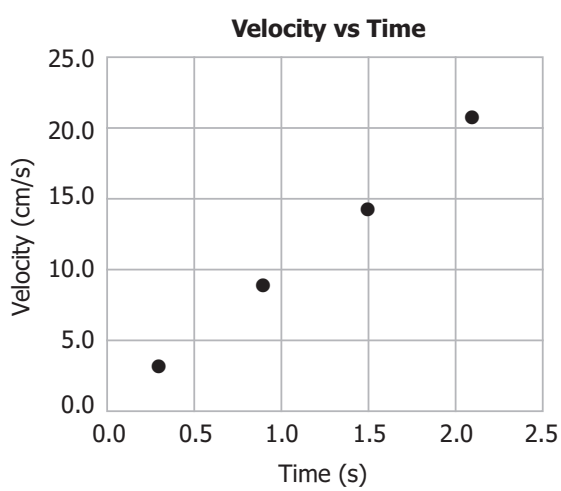
$$\vec{v}_{avg} = \frac{\vec{d}}{\Delta t}$$
$$\vec{v}_{avg} = \frac{7.2-1.8}{1.2-0.6}$$
$$\vec{v}_{avg} = 9.0 \text{ cm/s}$$

Approximates the instantaneous velocity at 1.5 s (the midpoint between t = 1.2 s and t = 1.8 s).

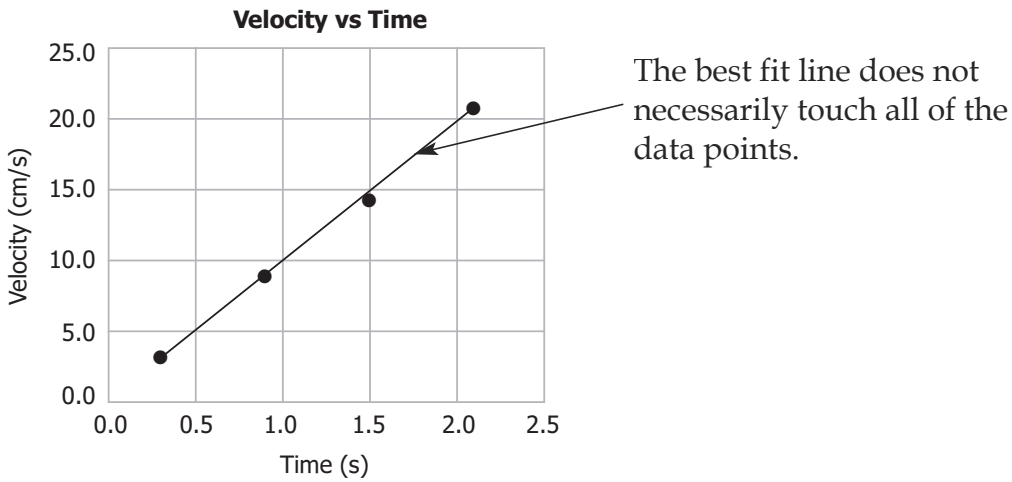
$$\vec{v}_{avg} = \frac{\vec{d}}{\Delta t}$$
$$\vec{v}_{avg} = \frac{16.2-7.2}{1.8-1.2}$$
$$\vec{v}_{avg} = 15 \text{ cm/s}$$

Approximates the instantaneous velocity at 1.5 s (the midpoint between t = 1.8 s and t = 2.4 s).

$$\vec{v}_{avg} = \frac{\vec{d}}{\Delta t}$$
$$\vec{v}_{avg} = \frac{28.8-16.2}{2.4-1.8}$$
$$\vec{v}_{avg} = 21 \text{ cm/s}$$



Notice that the points form nearly a straight line. Experimental error often results in lines that are nearly straight. In this case, we draw what is called a "best fit" line. That is, the straight line that best represents the data.



If the line is straight, then the slope (acceleration) is a constant. To find the acceleration, calculate the slope of the velocity-time graph. When you calculate the slope of a best fit line, be sure to use points that are on the line.

Video Viewing

View the video *Kinematics*, which can be found in the learning management system (LMS).

Purpose

To investigate the relationships between position, velocity, and acceleration for a mini-vehicle rolling down an inclined plane.

Apparatus

- inclined plane
- mini-vehicle
- stopwatch
- ruler

Procedure

1. Release the mini-vehicle from the top of the inclined plane.
2. Record the time at each interval in the table below.
3. Graph position versus time.
4. Calculate the average velocity for each interval from your data table and record the instantaneous velocity at the midpoint of each interval in a new table.
5. Graph instantaneous velocity versus time.
6. Draw a best fit line and calculate the slope (acceleration).

Data and Calculations

Position (cm)	Time (s)
0	
40	
80	
120	
160	
200	

Velocity (cm/s)	Time (s)

Acceleration = _____

Discussion

Discuss possible sources of error in this experiment and how you could reduce the error.

Conclusion

What do you conclude about the motion of an object rolling down an inclined plane?

NOTES

Assignment 1.2

Video Laboratory Activity: Kinematics (20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow these directions.

The Laboratory Report is the only part of this assignment that you submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words, in a brief paragraph (do not use point form), how the experiment was performed.

_____

_____

_____

_____

_____

(continued)

Assignment 1.2: Video Laboratory Activity: Kinematics (continued)

Data and Calculations:

- Include photocopies of your data measurements (e.g., tapes or tracks) if they were provided in the notes.
- The raw data for each part of the experiment should be recorded in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data (e.g., if you use a formula, write out the formula and show your substitutions and calculations). This should be done for each different calculation (i.e., whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be provided.

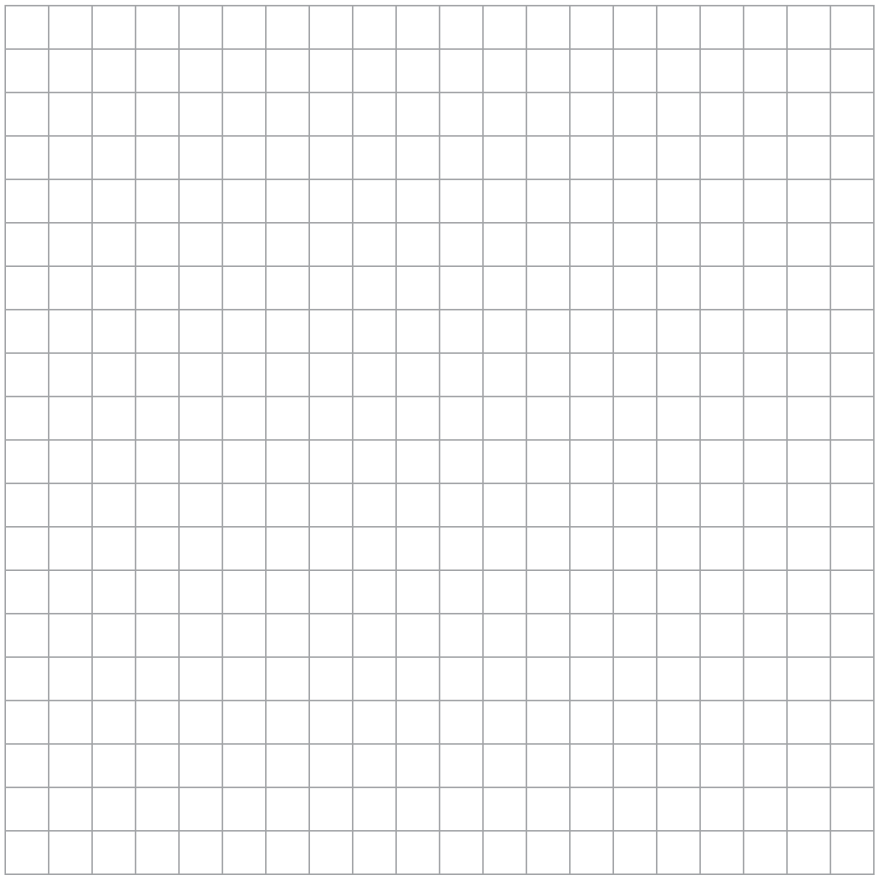
In the table record the time for which the car is at each of the following positions.

Position (cm)	Time (s)

(continued)

Assignment 1.2: Video Laboratory Activity: Kinematics (continued)

Graph Position versus Time on the grid below.



(continued)

Calculation of Instantaneous Velocity at the Midpoint of a Time Interval

Use the Position-Time graph above to determine the instantaneous velocity at the midpoint of each interval of time on the graph. The slope of the position-time graph for each interval gives the instantaneous velocity for that time interval. Record the midpoint of the time interval and the instantaneous velocity for that interval in the table below. Show one example of the calculation of instantaneous velocity in the space below.

Equation:

Substitution:

Solving:

Instantaneous Velocity at Midpoint (cm/s)	Midpoint of Time Interval

(continued)

Assignment 1.2: Video Laboratory Activity: Kinematics (continued)

Graph Velocity versus Time on the grid below.

From the Velocity-Time graph, calculate the average acceleration for the car. Show your work for a sample calculation.

Equation:

Substitution:

Solving:

(continued)

Assignment 1.2: Video Laboratory Activity: Kinematics (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce them.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. Errors are always made when making measurements. In the error analysis, your job is to look critically at the procedure, identify possible sources of error (there may be several), and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 1.2: Video Laboratory Activity: Kinematics (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

_____

_____

_____

_____

_____

Marking Rubric for Assignment 1.2

Section of Report	Possible	Actual
Purpose	1	
Apparatus and Procedure	2	
Completed Position-Time Table and Position-Time Graph	4	
Sample Instantaneous Velocity Calculation	2	
Completed Velocity-Time Table and Velocity-Time Graph	6	
Calculation of Average Acceleration	2	
Discussion	2	
Conclusion	1	
Total	**20**	

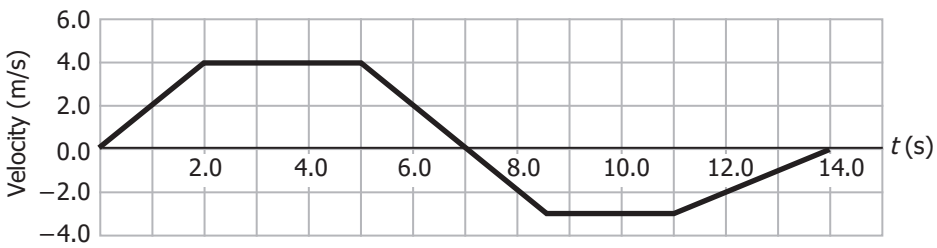
NOTES

Learning Activity 1.9

Velocity-Time Graph

There is one question in the following learning activity. Check your answer in the answer key at the end of the module.

1. For the velocity-time graph below, determine the acceleration for each interval. Fill in the chart with the appropriate information, and then plot a graph of acceleration versus time.



Run	Rise	Slope
Time Interval (s)	Change in velocity (m/s) $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$	Acceleration (m/s^2) $\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$
0.0–2.0	(+4.0 m/s) – (0.0 m/s) = +4.0	+4.0 m/s / 2.0 s = +2.0 m/s^2
2.0–5.0		

(continued)

Lesson Summary

Just by looking at a velocity-time graph, you can read the velocity at a given instant in time or the time for a given velocity. This is the **direct** information we obtain from a velocity-time graph.

The **indirect information**, you will remember, requires that you do a calculation. On a velocity-time graph, you can calculate using the following two points on the line:

- a time interval, Δt
- a change in velocity, $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$

and by calculating the slope, the acceleration, $\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$.

The **slope** of the **chord** on a **velocity-time** graph yields the **average acceleration**.

To determine the **instantaneous acceleration**, draw a **tangent** to the line on the **velocity-time graph** at the time in question. The **instantaneous acceleration** is given by the **slope** of this **tangent**.

The techniques for analyzing position-time and velocity-time graphs are identical.

The **slope** of a **position-time graph** gives **velocity-time** information.

The **slope** of a **velocity-time graph** gives **acceleration-time** information

The following graphic provides a visual representation of the relationships among the three graphs for motion and how we can transform one into the other by taking slopes.

Position-time graph

Take slope ↓ $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Velocity-time graph

Take slope ↓ $\vec{a} = \dfrac{\Delta \vec{v}}{\Delta t}$

Acceleration-time graph

Website

The following website includes an applet that simulates the motion of a car: www.walter-fendt.de/ph14e/acceleration.htm. Graphs of position-time, velocity-time, and acceleration-time are drawn in real time with the motion.

To simulate uniform motion (constant velocity), press Reset, set the velocity to 2.00 m/s and the acceleration to 0 m/s/s. Press Enter and run the simulation.

To simulate accelerated motion, press Reset, set the velocity to 0 m/s and the acceleration to 1.00 m/s/s. Press Enter and run the simulation.

Observe the effect of changing the initial velocity and the acceleration.

The following website includes an animation that requires the Adobe Flash Player:

http://faraday.physics.utoronto.ca/PVB/Harrison/Flash/ClassMechanics/ConstantAccel/ConstantAccel.html.

Run through the graphs for motion starting with position-time, then velocity-time, then acceleration-time, showing how the slope of one generates the value of the next graph.

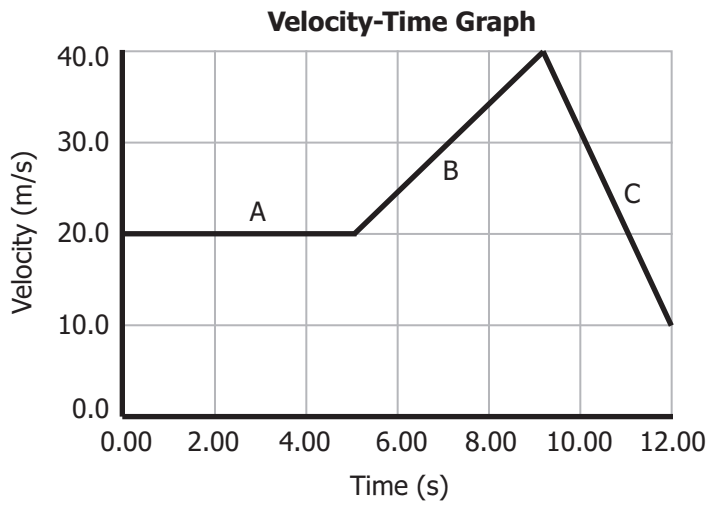
NOTES

Assignment 1.3, Part A

Acceleration-Time Graph (6 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 1, after you have completed Module 1.

The physics of a moving car and graphing.
The following graph describes the motion of a car.

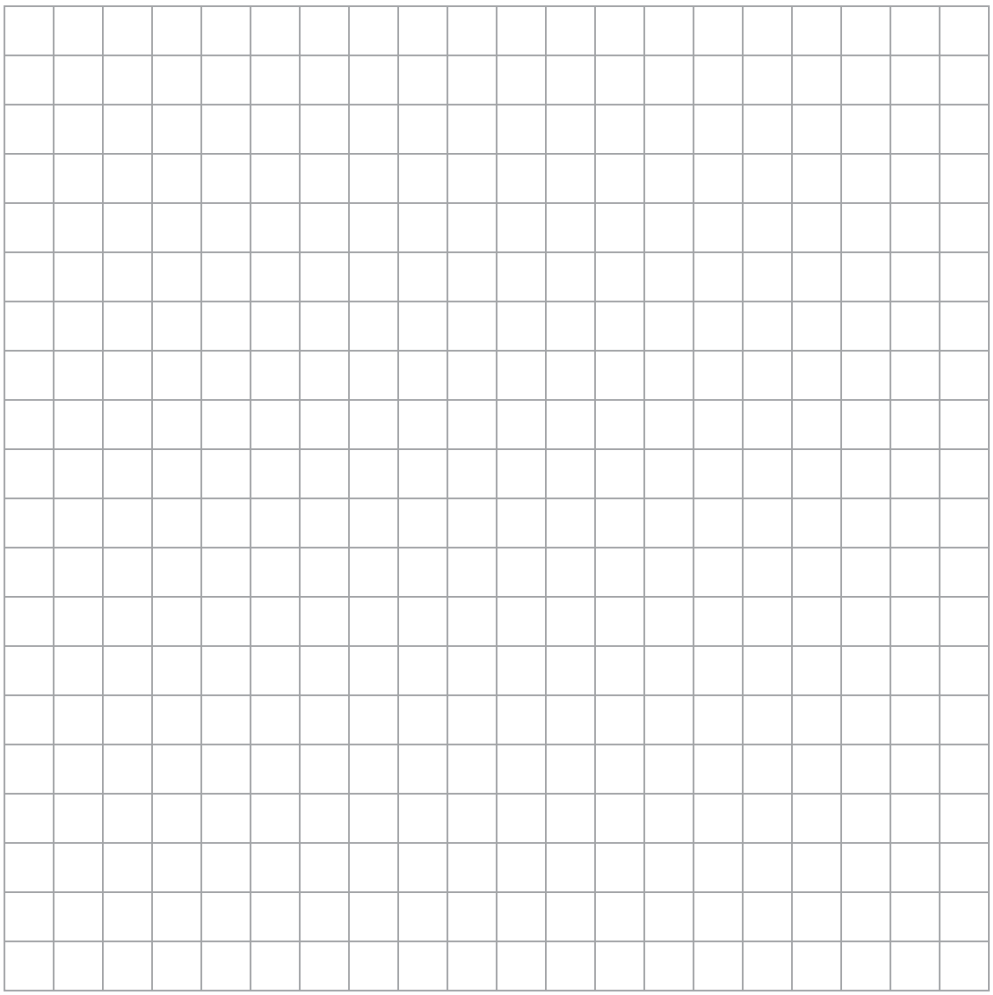


a) Complete the data table below showing time intervals and acceleration. Three time intervals corresponding to Regions A to C are shown. Show your work in the space provided in the table below.

Time Interval (seconds)	Change in Velocity (m/s)	Acceleration (m/s/s)
0.00–5.00		
5.00–9.00		
9.00–12.00		

Assignment 1.3, Part A: Acceleration-Time Graph (continued)

b) Graph the data to produce an acceleration-time graph.



Method of Assessment

The total of six marks for this assignment will be determined as follows:

- 1 mark for each of the three velocity data points in part (a)
- 1 mark for each of the three portions in the acceleration-time graph in part (d)

Lesson 6: Analyzing Motion Graphs Using Area (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ determine the displacement using the area on a velocity-time graph
- ❑ draw a graph of position-time for a given velocity-time graph
- ❑ determine the change in velocity using the area on an acceleration-time graph
- ❑ draw a graph of velocity-time for a given acceleration-time graph

Key Words

acceleration
velocity
area
displacement
change in velocity

Introduction

The idea to keep in mind in the study of the graphical representation of kinematics is that each graph tells a different version of the same story. We should be able to determine the motion that occurred regardless of which version of the story we are given.

In analyzing graphs, there are really only two things that can be calculated from a graph: the slope of the line, and the area between the line on the graph and the horizontal axis of the graph.

Up to now we have been using slopes to convert a position-time graph into a velocity-time graph, and to convert a velocity-time graph into an acceleration-time graph.

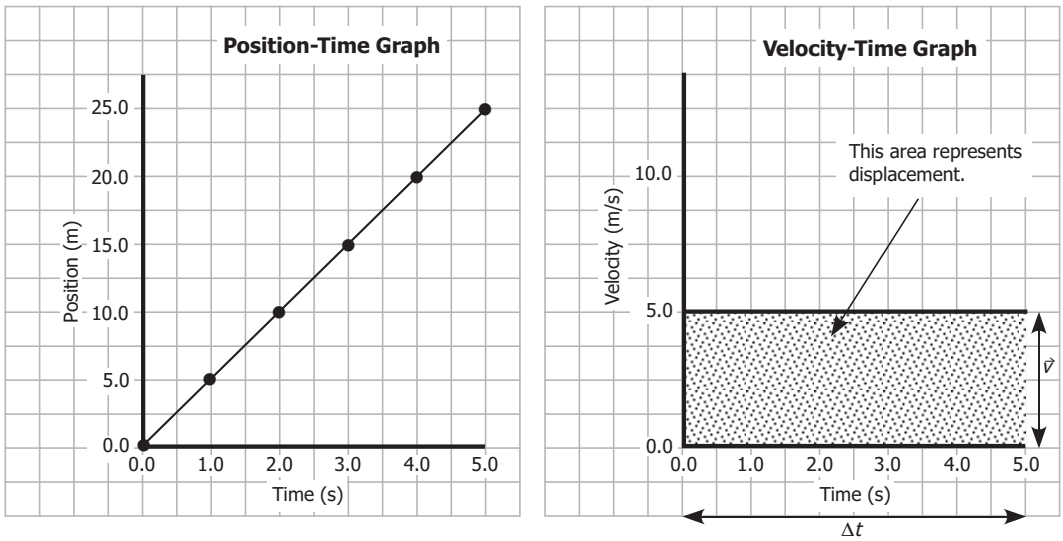
To convert graphs by going in the opposite direction—that is, from acceleration-time to velocity-time or from velocity-time to position-time—we will have to analyze areas.

Analyzing a Velocity-Time Graph in Order to Draw a Position-Time Graph

In a previous lesson, we discussed the situation of a van moving at a constant velocity of +5.0 m/s. We drew a position-time graph for that case.

We can also draw a velocity-time graph.

Since the speed of the object is constant at 5.0 m/s, the velocity-time graph is a horizontal line.



We learned that the velocity of an object can be calculated using velocity equals displacement over time interval: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$.

If we rearrange this equation, we can solve for the **displacement** using:

displacement equals velocity multiplied by time

$\vec{d} = \vec{v}\Delta t$.

Notice that this is not really a new equation. We are simply rearranging the equation for velocity.

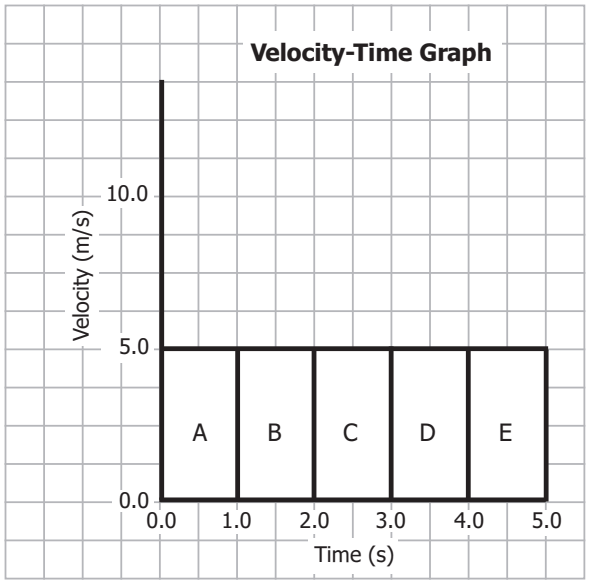
Over a time of 5.0 s, the van moving at a constant velocity of +5.0 m/s would experience a displacement of $\vec{d} = \vec{v}\Delta t = (+5.0\ \text{m/s})(5.0\ \text{s}) = +25\ \text{m}$.

If we look at the velocity-time graph, we can see that the horizontal line creates a rectangle under the line, between the line and the time axis. The area of a rectangle is given by the width, which is the height in this case, (5.0 m/s) times the length (5.0 s): area = (width)(length) = (5.0 m/s)(5.0 s) = 25 m. We can make the following general statement.

> The **displacement** in any interval is given by the area under the **velocity-time graph** for that interval.

We can find the area under the velocity-time curve for smaller time intervals and generate data for a position-time graph. This is done by dividing the area beneath the line of the velocity-time graph into regular shapes for which we can calculate the area.

In our example with the van, we can consider time intervals of one second.



We will use three columns of information to regenerate the time-position table for the van.

Section	Time Interval (s)	Displacement (m) (Area under V-T Graph) $\vec{d} = \vec{v}\Delta t$	Position at End of the Interval (m) $\overrightarrow{\text{pos}}_1 + \vec{d} = \overrightarrow{\text{pos}}_2$
	0.0		0.0
A	0.0 – 1.0	(+5.0 m/s)(1.0 s) = + 5.0 m	(0.0 m) + (+5.0 m) = 5.0 m
B	1.0 – 2.0	(+5.0 m/s)(1.0 s) = + 5.0 m	(5.0 m) + (+5.0 m) = 10.0 m
C	2.0 — 3.0	(+5.0 m/s)(1.0 s) = + 5.0 m	(10.0 m) + (+5.0 m) = 15.0 m
D	3.0 – 4.0	(+5.0 m/s)(1.0 s) = + 5.0 m	(15.0 m) + (+5.0 m) = 20.0 m
E	4.0 – 5.0	(+5.0 m/s)(1.0 s) = + 5.0 m	(20.0 m) + (+5.0 m) = 25.0 m

If we just consider the position at the end of each time interval, we arrive at the following table, which matches exactly the time-position table for the motion of the van with a velocity of +5.0 m/s from Lesson 5.

Time (s)	Position (m)
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0

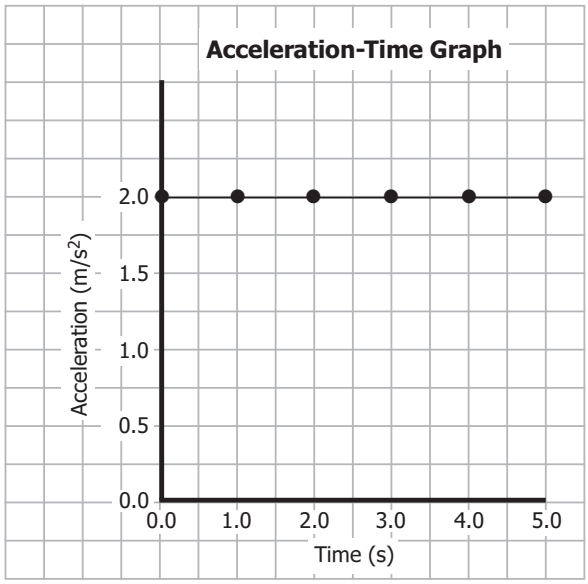
These data can be used to draw the graph of position-time for the motion of the van.

Moving from a **velocity-time graph** to a **position-time graph** requires that we take the **area** under the line on the velocity-time graph to give a **change in position** or **displacement**: $\vec{d} = \vec{v}\Delta t$.

Analyzing an Acceleration-Time Graph in Order to Draw a Velocity-Time Graph

To convert an acceleration-time graph into a velocity-time graph, we again use the technique of taking the area between the line on the graph and the time axis.

In a previous lesson, we saw that the acceleration of a runner was a constant value of 2.0 m/s^2. A graph of this acceleration on an acceleration-time graph would simply be a horizontal line.



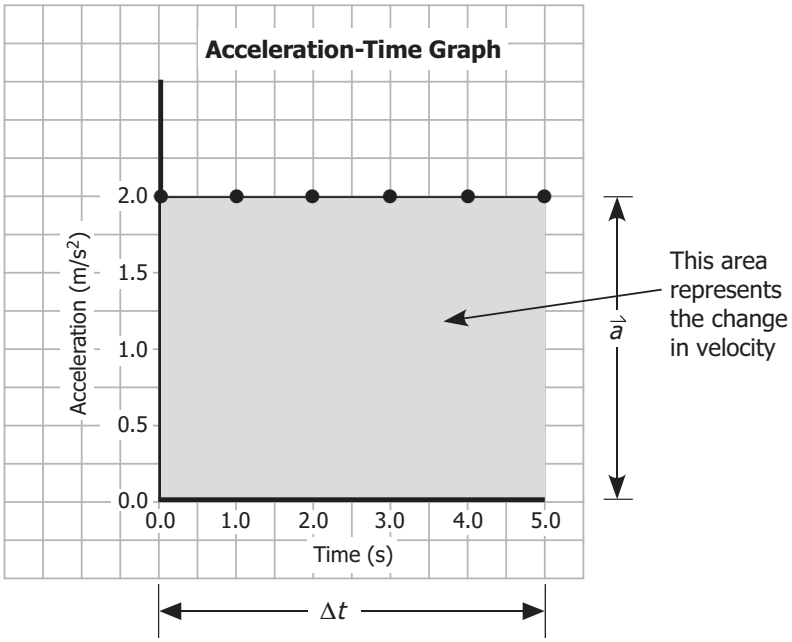
We have already seen that by determining the area under a velocity-time graph, we can create a position-time graph. We can also find the area under an acceleration-time graph to create a velocity-time graph.

We know the equation for acceleration is $\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t}$. We can rearrange this equation to solve for the change in velocity.

This yields $\Delta\vec{v} = \vec{a}\Delta t$.

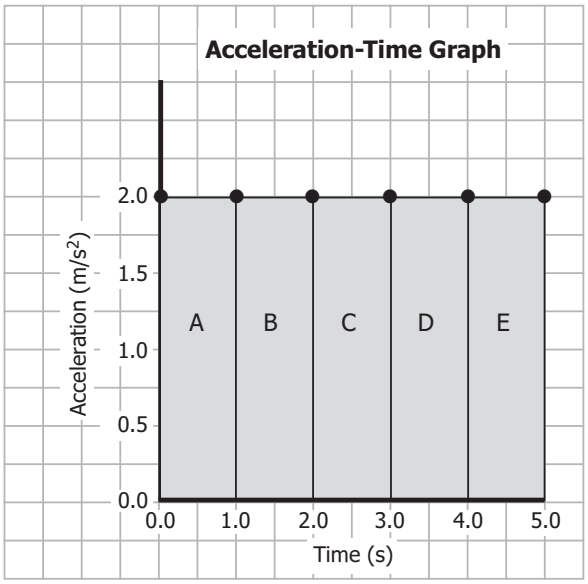
Notice that the product of the acceleration and the time interval gives the **CHANGE IN VELOCITY** and not just velocity. The velocity is just $\vec{v}$, while the change in velocity is $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$.

On the following graph, you can see that the height of the shaded area—the area under the line on the acceleration-time graph—represents the acceleration, $\vec{a}$, and the width represents the time interval, Δt.



We can find the area under the acceleration-time curve for smaller time intervals and generate data for a velocity-time graph. This is done by dividing the area beneath the line of the acceleration-time graph into regular shapes for which we can calculate the area.

In our example involving the runner, we can consider time intervals of one second.



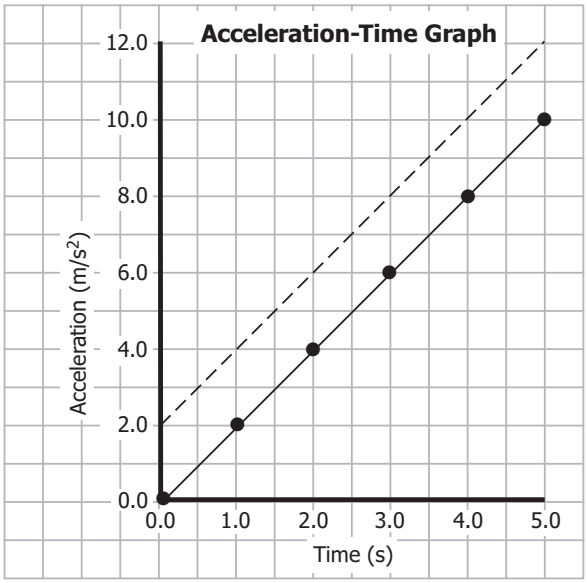
We will use three columns of information to generate the time-velocity table for the runner.

Time Interval (s)	Change in Velocity (m/s) $\Delta\vec{v} = \vec{a}\Delta t$	Velocity at End of the Interval (m/s) $\vec{v}_1 + \Delta\vec{v} = \vec{v}_2$
0.0		0.0 m/s
0.0–1.0	(+2.0 m/s^2)(1.0 s) = +2.0 m/s	0 + (+2.0 m) = 2.0 m/s
1.0–2.0	(+2.0 m/s^2)(1.0 s) = +2.0 m/s	2.0 + (+2.0 m) = 4.0 m/s
2.0–3.0	(+2.0 m/s^2)(1.0 s) = +2.0 m/s	4.0 + (+2.0 m) = 6.0 m/s
3.0–4.0	(+2.0 m/s^2)(1.0 s) = +2.0 m/s	6.0 + (+2.0 m) = 8.0 m/s
4.0–5.0	(+2.0 m/s^2)(1.0 s) = +2.0 m/s	8.0 + (+2.0 m) = 10.0 m/s

If we just consider the velocity at the end of each time interval, we arrive at the following table:

Time (s)	Velocity (m/s)
0.0	0.0
1.0	2.0
2.0	4.0
3.0	6.0
4.0	8.0
5.0	10.0

Graphing these data will reproduce the solid line of the velocity-time graph seen below. If the initial velocity is not 0.0 m/s, then the starting point of the line will begin at the initial velocity. For example, if the initial velocity is 2.0 m/s, the graph of velocity-time will begin there and then increase by 2.0 m/s for every second. This is shown as the dashed line. It has the same slope as the original line.



So moving from an **acceleration-time graph** to a **velocity-time graph** requires that we take the **area** under the line on the acceleration-time graph to give a **change in velocity**: $\Delta\vec{v} = \vec{a}\Delta t$.

The following graphic is a visual representation of the process of taking the area from an acceleration-time graph to a velocity-time graph or from a velocity-time graph to a position-time graph.

Position-time graph

Take area ↑ $\vec{d} = \vec{v}\Delta t$

Velocity-time graph

Take area ↑ $\Delta\vec{v} = \vec{a}\Delta t$

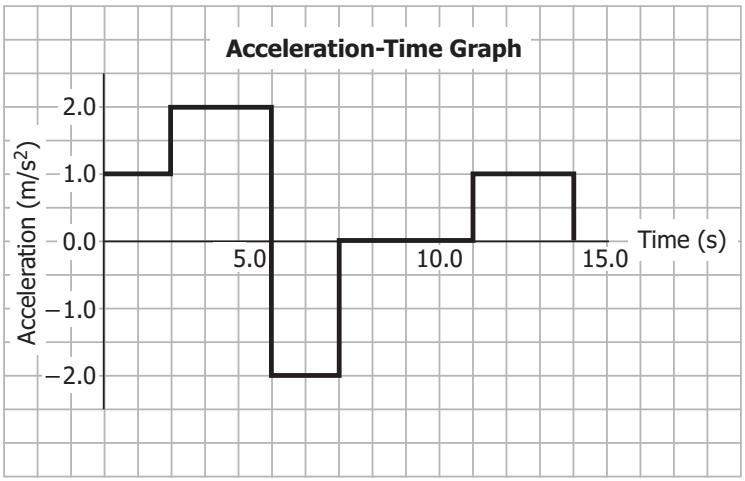
Acceleration-time graph

Learning Activity 1.10

Velocity-Time Graph

There is one question in the following learning activity. Check your answer in the answer key at the end of the module.

1. For the following acceleration-time graph, determine the change in velocity for each interval. Fill in the chart with the appropriate information and then plot a graph of velocity versus time. Assume the initial velocity is +3.0 m/s.



Time Interval (s)	Change in Velocity (m/s) $\Delta\vec{v} = \vec{a}\Delta t$	Velocity at End of the Interval (m/s) $\vec{v}_1 + \Delta\vec{v} = \vec{v}_2$
0.0		+3.0
0.0–2.0		
2.0–5.0		
5.0–7.0		
7.0–11.0		
11.0–14.0		

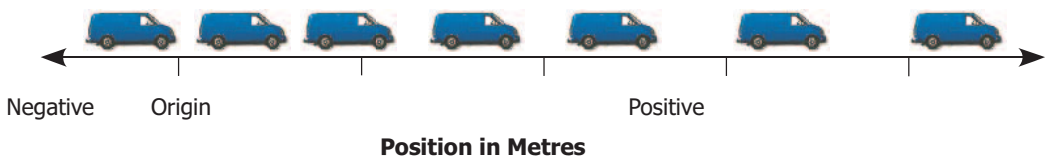
The Position-Time Graph and Constant Positive Acceleration

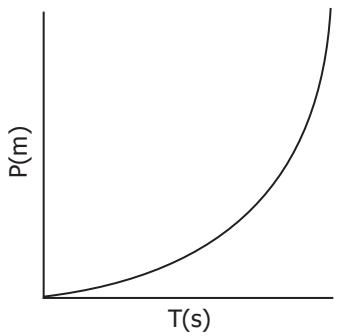
Converting Between Motion Graphs Qualitatively

Let's consider accelerated motion where **objects are speeding up or slowing down**. The velocity is not constant.

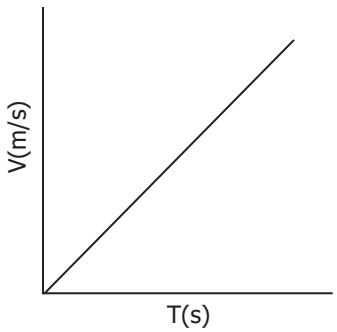
Since the slope on a position-time graph gives the velocity, a changing velocity will mean that the slope on the position-time graph must also change. A line with a changing slope is a curve. The slope of the curve at a given moment will calculate the velocity at that instant—the **instantaneous velocity**.

So if the slope on a position-time graph becomes more positive (the line becomes steeper), the instantaneous velocities are becoming more positive (larger speed in the positive direction).



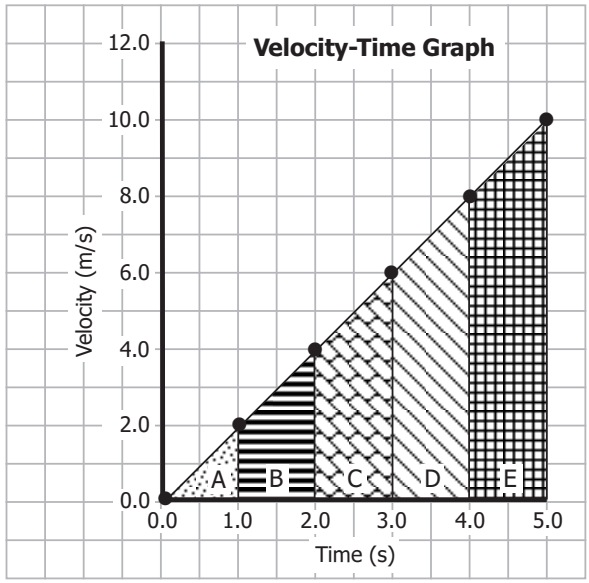


The slope at 0 seconds is 0 m/s. The slope of the graph is becoming more positive, larger in the positive direction. The velocity is increasing in the positive direction (speeding up in the positive direction). This is accelerated motion.



Since the acceleration is found from the slope of the velocity-time graph, the acceleration here will be **positive**.

Let's look at this quantitatively. In the previous section, we drew a velocity-time graph from a constant acceleration-time graph. Now we will draw the corresponding position-time graph. To do so, we determine the area under the velocity-time curve at various times and create a data table showing time and position.



To find the displacement from the velocity-time graph, divide the area beneath the line into regular shapes for which you can calculate the area. Here the total area is divided into 5 smaller areas, a triangle (A) and 4 trapezoids (B, C, D, and E).

The area between the line and the time axis must be found. This area has been subdivided into five smaller areas. The greater the number of areas, the more accurate the position-time graph will be.

The area of a triangle is found using ½ times the base times the altitude:

$$\text{area} = \frac{1}{2}(bh).$$

The area of a trapezoid is found by adding the lengths of the parallel sides and dividing the sum by 2. The answer is then multiplied by the altitude—the distance between the parallel lines.

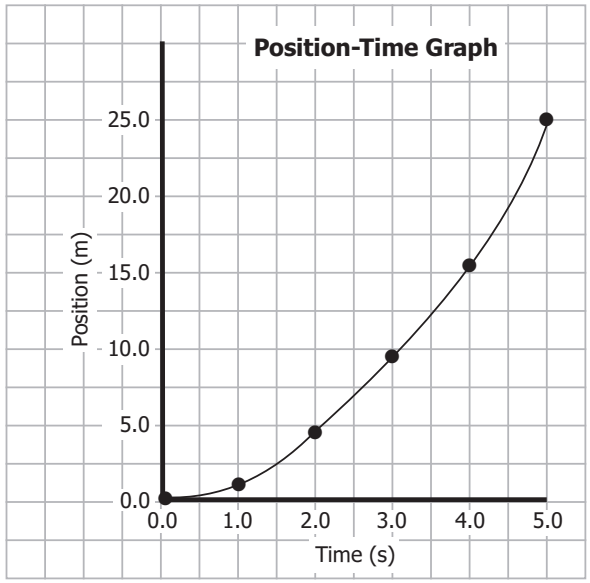
$$\text{area} = \left(\frac{(a+b)}{2}\right)h$$

Let's assume the initial position is 0.0 m at 0.0 s.

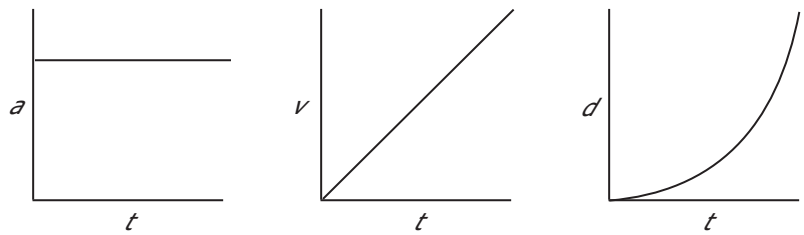
Section	Time Interval (s)	Displacement (m) $\vec{d} = \vec{v}\Delta t$	Position at End of the Interval (m) $\overrightarrow{\text{pos}}_1 + \vec{d} = \overrightarrow{\text{pos}}_2$
	0.0		0
A	0.0 – 1.0	$\frac{1}{2}(2.0\text{ m/s})(1.0\text{ s}) = +1.0\text{ m}$	$(0.0\text{ m}) + (1.0\text{ m}) = +1.0\text{ m}$
B	1.0 – 2.0	$\left(\frac{(2.0\text{ m/s} + 4.0\text{ m/s})}{2}\right)(1.0\text{ s}) = +3.0\text{ m}$	$(+1.0\text{ m}) + (+3.0\text{ m}) = +4.0\text{ m}$
C	2.0 – 3.0	$\left(\frac{(4.0\text{ m/s} + 6.0\text{ m/s})}{2}\right)(1.0\text{ s}) = +5.0\text{ m}$	$(+4.0\text{ m}) + (+5.0\text{ m}) = +9.0\text{ m}$
D	3.0 – 4.0	$\left(\frac{(6.0\text{ m/s} + 8.0\text{ m/s})}{2}\right)(1.0\text{ s}) = +7.0\text{ m}$	$(+9.0\text{ m}) + (+7.0\text{ m}) = +16.0\text{ m}$
E	4.0 – 5.0	$\left(\frac{(8.0\text{ m/s} + 10.0\text{ m/s})}{2}\right)(1.0\text{ s}) = +9.0\text{ m}$	$(+16.0\text{ m}) + (+9.0\text{ m}) = +25.0\text{ m}$

The graph you have to plot is the graph of position-time. The table tells you that the position is only for the end of the interval. This will give you a series of dots on the position-time graph. Because the velocity is always changing, the slope on the position-time graph must also change. This will require that a smooth curve be drawn through the points.

Time at the End of the Interval (s)	Position (m)
0.0	0.0
1.0	1.0
2.0	4.0
3.0	9.0
4.0	16.0
5.0	25.0



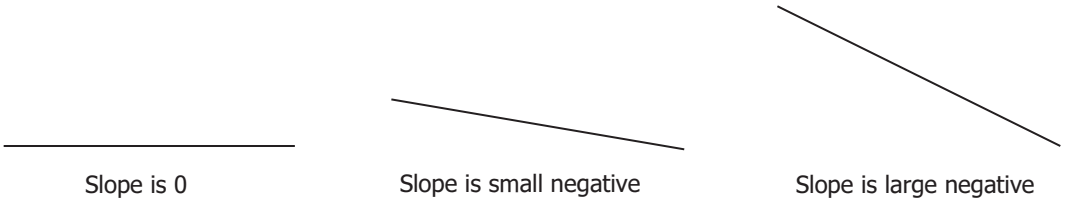
We can see that the position-time graph is gradually sloping up and to the right. This is a typical curve for a position-time graph when the acceleration is **constant and positive**. In general, the shapes of the *a-t*, *v-t*, and *d-t* graphs for **constant positive acceleration** are as shown in the following graphs.



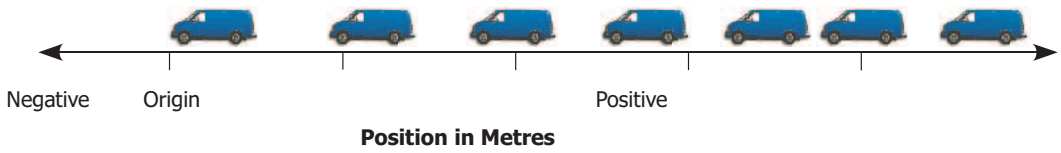
The Position-Time Graph and Constant Negative Acceleration

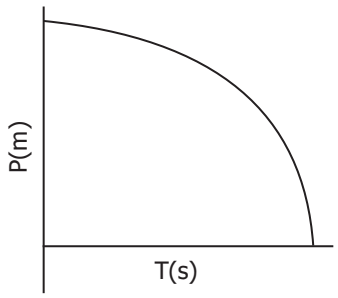
We have seen what the velocity-time and the position-time graphs look like for constant positive acceleration. We will now examine the case of constant negative acceleration.

Objects can also speed up when travelling in the negative direction. If an object starts from rest (slope on position-time graph = 0 m/s) and speeds up in the negative direction, the slope on the position-time graph will become more and more negative.

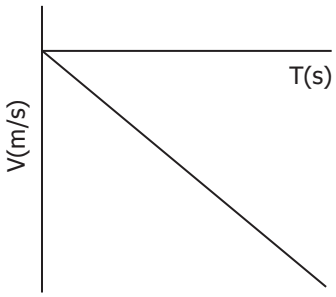


Again, the position-time graph will be a curve for which you calculate the instantaneous velocity, using the slope of the line at that moment in time. Here the velocity becomes more negative (larger speed in the negative direction).





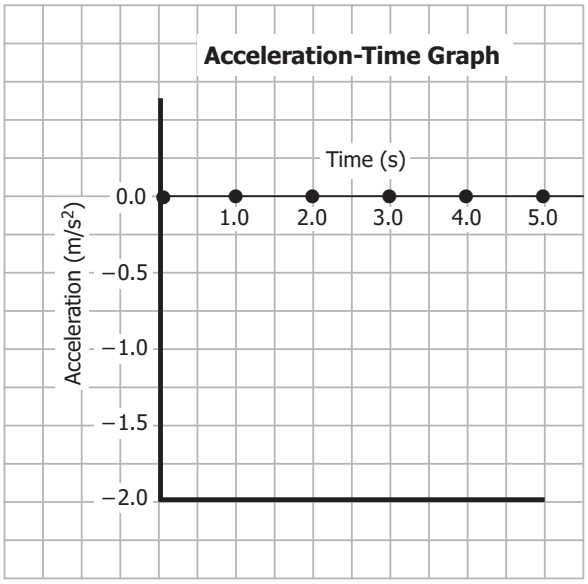
The object starts at rest to the right of the origin and moves towards the origin. The slope becomes more negative. The velocity becomes more negative (speeding up in the negative direction). The object's last position is at the origin.

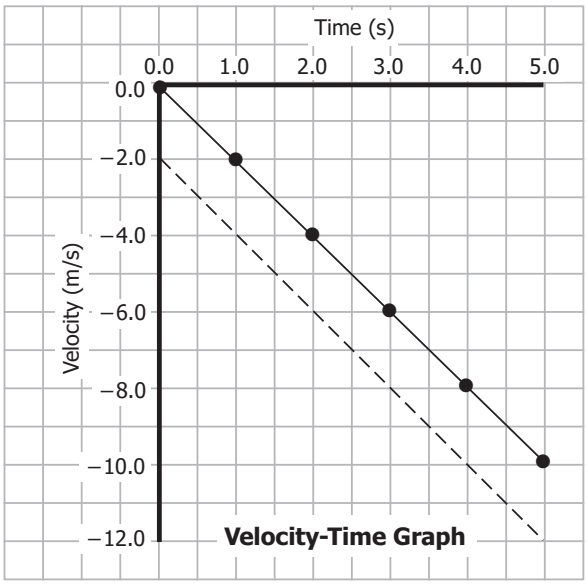


The slope of this velocity-time is **negative**—to the right and down. Therefore, since the slope on a velocity-time graph represents acceleration, the acceleration is **negative** as well.

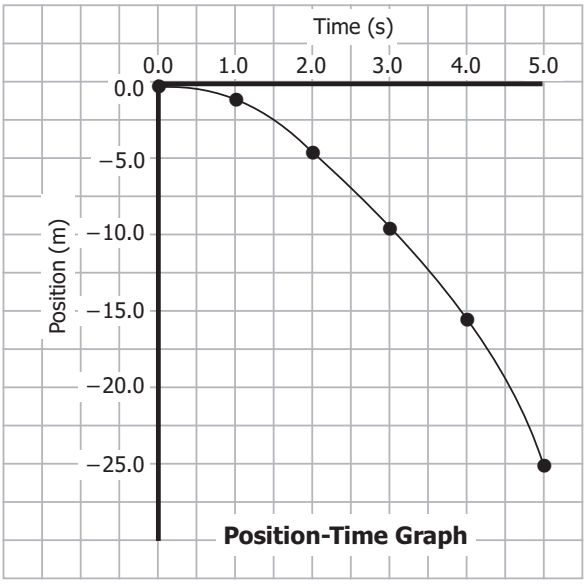
Now let's consider this in quantitative terms.

The following graph shows a constant negative acceleration of –2.00 m/s^2. We could create a data table for the velocity-time graph by finding the area between the horizontal axis and the acceleration line. This would result in negative areas and the velocity-time graph would be sloping downwards and to the right. The solid line shows the velocity, assuming the initial velocity is zero. The dashed line shows the velocity if the initial velocity is –2.0 m/s.



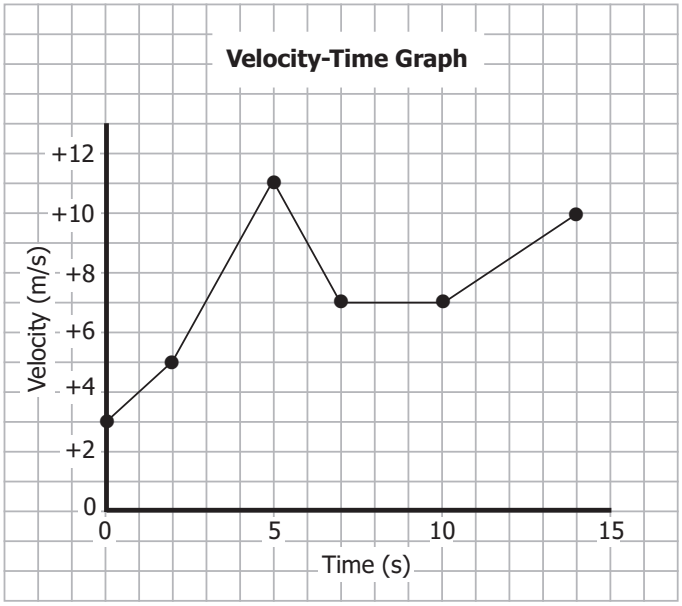


We could also determine the area under the velocity-time curve to produce a data table for a position-time graph. These areas would also be negative. The shape of the resulting position-time graph is shown below. Note that this position-time graph starts at 0 m at 0 s. It still has the same shape as the position-time graph in the graphic above.



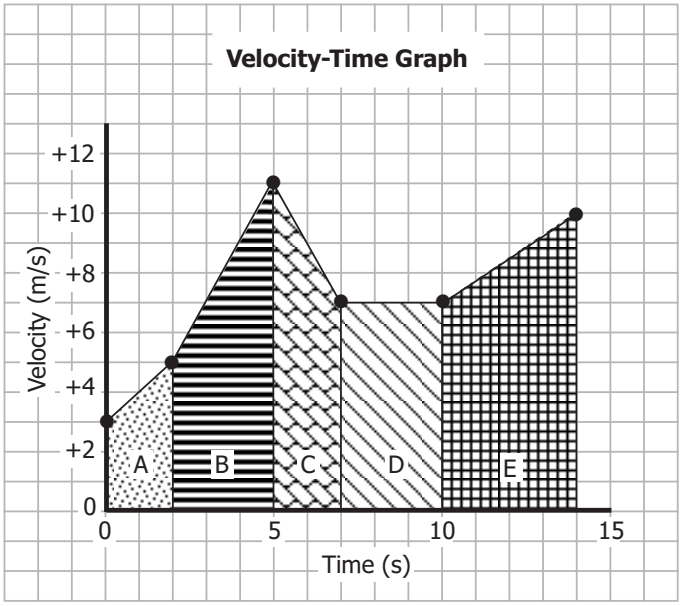
Example: Drawing a Position-Time Graph from a Velocity-Time Graph with Varying Velocities

So let's do one last example here to tie up all of these ideas. We will begin with a velocity-time graph with varying velocities (accelerated motion) and draw a graph of position-time.



Our task is to draw the position-time graph for this velocity-time graph. Assume that their position at 0.0 seconds is –35.0 m.

Again, to calculate area, divide the graph into regular shapes.



We'll use a table in order to keep track of all the work we have to do. This table will have the three major columns: time interval, displacement (this comes from the area), and position at the end of the interval.

The areas we have are rectangles and trapezoids.

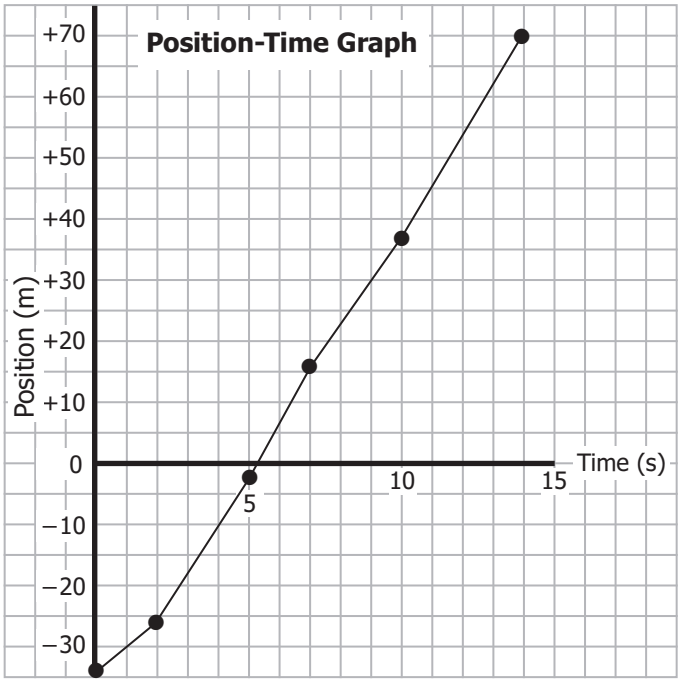
Section	Time Interval (s)	Displacement (m) $\vec{d} = \vec{v}\Delta t$	Position at End of the Interval (m) $\overrightarrow{\text{pos}}_1 + \vec{d} = \overrightarrow{\text{pos}}_2$
	0.0		-35.0
A	$0.0-2.0$	$\left(\frac{(+3.0\text{ m/s})+(+5.0\text{ m/s})}{2}\right)(2.0\text{ s})=+8.0\text{ m}$	$(-35.0\text{ m})+(+8.0\text{ m})=-27.0$
B	$2.0-5.0$	$\left(\frac{(+5.0\text{ m/s})+(+11.0\text{ m/s})}{2}\right)(3.0\text{ s})=+24\text{ m}$	$(-27.0\text{ m})+(+24\text{ m})=-3$
C	$5.0-7.0$	$\left(\frac{(+11.0\text{ m/s})+(+7.0\text{ m/s})}{2}\right)(2.0\text{ s})=+18\text{ m}$	$(-3\text{ m})+(+18\text{ m})=+15$
D	$7.0-10.0$	$(+7.0\text{ m/s})(3.0\text{ s})=+21\text{ m}$	$(+15\text{ m})+(+21\text{ m})=+36$
E	$10.0-14.0$	$\left(\frac{(+7.0\text{ m/s})+(+10.0\text{ m/s})}{2}\right)(4.0\text{ s})=+34\text{ m}$	$(+36\text{ m})+(+34\text{ m})=+70$

From these data, we can determine where the object was located at the end of the time interval.

Time (s)	Position (m)
0.0	–35.0
2.0	–27.0
5.0	–3
7.0	+15
10.0	+36
14.0	+70

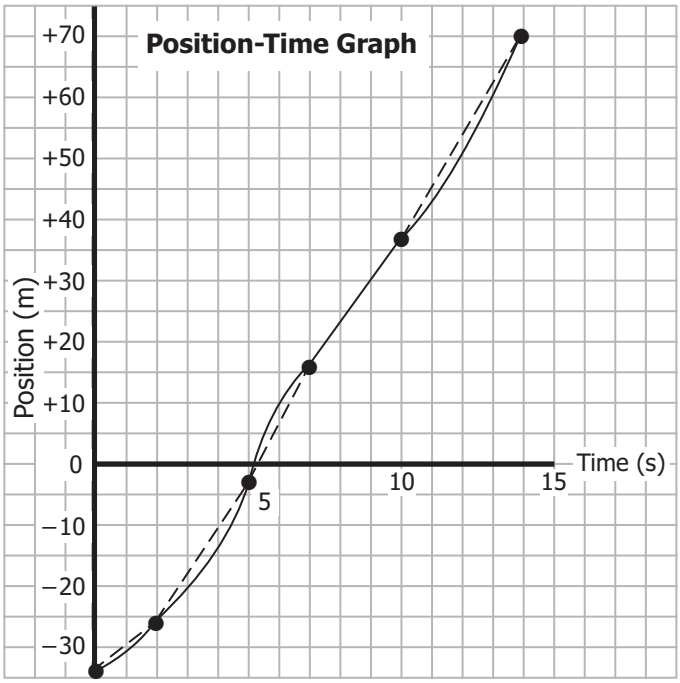
If we plot these data, the graph will consist of a set of points. To complete the graph, we simply join the points with straight-line segments. This is not entirely the proper thing to do, as the straight-line segments on a position-time graph have a constant slope, which indicates a constant velocity.

However, our initial velocity-time graph had varying velocities.



In real life, if the motion is accelerated, the resulting position-time graphs must have curves on them. The curve on a position-time graph indicates that the velocity is changing, which is, of course, what happens during accelerated motion.

So if we include this final detail, the position-time graph will appear as shown on the right.

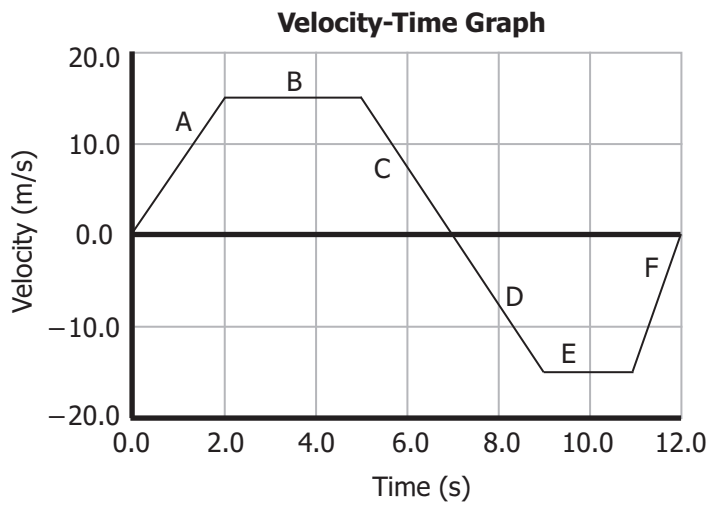


Learning Activity 1.11

The Physics of a Moving Bicycle

There is one question in the following learning activity. Check your answer in the answer key at the end of the module.

The following velocity-time graph shows the possible motion of a bicycle.



a) Produce a data table showing time and position, and then graph the data. The time portions of the table have been filled in. Assume the bicycle starts at 0.0 m at 0.0 s.

Section	Time Interval (s)	Displacement (m) $\vec{d} = \vec{v}\Delta t$	Position at End of the Interval (m) $\overrightarrow{\text{pos}}_1 + \vec{d} = \overrightarrow{\text{pos}}_2$
	0.0		0.0
A	0.0–2.0		
B	2.0–5.0		
C	5.0–7.0		
D	7.0–9.0		
E	9.0–11.0		
F	11.0–12.0		

(continued)

Learning Activity 1.11: The Physics of a Moving Bicycle (continued)

If we just consider the position at the end of each time interval, we arrive at the following table.

Time (s)	Position (m)
0.0	
2.0	
5.0	
7.0	
9.0	
11.0	
12.0	

b) Produce a data table showing time and acceleration, and then graph the data. The time portions of the table have been filled in.

Section	Time Interval (s)	Change in Velocity (m/s) $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$	Acceleration (m/s²) $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$
A	0.0–2.0		
B	2.0–5.0		
C	5.0–7.0		
D	7.0–9.0		
E	9.0–11.0		
F	11.0–12.0		

Lesson Summary

We started with the position-time version of the story of the motion—a position-time graph.

Velocity is the **rate of change of position** and is the **slope** of a **position-time graph**.

If you have a velocity-time graph, you can determine acceleration.

Acceleration is the **rate of change of velocity** and is the **slope** of a **velocity-time graph**.

A velocity-time graph also yields position-time information. More specifically, the area between the line on the graph of velocity-time and the time axis yields **displacement**.

In a like manner, the **area** between the line on the graph of **acceleration-time** and the time axis yields the **change in velocity**. This can be used to construct a velocity-time graph.

The following graphics give you a visual representation of the changes that occur as we transform one graph of motion into another type of graph.

Position-time graph

Take slope ↓ $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Velocity-time graph

Take slope ↓ $\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t}$

Acceleration-time graph

Position-time graph

Take area ↑ $\vec{d} = \vec{v}\Delta t$

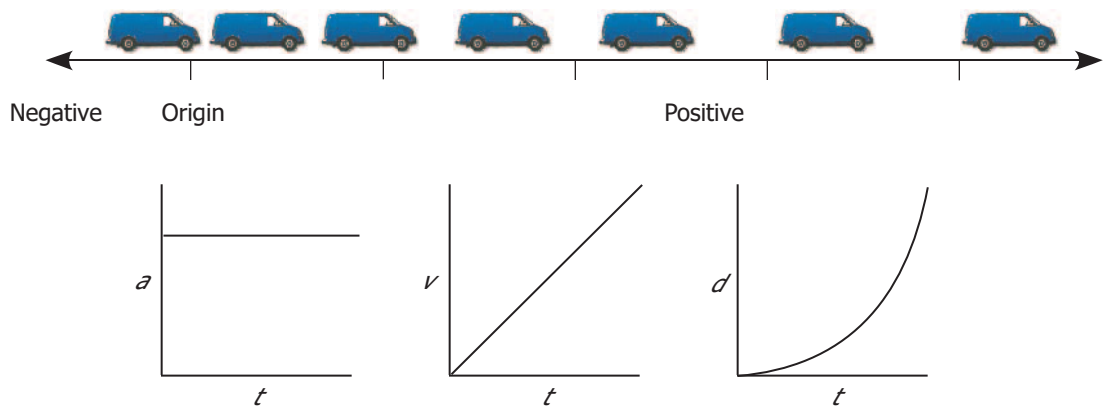
Velocity-time graph

Take area ↑ $\Delta\vec{v} = \vec{a}\Delta t$

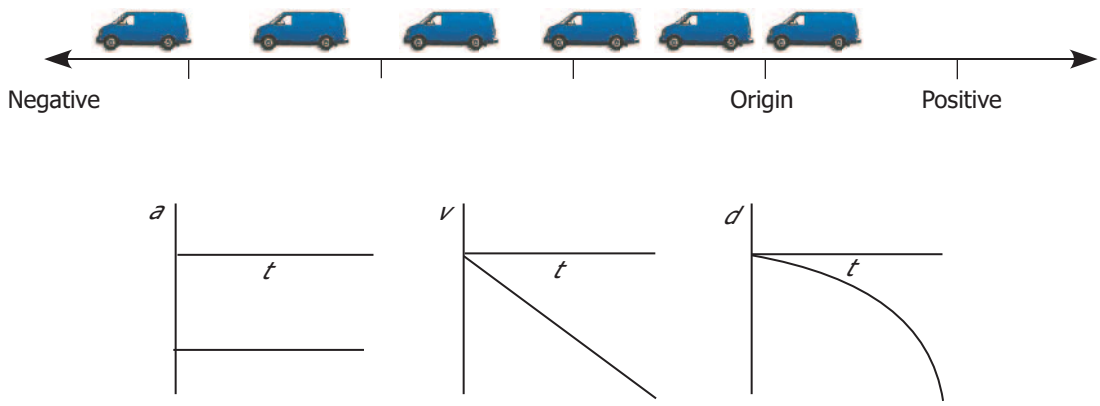
Acceleration-time graph

In general, the shapes of the *a-t*, *v-t*, and *d-t* graphs for constant acceleration are as shown on the following page.

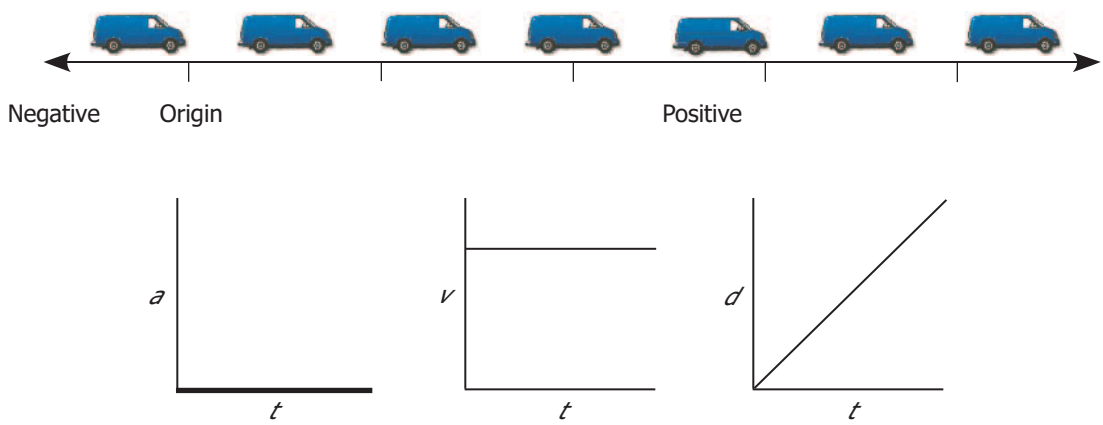
If the **acceleration** is **positive** and the **velocity** is **positive**:



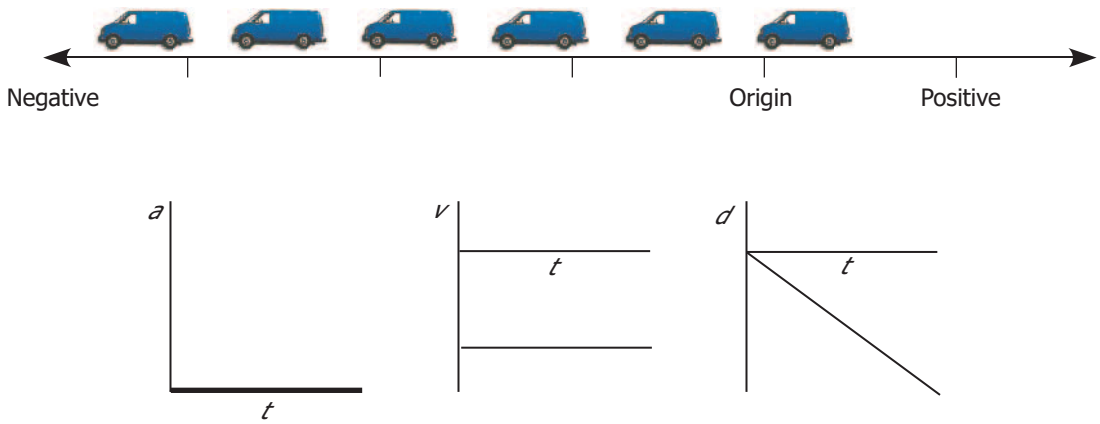
If the **acceleration** is **negative** and the **velocity** is **negative**:



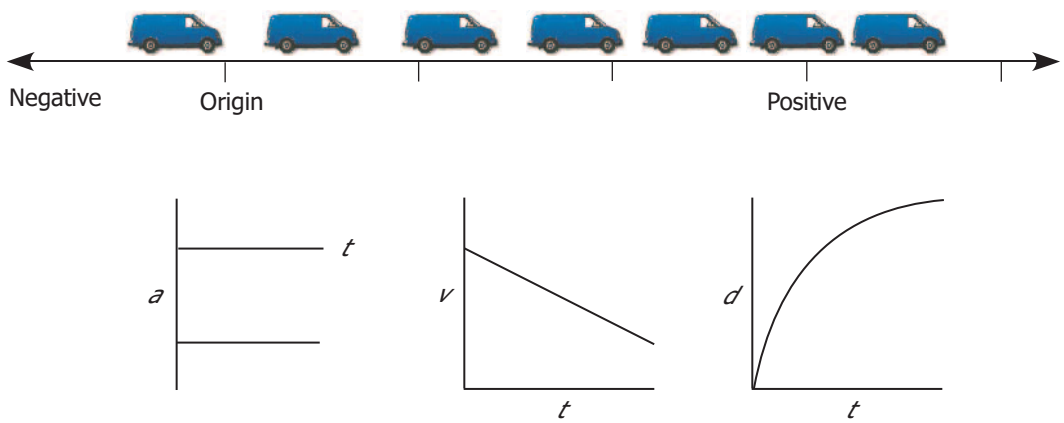
If the **acceleration** is 0 m/s^2 and the **velocity** is **positive**:



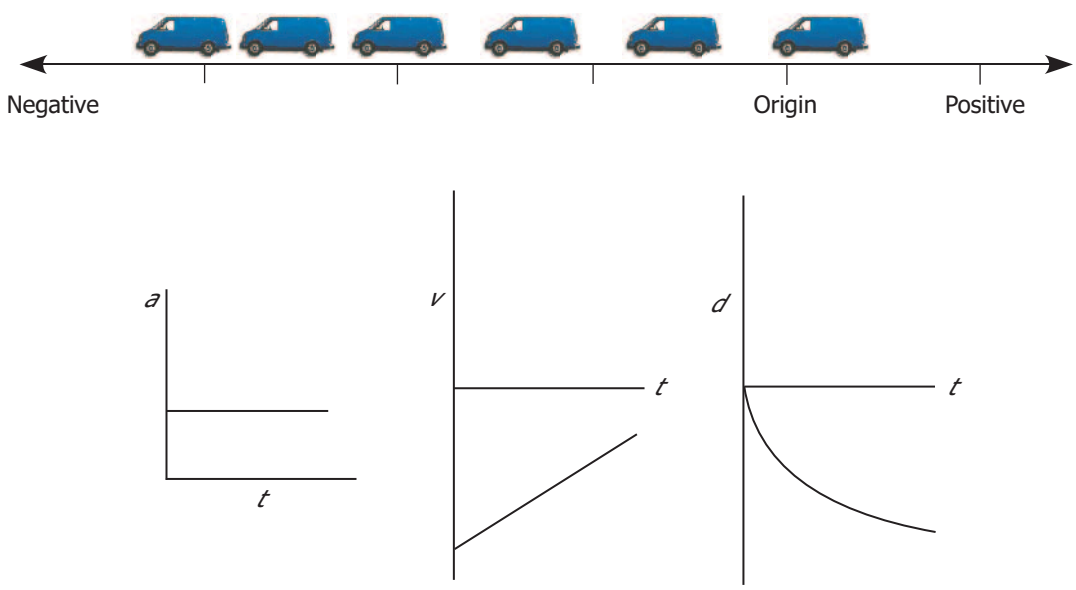
If the **acceleration** is 0 m/s^2 and the **velocity** is **negative**:



If the **acceleration** is **negative** and the **velocity** is **positive**:



If the **acceleration** is **positive** and the **velocity** is **negative**:



Websites

At the website http://surendranath.tripod.com/Applets.html, go to Applet Menu/Kinematics/Apply the Brakes. There you will find an applet that simulates a car travelling along a street at constant velocity braking to a stop. The graphs of position-time on the left and velocity-time on the right are drawn in real time as the car moves along.

Change the variables of velocity of the car and acceleration to observe the effect on braking distance and braking time.

At the website www.ngsir.netfirms.com/englishhtm/Kinematics.htm, you can see kinematics of one-dimensional motion. Change the velocity and acceleration and watch it generate graphs of position-time, velocity-time, and acceleration-time. Select uniform motion and observe the graphs.

Select simple acceleration and observe the graphs.

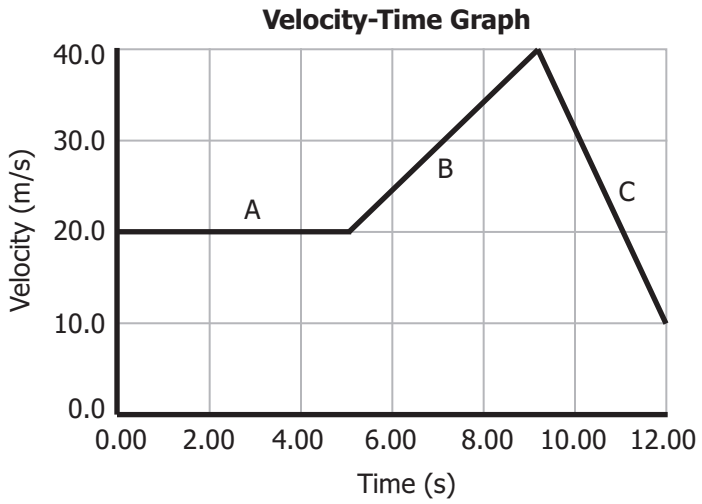
At the website http://jersey.uoregon.edu/vlab/block/Block.html, use the motion of a roller skating cow to generate the graphs of motion.

Assignment 1.3, Part B

Position-Time Graph 2 (6 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 1, after you have completed Module 1.

The physics of a moving car and graphing.
The following graph describes the motion of a car.



(continued)

Assignment 1.3, Part B: Position-Time Graph 2 (continued)

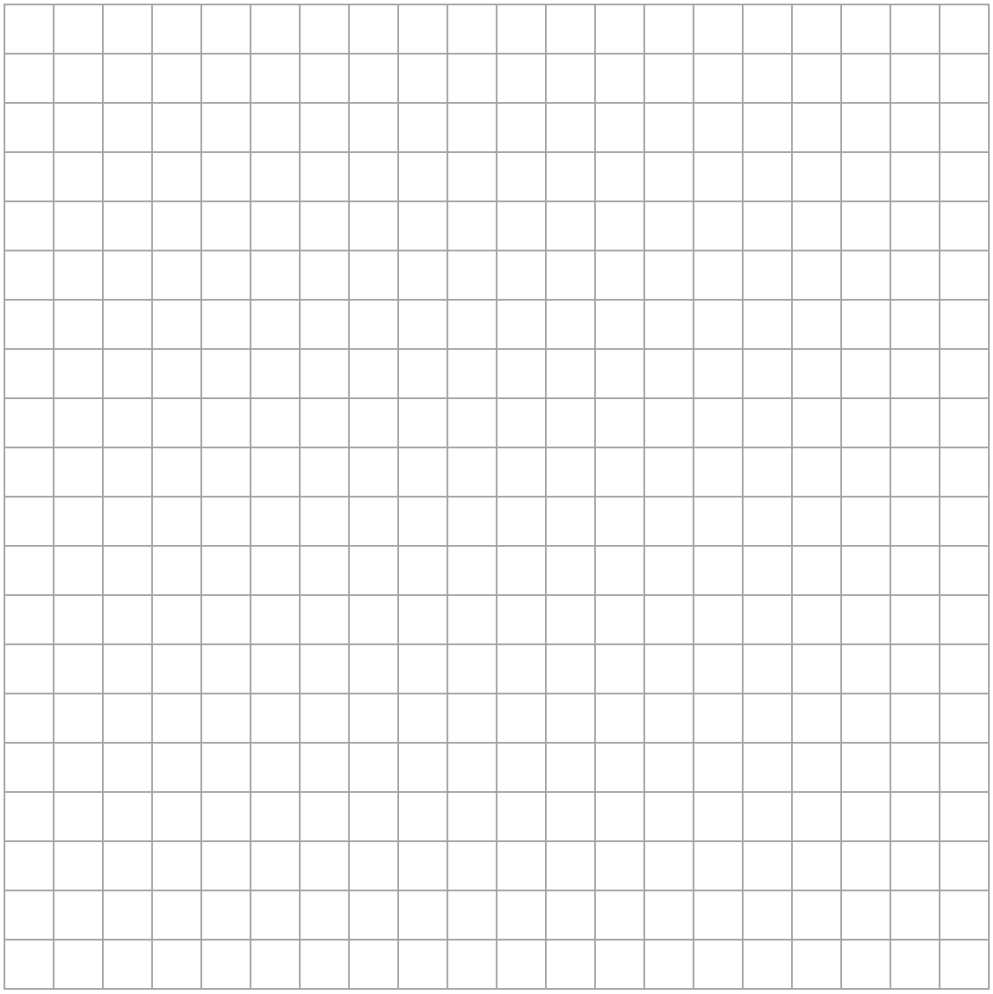
a) Complete the following data table showing time and position. Only four moments in time are shown.

Time Interval (s)	**Displacement (m)** $\vec{d} = \vec{v}\Delta t$	**Position at the End of the Interval (m)** $\overrightarrow{\text{pos}}_1 + \vec{d} = \overrightarrow{\text{pos}}_2$
0.00		0
0.00–5.00		
5.00–9.00		
9.00 – 12.00		

(continued)

Assignment 1.3, Part B: Position-Time Graph 2 (continued)

b) Graph the data to produce a position-time graph. Be sure to indicate the direction in which the lines may curve.



Method of Assessment

The total of six marks for this assignment will be determined as follows:

- 1 mark for each of the three position data points in part (a)
- 1 mark for each of the three portions of the curve in the position-time graph in part (b)

NOTES

Lesson 7: Deriving Equations for Motion Involving Uniformly Accelerated Motion (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ relate the slope or the shape of the area on a velocity-time graph for constant acceleration to the equations that are derived from the graph
- ❑ solve problems using the GUESS method
- ❑ solve problems using the equations of motion derived from a velocity-time graph

Key Words

uniformly accelerated motion
GUESS method

Introduction

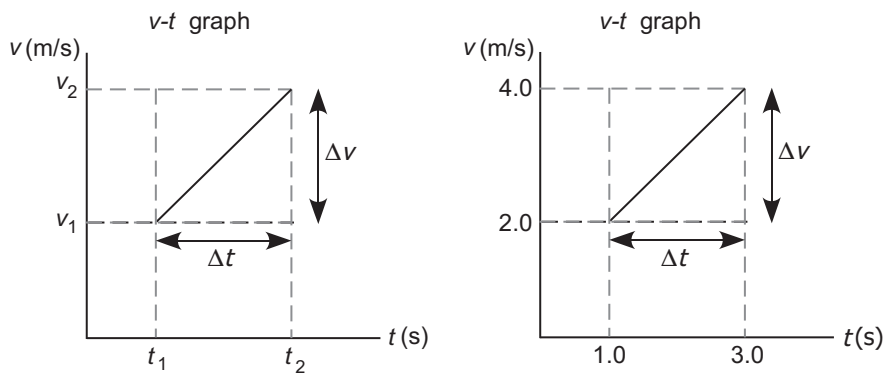
In this lesson, we will examine a velocity-time graph and derive from it four very useful equations for uniformly accelerated motion. These equations will become important in solving problems involving constant acceleration. The beauty of this lesson is that equations, which will be very useful to us later, are in fact being derived. This will help you to understand and appreciate where these equations come from and, therefore, how they can be applied to solving problems.

The equations being derived here are for **uniformly accelerated motion**. The motion of the object is one where the object is speeding up or slowing down. What you should see on a graph of velocity-time is a line sloping up or down, indicating that the velocity is changing.

Note: You are not responsible for the derivations of these equations. In Grade 11 Physics, your task is to be able to use the equations to solve problems.

Deriving the Equation for Acceleration

One graph that represents motion at a constant acceleration is the one shown below on the left. The graph on the right has values of velocity and time added to it.



In Grade 10 Science and earlier in this course, you learned that **uniform acceleration** can be defined as the change in velocity over the change in time. Mathematically, this can be written as

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$

In general, the slope of a straight line is given by the change in the y-value divided by the change in the x-value or $\Delta y/\Delta x$. For the velocity-time graph above, the change in y-value is Δv, and the change in x-value is Δt. By dividing $\Delta v/\Delta t$, we can see that this is also the definition of acceleration.

> Thus, for **constant acceleration**, the **slope** of a **velocity-time graph** gives **acceleration**.

The equation above may be rewritten as

$$\vec{v}_2 - \vec{v}_1 = \vec{a}\Delta t \text{ or}$$
$$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t \text{ or}$$
$$\vec{v}_2 = \vec{v}_1 + \vec{a}t$$

For the graph with values of velocity and time, the acceleration can be found using

$$\vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$

Acceleration is defined as the **rate of change of velocity**. On a **velocity-time graph**, the **slope** represents the **acceleration**.

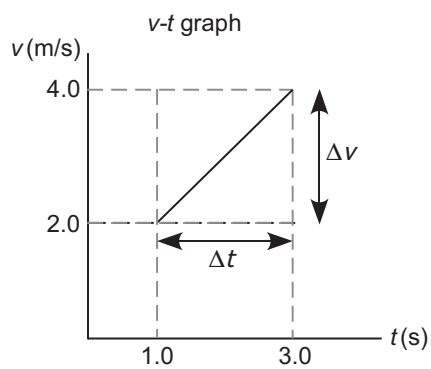
$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$

Quantity	Symbol	Unit
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)
Time interval	Δt	seconds (s)
Initial velocity	$\vec{v}_1$	metres/second (m/s)
Final velocity	$\vec{v}_2$	metres/second (m/s)
Change in velocity	$\Delta\vec{v}$	metres/second (m/s)

Always include direction with the vector quantities.

Example 1: Determining Acceleration from a Velocity-Time Graph

Determine the acceleration from the following velocity-time graph:



Given: From the graph, let's assume positive points to the right.

initial velocity $\vec{v}_1 = +2.0 \text{ m/s}$

final velocity $\vec{v}_2 = +4.0 \text{ m/s}$

time interval $\Delta t = 2.0 \text{ s}$

Unknown: acceleration $\vec{a} = ?$

Equation: $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ or $\vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$

Substitute: Substitute the values into the equation.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{\left(+4.0 \text{ m/s} - \left(+2.0 \text{ m/s}\right)\right)}{2.0 \text{ s}}$$

Solve: Now do the math.

$$\vec{a} = \frac{\left(+2.0 \text{ m/s}\right)}{2.0 \text{ s}} = +1.0 \text{ m/s}^2$$

The value of acceleration for this graph is $\vec{a} = 1.0\ \text{m/s}^2$.

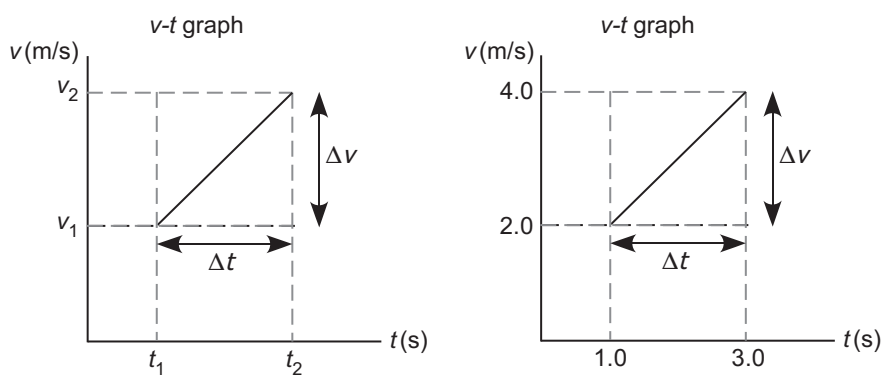
The value of the second velocity is already given as +4.0 m/s.

To confirm that the second velocity can be found using our derived equation of $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$, substitute in the appropriate values. The second velocity becomes

$$\vec{v}_2 = 2.0\ \text{m/s} + \left(1.0\ \text{m/s}^2\right)\left(2.0\ \text{s}\right) = +4.0\ \text{m/s}$$

Deriving the Equation for Displacement Given Initial Velocity, Final Velocity, and Time

Consider again the graphs used previously.



To find the displacement of an object undergoing uniformly accelerated motion, determine the **area** under the **velocity-time graph**.

One way to determine the area for the graph shown above is to find the area of a trapezoid. In general, the area of a trapezoid is given by

$$\text{area of trapezoid} = \frac{1}{2}(\text{sum of the parallel sides})(\text{height})$$

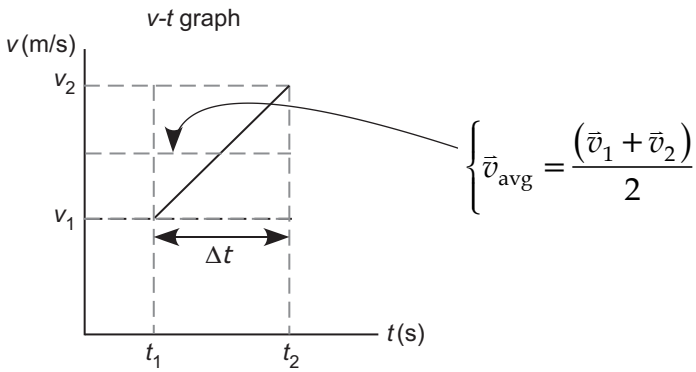
Normally, height is the distance between the parallel sides of a trapezoid.

For the example above,

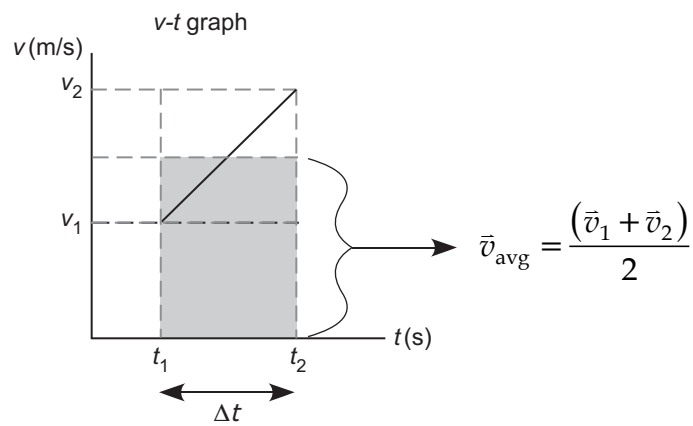
$$\text{area of trapezoid} = \frac{1}{2}(v_1 + v_2)(\Delta t), \text{ or in other words}$$

$$\vec{d} = \frac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$$

What does this mean on our velocity-time graph?



The little triangular area above the line for the average velocity can be flipped into the little triangular area below the line for the average velocity to complete a rectangle. This rectangle represents the **displacement**.



The **displacement** for **accelerated motion** can be determined by the area of a trapezoid on a graph of velocity-time.

$$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t = \vec{v}_{avg}\Delta t$$

Quantity	**Symbol**	**Unit**
Displacement	$\vec{d}$	metres (m)
Initial velocity	$\vec{v}_1$	metres/second (m/s)
Final velocity	$\vec{v}_2$	metres/second (m/s)
Time interval	Δt	seconds (s)
Average velocity	$\frac{(\vec{v}_1 + \vec{v}_2)}{2}$ or $\vec{v}_{avg}$	metres (m/s)

Given: From the graph, let's assume positive points to the right.

initial velocity	$\vec{v}_1 = +2.0\ \text{m/s}$
final velocity	$\vec{v}_2 = +4.0\ \text{m/s}$
time interval	$\Delta t = 2.0\ \text{s}$

Unknown: displacement $\vec{d} = ?$

Equation: $\vec{d} = \dfrac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t = \vec{v}_{\text{avg}}\Delta t$

Substitute: Substitute the values into the equation.

$$\vec{d} = \frac{(+2.0\ \text{m/s}) + (+4.0\ \text{m/s})}{2}(2.0\ \text{s})$$

Solve: Now do the math.

$$\vec{d} = \frac{(+6.0\ \text{m/s})}{2}(2.0\ \text{s}) = (+3.0\ \text{m/s})(2.0\ \text{s}) = +6.0\ \text{m}$$

The displacement is +6.0 m.

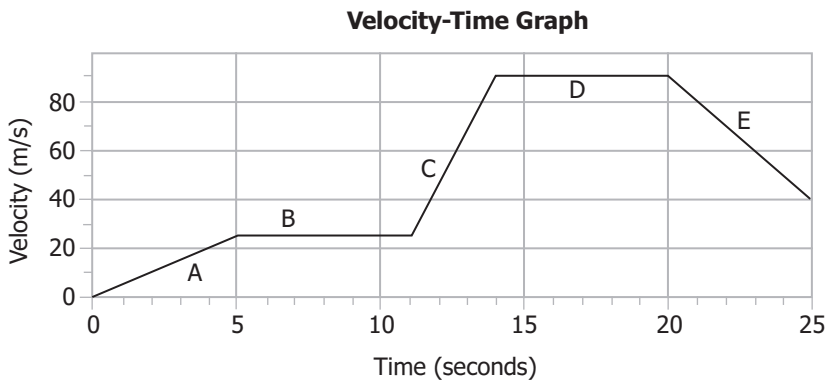
(The symbol Δx is often used to indicate a change of position. For the purposes of this discussion, we will use $\vec{d}$ to represent displacement.)

Note: In this case, the area that represents the displacement lies above the horizontal time axis. Therefore, the area and the displacement are positive.

Learning Activity 1.12

Displacement

Test your understanding of the derivation of the equations for uniformly accelerated motion by answering the questions below. Check your answers with the answer key at the end of the module.

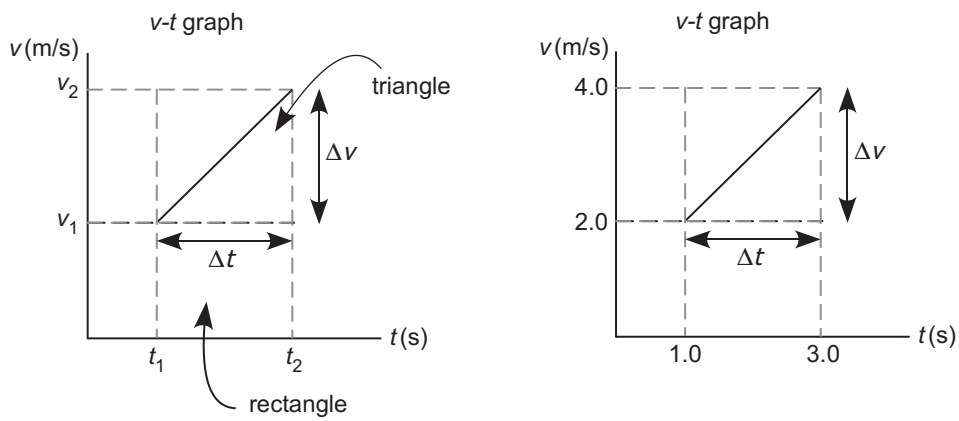


All of the questions refer to this velocity-time graph.

1. What on the velocity-time graph represents acceleration? …displacement?
2. Which of the two equations that have been derived so far in this lesson should be used to find
   a) the acceleration for the time interval A?
   b) the displacement for the time interval C?
   c) the displacement for the time interval B?
3. Calculate the displacement during time interval C.

Deriving the Equation for Displacement Given Initial Velocity, Acceleration, and Time

Another useful equation can be derived from the graph by considering the area of the rectangle and the area of the triangle under the solid line.



To find the displacement of an object undergoing uniformly accelerated motion, determine the area under the velocity-time graph.

total area = area of rectangle + area of triangle

The area of a rectangle is given by the length times the width. For the rectangle above,

area of rectangle = $v_1\Delta t$

The area of a triangle is given by one-half the base times the height.

area of triangle = $\frac{1}{2}\Delta v\Delta t$

total area = $v_1\Delta t + \frac{1}{2}\Delta v\Delta t$

Since the area under a velocity-time graph gives displacement,

$$\vec{d} = v_1\Delta t + \frac{1}{2}\Delta v\Delta t$$

We know from the definition of acceleration that $\Delta v = a\Delta t$. Therefore,

$$\vec{d} = v_1\Delta t + \frac{1}{2}(a\Delta t)\Delta t$$

Now let's add vector notation to this equation.

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

The **displacement** for **accelerated motion** can be determined by the area of a trapezoid on a graph of velocity-time. This area is divided into a **rectangle** and **triangle**. The area of each is calculated and added together to give the displacement.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Quantity	**Symbol**	**Unit**
Displacement	$\vec{d}$	metres (m)
Initial velocity	$\vec{v}_1$	metres/seconds (m/s)
Time interval	Δt	seconds (s)
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)

Given: From the graph, let's assume positive points to the right.

initial velocity $\vec{v}_1 = +2.0 \text{ m/s}$

acceleration $\vec{a} = +1.0 \text{ m/s}^2$

time interval $\Delta t = 2.0 \text{ s}$

Unknown: displacement $\vec{d} = ?$

Equation: $\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$

Substitute: Substitute the values into the equation.

$$\vec{d} = (+2.0 \text{ m/s})(2.0 \text{ s}) + \frac{1}{2}(+1.0 \text{ m/s}^2)(2.0 \text{ s})^2$$

Solve: Now do the math.

$$\vec{d} = +4.0 \text{ m} + (+2.0 \text{ m}) = +6.0 \text{ m}$$

This is the same value for displacement that we obtained in the previous section.

Deriving the Equation Relating Displacement, Initial Velocity, Final Velocity, and Acceleration

A final useful equation can be derived from two of the previous equations. Here, we will eliminate Δt from the two equations. This will yield an equation that does not contain a time interval. This relationship is very useful in some situations.

One of the equations was $\vec{v}_2 = \vec{v}_1 + \vec{a}t$. Square both sides of this equation.

$$v_2^2 = v_1^2 + 2av_1t + a^2t^2$$

Factor out the "$2a$" from the last two terms of the equation.

$$v_2^2 = v_1^2 + 2a\left[v_1t + \frac{1}{2}at^2\right]$$

The expression $v_1t + \frac{1}{2}at^2$ is equal to the displacement given by another derived equation above. Therefore,

$$v_2^2 = v_1^2 + 2ad$$

Note that Δt has disappeared. In this case, you can dispense with the vector notation, as the equation would require you to square a vector and multiply vectors, and this is beyond the scope of this course.

There is a kinematics equation **that does not include time interval**. This equation relates displacement, acceleration, initial velocity, and final velocity.

$$v_2^2 = v_1^2 + 2ad$$

Quantity	Symbol	Unit
Displacement	$\vec{d}$	metres (m)
Initial velocity	$\vec{v}_1$	metres/seconds (m/s)
Final velocity	$\vec{v}_2$	metres/seconds (m/s)
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)

Note: When working with this equation, vector notation can be omitted; however, when stating the answer, you must include the direction with the vector quantities.

Let's use this last kinematics equation to find the displacement from the graph without using the time interval.

Given: From the graph, let's assume positive points to the right.

initial velocity	$\vec{v}_1 = +2.0\ \text{m/s}$
final velocity	$\vec{v}_2 = +4.0\ \text{m/s}$
acceleration	$\vec{a} = +1.0\ \text{m/s}^2$
Unknown: displacement	$\vec{d} = ?$
Equation:	$v_2^2 = v_1^2 + 2ad$

This equation does not give displacement as the answer, so we rearrange the equation to isolate the displacement.

$$d = \frac{v_2^2 - v_1^2}{2a}$$

Substitute: Substitute the values into the equation.

$$\vec{d} = \frac{(4.0\ \text{m/s})^2 - (2.0\ \text{m/s})^2}{2(+1.0\ \text{m/s}^2)}$$

Solve: Now do the math.

$$\vec{d} = \frac{12}{2.0} = +6.0\ \text{m}$$

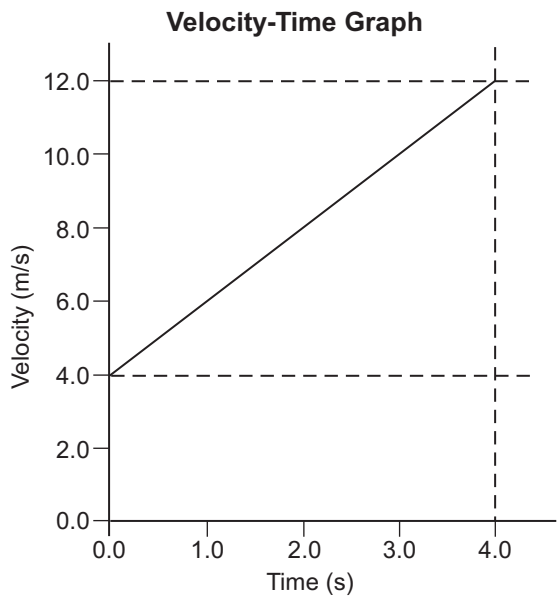
This is the same value as that obtained by the previous methods.

Learning Activity 1.13

The Physics of Uniformly Accelerated Motion

Answer these questions, and then check your answers with the answer key at the end of the module.

1. The four parts of this assignment refer to the following graph.



a) Using the equation $\vec{v}_2 - \vec{v}_1 = \vec{a}\Delta t$, determine the acceleration of the object.

b) Using the equation $\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$, determine the displacement of the object above over the four-second interval.

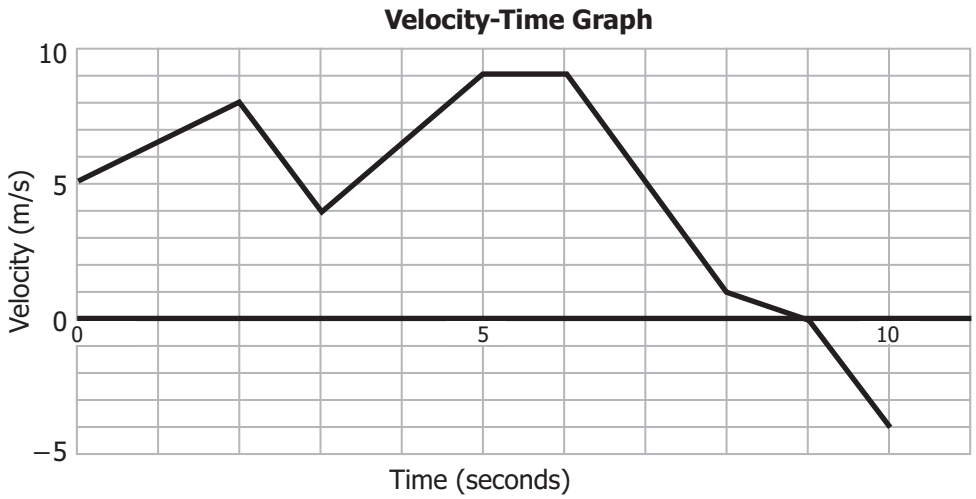
c) Using the equation $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$, verify that the displacement is the value you calculated in part (b).

d) Using the equation $v_2^2 = v_1^2 + 2ad$, verify that the displacement is the value you previously calculated.

(continued)

Learning Activity 1.13: The Physics of Uniformly Accelerated Motion (continued)

2. On the following velocity-time graph, indicate during which intervals of time the acceleration is positive, negative, or zero. This graph does not represent a real-life situation. It is presented simply to help reinforce the ideas about interpreting graphs.



3. For each of the time intervals for the graph in question #2, determine the displacement using one of the equations for kinematics that were derived in this lesson. You should be able to use all four of the kinematics equations that involve displacement at least once each.

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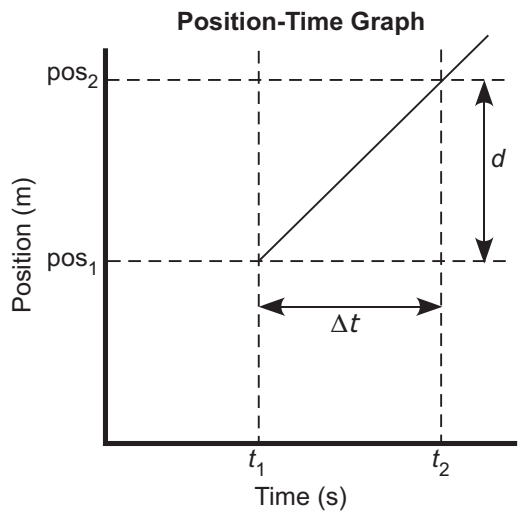
Lesson Summary

In Grade 10 Science, a graph of position-time was used to derive an equation for uniform motion. In this case, the acceleration is 0 m/s/s.

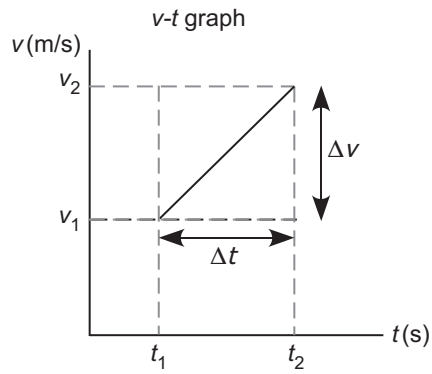


The slope of this position-time graph yielded the first equation for kinematics. From the graph, you can see the slope of the line as a rise that gives the change in position (displacement) $\vec{d}$. You can also see that the run is the time interval Δt. Therefore, the slope of the position-time graph represents displacement over time. This is the definition of velocity.

Kinematics Equation 1: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

In this lesson, we derived four very useful equations for **uniformly accelerated motion** from a **velocity-time** graph. We will be using these equations when we do problems involving the kinematics of uniformly accelerated motion. The next lesson will illustrate the use of these equations.

The equations can be derived from a velocity-time graph such as the one shown below.



The equations are as shown below.

Kinematics Equation 2: $\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t}$ or $\vec{a} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$

Kinematics Equation 3: $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$

Kinematics Equation 4: $\vec{d} = \vec{v}_1\Delta t + \dfrac{1}{2}\vec{a}\Delta t^2$

Kinematics Equation 5: $v_2^2 = v_1^2 + 2ad$

From a velocity-time graph, you should be able to derive kinematics equations #2–5.

You should also be able to apply the rules of algebra to isolate one of the variables in an equation.

For example, you should be able to rewrite the equation
$\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t}$ as $\vec{a} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ or $\vec{v}_2 - \vec{v}_1 = \vec{a}\Delta t$ or $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$.

Being able to do this will make problem solving much more efficient.

The equations for straight-line kinematics or for motion along a straight line are:

Kinematics Equation 1: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Kinematics Equation 2: $\vec{a} = \dfrac{\Delta \vec{v}}{\Delta t}$ or $\vec{a} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$

Kinematics Equation 3: $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$

Kinematics Equation 4: $\vec{d} = \vec{v}_1 \Delta t + \dfrac{1}{2}\vec{a}\Delta t^2$

Kinematics Equation 5: $v_2^2 = v_1^2 + 2ad$

Quantity	**Symbol**	**Unit**
Displacement	$\vec{d}$	metres (m)
Velocity	$\vec{v}$	metres/seconds (m/s)
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)
Time interval	Δt	seconds (s)
Initial velocity	$\vec{v}_1$	metres/seconds (m/s)
Final velocity	$\vec{v}_2$	metres/seconds (m/s)

Lesson 8: Constant Velocity and Acceleration: Problem Solving (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ determine the displacement of an object undergoing constant acceleration when the initial velocity and the final velocity are not zero
- ❑ use the following equations in solving problems involving the motion of objects

$$\vec{v} = \frac{\vec{d}}{\Delta t} \qquad \vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \qquad \vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$$

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2 \qquad v_2^2 = v_1^2 + 2ad$$

Introduction

In the previous lesson, we derived the kinematics equations that go along with accelerated motion. In this final lesson, we emphasize problem solving in kinematics. In order to solve the problems successfully, you must be very systematic. If you approach problem solving with the same technique over and over, your chances of success will improve. You will be introduced to the "GUESS" method of solving problems. This method does not guarantee that you will arrive at the right answer, but it definitely will improve your chances.

Problem-Solving Strategy for Kinematics Problems: The GUESS Method

When applying the equations for kinematics or when solving physics problems in general, it is a good idea to keep in mind the following problem-solving strategy. The "GUESS" method is not a substitute for understanding the concepts of physics; rather, it is an organizational tool that will make it more likely for you to be successful in solving problems.

The word "GUESS" is an acronym that stands for the following:

G stands for given
U stands for unknown
E stands for equation
S stands for substitute
S stands for solve

Here is a detailed explanation of each of these steps.

Given

You begin any problem by first reading it carefully. You must be able to extract the relevant information from the problem. The "GIVEN" refers to the information that is given in the question.

If possible, make a drawing that represents the situation being studied, which will help you to visualize the situation, to develop a reasoning strategy, and to explain the solution to anyone reading your answer.

Decide which direction is positive and which is negative.

It is important to decide which directions are positive (+) and which are negative (–) with respect to the reference point or origin of the coordinate system. Stick to this system while you are working through the problem.

Write down in symbolic form what you are given. Do this by writing down the values of the variables in the problem, paying careful attention to the signs of these variables.

Determine which variable you have by looking at its unit. In the part of the SI system that we use in physics, we use another acronym "**mks**" for the units of **length**, **mass**, and **time**. The unit for **length** is the metre (m). The unit for **mass** is the kilogram (kg). The unit for **time** is the second (s). Almost all of the other units that you will be using can be derived from these three basic units.

For the section on kinematics, the following are important variables: acceleration, $\vec{a}$, with units of m/s/s; velocity, $\vec{v}$, with units of m/s; time, t, with units of s; and displacement, $\vec{d}$ or distance, d, both of which have units of m. Some of the data may be implied, such as the phrase "starts from rest." This means that the initial velocity is zero and should be written as $\vec{v} = 0$ m/s.

For any quantities that are vectors, you must include the direction.

This first step in the problem-solving process is the most important. If you cannot extract the given information on the problem, then there's no way of solving it!

Unknown

Every problem requires you to determine an answer. This part of the problem-solving process requires you to identify the variable you're being asked to determine.

Equation

Now that you know the variables that were given in the question and the unknown that you are looking for, you must use an equation that links what is given to the unknown that you are required to find.

At this point, you may rearrange the equation to isolate the variable that represents the unknown. This usually facilitates the algebra that you must perform to solve the problem.

Substitute

Now that you have the equation, substitute the values of the given variables into the equation. At the beginning, it may be wise to include the units with the variables. One method of checking your answers is to ensure that the units on the left side are the same as the units on the right side of your equation.

Solve

The last step in this process is to do the mathematics and determine the value of the unknown.

You should include a statement at the end of the problem stating the value of the unknown, its proper unit, and, if it is a vector, its direction. Be sure to round off the answer to the correct number of significant digits.

Note: In some problems there may be no equation that directly relates the given information to the unknown variable. In cases like these, it may be necessary to solve for some other variable. Once you have this other variable, you can then, in fact, solve for the variable that is required by using a different equation.

Obviously, you need to know some physics to be able to solve problems correctly. If you do not understand the concept of the problem, there is little hope you'll be able to solve it successfully.

In the previous lesson, five equations for kinematics were developed.

The first equation was for uniform motion, where the acceleration is 0 m/s/s.

This equation was $\vec{v} = \frac{\vec{d}}{\Delta t}$.

The other four kinematics equations that were derived were for uniformly accelerated motion. They were

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ or } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

$$\vec{d} = \frac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$$

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

Note the following items: the signs of velocity and acceleration and the units are not given as standard SI units.

The Signs of Velocity and Acceleration

When you observe the motion of an object, it is relatively simple to determine the direction of the displacement and velocity. If an object moves to the right, it has a velocity to the right and a displacement to the right. If an object moves to the left, it has a displacement to the left and a velocity to the left. In place of right and left, you could use east and west, up and down, north and south, positive and negative, or any other convenient reference system.

The direction of the acceleration is less obvious. To ascertain the direction of the acceleration, use the following rule:

> If the object is **SPEEDING UP**, the velocity and acceleration have the **SAME DIRECTION**.
>
> If the object is **SLOWING DOWN**, the velocity and acceleration have the **OPPOSITE DIRECTION**.

Units

When solving problems, you must be sure that units are consistent. You cannot have a velocity in units of KM/H and a time in SECONDS. In order to solve problems like this, you should convert the given units into "mks" (metres, kilograms, and seconds).

Converting from one unit to another is relatively simple. Basically, it involves taking the original given units and replacing them with an equivalent amount of the required units. A common conversion you might have to perform would be changing kilometres per hour to metres per second.

Recall that 1 kilometre equals 1000 m and that one hour equals 60 minutes x 60 seconds/minute or 3600 seconds.

Here is how you would convert 90 kph to metres per second:

$$90 \text{ kph} = \frac{90 \text{ km}}{1 \text{ h}} = \frac{90000 \text{ m}}{3600 \text{ s}} = 25 \text{ m/s}$$

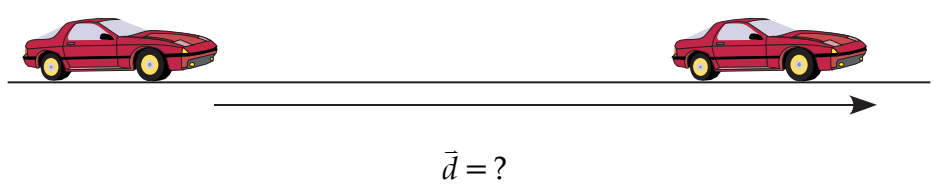
We will now look at examples of using the equations in solving problems, and at the same time applying the problem-solving strategy.

Example 1

A car moving at +3.0 m/s accelerates for 4.0 s with a uniform acceleration of +2.0 m/s^2. Find the displacement of the car.

Given: In this problem the positive direction points to the right.

$\vec{v}_1 = +3.0 \text{ m/s}$ $\qquad$ $\vec{a} = +2.0 \text{ m/s}^2$



initial velocity	$\vec{v}_1 = +3.0\ \text{m/s}$
acceleration	$\vec{a} = +2.0\ \text{m/s}^2$
time interval	$\Delta t = 4.0\ \text{s}$
Unknown: displacement	$\vec{d} = ?$
Equation:	$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$
Substitute:	$\vec{d} = (+3.0\ \text{m/s})(4.0\ \text{s}) + \frac{1}{2}(+2.0\ \text{m/s}^2)(4.0\ \text{s})^2$
Solve:	$\vec{d} = (+12\ \text{m}) + (+16\ \text{m}) = +28\ \text{m}$

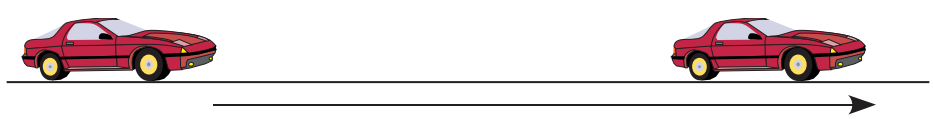
The car moves 28 m to the right.

Example 2

A car travelling at 10.0 m/s accelerates at a rate of 3.00 m/s^2 to a speed of 25.0 m/s. What is the displacement of the car during the acceleration?

Given: In this problem, the positive direction points to the right.

$\vec{v}_1 = +10.0\ \text{m/s}$ $\vec{a} = +3.00\ \text{m/s}^2$ $\vec{v}_2 = +25.0\ \text{m/s}$



$\vec{d} = ?$

initial velocity	$\vec{v}_1 = +10.0\ \text{m/s}$
acceleration	$\vec{a} = +3.00\ \text{m/s}^2$
final velocity	$\vec{v}_2 = +25.0\ \text{m/s}$
Unknown: displacement	$\vec{d} = ?$
Equation:	The equation that relates these four variables together without time would be the equation at number 5: $v_2^2 = v_1^2 + 2ad$. Since we're solving for displacement, we can rearrange the equation to $d = \frac{v_2^2 - v_1^2}{2a}$. Remember to drop the vector symbols in this case.

Substitute: $$d = \frac{(+25.0\ \text{m/s})^2 - (+10.0\ \text{m/s})^2}{2(+3.00\ \text{m/s}^2)}$$

Solve: $$d = \frac{(625)-(100)}{+6.00} = +87.5\ \text{m}$$

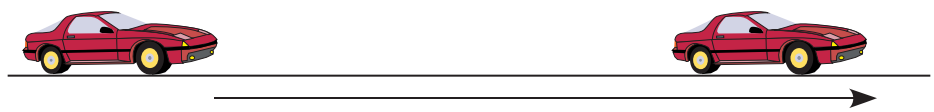
The car travels 87.5 m to the right.

Example 3

If a car accelerated at 5.00 m/s^2 and starts from rest, what is its velocity after 20.0 m?

Given: In this problem, the positive direction points to the right.

$\vec{v}_1 = 0.0\ \text{m/s}$ $\vec{a} = +5.00\ \text{m/s}^2$ $\vec{v}_2 = ?$



$\vec{d} = +20.0\ \text{m}$

initial velocity	$\vec{v}_1 = 0.0\ \text{m/s}$
acceleration	$\vec{a} = +5.00\ \text{m/s}^2$
displacement	$\vec{d} = +20.0\ \text{m}$
Unknown: final velocity	$\vec{v}_2 = ?$

Equation: The equation that relates these four variables together without time would be the equation at number 5: $v_2^2 = v_1^2 + 2ad$.

Substitute: $$v_2^2 = (0.0\ \text{m/s})^2 + 2(+5.00\ \text{m/s}^2)(+20.0\ \text{m})$$

Solve: $$v_2^2 = +200\ \text{m}^2/\text{s}^2$$

$$v_2 = \sqrt{200\ \text{m}^2/\text{s}^2} = 14.14\ \text{m/s}$$

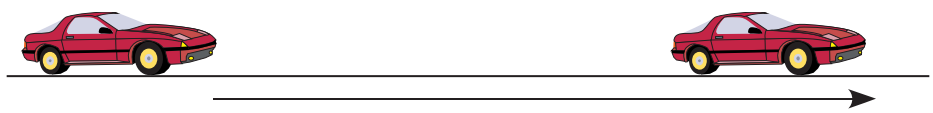
The car has a final velocity of 14.1 m/s to the right (rounded to 3 significant figures).

Example 4:

For the problem in example #3, determine the time interval required for the car to achieve its final velocity if it started from rest.

Given: In this problem, the positive direction points to the right.

$\vec{v}_1 = 0.0 \text{ m/s}$ $\vec{a} = +5.00 \text{ m/s}^2$ $\vec{v}_2 = +14.1 \text{ m}$



$\vec{d} = +20.0 \text{ m}$

initial velocity	$\vec{v}_1 = +20.0 \text{ m}$
acceleration	$\vec{a} = +5.00 \text{ m/s}^2$
displacement	$\vec{d} = +20.0 \text{ m}$
final velocity	$\vec{v}_2 = +14.1 \text{ m/s}$
Unknown: time interval	$\Delta t = ?$

Equation: You have enough information to be able to use any of the four equations for accelerated motion. Let's use the equation for acceleration:

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ rearranged to } \Delta t = \frac{\vec{v}_2 - \vec{v}_1}{\vec{a}}.$$

Substitute:

$$\Delta t = \frac{(+14.1 \text{ m/s}) - (0.0 \text{ m/s})}{(+5.00 \text{ m/s}^2)}$$

Solve:

$$\Delta t = \frac{(+14.1 \text{ m/s})}{(+5.00 \text{ m/s}^2)} = 2.82 \text{ s}$$

It took the car 2.82 s to accelerate from 0.0 m/s to +14.1 m/s.

You will often have a choice of equations to solve the problem. In that case, here are a couple of points to keep in mind. Firstly, use an equation that will use the information that is given in the question. This eliminates the chance of using an incorrectly calculated value when trying to determine the answer. Secondly, given a choice, use a simple equation (one of the ones without squared terms in them). This simplifies the math for you.

Learning Activity 1.14

Velocity and Acceleration

Answer these questions, and then check your answers with the answer key at the end of the module.

1. A sports car is moving initially at 10.0 m/s. It then undergoes a uniform acceleration of +1.20 m/s^2.

   a) What is the new velocity after a time of 30.0 s?

   b) What is the displacement of the car?

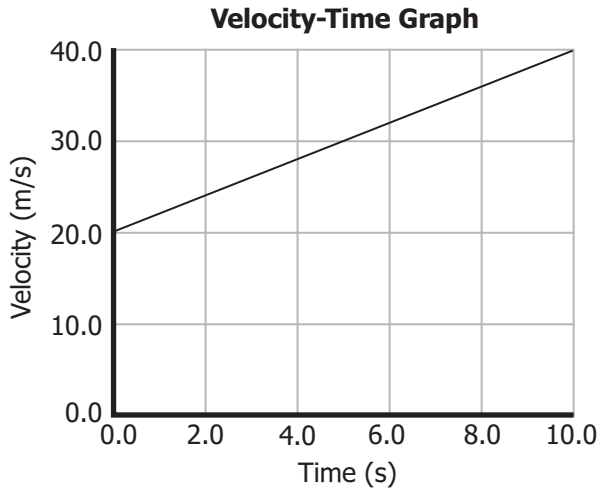
2. A speedboat has an acceleration of –2.00 m/s^2. The initial velocity of the boat is +16.0 m/s.

   a) What will be the final velocity of the speedboat after 5.00 s?

   b) What is the displacement of the boat?

3. A spacecraft is initially at rest with respect to a space station when it fires its rockets. These rockets make it accelerate at a rate of 10.0 m/s^2. What is the new velocity of the spacecraft after it has moved a distance of 2.15 x 10^5 m?

4. The following graph shows a car changing in velocity over time.



   Determine the displacement of the car.

Lesson Summary

Congratulations! You have almost completed the last lesson in Module 1.

Problems involving motion along a straight line can be solved using one of the five kinematics equations.

The first equation can be used to solve only problems where the object is moving with a constant velocity (i.e., the acceleration is 0 m/s^2).

The final four equations are for accelerated motion.

To increase your chances of successfully solving problems, use the GUESS method. This systematic approach to problem solving will enable you to solve problems more successfully.

The equations for straight-line kinematics or for motion along a straight line are:

Kinematics Equation 1: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Kinematics Equation 2: $\vec{a} = \dfrac{\Delta \vec{v}}{\Delta t}$ or $\vec{a} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$

Kinematics Equation 3: $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$

Kinematics Equation 4: $\vec{d} = \vec{v}_1 \Delta t + \dfrac{1}{2}\vec{a}\Delta t^2$

Kinematics Equation 5: $v_2^2 = v_1^2 + 2ad$

Quantity	**Symbol**	**Unit**
Displacement	$\vec{d}$	metres (m)
Velocity	$\vec{v}$	metres/seconds (m/s)
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)
Time interval	Δt	seconds (s)
Initial velocity	$\vec{v}_1$	metres/seconds (m/s)
Final velocity	$\vec{v}_2$	metres/seconds (m/s)

Assignment 1.3, Part C

Constant Velocity and Acceleration (6 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 1, after you have completed Module 1.

A skier starts from rest down a slope 500.0 m long. The skier accelerates at a constant rate of 2.00 m/s^2.

a) Find the velocity of the skier at the bottom of the slope.

Equation:

Substitution:

Solving:

b) Using the distance down the hill, and the two velocities, determine the time it took to descend the hill.

Equation:

Substitution:

Solving:

(continued)

Assignment 1.3, Part C: Constant Velocity and Acceleration (continued)

c) At what time is the skier at a spot 275 m down the hill from his starting point?

Equation:

Substitution:

Solving:

Method of Assessment

The total of six marks for this assignment will be determined as follows:

- In part (a), 0.5 marks for determining the correct equation for velocity and 1.5 marks for determining the final velocity
- In part (b), 1 mark for determining the correct equation for time in terms of displacement and the two velocities and 1 mark for determining the time
- In part (c), 0.5 marks for the correct equation and 1.5 mark for the correct time

Module 1 Summary

Congratulations on completing the first module of Grade 11 Physics.

Submitting Your Assignments

It is now time for you to submit Assignments 1.1 to 1.3 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 1 assignments and organize your material in the following order:

- Module 1 Cover Sheet (found at the end of the course Introduction)
- Assignment 1.1, Part A: Symbolic Mode
- Assignment 1.1, Part B: Significant Digits
- Assignment 1.1, Part C: Scalars and Vectors
- Assignment 1.1, Part D: Position-Time Graph 1
- Assignment 1.2: Video Laboratory Activity: Kinematics
- Assignment 1.3, Part A: Acceleration-Time Graph 1
- Assignment 1.3, Part B: Position-Time Graph 2
- Assignment 1.3, Part C: Constant Velocity and Acceleration

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

You're now ready to start Module 2.

NOTES

Grade 11 Physics (30S)

Module 1: Kinematics

Learning Activity Answer Keys

MODULE 1: KINEMATICS

Learning Activity 1.1: Recording Data

1. A person is moving slowly at a constant speed to the right. Every second, the distance travelled from the origin is recorded. The diagram below is one way to visually record the data. In this situation, the independent variable is the time.

   - At t = 0.0 s, the distance travelled d = 0.0 m.
   - At t = 2.0 s, d = 1.0 m
   - At t = 4.0 s, d = 2.0 m
   - At t = 6.0 s, d = 3.0 m
   - At t = 8.0 s, d = 4.0 m
   - At t = 10.0 s, d = 5.0 m

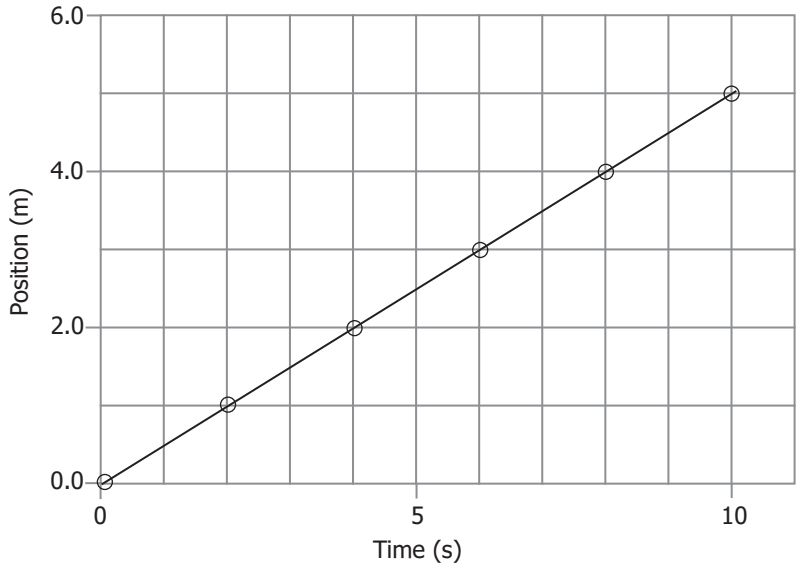
   a) Express the data above numerically in the form of a data table. Construct the data table horizontally. Be sure to label the rows correctly.

   Answer:

time (s)	0.0	2.0	4.0	6.0	8.0	10.0
distance (m)	0.0	1.0	2.0	3.0	4.0	5.0

   b) Now construct a graph of the data above.

   Answer:



c) To illustrate the symbolic mode, determine the mathematical equation that relates the distance and the time. Include the magnitude of the slope in your answer.

Answer:

If we use the coordinates (0, 0) and (10.0, 5.0), the slope of the line is

$$\frac{5.0\ \text{m} - 0.0\ \text{m}}{10.0\ \text{s} - 0.0\ \text{s}} = 0.50\ \text{m/s}.$$

If we eliminate the units from the slope, the equation of the line can therefore be written as $d = 0.50t$.

2. If you were asked by another student "What is physics?", what would you say?

Answers will vary.

You might say that physics began as the study of everything around us. Over time some phenomena have been classified into other categories, such as biology, chemistry, or astronomy, and removed from physics. Whatever remains is what we now call physics.

A more narrow definition could be that physics is the study of the relationships that exist within a given situation.

Learning Activity 1.2: Quantities

In your previous studies of science, you have been introduced to many quantities and many instruments used to measure these quantities. Fill in the missing parts in the table below.

Answer:

Quantity	Symbol of the Quantity	Unit	Vector or Scalar
time instant	t	second (s)	scalar
time interval	Δt	second (s)	scalar
distance travelled	Δd	metre (m)	scalar
displacement	$\Delta \vec{d}$	metre (m)	vector
mass	m	kilogram (kg)	scalar
length	l	metre (m)	scalar
speed	v	metres/second (m/s)	scalar
acceleration	$\vec{a}$	metre/second/second (m/s/s or m/s^2)	vector
velocity	$\vec{v}$	metres/second (m/s)	vector
force	$\vec{F}$	Newtons (N)	vector
energy	E	Joules (J)	scalar

Learning Activity 1.3: Significant Digits: Part 1

Write the answer to each question in the space provided in the table. The answers to these questions can be found in the answer key at the end of the module.

1. Determine the number of significant digits in each of the following numbers.

   Answer:

5.897	4	8.000	4	10001	5
0.333	3	8.001	4	0.008000	4
7	1	0.009	1	947.000	6
10000	1	12000	2	10000.0	6
10321	5	55040	4	375000	3

2. State the number of significant digits in each measurement.

   Answer:

a) 2509 m	4	g) 7.62 km	3
b) 0.00055 m	2	h) 0.0670 m	3
c) 5.060×10^5 m	4	i) 9.0000×10^{-5} m	5
d) 240 m	2	j) 2.4 m	2
e) 2400 m	2	k) 2400.0 m	5
f) 0.005050 m	4	l) 50 m	1

Learning Activity 1.4: Significant Digits: Part 2

1. A bowl contains 12 oranges. In this case, what type of number is 12?

   Answer: In this case, 12 is an exact number.

2. How many significant digits are in each of the following numbers?

   Answer:

a) 18	2	f) 125 000 000	3
b) 0.018	2	g) 125 000 000.0	10
c) 250	2	h) 1.0×10^{8}	2
d) 12000	2	i) 5.92×10^{-6}	3
e) 1008	4	j) 4.30450×10^{3}	6

3. Complete the following calculations. Round off the final answer to the correct number of significant digits.

   Answers:

   a) $2.8234 \times 6.1 = 17.22274 = 17$

   Since the first number contains five significant digits and the second number contains two significant digits, we will keep only two significant digits in our answer.

   Therefore, we round off the 7.

   b) $0.03940 \times 0.0090400 = 0.000356176 = 0.0003562$

   Since the first number contains four significant digits and the second number contains five significant digits, we will keep only four significant digits in our answer.

   Therefore, we round off the 1. In this case, the zeros after the decimal and preceding the 3 are used as placeholders. Zeros used as placeholders are not significant. You can check this using the Atlantic-Pacific procedure.

   c) $820 / 2.050 = 400 = 4.0 \times 10^{2}$

   The 820 contains two significant digits and the 2.050 contains four significant digits. Therefore, we keep only two significant digits in the answer. The answer 400 seems to contain only one significant digit. We must write the answer in scientific notation to avoid any ambiguity about which digits are significant.

d) 9000.0 / 5820 = 1.546391753 = 1.55

e) 738 + 25.92 = 763.92 = 764

$$\begin{array}{r} 73\mathbf{8} \\ +25.9\mathbf{2} \\ \hline 76\mathbf{3.92} \end{array}$$

The digits written in boldface type are all uncertain. Therefore, we round off the first of these uncertain digits—that is, the digit that lies in the largest place value. In this case, that place value is the ones.

f) 87000 – 640.0 = 86360.0 = 86000 or 8.6×10^4

$$\begin{array}{r} 8\mathbf{7}000 \\ -640.\mathbf{0} \\ \hline 8\mathbf{6360.0} \end{array}$$

Round this answer off at the digit that lies in the largest of the uncertain place values.

g) 0.002050 – 0.0003892 = 0.0016608 = 0.001661

$$\begin{array}{r} 0.00205\mathbf{0} \\ -0.000389\mathbf{2} \\ \hline 0.0016\mathbf{608} \end{array}$$

h) 90.25 + 4.984 – 6.3080 = 88.926 = 88.93

$$\begin{array}{r} 90.2\mathbf{5} \\ +4.98\mathbf{4} \\ -6.308\mathbf{0} \\ \hline 88.9\mathbf{26} \end{array}$$

i) 3.0625 x 8.0920 ÷ 140 = 0.1770125 = 0.18

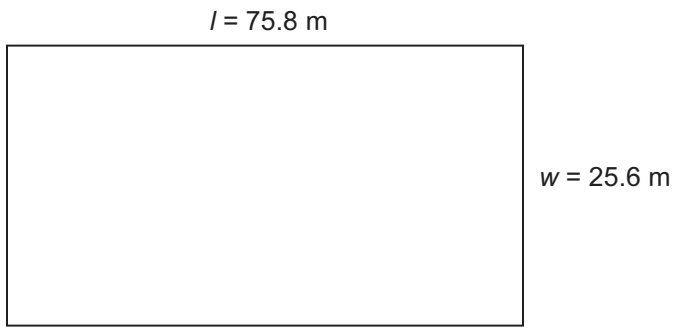
Since the 140 contains only two significant digits, we must keep two significant digits in the final answer.

Learning Activity 1.5: Average Speed

1. Your school is rectangular in shape. Around the school is a sidewalk that also forms a rectangle. Along the length of the school, the sidewalk is 75.8 m and along the width of the school the sidewalk is 25.6 m. It takes 65.3 seconds to walk on the sidewalk around the school and return to the starting point.

   a) What is the distance travelled?

   Answer:



The distance travelled is the distance around the rectangle or its perimeter.

$P = 2l + 2w$

$P = 2(75.8\text{ m}) + 2(25.6\text{ m})$

$P = 202.8\text{ m} = 203\text{ m}$ (rounded off to 3 significant digits due to multiplication rule)

   b) What was your average speed during this trip?

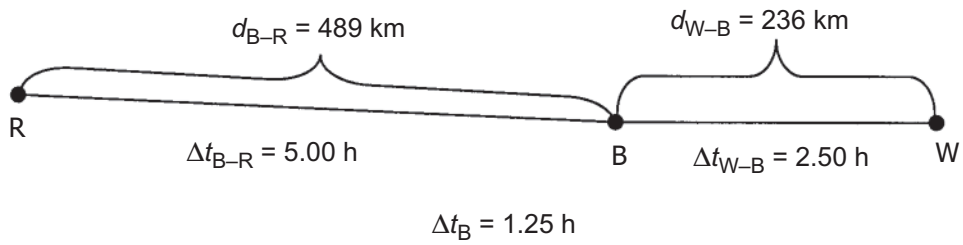
   Answer:

Given:

Distance travelled	$d = 203\text{ m}$
Time interval	$\Delta t = 65.3\text{ s}$
Unknown: average speed	$v_{avg} = ?$
Equation:	$v = \dfrac{d}{\Delta t}$
Substitute and solve:	$v = \dfrac{203\text{ m}}{65.3\text{ s}} = 3.108728943\text{ m/s}$

Your average speed for this trip is 3.11 m/s.

2. You are travelling in a car from Winnipeg to Regina. It takes you 2.50 hours to travel from your home to Brandon, a distance of 236 km. You stop in Brandon to have lunch and do some shopping, spending a total of 1.25 hours. The remaining 489 km of the trip to Regina requires 5.00 hours.



a) What is the average speed for the part of the trip from your home to Brandon?

Answer:

To answer this question, you only need to consider the distance between Winnipeg and Brandon and the time that it took to travel from Winnipeg to Brandon.

Given: Distance travelled $d_{W\text{-}B} = 236$ km

Time interval $\Delta t_{W\text{-}B} = 2.50$ h

Unknown: Average speed $v_{avg} = ?$

Equation: $$v = \frac{d}{\Delta t}$$

Substitute and solve: $$v = \frac{236 \text{ km}}{2.50 \text{ h}} = 94.4 \text{ km/h}$$

The average speed between Winnipeg and Brandon was 94.4 km/h.

b) What is the average speed for the whole trip from Winnipeg to Regina?

Answer:

Given: Distance travelled $d_{W-R} = d_{W-B} + d_{B-R} = 236 \text{ km} + 489 \text{ km}$
$= 725$ km

Total time interval $\Delta t_{total} = \Delta t_{W-B} + \Delta t_B + \Delta t_{B-R}$
$= 2.50 \text{ h} + 1.25 \text{ h} + 5.00 \text{ h} = 8.75 \text{ h}$

Unknown: Average speed $v_{avg} = ?$

Equation: $$v = \frac{d}{\Delta t}$$

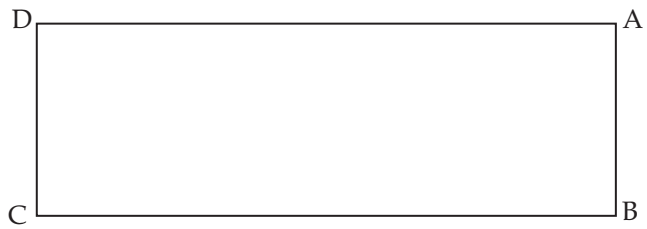
Substitute and solve: $$v = \frac{725 \text{ km}}{8.75 \text{ h}} = 82.85714... \text{ km/h}$$

The average speed from Winnipeg to Regina was 82.8 km/h.

Learning Activity 1.6: Velocity

For questions #1–3, use the information below.

A city block is laid out in a grid, running in north-south and east-west directions. The blocks measure 135 m in length in the east-west direction, and 45.0 m in width in the north-south direction. A city block is drawn below.



Answers:

1. On your bicycle, you travel from A to B during 9.00 s.
   a) What is your average speed?

   $d = 45.0 \qquad \Delta t = 9.00 \text{ s}$

   $v_{avg} = ?$

   $$v_{avg} = \frac{d}{\Delta t} = \frac{45.0 \text{ m}}{9.00 \text{ s}} = 5.00 \text{ m/s}$$

   b) What is your average velocity?

   $$\vec{v}_{avg} = \frac{\vec{d}}{\Delta t} = \frac{45.0 \text{ m [S]}}{9.00 \text{ s}} = 5.00 \text{ m/s [S]}$$

2. If you travel from A to B to C to D, what is your
   a) distance travelled?

   $\Delta\vec{d}_{AB} = 45.0 \text{ m} \qquad \Delta\vec{d}_{BC} = 135.0 \text{ m} \qquad \Delta\vec{d}_{CD} = 45.0 \text{ m}$

   $\Delta\vec{d}_{TOTAL} = 45.0 \text{ m} + 135.0 \text{ m} + 45.0 \text{ m} = 225.0 \text{ m}$

   b) displacement?

   The displacement from A to B to C to D is the same as going directly from A to D, which is 135 m [W].

3. If the journey in #2 took 55.0 s, calculate
   a) your average speed

$d_{\text{TOTAL}} = 225 \text{ m} \qquad \Delta t = 55.0 \text{ s}$

$v_{\text{avg}} = ?$

$$v_{\text{avg}} = \frac{d}{\Delta t} = \frac{225 \text{ m}}{55.0 \text{ s}} = 4.09 \text{ m/s}$$

   b) your average velocity

$\vec{d} = 135 \text{ m [W]} \qquad \Delta t = 55.0 \text{ s}$

$$\vec{v}_{\text{avg}} = \frac{\Delta \vec{d}}{\Delta t} = \frac{135 \text{ m [W]}}{55.0 \text{ s}} = 2.45 \text{ m/s [West]}$$

4. A car is travelling around a circular track. Write down which one of the following statements is incorrect and why.
   a) The car travelled around the track at a constant velocity.
   b) The car travelled around the track at a constant speed.

   Answer:

   The velocity of the car is a vector quantity with both magnitude and direction. The speed of the car is a scalar quantity and has nothing to do with direction. It is possible to drive a car around a track at a constant speed. As the car drives around the track, however, it must change direction. Therefore, the direction of the velocity changes and the velocity cannot be constant.

5. Sound travels at a constant speed of 343 m/s in air.
   a) How much time does it take the sound of thunder to travel a distance of 5005 m?

   Answer:

   Given: Speed $v = 343$ m/s

   Distance $d = 5005$ m

   Equation: $v = \dfrac{d}{\Delta t}$ rearranged to $\Delta t = \dfrac{d}{v}$

   Substitute and solve: $\Delta t = \dfrac{5005 \text{ m}}{343 \text{ m/s}} = 14.6 \text{ s}$

   The time it takes the sound to travel is 14.6 s.

b) If the sound reflects back to the place where it originated, what is the average velocity of the sound?

Answer:

Since the sound reflected back to its place of origin, the displacement is zero and the average velocity is 0 m/s.

6. Andy Green in the car *ThrustSSC* established a world record in 1997. The speed of the car was 341.1 m/s (1228 km/h). The car was powered by two jet engines. It was also the first car to officially exceed the speed of sound. To establish such a record, the driver makes two runs through the course, one in each direction, to nullify wind effects. First, the car travelled from left to right, a distance of 1609 m in a time of 4.740 s. Then the car travelled the same distance in the reverse direction in a time of 4.695 s. Determine the average velocity in each run.

Answer:

In the first run, the car moved with a positive displacement.

Given: Time interval $\Delta t = 4.740$ s

Displacement $\vec{d} = +1609$ m

Equation: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Substitute and solve: $\vec{v} = \dfrac{\vec{d}}{\Delta t} = \dfrac{+1609 \text{ m}}{4.740 \text{ s}} = +339.4 \text{ m/s}$

The positive sign would not normally be included in an answer. It is done here just for emphasis.

In the second run, the car moved a negative displacement $\left(\vec{d} = -1609 \text{ m}\right)$.

Given: Time interval $\Delta t = 4.695$ s

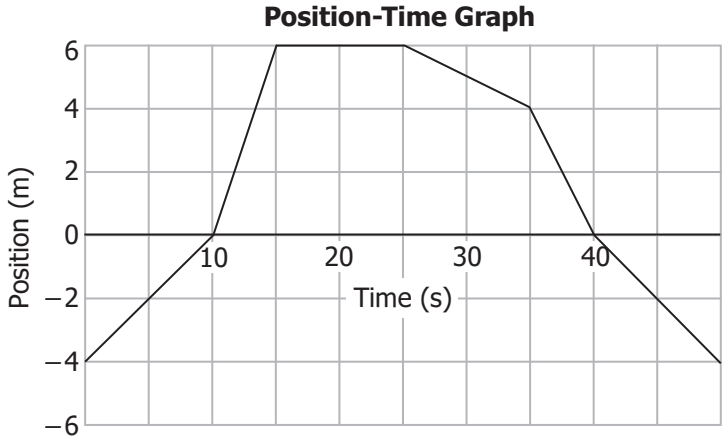
Displacement $\vec{d} = -1609$ m

Equation: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Substitute and solve: $\vec{v} = \dfrac{\vec{d}}{\Delta t} = \dfrac{-1609 \text{ m}}{4.695 \text{ s}} = -342.7 \text{ m/s}$

The velocity on the return trip was –342.7 m/s. Here, we must include the negative sign to give the correct direction for the velocity. We could also say 342.7 m/s to the left.

Learning Activity 1.7: Position–Time Graph: Part 1



The position-time graph above represents the motion of a remote-controlled toy truck as it moves back and forth along a straight line path. The origin marks the position of the boy who controls the truck. The boy has not yet learned how to make the truck change its direction of motion.

A positive position marks positions to the right of the boy, and a negative position marks positions to the left of the boy.

Answers:

1. During which time intervals is the truck to the right of the boy? 10–40 s

   To the left of the boy? 0 s–10 s, 40 s–50 s

2. During which time intervals is the truck moving in the positive direction?

   0 s–15 s,

   In the negative direction? 25 s – 50 s

   Not moving? 15 s—25 s

3. What is the position of the truck at 0 seconds? –4 m

   15 seconds? +6 m

   30 seconds? +5 m

   45 seconds? –2 m

4. When is the truck in front of the boy? At 10 s and at 40 s

   The graph of position-time gives **directly** some information about the motion. This tells the position-time version of the story of this motion—that is, where the truck is at a particular instant in time.

   The graph of position-time also gives **indirect** information about the motion of the truck.

The following questions deal with obtaining this indirect information like distance travelled, displacement, average speed, and average velocity.

5. How far did the truck travel during the following time intervals:

   Answers:

   0-10 s? 4 m

   10-15 s? 6 m

   15-25 s? 0 m

   25-35 s? 2 m

   35-40 s? 4 m

   40–0 s? 4 m

6. What was the displacement of the truck during the following intervals:

   Answers:

   0-10 s? +4 m

   10-15 s? +6 m

   15-25 s? 0 m

   25-35 s? –2 m

   35-40 s? –4 m

   40–50 s? –4 m

7. Average speed is given by the distance travelled divided by the time interval. Calculate the average speed for each interval:

   Answers:

   0-10 s? $v = \frac{d}{\Delta t} = \frac{4\text{ m}}{10\text{ s}} = 0.4\text{ m/s}$

   10-15 s? 1.2 m/s

   15-25 s? 0 m/s

   25-35 s? 0.2 m/s

   35-40 s? 0.8 m/s

   40-50 s? 0.4 m/s

8. The following relationship is used to calculate average velocity:

   average velocity = displacement/time interval or $\vec{v} = \frac{\vec{d}}{\Delta t}$.

   This relationship also represents the slope of the line on a position-time graph.

   Calculate the average velocity for each time interval by calculating the slope of the line segment. Show your work.

   Answer:

Run = Δt Time Interval	**Rise = $\vec{d}$ Displacement**	**Slope = $\vec{v} = \frac{\vec{d}}{\Delta t}$**
0 – 10 s	0 m – (–4 m) = + 4 m	$\frac{+4\text{ m}}{10\text{ s}} = +0.4\text{ m/s}$
10 – 15 s	+6 m – 0 m = +6 m	+1.2 m/s
15 – 25 s	+6 m – (+6 m) = 0 m	0 m/s
25 – 35 s	+4 m – (+6 m) = –2 m	–0.2 m/s
35 – 40 s	0 m – (+4 m) = –4 m	–0.8 m/s
40 – 50 s	–4 m – 0 m = –4 m	–0.4 m/s

9. How do the signs of the velocities in #9 compare with the direction of motion in #2?

   Answer:

   When the truck has a negative velocity, it moves in the negative direction (towards the boy's left).

   When the truck has a positive velocity, it moves in the positive direction (towards the boy's right).

10. In terms of the truck's motion, what does a negative velocity mean?

    Answer: A negative velocity means that the truck is moving towards the boy's left.

    A positive velocity?

    Answer: A positive velocity means the truck is moving to the boy's right.

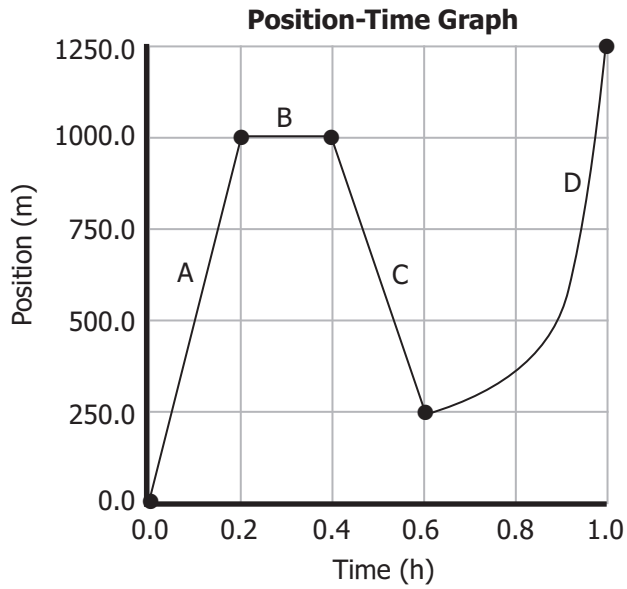
    A velocity of 0 m/s?

    Answer: A velocity of 0 m/s means the truck is standing still at one position.

Learning Activity 1.8: Position–Time Graph: Part 2

The physics of a position-time graph and a person exercising

The graph below shows a possible situation for a person who is exercising.



a) For the segments A to C above, calculate the velocity. (Note: convert each of the time intervals into seconds so that the units of velocity are in m/s. 1 h has 3600 s.)

Answer:

Determine the time intervals for each segment, then convert the time into seconds.

Each of the intervals (A, B, and C) is 0.20 h in duration.

Each time interval, Δt, is 0.20 h.

Since there are 3600 s in 1 h, we multiply 0.20 h by the fraction $\frac{3600\text{ s}}{1\text{ h}}$ to get rid of hours.

So, $\Delta t = 0.20\text{ h} \times \frac{3600\text{ s}}{1\text{ h}} = 720\text{ s}.$

The run for each interval is 720 s.

For each of the intervals, determine the rise over the run.

For Part A: $\vec{v}_A = \frac{\vec{d}_A}{\Delta t} = \frac{1000.0\text{ m} - 0\text{ m}}{720\text{ s}} = \frac{1000.0\text{ m}}{720\text{ s}} = 1.39\text{ m/s or } 1.4\text{ m/s}.$

For Part B: $\vec{v}_B = \dfrac{1000.0\text{ m} - 1000.0\text{ m}}{720\text{ s}} = \dfrac{0.0\text{ m}}{720\text{ s}} = 0.0\text{ m/s}.$

For Part C: $\vec{v}_C = \dfrac{250.0\text{ m} - 1000.0\text{ m}}{720\text{ s}} = \dfrac{-750.0\text{ m}}{720\text{ s}} = -1.04\text{ m/s or } -1.0\text{ m/s}.$

b) During which of the time intervals, A to C, was the runner moving the fastest?

Answer:

This occurred when the slope was the greatest. This is during Part A.

c) During which of the time intervals was the runner returning towards the starting point?

Answer:

This occurred when the velocity was negative—that is, in Part C.

d) During which of the time intervals was the runner most likely resting?

Answer:

This occurred during Part B when the slope was zero.

e) What was the average velocity over the whole run?

Answer:

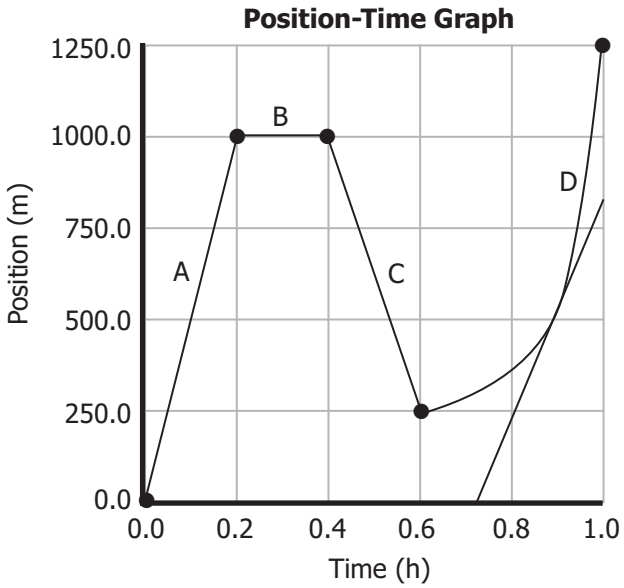
Draw a chord joining the initial position at 0.0 hours to 1.00 hours. The slope of this chord gives the average velocity for the whole run. Remember to convert the time from hours into seconds.

For the whole run, the average velocity was

$$\vec{v}_{avg} = \frac{\vec{d}_{TOTAL}}{\Delta t_{TOTAL}} = \frac{1250.0\text{ m} - 0\text{ m}}{(1.00\text{ h}) - (0.0\text{ h})} = \frac{1250.0\text{ m}}{(1.00\text{ h})} = \frac{1250.0\text{ m}}{3600\text{ s}} = 0.35\text{ m/s}.$$

f) For the time interval corresponding to D, determine the instantaneous velocity at a position of 500.0 m.

Answer:



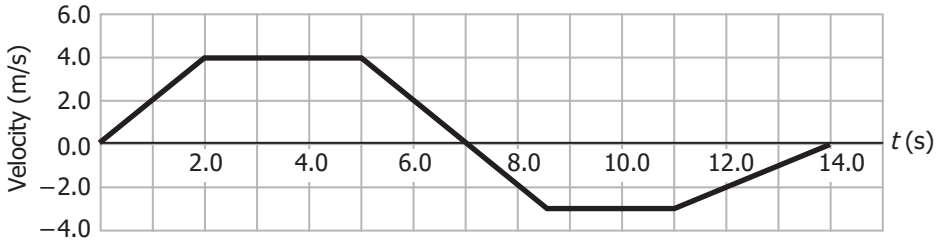
Draw a tangent line in interval D at the 500.0 m point, and find the slope of the line.

If we assume that at a time of 1.0 h (3.6×10^3 s) the position is 800.0 m, and that at a time of 0.72 h (2.6×10^3 s) the position is 0.0 m, then the slope of the tangent line is $\vec{v} = \dfrac{800.0\ \text{m} - 0.0\ \text{m}}{(3.6 \times 10^3\,\text{s}) - (2.6 \times 10^3\,\text{s})} = 0.792\ \text{m/s} = 0.79\ \text{m/s}.$

Due to the difficulty in drawing the tangent accurately, any answer in the 0.7 m/s to 0.8 m/s range is acceptable.

Learning Activity 1.9: Velocity–Time Graph: Part 1

1. For the velocity-time graph given below, determine the acceleration for each interval. Fill in the chart with the appropriate information, then plot a graph of acceleration versus time.

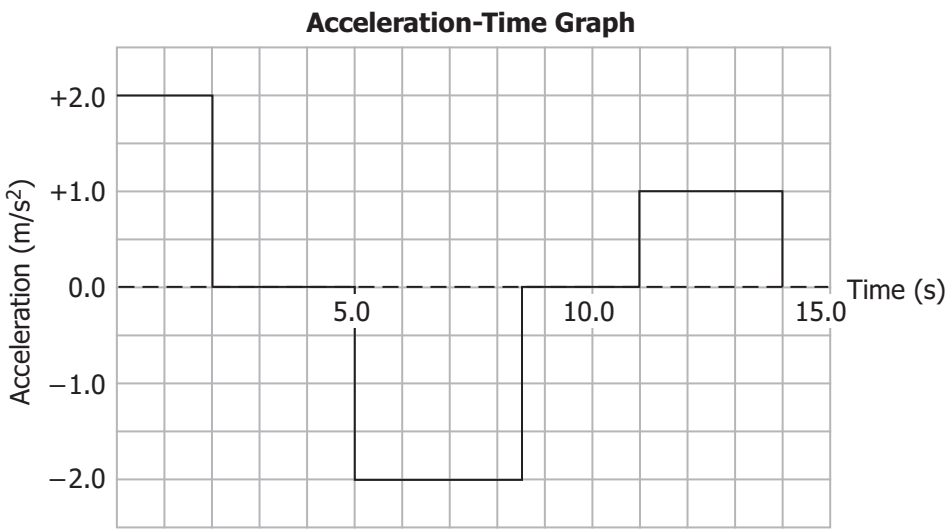


Answer:

Determining the acceleration from a velocity-time graph requires that you find the slope. On this particular graph, the velocities are sometimes constant and sometimes change over the time intervals.

For each section of the graph over which the slope is different, you must calculate the slope separately. The table below will organize the slope calculations.

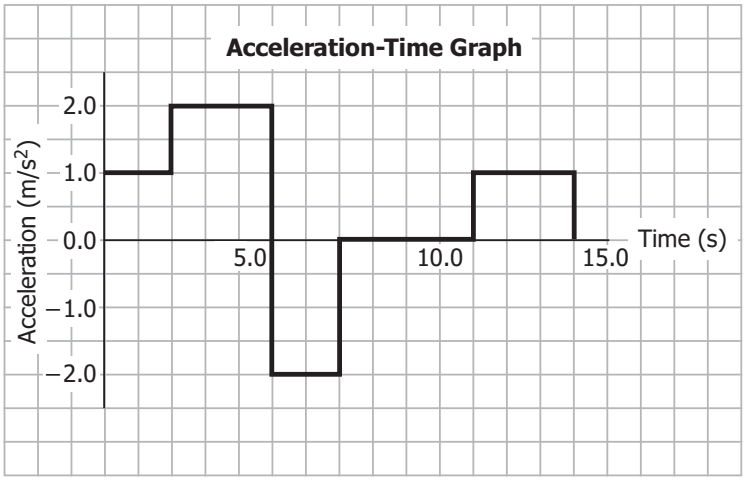
Run	Rise	Slope
Time Interval (s)	Change in velocity (m/s) $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$	Acceleration (m/s^2) $\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$
0.0–2.0	(+4.0 m/s) – (0.0 m/s) = +4.0	+4.0 m/s / 2.0 s = +2.0 m/s^2
2.0–5.0	(+4.0 m/s) – (+4.0 m/s) = 0	0.0 m/s / 3.0 s = 0.0 m/s^2
5.0–8.5	(–3.0 m/s) – (+4.0 m/s) = –7.0	–7.0 m/s / 3.5 s = –2.0 m/s^2
8.5–11.0	(–3.0 m/s) – (–3.0 m/s) = 0	0.0 m/s / 2.5 s = 0.0 m/s^2
11.0–14.0	(0.0 m/s) – (–3.0 m/s) = +3.0	+3.0 m/s / 3.0 s = +1.0 m/s^2



These types of graphs with sharp corners and more than 1 acceleration at the same time are impossible. However, we use these "idealized" graphs so that we can perform the required physics without getting bogged down with the graphing.

Learning Activity 1.10: Velocity–Time Graph: Part 2

1. For the acceleration-time graph given below, determine the change in velocity for each interval. Fill in the chart with the appropriate information, then plot a graph of velocity versus time. Assume the initial velocity is +3.0 m/s.

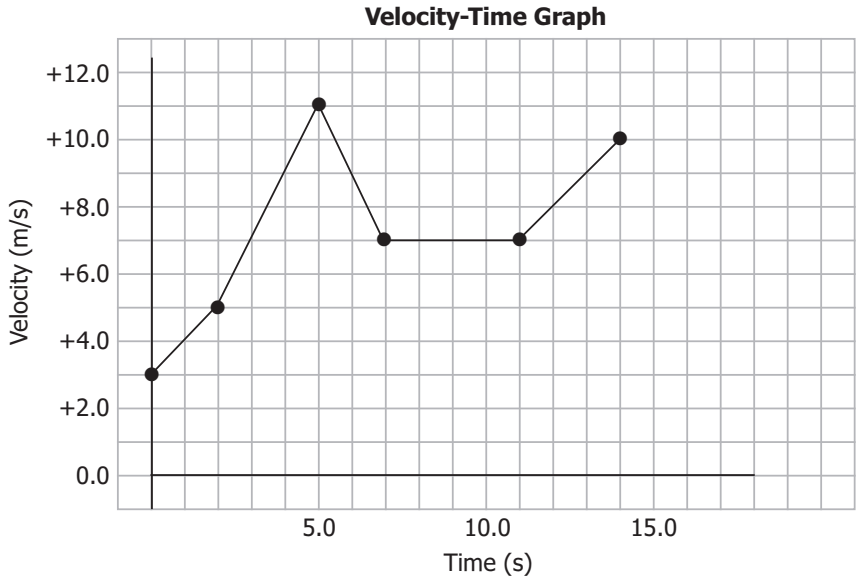


Answer:

Here you must take the area beneath the between the line and the time axis. There will be five of these areas.

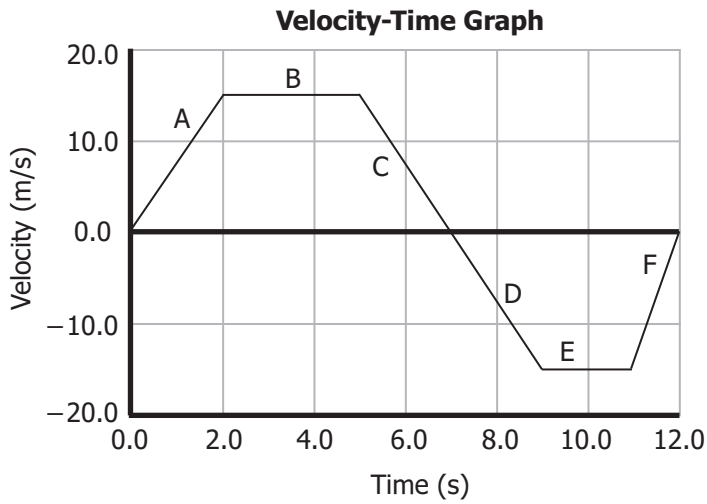
Time Interval (s)	Change in Velocity (m/s) $\Delta\vec{v} = \vec{a}\Delta t$	Velocity at End of the Interval (m/s) $\vec{v}_1 + \Delta\vec{v} = \vec{v}_2$
0.0		+3.0
0.0–2.0	(+1.0 m/s²)(2.0 s) = +2.0	+3.0 m/s + (+2.0 m/s) = +5.0
2.0–5.0	(+2.0 m/s²)(3.0 s) = +6.0	+5.0 m/s + (+6.0 m/s) = +11.0
5.0–7.0	(–2.0 m/s²)(2.0 s) = –4.0	+11.0 m/s + (–4.0 m/s) = +7.0
7.0–11.0	(0.0 m/s²)(4.0 s) = 0.0	+7.0 m/s + (+0.0 m/s) = +7.0
11.0–14.0	(+1.0 m/s²)(3.0 s) = +3.0	+7.0 m/s + (+3.0 m/s) = +10.0

The graph of velocity-time is made by plotting the velocity at the end of each time interval at the time representing the end of each time interval. This will give a series of points. Join these points with line segments to complete the graph.



Learning Activity 1.11: The Physics of a Moving Bicycle

The following velocity-time graph shows the possible motion of a bicycle.



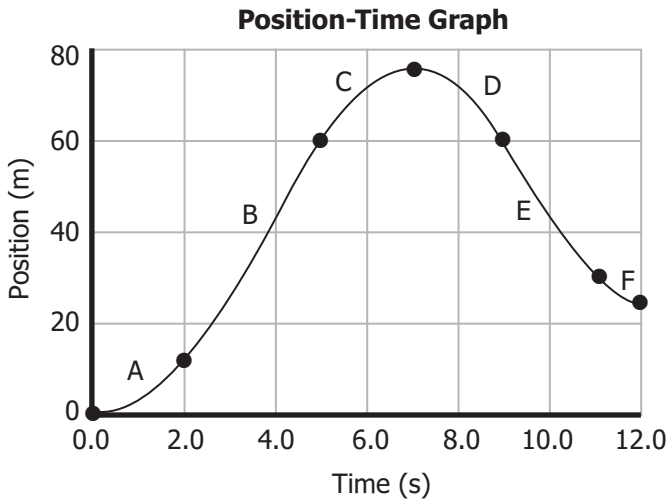
a) Produce a data table showing time and position, and then graph the data. The time portions of the table have been filled in. Assume the bicycle starts at 0.0 m at 0.0 s.

Answer:

Section	Time Interval (s)	Displacement (m) $\vec{d} = \vec{v}\Delta t$	Position at End of the Interval (m) $\overrightarrow{\text{pos}}_1 + \vec{d} = \overrightarrow{\text{pos}}_2$
	0.0		0.0
A	0.0 – 2.0	$\frac{1}{2}\left(\left(+15.0\text{ m/s}\right)\left(2.0\text{ s}\right)\right) = +15\text{ m}$	0.0 m + (+15 m) = +15
B	2.0 – 5.0	(+15.0 m/s)(3.0 s) = +45 m	+15 m + (+45 m) = +60
C	5.0 – 7.0	$\frac{1}{2}\left(\left(+15\text{ m/s}\right)\left(2.0\text{ s}\right)\right) = +15\text{ m}$	+60 m + (+15 m) = +75
D	7.0 – 9.0	$\frac{1}{2}\left(\left(-15.0\text{ m/s}\right)\left(2.0\text{ s}\right)\right) = -15\text{ m}$	+75 m + (–15 m) = +60
E	9.0 – 11.0	(–15.0 m/s)(2.0 s) = –30 m	+60 m + (–30 m) = +30
F	11.0 – 12.0	$\frac{1}{2}\left(\left(-15\text{ m/s}\right)\left(1.0\text{ s}\right)\right) = -7.5\text{ m}$	+30 m + (–7.5 m) = +22.5

If we just consider the position at the end of each time interval, we arrive at the table below.

Time (s)	Position (m)
0.0	0.0
2.0	15
5.0	60
7.0	75
9.0	60
11.0	30
12.0	22.5



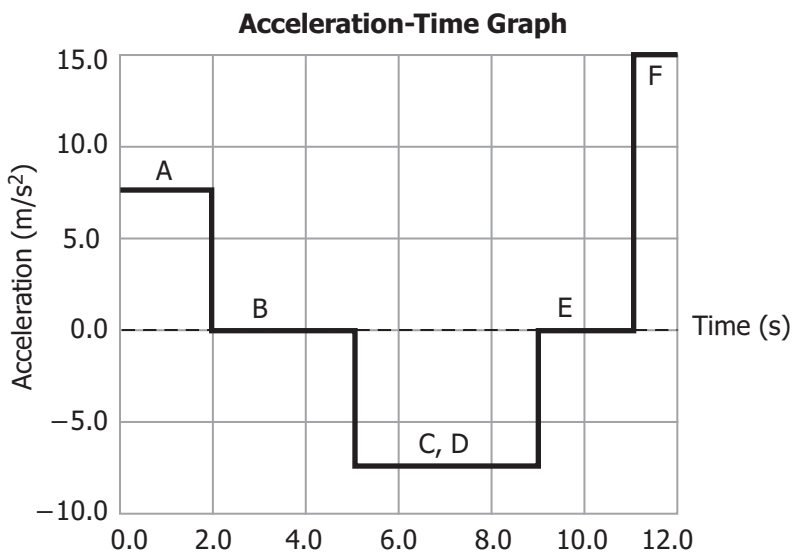
b) Produce a data table showing time and acceleration, and then graph the data. The time portions of the table have been filled in.

Answer:

Here you are looking for the slope of the velocity-time graph. Your table should have in it: time interval (run), change in velocity (rise), and acceleration (slope).

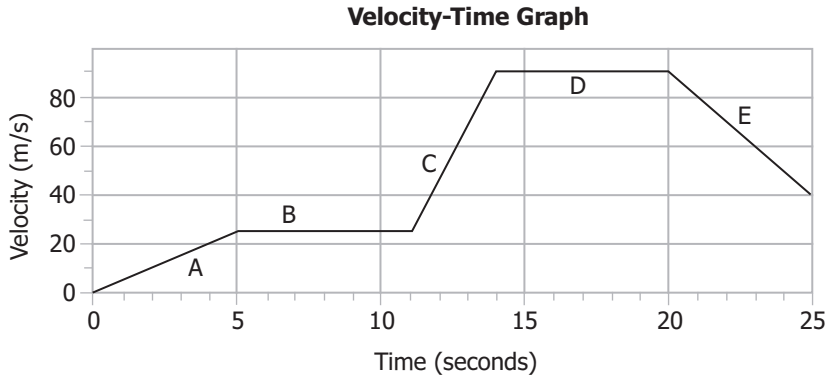
Section	Time Interval (s)	Change in Velocity (m/s) $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$	Acceleration (m/s²) $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$
A	0.0 – 2.0	(+15.0 m/s) – (0.0 m/s) = +15.0 m/s	$\frac{15.0\ \text{m/s}}{2.0\ \text{s}} = 7.5\ \text{m/s}^2$
B	2.0 – 5.0	(+15.0 m/s) – (+15.0 m/s) = 0.0 m/s	$\frac{0.0\ \text{m/s}}{3.0\ \text{s}} = 0.0\ \text{m/s}^2$
C	5.0 — 7.0	(0.0 m/s) – (+15 m/s) = –15.0 m/s	$\frac{-15.0\ \text{m/s}}{2.0\ \text{s}} = -7.5\ \text{m/s}^2$
D	7.0 – 9.0	(–15.0 m/s) – (0.0 m/s) = –15.0 m/s	$\frac{-15.0\ \text{m/s}}{2.0\ \text{s}} = -7.5\ \text{m/s}^2$
E	9.0 – 11.0	(–15.0 m/s) – (–15.0 m/s) = 0.0 m/s	$\frac{0.0\ \text{m/s}}{2.0\ \text{s}} = 0.0\ \text{m/s}^2$
F	11.0 – 12.0	(0.0 m/s) – (–15.0 m/s) = +15.0 m/s	$\frac{15.0\ \text{m/s}}{1.0\ \text{s}} = +15\ \text{m/s}^2$

Since the acceleration is constant over each time interval, you will end up with a "bar" graph.



Learning Activity 1.12: Displacement

Test your understanding of the derivation of these equations for uniformly accelerated motion by trying the questions below. You may check your work against the answer key provided at the end of Module 1.



All of the questions refer to the velocity-time graph given above.

Answers:

1. What on the velocity-time graph represents acceleration? Displacement?

   On a velocity-time graph, the slope of the line gives acceleration. On the velocity-time graph, the area beneath the curve gives displacement.

2. Which of the two equations that have been derived so far in this lesson should be used to find

   a) the acceleration for the time interval A?

      Acceleration involves finding the slope using the formula $\vec{a} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$.

   b) the displacement for the time interval C?

      Displacement is found using the area formula for a trapezoid:

      $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t.$

   c) the displacement for the time interval B?

      Displacement is found using the area formula for a trapezoid:

      $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t.$

      In this case, the initial velocity and final velocity are the same; therefore, the average velocity is the same as the initial velocity and final velocity.

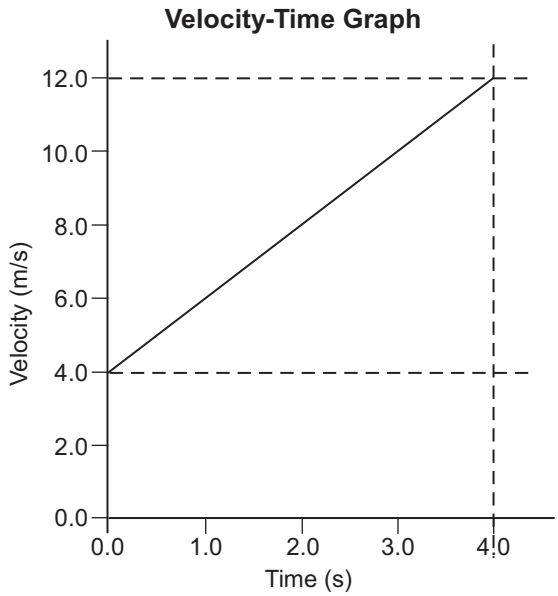
3. Calculate the displacement during time interval C.

From the graph:

Initial velocity	$\vec{v}_1 = +25 \text{ m/s}$
Final velocity	$\vec{v}_2 = +90 \text{ m/s}$
Time interval	$\Delta t = 3.0 \text{ s}$
Unknown: Displacement	$\vec{d} = ?$
Equation:	$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$
Substitute:	$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t = \frac{(25 \text{ m/s} + 90 \text{ m/s})}{2}(3.0 \text{ s})$
Solve:	$\vec{d} = \frac{(57.5 \text{ m/s})}{2}(3.0 \text{ s}) = 172.5 \text{ m} = 170 \text{ m}$

Learning Activity 1.13: The Physics of Uniformly Accelerated Motion

1. The four parts of this assignment refer to the following graph:



Answers:

a) Using the equation $\vec{v}_2 - \vec{v}_1 = \vec{a}\Delta t$, determine the acceleration of the object.

$$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{12\text{ m/s} - 4.0\text{ m/s}}{4.0\text{ s}} = +2.0\text{ m/s}^2$$

b) Using the equation $\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$, determine the displacement of the object above.

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t = \frac{1}{2}\left(+4.0\text{ m/s} + (+12.0\text{ m/s})\right)4.0\text{ s} = +32\text{ m}$$

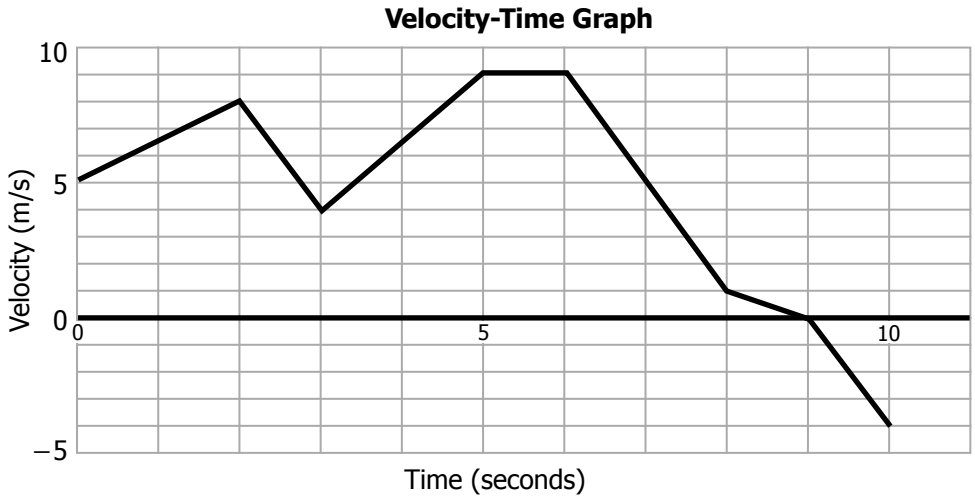
c) Using the equation $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$ verify that the displacement is the value you calculated above.

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2 = (+4.0\text{ m/s})(4.0\text{ s}) + \frac{1}{2}(+2.0\text{ m/s}^2)(4.0\text{ s}) = +32\text{ m}$$

d) Using the equation $v_2^2 = v_1^2 + 2ad$, verify that the displacement is the value you calculated above.

$$d = \frac{v_2^2 - v_1^2}{2a} = \frac{(+12.0\text{ m/s})^2 - (+4.0\text{ m/s})^2}{2(+2.0\text{ m/s}^2)} = +32\text{ m}$$

2. On the following velocity-time graph, indicate during which intervals of time the acceleration is positive, negative, or zero. This graph does not represent a real-life situation. It is presented simply to help reinforce the ideas about interpreting graphs.



Answer:

The equation for acceleration is $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$, which represents the slope of the velocity-time graph.

The slope is positive during the time intervals 0 s–2 s, and 3 s–5 s.

The slope is negative during the time intervals 2 s–3 s, 6 s–8 s, 8 s–9 s, and 9 s–10 s.

The slope is zero during the interval from five seconds to six seconds.

3. For each of the time intervals for the graph in question #2, determine the displacement using one of the equations for kinematics that were derived in this lesson. You should be able to use all four of the kinematics equations that involve displacement at least once each.

Answer:

The area beneath the curve of a velocity-time graph represents the displacement.

The shape of the area for the first interval from zero to two seconds is a trapezoid.

For this interval, we have the following information:

Initial velocity	= 5 m/s
Final velocity	= +8 m/s
Time interval	= 2 s
Acceleration	= +1.5 m/s/s

With all of this information, you have several choices for the equations that you can use to determine the displacement.

This information allows us to use the third kinematics equation $\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$ to find the unknown, the displacement.

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{d} = \frac{1}{2}\left(+5 \text{ m/s} + (+8 \text{ m/s})\right)2 \text{ s} = \frac{1}{2}(+13 \text{ m/s})2 \text{ s} = +13 \text{ m}$$

For the interval from 2 s to 3 s, we have the following information:

Initial velocity	= +8 m/s
Final velocity	= +4 m/s
Time interval	= 1 s
Acceleration	= -4 m/s/s

For this one, let us use the fourth kinematics equation: $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$.

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$\vec{d} = (+8 \text{ m/s})(1 \text{ s}) + \frac{1}{2}(-4 \text{ m/s/s})(1 \text{ s})^2 = +8 \text{ m} + (-2 \text{ m}) = +6 \text{ m}$$

For the interval from 3 s to 5 s, we have the following information:

Initial velocity	= +4 m/s
Final velocity	= +6 m/s
Time interval	= 1 s
Acceleration	= +2.5 m/s/s

Again, this is accelerated motion. Here, you could use kinematics equation 5, $v_2^2 = v_1^2 + 2ad$, to solve for displacement.

Here we can arrange by isolating the displacement. Rearranging equations using variables tends to be easier than rearranging the same equations with numbers in them.

$$d = \frac{v_2^{\,2} - v_1^{\,2}}{2a}$$

$$d = \frac{(+9\text{ m/s})^2 - (+4\text{ m/s})^2}{2(+2.5\text{ m/s/s})} = \frac{81-(+16)}{+5} = +13\text{ m}$$

The next time interval from five to six seconds has an acceleration of 0 m/s/s. On a velocity-time graph, the shape of the area you must find will either be a square or a rectangle.

You could use kinematics equation 3, in which case the initial and final velocity would be equal. You could use kinematics equation 4, in which case the second part of the equation would disappear since the acceleration is 0 m/s/s. You cannot use kinematics equation 5, since you end up dividing by an acceleration of 0 m/s/s, which, of course, is impossible. If the acceleration is 0 m/s/s, your best bet is to use kinematics equation 1.

For the interval from 6 s to 7 s, you have the following information:

Initial velocity	= +9 m/s
Final velocity	= +9 m/s
Time interval	= 1 s
Acceleration	= 0 m/s/s

Here you will solve for the displacement using kinematics equation 1:

$$\bar{v} = \frac{\vec{d}}{\Delta t}.$$

If we rearrange the equation to solve for the displacement, it becomes

$$\vec{d} = \bar{v}\Delta t.$$

$$\vec{d} = (+9\text{ m/s})(1\text{ s}) = +9\text{ m}$$

We hope that by now you have caught on to the idea that because of the variety of kinematics equations, you're able to use more than one to solve a particular problem. Another thing you should realize is that many times you will have options available to you, and you should choose the option that is the simplest to work with.

For the rest of the intervals, you are provided with the answers below. Determine the displacements and check your work.

For the time interval from six to eight seconds, the displacement is +10 m.

For the time interval from eight to nine seconds, the displacement is +0.5 m.

For the time interval from nine to 10 seconds, the displacement is –2 m. Note that this displacement is negative. You'll notice on the graph that this area lies below the horizontal time axis in the negative region of area on this velocity-time graph.

Learning Activity 1.14: Velocity and Acceleration

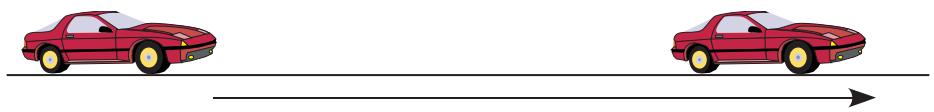
1. A sports car is moving initially at 10.0 m/s. It then undergoes a uniform acceleration of 1.20 m/s^2.

   a) What is the new velocity after a time of 30.0 s?

   Answer:

   Given: In this problem, the positive direction points to the right.

   $\vec{v}_1 = +10.0 \text{ m/s}$ $\quad$ $\vec{a} = +1.20 \text{ m/s}^2$ $\quad$ $\vec{v}_2 = ?$



$\vec{d} = ?$

initial velocity	$\vec{v}_1 = +10.0 \text{ m/s}$
acceleration	$\vec{a} = +1.20 \text{ m/s}^2$
time interval	$\Delta t = 30.0 \text{ s}$
Unknown: final velocity	$\vec{v}_2 = ?$
Equation:	$\Delta\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ rearranged to $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$
Substitute:	$\vec{v}_2 = (+10.0 \text{ m/s}) + (+1.20 \text{ m/s}^2)(30.0 \text{ s})$
Solve:	$\vec{v}_2 = (+10.0 \text{ m/s}) + (+36.0 \text{ m/s}) = +46.0 \text{ m/s}$

The final velocity of the car is 46.0 m/s to the right.

   b) What is the displacement of the car?

   Answer:

Unknown: Displacement	$\vec{d} = ?$
Equation:	Try not to use the final velocity, since it is a value you calculated.
	Therefore, use equation 4: $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$
Substitute:	$\vec{d} = (+10.0 \text{ m/s})(30.0 \text{ s}) + \frac{1}{2}(+1.20 \text{ m/s}^2)(30.0 \text{ s})^2$
	Since the number of significant digits is 3 in each of these steps, we must round each part off to 3 significant digits.

Solve: $\vec{d} = +300\text{ m} + (+540\text{ m}) = +840\text{ m}$

$= 8.40 \times 10^2\text{ m}$

The displacement of the car is +8.40 x 10^2 m to the right.

2. A speedboat has an acceleration of –2.00 m/s^2. The initial velocity of the boat is +16.0 m/s.

   a) What will be the final velocity of the speedboat after 5.00 s?

   Answer:

   Let right be the positive direction. Here, the boat is moving to the right, but the acceleration is negative so it points to the left. This question requires attention to the signs of the quantities.

   Given: Initial velocity $\vec{v}_1 = +16.0\text{ m/s}$

   Acceleration $\vec{a} = -2.00\text{ m/s}^2$

   Time interval $\Delta t = 5.00\text{ s}$

   Unknown: Final velocity $\vec{v}_2 = ?$

   Equation: $\Delta\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ rearranged to $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$

   Substitute: $\vec{v}_2 = (+16.0\text{ m/s}) + (-2.00\text{ m/s}^2)(5.00\text{ s})$

   Solve: $\vec{v}_2 = (+16.0\text{ m/s}) + (-10.0\text{ m/s}) = +6.0\text{ m/s}$

   The final velocity of the car is 6.0 m/s to the right.

   b) What is the displacement of the boat?

   Answer:

   Equation: Try not to use the final velocity, since it is a value you calculated.

   Therefore, use equation 4: $\vec{d} = \vec{v}_1\Delta t + \dfrac{1}{2}\vec{a}\Delta t^2$

   Substitute: $\vec{d} = (+16.0\text{ m/s})(5.00\text{ s}) + \dfrac{1}{2}(-2.00\text{ m/s}^2)(5.00\text{ s})^2$

   Since the number of significant digits is 3 in the first of these steps, round off the first answer to 3 significant digits. There are 3 significant digits in the second step, so we must also round this part off to 3 significant digits.

Solve:

$$\begin{aligned} \vec{d} = & \ +80 \text{ m} \\ + & \ -25.0 \text{ m} \\ \hline & +55.0 \text{ m} \end{aligned}$$

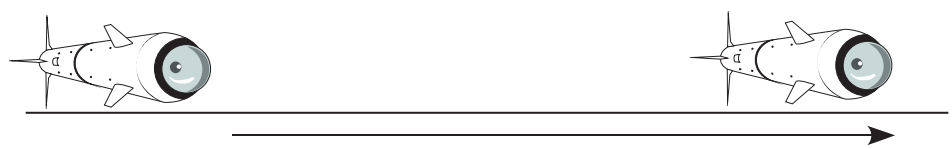
The boat travelled +55.0 m.

3. A spacecraft is initially at rest with respect to a space station when it fires its rockets. These rockets make it accelerate at a rate of 10.0 m/s^2. What is the new velocity of the spacecraft after is has moved a distance of 2.15 x 10^5 m?

Answer:

Given: In this problem, the positive direction points to the right.

$\vec{v}_1 = 0.0 \text{ m/s}$ $\quad$ $\vec{a} = +10.0 \text{ m/s}^2$ $\quad$ $\vec{v}_2 = ?$



$\vec{d} = 2.15 \times 10^5 \text{ m}$

Initial velocity	$\vec{v}_1 = 0.0 \text{ m/s}$
Acceleration	$\vec{a} = +10.0 \text{ m/s}^2$
Displacement	$\vec{d} = 2.15 \times 10^5 \text{ m}$
Unknown: Final velocity	$\vec{v}_2 = ?$

Equation: The equation that relates these four variables together without time would be equation 5:

$$v_2^{\ 2} = v_1^{\ 2} + 2ad.$$

Substitute:

$$v_2^{\ 2} = (0.0 \text{ m/s})^2 + 2(+10.0 \text{ m/s}^2)(2.15x10^5 \text{ m})$$

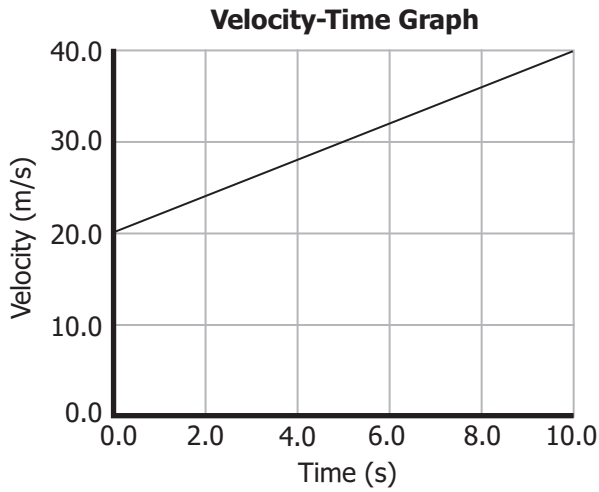
Solve:

$$v_2^{\ 2} = 4.30 \times 10^6 \text{ m}^2/\text{s}^2$$

$$v_2 = \sqrt{4.30 \times 10^6 \text{ m}^2/\text{s}^2} = 2.07 \times 10^3 \text{ m/s}$$

The spacecraft travels 2.07 x 10^3 m/s to the right.

4. The following graph shows a car changing in velocity over time.



Determine the displacement of the car.

Answer:

Given: From the graph, you have the following:

Given: Initial velocity $\vec{v}_1 = +20.0 \text{ m/s}$

Final velocity $\vec{v}_2 = +40.0 \text{ m/s}$

Time interval $\Delta t = 10.0 \text{ s}$

Unknown: Displacement $\vec{d} = ?$

Equation: $\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$

Substitute: $\vec{d} = \left(\frac{(+20.0 \text{ m/s}) + (+40.0 \text{ m/s})}{2}\right)10.0 \text{ s}$

Solve: $\vec{d} = (+30.0 \text{ m/s})(10.0 \text{ s}) = +300 \text{ m}$

$= +3.00 \times 10^2 \text{ m}$

The displacement of the car is $+3.00 \times 10^2$ m.

NOTES

Grade 11 Physics (30S)

Module 1 Appendices: Basic Skills

- Appendix A: Rounding Off
- Appendix B: Basic Mathematics
- Appendix C: Algebra
- Appendix D: Geometry
- Appendix E: Trigonometry
- Appendix F: Scientific Notation
- Appendix G: Calculator Usage
- Appendix H: Graphing Lines
- Appendix I: Measurement Units

Module 1 Appendices: Basic Skills

These appendices contain a review of basic skills that you need to be very familiar with in order to complete this course. They are listed here to help you review them. Feel free to read them, complete the learning activities, and check your answers by using the answer keys that are found immediately following each learning activity.

If you need help with any of these, remember to contact your tutor/marker.

Appendix A: Rounding Off

Appendix B: Basic Mathematics
- Negative Numbers
- Squares and Roots
- Order of Operations
- Fractions

Appendix C: Algebra

Appendix D: Geometry
- Rectangles
- Circles
- Triangles
- Trapezoids

Appendix E: Trigonometry

Appendix F: Scientific Notation

Appendix G: Calculator Usage

Appendix H: Graphing Lines

Appendix I: Measurement Units
- Prefixes
- Working with Units

Appendix A: Rounding Off

When extra significant digits exist in a result, rounding is required to maintain accuracy. Rounding, though, is not simply removing the extra digits displayed on your calculator. There are some distinct rules for rounding off numbers.

A number may be rounded off to any specified number of decimal places or significant digits.

Identify the number to be rounded off, either by place value or by the rules for calculations and significant digits. The number following the number to be rounded off is called the **trailing digit**.

Example:

6**1**<u>2</u>400

If we are to round at this number off to the 10 000 place value, you can see that the number to be rounded off is the 1 (in bold type). Therefore, the trailing digit will be the 2 (the underlined digit).

Here are the rules for rounding off numbers.

1. If the trailing digit is less than 5, the number to be rounded off is unchanged;
2. If the trailing digit is more than 5 the number to be rounded off is increased by 1.
3. If the trailing digit is a 5 and the number to be rounded off is
   i) even, then the number to be rounded off remains the same
   ii) odd, then the number to be rounded off is increased by one

   In other words, if the trailing digit is 5, round off to an EVEN number.

Example: Express 283.350 correct to:

a) 2 decimal places
b) to the nearest tenth
c) 3 significant digits
d) 2 significant digits

Solution:

a) 283.35

   Rounding off to two decimal places means we are rounding off the 5, which has a trailing digit of 0. Since 0 is less than 5, the number to be rounded off remains unchanged (Rule 1). We already know where the decimal is located, so we drop all digits that follow the trailing digit.

b) 283.4

The tenths place value is occupied by the second 3 and is trailed by the 5. When the trailing digit is a five, we must use Rule 3. The number to be rounded off is 3, an odd number. So we must increase the number to be rounded off by 1 so that it becomes an even number. Again, we know where the decimal is located so we simply drop all the digits that follow the number to be rounded off.

c) 283

Rounding to three significant digits means that we will be rounding the third significant digit when we count digits starting from the left. The first 3 represents the third significant digit and it is trailed by a 3. By Rule 1, when a number to be rounded off is trailed by a number less than five, the number to be rounded off will remain the same.

d) 280

Rounding to two significant digits means that we will be rounding the second significant digit when we count digits starting from the left.

The 8 represents the second significant digit and it is trailed by a 3. By Rule 1, when a number to be rounded off is trailed by a number less than five, the number to be rounded off will remain the same.

In this case, we replaced the trailing digit with a 0, which brings us to the decimal point. We must write in this zero as a placeholder.

Learning Activity 1

Round off the following numbers to the place value of the digit that is underlined.

1. 6<u>7</u> 080	
2. 0.00<u>7</u> 625	
3. 97<u>8</u> 500	
4. 8 9<u>7</u>5 652	
5. 15 <u>2</u>45.86	
6. 0.005 9<u>2</u>5 61	
7. 0.03<u>9</u> 536 4	
8. 0.8<u>0</u>5 36	
9. 5.2<u>0</u>61 x 10^{-6}	
10. <u>6</u>.7543 x 10^{8}	

Learning Activity 1 Answer Key

Round off the following numbers to the place value of the digit that is underlined.

1.	6<u>7</u> 080	1.	67 000
2.	0.00<u>7</u> 625	2.	0.008
3.	97<u>8</u> 500	3.	978 000
4.	8 9<u>7</u>5 652	4.	8 980 000
5.	15 <u>2</u>45.86	5.	15 200
6.	0.005 9<u>2</u>5 61	6.	0.005 92
7.	0.03<u>9</u> 536 4	7.	0.040
8.	0.8<u>0</u>5 36	8.	0.80
9.	5.2<u>0</u>61 x 10^{-6}	9.	5.21 x 10^{-6}
10.	<u>6</u>.7543 x 10^{8}	10.	7 x 10^{8}

Appendix B: Basic Mathematical Skills

This part of the appendix is intended to help you with the basic skills that you will need to succeed in this course. As the need arises, please refer to this appendix for help with these basic skills.

Negative Numbers

Negative numbers are not useful for counting (you can't really have "negative two apples"), but they are very handy for other things: you can have "negative 200 dollars" (as in owing money to somebody else). You would have to gain 200 dollars just to be at zero (after paying off your debt). Basic rules to remember when dealing with negative numbers include:

- Adding a negative number is exactly like subtracting the positive version of that number (i.e., 10 + [–3] is the same as 10 – 3, so 10 + [–3] = 7).
- Subtracting a negative number is exactly like adding the positive version of that number (i.e., 10 – [–3] is the same as 10 + 3, so 10 – [–3] = 13).
- When multiplying or dividing with negative numbers, remember that two negatives "cancel" to give a positive while only one negative leads to a negative answer (i.e., 5 x [–3] = –15, while [–5] x [–3] = 15).

Learning Activity 1

1. Determine the answers to the following without the use of a calculator
   a) 5 – (–2)
   b) (–6)(5)
   c) (–12) ÷ (–6)

Learning Activity 1 Answer Key

a) Remember that subtracting a negative number is just like adding the positive version of that number, so 5 – (–2) is the same as 5 + 2, which is 7.

b) Numbers written with only parentheses separating them have a "hidden" multiplication sign, so (–6)(5) is just a shorthand way of writing (–6) x 5. When multiplying numbers, if there is only one negative number, then the answer will be negative. Since 6 x 5 is 30, the answer to this question will be –30.

c) 12 divided by 6 is 2. Since both numbers in the original question are negative, and two negatives make a positive when multiplying or dividing, the answer to this question is also 2.

Squares and Square Roots

It is assumed that you have an understanding of the four basic operations of addition, subtraction, multiplication, and division (and now negative numbers). There are two other basic operations that will be needed frequently in our course: squares and square roots (which are special cases of what is more generally referred to as "powers" or "exponents").

The square of a number is simply the number multiplied by itself. Squaring is written as a small number two above and to the right of the number to be squared. As an example, "three squared" would be written as 3^2 and means 3×3. This means that $3^2 = 9$.

The square root of a number is the exact opposite of the square of a number. The square root of a number is the number that, when squared, is equal to the original number. For example, the square root of 16 is 4 because 4 squared is 16. Square roots are symbolized by this symbol: $\sqrt{\ }$, so the example just seen could be written as $\sqrt{16} = 4$.

Learning Activity 2

1. Determine the answers to the following without the use of a calculator.

   a) 7^2

   b) $\sqrt{25}$

   c) $\sqrt{9}^2$

Learning Activity 2 Answer Key

a) 7^2 simply means 7 times itself. 7×7 is 49, which is the answer here.

b) $\sqrt{25}$ means that you have to find the number that, when multiplied by itself (or "squared"), gives an answer of 25. $1^2 = 1$ ... $2^2 = 4$ ... $3^2 = 9$ ... $4^2 = 16$ ... $5^2 = 25$ ... since 5^2 is 25, we know the answer to this question: $\sqrt{25} = 5$.

c) This question combines both squares and square roots: try to find the square root of 9 (it is 3 ... see previous question), but this is not the answer to this question because we now have to square this 3 to get an answer of 9. Notice how squaring and square rooting really are opposites. We started with a 9 in the question and, after doing both a square root and then a square, we were back to what we started with.

Order of Operations

A potentially confusing question would be 2 + 3 x 4 because there seems to be two different possible answers: you might first add 2 and 3 (to get 5) and then multiply this by 4 to get an answer of 20, or you might add 2 to the answer of 3 x 4 (which is 12) to get an answer of 14. For everyone to get the same answer to questions like this, mathematicians have decided on a standard way of doing math. The official rule, or "order of operations," is that you must do multiplications and divisions before you do additions and subtractions. This means that the only correct answer to this problem is 14 (20 is incorrect because it doesn't follow the order of operations").

What if you want to take two plus three and then multiply the answer you get by four? How would you write this down, so that the answer will be 20? Mathematicians use brackets to overrule the order of operations mentioned above. Anything inside brackets must be done before anything outside the brackets. Writing (2 + 3) x 4 forces us to do the addition before the multiplication, and so get the correct answer of 20.

Squares and square roots are given a higher priority than the four basic operations, and so must be done before them: only brackets have an even higher priority.

The order of operations can be summed up in a non-sensical word: BEDMAS. Actually, BEDMAS isn't even a word, but the letters can help you remember the order in which operations get done: **B**rackets must always be done first (what is inside them), followed by **E**xponents (squares, square roots, and other powers), followed by **D**ivision and **M**ultiplication, and finally **A**ddition and **S**ubtraction.

As an example, consider $(4 + 3 \times 2)^2/2$. This example has brackets, addition, multiplication, an exponent, and division. According to the order of operations, brackets must be done first (this is the "B" in BEDMAS). Looking inside the brackets, we must calculate 4 + 3 x 2 first. Even in the brackets, the order of operations must be followed, so we do the multiplication before the addition: 4 + 3 x 2 = 4 + 6 = 10, so we have a ten inside the brackets. The original example can now be written as $10^2/2$. With the brackets taken care of, we can look at the exponents ("E" in BEDMAS). We evaluate 10^2 to be 10 x 10 = 100, so we now have 100/2, which is 50.

Learning Activity 3

1. Determine the answers to the following without the use of a calculator

   a) $7+(2\times 3)$

   b) $(7+2)\times 3$

   c) $7+2\times 3$

   d) $7+(2\times 3)^2$

   e) $(7+2)^2\times 3$

   f) $7+2\times 3^2$

   g) $\frac{6+9}{3}$

   h) $6+9\div 3$

   i) $(6+9)\div 3$

   j) $\sqrt{9}$

   k) $\sqrt{9+7}$

   l) $\sqrt{9}+7$

Learning Activity 3 Answer Key

a) We start inside the brackets: 2 x 3 is 6, so we can rewrite the question as 7 + 6, which is 13.

b) Again, brackets first: 7 + 2 = 9, so question is now 9 x 3, which is 27.

c) No brackets (or exponents), so start with the multiplication: 2 x 3 = 6, 7 + 6 = 13. Note that the brackets in part (a) above were actually not doing anything. They could have been removed without affecting the question (this is not always the case).

d) In the brackets, we have 2 x 3 = 6, so the question is now $7 + 6^2$. According to BEDMAS, we have exponents (E) before the addition (A), so we find 6^2, which means 6 x 6 = 36. The question can now be written as 7 + 36 = 43.

e) Brackets first: 7 + 2 = 9. Next do the exponent (squaring): $9^2 = 81$. Finally, multiply by 3 to get the answer 243.

f) Square the 3 to get 9, multiply by 2 to get 18, then add 7 to get 25.

g) This is a tricky one, as there are two ways of looking at it. Since the division line is under both the 6 and the 9, you could interpret this question as being 6 divided by three added to 9 divided by three. This would equate to $2 + 3 = 5$. A different (but still correct) way to think of it would be to consider the division line as holding the 6 + 9 together rather like brackets. This would put the addition before the division by order of operations, since brackets must be done first: 6 + 9 is 15. Next, do the division: $15 \div 3 = 5$.

h) Division first: $9 \div 3 = 3$; $6 + 3 = 9$.

i) Brackets first: $6 + 9 = 15$; $15 \div 3 = 5$. Notice that (g) and (i) are actually the same question.

j) This question is asking for the number that when multiplied by itself gives an answer of 9. Since 3×3 is 9, the answer is 3.

k) There is only one correct way of interpreting this question: the square root symbol extends over the 9 + 7, and so is acting like brackets holding them together. You must do what is inside these "brackets" first: $9 + 7 = 16$. With that taken care of, we find the 16 still under a square root: the square root of 16 is 4, which is the answer.

l) As mentioned in the notes on square roots, square roots are really a special case of exponents, and so must be done before addition: the square root of 9 is 3. The addition can then be done to get the answer 10.

Fractions

Integers are one kind of number, examples of which are –5, 0, and 213. There are, of course, numbers that are "in between" the integers (between 1 and 2, for example). We can conveniently represent these numbers as either fractions or decimals—both are useful. Fractions consist of two parts: a number on top, which is called the numerator, and a number on the bottom, which is the denominator. (Fractions may also be written sideways, with a slash separating the numerator and denominator: $\frac{2}{3} = 2/3$. The denominator indicates the number of equal pieces that one unit is divided into, while the numerator tells how many of those pieces you have. In the example of 2/3, consider that you have "one" of something—perhaps a cookie. Now chop this one into three equal pieces (this is the three in the denominator), and take two of these pieces (this is the two in the numerator). An understanding of fractions is important not only for our course, but also for everyday use. (Think of this the next time you want to make only half of a recipe that calls for 3/4 of a teaspoon of baking powder).

Fractions are really nothing more than division. As an example, let's look at a very common fraction: 1/2. When you looked at the symbol, did you read it as "a half"? Probably you did, because that's what most people call it. It is, however, nothing more than "one divided by two." Think about it: if you want to eat "half of a pie," you take the one pie and divide it into two equal pieces (one divided by two ... get it?). Each of these pieces is a half of the pie, or "1/2."

Notice that you could have obtained the same result by cutting the pie into four equal pieces, and eating two of them: 2/4 is the same as 1/2. Of course, 2/4 looks less obvious. We say that it can be "reduced" to 1/2. To reduce a fraction, try to find a number that divides evenly into both the top and bottom parts. For example, 14/21 can be reduced, since 7 goes into 14 twice, and into 21 three times, so 14/21 = 2/3. Notice that even integers can be thought of as being fractions: 2 can be thought of as being 2/1. We usually choose not to write a denominator of one.

Learning Activity 4

1. Reduce the following fractions:

   a) $\frac{3}{6}$

   b) $\frac{8}{12}$

   c) $\frac{21}{3}$

Learning Activity 4 Answer Key

a) On inspecting this fraction, we find that the numerator is 3 while the denominator is 6. Thinking of "a number that divides evenly into both the top and bottom parts," we find that 3 goes into the numerator once (of course, three goes into three once!) and 3 goes into the denominator twice (i.e., 6 divided by 3 is 2). This fraction can be reduced to 1/2. This should make a lot of sense, as a cake cut into 6 equal size pieces would have three out of these 6 pieces representing "half" of the cake.

b) Using the technique above, we find that 4 goes into both the 8 (twice) and the 12 (three times). The fraction can be reduced to 2/3. (Note that if you thought of 2 going into the 8 four times, and into the 12 six times you would get the fraction 4/6 which is not wrong—but not really right either since 4/6 can itself be reduced again to 2/3).

c) 3 goes into 21 seven times and into 3 once. This fraction can be reduced to 7/1. Note that we usually choose to not write denominators of 1, and so the best answer here is simply "7." (Of course, you could have chosen to not even see this as a fraction question, but rather as a simple division question: 21 ÷ 3 = 7, but don't forget that fractions really are division!)

Multiplying and Dividing Fractions

Multiplying fractions is easy: simply multiply the numerators to get the numerator of the answer, and then multiply the denominators to get the denominator of the answer. For example, 2/3 x 3/4 would be done by first multiplying the numerators: 2 x 3 is 6. The denominators are then multiplied: 3 x 4 is 12. The answer is 6/12, which can be reduced (6 goes into 6 once and into 12 twice) to 1/2.

Dividing fractions is also quite easy: the rule here is to "invert" the second fraction in the division (switch numerator and denominator), and then treat as multiplication. For example, 2/3 ÷ 4/3 would be solved by first inverting the 4/3 to 3/4, and then multiplying: 2/3 ÷ 4/3 = 2/3 x 3/4 = 1/2 (as seen above).

Learning Activity 5

1. Evaluate the following. Express answers as fractions and reduce if possible.

   a) $\frac{1}{2} \times \frac{1}{4}$

   b) $\frac{1}{2} \div \frac{1}{4}$

   c) $\frac{3}{8} \times \frac{2}{3}$

   d) $\frac{2^2}{3}$

   e) $\left(\frac{2}{3}\right)^2$

   f) $\left(\frac{2^2}{3}\right)^2$

Learning Activity 5 Answer Key

a) Multiply the numerators to find the numerator of the answer: 1 x 1 = 1. Next, multiply the denominators to find the denominator of the answer: 2 x 4 = 8. Finally, assemble the new fraction: 1/8.

b) For division, we "invert" the second fraction and multiply to solve the answer to the question $\frac{1}{2} \times \frac{4}{1}$, which would be 4/2, which can reduce to 2/1 or, more simply, "2."

c) Multiplying as in (a), the first answer is 6/24, which can reduce to 1/4.

d) Exponents still get priority, so this is simply going to be 4/3, which cannot be reduced.

e) Remember that the little 2 for squaring says "this thing multiplied by itself" where "this thing" is what is found to the left of the square symbol. The brackets here serve to hold the fraction together, and so this question is really 2/3 squared, or 2/3 multiplied by itself. Thinking then of 2/3 x 2/3, we use the same rules as above to get 4/9, which cannot be reduced.

f) Brackets first: What is inside the brackets? A square. Square the 2 to get $(4/3)^2$ which, like e) above, is really (4/3) x (4/3) which is 16/9, which cannot be reduced.

Adding and Subtracting Fractions

Fractions may not be added or subtracted unless they have the same denominator. If fractions have the same denominator, then simply add or subtract the numerators: this will be the numerator of the answer. Do *nothing* with the denominator, as it will simply be the denominator of the answer. For example, 5/6 – 4/6 = 1/6 (the numerators were subtracted: 5 – 4 = 1, and the denominator was left unchanged).

Of course, you can always change the denominator of a fraction by multiplying it by any number you want (except zero). This is allowed provided you do the same to the numerator. You can think of this as being the reverse of reducing a fraction. 1/3 is a fraction with a denominator of 3. If a denominator of 12 is desired, then you can multiply the 3 by 4 to get 12. The 1 in the numerator must also be multiplied by 4 to give the new fraction of 4/12 (which is the same as the original 1/3).

For example, consider 1/4 + 1/8. Since the denominators are not the same, we cannot add them unless we change their form. A little thought will show that the first fraction could have its numerator and denominator multiplied by 2 to give 1/4 = 2/8. If we use this 2/8 in place of the 1/4, we have 2/8 + 1/8, which is 3/8.

Learning Activity 6

1. Evaluate the answer to the following. Reduce the answers if possible.

   a) $\frac{1}{2}+\frac{1}{2}$

   b) $\frac{3}{4}-\frac{1}{4}$

   c) $\frac{5}{16}+\frac{7}{16}$

2. Evaluate the answer to the following. Reduce the answers if possible.

   a) $\frac{1}{2}+\frac{3}{4}$

   b) $\frac{5}{8}-\frac{3}{4}$

   c) $\frac{1}{2}+\frac{1}{3}$

Learning Activity 6 Answer Key

1. a) This question can probably be answered based on common knowledge, but look at how the rules work: both fractions have the same denominator (2), so the answer is a fraction with that same denominator, and a numerator that is 1 + 1 = 2. This makes the answer 2/2 which reduces to 1/1 or, more simply, "1."

   b) Again, the denominators are the same, this time 4, so the answer has a denominator of 4. 3 – 1 is 2, giving an answer of 2/4, which reduces to 1/2.

   c) Just like a) above, add numerators to get 12/16. This fraction can be reduced, since 4 goes into both parts of the fraction. It then becomes 3/4.

2. a) We need common denominators to add or subtract fractions. We can make this happen if we take the first fraction and multiply its numerator and denominator by 2. This fraction then becomes 2/4, which can be added to the 3/4 to give an answer of 5/4.

   b) Much the same as above, change the second fraction to 6/8. We now have 5/8 – 6/8. The answer will have a denominator of 8, and a numerator of 5 – 6. Don't forget about negative numbers! 5 subtract 6 is negative one (–1) which makes the answer –1/8.

c) Getting a common denominator here will involve changing the form of both fractions. It requires a little insight to realize that the denominators 2 and 3 could both easily be made into the same number: 6. Take the first fraction and turn it into 3/6. Next turn the second fraction into 2/6. Finally, add 3/6 and 2/6 to get the answer 5/6.

Appendix C: Algebra

Introduction

This is an extension of what was covered in the previous lesson. We are now adding a new concept: that of **variables**, which are usually represented by letters. While basic calculations have answers that are numbers, algebraic equations can have answers that have variables (letters) in addition to, or instead of, numbers. We will do a lot of work in this area throughout this course, and so it is important that you learn how to properly work with variables.

Basic Algebra

The main difference between "arithmetic math" (math with numbers only) and algebra is that algebra uses variables as well as ordinary numbers. An "ordinary" number is really nothing more than a symbol that represents some *fixed (or constant) amount.* As an example, consider "2." This "2" thing is really just a symbol that we know to represent one precise value, or location on a number line.

Variables are also numbers. It is essential that the consequence of this be understood: being numbers, variables should always be treated like numbers. Unlike the constant value numbers (such as 2), variables may represent any value, and in fact may represent several different values at the same time, or even all values. When written as part of an equation, the value of the variable is understood to be "all values that make the equation true." An equation is considered true if the two sides of the equal sign are, in fact, equal.

As an example, consider the algebraic equation $2F = 10$. This equation contains two constant value numbers (which we call "numbers" for short): the 2 and the 10, and the variable number F (which we call a "variable" for short). The presence of a variable makes this an *algebraic equation*. The variable F represents any number that will make the equation true. This particular equation is simple enough that it has likely occurred to you that if $F = 5$ (and nothing else), then the equation would be true. By saying that $F = 5$, we can say that "the equation has been solved: $F = 5$."

Here are a few equations that you should be able to solve merely by carefully thinking about what value each variable could have in order to make the equation true.

Learning Activity 1

1. For each equation, find the value of the letter that would make the equation true.

   a) $5 + x = 7$

   b) $20 - p = 12$

   c) $10 + d = 4$

   d) $3F = 18$

   e) $4V = 14$

   f) $\frac{45}{v} = 9$

   g) $z^2 = 36$

   h) $\sqrt{a} = 12$

   i) $(B + 2)^2 = 25$

Learning Activity 1 Answer Key

a) $x = 2$ b) $p = 8$ c) $d = -6$ d) $F = 6$ e) $V = 3.5$ f) $v = 5$
g) $z = 6$ h) $a = 144$ i) $B = 3$

Of course, algebraic equations are not always so obvious. Consider $x^3 + 6x^2 - 7x = 0$. It is not very obvious that x represents three values: –7, 0, and 1, any of which will make this equation true (confirm this on your own). Throughout this course, we will aim to improve your skill at "solving equations."

Before working with algebraic equations, it is worth noting that the appearance of an equation (algebraic or not) may be changed without affecting the truth of the equation itself. The general rule here is that if an equation is true, then it will still be true if you change both sides of the equation in the same way. Said more simply, you may safely do the following:

> Change the appearance of an equation by doing any operation (+ – x ÷, etc.) identically to both sides of the equation.

Changing the appearance of an equation can make it more clear as to what value or values of the variable are solutions, which makes this a valuable technique.

Consider the example $(5 + p)^2 = 64$. If we needed to "solve this equation," then our task is to simply find the value (or values) of the variable (in this case, p) that would make the equation true. We might be tempted to simply guess at an answer and see if it works, but this is generally not a good strategy. Instead, consider it your goal to rearrange the equation so as to end up with the variable alone on one side of the equal sign. This means that everything else must be "peeled away." This can be done by applying carefully chosen operations—in particular, the opposite of what is to be removed. This will be made more clear by working through this example:

$$(5 + p)^2 = 64$$

In trying to solve this equation for p, by the order of operations the very first thing we would need to deal with is the square. So let us remove the square by applying the exact opposite—the square root—to both sides of the equation:

$$\sqrt{(5+p)^2} = \sqrt{64}$$

Since squares and square roots are opposite operations, we can not completely disregard the square root and square on the left side of the equation. In effect, opposite operations "undo" each other. This allows us to rewrite the equation as

$$5 + p = \sqrt{64}$$

Of course, the square root of 64 is 8, and so we could rewrite the equation once more as

$$5 = p = 8$$

By now, it is probably clear what the value of p is, but let's continue with our original goal, which was to obtain an equation with the variable alone on one side of the equation. At this point, p is not alone because there is also a 5 on the same side. We can remove this 5 by subtracting it, and may do so provided that we also subtract 5 from the other side of the equation. This means that the equation can now be written as

$$5 + p - 5 = 8 - 5$$

Of course, this leaves p alone on the left side of the equation, since there is no need to write $5 - 5$. We can then evaluate the right side of the equation: $8 - 5 = 3$. This means that we now have the equation $p = 3$. We have "solved" the original equation. We can be sure of this by going back to the original equation, and using the value we have come up with for the variable:

$$\sqrt{(5+p)^2} = \sqrt{64} \rightarrow \sqrt{(5+3)^2} = \sqrt{64}$$

We can then test to see if this equation is true by evaluating each side of the equation:

$$\sqrt{(5+3)^2} = \sqrt{64}$$
$$\sqrt{(8)^2} = 8$$
$$\sqrt{64} = 8$$
$$8 = 8$$

Upon confirming that the two sides are, in fact, equal, we have confirmed that we did successfully solve the equation we were originally presented with.

Learning Activity 2

1. Solve each of the following equations for B.
   a) $12 = B + 5$
   b) $12 = \frac{B}{3}$
   c) $48 = \frac{336}{B}$
   d) $A = BC + DE^2$
   e) $A^2 = B^2 + CD$
   f) $72 + b^2 = c^2 - 36$

Learning Activity 2 Answer Key

a) $12 = B + 5$ Undo the addition of 5 by subtracting 5 from each side.

$$12 - 5 = B + 5 - 5$$
$$7 = B$$

b) $12 = \frac{B}{3}$ Undo the division by 3 by multiplying each side by 3.

$$3(12) = 3\left[\frac{B}{3}\right]$$
$$36 = B$$

c) $$48 = \frac{336}{B}$$

Bring B up into the numerator by multiplying each side by B.

$$B(48) = \left[\frac{336}{B}\right]B$$

Isolate the B by dividing each side by 48.

$$\frac{48B}{48} = \frac{336}{48}$$

d) $$A = BC + DE^2$$

Isolate the term with the B by subtracting DE^2 from each side.

$$A - DE^2 = BC + DE^2 - DE^2$$

$$A - DE^2 = BC$$

Isolate the B by dividing each side by C.

$$\frac{A - DE^2}{C} = \frac{BC}{C}$$

e) $$A^2 = B^2 + CD$$

Isolate the term with the B by subtracting CD from each side.

$$A^2 - CD = B^2 + CD - CD$$

Since B is squared, we undo squaring by taking the square root of each side.

$$\sqrt{A^2 - CD} = \sqrt{B^2}$$

$$\sqrt{A^2 - CD} = B$$

f) $$72 + b^2 = c^2 - 36$$

Isolate the b by subtracting 72 from each side.

$$72 - 72 + b^2 = c^2 - 36 - 72$$

$$b^2 = c^2 - 108$$

Since b is squared, we undo squaring by taking the square root of each side.

$$b = \sqrt{c^2 - 108}$$

NOTES

Appendix D: Geometry

From the Greek words "ge" (earth) and "metreein" (to measure), this is the branch of mathematics that helps us work with shapes and their measures. It was originally developed to help measure sections of land.

Rectangles

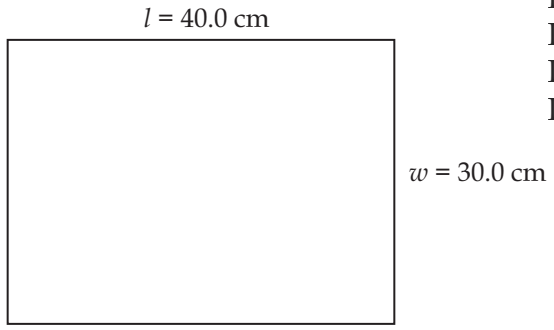
A rectangle is a four-sided figure that has all right angles (a right angle is an angle of 90°). Opposite sides are equal in length and are parallel. One key measurement of a rectangle is perimeter, which is the distance around the rectangle, and can be found by adding up the lengths of the four sides. Another measure of rectangles is that of area, which is loosely how much space it takes up. The area for a rectangle is the length multiplied by the width.

Learning Activity 1

1. A rectangle measures 30.0 cm on one side and 40.0 cm on the other side. For this rectangle, find the:
   a) perimeter
   b) area

Learning Activity 1 Answer Key

a) perimeter



Perimeter = Distance around
$P = 2l + 2w$
$P = 2(40.0\text{ cm}) + 2(30.0\text{ cm})$
$P = 80.0\text{ cm} + 60.0\text{ cm} = 140.0\text{ cm}$

b) area

Area = length x width
Area = (40.0 cm)(30.0 cm) = 1200 cm^2
To 3 significant digits the answer is 1.20×10^3 cm^2.

Circles

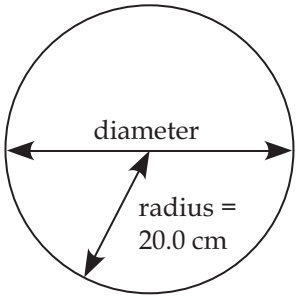
Circles are measured by radius (distance from centre to edge), diameter (distance from edge to opposite edge, through the centre .... diameter = radius x 2), circumference, which is the special name for the perimeter (distance around) a circle. Circumference = π x diameter (symbolized as $C = \pi d$, or $C = 2\pi r$), where π is a Greek letter "pi," which has an approximate value of 3.14 Finally, the area of a circle can be found as π x radius squared symbolized as $A = \pi r^2$.

Learning Activity 2

1. A circle has a radius of 20.0 cm. For this circle, find the:
   a) diameter
   b) circumference
   c) area

Learning Activity 2 Answer Key

a) diameter



Diameter = 2 x radius
D = 2(20.0 cm) = 40.0 cm

b) circumference

Circumference = 2π(radius) = 2π(20.0 cm) = 125.6 cm

The circumference rounded to 3 significant digits is 126 cm.

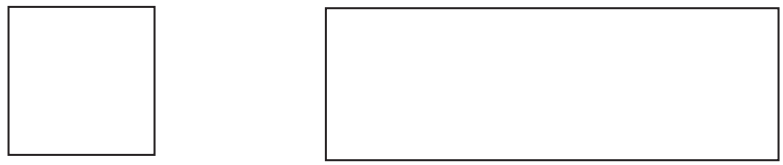
c) area

Area = $\pi(\text{radius})^2$
$A = \pi(20.0\text{ cm})^2 = 1256\text{ cm}^2$

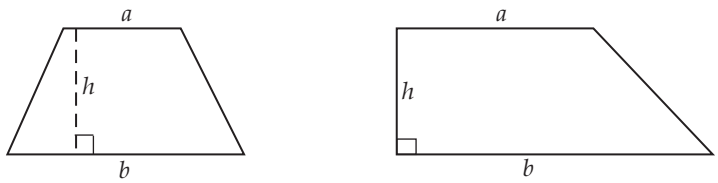
The area rounded to 3 significant digits is 1260 cm^2.

Trapezoids

Trapezoids are four-sided figures like squares and rectangles. In squares and rectangles, the opposite sides are parallel to each other and equal in length. All of the angles in the corners are 90°.

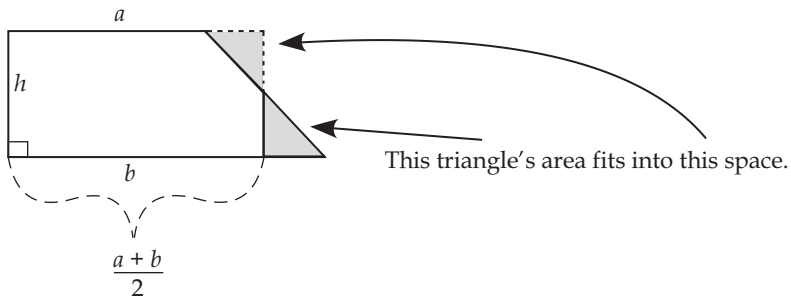


In a trapezoid, only two of the sides are parallel to each other. These two sides are not equal in length.



The parallel sides are labelled "*a*" and "*b*." The perpendicular distance between the parallel sides is called the altitude and is labelled "*h*."

If you consider the shape of the trapezoid, you should see that if you could average the length of the parallel sides, you would then have a rectangle. This is best illustrated by the trapezoid on the right.



So you now have a rectangle with a length of $\frac{a+b}{2}$ and a width of *h*.

The area of a trapezoid is simply the area of this rectangle.

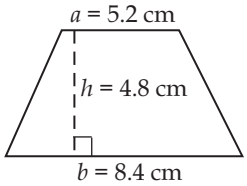
$$\text{Area} = \left(\frac{a+b}{2}\right)h$$

You might say, "Add the lengths of the two parallel sides and divide this sum by two to give the average length of the trapezoid. Then multiply the average length by the distance between the two parallel sides to obtain the area of the trapezoid."

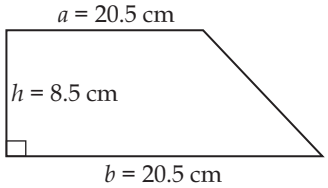
Learning Activity 3

1. Find the areas of the following trapezoids:

a)



b)



Learning Activity 3 Answer Key

a) Given: $a = 5.2$ cm

$b = 8.4$ cm

$h = 4.8$ cm

Equation: $\text{Area} = \left(\frac{a+b}{2}\right)h$

$$\text{Area} = \left(\frac{5.2\text{ cm} + 8.4\text{ cm}}{2}\right)(4.8\text{ cm}) = (6.8\text{ cm})(4.8\text{ cm})$$
$$= 32.64\text{ cm}^2 = 33\text{ cm}^2$$

b) Given: $a = 12.4$ cm

$b = 20.5$ cm

$h = 8.5$ cm

Equation: $\text{Area} = \left(\frac{a+b}{2}\right)h$

$$\text{Area} = \left(\frac{12.4\text{ cm} + 20.5\text{ cm}}{2}\right)(8.5\text{ cm}) = (16.45\text{ cm})(8.5\text{ cm})$$
$$= 139.825\text{ cm}^2 = 140\text{ cm}^2$$

Triangles

Of the many types of triangles, the most important one for us is the "right triangle," which has one right angle in it (it is worth noting that the side opposite the right angle is named the "hypotenuse," while the other two are called "legs"). For right triangles, there is a special connection between the lengths of the three sides: this is the "Pythagorean Theorem," which states that the length of the hypotenuse, when squared, is the same as the sum of the squares of the lengths of the legs. This is written as $a^2 + b^2 = c^2$ where a and b are the lengths of the legs and c is the length of the hypotenuse. Note that the three angles in a triangle always add up to 180°.

Geometry is the branch of math that focuses on measuring space and shapes (such as triangles). Geometry was one of the earliest developed branches of math, having important applications in surveying. In fact, the Egyptians, in about 235 BCE, were able to use geometry to determine the radius of the Earth (yes, they knew it was round!). Even earlier, the Greeks used geometry to calculate the distance to the moon and sun, as well as their sizes. Interestingly, these ancient people also knew that the Earth was round. It was only later in history when people "forgot" this early wisdom and began to think that it was flat.

In addition to the geometry discussed in the basic skills module, some higher-level trigonometry (the study of triangles) will be needed in this course. Triangles can be classified in the following ways:

- *scalene* triangles are those triangles with all three sides being different in length
- *isosceles* triangles are those triangles with two sides being equal in length
- *equilateral* triangles are those triangles with all three sides being equal in length
- *right* triangles are those triangles that have a right (or 90°) angle

Learning Activity 4

1. A right triangle has two sides forming the right angle of 6 cm and 8 cm. One of the angles is 37.0°. For this triangle, find to 3 significant digits:
   a) the size of the other angle
   b) the size of the third side

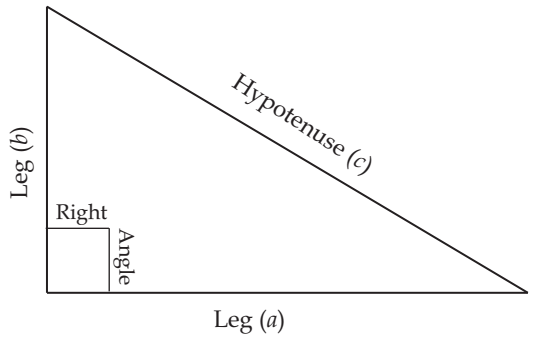
Learning Activity 4 Answer Key

a) The sum of the interior angles of a triangle is 180°.

$\angle A = 37.0°$
$\angle B = 90.0°$
$\angle C = ?$
$\angle A + \angle B + \angle C = 180°$
$37.0° + 90.0° + \angle C = 180°$
$\angle C = 180° - 37.0° - 90.0° = 53.0°$

b) Leg 1 = 6.00 cm
Leg 2 = 8.00 cm
Hypotenuse = ?
$\text{Hypotenuse}^2 = \text{Leg } 1^2 + \text{Leg } 2^2$
$\text{Hypotenuse}^2 = (6.00 \text{ cm})^2 + (8.00 \text{ cm})^2 = 100$
$\text{Hypotenuse} = \sqrt{100} = 10.0 \text{ cm}$
The third side is 10.0 cm long.

Appendix E: Trigonometry

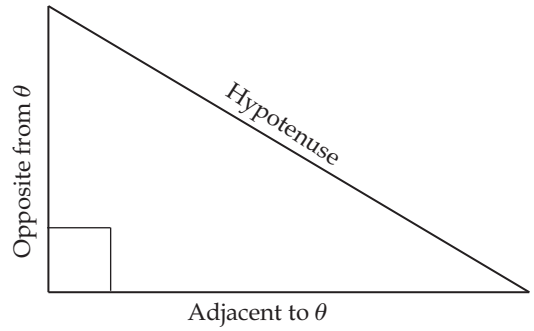


Of particular interest here is the right triangle. The two sides that form the right angle are called the **legs** of the triangle, and the third side (which is opposite the right angle) is called the **hypotenuse**. The two legs are often assigned to the variables a and b, while the hypotenuse is labelled c. The Pythagorean relationship, which relates the lengths of these three sides, can be written as $a^2 + b^2 = c^2$, as was mentioned in the basic skills module.

All triangles have three angles that add up to 180°. A right triangle has one of these angles being 90°, and so the other two angles together must add up to the other 90°. Angles that add up to 90° are said to be **complementary**, but the exact sizes of these angles are dependent on how long the sides of the triangle are. In fact, there is a mathematical relationship connecting the size of these angles to the lengths of the sides.

At this point, we are ready to double the number of mathematical operations that we are using. So far, we have worked with six operations: adding, subtracting, multiplying, dividing, powers (such as squaring) and roots (such as the square root). There are six more operations that are very useful when working with triangles. We will begin by looking at three: sine (abbreviated as **sin**), cosine (abbreviated as **cos**), and tangent (abbreviated as **tan**). Notice that your calculator has buttons for each of these, just as it does for adding, subtracting, et cetera.

To use these "trig functions," as they are often called, we must start by naming one of the non-right angles of the right triangle. Just as it is common to use letters to name the sides (a, b, and c, for example), it is quite common to use Greek letters to label the angles. The most commonly used Greek letter for angles is the letter "theta," written as "θ."



Having chosen one of the angles to be called θ (it doesn't matter which one we pick so long as it is not the right angle), we can now refer to the legs as being either "opposite"

(across from) or "adjacent" (next to) θ. The three trig functions relate angle θ to the lengths of these three sides in the following ways:

- sin (θ) = opposite/hypotenuse
- cos (θ) = adjacent/hypotenuse
- tan (θ) = opposite/adjacent

A convenient way to remember these relationships is by the non-sensical "word" (actually, it is an acronym) SOHCAHTOA, which has the letters referring to the above (**s**in = **o**pposite over **h**ypotenuse ... **c**os = **a**djacent over **h**ypotenuse ... **t**an = **o**pposite over **a**djacent).

Note in the above that theta is not being multiplied by anything. Sin, cos, and tan are special words in mathematics. Sin (θ), for example, means "sine of theta" and not "sine times theta." You may not, at this point, really understand what "sine of theta" means, but luckily your calculator does.

On your calculator, be sure that the angles are measured in degrees. Check the display on the calculator. Near the top of the window, there should be a tiny "DEG," which signifies that the calculator is programmed for degrees.

Learning Activity 1

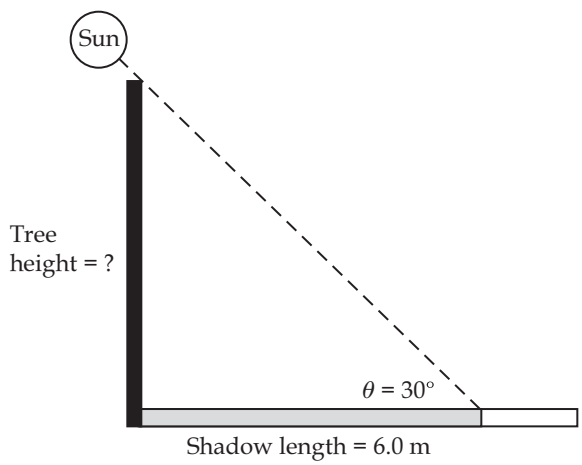
1. Try to use your calculator to determine the following (you may round off after three decimal places):
   a) sin (45°) =
   b) sin (30°) =
   c) cos (30°) =
   d) cos (15°) =
   e) tan (45°) =
   f) tan (75°) =

Learning Activity 1 Answer Key

a) sin (45°) = 0.707
b) sin (30°) = 0.500
c) cos (30°) = 0.866
d) cos (15°) = 0.966
e) tan (45°) = 1.00
f) tan (75°) = 3.73

The above is useful for situations in which you already know the value of the angle theta, and the length of only one of the sides. Consider the following example:

You would like to know the height of a tree. While you do have a tape measure, you can't think of any convenient way to directly measure the tree (it is too tall), so you decide to use trigonometry instead. While the sun is shining, you measure the length of the shadow to be 6.0 metres (about 20 feet). You estimate the sun to be about 30 degrees up in the sky (as seen in the picture here). About how tall is the tree?



According to the diagram, relative to the 30° angle, the tree height is the **opposite side** and the shadow length is the **adjacent side**.

The trigonometric function to be used should include the opposite side and the adjacent side.

Therefore, we use $\tan\theta = \dfrac{\text{opposite}}{\text{adjacent}}$.

Substitute and solve for the missing side, the height of the tree.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{\text{tree height}}{\text{shadow length}}$$

$$\tan 30° = \frac{\text{tree height}}{6.0\text{ m}}$$

$$0.57735 = \frac{\text{tree height}}{6.0\text{ m}}$$

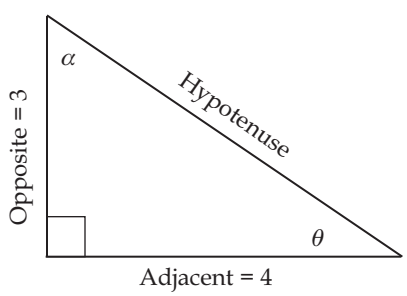
$$\text{tree height} = 3.4641\text{ m}$$

Rounding off to 2 significant digits gives a height for the tree of 3.5 m.

Just as the first six operations come in pairs that are "opposites" of each other (addition and subtraction, multiplication and division, powers and roots), each of the new three operations have an opposite. They are somewhat unimaginatively named "inverse sine" (the opposite of sine), "inverse cosine" (the opposite of cosine), and "inverse tangent" (the opposite of tangent). These three operations are abbreviated by placing a small symbol that looks exactly like a power of negative one (but is NOT a power at all) after the three-letter abbreviation for its opposite. The six "trig functions" then are paired into opposites as sin and $\sin^{-1}$, cos and $\cos^{-1}$, and tan and $\tan^{-1}$. These inverse functions are useful for peeling away the three base trig functions when solving for angles.

Note that most calculators have these three operations as a second feature of the sin, cos, and tan buttons, in which case you must usually press the "second function" or "inverse" button before you press the sin, cos, or tan button.

As an example, consider a right triangle with lengths 3, 4, and 5. Draw this triangle, and use the inverse trig functions to determine the two non-right angles to the nearest 0.1°.



In the diagram on the left, you are given the following relative to the angle θ:

Opposite = 3
Adjacent = 4

To calculate angle θ, use the equation:

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

Substitute and solve for the angle θ.

$$\tan\theta = \frac{3}{4} = 0.75$$
$$\theta = 36.87°$$

The angle θ = 36.9°.

The sum of the interior angles of any triangle is 180°.

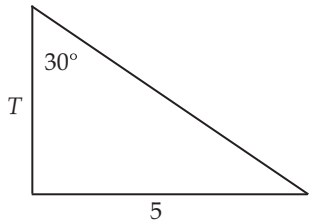
Since you know two of the angles (the right angle and θ), you can calculate the third angle α.

$\alpha + \theta + 90.0° = 180°$
$\alpha + 36.9° + 90.0° = 180°$
$\alpha = 53.1°$

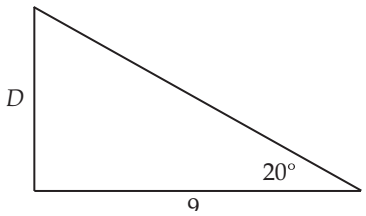
Learning Activity 2

1. Using trigonometry, find the size of the side of the triangle labelled with a letter.

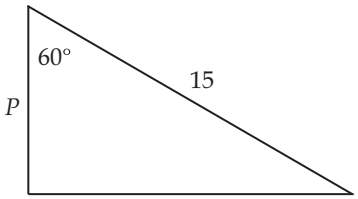
a)



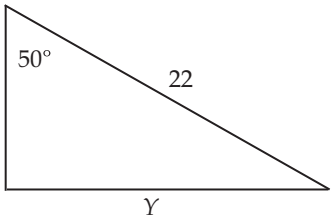
b)



c)

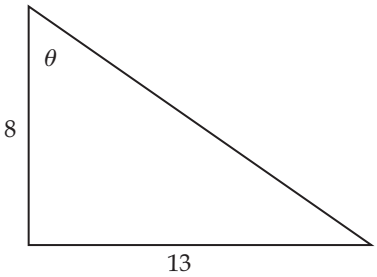


d)

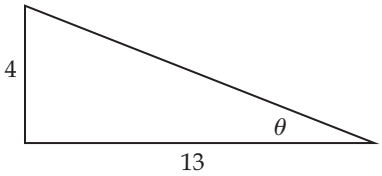


2. Find the size of the angle θ in each of the following triangles. You may round off to two decimal places.

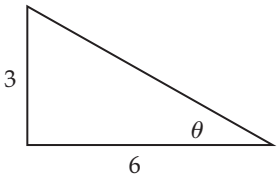
a)



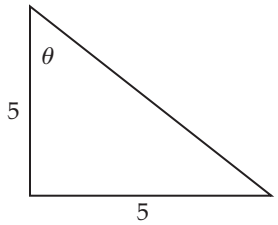
b)



c)



d)



Learning Activity 2 Answer Key

1. a) $\theta = 30°$

$\text{opposite} = 5$

$\text{adjacent} = T$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\tan 30° = \frac{5}{T}$$

$$T = \frac{5}{\tan 30°} = \frac{5}{0.57735} = 8.660$$

The length of side T is 8.7.

b) $\theta = 20°$

$\text{adjacent} = 9$

$\text{opposite} = D$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\tan 20° = \frac{D}{9}$$

$$0.36397 = \frac{D}{9}$$

$D = 3.275$

The length of the side is 3.3.

c) $\theta = 60°$

$\text{hypotenuse} = 15$

$\text{adjacent} = P$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\cos 60° = \frac{P}{15}$$

$$P = (\cos 60°)(15) = (0.500)(15) = 7.5$$

The length of the hypotenuse is 7.5.

d) $\theta = 50°$

$\text{hypotenuse} = 22$

$\text{opposite} = Y$

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\sin 50° = \frac{\text{opposite}}{22}$$

$$\text{opposite} = \sin 50°(22)$$

$$\text{opposite} = (0.766)(22) = 16.85 = 17$$

The length of the side is 17.

2. a) $\tan\theta = \dfrac{\text{opposite}}{\text{adjacent}} = \dfrac{13}{8}$

$\theta = \tan^{-1}\dfrac{13}{8} = \tan^{-1} 1.625 = 58°$

b) $\tan\theta = \dfrac{\text{opposite}}{\text{adjacent}} = \dfrac{4}{13}$

$\theta = \tan^{-1}\dfrac{4}{13} = \tan^{-1} 0.30769 = 17°$

c) $\tan\theta = \dfrac{\text{opposite}}{\text{adjacent}} = \dfrac{3}{6}$

$\theta = \tan^{-1}\dfrac{3}{6} = \tan^{-1} 0.5 = 26°$

d) $\tan\theta = \dfrac{\text{opposite}}{\text{adjacent}} = \dfrac{5}{5}$

$\theta = \tan^{-1}\dfrac{5}{5} = \tan^{-1} 1 = 45°$

NOTES

Appendix F: Scientific Notation

As frightening as "scientific notation" may sound, it is nothing more than a convenient shorthand. In math (and physics), it is sometimes common to work with very large numbers (such as the distance to Saturn , which is very approximately 1,300,000,000 km) and very small numbers, such as the time that it takes light to cross a classroom (which is very approximately 0.00000003 s if the room is 10 m wide).

Rather than write the numbers as they appear above, we can write them in scientific notation, which has the advantage that we don't have to write all of those zeros. First, make sure you understand powers.

You have already worked with powers. Squaring is an example of powers. 10^2 means ten multiplied by itself: 10 x 10. Notice that there are two tens in this multiplication and the answer is one hundred which also has two zeros, and that this was what we got from 10^2. What would happen if we took 10^3 or 10^4? Try it, and notice that this pattern continues.

Powers of ten are convenient ways of getting lots of zeros. What if we chopped off the zeros from a large number, and replaced all of the zeros by an exponent of ten? This may save time if there are enough zeros. In the example above, 1,300,000,000 could be thought of as being "13 followed by 8 zeros." Of course, 13 x 10 would be 130, while 13 x 10^2 would be 1300. How could we get the shorter version of 1,300,000,000?

The answer is 13 x 10^8—and we are now only one step away from having scientific notation. Proper scientific notation insists that there be a decimal after the first digit (this would be between the 1 and 3 here). But putting the decimal here to 1.3 x 10^8 won't be the answer, as taking 1.3 times ten for the first time simply gives us 13, while the next seven multiplications by ten add seven zeros—we need 8! The solution is to make it 1.3 x 10^9, where you can think of the exponent 9 as being the number of moves that the decimal makes to the right. The first move shifts it from 1.3 to 13, and the next 8 moves insert zeros.

Learning Activity 1

1. In these examples, switch from the full number to scientific notation.
   a) Light is fast: it moves at about 1,100,000,000 km/h
   b) Earth has a circumference (distance around) of about 40,100,000 m

Switch these examples from scientific notation to "normal" (actually "normal" is called "standard notation").

c) A very large number is a trillion, which is 1×10^{12}

d) If you are 30 years old, then you are about this many *seconds* old: 9.47×10^{8}

Learning Activity 1 Answer Key

1. a) 1.1×10^{9} km/h
   b) 4.01×10^{7} m
   c) 1 000 000 000 000
   d) 947 000 000 s

Very small numbers have the opposite problem: to be written in standard notation, we must move the decimal number the *other way*. Just as multiplying a number by 10 makes it larger, dividing by ten makes it smaller. For example, $2 \div 10 \div 10 \div 10 = 0.002$. This could be better written as $2 \div 10^{3} = 0.002$, but scientific notation does not write it this way: it turns out that multiplying by 10 *to a negative exponent* is the same as dividing by ten with a positive exponent. In other words, the scientific notation version of 0.002 is 2×10^{-3}. This is best thought of as before: the power of ten tells how many times to move the decimal. If the power is positive, then move the decimal to the right (making it a large number). If the power is negative, move the decimal to the left (making it a small number).

Learning Activity 2

1. Try these: switch from standard notation to scientific notation.
   a) The eye of an ant is about 0.000 1 m wide.
   b) Atoms are small! A hydrogen atom is about 0.000 000 000 2 m wide.
2. Switch these from scientific notation to standard notation:
   a) The thickness of a piece of paper is about 1×10^{-4} m.
   b) An influenza virus is about 5×10^{-8} m wide.

Learning Activity 2 Answer Key

1. a) 1×10^{-4} m
   b) 2×10^{-10} m
2. a) 0.000 1 m
   b) 0.000 000 05 m

NOTES

Appendix G: Using a Calculator

Knowing how to use your calculator efficiently will be very important in this course. This section is designed to help you get to know how to make the best use of some of the commonly used features.

First of all, you likely already know how to use your calculator for basic functions, such as addition, subtraction, multiplication and division. Here we will learn how to use the calculator to do squares and square roots, negative numbers, scientific notation, and understand how it does order of operations, including the use of brackets.

Different brands of calculators sometimes work a little differently from each other, so it is important that you figure out your calculator. The following questions should be done entirely on your calculator—even if you can do some of them in your head! There is plenty of room on this sheet next to each question for you to write down notes that will help you remember special steps needed to operate your calculator. The correct answer is given. Your goal is to learn how to use your calculator to obtain these answers.

Although there is no single "correct" way to use your calculator, you should aim to use it as efficiently as possible. This will be especially important later in the course, as well as in future courses where using the calculator will be just one small part of a much larger problem. In general, you should be able to determine the answers to the following questions without writing partial answers down (only press the "equals" button once—at the end of the question!).

a) $5 + 2 \times 3 = 11$	b) $2 \times 4 + 3 \times 5 = 23$
c) $(2 + 3) \times 4 = 20$	d) $(8 - 6) \div 2 = 1$
e) $(-5) + 9 = 4$	f) sqrt {25} = 5
g) sqrt {30 + 6} = 6	h) $2 \times 10^3 = 2000$
i) $(6.67 \times 10^{-11}) \times (3 \times 10^8) = 0.02001$	j) $20000000 \times 20000 = 4 \times 10^{11}$

NOTES

Appendix H: Graphing Lines

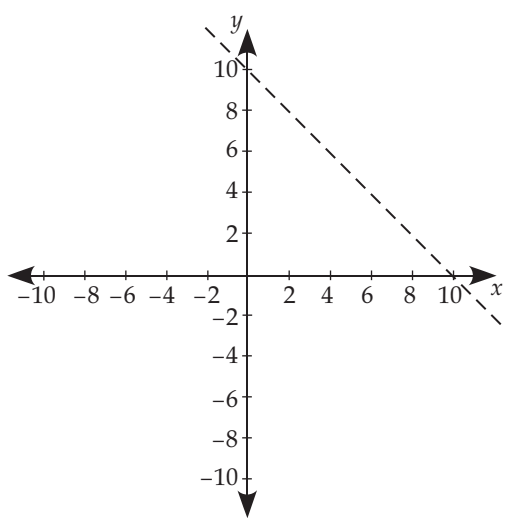
Equations involving an x and a y are commonly graphed by first solving the equation for y. The equation might then resemble (or could be made to resemble) the so called "slope intercept" form which looks like y = (a number .... call it "m")x + (another number ... call it b)—that is "$y = mx + b$."

As an example, consider the equation $x + y = 10$. Solving this for y can be achieved by subtracting x from both sides of the equation, resulting in $y = 10 - x$. This could be forced into the slope intercept look of $y = mx + b$ by reversing the order of the right side, and going out of our way to write in a "1" times the x: $y = -1x + 10$. Here $m = -1$ and $b = 10$. Knowing this makes it very easy to graph.

If an algebraic equation can be made to look like $y = mx + b$, then the graph of it is a straight line. This straight line has a ***y*-intercept** of "b" which means that it intercepts (or crosses over) the y-axis at the value of b. Furthermore, it is said to have a **slope** of m, which indicates the steepness of the line: a slope of zero would be horizontal, while a positive slope slants up to the right, and negative slopes slant down to the right. In either case the "larger" the value of m, the steeper the line is.

The value of m can be used to get more points on the graph, starting at the y-intercept. Slope m can always be given a fraction look if it is not already. The fraction can then be thought of as m = {rise} over {run} where "rise" refers to how far up (or down if negative) you should go from the starting point of the y-intercept, and "run" tells you how far over to the right you should also move, to get to another point on the graph. Having this new point and the y-intercept means that you can connect the two points to make a line that is the completed graph.

Complete the graph of $x + y = 10$ here:



Change the equation to the $y = mx + b$ form.

It now looks like $y = -1x + 10$.

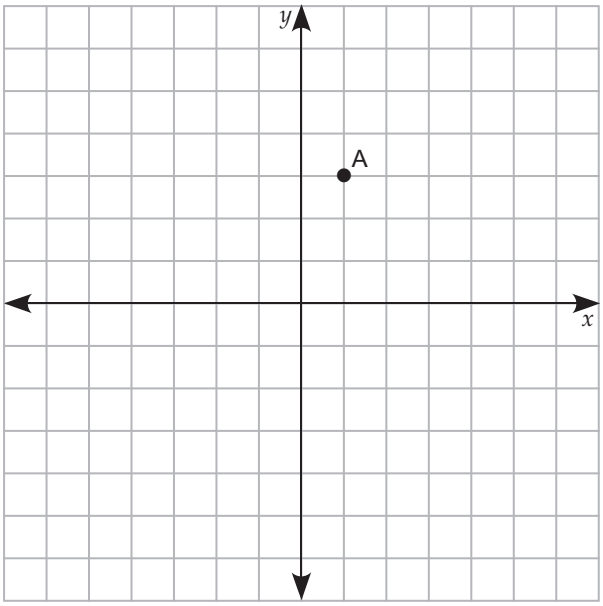
Therefore the y-intercept is $b = 10$ and the slope is $m = -1$.

Draw the line passing through (0, 10) with a slope of –1.

Learning Activity 1

1. Create a table of values listing 5 pairs of solutions for $x - y = 12$
2. Plot the following points onto the provided graph. A has been done as an example.

   A (1, 3)
   B (–2, 5)
   C (6, –3)
   D (0, –4)
   E (–1, 0)
   F (–3, –5)
   G (–1, –3)



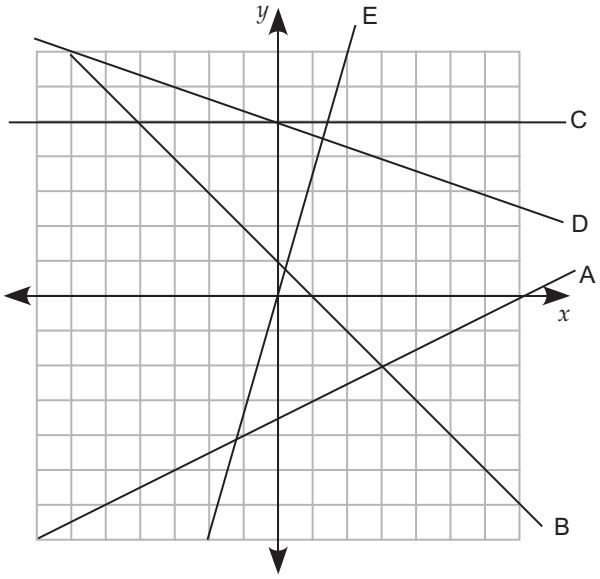
3. For each of the lettered lines, state the y-intercept, find the slope, and write the equation of the line in $y = mx + b$ form. Line A has been done as an example.

   Line A has a y-intercept of –3.5 (this is where it crosses through the y-axis). This makes $b = -3.5$.

   It has a slope of $\frac{1}{2}$ since it rises 1 unit for every 2 units moved to the right.

   This makes $m = \frac{1}{2}$.

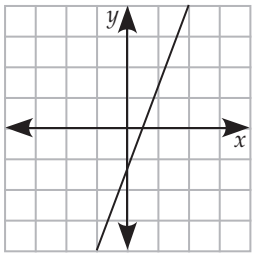
   The equation of line A is, therefore, $y = \frac{1}{2}x - 3.5$.



4. For each of the following equations solve for y (if necessary), then state the y-intercept and slope. Finally, draw and label the line on a coordinate system. Line A has been done as an example.

   a) $y = 2x - 1$

   This line has y-intercept of –1 and a slope of 2 (or 2/1).



   b) $y = x + 1$

   c) $y = \frac{-1}{3}x$

   d) $y = x$

   e) $y = -x + 2$

   f) $2y = x + 6$

   g) $\frac{y}{2} = x - 1$

   h) $x = 2y + 4$

   i) $2x + 3y - 6 = 0$

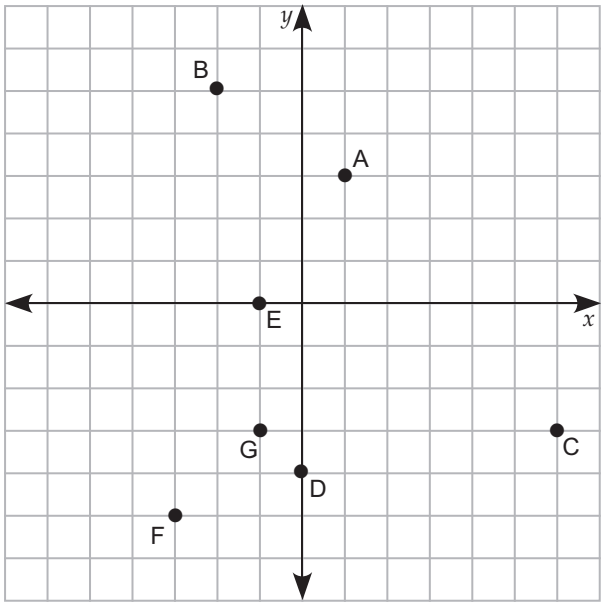
Learning Activity 1 Answer Key

1. Rearrange to $-y = -x + 12$,

   Then $y = x - 12$

x	0	1	2	3	4
y	–12	–11	–10	–9	–8

2.



3. b) $b = 1$

The slope is –1. The rise is –2 for a run of 2 to the right. This makes $m = -1$.

The equation of line B is therefore $y = -1x + 1$.

c) $b = 5$

The slope is 0. Horizontal lines have a slope of 0. This makes $m = 0$.

The equation of line C is therefore $y = +5$.

d) $b = 5$

The slope is $\frac{-1}{3}$. The rise is –2 for a run of 6 to the right. This makes

$m = \frac{-1}{3}$.

The equation of line D is therefore $y = \left(\frac{-1}{3}\right)x + 5$.

e) $b = 0$

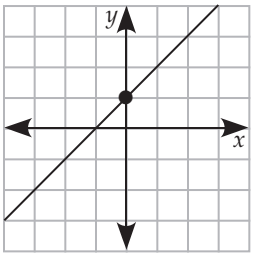
The slope is $\frac{7}{2}$. The rise is 7 for a run of 2 to the right. This makes

$m = \frac{7}{2}$.

The equation of line E is therefore $y = \left(\frac{7}{2}\right)x + 0$ or $y = \left(\frac{7}{2}\right)x$.

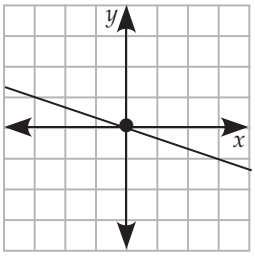
4. b) $y = x + 1$

This line has a y-intercept of +1 and a slope of 1 (or 1/1).



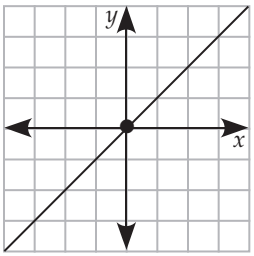
c) $y = -\frac{1}{3}x$

This line has a y-intercept of 0 and a slope of –1/3.



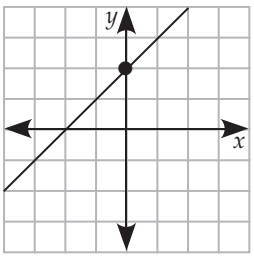
d) $y = x$

This line has a y-intercept of 0 and a slope of 1.



e) $y = -x + 2$

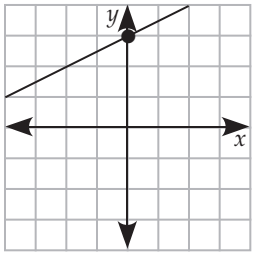
This line has a y-intercept of +2 and a slope of –1.



f) $2y = x + 6$

Rearrange the equation to $y = \left(\frac{1}{2}\right)x + 3.$

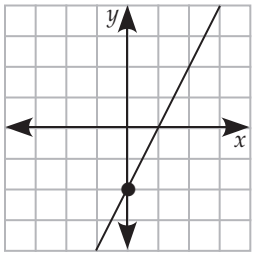
This line has a y-intercept of +3 and a slope of 1/2.



g) $\frac{y}{2} = x - 1$

Rearrange to $y = 2x - 2$

This line has a y-intercept of –2 and a slope of 2.

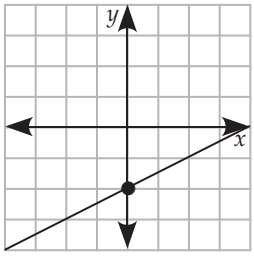


h) $x = 2y + 4$

Rearrange to $-2y = -x + 4$

Then $y = \left(\frac{1}{2}\right)x - 2.$

This line has a y-intercept of –2 and a slope of 1/2.

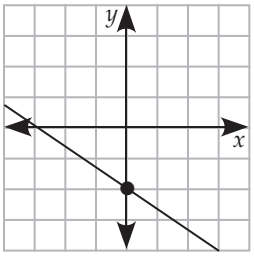


i) $2x + 3y - 6 = 0$

Rearrange $3y = -2x + 6$

Then $y = \frac{-2}{3}x + 2$.

This line has a y-intercept of $+2$ and a slope of $\frac{-2}{3}$.



NOTES

Appendix I: Measurement Units

In this lesson, we will discuss the units that go with measurements and how to convert between those units.

Try to picture something that is "6 tall." Perhaps you thought of a person that is 6 *feet* tall, or a greeting card that is 6 *inches* tall, or an ant that is 6 *millimetres* tall, or perhaps you simply thought "6 *what* tall?" in which case you see that "6 tall" isn't very meaningful. Measurements are made meaningful by the use of units. Inches, feet, centimetres, and metres are all examples of units for length. A unit is a standard size for a particular type of measurement. Measurements are then made by comparing other things to the size of the unit.

Two common sets of units are imperial and metric. Imperial units include pounds, inches, feet, miles, gallons, and quarts. Metric units include kilograms, centimetres, metres, kilometres, and litres. One major advantage that metric units have over imperial units is that each measurable quantity (length, mass, time, et cetera) has a basic unit that is easily built into larger or smaller units by powers of ten. As an example, consider length. In the imperial system, length is measured by miles, yards, feet, and inches (and more!). One mile is the same as 440 yards. A yard is the same as 3 feet. A foot is the same as 12 inches. This seems a little complicated when compared to the metric equivalent: the standard of length is the metre. There are also kilometres, which are 1000 metres, and centimetres, which are each one-hundredth of a metre, and millimetres, which are each one-thousandth of a metre.

Metric Prefixes

As mentioned above, the metric units can be easily made into larger or smaller units. This is done by the use of prefixes, which are placed before the unit name. Each prefix stands for a multiple of ten, which is easily written with scientific notation. In fact, you can think of these prefixes as being shorthand for scientific notation. **Memorize** the following table (but not the examples):

Prefix	Abbreviation	Scientific Notation	Example
mega	M	$\times 10^6$ or million	Some computers have 512 MB of memory. MB = megabyte = million bytes (a byte is a basic unit of information). 512 MB = 512 $\times 10^6$ B = 512 000 000 B
kilo	k	$\times 10^3$ or thousand	A kg (kilogram) of hamburger is exactly a thousand grams. 1 kg = 1 $\times 10^3$ g = 1000 g
centi	c	$\times 10^{-2}$ or hundredth	A cm (centimetre) is literally a hundredth of a metre—this page is about 21.5 cm wide. 21.5 cm = 21.5 $\times 10^{-2}$ m = 21.5/1000 g = 0.215 g
milli	m	$\times 10^{-3}$ or thousandth	A cup of coffee contains roughly 100 mg (milligrams) of caffeine. 100 mg = 100 $\times 10^{-3}$ g = 100/1000 g = 0.1 g
micro	μ Greek Letter "mu" (pronounced "m-you")	$\times 10^{-6}$ or millionth	A μs (microsecond) is literally a millionth of a second—this is much less than the "blink of an eye." 1 μs = 1 $\times 10^{-6}$ s = 1/1000 000 s = 0.000001 s

Working with Units

The units of choice for use in physics are known as the **International System** of units, or SI for short (it is abbreviated as SI from "Système International," as it originated in France). Note that SI units are related to metric units, but metric and SI are not the same thing. While metric units include several variations of units for each type of measurement, the SI system chooses only one metric unit to be the "official" SI unit for use. For example, centimetres, metres, and kilometres are all metric, but only the metre is considered to be the SI unit. For now, here are the types of measurement that you should be familiar with, and the corresponding SI units:

Measurement	SI Unit	Abbreviation	Example
length	metre	m	A 3-year-old is about 1 m tall.
mass	kilogram	kg	A 2-litre bottle of pop is very near 2 kg.
time	second	s	An hour is equal to 3600 s.

When measurements appear in equations, it is important to recognize that the units are very much a part of the math. Generally, you should treat units in the same way that you treat variables. As an example, to find the volume of a box-shaped object, you use the formula $V = lwh$ where l stands for length, w stands for width, and h stands for height. If the length was 1 m and the width was 2 m while the height was 3 m, the volume would be found as V = (1 m)(2 m)(3 m). The order in which you multiply is not important, so multiplying the above might be easier thought of as (1)(2)(3)(m)(m)(m) = 6 m^3. Note that this answer would be read as "six cubic metres" or "six metres cubed."

The fact that units can be treated like variables leads to an interesting fact: units can "cancel," and so disappear from a measurement. We can take advantage of this to convert from one unit to another. Here is how it works:

A measurement can be multiplied by one (1) without changing the size of the measurement. We can make fractions that are equal to one by using knowledge of two units. For example, since one foot is equal to 12 inches (12 ft. = 12 in.),

$$\text{then } \frac{1 \text{ ft.}}{12 \text{ in.}} = 1$$

$$\text{and } \frac{12 \text{ in.}}{1 \text{ ft.}} = 1$$

We can now convert between the two easily. For example, if a person's height is 6 feet (height = 6 ft.), then we can convert this to inches, as shown here:

$$6 \text{ ft.} \times \frac{12 \text{ in.}}{1 \text{ ft.}} = 72 \text{ in.}$$

We chose the fraction that will allow feet to be cancelled from the answer.

If a person is 68 in. tall, how many feet is he?

$$68 \text{ in.} \times \frac{1 \text{ ft.}}{12 \text{ in.}} = \frac{68}{12} \text{ ft.}$$

This reduces to $5\frac{2}{3}$ ft. We would commonly say 5 feet and 8 inches.

Converting Between Metric Units

You know that there are 100 cm in 1 m.

So the fractions you can make are $\frac{100\text{ cm}}{1\text{ m}} = 1$ or $\frac{1\text{ m}}{100\text{ cm}} = 1$.

Determine the number of cm in 82.47 m.

Since you need to cancel out the m, multiply by $\frac{100\text{ cm}}{1\text{ m}} = 1$.

$$82.47\text{ m} \times \frac{100\text{ cm}}{1\text{ m}} = 8247\text{ cm}$$

In scientific notation, this is 8.247×10^3 cm.

Learning Activity 1

1. Switch the following from measurements involving prefixes to measurements involving the base unit (g, m, s) and scientific notation:
   a) 23 kg
   b) 590 Mm
   c) 180 ms
   d) 48 km
   e) 63 cm
   f) 188 cm
   g) 0.3 mm
   h) 12 ms
2. Switch the following from measurements involving scientific notation to measurements involving prefixes:
   a) 6.8×10^3 s
   b) 9.3×10^{-2} g
   c) 3.6×10^6 m
   d) 8.4×10^4 m
3. Switch the following from one prefix to another:
   a) 41 cm to mm
   b) 101 m to km
   c) 0.5 kg to g
   d) 54 Ms to ks

4. Convert from one unit to another:
   a) Knowing that 1 in. = 2.54 cm, determine the height of a 66 inch person into cm.
   b) Knowing that 1 metre = 3.28 feet, determine the length of a 110-yard football field in metres
   c) Knowing that 1 cup = 250 mL, determine how many mL make up $4\frac{1}{2}$ cups
   d) Determine how many seconds are in October
   e) A "light year" (ly) is the same as 9.47×10^{15} m. How far away (in metres) is a star that is 250 light years away?
   f) Convert the speed limit of 90 km/h into the SI unit for speed: m/s. Hint: Convert this measurement twice, being careful of how the units cancel in both cases.

Learning Activity 1 Answer Key

1. a) $23 \text{ kg} = 23 \times 10^3 \text{ g} = 2.3 \times 10^4 \text{ g}$
   Since $k = 10^3$, replace the k by 10^3.
   b) $590 \text{ Mm} = 590 \times 10^6 \text{ m} = 5.9 \times 10^8 \text{ m}$
   Since $M = 10^6$, replace the M by 10^6.
   c) $180 \text{ ms} = 180 \times 10^{-3} \text{ m} = 1.8 \times 10^{-1} \text{ m}$
   Since $m = 10^{-3}$, replace the m by 10^{-3}.
   d) $48 \text{ km} = 48 \times 10^3 \text{ m} = 4.8 \times 10^4 \text{ m}$
   Since $k = 10^3$, replace the k by 10^3.
   e) $63 \text{ cm} = 63 \times 10^{-2} \text{ m} = 6.3 \times 10^{-1} \text{ m}$
   Since $c = 10^{-2}$, replace the c by 10^{-2}.
   f) $188 \text{ cm} = 188 \times 10^{-2} \text{ m} = 1.88 \times 10^0 \text{ m}$
   Since $c = 10^{-2}$, replace the c by 10^{-2}.
   g) $0.3 \text{ mm} = 0.3 \times 10^{-3} \text{ m} = 3 \times 10^{-4} \text{ m}$
   Since $m = 10^{-3}$, replace the m by 10^{-3}.
   h) $12 \text{ ms} = 12 \times 10^{-3} \text{ m} = 1.2 \times 10^{-2} \text{ m}$
   Since $m = 10^{-3}$, replace the m by 10^{-3}.

2. a) 6.8×10^3 s = 6.8 ks
   b) 9.3×10^{-2} g = 9.3 cg
   c) 3.6×10^6 m = 3.6 Mm
   d) 8.4×10^4 m = 84×10^3 m = 84 km

3. a) 41 cm: to mm

   There are 10 mm in 1 cm. Since we want to get rid of the cm, the fraction we use is $\frac{10\text{ mm}}{1\text{ cm}}$.

   $$41\text{ cm} \times \frac{10\text{ mm}}{1\text{ cm}} = 410\text{ mm}$$

   b) 101 m: to km

   There are 1000 m in 1 km. Since we want to get rid of the m, the fraction we use is $\frac{1\text{ km}}{1000\text{ m}}$.

   $$101\text{ m} \times \frac{1\text{ km}}{1000\text{ m}} = 0.101\text{ km}$$

   c) 0.5 kg: to g

   There are 1000 g in 1 kg. Since we want to get rid of the kg, the fraction we use is $\frac{1000\text{ g}}{1\text{ kg}}$.

   $$0.5\text{ kg} \times \frac{1000\text{ g}}{1\text{ kg}} = 500\text{ g}$$

   d) 54 Ms to ks

   Mega (M) means 10^6 and kilo means 10^3, so there are 10^3 (1000) ks in 1 Ms.

   Since we want to get rid of the Ms, the fraction we use is $\frac{1000\text{ ks}}{1\text{ Ms}}$.

   $$54\text{ Ms} \times \frac{1000\text{ ks}}{1\text{ Ms}} = 54000\text{ ks} = 5.4 \times 10^4\text{ s}$$

4. a) Since you want to get rid of the inches, multiply using the fraction $\frac{2.54 \text{ cm}}{1 \text{ in.}}$.

$$66 \text{ in.} \times \frac{2.54 \text{ cm}}{1 \text{ in.}} = 167.64 \text{ cm}$$

b) First convert the yards to feet. Since there are 3 ft. in 1 yd., 110 yd. will be 330 ft.

Since you want to get rid of the feet, multiply using the fraction $\frac{1 \text{ m}}{3.28 \text{ ft.}}$.

$$330 \text{ ft.} \times \frac{1 \text{ m}}{3.28 \text{ ft.}} = 100.6 \text{ m}$$

c) Since you want to get rid of the cups, multiply using the fraction $\frac{250 \text{ mL}}{1 \text{ cup}}$.

$$4\frac{1}{2} \text{ cups} \times \frac{250 \text{ mL}}{1 \text{ cup}} = 1125 \text{ mL}$$

d) October has 31 days. There are 24 hours per day. There are 60 minutes per hour and 60 seconds per minute. In this case, we want to arrange our fractions to cancel the units so that only seconds remain.

$$31 \text{ days} \times \frac{24 \text{ hours}}{1 \text{ day}} \times \frac{60 \text{ minutes}}{1 \text{ hour}} \times \frac{60 \text{ seconds}}{1 \text{ minute}} = 2678400 \text{ s}$$

e) Since you want to get rid of the light years, multiply using the fraction $\frac{9.47 \times 10^{15} \text{ m}}{1 \text{ ly}}$.

$$250 \text{ ly} \times \frac{9.47 \times 10^{15} \text{ m}}{1 \text{ ly}} = 2.37 \times 10^{18} \text{ m}$$

f) Convert the km to m first.

Since you want to get rid of km, multiply by the fraction $\frac{1000\text{ m}}{1\text{ km}}$.

$$90\text{ km} \times \frac{1000\text{ m}}{1\text{ km}} = 90000\text{ m}$$

Now convert the hours into seconds.

Since you want to get rid of hours, multiply by the fraction $\frac{60\text{ minutes}}{1\text{ hour}}$.

This gives the time in minutes. To get rid of minutes, multiply by $\frac{60\text{ seconds}}{1\text{ minute}}$.

$$1\text{ hour} \times \frac{60\text{ minutes}}{1\text{ hour}} \times \frac{60\text{ seconds}}{1\text{ minute}} = 3600\text{ seconds}$$

Finally, replace the km and hours with these new amounts in m and seconds.

$$\frac{90\text{ km}}{1\text{ hour}} = \frac{90000\text{ m}}{3600\text{ s}} = 25\text{ m/s}$$

Grade 11 Physics (30S)

Module 1: Kinematics

Learning Activity Answer Keys

MODULE 1: KINEMATICS

Learning Activity 1.1: Recording Data

1. A person is moving slowly at a constant speed to the right. Every second, the distance travelled from the origin is recorded. The diagram below is one way to visually record the data. In this situation, the independent variable is the time.

   - At t = 0.0 s, the distance travelled d = 0.0 m.
   - At t = 2.0 s, d = 1.0 m
   - At t = 4.0 s, d = 2.0 m
   - At t = 6.0 s, d = 3.0 m
   - At t = 8.0 s, d = 4.0 m
   - At t = 10.0 s, d = 5.0 m

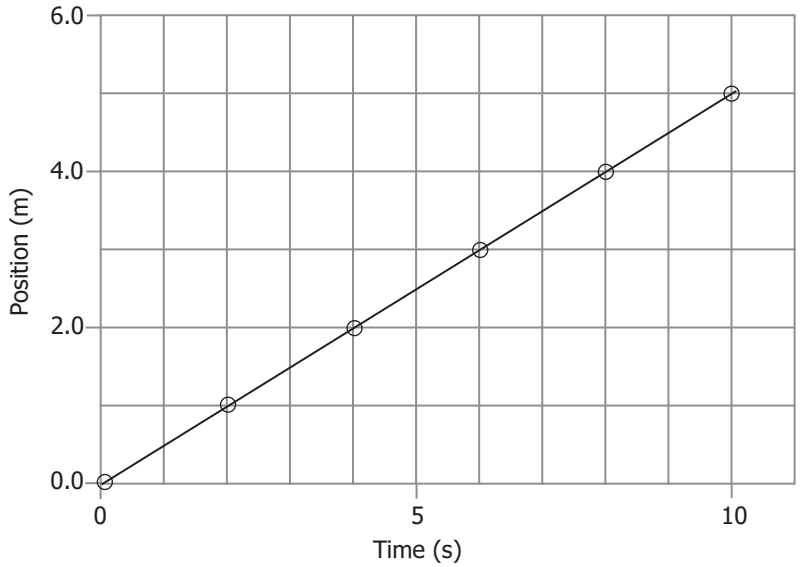
   a) Express the data above numerically in the form of a data table. Construct the data table horizontally. Be sure to label the rows correctly.

   Answer:

time (s)	0.0	2.0	4.0	6.0	8.0	10.0
distance (m)	0.0	1.0	2.0	3.0	4.0	5.0

   b) Now construct a graph of the data above.

   Answer:



c) To illustrate the symbolic mode, determine the mathematical equation that relates the distance and the time. Include the magnitude of the slope in your answer.

Answer:

If we use the coordinates (0, 0) and (10.0, 5.0), the slope of the line is

$$\frac{5.0\ \text{m} - 0.0\ \text{m}}{10.0\ \text{s} - 0.0\ \text{s}} = 0.50\ \text{m/s}.$$

If we eliminate the units from the slope, the equation of the line can therefore be written as $d = 0.50t$.

2. If you were asked by another student "What is physics?", what would you say?

Answers will vary.

You might say that physics began as the study of everything around us. Over time some phenomena have been classified into other categories, such as biology, chemistry, or astronomy, and removed from physics. Whatever remains is what we now call physics.

A more narrow definition could be that physics is the study of the relationships that exist within a given situation.

Learning Activity 1.2: Quantities

In your previous studies of science, you have been introduced to many quantities and many instruments used to measure these quantities. Fill in the missing parts in the table below.

Answer:

Quantity	Symbol of the Quantity	Unit	Vector or Scalar
time instant	t	second (s)	scalar
time interval	Δt	second (s)	scalar
distance travelled	Δd	metre (m)	scalar
displacement	$\Delta \vec{d}$	metre (m)	vector
mass	m	kilogram (kg)	scalar
length	l	metre (m)	scalar
speed	v	metres/second (m/s)	scalar
acceleration	$\vec{a}$	metre/second/second (m/s/s or m/s^2)	vector
velocity	$\vec{v}$	metres/second (m/s)	vector
force	$\vec{F}$	Newtons (N)	vector
energy	E	Joules (J)	scalar

Learning Activity 1.3: Significant Digits: Part 1

Write the answer to each question in the space provided in the table. The answers to these questions can be found in the answer key at the end of the module.

1. Determine the number of significant digits in each of the following numbers.

   Answer:

5.897	4	8.000	4	10001	5
0.333	3	8.001	4	0.008000	4
7	1	0.009	1	947.000	6
10000	1	12000	2	10000.0	6
10321	5	55040	4	375000	3

2. State the number of significant digits in each measurement.

   Answer:

a) 2509 m	4	g) 7.62 km	3
b) 0.00055 m	2	h) 0.0670 m	3
c) 5.060×10^5 m	4	i) 9.0000×10^{-5} m	5
d) 240 m	2	j) 2.4 m	2
e) 2400 m	2	k) 2400.0 m	5
f) 0.005050 m	4	l) 50 m	1

Learning Activity 1.4: Significant Digits: Part 2

1. A bowl contains 12 oranges. In this case, what type of number is 12?

   Answer: In this case, 12 is an exact number.

2. How many significant digits are in each of the following numbers?

   Answer:

a) 18	2	f) 125 000 000	3
b) 0.018	2	g) 125 000 000.0	10
c) 250	2	h) 1.0×10^{8}	2
d) 12000	2	i) 5.92×10^{-6}	3
e) 1008	4	j) 4.30450×10^{3}	6

3. Complete the following calculations. Round off the final answer to the correct number of significant digits.

   Answers:

   a) $2.8234 \times 6.1 = 17.22274 = 17$

   Since the first number contains five significant digits and the second number contains two significant digits, we will keep only two significant digits in our answer.

   Therefore, we round off the 7.

   b) $0.03940 \times 0.0090400 = 0.000356176 = 0.0003562$

   Since the first number contains four significant digits and the second number contains five significant digits, we will keep only four significant digits in our answer.

   Therefore, we round off the 1. In this case, the zeros after the decimal and preceding the 3 are used as placeholders. Zeros used as placeholders are not significant. You can check this using the Atlantic-Pacific procedure.

   c) $820 / 2.050 = 400 = 4.0 \times 10^{2}$

   The 820 contains two significant digits and the 2.050 contains four significant digits. Therefore, we keep only two significant digits in the answer. The answer 400 seems to contain only one significant digit. We must write the answer in scientific notation to avoid any ambiguity about which digits are significant.

d) 9000.0 / 5820 = 1.546391753 = 1.55

e) 738 + 25.92 = 763.92 = 764

$$\begin{array}{r} 73\mathbf{8} \\ +25.9\mathbf{2} \\ \hline 76\mathbf{3.92} \end{array}$$

The digits written in boldface type are all uncertain. Therefore, we round off the first of these uncertain digits—that is, the digit that lies in the largest place value. In this case, that place value is the ones.

f) 87000 – 640.0 = 86360.0 = 86000 or 8.6×10^4

$$\begin{array}{r} 8\mathbf{7}000 \\ -640.\mathbf{0} \\ \hline 8\mathbf{6360.0} \end{array}$$

Round this answer off at the digit that lies in the largest of the uncertain place values.

g) 0.002050 – 0.0003892 = 0.0016608 = 0.001661

$$\begin{array}{r} 0.00205\mathbf{0} \\ -0.000389\mathbf{2} \\ \hline 0.0016\mathbf{608} \end{array}$$

h) 90.25 + 4.984 – 6.3080 = 88.926 = 88.93

$$\begin{array}{r} 90.2\mathbf{5} \\ +4.98\mathbf{4} \\ -6.308\mathbf{0} \\ \hline 88.9\mathbf{26} \end{array}$$

i) 3.0625 x 8.0920 ÷ 140 = 0.1770125 = 0.18

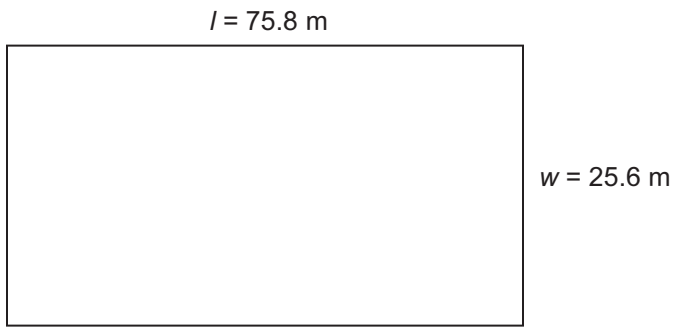
Since the 140 contains only two significant digits, we must keep two significant digits in the final answer.

Learning Activity 1.5: Average Speed

1. Your school is rectangular in shape. Around the school is a sidewalk that also forms a rectangle. Along the length of the school, the sidewalk is 75.8 m and along the width of the school the sidewalk is 25.6 m. It takes 65.3 seconds to walk on the sidewalk around the school and return to the starting point.

   a) What is the distance travelled?

   Answer:



The distance travelled is the distance around the rectangle or its perimeter.

$P = 2l + 2w$

$P = 2(75.8\text{ m}) + 2(25.6\text{ m})$

$P = 202.8\text{ m} = 203\text{ m}$ (rounded off to 3 significant digits due to multiplication rule)

   b) What was your average speed during this trip?

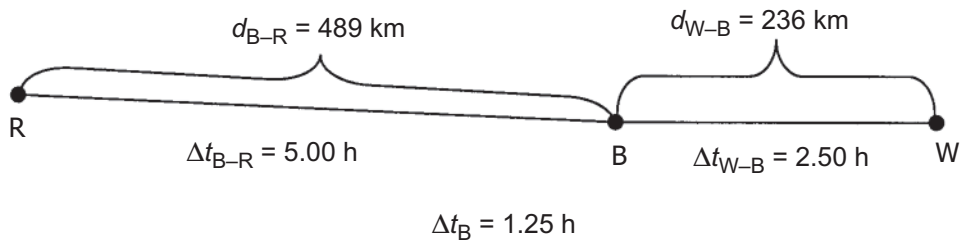
   Answer:

Given:

Distance travelled	$d = 203\text{ m}$
Time interval	$\Delta t = 65.3\text{ s}$
Unknown: average speed	$v_{avg} = ?$
Equation:	$v = \dfrac{d}{\Delta t}$
Substitute and solve:	$v = \dfrac{203\text{ m}}{65.3\text{ s}} = 3.108728943\text{ m/s}$

Your average speed for this trip is 3.11 m/s.

2. You are travelling in a car from Winnipeg to Regina. It takes you 2.50 hours to travel from your home to Brandon, a distance of 236 km. You stop in Brandon to have lunch and do some shopping, spending a total of 1.25 hours. The remaining 489 km of the trip to Regina requires 5.00 hours.



a) What is the average speed for the part of the trip from your home to Brandon?

Answer:

To answer this question, you only need to consider the distance between Winnipeg and Brandon and the time that it took to travel from Winnipeg to Brandon.

Given: Distance travelled $d_{W\text{-}B} = 236$ km

Time interval $\Delta t_{W\text{-}B} = 2.50$ h

Unknown: Average speed $v_{avg} = ?$

Equation: $$v = \frac{d}{\Delta t}$$

Substitute and solve: $$v = \frac{236 \text{ km}}{2.50 \text{ h}} = 94.4 \text{ km/h}$$

The average speed between Winnipeg and Brandon was 94.4 km/h.

b) What is the average speed for the whole trip from Winnipeg to Regina?

Answer:

Given: Distance travelled $d_{W-R} = d_{W-B} + d_{B-R} = 236 \text{ km} + 489 \text{ km}$
$= 725$ km

Total time interval $\Delta t_{total} = \Delta t_{W-B} + \Delta t_B + \Delta t_{B-R}$
$= 2.50 \text{ h} + 1.25 \text{ h} + 5.00 \text{ h} = 8.75 \text{ h}$

Unknown: Average speed $v_{avg} = ?$

Equation: $$v = \frac{d}{\Delta t}$$

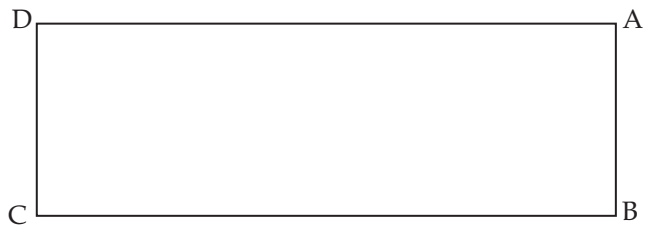
Substitute and solve: $$v = \frac{725 \text{ km}}{8.75 \text{ h}} = 82.85714... \text{ km/h}$$

The average speed from Winnipeg to Regina was 82.8 km/h.

Learning Activity 1.6: Velocity

For questions #1–3, use the information below.

A city block is laid out in a grid, running in north-south and east-west directions. The blocks measure 135 m in length in the east-west direction, and 45.0 m in width in the north-south direction. A city block is drawn below.



Answers:

1. On your bicycle, you travel from A to B during 9.00 s.
   a) What is your average speed?

   $d = 45.0 \qquad \Delta t = 9.00 \text{ s}$

   $v_{avg} = ?$

   $$v_{avg} = \frac{d}{\Delta t} = \frac{45.0 \text{ m}}{9.00 \text{ s}} = 5.00 \text{ m/s}$$

   b) What is your average velocity?

   $$\vec{v}_{avg} = \frac{\vec{d}}{\Delta t} = \frac{45.0 \text{ m [S]}}{9.00 \text{ s}} = 5.00 \text{ m/s [S]}$$

2. If you travel from A to B to C to D, what is your
   a) distance travelled?

   $\Delta\vec{d}_{AB} = 45.0 \text{ m} \qquad \Delta\vec{d}_{BC} = 135.0 \text{ m} \qquad \Delta\vec{d}_{CD} = 45.0 \text{ m}$

   $\Delta\vec{d}_{TOTAL} = 45.0 \text{ m} + 135.0 \text{ m} + 45.0 \text{ m} = 225.0 \text{ m}$

   b) displacement?

   The displacement from A to B to C to D is the same as going directly from A to D, which is 135 m [W].

3. If the journey in #2 took 55.0 s, calculate
   a) your average speed

$d_{\text{TOTAL}} = 225 \text{ m} \qquad \Delta t = 55.0 \text{ s}$

$v_{\text{avg}} = ?$

$$v_{\text{avg}} = \frac{d}{\Delta t} = \frac{225 \text{ m}}{55.0 \text{ s}} = 4.09 \text{ m/s}$$

   b) your average velocity

$\vec{d} = 135 \text{ m [W]} \qquad \Delta t = 55.0 \text{ s}$

$$\vec{v}_{\text{avg}} = \frac{\Delta \vec{d}}{\Delta t} = \frac{135 \text{ m [W]}}{55.0 \text{ s}} = 2.45 \text{ m/s [West]}$$

4. A car is travelling around a circular track. Write down which one of the following statements is incorrect and why.
   a) The car travelled around the track at a constant velocity.
   b) The car travelled around the track at a constant speed.

   Answer:

   The velocity of the car is a vector quantity with both magnitude and direction. The speed of the car is a scalar quantity and has nothing to do with direction. It is possible to drive a car around a track at a constant speed. As the car drives around the track, however, it must change direction. Therefore, the direction of the velocity changes and the velocity cannot be constant.

5. Sound travels at a constant speed of 343 m/s in air.
   a) How much time does it take the sound of thunder to travel a distance of 5005 m?

   Answer:

   Given: Speed $v = 343$ m/s

   Distance $d = 5005$ m

   Equation: $v = \dfrac{d}{\Delta t}$ rearranged to $\Delta t = \dfrac{d}{v}$

   Substitute and solve: $\Delta t = \dfrac{5005 \text{ m}}{343 \text{ m/s}} = 14.6 \text{ s}$

   The time it takes the sound to travel is 14.6 s.

b) If the sound reflects back to the place where it originated, what is the average velocity of the sound?

Answer:

Since the sound reflected back to its place of origin, the displacement is zero and the average velocity is 0 m/s.

6. Andy Green in the car *ThrustSSC* established a world record in 1997. The speed of the car was 341.1 m/s (1228 km/h). The car was powered by two jet engines. It was also the first car to officially exceed the speed of sound. To establish such a record, the driver makes two runs through the course, one in each direction, to nullify wind effects. First, the car travelled from left to right, a distance of 1609 m in a time of 4.740 s. Then the car travelled the same distance in the reverse direction in a time of 4.695 s. Determine the average velocity in each run.

Answer:

In the first run, the car moved with a positive displacement.

Given: Time interval $\Delta t = 4.740$ s

Displacement $\vec{d} = +1609$ m

Equation: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Substitute and solve: $\vec{v} = \dfrac{\vec{d}}{\Delta t} = \dfrac{+1609 \text{ m}}{4.740 \text{ s}} = +339.4 \text{ m/s}$

The positive sign would not normally be included in an answer. It is done here just for emphasis.

In the second run, the car moved a negative displacement $\left(\vec{d} = -1609 \text{ m}\right)$.

Given: Time interval $\Delta t = 4.695$ s

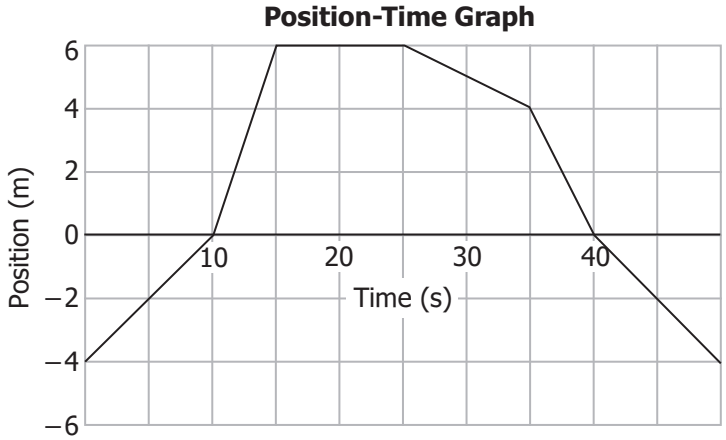
Displacement $\vec{d} = -1609$ m

Equation: $\vec{v} = \dfrac{\vec{d}}{\Delta t}$

Substitute and solve: $\vec{v} = \dfrac{\vec{d}}{\Delta t} = \dfrac{-1609 \text{ m}}{4.695 \text{ s}} = -342.7 \text{ m/s}$

The velocity on the return trip was –342.7 m/s. Here, we must include the negative sign to give the correct direction for the velocity. We could also say 342.7 m/s to the left.

Learning Activity 1.7: Position–Time Graph: Part 1



The position-time graph above represents the motion of a remote-controlled toy truck as it moves back and forth along a straight line path. The origin marks the position of the boy who controls the truck. The boy has not yet learned how to make the truck change its direction of motion.

A positive position marks positions to the right of the boy, and a negative position marks positions to the left of the boy.

Answers:

1. During which time intervals is the truck to the right of the boy? 10–40 s

   To the left of the boy? 0 s–10 s, 40 s–50 s

2. During which time intervals is the truck moving in the positive direction?

   0 s–15 s,

   In the negative direction? 25 s – 50 s

   Not moving? 15 s—25 s

3. What is the position of the truck at 0 seconds? –4 m

   15 seconds? +6 m

   30 seconds? +5 m

   45 seconds? –2 m

4. When is the truck in front of the boy? At 10 s and at 40 s

   The graph of position-time gives **directly** some information about the motion. This tells the position-time version of the story of this motion—that is, where the truck is at a particular instant in time.

   The graph of position-time also gives **indirect** information about the motion of the truck.

The following questions deal with obtaining this indirect information like distance travelled, displacement, average speed, and average velocity.

5. How far did the truck travel during the following time intervals:

   Answers:

   0-10 s? 4 m

   10-15 s? 6 m

   15-25 s? 0 m

   25-35 s? 2 m

   35-40 s? 4 m

   40–0 s? 4 m

6. What was the displacement of the truck during the following intervals:

   Answers:

   0-10 s? +4 m

   10-15 s? +6 m

   15-25 s? 0 m

   25-35 s? –2 m

   35-40 s? –4 m

   40–50 s? –4 m

7. Average speed is given by the distance travelled divided by the time interval. Calculate the average speed for each interval:

   Answers:

   0-10 s? $v = \frac{d}{\Delta t} = \frac{4\text{ m}}{10\text{ s}} = 0.4\text{ m/s}$

   10-15 s? 1.2 m/s

   15-25 s? 0 m/s

   25-35 s? 0.2 m/s

   35-40 s? 0.8 m/s

   40-50 s? 0.4 m/s

8. The following relationship is used to calculate average velocity:

   average velocity = displacement/time interval or $\vec{v} = \frac{\vec{d}}{\Delta t}$.

   This relationship also represents the slope of the line on a position-time graph.

   Calculate the average velocity for each time interval by calculating the slope of the line segment. Show your work.

   Answer:

Run = Δt Time Interval	**Rise = $\vec{d}$ Displacement**	**Slope = $\vec{v} = \frac{\vec{d}}{\Delta t}$**
0 – 10 s	0 m – (–4 m) = + 4 m	$\frac{+4\text{ m}}{10\text{ s}} = +0.4\text{ m/s}$
10 – 15 s	+6 m – 0 m = +6 m	+1.2 m/s
15 – 25 s	+6 m – (+6 m) = 0 m	0 m/s
25 – 35 s	+4 m – (+6 m) = –2 m	–0.2 m/s
35 – 40 s	0 m – (+4 m) = –4 m	–0.8 m/s
40 – 50 s	–4 m – 0 m = –4 m	–0.4 m/s

9. How do the signs of the velocities in #9 compare with the direction of motion in #2?

   Answer:

   When the truck has a negative velocity, it moves in the negative direction (towards the boy's left).

   When the truck has a positive velocity, it moves in the positive direction (towards the boy's right).

10. In terms of the truck's motion, what does a negative velocity mean?

    Answer: A negative velocity means that the truck is moving towards the boy's left.

    A positive velocity?

    Answer: A positive velocity means the truck is moving to the boy's right.

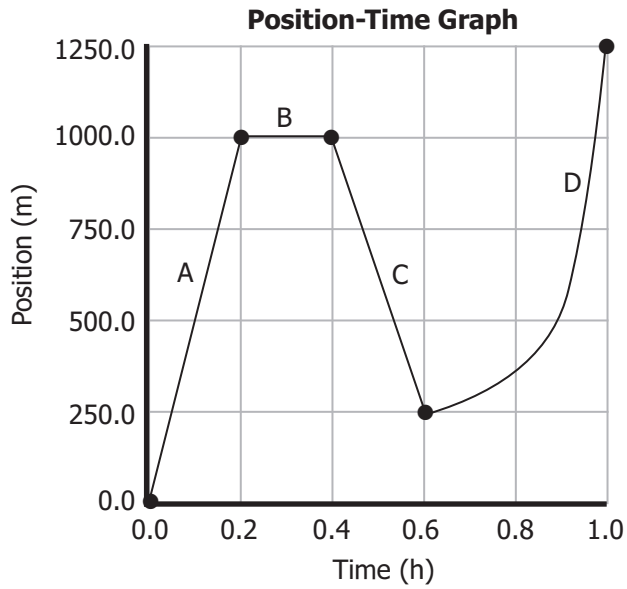
    A velocity of 0 m/s?

    Answer: A velocity of 0 m/s means the truck is standing still at one position.

Learning Activity 1.8: Position–Time Graph: Part 2

The physics of a position-time graph and a person exercising

The graph below shows a possible situation for a person who is exercising.



a) For the segments A to C above, calculate the velocity. (Note: convert each of the time intervals into seconds so that the units of velocity are in m/s. 1 h has 3600 s.)

Answer:

Determine the time intervals for each segment, then convert the time into seconds.

Each of the intervals (A, B, and C) is 0.20 h in duration.

Each time interval, Δt, is 0.20 h.

Since there are 3600 s in 1 h, we multiply 0.20 h by the fraction $\frac{3600\text{ s}}{1\text{ h}}$ to get rid of hours.

So, $\Delta t = 0.20\text{ h} \times \frac{3600\text{ s}}{1\text{ h}} = 720\text{ s}.$

The run for each interval is 720 s.

For each of the intervals, determine the rise over the run.

For Part A: $\vec{v}_A = \frac{\vec{d}_A}{\Delta t} = \frac{1000.0\text{ m} - 0\text{ m}}{720\text{ s}} = \frac{1000.0\text{ m}}{720\text{ s}} = 1.39\text{ m/s or } 1.4\text{ m/s}.$

For Part B: $\vec{v}_B = \dfrac{1000.0\text{ m} - 1000.0\text{ m}}{720\text{ s}} = \dfrac{0.0\text{ m}}{720\text{ s}} = 0.0\text{ m/s}.$

For Part C: $\vec{v}_C = \dfrac{250.0\text{ m} - 1000.0\text{ m}}{720\text{ s}} = \dfrac{-750.0\text{ m}}{720\text{ s}} = -1.04\text{ m/s or } -1.0\text{ m/s}.$

b) During which of the time intervals, A to C, was the runner moving the fastest?

Answer:

This occurred when the slope was the greatest. This is during Part A.

c) During which of the time intervals was the runner returning towards the starting point?

Answer:

This occurred when the velocity was negative—that is, in Part C.

d) During which of the time intervals was the runner most likely resting?

Answer:

This occurred during Part B when the slope was zero.

e) What was the average velocity over the whole run?

Answer:

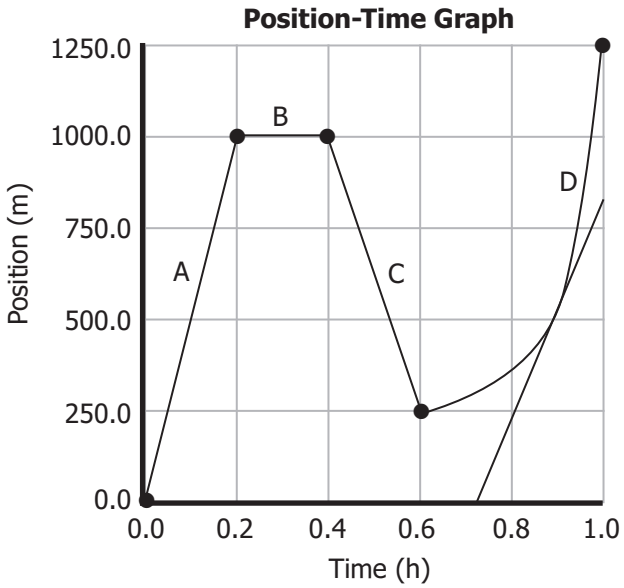
Draw a chord joining the initial position at 0.0 hours to 1.00 hours. The slope of this chord gives the average velocity for the whole run. Remember to convert the time from hours into seconds.

For the whole run, the average velocity was

$$\vec{v}_{avg} = \frac{\vec{d}_{TOTAL}}{\Delta t_{TOTAL}} = \frac{1250.0\text{ m} - 0\text{ m}}{(1.00\text{ h}) - (0.0\text{ h})} = \frac{1250.0\text{ m}}{(1.00\text{ h})} = \frac{1250.0\text{ m}}{3600\text{ s}} = 0.35\text{ m/s}.$$

f) For the time interval corresponding to D, determine the instantaneous velocity at a position of 500.0 m.

Answer:



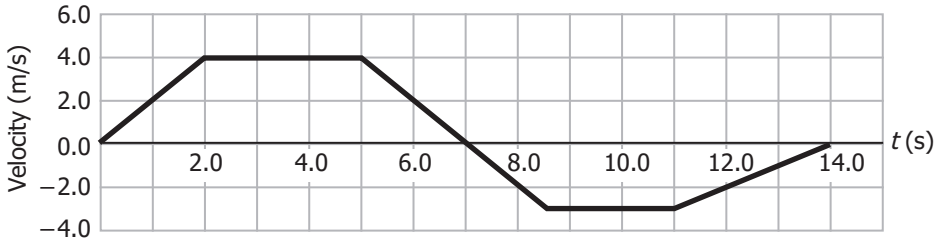
Draw a tangent line in interval D at the 500.0 m point, and find the slope of the line.

If we assume that at a time of 1.0 h (3.6×10^3 s) the position is 800.0 m, and that at a time of 0.72 h (2.6×10^3 s) the position is 0.0 m, then the slope of the tangent line is $\vec{v} = \dfrac{800.0\ \text{m} - 0.0\ \text{m}}{(3.6 \times 10^3\,\text{s}) - (2.6 \times 10^3\,\text{s})} = 0.792\ \text{m/s} = 0.79\ \text{m/s}.$

Due to the difficulty in drawing the tangent accurately, any answer in the 0.7 m/s to 0.8 m/s range is acceptable.

Learning Activity 1.9: Velocity–Time Graph: Part 1

1. For the velocity-time graph given below, determine the acceleration for each interval. Fill in the chart with the appropriate information, then plot a graph of acceleration versus time.

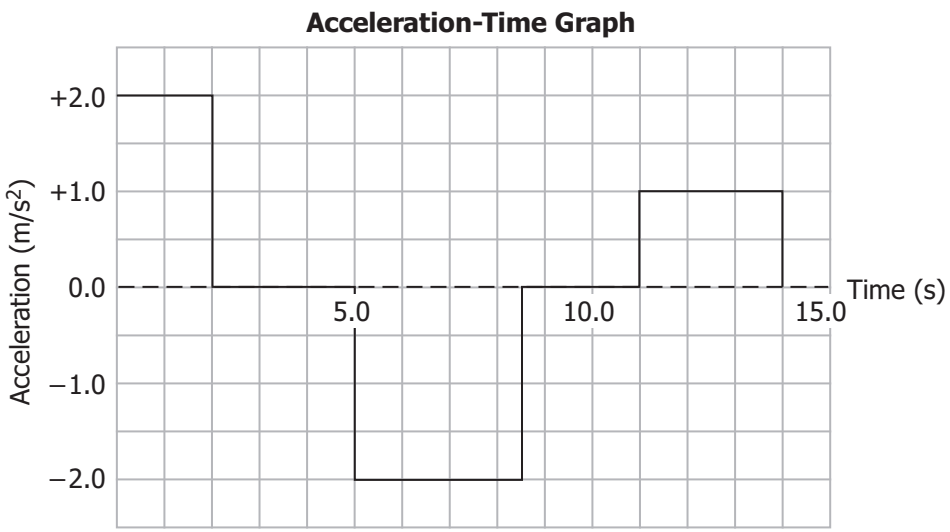


Answer:

Determining the acceleration from a velocity-time graph requires that you find the slope. On this particular graph, the velocities are sometimes constant and sometimes change over the time intervals.

For each section of the graph over which the slope is different, you must calculate the slope separately. The table below will organize the slope calculations.

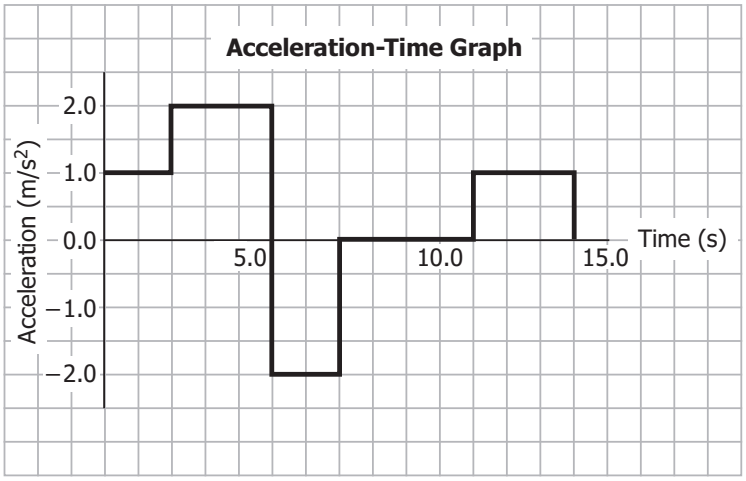
Run	Rise	Slope
Time Interval (s)	Change in velocity (m/s) $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$	Acceleration (m/s^2) $\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$
0.0–2.0	(+4.0 m/s) – (0.0 m/s) = +4.0	+4.0 m/s / 2.0 s = +2.0 m/s^2
2.0–5.0	(+4.0 m/s) – (+4.0 m/s) = 0	0.0 m/s / 3.0 s = 0.0 m/s^2
5.0–8.5	(–3.0 m/s) – (+4.0 m/s) = –7.0	–7.0 m/s / 3.5 s = –2.0 m/s^2
8.5–11.0	(–3.0 m/s) – (–3.0 m/s) = 0	0.0 m/s / 2.5 s = 0.0 m/s^2
11.0–14.0	(0.0 m/s) – (–3.0 m/s) = +3.0	+3.0 m/s / 3.0 s = +1.0 m/s^2



These types of graphs with sharp corners and more than 1 acceleration at the same time are impossible. However, we use these "idealized" graphs so that we can perform the required physics without getting bogged down with the graphing.

Learning Activity 1.10: Velocity–Time Graph: Part 2

1. For the acceleration-time graph given below, determine the change in velocity for each interval. Fill in the chart with the appropriate information, then plot a graph of velocity versus time. Assume the initial velocity is +3.0 m/s.

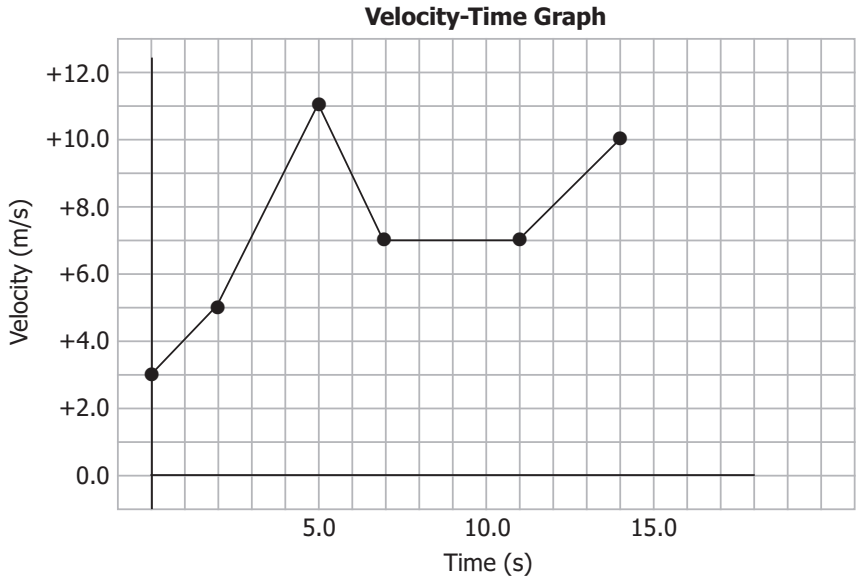


Answer:

Here you must take the area beneath the between the line and the time axis. There will be five of these areas.

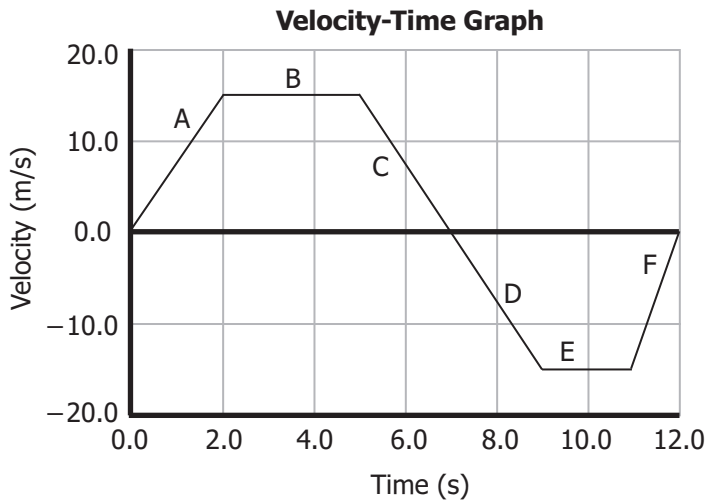
Time Interval (s)	Change in Velocity (m/s) $\Delta\vec{v} = \vec{a}\Delta t$	Velocity at End of the Interval (m/s) $\vec{v}_1 + \Delta\vec{v} = \vec{v}_2$
0.0		+3.0
0.0–2.0	(+1.0 m/s²)(2.0 s) = +2.0	+3.0 m/s + (+2.0 m/s) = +5.0
2.0–5.0	(+2.0 m/s²)(3.0 s) = +6.0	+5.0 m/s + (+6.0 m/s) = +11.0
5.0–7.0	(–2.0 m/s²)(2.0 s) = –4.0	+11.0 m/s + (–4.0 m/s) = +7.0
7.0–11.0	(0.0 m/s²)(4.0 s) = 0.0	+7.0 m/s + (+0.0 m/s) = +7.0
11.0–14.0	(+1.0 m/s²)(3.0 s) = +3.0	+7.0 m/s + (+3.0 m/s) = +10.0

The graph of velocity-time is made by plotting the velocity at the end of each time interval at the time representing the end of each time interval. This will give a series of points. Join these points with line segments to complete the graph.



Learning Activity 1.11: The Physics of a Moving Bicycle

The following velocity-time graph shows the possible motion of a bicycle.



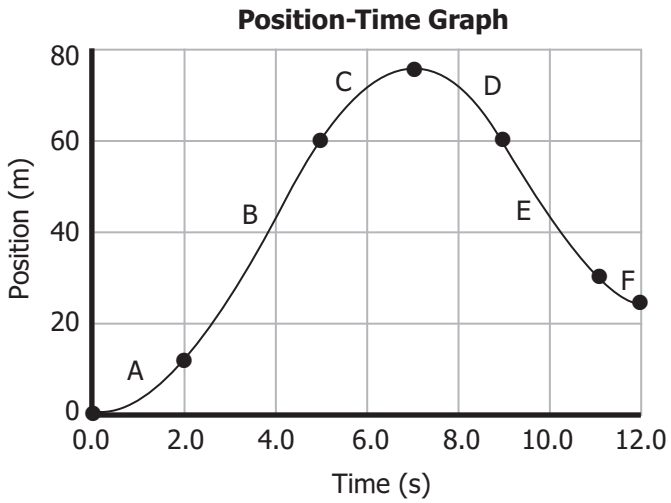
a) Produce a data table showing time and position, and then graph the data. The time portions of the table have been filled in. Assume the bicycle starts at 0.0 m at 0.0 s.

Answer:

Section	Time Interval (s)	Displacement (m) $\vec{d} = \vec{v}\Delta t$	Position at End of the Interval (m) $\overrightarrow{\text{pos}}_1 + \vec{d} = \overrightarrow{\text{pos}}_2$
	0.0		0.0
A	0.0 – 2.0	$\frac{1}{2}\left(\left(+15.0\text{ m/s}\right)\left(2.0\text{ s}\right)\right) = +15\text{ m}$	0.0 m + (+15 m) = +15
B	2.0 – 5.0	(+15.0 m/s)(3.0 s) = +45 m	+15 m + (+45 m) = +60
C	5.0 – 7.0	$\frac{1}{2}\left(\left(+15\text{ m/s}\right)\left(2.0\text{ s}\right)\right) = +15\text{ m}$	+60 m + (+15 m) = +75
D	7.0 – 9.0	$\frac{1}{2}\left(\left(-15.0\text{ m/s}\right)\left(2.0\text{ s}\right)\right) = -15\text{ m}$	+75 m + (–15 m) = +60
E	9.0 – 11.0	(–15.0 m/s)(2.0 s) = –30 m	+60 m + (–30 m) = +30
F	11.0 – 12.0	$\frac{1}{2}\left(\left(-15\text{ m/s}\right)\left(1.0\text{ s}\right)\right) = -7.5\text{ m}$	+30 m + (–7.5 m) = +22.5

If we just consider the position at the end of each time interval, we arrive at the table below.

Time (s)	Position (m)
0.0	0.0
2.0	15
5.0	60
7.0	75
9.0	60
11.0	30
12.0	22.5



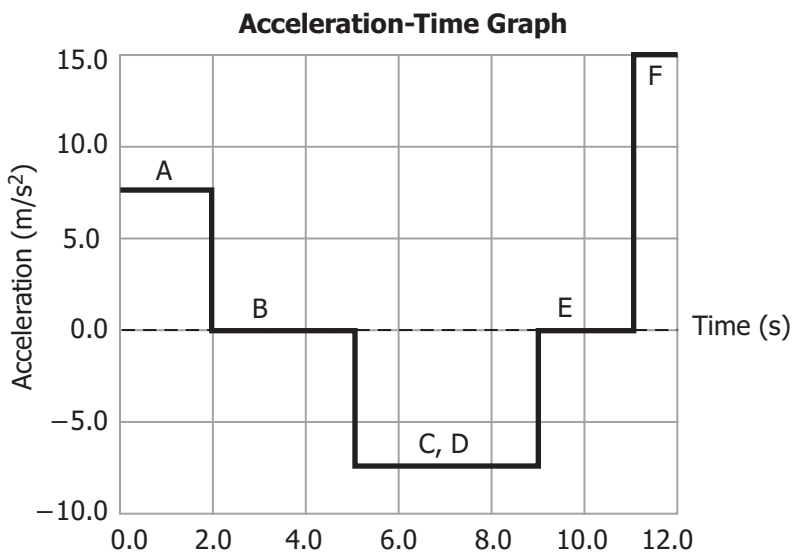
b) Produce a data table showing time and acceleration, and then graph the data. The time portions of the table have been filled in.

Answer:

Here you are looking for the slope of the velocity-time graph. Your table should have in it: time interval (run), change in velocity (rise), and acceleration (slope).

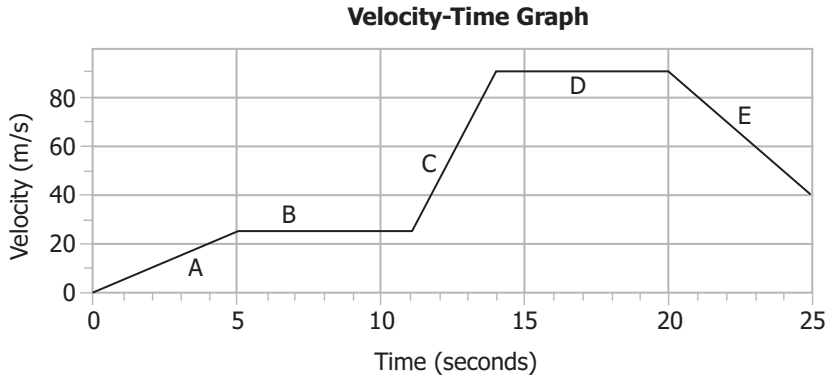
Section	Time Interval (s)	Change in Velocity (m/s) $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$	Acceleration (m/s²) $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$
A	0.0 – 2.0	(+15.0 m/s) – (0.0 m/s) = +15.0 m/s	$\frac{15.0\ \text{m/s}}{2.0\ \text{s}} = 7.5\ \text{m/s}^2$
B	2.0 – 5.0	(+15.0 m/s) – (+15.0 m/s) = 0.0 m/s	$\frac{0.0\ \text{m/s}}{3.0\ \text{s}} = 0.0\ \text{m/s}^2$
C	5.0 — 7.0	(0.0 m/s) – (+15 m/s) = –15.0 m/s	$\frac{-15.0\ \text{m/s}}{2.0\ \text{s}} = -7.5\ \text{m/s}^2$
D	7.0 – 9.0	(–15.0 m/s) – (0.0 m/s) = –15.0 m/s	$\frac{-15.0\ \text{m/s}}{2.0\ \text{s}} = -7.5\ \text{m/s}^2$
E	9.0 – 11.0	(–15.0 m/s) – (–15.0 m/s) = 0.0 m/s	$\frac{0.0\ \text{m/s}}{2.0\ \text{s}} = 0.0\ \text{m/s}^2$
F	11.0 – 12.0	(0.0 m/s) – (–15.0 m/s) = +15.0 m/s	$\frac{15.0\ \text{m/s}}{1.0\ \text{s}} = +15\ \text{m/s}^2$

Since the acceleration is constant over each time interval, you will end up with a "bar" graph.



Learning Activity 1.12: Displacement

Test your understanding of the derivation of these equations for uniformly accelerated motion by trying the questions below. You may check your work against the answer key provided at the end of Module 1.



All of the questions refer to the velocity-time graph given above.

Answers:

1. What on the velocity-time graph represents acceleration? Displacement?

   On a velocity-time graph, the slope of the line gives acceleration. On the velocity-time graph, the area beneath the curve gives displacement.

2. Which of the two equations that have been derived so far in this lesson should be used to find

   a) the acceleration for the time interval A?

      Acceleration involves finding the slope using the formula $\vec{a} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$.

   b) the displacement for the time interval C?

      Displacement is found using the area formula for a trapezoid:

      $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t.$

   c) the displacement for the time interval B?

      Displacement is found using the area formula for a trapezoid:

      $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t.$

      In this case, the initial velocity and final velocity are the same; therefore, the average velocity is the same as the initial velocity and final velocity.

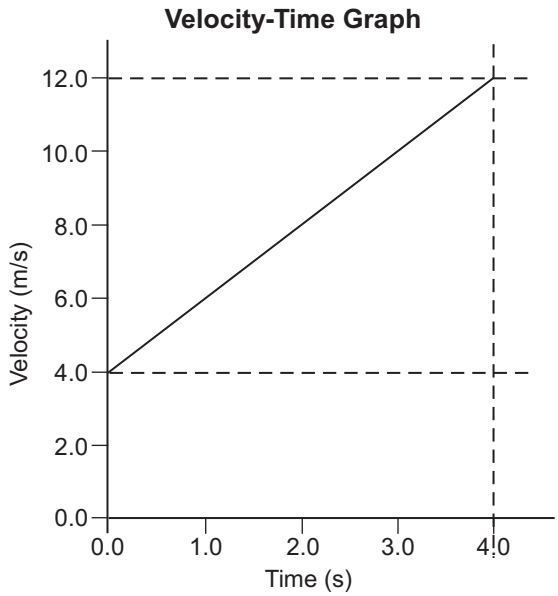
3. Calculate the displacement during time interval C.

From the graph:

Initial velocity	$\vec{v}_1 = +25 \text{ m/s}$
Final velocity	$\vec{v}_2 = +90 \text{ m/s}$
Time interval	$\Delta t = 3.0 \text{ s}$
Unknown: Displacement	$\vec{d} = ?$
Equation:	$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$
Substitute:	$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t = \frac{(25 \text{ m/s} + 90 \text{ m/s})}{2}(3.0 \text{ s})$
Solve:	$\vec{d} = \frac{(57.5 \text{ m/s})}{2}(3.0 \text{ s}) = 172.5 \text{ m} = 170 \text{ m}$

Learning Activity 1.13: The Physics of Uniformly Accelerated Motion

1. The four parts of this assignment refer to the following graph:



Answers:

a) Using the equation $\vec{v}_2 - \vec{v}_1 = \vec{a}\Delta t$, determine the acceleration of the object.

$$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{12\text{ m/s} - 4.0\text{ m/s}}{4.0\text{ s}} = +2.0\text{ m/s}^2$$

b) Using the equation $\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$, determine the displacement of the object above.

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t = \frac{1}{2}\left(+4.0\text{ m/s} + (+12.0\text{ m/s})\right)4.0\text{ s} = +32\text{ m}$$

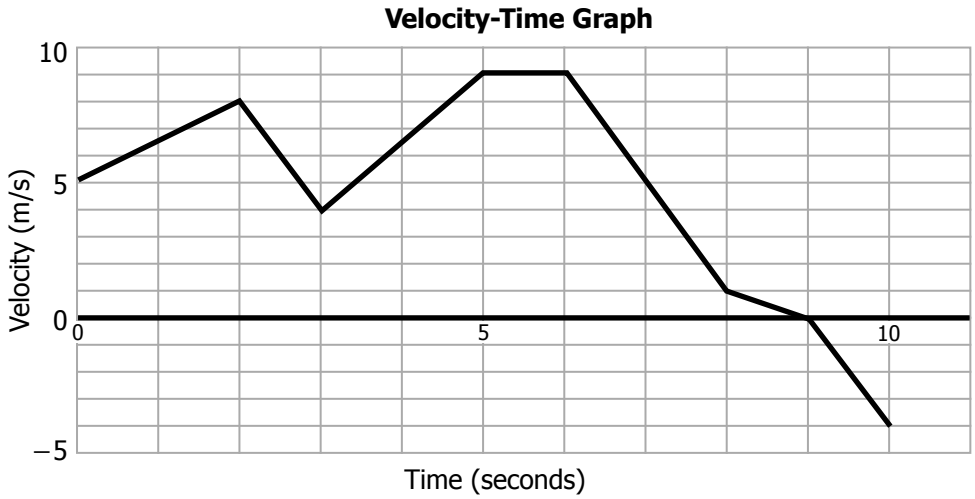
c) Using the equation $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$ verify that the displacement is the value you calculated above.

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2 = (+4.0\text{ m/s})(4.0\text{ s}) + \frac{1}{2}(+2.0\text{ m/s}^2)(4.0\text{ s}) = +32\text{ m}$$

d) Using the equation $v_2^2 = v_1^2 + 2ad$, verify that the displacement is the value you calculated above.

$$d = \frac{v_2^2 - v_1^2}{2a} = \frac{(+12.0\text{ m/s})^2 - (+4.0\text{ m/s})^2}{2(+2.0\text{ m/s}^2)} = +32\text{ m}$$

2. On the following velocity-time graph, indicate during which intervals of time the acceleration is positive, negative, or zero. This graph does not represent a real-life situation. It is presented simply to help reinforce the ideas about interpreting graphs.



Answer:

The equation for acceleration is $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$, which represents the slope of the velocity-time graph.

The slope is positive during the time intervals 0 s–2 s, and 3 s–5 s.

The slope is negative during the time intervals 2 s–3 s, 6 s–8 s, 8 s–9 s, and 9 s–10 s.

The slope is zero during the interval from five seconds to six seconds.

3. For each of the time intervals for the graph in question #2, determine the displacement using one of the equations for kinematics that were derived in this lesson. You should be able to use all four of the kinematics equations that involve displacement at least once each.

Answer:

The area beneath the curve of a velocity-time graph represents the displacement.

The shape of the area for the first interval from zero to two seconds is a trapezoid.

For this interval, we have the following information:

Initial velocity	= 5 m/s
Final velocity	= +8 m/s
Time interval	= 2 s
Acceleration	= +1.5 m/s/s

With all of this information, you have several choices for the equations that you can use to determine the displacement.

This information allows us to use the third kinematics equation $\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$ to find the unknown, the displacement.

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{d} = \frac{1}{2}\left(+5 \text{ m/s} + (+8 \text{ m/s})\right)2 \text{ s} = \frac{1}{2}(+13 \text{ m/s})2 \text{ s} = +13 \text{ m}$$

For the interval from 2 s to 3 s, we have the following information:

Initial velocity	= +8 m/s
Final velocity	= +4 m/s
Time interval	= 1 s
Acceleration	= -4 m/s/s

For this one, let us use the fourth kinematics equation: $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$.

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$\vec{d} = (+8 \text{ m/s})(1 \text{ s}) + \frac{1}{2}(-4 \text{ m/s/s})(1 \text{ s})^2 = +8 \text{ m} + (-2 \text{ m}) = +6 \text{ m}$$

For the interval from 3 s to 5 s, we have the following information:

Initial velocity	= +4 m/s
Final velocity	= +6 m/s
Time interval	= 1 s
Acceleration	= +2.5 m/s/s

Again, this is accelerated motion. Here, you could use kinematics equation 5, $v_2^2 = v_1^2 + 2ad$, to solve for displacement.

Here we can arrange by isolating the displacement. Rearranging equations using variables tends to be easier than rearranging the same equations with numbers in them.

$$d = \frac{v_2^{\,2} - v_1^{\,2}}{2a}$$

$$d = \frac{(+9\text{ m/s})^2 - (+4\text{ m/s})^2}{2(+2.5\text{ m/s/s})} = \frac{81-(+16)}{+5} = +13\text{ m}$$

The next time interval from five to six seconds has an acceleration of 0 m/s/s. On a velocity-time graph, the shape of the area you must find will either be a square or a rectangle.

You could use kinematics equation 3, in which case the initial and final velocity would be equal. You could use kinematics equation 4, in which case the second part of the equation would disappear since the acceleration is 0 m/s/s. You cannot use kinematics equation 5, since you end up dividing by an acceleration of 0 m/s/s, which, of course, is impossible. If the acceleration is 0 m/s/s, your best bet is to use kinematics equation 1.

For the interval from 6 s to 7 s, you have the following information:

Initial velocity	= +9 m/s
Final velocity	= +9 m/s
Time interval	= 1 s
Acceleration	= 0 m/s/s

Here you will solve for the displacement using kinematics equation 1:

$$\bar{v} = \frac{\vec{d}}{\Delta t}.$$

If we rearrange the equation to solve for the displacement, it becomes

$$\vec{d} = \bar{v}\Delta t.$$

$$\vec{d} = (+9\text{ m/s})(1\text{ s}) = +9\text{ m}$$

We hope that by now you have caught on to the idea that because of the variety of kinematics equations, you're able to use more than one to solve a particular problem. Another thing you should realize is that many times you will have options available to you, and you should choose the option that is the simplest to work with.

For the rest of the intervals, you are provided with the answers below. Determine the displacements and check your work.

For the time interval from six to eight seconds, the displacement is +10 m.

For the time interval from eight to nine seconds, the displacement is +0.5 m.

For the time interval from nine to 10 seconds, the displacement is –2 m. Note that this displacement is negative. You'll notice on the graph that this area lies below the horizontal time axis in the negative region of area on this velocity-time graph.

Learning Activity 1.14: Velocity and Acceleration

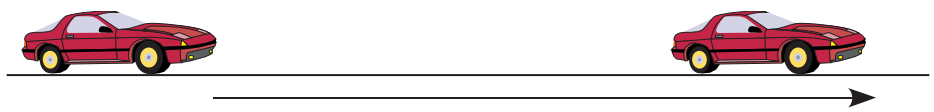
1. A sports car is moving initially at 10.0 m/s. It then undergoes a uniform acceleration of 1.20 m/s^2.

   a) What is the new velocity after a time of 30.0 s?

   Answer:

   Given: In this problem, the positive direction points to the right.

   $\vec{v}_1 = +10.0 \text{ m/s}$ $\quad$ $\vec{a} = +1.20 \text{ m/s}^2$ $\quad$ $\vec{v}_2 = ?$



$\vec{d} = ?$

initial velocity	$\vec{v}_1 = +10.0 \text{ m/s}$
acceleration	$\vec{a} = +1.20 \text{ m/s}^2$
time interval	$\Delta t = 30.0 \text{ s}$
Unknown: final velocity	$\vec{v}_2 = ?$
Equation:	$\Delta\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ rearranged to $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$
Substitute:	$\vec{v}_2 = (+10.0 \text{ m/s}) + (+1.20 \text{ m/s}^2)(30.0 \text{ s})$
Solve:	$\vec{v}_2 = (+10.0 \text{ m/s}) + (+36.0 \text{ m/s}) = +46.0 \text{ m/s}$

The final velocity of the car is 46.0 m/s to the right.

   b) What is the displacement of the car?

   Answer:

Unknown: Displacement	$\vec{d} = ?$
Equation:	Try not to use the final velocity, since it is a value you calculated.
	Therefore, use equation 4: $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$
Substitute:	$\vec{d} = (+10.0 \text{ m/s})(30.0 \text{ s}) + \frac{1}{2}(+1.20 \text{ m/s}^2)(30.0 \text{ s})^2$
	Since the number of significant digits is 3 in each of these steps, we must round each part off to 3 significant digits.

Solve: $\vec{d} = +300\text{ m} + (+540\text{ m}) = +840\text{ m}$

$= 8.40 \times 10^2\text{ m}$

The displacement of the car is +8.40 x 10^2 m to the right.

2. A speedboat has an acceleration of –2.00 m/s^2. The initial velocity of the boat is +16.0 m/s.

   a) What will be the final velocity of the speedboat after 5.00 s?

   Answer:

   Let right be the positive direction. Here, the boat is moving to the right, but the acceleration is negative so it points to the left. This question requires attention to the signs of the quantities.

   Given: Initial velocity $\vec{v}_1 = +16.0\text{ m/s}$

   Acceleration $\vec{a} = -2.00\text{ m/s}^2$

   Time interval $\Delta t = 5.00\text{ s}$

   Unknown: Final velocity $\vec{v}_2 = ?$

   Equation: $\Delta\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ rearranged to $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$

   Substitute: $\vec{v}_2 = (+16.0\text{ m/s}) + (-2.00\text{ m/s}^2)(5.00\text{ s})$

   Solve: $\vec{v}_2 = (+16.0\text{ m/s}) + (-10.0\text{ m/s}) = +6.0\text{ m/s}$

   The final velocity of the car is 6.0 m/s to the right.

   b) What is the displacement of the boat?

   Answer:

   Equation: Try not to use the final velocity, since it is a value you calculated.

   Therefore, use equation 4: $\vec{d} = \vec{v}_1\Delta t + \dfrac{1}{2}\vec{a}\Delta t^2$

   Substitute: $\vec{d} = (+16.0\text{ m/s})(5.00\text{ s}) + \dfrac{1}{2}(-2.00\text{ m/s}^2)(5.00\text{ s})^2$

   Since the number of significant digits is 3 in the first of these steps, round off the first answer to 3 significant digits. There are 3 significant digits in the second step, so we must also round this part off to 3 significant digits.

Solve:

$$\begin{aligned} \vec{d} = & \ +80 \text{ m} \\ + & \ -25.0 \text{ m} \\ \hline & +55.0 \text{ m} \end{aligned}$$

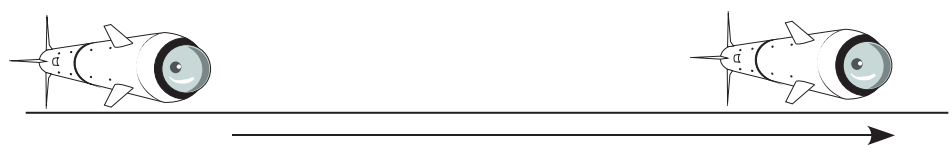
The boat travelled +55.0 m.

3. A spacecraft is initially at rest with respect to a space station when it fires its rockets. These rockets make it accelerate at a rate of 10.0 m/s^2. What is the new velocity of the spacecraft after is has moved a distance of 2.15 x 10^5 m?

Answer:

Given: In this problem, the positive direction points to the right.

$\vec{v}_1 = 0.0 \text{ m/s}$ $\quad$ $\vec{a} = +10.0 \text{ m/s}^2$ $\quad$ $\vec{v}_2 = ?$



$\vec{d} = 2.15 \times 10^5 \text{ m}$

Initial velocity	$\vec{v}_1 = 0.0 \text{ m/s}$
Acceleration	$\vec{a} = +10.0 \text{ m/s}^2$
Displacement	$\vec{d} = 2.15 \times 10^5 \text{ m}$
Unknown: Final velocity	$\vec{v}_2 = ?$

Equation: The equation that relates these four variables together without time would be equation 5:

$$v_2^{\ 2} = v_1^{\ 2} + 2ad.$$

Substitute:

$$v_2^{\ 2} = (0.0 \text{ m/s})^2 + 2(+10.0 \text{ m/s}^2)(2.15x10^5 \text{ m})$$

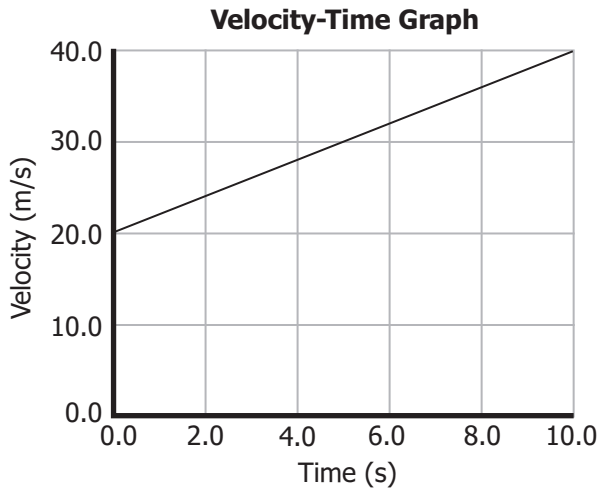
Solve:

$$v_2^{\ 2} = 4.30 \times 10^6 \text{ m}^2/\text{s}^2$$

$$v_2 = \sqrt{4.30 \times 10^6 \text{ m}^2/\text{s}^2} = 2.07 \times 10^3 \text{ m/s}$$

The spacecraft travels 2.07 x 10^3 m/s to the right.

4. The following graph shows a car changing in velocity over time.



Determine the displacement of the car.

Answer:

Given: From the graph, you have the following:

Given: Initial velocity $\vec{v}_1 = +20.0 \text{ m/s}$

Final velocity $\vec{v}_2 = +40.0 \text{ m/s}$

Time interval $\Delta t = 10.0 \text{ s}$

Unknown: Displacement $\vec{d} = ?$

Equation: $\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$

Substitute: $\vec{d} = \left(\frac{(+20.0 \text{ m/s}) + (+40.0 \text{ m/s})}{2}\right)10.0 \text{ s}$

Solve: $\vec{d} = (+30.0 \text{ m/s})(10.0 \text{ s}) = +300 \text{ m}$

$= +3.00 \times 10^2 \text{ m}$

The displacement of the car is $+3.00 \times 10^2$ m.

NOTES

Topic 1 - Audio/Videos

Multimedia Physics Studio - A collection of animations on all physics topics.
Physics at Internet4Classrooms
Relative Motion - A simulation of relative motion.

Module 1

1. The Scientific Method, Theories, Laws, and Models
2. Experiments and Variables
3. Significant Figures Made Easy!
4. Introduction to Physics - Lesson 9 - Using Sig Figs
5. High School Physics: Vectors and Scalars
6. Describing Motion
7. Position Distance & Displacement - Average Speed & Velocity Word Problems & Graphs - Physics
8. Understanding and Walking Position as a function of Time Graphs
9. Position vs. time graphs | One-dimensional motion | Physics | Khan Academy
10. Position vs. Time Graph: Constant Velocity
11. Match That Graph
    a. Click on the link Launch Concept Builder. Follow the instructions to load the program.Start with the Apprentice Level questions. For more challenging questions move on to the Master Level and the Wizard Level. This interactive concept builder requires the student to match position-time and velocity-time graphs. If you make an error click on the Help Me button to receive some helpful explanations and hints which will help you understand the concepts.
12. Velocity vs. Time Graph: Part 1
13. Walking Position, Velocity and Acceleration as a Function of Time Graphs
14. Velocity Time Graphs
15. Motion with Constant Acceleration
    a. In this animation you set the initial velocity and the acceleration. Then the animation draws in real time the graph of position-time, velocity-time and acceleration time one beneath the other.

       For non-accelerated motion with constant velocity use the following settings.
       Press RESET.
       Initial Position = 0 m; Velocity = 2.00 m/s; Acceleration = 0.00 m/s/s
       Press Reset
       Initial Position = 25 m; Velocity = -2.00 m/s; Acceleration = 0.00 m/s/s
       For accelerated motion (non-constant velocity) use the following setting.
       Initial Position = 0 m; Velocity = 2.00 m/s; Acceleration = 2.00 m/s/s
       Press Reset
       Initial Position = 25 m; Velocity = -2.00 m/s; Acceleration = -1.00 m/s/s

Press Reset
Initial Position = 10 m; Velocity = +2.00 m/s; Acceleration = -1.00 m/s/s

16. Graphing the Drop of a Ball from 2.0 Meters - An Introductory Free-Fall Acceleration Problem
17. Grade 11 Physics Track 1 Mod A1.2 Kinematics
18. Velocity Time Graphs Part 4 Area Kinematics Physics Tutorial
19. Velocity time graph area under curve is displacement
20. Acceleration Time Graphs Area Kinematics Physics Tutorial
21. Graphing Summary Kinematics High School & College Physics Tutorial
22. Physics - Analysing Motion Graphs
23. Introduction to Uniformly Accelerated Motion with Examples of Objects in UAM
24. Kinematics 6: Uniform Accelerated Motion
25. Constant Velocity compared to Constant Acceleration
26. Position vs. Time Graph: Constant Velocity and Acceleration
27. A Basic Acceleration Example Problem and Understanding Acceleration Direction
28. Relating the Motion of an Object to the Sign of the Acceleration (II)
29. Uniformly Accelerated Motion Examples
30. High School Physics: Kinematic Equations
31. 1D KINEMATIC MOTION PRACTICE - Acceleration Example Problem

Grade 11 Physics (30S)

Module 2: Vectors

This module contains the following

- Introduction to Module 2
- Lesson 1: An Introduction to Vectors
- Lesson 2: Resolving Vectors
- Lesson 3: Adding and Subtracting Vectors
- Lesson 4: A Vector Journey
- Module 2 Summary

Module 2: Vectors

Introduction to Module 2

Welcome to Module 2. The purpose of this module is to develop the skills necessary for working with quantities that are vectors. In physics, it is very important to distinguish between vector quantities and scalar quantities. It turns out that when working with scalars, 2 + 2 is *always* equal to 4. However, when working with vectors, 2 + 2 is *sometimes* equal to 4. We may also find that 2 + 2 = 3 or 2 + 2 = 2 or 2 +2 = 1 or 2 + 2 = 0.

- **Lesson 1: An Introduction to Vectors** describes what constitutes a vector and how to draw a vector on a scale diagram, and introduces some basic vector algebra.
- **Lesson 2: Resolving Vectors** describes how to resolve a vector into its components.
- **Lesson 3: Adding and Subtracting Vectors** provides a method of adding and subtracting vectors by using a scale diagram or by using the component method.
- **Lesson 4: A Vector Journey** provides an opportunity to employ the skills learned throughout the module.

Assignments in Module 2

When you have completed the assignments for Module 2, submit your completed assignments to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 2.1, Part A	Drawing Vectors
2	Assignment 2.1, Part B	Sketching Vectors
3	Assignment 2.1, Part C	Adding Vectors
4	Assignment 2.2	Vector Journey

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Lesson 1: An Introduction to Vectors (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ differentiate between quantities that are scalars and those that are vectors
- ❑ draw a vector to scale on a vector diagram
- ❑ calculate the product of a vector and a scalar
- ❑ calculate the quotient of a vector and a scalar

Key Words

vector	scalar
distance	displacement

Introduction

While some of this work about vectors and scalars will be review, this lesson will take you beyond the rudimentary work you have done to date. You will learn how to represent vectors on a diagram. You will be surprised to discover that you can combine a vector and a scalar using multiplication and division.

Vectors and Scalars

In one way or another, everybody must work with numbers. You likely think you have a pretty good grasp of what a number is, but numbers are more complicated than what people typically consider them to be.

The typical conception of numbers (i.e., "normal" numbers) are called **scalars**. These numbers tell only one thing, and that is "how much." Another way of saying "how much" is **magnitude**.

Scalar numbers, then, tell only **magnitude** or **size**.

Scalar numbers, however, are not the only type of number. Another type of number that is very important (especially in applications such as physics) is called a **vector**. Vector numbers are not all that different from scalar numbers: vectors tell magnitude (just like scalars), but they also do more. They have a second part, which is **direction**.

Vector numbers have both a **magnitude** and a **direction.**

An example of a vector would be "3 to the right." Think of "3 to the right" as one single number: a vector. Do not think of it as "a number … and also a direction" even though it has these two parts.

Our Primordial Vector—Displacement

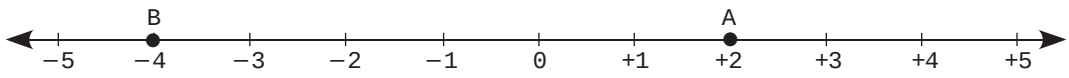
Our introduction to vectors will consider the vectors associated with motion. In particular, we will consider displacement, which is our primordial or most basic vector. Any other quantities that are specified by magnitude and direction, like displacement, must also be vector quantities.

In order to talk about motion, we must be able to indicate where an object is located. An object moves when it changes its location.

The **reference point** is the zero location in a coordinate system or frame of reference.

Position is the location of an object in relation to the location of a specific point called the reference point.

In straight-line kinematics, we are dealing only with motion along a straight line. A classic example would be the number line, where each integer is marked on the line relative to the position of 0, the **reference point**. Numbers to the right of zero are considered to be positive numbers and numbers to the left are considered to be negative numbers. In the same way, we can mark positions along a line.



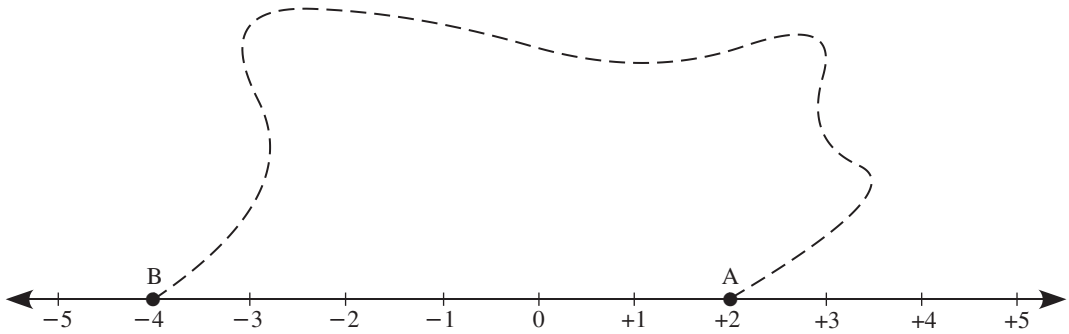
The reference point is zero, which we mark as 0 m.

The point A is located at a position of +2 m—that is, 2 m to the right of the reference point. Normally, we consider motion to the right or up to be positive. In a given question, you should specify the directions for the motions.

The point B is located at a position of –4 m—that is, 4 m to the left of the reference point. Again, we consider motion to the left or down to be negative.

The points A and B represent two positions. A represents position 1 (pos_1) and B represents position 2 (pos_2). If the object moved from position A over to position B, then position A is called the **initial position** (pos_1) and position B is called the **final position** (pos_2).

Let's say an ant was to walk from position A to position B. Ants are not likely to walk in a straight line but rather to wander. A possible path is indicated below with the dashed line.



Along the path indicated by the dashed line, the ant travels a distance of 15 m during a time of 45 seconds.

Distance (*d*) is the length of path travelled by an object. It has no direction and is therefore a **scalar** quantity.

Displacement ($\vec{d}$) is the vector quantity that points between the initial position and the final position of an object in a particular frame of reference.

Displacement represents the change in position—that is, the final position minus the initial position. The symbol for displacement is $\vec{d}$. Displacement represents not only how far the object has travelled but also which direction. Both of these must be specified—that is, magnitude and direction—for displacement. Therefore, displacement is a **vector** quantity.

Again, a **magnitude** and a **direction** must be identified for displacement to be completely specified. Displacement is the first vector that you meet and is called the primordial vector. All other vectors are like the displacement vector.

Displacement represents the change in position of an object. Displacement is calculated by subtracting as follows: final position – initial position.

$$\vec{d} = \text{pos}_2 - \text{pos}_1$$

Quantity	Symbol	Unit
Initial position	pos_1	metres (m)
Final position	pos_2	metres (m)
Displacement	$\vec{d}$	metres (m)

Displacement is a *vector* quantity.

The ant's initial position was +2 m and its final position was –4 m.

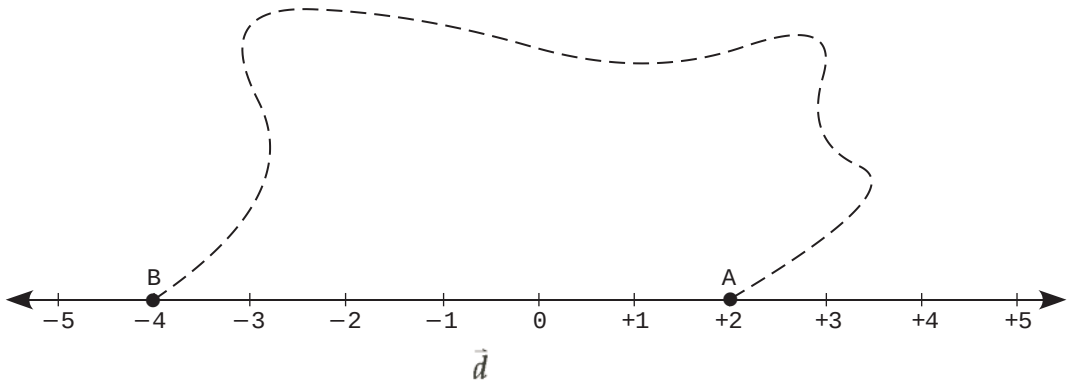
$$\text{pos}_1 = +2 \text{ m}$$
$$\text{pos}_2 = -4 \text{ m}$$

displacement = $\text{pos}_2 - \text{pos}_1$

$$\vec{d}_{\text{tot}} = \text{pos}_2 - \text{pos}_1$$
$$\vec{d}_{\text{tot}} = -4 \text{ m} - (+2 \text{ m}) = -6 \text{ m}$$

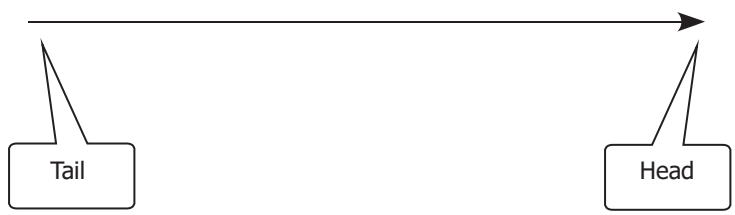
The displacement of the ant is –6 m or 6 m to left.

The displacement vector $\vec{d}$ is 6 m long and points to the left.



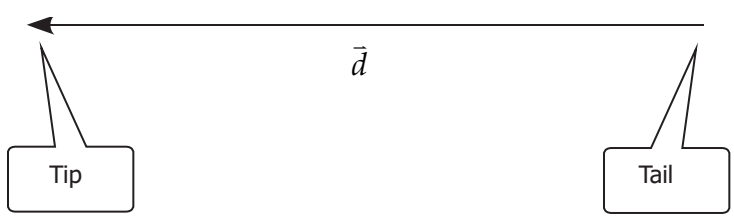
Drawing Vectors

A **vector on a diagram** is represented by a **directed line segment**.



A directed line segment is just an arrow. A drawn arrow has two ends to it. We refer to these two ends as the **tip** (with the arrowhead) and the **tail** (the other end). The direction of the vector is given by the direction in which the tip of the vector points.

Vectors are represented using a **directed line segment (an arrow)**.



The **length** of the vector represents the **magnitude** of the quantity. The arrow points in the direction of the vector.

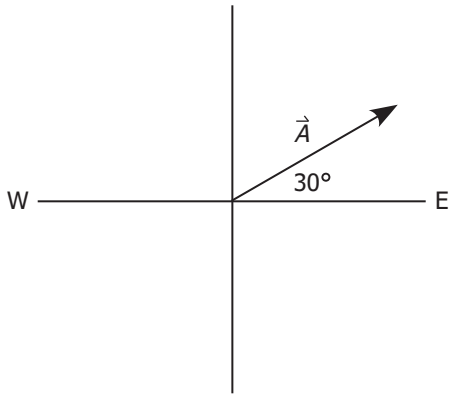
A displacement vector $\vec{d}$ is drawn in the diagram above.

The direction the vector points is typically described like compass points: north, south, east, and west.

Vectors that don't point in one of these four directions have their direction indicated by an angle (in degrees) and a description of where that angle is found in this format: [Degree–Direction–Direction].

The second direction represents the axis from which you start to measure the angle. You then rotate in the direction of the first direction to sweep out the angle.

The arrowhead points in the direction of the vector. The direction of the vector, however, is **measured at the tail of the vector**. When drawing a vector, we always mark the direction at the tail of the vector between the vector and one of the axes of our coordinate system, as indicated in the diagram below.



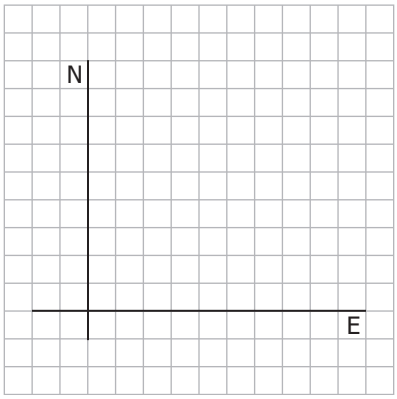
The vector being represented is the vector $\vec{A}$. Let's say that $\vec{A}$ represents a displacement of 10 m [30° north of east].

Procedural Step

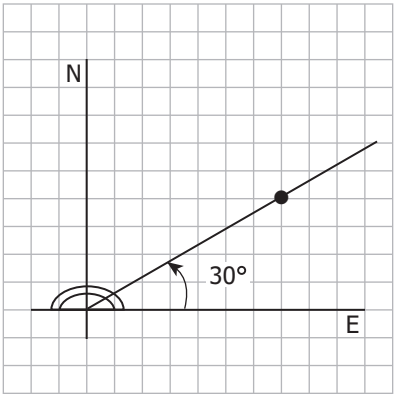
Establish a coordinate system and choose a scale. In this case, an appropriate scale would be 1.0 cm = 2.0 m.

The length of the vector arrow should then be 5.0 cm.

Diagram



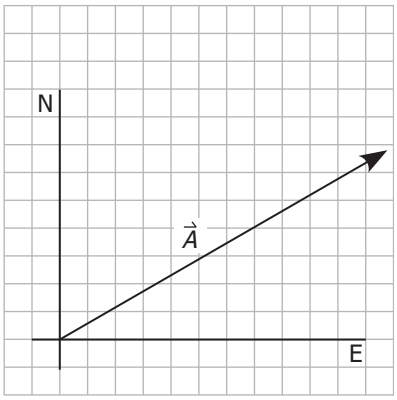
You would want to place the tail of the vector at the origin.



To draw the vector pointing in the correct direction, you must measure the angle at the foot of the vector and mark it on the diagram. Place the crosshairs of a protractor at the origin and, starting from east, measure an angle going 30° north. Place a mark on your paper to indicate this direction.

Note: North of East means you started at East (second direction), then went North (first direction).

Finally, draw in the vector arrow 5.0 cm long, starting at the origin out towards the mark indicating 30° north of east. Be sure to place an arrowhead at the head of the vector. Label the vector.



$\vec{A}$ = 10 m [30° north of east]

As discussed earlier in Module 1, there are many types of quantities that are vector quantities, such as velocity, acceleration, force, and weight. We will be working with all of these quantities.

In addition, be sure that you specify all the information about the vector when giving a vector quantity.

> When written, vector quantities should have the following: magnitude, unit, and a direction.

A **displacement**, $\vec{A}$, is given by 10 m [30° north of east].

The quantity 10 m represents **distance**, a scalar.

Learning Activity 2.1

Vectors and Scalars

Once you have completed the questions, check your answer against the answer key provided at the end of this module.

1. Identify the following quantities and state whether they are vectors or scalars.

	Quantity	Vector/Scalar
22 m		
1.35 m/s [E]		
62 N [N]		
35 s		
18 cm/s^2		

2. Draw the following vectors. Indicate the scale that is used.

   a) $\vec{A}$ = 45 m [W]

   b) $\vec{B}$ = 350 cm/s [22° S of E]

   c) $\vec{C}$ = 6000 N [40° N of W]

Working with Vectors

Now that you know how to draw a vector on a vector diagram, let's examine some of the mathematics of vectors.

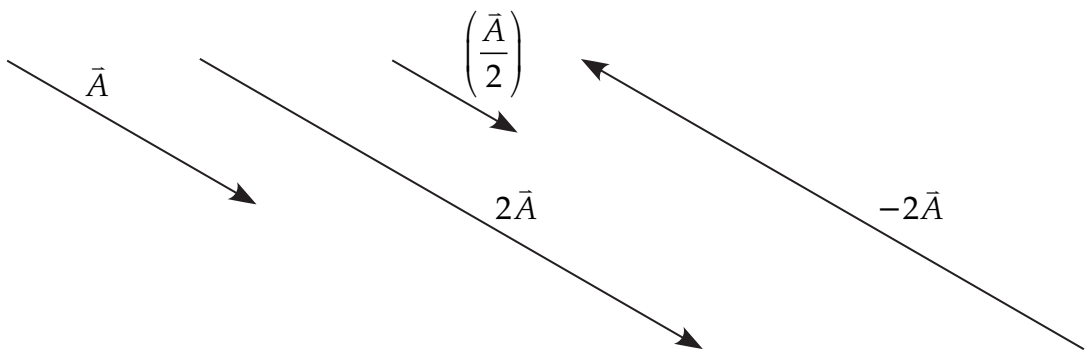
To begin, let's consider how vectors and scalars can be combined.

You know from basic algebra that you can only add apples to apples and oranges to oranges. Since vectors and scalars are different kinds of numbers, we cannot add these together, but we can multiply a vector by a scalar or divide a vector by a scalar. In fact, you have already performed these operations.

Multiplying a Vector by a Scalar

Let's say we have a vector $\vec{A}$ = 30 m [25° S of E].

If we multiply the vector $\vec{A}$ by 2, a scalar, the answer is $2\vec{A}$. Multiplying the vector by two will double its size but not change its direction.



Suppose we divided the vector $\vec{A}$ by two $\left(\frac{\vec{A}}{2}\right)$. Dividing the vector by two will halve the size but not change its direction.

Multiplying the vector $\vec{A}$ by $-2\left(-2\vec{A}\right)$ will again double the size of the vector. The negative sign will affect the direction. It will cause of the product to point in the **opposite** direction.

Suppose the scalar has units.

If $\vec{B}$ = 22 m/s [17° N of E] and we multiply by 5.0 s, then we must consider what happened to the size, units, and direction for the product.

Multiplying 22 x 5.0 is 110. This is the size of the product.

Multiplying m/s by s gives m. The multiplication in this case has changed a velocity into a displacement.

Finally, since the time is a positive value, the direction of the product will remain the same as the direction of $\vec{B}$.

Let's call the product $\vec{C}$ = 110 m [17° N of E].

Scale: 1 cm = 5 m/s

$\vec{B}$ = 22 m/s [17° N of E]

This is a **velocity** vector drawn on a velocity diagram.

Scale: 1 cm = 20 m

$\vec{C}$ = 110 m [17° N of E]

This is a **displacement** vector. This vector is drawn on a displacement diagram using a different scale.

In the previous module, you multiplied velocity by the time interval to give displacement, using this equation: $\vec{v}\Delta t = \vec{d}$.

In a similar way, you can divide a vector by a scalar to give a different quantity.

Using $\vec{v} = \dfrac{\vec{d}}{\Delta t}$, you divide the vector, displacement, by the scalar, time interval, to get the new vector quantity, velocity.

Learning Activity 2.2

Drawing Vectors

1. Perform the operation and identify the quantity that results for each of the following:

	Answer	Quantity
a) (2 m/s^2 [N])(4 s)		
b) 3(9.0 m [SW])		
c) –5(3.2 m/s [E])		
d) –½(42 cm [30° W of N])		
e) (5.6 cm/s [30° W of N])(8.2 s)		
f) (16.2 m [12° E of S]) / (5.3 s)		

2. Given that $\vec{A}$ = 48 m/s [16° N of W], draw the vector and write out the procedural steps. You need only draw one diagram and include all of the work on it.

Lesson Summary

Scalar numbers tell only **magnitude**, or **size**.

Vector numbers have both a **magnitude** and a **direction**.

Any other quantities that are specified by magnitude and direction must also be vector quantities like our **primordial vector**, displacement.

A **vector on a diagram** is represented by a **directed line segment**.

We refer to these two ends as the **tip** (with the arrowhead) and the **tail** (the other end). The direction of the vector is given by the direction in which the tip of the vector points.

Directions are generally given in the form "degree–direction–direction." Start all measurements of angles from the second direction, and then rotate towards the first direction to sweep out the angle.

Steps for the procedure in drawing a vector:

1. Draw a coordinate system and choose a scale. The scale should be such that any vectors drawn should be at least 5 cm in size. Determine the length of the vector arrow according to this scale.
2. Draw in the tail of the vector at the origin of the coordinate system. Use your protractor with its crosshairs at the origin to measure the angle from one of the major directions. Mark this angle on the paper.
3. Draw a line segment of appropriate length from the origin in the direction that was measured in step 2. Place an arrowhead on the line segment. Label the vector.

Multiplying a vector by a scalar without units results in a product which is the same type of quantity but has a different size and the same or opposite direction.

Multiplying the vector by a scalar with units results in a product that is another type of quantity. Generally, the products have a different size but are usually in the same direction.

Assignment 2.1, Part A

Drawing Vectors (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 2, after you have completed Module 2.

Given that $\vec{A}$ = 620 m/s [42° S of W], draw the vector and write out the procedural steps.

You need only draw one diagram and include all of the work on it.

(continued)

Assignment 2.1, Part A: Drawing Vectors (continued)

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining a scale and correct length of the vector according to the scale
- 1 mark for each of the other two steps of the procedure
- 2 marks for drawing and labelling the vector correctly

Lesson 2: Resolving Vectors (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the components of a vector
- ❑ list the properties of vector components
- ❑ determine the components of a given vector

Key Words

vector	components	trigonometry
sine	cosine	tangent
opposite side	adjacent side	hypotenuse

Introduction

In this lesson, we will study more of the properties of vectors. You will start with any given vector and break it apart into smaller vectors, called components. This is an important skill that will prepare you for the task of adding or subtracting vectors.

Vector Components

Most of you probably possess a stereo system. If you start with a complete stereo system and break it apart, the individual parts are called the components. The parts may include items such as the receiver, the CD player, and the speakers. After being taken apart, these parts can be put back together to produce the complete stereo system once more.

There are two processes involved here. One process involves starting with the parts and producing the whole. You can think of this as addition. The second process involves starting with the whole and breaking it into the parts.

Let's put these ideas into use with vectors.

Surprisingly, the opposite of adding vectors is not subtracting vectors. Adding vectors is the process of combining two vectors into one.

> **Resolving** is the process of taking one vector and "breaking it" into two. Each of the "vector fragments" is called a **component** of the original vector.

The main reason why this will need to be done is that we often prefer vectors that point in convenient directions, such as north, east, south, and west. Vectors that do not point in a convenient direction can be made into a pair of vectors (the components)—each of these vectors pointing in one of the preferred directions.

Properties of Vector Components

Vector components have the following properties. By the end of this module, we will have used all of these properties of vector components.

1. On a plane, each vector has two components, and each one points along one of the major axes on our coordinate system. Therefore, the components of a vector are always perpendicular to each other.
2. If we add the two components of a given vector together, the sum will be a given vector.
3. The components of a vector are independent of each other. In other words, what happens to one component of a vector has no effect on what happens to the other component of the vector.

Frames of Reference

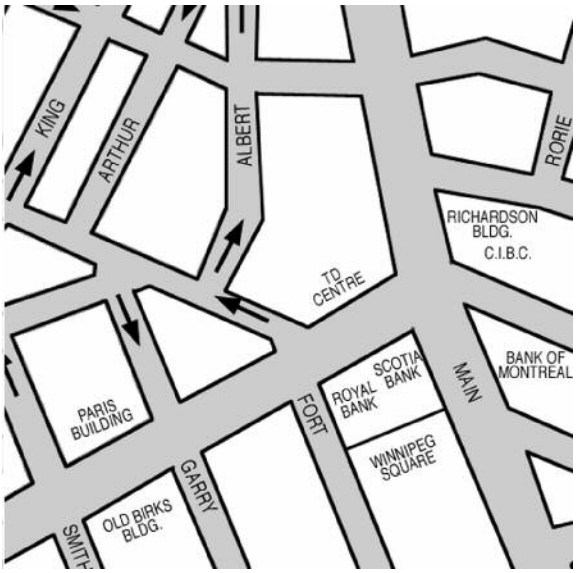
You can think of a **frame of reference** as a **point of view**. From your point of view, a situation will appear in a certain way, and this appearance may be different from another person's point of view. For example, if you are seated at a table reading a book, the print should appear right-side up as you read from left to right across the page. To a person seated on the opposite side of the table, the print on the page would be upside down and it would appear to him that you are reading from his right to his left. So in order for us to communicate clearly, we must always specify our frame of reference.

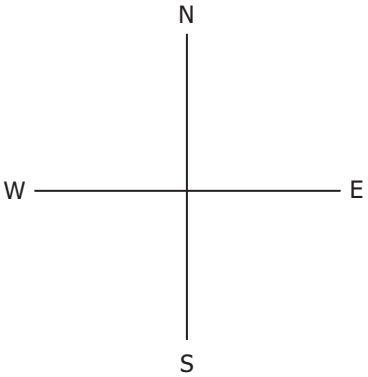
One frame of reference may be a line (one dimension). We have already discussed the number line as a good frame of reference.

More often, we have to describe events as they occur on a plane. A plane is just a flat surface, like a piece of paper lying on a table or desk. A plane has two dimensions: length and width.

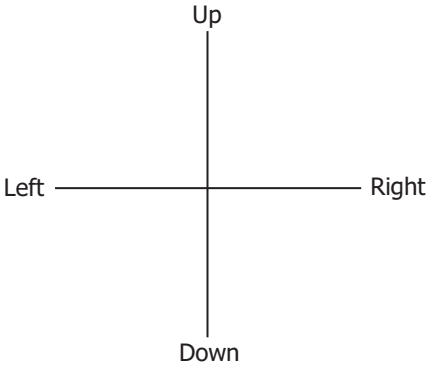
If we are describing motion and we want to include directions in two dimensions, we can use the major directions of north, south, east, and west. In this case, our frame of reference is a surface that lies in the horizontal plane, like a map on a level, **horizontal table**. We look at this map from above.

Below is a map of downtown Winnipeg.

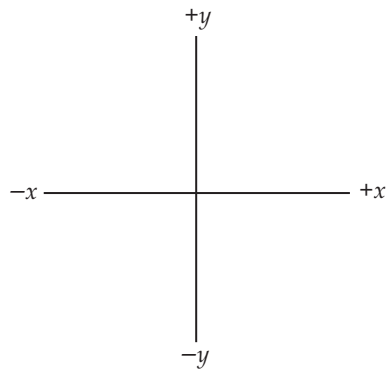




Another common point of view involves observing a **plane that lies in the vertical direction**, much like looking at a whiteboard or blackboard in a classroom, in which case you would be looking at the plane from the side. What you observe on this plane is that objects move left or right or they move up or down. So this frame of reference appears as follows:



The frame of reference that you should be familiar with from mathematics is, of course, the **Cartesian coordinate system** (the x–y frame). The nice thing about this frame of reference is that you can use it as though it is in the horizontal plane (lying on a horizontal desk) or in the vertical plane (on a blackboard). As long as you give your point of view (indicate how you are looking at this plane), the descriptions of motion on the plane should be understood by everyone.



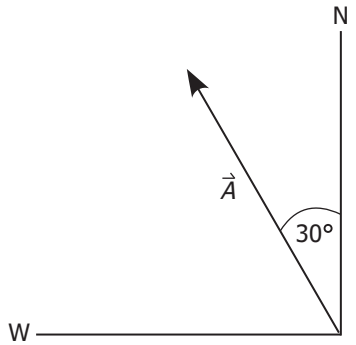
Now, the frame of reference you choose is up to you. Normally, try to choose a frame that will provide the simplest descriptions of the given situation.

Resolving a Vector

To resolve a vector, simply consider the vector to be the hypotenuse of a soon-to-be-drawn right triangle, which has one leg that is horizontal (the "x-component"), and one that is vertical (the "y-component"). By knowing the size of the original vector and the direction it is pointing, the sizes of the components can be found with trigonometry.

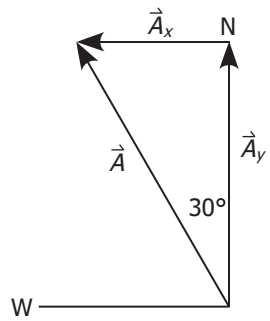
Example:

Resolve the vector $\vec{A}$ = 10.0 m [30.0° W of N].



The vector is drawn here. Notice that the vector slants between north and west, which means that it has a component in each of these directions. It is usually easiest to build the right triangle around the given angle—30° in this case.

The components have now been drawn in. Since the original vector was labelled $\vec{A}$, the components have been labelled $\vec{A}_x$ and $\vec{A}_y$.



The size of the components can now be found. Note that this will always involve using sine and cosine, but which component is found with cosine and which with sine can change. Remember that the length of the hypotenuse is known to be 10.0 m.

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{A}_x}{\vec{A}}$$

$$\sin 30.0° = \frac{\vec{A}_x}{10.0\text{ m}}$$

which means (solving for $\vec{A}_x$)

$\vec{A}_x$ = (10.0 m) sin (30.0°) so

$\vec{A}_x$ = 5.00 m [W]

Similarly, we can find the vertical or y-component, using cosine.

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{A}_y}{\vec{A}}$$

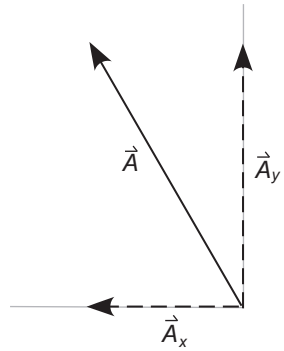
$$\cos 30.0° = \frac{\vec{A}_y}{10.0\text{ m}}$$

which means (solving for $\vec{A}_y$)

$\vec{A}_y$ = (10.0 m)(cos 30.0°) so

$\vec{A}_y$ = 8.66 m [N]

You will find that the two components are perpendicular to each other and point along the major axes.



Notice that we used the subscripts X and Y to differentiate the components. Generally, we can refer to the **horizontal component** as the ***x*-component** and the **vertical component** as the ***y*-component**.

If you used the Cartesian coordinate system for your drawing, then remember that up and right are **positive** and down and left are **negative**.

You can assign the signs (+ or –) to indicate direction for the components.

Note: If you need to refresh your knowledge of trigonometry, please check out the Module 1 Appendix.

Vectors with Zero Components and Vectors that are Equal

It is possible for vectors to have one of the components equal to zero. In the case of a vector that is vertical, there is no *x*-component. In this case, the *y*-component of the vector is itself equal to the whole vector.

Vector equivalent to 1.0 N north
y-component of vector is +1.0 N
x-component of vector is 0.0 N

For a vector that is pointing in a horizontal direction, there is no *y*-component. The *x*-component of the vector is itself equal to the whole vector.

Vector equivalent to 1.0 N west
y-component of vector is 0.0 N
x-component of vector is –1.0 N

For a vector to be zero, both the *x*-component and the *y*-component of a vector must be zero. So if a vector $\vec{A} = 0$, then $\vec{A}_x = 0$ and $\vec{A}_y = 0$. This may seem trivial, but in later studies we will find that the sum of the forces acting on an object may be zero, so there is no net force. The object is said to be at equilibrium.

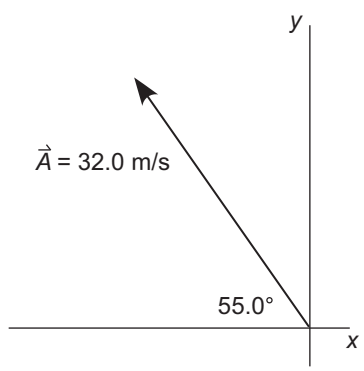
For two vectors to be **equal**, they must have the same **magnitude** and **direction**. Two vectors $\vec{A}$ and $\vec{B}$ are equal only if the components of the vector are also equal—that is, $\vec{A}_x = \vec{B}_x$ and $\vec{A}_y = \vec{B}_y$.

Learning Activity 2.3

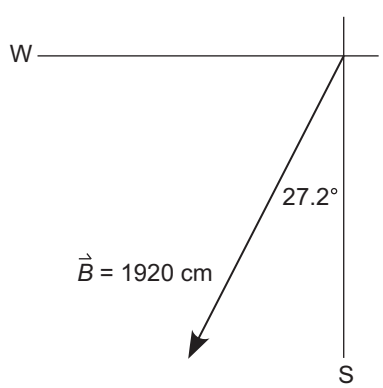
Calculating the Components of Vectors

1. Calculate the components of the following vectors:

a)



b)



(continued)

Learning Activity 2.3: Calculating the Components of Vectors (continued)

2. Calculate the components of the following vectors. Sketch the vector with its tail at the origin. This sketch does not have to be to scale but should be a reasonable facsimile of the vector.

   a) $\vec{M}$ = 21.2 m/s [16.3° S of E]

   b) $\vec{N}$ = 49500 mm/s^2 [61.5° E of N]

Lesson Summary

Resolving vectors means to find their components.

Components of vectors have the following properties:

1. On a plane, each vector has two components, and each one points along one of the major axes on our coordinate system. Therefore, the components of a vector are always perpendicular to each other.
2. If we add the two components of a given vector together, the sum will be a given vector.
3. The components of a vector are independent of each other. In other words, what happens to one component of a vector has no effect on what happens to the other component of the vector.

To resolve a vector into its components, use the following steps:

1. Draw a coordinate system and draw the vector with its tail at the origin. Be sure to mark in the given angle.
2. Draw a right triangle, making the given vector the hypotenuse. Draw in the two legs, one parallel to one major axis and the other parallel to the other major axis, so as to enclose the given angle.
3. Use trigonometry to determine the size of the components of the given vector.

Assignment 2.1, Part B

Sketching Vectors (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 2, after you have completed Module 2.

Given that $\vec{A}$ = 625 m/s [48.0° S of W], sketch the vector and its components and label them. Include directions with your answers.

(continued)

Assignment 2.1, Part B: Sketching Vectors (continued)

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 2 marks for making a reasonable sketch and labelling the angle, the vector, and its components
- 1 mark for choosing the correct trigonometric functions for determining the components
- 2 marks for showing the work and correctly determining the components

Lesson 3: Adding and Subtracting Vectors (3 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ add and subtract vectors that are on the same line or at right angles to each other
- ❑ add vectors using a scale diagram
- ❑ subtract vectors using a scale diagram
- ❑ add vectors using the component method
- ❑ subtract vectors using the component method

Key Words

vector	scalar	distance
displacement	vector addition	vector subtraction
tip-to-tail method	resultant	graphical method

Introduction

In the first lesson of this module, we investigated some of the mathematics involving operations with vectors and scalars. You saw that you could multiply a vector by a scalar or divide a vector by a scalar, but that in basic algebra you can only add like terms together. Applying this idea to physics, you can only add like "quantities" together. Usually, you check out the units and add a quantity with a unit of m/s to another quantity with a unit of m/s, so this lesson is about adding "like vectors" together.

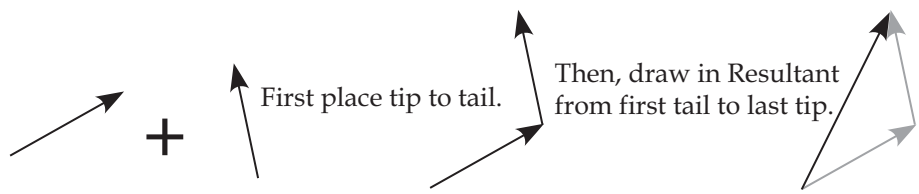
Vector Addition

When you add two numbers together, you call the answer the "sum." For vectors, we may call the answer to an addition problem "the sum," but we instead often refer to it as the **resultant** $(\vec{R})$.

> The **resultant vector** is the vector representing the sum of two or more vectors.

Adding Vectors Graphically

One method for adding vectors is called the **graphical technique**. In the graphical technique, you draw the vectors carefully with a ruler, to scale, and place them "tip to tail." The resultant can then be found by drawing in a new arrow that starts at the tail of the first vector, and extends straight out to the tip of the last arrow, as shown below. Notice that relocating a vector does not change the vector as long as the size and orientation are not changed.

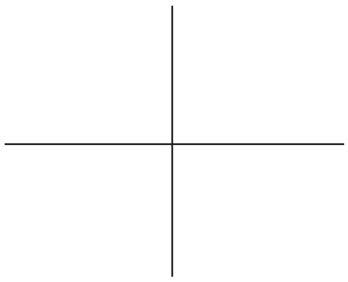
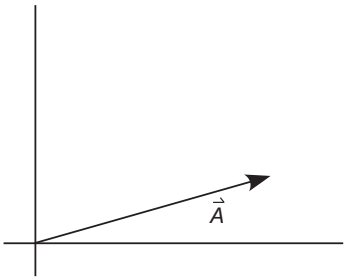
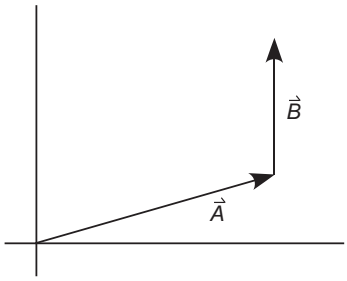
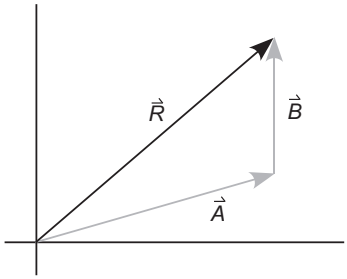
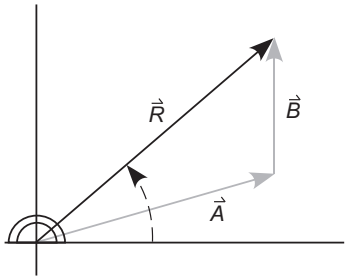


The newly drawn resultant could then be measured with a ruler and its direction determined with a protractor. This technique is limited by the exactness of the drawing and measurements.

A more-detailed procedure for adding vectors graphically (using a scale diagram) is given below. The problem we are solving is:

Find the sum of $\vec{A}$ and $\vec{B}$.

Expressing this mathematically gives: $\vec{A} + \vec{B} = \vec{R}$

Procedural Step	Graph or Diagram
Establish a coordinate system and choose the scale. Determine the length of each given vector according to the scale.	
Place the first vector ($\vec{A}$) in the coordinate system. Place the foot of the sector at the origin.	
Place the **tail** of the second vector ($\vec{B}$) at the tip of the first vector. This is where the name "tip-to-tail" originates.	
Draw a vector from the tail of the first vector ($\vec{A}$) to the tip of the second vector ($\vec{B}$). This is the resultant. Label it "$\vec{R}$."	
With a ruler, measure the length of the resultant ($\vec{R}$). Convert this length to the magnitude of the resultant using the scale. With a protractor, placed with its crosshairs at the origin, measure the angle between the resultant vector and the horizontal axis.	

Once you have the size and direction of the resultant vector, make a statement to conclude the question. **Be sure to include the direction with your vector answer.**

Adding Vectors in One-Dimension–Adding Parallel Vectors

You may realize that it is not necessary to go through the steps of carefully drawing out vectors to be added. Instead, vectors may be added mathematically.

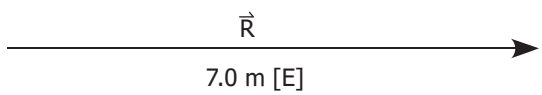
Parallel vectors are the simplest. They are more than one vector that all point in exactly the same direction. When these kinds of vectors are to be added, the resultant will simply be the length of the two vectors combined, and will be pointing in the same direction. This can be seen in the following example:

Example 1: Adding Parallel Vectors

Add the vectors $\vec{A} = 3.0$ m [E] and $\vec{B} = 4.0$ m [E].

Rather than carefully drawing them, consider a rough sketch of the vectors placed tip-to-tail:

The resultant is the new vector found from the tail of the first vector and ending at the tip of the last vector. Clearly, this will be the vector that is 7.0 m [E].



This means that the question can now be answered as

$$\vec{A} + \vec{B} = \vec{R}$$

$$\vec{R} = 3.0 \text{ m [E]} + 4.0 \text{ m [E]} = 7.0 \text{ m [E]}$$

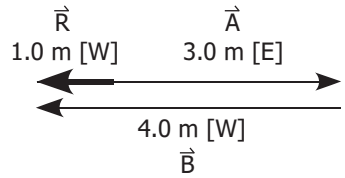
Adding Antiparallel Vectors

Antiparallel vectors are vectors that point in exactly opposite directions.

Again, rather than carefully drawing them, it should be clear from a rough sketch that the resultant will now be the difference (subtract!) between the two, and will point in the direction of the larger vector.

Example 2: Adding Antiparallel Vectors

Add the vectors $\vec{A} = 3.0$ m [E] and $\vec{B} = 4.0$ [W].



This means that the question can now be answered as

$$\vec{A} + \vec{B} = \vec{R}$$
$$\vec{R} = 3.0 \text{ m [E]} + 4.0 \text{ m [W]} = 1.0 \text{ [W]}$$

Learning Activity 2.4

Adding Vectors: Part 1

1. Add the following vectors:

   a) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [W]

   b) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [E]

   c) $\vec{A}$ = 18.3 m/s [N] and $\vec{B}$ = 3.6 m/s [N]

   d) $\vec{A}$ = 5.6 m/s^2 [N] and $\vec{B}$ = 6.8 m/s^2 [S]

2. In airports, there are moving sidewalks. Suppose that a particular sidewalk's surface is moving at 2.0 m/s [N]. What would your velocity be, relative to the floor beside the sidewalk, if you were standing on the sidewalk and

   a) not walking?

   b) walking at 1.5 m/s [N]?

   c) walking at 2.0 m/s [S]?

Adding Vectors in Two Dimensions Using the Graphical Method (Scale Diagram)

Adding Perpendicular Vectors

It requires a bit more work to add vectors that do not point along the same line. Essentially, we will be following the "tip-to-tail" method, as was outlined earlier. We will be limiting our work to adding vectors that are perpendicular to each other.

Example 3: Adding Perpendicular Vectors Graphically

Your friend lives two blocks to the south and three blocks to the east of your house. When you walk to your friend's home, you travel 125 m [S] and then 245 m [E]. What is the displacement from your home to your friend's home?

Given: You're given two displacements in this problem:

Displacement 1	$\vec{d}_1 = 125 \text{ m [S]}$
Displacement 2	$\vec{d}_2 = 245 \text{ m [E]}$
Unknown: Total displacement	$\vec{d}_{\text{total}} =$
Equation:	The total displacement is just the sum of the separate displacements. $\vec{d}_{\text{total}} = \vec{d}_1 + \vec{d}_2$
Substitute:	$\vec{d}_{\text{total}} = 125 \text{ m [S]} + 245 \text{ m [E]}$
Solve:	We are going to use the procedure outlined earlier for adding vectors graphically.

Here are the steps:

1. Draw a coordinate system and choose the scale. An appropriate scale would be 1 cm = 25 m. If possible, choose a scale that will make the shortest vector at least 5 cm in length.

   On the scale, the first displacement is 5.0 cm and the second displacement is 9.8 cm.

2. Draw the first displacement with its tail at the origin.

   This will be a vector 5.0 cm long pointing south.

3. Place the tail of the second displacement on the tip of the first displacement and draw in the vector for the second displacement.

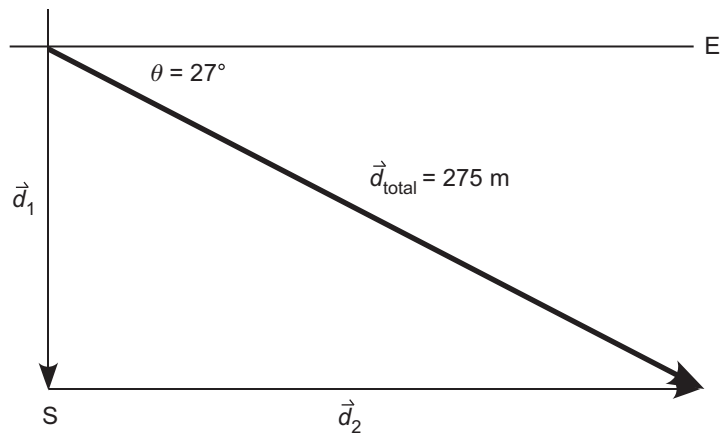
   This will be a vector 9.8 cm long pointing east.

4. Draw a vector from the tail of the first vector to the tip of the second vector. This is the resultant vector $\left(\vec{d}_{\text{total}}\right)$.
5. Measure the length of the resultant vector. The length is 11.0 cm. Using the scale, convert it into the magnitude for the total displacement.

   11.0 cm x (25 m/1 cm) = 275 m

6. Place a protractor with the crosshairs at the origin and measure the angle from the horizontal axis (east) to the resultant vector.

   This angle is 27° S of E.



The displacement from your house to your friend's house is 275 m [27° south of east].

If you must add three vectors, simply add the first two vectors using the tip-to-tail method, and then place the tail of the third vector on the tip of the second vector. The resultant will start with its tail on the tail of the **first vector** and end with its tip on the tip of the **last (third) vector**.

Learning Activity 2.5

Adding Vectors: Part 2

1. Add the following vectors:

   a) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [N]

   b) $\vec{A}$ = 8.2 m/s [W], $\vec{B}$ = 4.2 m/s [S], and $\vec{C}$ = 5.2 m/s [E]

Adding Vectors in Two Dimensions Using the Component Method (Trigonometry)

Again, we will apply this technique only to vectors that are perpendicular to each other. The advantage of adding vectors using components is that the result will be very accurate.

We will still use the **tip-to-tail** method of arranging the vectors and producing a right triangle. The resultant will be the **hypotenuse**, while the two vectors being added are the **legs**. Finding the size of the resultant is done with the Pythagorean Theorem, and the direction it is pointing can be found by using trigonometry (inverse tangent, to be exact). Note that the angle θ must be placed inside the triangle at the tail end of the resultant.

Here are the steps by which vectors are added according to the component method:

1. Add all the vectors that point along the horizontal direction. This will form the x-component of our resultant.
2. Add all the vectors that point along the vertical direction. This will form the y-component of our resultant
3. On a coordinate system, sketch in the x-component. Using the tip-to-tail method, sketch in the y-component. Draw in the resultant from the tail of the first component to the tip of the second component.
4. Using the Theorem of Pythagoras, determine the magnitude of the resultant.
5. Draw in the angle between the resultant vector and one of the legs of the triangle at the **tail** of the resultant vector. Use the inverse of the tangent function to determine the size of this angle.

Again, this process can be used to add any number of vectors pointing perpendicular to each other. There will always be only one x-component and one y-component for the resultant.

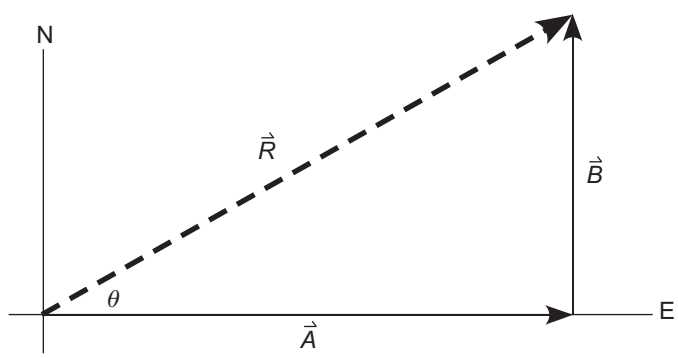
Example 4: Adding Vectors using the Component Method

Add the following vectors using the component method.

$$\vec{A} = 385 \text{ m [E] and } \vec{B} = 218 \text{ m [N]}$$

Here we want to find: $\vec{A} + \vec{B} = \vec{R}$.

1. There is only one vector pointing in the horizontal direction.
   This is $\vec{A}$ = 385 m [E].
2. There is only one vector pointing along the vertical direction.
   This is $\vec{B}$ = 218 m [N].
3. Draw a coordinate system and sketch the vectors using the tip-to-tail method. Draw in the resultant.



4. Using the Theorem of Pythagoras, determine the size of the hypotenuse (magnitude of the resultant).

   $$R^2 = A^2 + B^2$$

   $$R^2 = (385 \text{ m})^2 + (218 \text{ m})^2 = 195749 \text{ m}^2$$

   $$R = \sqrt{195749 \text{ m}^2} = 442 \text{ m}$$

   Notice we work only with the magnitudes here, so we can treat these as scalars.

5. The angle θ is drawn in at the **tail** of the resultant between the resultant vector and a major axis **INSIDE THE TRIANGLE**.

   In this triangle, $\vec{A}$ is the side adjacent to the angle and $\vec{B}$ is the side opposite to the angle. The trig function that relates these sides to the angle is tangent.

   So we must take the inverse tangent of the ratio of these two sides (opposite over adjacent) to determine the angle.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{218}{385}$$

$$\theta = \tan^{-1}\frac{218}{385} = 29.5°$$

   The angle is 29.5° N of E.

   The resultant or sum of these two vectors is 442 m [29.5° N of E].

Example 5: Adding Four Vectors using the Component Method

Add the following vectors using the component method:

$\vec{A} = 35.0\text{ m [W]}$

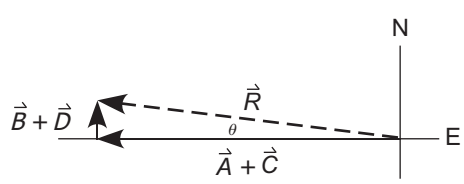
$\vec{B} = 18.2\text{ m [N]}$

$\vec{C} = 17.3\text{ m [W]}$

$\vec{D} = 12.2\text{ m [S]}$

We want to find the sum according to $\vec{A} + \vec{B} + \vec{C} + \vec{D} = \vec{R}$.

1. Add vectors pointing along the x-axis.
   $\vec{A} + \vec{C} = 35.0\text{ m [W]} + 17.3\text{ m [W]} = 52.3\text{ m [W]}$
2. Add vectors pointing along the y-axis.
   $\vec{B} + \vec{D} = 18.2\text{ m [N]} + 12.2\text{ m [S]} = 6.0\text{ m [N]}$
3. Draw a coordinate system and sketch the vectors using the tip-to-tail method. Draw in the resultant.



4. Using the Theorem of Pythagoras, determine the size of the hypotenuse (magnitude of the resultant).

$$R^2 = (52.3\ \text{m})^2 + (6.0\ \text{m})^2 = 2771.29\ \text{m}^2$$

$$R = \sqrt{2771.29\ \text{m}^2} = 52.6\ \text{m}$$

5. The angle θ is drawn in at the tail of the resultant between the resultant vector and a major axis **INSIDE THE TRIANGLE**.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{6.0}{52.3}$$

$$\theta = \tan^{-1}\frac{6.0}{52.3} = 6.5°$$

The angle is 6.5° N of W.

The resultant or sum of these four vectors is 52.6 m [6.5° N of W].

Subtraction of Vectors

To understand how to perform the subtraction of vectors, we refer to some algebra that you have already learned about integers.

Suppose you had the following problem:

(+3) – (+6)

To do this, you would add the opposite of the term being subtracted. The question now becomes

(+3) + (–6)

Of course, the answer is –3.

The key to consider is the **"add the opposite"** step.

With the subtraction of vectors, we employ the same technique.

Subtracting Vectors: The subtraction of vectors is accomplished by changing the subtraction question into an addition question by "adding the opposite" of the vector being subtracted.

$$\vec{A} - \vec{B} = \vec{R} \quad \text{becomes} \quad \vec{A} + (-\vec{B}) = \vec{R}$$

The opposite of a vector is simply a vector of the same size pointing in the opposite direction.

So the opposite of $\vec{A} = 35.0\ \text{m}\ [\text{W}]$ is $-\vec{A} = 35.0\ \text{m}\ [\text{E}]$.

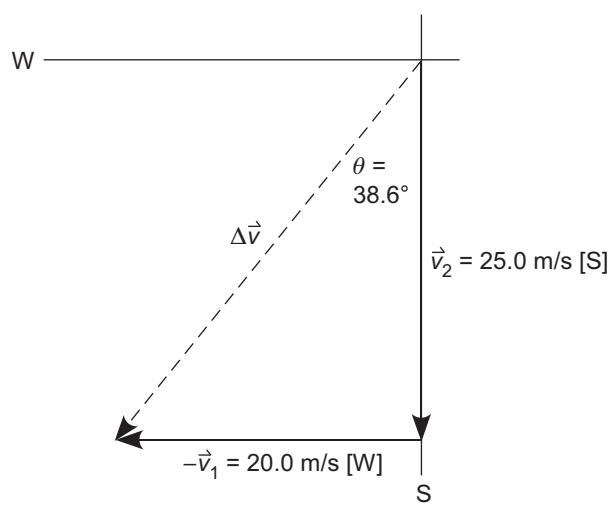
Example 6: Subtracting Vectors

You know that objects speed up or slow down. Objects also turn and change their directions of motion. Each of these is a **change in velocity**.

Determine the change in velocity for a car that is travelling at 20.0 m/s [E] at one time and then is travelling at 25.0 m/s [S]. What is the change in the velocity of the car?

Given:

initial velocity	$\vec{v}_1 = 20.0 \text{ m/s [E]}$
final velocity	$\vec{v}_2 = 25.0 \text{ m/s [S]}$
Unknown: change in velocity	$\Delta\vec{v} = ?$
Equation:	$\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$ We must add the opposite, so $\Delta\vec{v} = \vec{v}_2 + (-\vec{v}_1)$
Substitute:	$\Delta\vec{v} = (25.0 \text{ m/s [S]}) + (-20.0 \text{ m/s [E]})$ The opposite of east is west, so $\Delta\vec{v} = (25.0 \text{ m/s [S]}) + (20.0 \text{ m/s [W]})$
Solve:	This is solved using a vector diagram or by the component method.



The change in velocity is 32.0 m/s [38.6° W of S].

Learning Activity 2.6

Adding Vectors: Part 3

There are three problems in this exercise. You may use either method of adding vectors except in the cases where a method is specified.

1. In the countryside, roads are laid out in a grid, making squares that are 1.6 km on a side. To travel from one homestead to another requires the following displacements. First, travel 4.0 km [S], then 9.6 km [W], and finally 7.0 km [S] again.
   a) What was the total displacement?
   b) If the journey required 18.0 minutes, calculate the average velocity in kilometres per hour.
2. A bicyclist is travelling at 8.25 m/s [S] as he enters a circular curve in the road. After 15.0 s, the cyclist is moving at 6.45 m/s [E].
   a) What was the change in the velocity of the cyclist?
   b) What was the average vector acceleration?
3. Using the graphical method, find $\vec{B} - \vec{A}$ if $\vec{A}$ = 2600 m [N] and $\vec{B}$ = 1800 m [W].

Lesson Summary

The addition of vectors involves the **tip-to-tail method**. In this process, follow these steps:

1. Draw a coordinate system and sketch the first vector with its tail at the origin.
2. Draw the second vector with its tail on the tip of the first vector.
3. Draw the resultant vector with its tail beginning on the tail of the first vector and its tip drawn at the tip of the last vector.

To add **parallel vectors**, add the magnitudes of the given vectors to obtain the magnitude of the resultant. The direction of the resultant is the same as the direction of the given vectors.

To add **antiparallel vectors**, obtain the magnitude of the resultant vector by finding the difference between the magnitudes of the two given vectors. The direction of the resultant is given by the direction of the larger of the given vectors.

To add **perpendicular vectors** using the **graphical method** (scale diagram), follow these steps:

1. Draw a coordinate system and choose the scale.
2. Draw the first vector with its tail at the origin.
3. Place the tail of the second vector on the tip of the first vector, and draw in the second vector.
4. Draw the vector from the tail of the first vector to the tip of the second vector. This is the resultant vector.
5. Measure the length of the resultant vector. Using the scale, convert it into the magnitude for the resultant vector.
6. Place a protractor with the crosshairs at the origin, and measure the angle from the horizontal axis to the resultant vector. Fully state the vector answer.

To use the **component method** to add vectors that are **perpendicular** to each other, draw a sketch for the addition of the x-component and the y-component, following the tip-to-tail method. Draw in the resultant vector. To determine the magnitude of the resultant vector, use the theorem of Pythagoras. To determine the direction of the resultant vector, use the tangent function.

To **subtract vectors**, change the question from subtraction into addition by **"adding the opposite"** of the vector that is being subtracted. Then add the vectors as outlined in the steps above. The **"opposite"** of a given vector is just a vector of the same length pointing in the opposite direction.

Websites

Adding Vectors

At the website http://surendranath.tripod.com/Applets.html, go to the Applet Menu/Some Math/Vectors/Vector Addition. Here, there is an applet that allows you to practice adding vectors using the tip-to-tail method.

Select the "Triangle Law" and add.

Simply click on a spot on the page and drag the mouse to create Vector 1 in red. The quantity is given at the top of the screen (magnitude and direction). Place your cursor on the head of Vector 1 and drag to create Vector 2 in blue. Drag the vectors to make the resultant appear in black. The magnitude and direction are given in black on the screen.

Try adding parallel vectors, antiparallel vectors, and vectors at right angles.

At the website www.walter-fendt.de/ph14e/resultant.htm, there is an applet that allows you to add any number of vectors together. The applet animates placing the vectors using the tip-to-tail method to find the resultant.

You can also control the size of the vectors and their direction.

NOTES

Assignment 2.1, Part C

Adding Vectors (10 MARKS)

Given the following vectors:

$\vec{A} = 35.0 \text{ m } [\text{W}]$

$\vec{B} = 18.2 \text{ m } [\text{N}]$

$\vec{C} = 17.3 \text{ m } [\text{W}]$

$\vec{D} = 12.2 \text{ m } [\text{S}]$

1. Add the vectors $\vec{B} + \vec{C} + \vec{D}$ using the component method.

(continued)

Assignment 2.1: Part C: Adding Vectors (continued)

2. Find the difference between $\vec{D} - \vec{C}$ using the graphical method (scale diagram).

Method of Assessment

The total of 10 marks for this assignment will be determined as follows:

Question 1—Marks will be awarded for the correct use of the component method to determine the sum as follows:

- 1 mark for combining vectors to obtain the components
- 2 marks for an appropriate sketch showing the labelled vectors and angle
- 1 mark for correctly determining the magnitude of the sum
- 1 mark for correctly determining the angle for the resultant

Question 2—Five marks will be awarded for the correct use of the steps in the graphical solution to the problem.

LESSON 4: A VECTOR JOURNEY (1.5 HOURS)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ add vectors graphically
- ❑ add vectors using the component method

Introduction

This lesson deals with an activity where you find the displacement between two locations in a school. The displacements are measured along the lines of the tiles that form a grid on the floor. The lines run in the north-south or east-west directions. The displacement from one point to another point on the same floor is represented by the vector sum of all of the individual displacements required to travel from one point to the other. A map of the school is provided.

A Vector Journey

Objective: To determine the displacement between two points on a plane (the floor of the school)

Apparatus: Measuring device such as a metre stick or a measuring tape

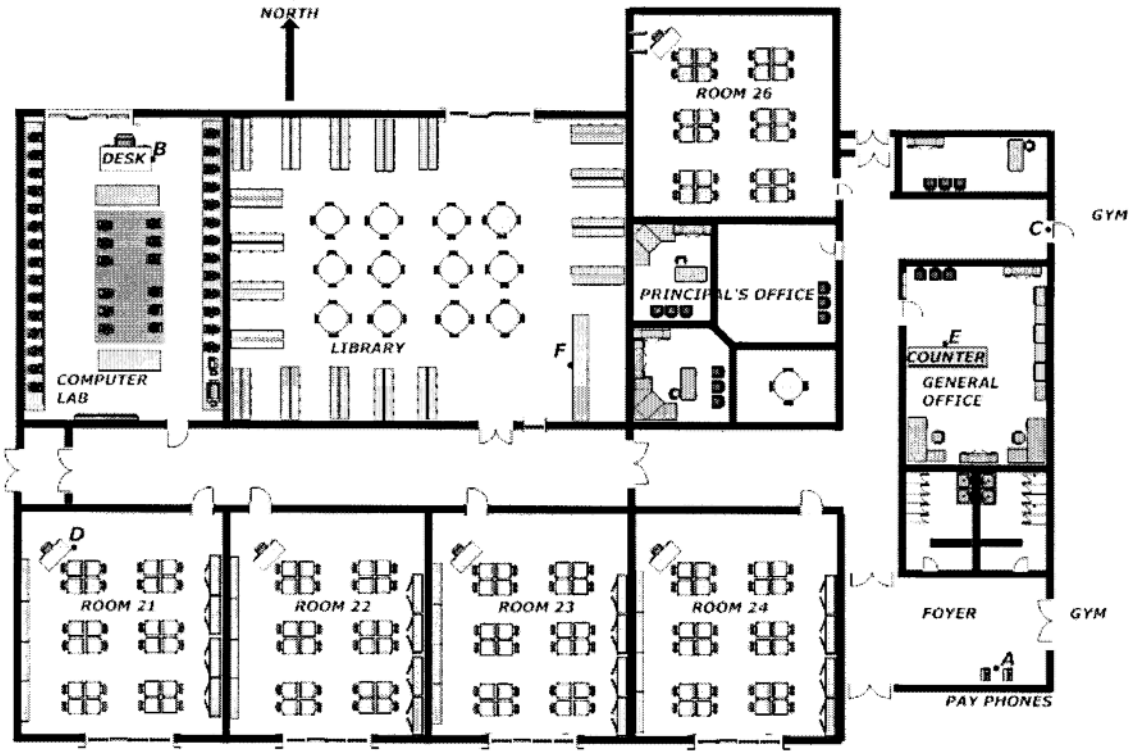
Procedure:

1. Start at a given point (A, B, or C).
2. Using a metre stick or tape measure, measure the vectors in the north-south direction and the east-west direction that are needed to proceed from the starting point to the end point of your journey (D, E, or F).
3. The front of the school is south and the gym side of the school is east.
4. Use any lines on the floor to aid you in maintaining the proper direction.
5. List all of the vector displacements measured to the nearest 0.1 m in the order that the measurements were made.
6. Add these vector displacements in the order that they were made using a scale diagram.

7. Add the collinear vectors for the east-west direction and for the north-south direction. Add these mathematically using Pythagoras and trigonometry. Include a sketch.
8. Repeat these steps for your second vector journey.

Main Floor	**Start**	**Finish**
1.	Pay phones (A)	Teacher's desk in computer lab (B)
2.	Door to gym (C)	Teacher's desk in room 21 (D)
3.	Counter in general office (E)	Counter in library (F)

Observations:
Please refer to the map of the school that is provided below.



Journey #1:
Here is a description of the journey from the pay phones in the foyer (A) to the desk in the computer lab (B).

I started at the pay phones (POINT A) and walked 2.5 m [N]. I then turned to my left and went 5.8 m [W], which placed me in front of the doors to the main hallway. I then travelled 7.5 m [N] along the main hallway. When I reached the next hallway, I turned to the left again and proceeded 32.8 m [W]. I then turned to my right and entered the computer lab, walking 14.4 m [N]. This placed me beside the teacher's desk. I finally moved 1.3 m [W] and arrived at the desk (POINT B).

Journey #2:
Here is a description of the journey from the door to the gym (C) to the teacher's desk in the room 21 (D).

I started at the door to the gym (POINT C) and walked 8.2 m [W] into the main hallway. I then turned to my left and went 10.6 m [S], which placed me at the junction between the two main hallways. I then turned to my right and travelled 33.5 m [W] along the hallway, stopping in front of the door to room 21. I turned to the left and proceeded 4.8 m [S], which placed me inside room 21. I then turned to my right and moved 6.3 m [W], which placed me beside the teacher's desk (POINT D).

Journey #3:
Here is a description of the journey from the counter in the general office (E) to the counter in the library (F).

I began at the counter in the general office (POINT E) and walked 1.5 m [N]. I turned to my left and walked 3.0 m [W] out of the door to the general office and into the main hallway. Once again, I turned to my left and proceeded 7.5 m [S] until I was at the junction of the two main hallways. I turned to my right and walked 18.5 m [W], stopping in front of the doors to the library. I turned to my right again and went into the library, moving 5.0 m [N]. Finally, I turned to my right yet again and walked 3.5 m [E], stopping at the counter in the library (POINT F).

NOTES

Assignment 2.2

Vector Journey (16 MARKS)

Prepare a report on this Vector Journey activity by answering the following questions. Be sure to show your work. This report is to be submitted to the Distance Learning Unit along with all of the Module 2 assignments after you have completed Module 2.

Report

1. For Journey #1, list the displacements measured in the order they were measured. Use $\vec{d}_1$, $\vec{d}_2$, $\vec{d}_3$, etc. *(1 mark)*
2. Show your work in determining the displacement for this journey by the graphical method (scale diagram). *(3½ marks)*

   Include the following information:

   Scale *(½ mark)*
   The conversion of all vectors according to the scale *(1 mark)*
   A diagram of the addition of the vectors **in the order given** (draw $\vec{d}_1$, then add $\vec{d}_2$, then $\vec{d}_3 \ldots$ until all vectors are drawn tip to tail). *(1 mark)*
   The correct length of the resultant vector *(½ mark)*
   The correct direction for the resultant vector *(½ mark)*

3. Show the work in determining the displacement for Journey #1 by the component method. *(2½ marks)*

   Include the following information:

   Addition of the components in the north-south and in the east-west direction *(1 mark)*
   A sketch for the addition of the components to produce the resultant vector *(½ mark)*
   The correct length of the resultant vector *(½ mark)*
   The correct direction for the resultant vector *(½ mark)*

4. How do the displacements found by the different methods compare? Why? *(1 mark)*
5. Repeat parts 1 to 4 for another one of the remaining journeys. **Note that you need to do this for only one of *either* Journey #2 or Journey #3.** *(8 marks)*

NOTES

MODULE 2 SUMMARY

Congratulations on completing the second module of Grade 11 Physics!

Submitting Your Assignments

It is now time for you to submit Assignments 2.1 and 2.2 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 2 assignments and organize your material in the following order:

- Module 2 Cover Sheet (found at the end of the course Introduction)
- Assignment 2.1, Part A: Drawing Vectors
- Assignment 2.1, Part B: Sketching Vectors
- Assignment 2.1, Part C: Adding Vectors
- Assignment 2.2: Vector Journey

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

You're now ready to start Module 3.

NOTES

Grade 11 Physics (30S)

Module 2: Vectors

Learning Activity Answer Keys

MODULE 2: VECTORS

Learning Activity 2.1: Vectors and Scalars

1. Identify the following quantities and state whether they are vectors or scalars.

   Answer:

	Quantity	Vector/Scalar
22 m	distance	scalar
1.35 m/s [E]	velocity	vector
62 N [N]	force	vector
35 s	time interval	scalar
18 cm/s^2	acceleration	vector

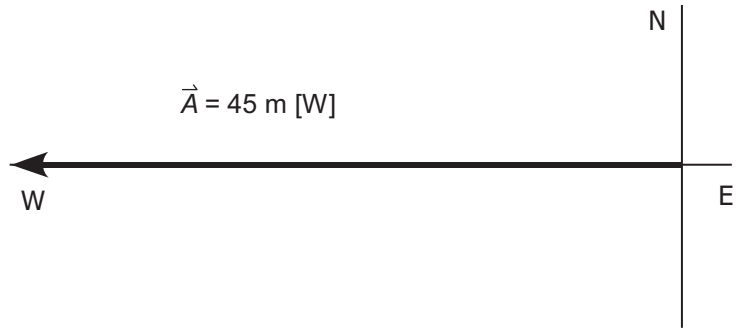
2. Draw the following vectors. Indicate the scale that is used.

   Answers:

   a) $\vec{A} = 45 \text{ m } [\text{W}]$

   An appropriate scale would be 1 cm = 5 m. Vectors should be drawn using a scale that will make the length of the vector longer than 5 cm. This will make the diagrams large enough to provide some accuracy.

   This vector will be 9.0 cm in size.

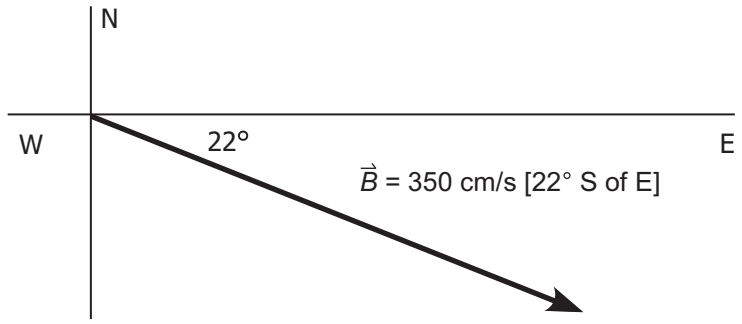


b) $\vec{B} = 350 \text{ cm/s} \left[22° \text{ S of E}\right]$

Scale: 1 cm = 50 cm/s

This vector will be 7.0 cm in size.

This vector will be drawn in the south-east quadrant.

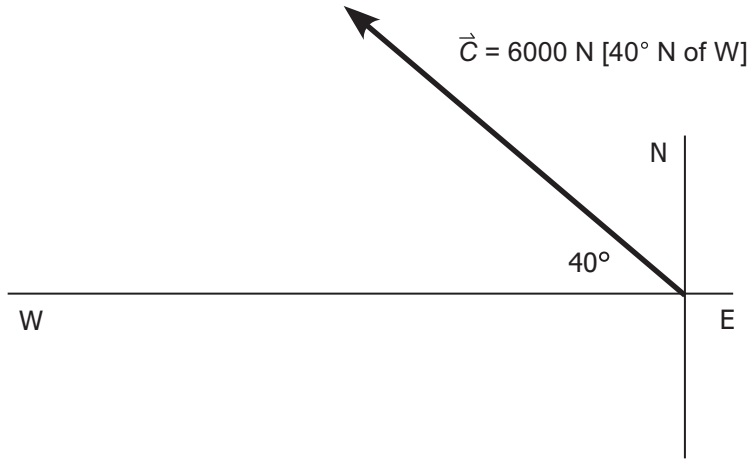


c) $\vec{C} = 6000 \text{ N} \left[40° \text{ N of W}\right]$

Scale: 1 cm = 1000 N

This vector will be 6.0 cm in size.

This vector will be drawn in the north-west quadrant.



Learning Activity 2.2: Drawing Vectors

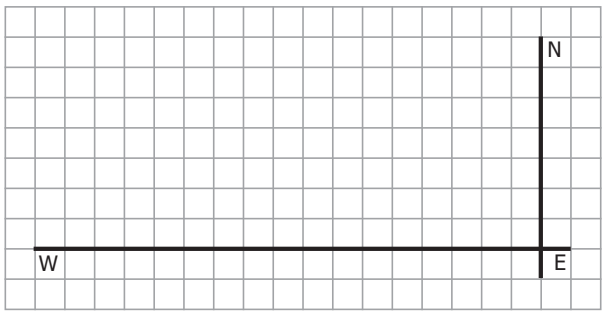
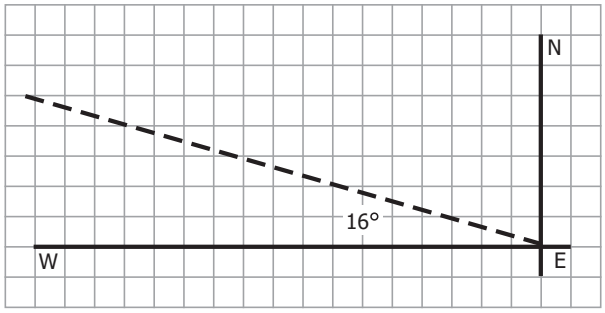
1. Perform the operation and identify the quantity that results for each of the following:

   Answers:

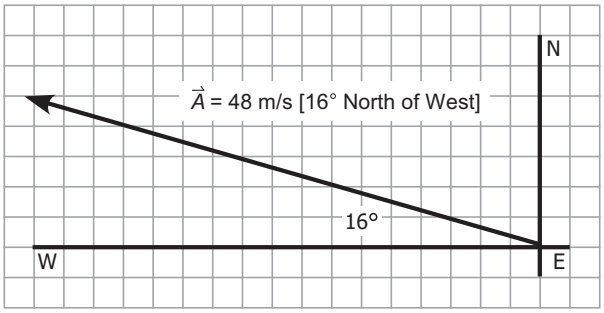
	Answer	Quantity
a) (2 m/s^2 [N])(4 s)	8 m/s [N]	velocity
b) 3(9.0 m [SW])	27 m [SW]	displacement
c) –5(3.2 m/s [E])	16 m/s [W]	velocity
d) –½(42 cm [30° W of N])	21 cm [30° E of S]	displacement
e) (5.6 cm/s [30° W of N])(8.2 s)	46 cm [30° W of N]	displacement
f) (16.2 m [12° E of S]) / (5.3 s)	3.0 m/s [12° E of S]	velocity

2. Given that $\vec{A}$ = 48 m/s [16° N of W], draw the vector, writing out the procedural steps. You need draw only 1 diagram with all of the work on that diagram.

   Answer:

Procedural Step	Diagram
Establish a coordinate system and choose a scale. In this case, an appropriate scale would be 1.0 cm = 5.0 m/s. The length of the vector arrow should then be 9.6 cm.	
Place the crosshairs of a protractor at the origin and, starting from west, measure an angle going 16° north. Place a mark on your paper to indicate this direction.	

Finally, draw in the vector arrow 9.6 cm long, starting at the origin out towards the mark indicating 16° north of west. Place an arrowhead at the head of the vector. Label the vector.

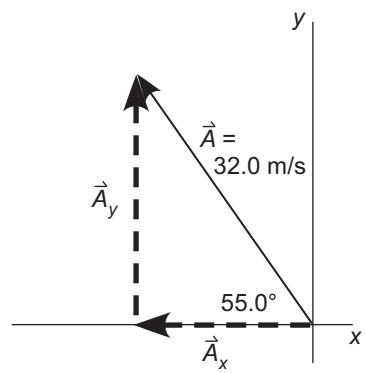


Learning Activity 2.3: Calculating the Components of Vectors

1. Calculate the components of the following vectors:

   Answers:

   a)



To find the horizontal (x) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{A}_X}{\vec{A}}$$

$$\cos 55.0° = \frac{\vec{A}_X}{32.0\ \text{m/s}}$$

$$\vec{A}_X = (\cos 55.0°)(32.0\ \text{m/s}) = -18.4\ \text{m/s}$$

This horizontal component is negative since it points to the left.

To find the vertical component, use

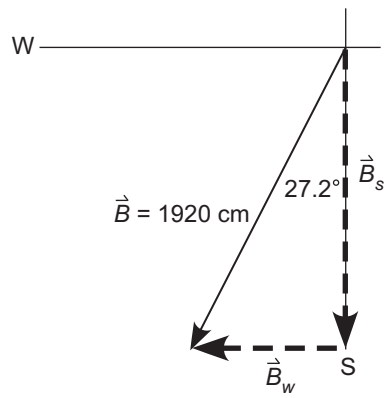
$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{A}_Y}{\vec{A}}$$

$$\sin 55.0° = \frac{\vec{A}_Y}{32.0\ \text{m/s}}$$

$$\vec{A}_Y = (\sin 55.0°)(32.0\ \text{m/s}) = +26.2\ \text{m/s}$$

The vertical component is +26.2 m/s.

b)



To find the westerly or horizontal component, use

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{B}_W}{\vec{B}}$$

$$\sin 27.2° = \frac{\vec{B}_W}{1920\text{ cm}}$$

$$\vec{B}_W = (\sin 27.2°)(1920\text{ cm}) = 878\text{ cm [W]}$$

The horizontal component is 878 cm [W].

To find the southerly or vertical (y) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{B}_S}{\vec{B}}$$

$$\cos 27.2° = \frac{\vec{B}_S}{1920\text{ cm}}$$

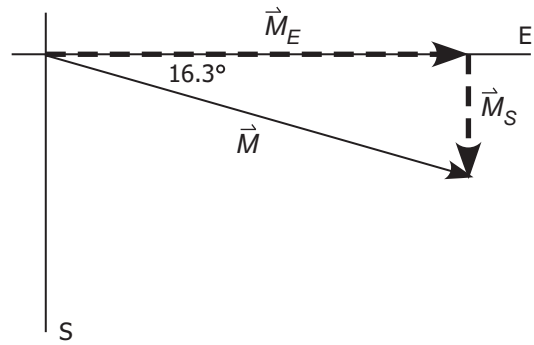
$$\vec{B}_S = (\cos 27.2°)(1920\text{ cm}) = 1710\text{ cm [S]}$$

The vertical component is 1710 cm [S].

2. Calculate the components of the following vectors. Sketch the vector with its tail at the origin. This sketch does not have to be to scale but should be a reasonable facsimile of the vector.

   Answers:

a) $\vec{M} = 21.2 \text{ m/s } [16.3° \text{ S of E}]$



To find the horizontal (x) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{M}_E}{\vec{M}}$$

$$\cos 16.3° = \frac{\vec{M}_E}{21.2 \text{ m/s}}$$

$$\vec{M}_E = (\cos 16.3°)(21.2 \text{ m/s}) = 20.3 \text{ m/s [E]}$$

This horizontal component is 20.3 m/s [E].

To find the vertical component, use

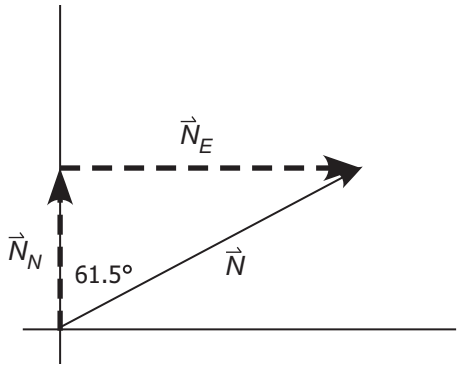
$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{M}_S}{\vec{M}}$$

$$\sin 16.3° = \frac{\vec{M}_S}{21.2 \text{ m/s}}$$

$$\vec{M}_S = (\sin 16.3°)(21.2 \text{ m/s}) = 5.95 \text{ m/s [S]}$$

The vertical component is 5.95 m/s [S].

b) $\vec{N} = 49500\ \text{mm/s}^2\ [61.5°\ \text{E of N}]$



To find the easterly or horizontal component, use

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{N}_E}{\vec{N}}$$

$$\sin 61.5° = \frac{\vec{N}_E}{49500\ \text{mm/s}^2}$$

$$\vec{N}_E = (\sin 61.5°)(49500\ \text{mm/s}^2) = 43500\ \text{mm/s}^2\ [\text{E}]$$

This horizontal component is 43500 mm/s^2 [E].

To find the northerly or vertical (y) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{N}_N}{\vec{N}}$$

$$\cos 61.5° = \frac{\vec{N}_N}{49500\ \text{mm/s}^2}$$

$$\vec{N}_N = (\cos 61.5°)(49500\ \text{mm/s}^2) = 23600\ \text{mm/s}^2\ [\text{N}]$$

The vertical component is 23600 mm/s^2 [N].

Learning Activity 2.4: Adding Vectors: Part 1

1. Add the following vectors.

   Answers:

   a) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [W]

   These vectors point in the same direction. Simply add the magnitudes and keep the same direction.

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$202\text{ m }[\text{W}]+357\text{ m }[\text{W}]=\vec{R}$$
   $$\vec{R}=559\text{ m }[\text{W}]$$

   b) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [E]

   These vectors are antiparallel. We find the difference of the magnitudes and attach the sign of the larger one as the direction of the resultant.

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$202\text{ m }[\text{W}]+357\text{ m }[\text{E}]=\vec{R}$$
   $$\vec{R}=155\text{ m }[\text{E}]$$

   c) $\vec{A}$ = 18.3 m/s [N] and $\vec{B}$ = 3.6 m/s [N]

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$18.3\text{ m/s }[\text{N}]+3.6\text{ m/s }[\text{N}]=\vec{R}$$
   $$\vec{R}=21.9\text{ m/s }[\text{N}]$$

   d) $\vec{A}$ = 5.6 m/s^2 [N] and $\vec{B}$ = 6.8 m/s^2 [S]

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$5.6\text{ m/s}^2\ [\text{N}]+6.8\text{ m/s}^2\ [\text{S}]=\vec{R}$$
   $$\vec{R}=1.2\text{ m/s}^2\ [\text{S}]$$

2. There are moving sidewalks in airports. Suppose that a particular sidewalk's surface is moving at 2.0 m/s [N]. What would your velocity be relative to the floor beside the sidewalk if you were standing on the sidewalk and

   a) not walking?

      Answer:

      If you were not walking but just standing on the sidewalk, the sidewalk would carry you at 2.0 m/s [N]. Therefore, your velocity relative to the floor would be 2.0 m/s [N].

   b) walking at 1.5 m/s [N]?

      Answer:

      If you are walking at 1.5 m/s [N] on the sidewalk, then your motion as seen from the frame of reference of the floor would be the vector sum of the two motions: your motion next to the sidewalk plus the motion of the sidewalk next to the floor.

      $$\vec{v}_{\text{PERSON-FLOOR}} = \vec{v}_{\text{PERSON-SIDEWALK}} + \vec{v}_{\text{SIDEWALK-FLOOR}}$$
      $$\vec{v}_{\text{PERSON-FLOOR}} = 1.5 \text{ m/s [N]} + 2.0 \text{ m/s [N]} = 3.5 \text{ m/s [N]}$$

      Your velocity relative to the floor is 3.5 m/s [N].

   c) walking at 2.0 m/s [S]?

      Answer:

      Here you are walking in the opposite direction from which the sidewalk is moving.

      $$\vec{v}_{\text{PERSON-FLOOR}} = \vec{v}_{\text{PERSON-SIDEWALK}} + \vec{v}_{\text{SIDEWALK-FLOOR}}$$
      $$\vec{v}_{\text{PERSON-FLOOR}} = 2.0 \text{ m/s [S]} + 2.0 \text{ m/s [N]} = 0 \text{ m/s}$$

      You are not moving relative to the floor.

Learning Activity 2.5: Adding Vectors: Part 2

1. Add the following vectors using a scale diagram.

   Answer:

   a) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [N]

   You are finding the vector sum:

   $$\vec{A} + \vec{B} = \vec{R}$$

   Here are the steps.

   1. Draw a coordinates system and choose the scale. An appropriate scale would be 1 cm = 50 m.

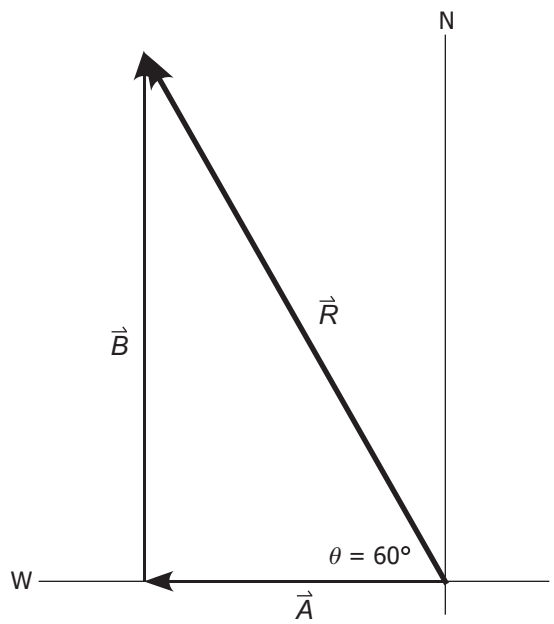
      On the scale, the vector $\vec{A}$ is 4.0 cm and the second displacement $(\vec{B})$ is 7.1 cm.
   2. Draw the first displacement (A) with its tail at the origin.

      This will be a vector 4.0 cm long pointing west.
   3. Placing the tail of the second displacement $(\vec{B})$ on the tip of the first displacement $(\vec{A})$, draw in the vector for the second displacement (B).

      This will be a vector 7.1 cm long pointing north.
   4. Draw a vector from the tail of the first vector $(\vec{A})$ to the tip of the second vector. This is the resultant vector $(\vec{R})$.
   5. Measure the length of the resultant vector $(\vec{R})$. The length is 8.2 cm. Using the scale, convert it into the magnitude for the total displacement.

      8.2 cm x (50 m/1cm) = 410 m
   6. Placing a protractor with the crosshairs at the origin, measure the angle from the horizontal axis (east) to the resultant vector.

      This angle is 60° N of W.



The resultant is 410 m [60° N of W].

b) $\vec{A}$ = 8.2 m/s [W], $\vec{B}$ = 4.2 m/s [S] and $\vec{C}$ = 5.2 m/s [E].

$\vec{A}+\vec{B}+\vec{C}=\vec{R}$

1. Draw a coordinates system and choose the scale. An appropriate scale would be 1 cm = 1 m/s.

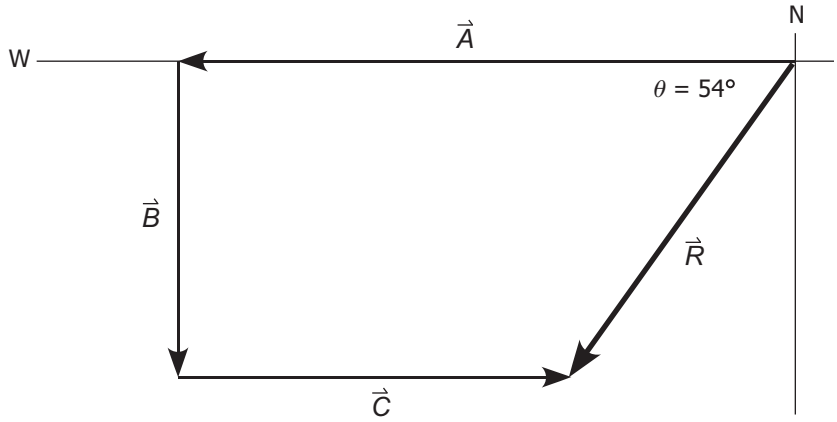
   On this scale, the vector $\vec{A}$ is 8.2 cm, the second velocity vector $\vec{B}$ is 4.2 cm, and the third velocity vector $\vec{C}$ is 5.2 cm.
2. Draw the first displacement $(\vec{A})$ with its tail at the origin.

   This will be a vector 8.2 cm long pointing west.
3. Placing the tail of the second displacement $(\vec{B})$ on the tip of the first displacement $(\vec{A})$, draw in the vector for the second displacement $(\vec{B})$.

   This will be a vector 4.2 cm long pointing south.
4. Placing the tail of the third vector $\vec{C}$ on the tip of the second vector $\vec{B}$, draw vector $\vec{C}$ 5.2 cm long pointing east. You will have to use your protractor to determine which direction points east.
5. Draw a vector from the tail of the first vector $(\vec{A})$ to the tip of the third vector $\vec{C}$. This is the resultant vector $(\vec{R})$.
6. Measure the length of the resultant vector $(\vec{R})$. The length is 5.2 cm. Using the scale, convert it into the magnitude for the total displacement.

   5.2 cm x (1 m/s /1 cm) = 5.2 m/s

7. Placing a protractor with the crosshairs at the origin, measure the angle from the horizontal axis (west) to the resultant vector.



This angle is 54° S of W.

The resultant is 5.2 m/s [54° S of W].

Learning Activity 2.6: Adding Vectors: Part 3

There are three problems in this exercise. You may use either method of adding vectors, except in the cases where a method is specified. You may check your answers against the answer key provided at the end of Module 2.

1. In the countryside, roads are laid out in a grid, making squares that are 1.6 km on a side. To travel from one homestead to another requires the following displacements:

   First travel 4.0 km [S], then 9.6 km [W], and finally 7.0 km [S] again.

   a) What is the total displacement?

   Answer:

   Given: Displacement 1 $\vec{A} = 4.0 \text{ km [S]}$

   Displacement 2 $\vec{B} = 9.6 \text{ km [W]}$

   Displacement 3 $\vec{C} = 7.0 \text{ km [S]}$

   Unknown: Total displacement $\vec{R} = ?$

   Equation: $\vec{R} = \vec{A} + \vec{B} + \vec{C}$

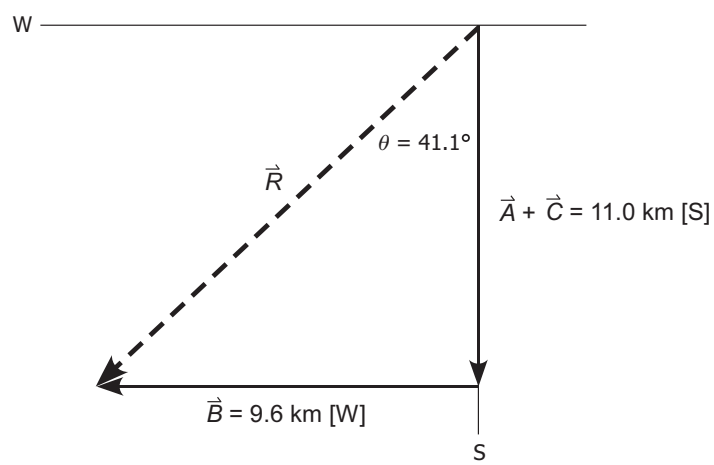
   $\vec{A} + \vec{C}$ runs in the same direction, so combine these first.

   $\vec{A} + \vec{C} = 4.0 \text{ km [S]} + 7.0 \text{ km [S]} = 11.0 \text{ km [S]}$

   $\vec{R} = \left(\vec{A} + \vec{C}\right) + \vec{B}$

   Substitute: $\vec{R} = \left(11.0 \text{ km [S]}\right) + 9.6 \text{ km [W]}$

   Solve:



$$\tan^{-1}\frac{9.6}{11.0} = \theta$$

$$\theta = 41.1°$$

The angle is 41.1° W of S.

$$\vec{R}^2 = (9.6)^2 + (11.0)^2 = 213.16$$

$$\vec{R} = \sqrt{213.16} = 14.6 \text{ km}$$

The total displacement for this journey was 14.6 km [41.1° W of S].

b) If the journey required 18.0 minutes, calculate the average velocity in kilometres per hour.

Answer:

Given: Total displacement $\vec{d}_{\text{TOTAL}} = 14.6 \text{ km } [41.1° \text{ W of S}]$

Total time $\Delta t_{\text{TOTAL}} = 18.0 \text{ minutes} = 0.300 \text{ h}$

Unknown: Average velocity $\vec{v}_{\text{avg}} = ?$

Equation: $\vec{v}_{\text{avg}} = \dfrac{\vec{d}_{\text{TOTAL}}}{\Delta t_{\text{TOTAL}}}$

Substitute: $\vec{v}_{\text{avg}} = \dfrac{14.6 \text{ km } [41.1° \text{ W of S}]}{0.300 \text{ h}}$

Solve: $\vec{v}_{\text{avg}} = 48.7 \text{ km/h } [41.1° \text{ W of S}]$

The average velocity for this journey is 48.7 km/h [41.1° W of S].

2. A bicyclist is travelling at 8.25 m/s [S] as he enters a circular curve in the road. After 15.0 s, the cyclist is moving at 6.45 m/s [E].

a) What was the change in the velocity of the cyclist?

Answer:

Given: Initial velocity $\vec{v}_1 = 8.25 \text{ m/s [S]}$

Final velocity $\vec{v}_2 = 6.45 \text{ m/s [E]}$

Unknown: Change in velocity $\Delta\vec{v} = ?$

Equation: $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$

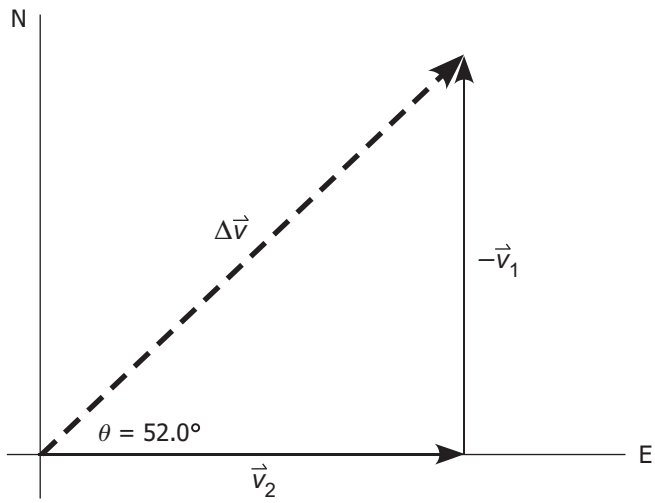
We must add the opposite, so

$\Delta\vec{v} = \vec{v}_2 + (-\vec{v}_1)$.

Substitute: $\Delta\vec{v} = (6.45 \text{ m/s [E]}) + (-8.25 \text{ m/s [S]})$

Solve: $\Delta\vec{v} = (6.45 \text{ m/s [E]}) + (8.25 \text{ m/s [N]})$

(The opposite of south is north).



The angle is 52.0°N of E.

$$\Delta\vec{v}^2 = (8.25)^2 + (6.45)^2 = 109.665$$

$$\Delta\vec{v} = \sqrt{109.665} = 10.5 \text{ m/s}$$

The change in velocity for the cyclist is 10.5 m/s [52.0° N of E].

b) What was the average vector acceleration?

Answer:

The average vector acceleration is calculated as the change in velocity over the time interval.

$$\Delta\vec{a}_{\text{avg}} = \frac{\Delta\vec{v}}{\Delta t} = \frac{10.5 \text{ m/s [52.0° N of E]}}{15.0 \text{ s}} = 0.700 \text{ m/s}^2 \text{ [52.0° N of E]}$$

3. Using the graphical method, find $\vec{B} - \vec{A}$ if $\vec{A} = 2600$ m [N] and $\vec{B} = 1800$ m [W].

Since this is subtraction, we must add the opposite of vector $\vec{A}$.

If $\vec{R} = \vec{B} - \vec{A}$, then $\vec{R} = \vec{B} + (-\vec{A})$.

$\vec{R} = (1800 \text{ m [W]}) + (2600 \text{ m [S]})$

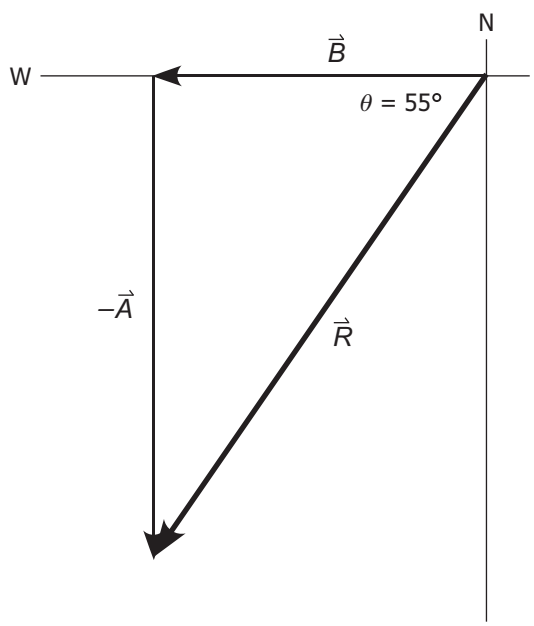
Answer:

1. Draw a coordinate system and choose the scale. An appropriate scale would be 1 cm = 400 m.

   On the scale, the vector $\vec{A}$ is 6.5 cm and the second displacement $(\vec{B})$ is 4.5 cm.

2. Draw the first displacement $(\vec{B})$ with its tail at the origin.
   This will be a vector 4.5 cm long pointing west.
3. Placing the tail of the second displacement $(-\vec{A})$ on the tip of the first displacement $(\vec{B})$, draw in the vector for the second displacement $(-\vec{A})$.

   This will be a vector 6.5 cm long pointing south.
4. Draw a vector from the tail of the first vector $(\vec{A})$ to the tip of the second vector. This is the resultant vector $(\vec{R})$.



5. Measure the length of the resultant vector $(\vec{R})$. The length is 7.9 cm. Using the scale, convert it into the magnitude for the total displacement.
   7.9 cm x (400 m/1 cm) = 3160 m = 3200 m
6. Placing a protractor with the crosshairs at the origin, measure the angle from the horizontal axis (east) to the resultant vector.

This angle is 55° S of W.

The difference $\vec{R} = \vec{B} + (-\vec{A})$ is 3200 m [55° S of W].

NOTES

Grade 11 Physics (30S)

Module 2: Vectors

Learning Activity Answer Keys

MODULE 2: VECTORS

Learning Activity 2.1: Vectors and Scalars

1. Identify the following quantities and state whether they are vectors or scalars.

   Answer:

	Quantity	Vector/Scalar
22 m	distance	scalar
1.35 m/s [E]	velocity	vector
62 N [N]	force	vector
35 s	time interval	scalar
18 cm/s^2	acceleration	vector

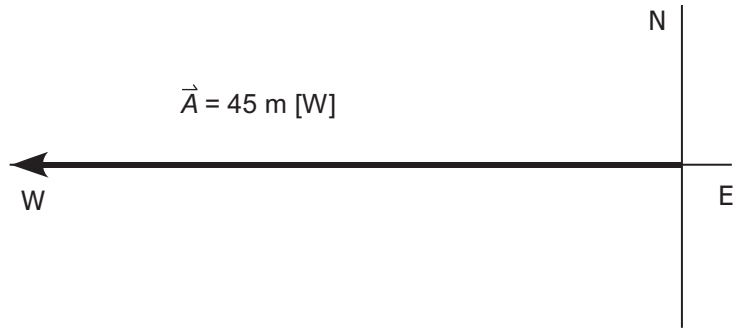
2. Draw the following vectors. Indicate the scale that is used.

   Answers:

   a) $\vec{A} = 45 \text{ m } [\text{W}]$

   An appropriate scale would be 1 cm = 5 m. Vectors should be drawn using a scale that will make the length of the vector longer than 5 cm. This will make the diagrams large enough to provide some accuracy.

   This vector will be 9.0 cm in size.

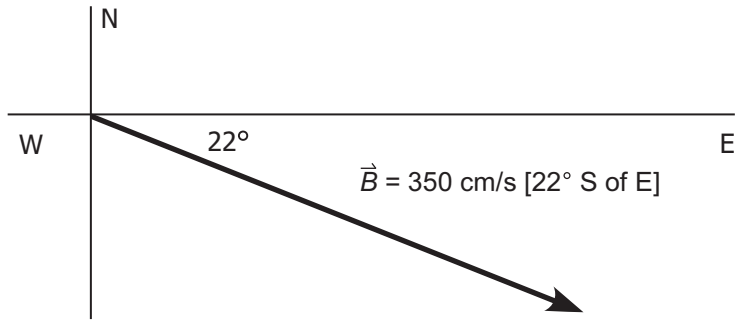


b) $\vec{B} = 350 \text{ cm/s} \left[22° \text{ S of E}\right]$

Scale: 1 cm = 50 cm/s

This vector will be 7.0 cm in size.

This vector will be drawn in the south-east quadrant.

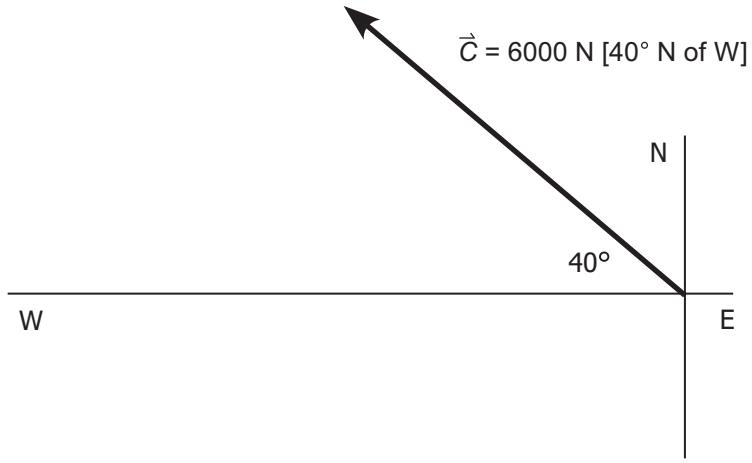


c) $\vec{C} = 6000 \text{ N} \left[40° \text{ N of W}\right]$

Scale: 1 cm = 1000 N

This vector will be 6.0 cm in size.

This vector will be drawn in the north-west quadrant.



Learning Activity 2.2: Drawing Vectors

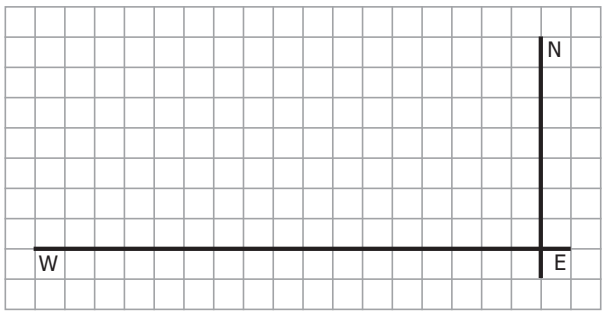
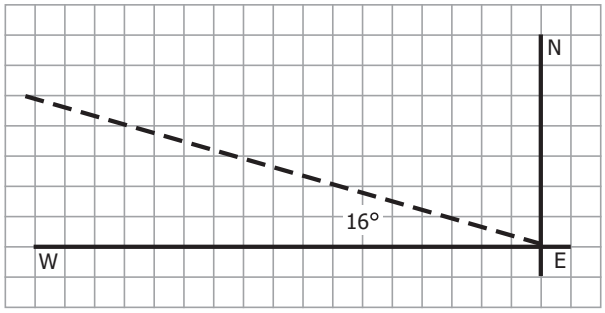
1. Perform the operation and identify the quantity that results for each of the following:

   Answers:

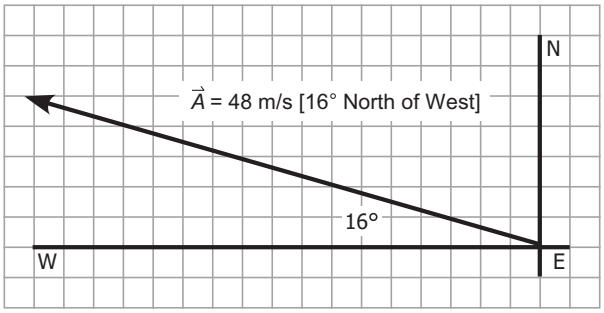
	Answer	Quantity
a) (2 m/s^2 [N])(4 s)	8 m/s [N]	velocity
b) 3(9.0 m [SW])	27 m [SW]	displacement
c) –5(3.2 m/s [E])	16 m/s [W]	velocity
d) –½(42 cm [30° W of N])	21 cm [30° E of S]	displacement
e) (5.6 cm/s [30° W of N])(8.2 s)	46 cm [30° W of N]	displacement
f) (16.2 m [12° E of S]) / (5.3 s)	3.0 m/s [12° E of S]	velocity

2. Given that $\vec{A}$ = 48 m/s [16° N of W], draw the vector, writing out the procedural steps. You need draw only 1 diagram with all of the work on that diagram.

   Answer:

Procedural Step	Diagram
Establish a coordinate system and choose a scale. In this case, an appropriate scale would be 1.0 cm = 5.0 m/s. The length of the vector arrow should then be 9.6 cm.	
Place the crosshairs of a protractor at the origin and, starting from west, measure an angle going 16° north. Place a mark on your paper to indicate this direction.	

Finally, draw in the vector arrow 9.6 cm long, starting at the origin out towards the mark indicating 16° north of west. Place an arrowhead at the head of the vector. Label the vector.

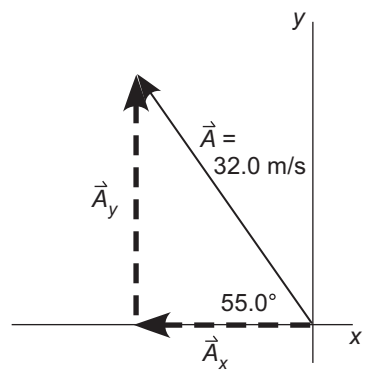


Learning Activity 2.3: Calculating the Components of Vectors

1. Calculate the components of the following vectors:

   Answers:

   a)



To find the horizontal (x) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{A}_X}{\vec{A}}$$

$$\cos 55.0° = \frac{\vec{A}_X}{32.0\ \text{m/s}}$$

$$\vec{A}_X = (\cos 55.0°)(32.0\ \text{m/s}) = -18.4\ \text{m/s}$$

This horizontal component is negative since it points to the left.

To find the vertical component, use

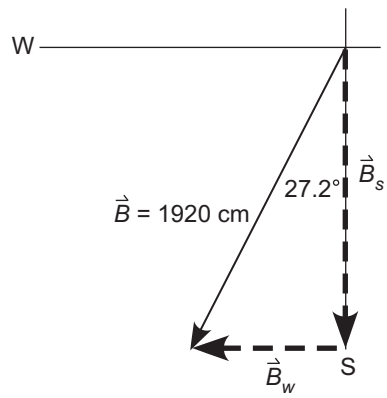
$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{A}_Y}{\vec{A}}$$

$$\sin 55.0° = \frac{\vec{A}_Y}{32.0\ \text{m/s}}$$

$$\vec{A}_Y = (\sin 55.0°)(32.0\ \text{m/s}) = +26.2\ \text{m/s}$$

The vertical component is +26.2 m/s.

b)



To find the westerly or horizontal component, use

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{B}_W}{\vec{B}}$$

$$\sin 27.2° = \frac{\vec{B}_W}{1920\text{ cm}}$$

$$\vec{B}_W = (\sin 27.2°)(1920\text{ cm}) = 878\text{ cm [W]}$$

The horizontal component is 878 cm [W].

To find the southerly or vertical (y) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{B}_S}{\vec{B}}$$

$$\cos 27.2° = \frac{\vec{B}_S}{1920\text{ cm}}$$

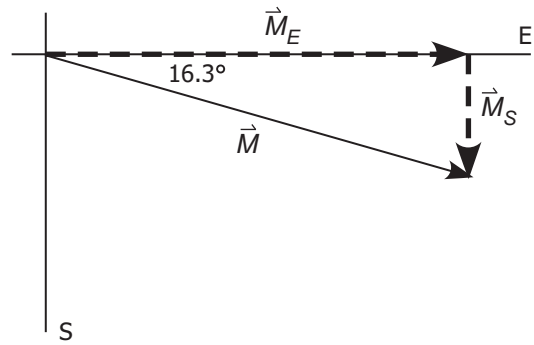
$$\vec{B}_S = (\cos 27.2°)(1920\text{ cm}) = 1710\text{ cm [S]}$$

The vertical component is 1710 cm [S].

2. Calculate the components of the following vectors. Sketch the vector with its tail at the origin. This sketch does not have to be to scale but should be a reasonable facsimile of the vector.

   Answers:

a) $\vec{M} = 21.2 \text{ m/s } [16.3° \text{ S of E}]$



To find the horizontal (x) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{M}_E}{\vec{M}}$$

$$\cos 16.3° = \frac{\vec{M}_E}{21.2 \text{ m/s}}$$

$$\vec{M}_E = (\cos 16.3°)(21.2 \text{ m/s}) = 20.3 \text{ m/s [E]}$$

This horizontal component is 20.3 m/s [E].

To find the vertical component, use

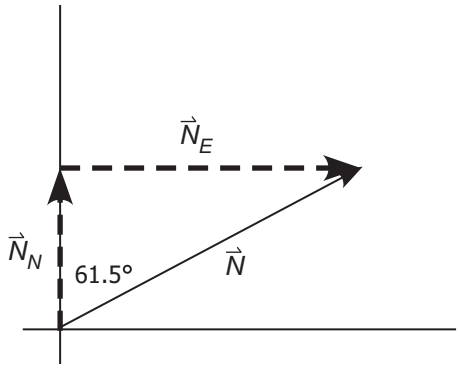
$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{M}_S}{\vec{M}}$$

$$\sin 16.3° = \frac{\vec{M}_S}{21.2 \text{ m/s}}$$

$$\vec{M}_S = (\sin 16.3°)(21.2 \text{ m/s}) = 5.95 \text{ m/s [S]}$$

The vertical component is 5.95 m/s [S].

b) $\vec{N} = 49500\ \text{mm/s}^2\ [61.5°\ \text{E of N}]$



To find the easterly or horizontal component, use

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{N}_E}{\vec{N}}$$

$$\sin 61.5° = \frac{\vec{N}_E}{49500\ \text{mm/s}^2}$$

$$\vec{N}_E = (\sin 61.5°)(49500\ \text{mm/s}^2) = 43500\ \text{mm/s}^2\ [\text{E}]$$

This horizontal component is 43500 mm/s^2 [E].

To find the northerly or vertical (y) component, use

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{N}_N}{\vec{N}}$$

$$\cos 61.5° = \frac{\vec{N}_N}{49500\ \text{mm/s}^2}$$

$$\vec{N}_N = (\cos 61.5°)(49500\ \text{mm/s}^2) = 23600\ \text{mm/s}^2\ [\text{N}]$$

The vertical component is 23600 mm/s^2 [N].

Learning Activity 2.4: Adding Vectors: Part 1

1. Add the following vectors.

   Answers:

   a) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [W]

   These vectors point in the same direction. Simply add the magnitudes and keep the same direction.

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$202\text{ m }[\text{W}]+357\text{ m }[\text{W}]=\vec{R}$$
   $$\vec{R}=559\text{ m }[\text{W}]$$

   b) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [E]

   These vectors are antiparallel. We find the difference of the magnitudes and attach the sign of the larger one as the direction of the resultant.

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$202\text{ m }[\text{W}]+357\text{ m }[\text{E}]=\vec{R}$$
   $$\vec{R}=155\text{ m }[\text{E}]$$

   c) $\vec{A}$ = 18.3 m/s [N] and $\vec{B}$ = 3.6 m/s [N]

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$18.3\text{ m/s }[\text{N}]+3.6\text{ m/s }[\text{N}]=\vec{R}$$
   $$\vec{R}=21.9\text{ m/s }[\text{N}]$$

   d) $\vec{A}$ = 5.6 m/s^2 [N] and $\vec{B}$ = 6.8 m/s^2 [S]

   $$\vec{A}+\vec{B}=\vec{R}$$
   $$5.6\text{ m/s}^2\ [\text{N}]+6.8\text{ m/s}^2\ [\text{S}]=\vec{R}$$
   $$\vec{R}=1.2\text{ m/s}^2\ [\text{S}]$$

2. There are moving sidewalks in airports. Suppose that a particular sidewalk's surface is moving at 2.0 m/s [N]. What would your velocity be relative to the floor beside the sidewalk if you were standing on the sidewalk and

   a) not walking?

      Answer:

      If you were not walking but just standing on the sidewalk, the sidewalk would carry you at 2.0 m/s [N]. Therefore, your velocity relative to the floor would be 2.0 m/s [N].

   b) walking at 1.5 m/s [N]?

      Answer:

      If you are walking at 1.5 m/s [N] on the sidewalk, then your motion as seen from the frame of reference of the floor would be the vector sum of the two motions: your motion next to the sidewalk plus the motion of the sidewalk next to the floor.

      $$\vec{v}_{\text{PERSON-FLOOR}} = \vec{v}_{\text{PERSON-SIDEWALK}} + \vec{v}_{\text{SIDEWALK-FLOOR}}$$
      $$\vec{v}_{\text{PERSON-FLOOR}} = 1.5 \text{ m/s [N]} + 2.0 \text{ m/s [N]} = 3.5 \text{ m/s [N]}$$

      Your velocity relative to the floor is 3.5 m/s [N].

   c) walking at 2.0 m/s [S]?

      Answer:

      Here you are walking in the opposite direction from which the sidewalk is moving.

      $$\vec{v}_{\text{PERSON-FLOOR}} = \vec{v}_{\text{PERSON-SIDEWALK}} + \vec{v}_{\text{SIDEWALK-FLOOR}}$$
      $$\vec{v}_{\text{PERSON-FLOOR}} = 2.0 \text{ m/s [S]} + 2.0 \text{ m/s [N]} = 0 \text{ m/s}$$

      You are not moving relative to the floor.

Learning Activity 2.5: Adding Vectors: Part 2

1. Add the following vectors using a scale diagram.

   Answer:

   a) $\vec{A}$ = 202 m [W] and $\vec{B}$ = 357 m [N]

   You are finding the vector sum:

   $$\vec{A} + \vec{B} = \vec{R}$$

   Here are the steps.

   1. Draw a coordinates system and choose the scale. An appropriate scale would be 1 cm = 50 m.

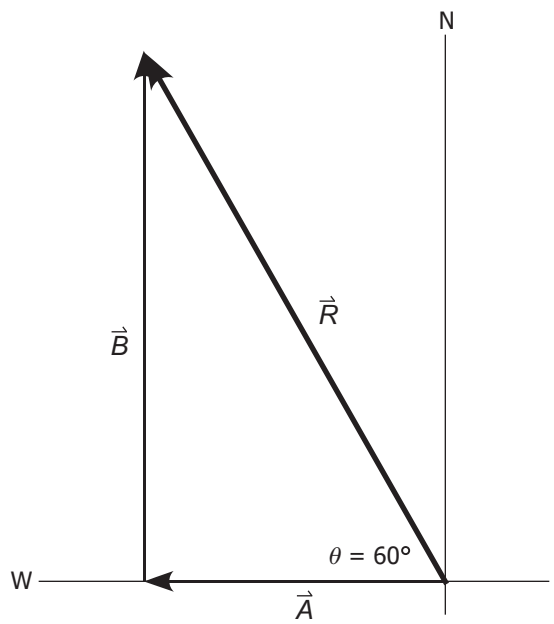
      On the scale, the vector $\vec{A}$ is 4.0 cm and the second displacement $(\vec{B})$ is 7.1 cm.
   2. Draw the first displacement (A) with its tail at the origin.

      This will be a vector 4.0 cm long pointing west.
   3. Placing the tail of the second displacement $(\vec{B})$ on the tip of the first displacement $(\vec{A})$, draw in the vector for the second displacement (B).

      This will be a vector 7.1 cm long pointing north.
   4. Draw a vector from the tail of the first vector $(\vec{A})$ to the tip of the second vector. This is the resultant vector $(\vec{R})$.
   5. Measure the length of the resultant vector $(\vec{R})$. The length is 8.2 cm. Using the scale, convert it into the magnitude for the total displacement.

      8.2 cm x (50 m/1cm) = 410 m
   6. Placing a protractor with the crosshairs at the origin, measure the angle from the horizontal axis (east) to the resultant vector.

      This angle is 60° N of W.



The resultant is 410 m [60° N of W].

b) $\vec{A}$ = 8.2 m/s [W], $\vec{B}$ = 4.2 m/s [S] and $\vec{C}$ = 5.2 m/s [E].

$\vec{A}+\vec{B}+\vec{C}=\vec{R}$

1. Draw a coordinates system and choose the scale. An appropriate scale would be 1 cm = 1 m/s.

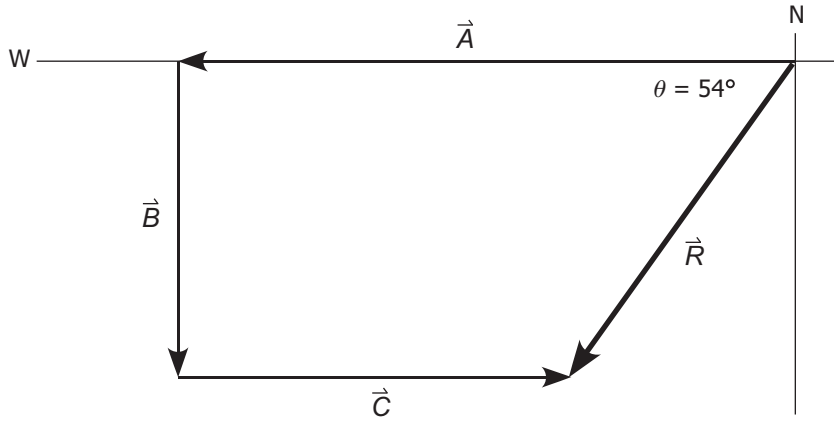
   On this scale, the vector $\vec{A}$ is 8.2 cm, the second velocity vector $\vec{B}$ is 4.2 cm, and the third velocity vector $\vec{C}$ is 5.2 cm.
2. Draw the first displacement $(\vec{A})$ with its tail at the origin.

   This will be a vector 8.2 cm long pointing west.
3. Placing the tail of the second displacement $(\vec{B})$ on the tip of the first displacement $(\vec{A})$, draw in the vector for the second displacement $(\vec{B})$.

   This will be a vector 4.2 cm long pointing south.
4. Placing the tail of the third vector $\vec{C}$ on the tip of the second vector $\vec{B}$, draw vector $\vec{C}$ 5.2 cm long pointing east. You will have to use your protractor to determine which direction points east.
5. Draw a vector from the tail of the first vector $(\vec{A})$ to the tip of the third vector $\vec{C}$. This is the resultant vector $(\vec{R})$.
6. Measure the length of the resultant vector $(\vec{R})$. The length is 5.2 cm. Using the scale, convert it into the magnitude for the total displacement.

   5.2 cm x (1 m/s /1 cm) = 5.2 m/s

7. Placing a protractor with the crosshairs at the origin, measure the angle from the horizontal axis (west) to the resultant vector.



This angle is 54° S of W.

The resultant is 5.2 m/s [54° S of W].

Learning Activity 2.6: Adding Vectors: Part 3

There are three problems in this exercise. You may use either method of adding vectors, except in the cases where a method is specified. You may check your answers against the answer key provided at the end of Module 2.

1. In the countryside, roads are laid out in a grid, making squares that are 1.6 km on a side. To travel from one homestead to another requires the following displacements:

   First travel 4.0 km [S], then 9.6 km [W], and finally 7.0 km [S] again.

   a) What is the total displacement?

   Answer:

   Given: Displacement 1 $\vec{A} = 4.0 \text{ km [S]}$

   Displacement 2 $\vec{B} = 9.6 \text{ km [W]}$

   Displacement 3 $\vec{C} = 7.0 \text{ km [S]}$

   Unknown: Total displacement $\vec{R} = ?$

   Equation: $\vec{R} = \vec{A} + \vec{B} + \vec{C}$

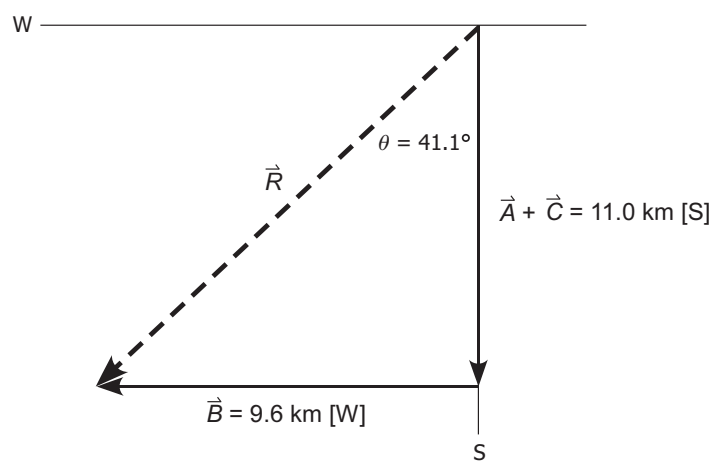
   $\vec{A} + \vec{C}$ runs in the same direction, so combine these first.

   $\vec{A} + \vec{C} = 4.0 \text{ km [S]} + 7.0 \text{ km [S]} = 11.0 \text{ km [S]}$

   $\vec{R} = \left(\vec{A} + \vec{C}\right) + \vec{B}$

   Substitute: $\vec{R} = \left(11.0 \text{ km [S]}\right) + 9.6 \text{ km [W]}$

   Solve:



$$\tan^{-1}\frac{9.6}{11.0} = \theta$$

$$\theta = 41.1°$$

The angle is 41.1° W of S.

$$\vec{R}^2 = (9.6)^2 + (11.0)^2 = 213.16$$

$$\vec{R} = \sqrt{213.16} = 14.6 \text{ km}$$

The total displacement for this journey was 14.6 km [41.1° W of S].

b) If the journey required 18.0 minutes, calculate the average velocity in kilometres per hour.

Answer:

Given: Total displacement $\vec{d}_{\text{TOTAL}} = 14.6 \text{ km } [41.1° \text{ W of S}]$

Total time $\Delta t_{\text{TOTAL}} = 18.0 \text{ minutes} = 0.300 \text{ h}$

Unknown: Average velocity $\vec{v}_{\text{avg}} = ?$

Equation: $\vec{v}_{\text{avg}} = \dfrac{\vec{d}_{\text{TOTAL}}}{\Delta t_{\text{TOTAL}}}$

Substitute: $\vec{v}_{\text{avg}} = \dfrac{14.6 \text{ km } [41.1° \text{ W of S}]}{0.300 \text{ h}}$

Solve: $\vec{v}_{\text{avg}} = 48.7 \text{ km/h } [41.1° \text{ W of S}]$

The average velocity for this journey is 48.7 km/h [41.1° W of S].

2. A bicyclist is travelling at 8.25 m/s [S] as he enters a circular curve in the road. After 15.0 s, the cyclist is moving at 6.45 m/s [E].

a) What was the change in the velocity of the cyclist?

Answer:

Given: Initial velocity $\vec{v}_1 = 8.25 \text{ m/s [S]}$

Final velocity $\vec{v}_2 = 6.45 \text{ m/s [E]}$

Unknown: Change in velocity $\Delta\vec{v} = ?$

Equation: $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$

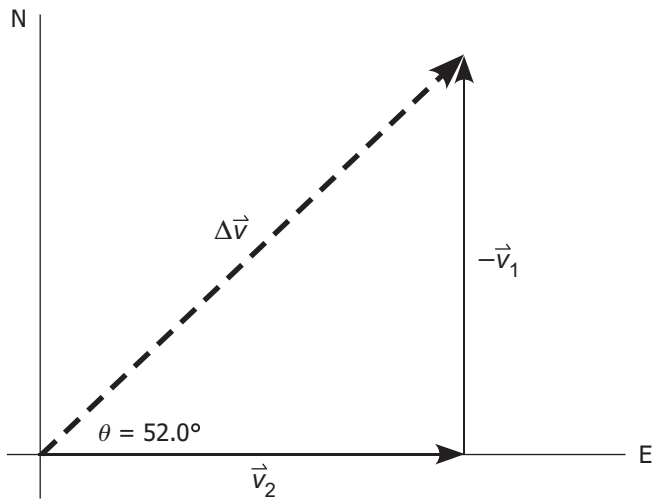
We must add the opposite, so

$\Delta\vec{v} = \vec{v}_2 + (-\vec{v}_1)$.

Substitute: $\Delta\vec{v} = (6.45 \text{ m/s [E]}) + (-8.25 \text{ m/s [S]})$

Solve: $\Delta\vec{v} = (6.45 \text{ m/s [E]}) + (8.25 \text{ m/s [N]})$

(The opposite of south is north).



The angle is 52.0°N of E.

$$\Delta\vec{v}^2 = (8.25)^2 + (6.45)^2 = 109.665$$

$$\Delta\vec{v} = \sqrt{109.665} = 10.5 \text{ m/s}$$

The change in velocity for the cyclist is 10.5 m/s [52.0° N of E].

b) What was the average vector acceleration?

Answer:

The average vector acceleration is calculated as the change in velocity over the time interval.

$$\Delta\vec{a}_{\text{avg}} = \frac{\Delta\vec{v}}{\Delta t} = \frac{10.5 \text{ m/s [52.0° N of E]}}{15.0 \text{ s}} = 0.700 \text{ m/s}^2 \text{ [52.0° N of E]}$$

3. Using the graphical method, find $\vec{B} - \vec{A}$ if $\vec{A} = 2600$ m [N] and $\vec{B} = 1800$ m [W].

Since this is subtraction, we must add the opposite of vector $\vec{A}$.

If $\vec{R} = \vec{B} - \vec{A}$, then $\vec{R} = \vec{B} + (-\vec{A})$.

$\vec{R} = (1800 \text{ m [W]}) + (2600 \text{ m [S]})$

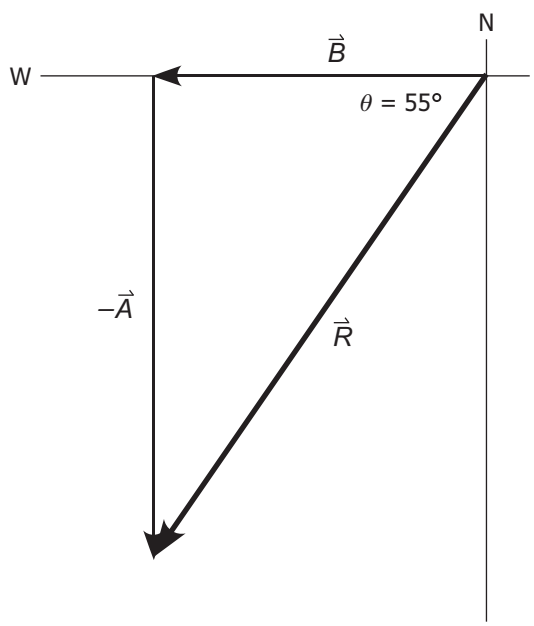
Answer:

1. Draw a coordinate system and choose the scale. An appropriate scale would be 1 cm = 400 m.

   On the scale, the vector $\vec{A}$ is 6.5 cm and the second displacement $(\vec{B})$ is 4.5 cm.

2. Draw the first displacement $(\vec{B})$ with its tail at the origin.
   This will be a vector 4.5 cm long pointing west.
3. Placing the tail of the second displacement $(-\vec{A})$ on the tip of the first displacement $(\vec{B})$, draw in the vector for the second displacement $(-\vec{A})$.

   This will be a vector 6.5 cm long pointing south.
4. Draw a vector from the tail of the first vector $(\vec{A})$ to the tip of the second vector. This is the resultant vector $(\vec{R})$.



5. Measure the length of the resultant vector $(\vec{R})$. The length is 7.9 cm. Using the scale, convert it into the magnitude for the total displacement.
   7.9 cm x (400 m/1 cm) = 3160 m = 3200 m
6. Placing a protractor with the crosshairs at the origin, measure the angle from the horizontal axis (east) to the resultant vector.

This angle is 55° S of W.

The difference $\vec{R} = \vec{B} + (-\vec{A})$ is 3200 m [55° S of W].

NOTES

Topic 1 - Audio/Videos

Module 2

1. Introduction to Vectors
2. How to use Cardinal Directions with Vectors
3. An Introduction to Vectors and Scalars 1
4. An Introduction to Vectors and Scalars 2: Scalars, Vectors, and Vector Operations
5. Drawing Vector Diagrams
    a. Watch the start of this video to observe how vectors are drawn to scale on a vector diagram using a ruler and protractor. What is missing from the procedure is the conversion of the real length of 6 miles to the scale length using a scaling factor. The scaling factor is 1 cm = 1 mile. The calculation to convert the magnitude to the scale length is: (6 miles) x (1 cm/ 1 mile) = 6 cm
    b. Watch the remainder of this video to observe how 2 vectors are added together using the tip to tail method by drawing the vector accurately to scale on a vector diagram using a ruler and protractor. The instructor does not use symbols to label the vector. Call the 12.0 m [N] the vector A (A with an arrow over top). Call the 8.0 m [E] the vector B (B with an arrow over top). Call the resultant vector R (R with an arrow over top). The equation is Vector R = Vector A + Vector B. Vector A and vector B are converted to their scale lengths using a scaling factor of 1 cm = 1 m. Vector R is converted to its actual length using the same scaling factor.
6. Introduction to Vector Components
7. Resolution of Vectors into Components
8. Visually adding and subtracting vectors
9. Head-to-Tail Method of Vector Addition
10. Drawing Vector Diagrams
    a. Watch this video from 6:37 to 14:00. Watch this video to observe how 2 vectors are added together using the tip to tail method by drawing the vector accurately to scale on a vector diagram using a ruler and protractor. The instructor does no use symbols to label the vector.
    Call the 12.0 m [N] the vector A (A with an arrow over top).
    Call the 8.0 m [E] the vector B (B with an arrow over top).
    Call the resultant vector R (R with an arrow over top).
    The equation is Vector R = Vector A + Vector B.
    Vector A and vector B are converted to their scale lengths using a scaling factor of 1 cm = 1 m.
    Vector R is converted to its actual length using the same scaling factor.
11. Introductory Tip-to-Tail Vector Addition Problem
12. How to Find the Distance Between Two Points - How to Use the Distance Formula
13. Distance and Displacement

Grade 11 Physics (30S)

Module 3: Dynamics

This module contains the following

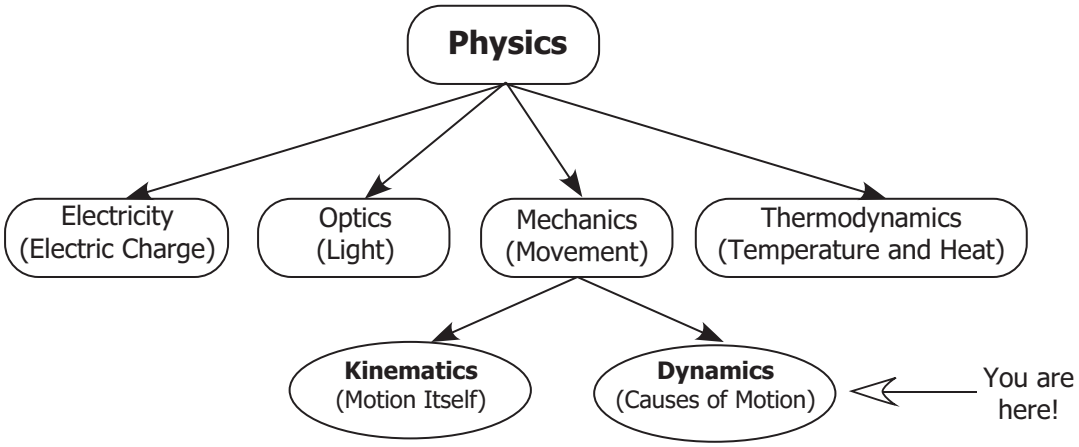
- Introduction to Module 3
- Lesson 1: Fundamental Forces
- Lesson 2: Newton's Laws of Motion
- Lesson 3: Video Laboratory Activity: Dynamics
- Lesson 4: Free-Body Diagrams
- Lesson 5: Linking Newton's Second Law and Kinematics
- Lesson 6: The Vector Nature of Newton's Second Law
- Module 3 Summary

Module 3: Dynamics

Introduction to Module 3

Welcome to Module 3. In the first module, we began our study of mechanics by learning the principles of kinematics—a description of motion itself. In this module, we continue our investigation of mechanics with a discussion of dynamics—the second part of mechanics. In dynamics, we do not stop at describing motion; we attempt to explain why the motion occurs the way it does. This involves understanding the forces that act on objects.

- **Lesson 1: Fundamental Forces** introduces the concept of force and the different types of forces found in nature.
- **Lesson 2: Newton's Law of Motion** builds on your previous introduction to these laws qualitatively in Grade 10 Science by dealing with them quantitatively as well.
- **Lesson 3: Video Laboratory Assignment: Dynamics** is an analysis of an experiment on Newton's laws.
- **Lesson 4: Free-Body Diagrams** describes how to keep track of forces using free-body diagrams.
- **Lesson 5: Linking Newton's Second Law and Kinematics** deals with linking kinematics (how things move) with dynamics (why things move).
- **Lesson 6: The Vector Nature of Newton's Second Law** focuses on the vector nature of Newton's Second Law.



Assignments in Module 3

When you complete Module 4, you will submit your Module 3 assignments, along with your Module 4 assignments, to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	There are no assignments in Lesson 1.	
2	There are no assignments in Lesson 2.	
3	Assignment 3.1	Video Laboratory Activity: Dynamics
4	Assignment 3.2, Part A	Free-Body Diagrams
5	Assignment 3.2, Part B	Dynamics and Kinematics
6	Assignment 3.2, Part C	The Vector Nature of Newton's Second Law

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Lesson 1: Fundamental Forces (0.5 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "force"
- ❑ distinguish between the four fundamental forces: gravitational, electromagnetic, strong nuclear, and weak nuclear in terms of their range, relative strength, and the context in which they act
- ❑ identify to which category of the four fundamental forces any given force belongs

Key Words

force
gravitational force
electromagnetic force
strong nuclear force
weak nuclear force

Introduction

We begin our study of dynamics with a discussion of what a force is, and then describe the four so-called "fundamental" forces—a system in which all forces can be identified as belonging to one of only four types. Force is a very important idea in physics, and we will work with forces throughout this entire module, as well as parts of future modules.

Force

Force is a very important concept in dynamics.

A **force** can be loosely described as a "push" or a "pull."

Notice that in everyday use, the word "force" is most often used as a verb: someone might "force a door open" or "force you to do your homework." This is not the case in physics, where we usually use the word as a noun. We tend to think of forces as things that can cause or change motion. So instead of saying "force the door open," we might say "apply a force in order to open the door." It is the same action either way, but visualizing forces as things is very helpful toward understanding them.

Here is a very brief list of some examples of forces:

- kicking a ball (your foot exerts a force onto the ball)
- wind blowing a leaf (the air exerts a force onto the leaf)
- the weight of your body (earth's gravity exerts a downward force on your body)
- the attraction of a fridge magnet to a fridge (the fridge exerts a force on the magnet)

Fundamental Forces

Because there are so many forces around us, we find it useful to categorize them. There are two very different ways of doing so. The first way is to inspect the forces at the most detailed level possible to look for similarities. By studying forces so closely, we are attempting to get at the deepest level of understanding possible. The word "fundamental" suggests this idea in that "fundamental" may not always be "practical," but if you want a deep understanding, then this is the way to go.

Surprisingly, physicists have come to realize that all forces fit nicely into the following four categories:

Category 1: The Strong Nuclear Force

Although likely unfamiliar to you, this is a very common force that is at work all the time. Matter is made up of primarily protons, neutrons, and electrons. Protons and neutrons are found together within the nucleus of atoms, which is a very tiny region at the centre of the atom. They cluster together to make up nuclei (the plural form of nucleus) because these particles are attracted to each other (protons are attracted to protons, neutrons are attracted to neutrons, and even protons and neutrons attract each other).

> The **strong nuclear force** is an attractive force that holds protons and neutrons in the nucleus of an atom.

As its name suggests, the strong nuclear force is the strongest of the four forces, but it has a very severe limitation: it is only strong if the particles involved are very, very close together. (Typically, the distance found within a nucleus is 10^{-15} m or so. The strong force can be safely ignored if the distances are any bigger). This distance is only a few times the diameter of a proton. This tiny range accounts for this force not coming directly into our normal experience and, as a result, was not discovered until the 20th century.

Category 2: The Weak Nuclear Force

Don't let the name fool you—this force is the second strongest of all the fundamental forces, but is named "weak" to distinguish it from the strong nuclear force above. This is a complicated kind of force, so we won't say much about it here.

> The **weak nuclear force** acts between certain subatomic particles, and is partly responsible for radioactivity.

The weak nuclear force is a million times fainter than the strong force and a hundred times shorter in range, but it is much stronger than gravitational force. So it is also safe to ignore outside the tiny space of a nucleus.

Category 3: The Electromagnetic Force:

> The **electromagnetic force** is the force that charged particles exert on each other.

You are familiar with this force in two separate forms: charged objects may attract or repel each other, and magnets may attract or repel each other. Both of these are examples of the electromagnetic force. The tricky thing about this force is that it is surprisingly common, but often difficult to identify.

As an example, the force involved in kicking a ball is an example of the electromagnetic force. At first this may seem strange, as it doesn't seem to involve anything electrically charged or magnetic. This is until you realize that your foot is made up of atoms that each have negative electrons on the outside. The ball similarly has negative electrons. Kicking a ball basically involves quickly bringing the negative electrons of your foot right up to the negative electrons of the ball so that they repel. In fact, they can repel so suddenly and dramatically that it will cause the ball to go flying!

The electromagnetic force does not suffer from the severe distance restriction that the two nuclear forces have. This means that this force acts over practically unlimited distances. Simply put, charged objects exert force on each other no matter how far apart they are, though these forces are strongest when the charges are closest together. Although you will learn more about this force in a future module, it is worth mentioning the fact that this force can be attractive (the charges pull themselves together) or repulsive (the charges push themselves apart). This means that it is possible for there to be no overall electromagnetic force between objects, even though they are made up of charges; the attractions and repulsions can "cancel" each other off if the set-up is right, which it often is. So while these forces are always present, they may not always be evident.

Other examples of the electromagnetic force are contact forces such as those found between a fist and a punching bag, or between a hamburger and teeth. Other contact forces, such as friction, and the pull or push of a spring on an object are considered to be electromagnetic forces.

Category 4: The Gravitational Force

This force is the weakest of the four, but is likely the one that is most familiar to you. This force is commonly experienced as the "weight" that all objects have.

> The **gravitational force** is an attraction between two objects because of their mass.

This force is very weak, and so is only noticeable if at least one of the objects involved has considerable mass and is not too far away (it depends on distance, much like the electromagnetic force where there is no distance limit, but closer is better). Your body is attracted gravitationally to a car, but both objects have so little mass that this force is not ordinarily detectable. Your body is also gravitationally attracted to the earth, which is very noticeable due to the earth's tremendous mass and nearness.

The reason that we tend to think of gravitational forces as being very strong is that, unlike the electromagnetic force, this force is always attractive—there is no possibility of two objects having gravitational forces "cancelling off."

One thing you will need to do is identify which of the four fundamental force categories that any force belongs to. This is most easily done by elimination: gravitational forces are easy to identify as they involves masses (typically, one will be large, such as a planet) that are attracting each other because of their mass alone (you will actually learn more about this if you choose to study Grade 12 physics). The strong nuclear force is also easy to identify as it

is notable only inside the nucleus of an atom, and is a strong attraction of nuclear particles (protons and neutrons) holding the nucleus together. The weak nuclear force is readily identified by its link to radioactivity.

> **Any force that is not identified as one of the other three must be electromagnetic**—these are forces of attraction or repulsion due to electric charge of the objects only.

A Final Note

Our understanding of which forces are fundamental is continually evolving. For instance, in the 1860s and 1870s, James Clerk Maxwell showed that the electric and magnetic forces could be explained as manifestations of a single electromagnetic force. In the 1970s, Sheldon Glashow, Abdus Salam, and Steven Weinberg presented the theory that explains how the electromagnetic and the weak nuclear force are related to each other in a force called the electroweak force.

Learning Activity 3.1

Fundamental Forces

After you have answered these questions, check your answers in the answer key at the end of the module.

1. For each of the following situations, which of the four fundamental forces is acting?
   a) In radioactivity, a proton may change into a neutron.
   b) An electron will repel another electron.
   c) The protons in a nucleus are held together so that they do not push each other apart.
   d) An attractive force exists between two neutrons that are not charged, but are attracted because they have mass.

(continued)

Learning Activity 3.1: Fundamental Forces (continued)

2. Complete the following table about the properties of the four fundamental forces.

Property	Fundamental Force
Acts between charged particles	
Acts in the nucleus	
Has the shortest range of all of the forces	
Has unlimited range	
The weakest force	
Acts between protons	
Due to the fact objects have mass	
Can be attractive or repulsive	
Is only attractive	

3. Identify to which of the four fundamental forces each of the following forces belongs.

Force	Category of Force
Weight	
Spring pulling a book	
Occurs between neutrons	
Occurs between particles smaller than protons	
Allows a balloon to "stick" to a wall	
Friction	
Bat hitting a ball	

Lesson Summary

A **force** is a push or a pull.

The **strong nuclear force** is an attractive force that holds protons and neutrons in the nucleus of an atom. It is an extremely strong force that counters the electromagnetic repulsive force between protons, and only acts at short ranges of about 10^{-15} metres.

The **weak nuclear force** is only weak compared to the strong nuclear force, and has an even shorter range. It is responsible for radioactive decay.

The **gravitational force** is an attraction between two objects because of their mass. It is always attractive. Gravity is the weakest of all the fundamental forces and its range is unlimited.

The **electromagnetic force** is the force that charged particles exert on each other. It can be either attractive or repulsive. It is much stronger than the gravitational force and its range is unlimited.

NOTES

Lesson 2: Newton's Laws of Motion (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "Newton"
- ❑ state Newton's Laws of Motion and use the laws in problem solving

Key Words

Newton's Laws of Motion	inertia	net force
external force	acceleration	action
reaction	direct variation	inverse variation
law	Newton	

Introduction

In Grade 10 Science, you were introduced to Newton's Laws of Motion. In particular, you studied how Newton's Laws applied to cars and passengers in cars as they travelled or were involved in crashes. We begin our discussion of Newton's Laws of Motion starting with the First Law, which is a non-mathematical law that describes whether or not an object will change its motion when forces act on it. Newton's Second Law describes in a mathematical way the acceleration of a mass when an unbalanced force acts on it. The Third Law deals with the forces of interaction between objects.

Newton's Laws

Much of what we will study is the result of the work of **Sir Isaac Newton** (1642–1727), who is arguably one of the most brilliant people that has ever lived. Newton, who lived roughly 300 years ago, clarified the physics of dynamics with what we now refer to as "Newton's Laws of Motion," of which there are three: **Newton's First Law**, **Newton's Second Law**, and **Newton's Third Law**.

Newton's First Law

Let's start with a short story told by a famous physicist, Richard Feynman (1918–1988), about an early experience with Newton's First Law:

When I was still pretty young – I don't know how old exactly – I had a ball in a wagon I was pulling, and I noticed something, so I ran up to my father to say that, "When I pull the wagon, the ball runs to the back, and when I am running with the wagon and stop, the ball runs to the front. Why?"

He said, "That nobody knows." He said, "It's very general, though, it happens all the time to anything; anything that is moving tends to keep moving; anything standing still tries to maintain that condition. If you look close you will see the ball does not run to the back of the wagon where you start from standing still. It moves forward a bit too, but not as fast as the wagon."

"The back of the wagon catches up with the ball which has trouble getting started moving. It's called inertia, that principle." I did run back to check, and sure enough the ball didn't go backwards.

(Richard Feynman, from his lecture on "What is Science?" given to the NSTA, *Physics Teacher* 7.6, 1968, pp. 313–320)

This story reveals something that is actually very notable: while we do have the word "inertia" to describe the tendency that objects prefer to maintain their velocity, we don't know why they act this way. Inertia is very closely related to Newton's First Law, both of which are simply summaries of what we know to be true with no explanation for why they are true. This is actually what a "**law**" in physics is: a statement of something that we observe to always be true, with no explanation of why it is true.

> A "**law**" in physics is a statement of something that we observe to always be true, with no explanation of why it is true.

Before Newton, it was believed that an object must have a force continually applied to it to keep it moving. This seems obvious, as it appears to be true everywhere we look—anything moving has a force making it move, and if the push is removed it stops moving. For example, a moving car is moving because the engine produces a force—if the engine is shut off while the car is moving, the car will soon stop.

Galileo Galilei (1564–1642) challenged this idea with a simple thought experiment: he argued that if an object is pushed to slide on a surface, it will slide some distance and then stop. But if a smoother surface is used, it will travel further before it stops. Of course, if an even smoother surface is used it will move further still. He concluded that if a "perfectly smooth" surface could be made, then the object would keep moving, around the whole earth forever. He realized that a force was not really needed to keep an object moving, but is needed to oppose the real-life imperfection of the environment.

Newton was able to use this idea, as well as his own, to develop his series of laws. In fact, the main idea of Newton's First Law is that a force is not needed for an object to move (but is needed to get it going). Here is one way of stating Newton's First Law: **If no forces act on an object, then the object will be doing one of two things: it may be sitting still, or it may be moving with a constant velocity—but it won't be accelerating!**

To gain a better understanding of Newton's First Law, think about a hockey puck on smooth ice (this comes close to the "perfectly smooth surface" that Galileo was trying to imagine). If the puck is stationary and nobody is applying any forces to it, it will remain at rest on the ice. After the puck is hit by a player (this would be a force, though one that doesn't last for very long), it coasts on its own across the ice, slowing down slightly because of friction. Since the ice is very slippery, there is only a small amount of friction to slow the puck down. In fact, if it were possible to remove all friction and air resistance, and if the rink were infinitely large, the puck would coast forever in a straight line at a constant speed. Left to itself, the puck would not lose any velocity. This is the essence of Newton's First Law of Motion, which we can state a little more precisely as follows:

> **Newton's First Law:** An object will have a constant velocity unless there is a net force acting on it.

Let's clear up the word "**net**" in "net force." The word "net" is sometimes used to represent "total." People who work at paying jobs sometimes speak of their "net pay"—this is, their total pay, considering all earnings and deductions. The phrase "net force" then means "sum of all forces acting on an object." Since force has both a magnitude (how much force, or how hard the force is) and a direction (which way the force is acting), force is a vector. This means that we must add forces in the way that we added vectors in the previous module.

We abbreviate force as $\vec{F}$ and net force as $\vec{F}_{\text{NET}}$ or $\Sigma\vec{F}$ (the "Σ" symbol is the Greek letter *sigma*, which is used in math for "sum of" or "total"). Newton's First Law is typically used in one of two ways: if you ever have an object with constant velocity, then you can conclude that there is no net force on it. Conversely, if you are told (or determine) that there is no net force on an object, then you can conclude that it must have a constant velocity. Realize in all of this that "constant velocity" may also mean being at rest (constant velocity of zero). Of course, if an object is not moving with constant velocity, then it is accelerating and so, by Newton's First Law, there must be a net force that is responsible.

There are several implications about Newton's First Law that must be understood:

- An **external force** is required to change the velocity of an object. Internal forces have no effect on the object's motion. For example, the driver pushing on the dashboard does not cause the car's velocity to change.
- The external forces must be unbalanced. Two equal, opposing forces acting on an object will not change its velocity. For an object's velocity to change, the vector sum of the applied forces must be different than zero (there is a net force acting on the object).
- Objects remain at rest unless acted upon by an external unbalanced force (net force).
- Moving objects continue to move in a straight line at a constant speed unless acted upon by an external unbalanced force (net force).

The ability of an object to resist changes in its state of motion is a fundamental property of all matter. Newton called this property "**inertia**."

> **Inertia** is the ability of an object to resist changes in its state of motion.

Because of inertia, a moving object tends to remain at rest (inertia of rest) or in motion along a straight line at a constant speed (inertia of motion). Newton's First Law can be referred to as the law of inertia.

Here are a few examples you may have experienced that involve Newton's First Law. The most obvious example is when you are sitting in a chair. As long as you do not exert a net force on yourself (try to stand or lift yourself), you remain motionless. This is the inertia of rest. If you have skateboarded, inline skated, or skated on ice, you know that once you are in motion you can stop propelling yourself and you will keep moving. This is the inertia of motion.

Learning Activity 3.2

Newton's First Law

When you have answered these questions, check your answers with the answer key at the end of this module.

1. Why is it particularly dangerous to drive on an icy highway? (Hint: Consider the inertia of the vehicle and the low frictional force between the wheels and the icy surface.)
2. Why do you lunge forward when your car suddenly comes to a halt? Why are you "thrown backward" when your car rapidly accelerates?
3. Why is your body pressed against the left side of the seat when the roller-coaster car in which you are riding suddenly veers to the right?

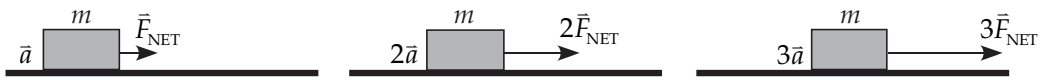
Newton's Second Law

While Newton's First Law "specializes" in objects that are not accelerating, Newton's Second Law "specializes" in objects that are accelerating.

> **Newton's Second Law:** An object's acceleration is proportional to the net force acting on it, and inversely proportional to the object's mass.

This is a technical way of saying that objects accelerate better when they are pushed harder. If the **net force increases** so to does the acceleration increase. This is called a **direct variation** and is written as $\vec{a} \; \alpha \; \vec{F}_{\text{NET}}$.

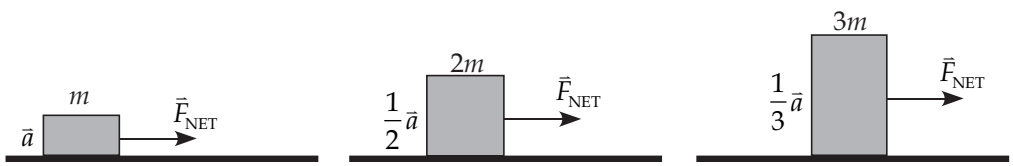
In the drawings below, the mass is held constant as it slides along a frictionless surface. The net force is increased and the resulting acceleration is determined.



From this series of drawings we can see that the acceleration is directly proportional to the force applied: $\vec{a} \alpha \vec{F}_{NET}$.

The second part is that very massive objects do not accelerate as well as less massive objects. If the mass increases for a given net force, the acceleration of the object decreases. This is called an inverse variation and is written as $\vec{a} \alpha \frac{1}{m}$.

The diagram below shows three situations. The same force is applied to three different masses on a horizontal frictionless surface. In the first situation, a net force $\vec{F}_{NET}$ is applied to a mass m, and the mass accelerates at a value of $\vec{a}$. In the second situation, the same force $\vec{F}_{NET}$ is applied to twice the mass, $2m$. This results in an acceleration of $\frac{1}{2}\vec{a}$. In the third situation, the force $\vec{F}_{NET}$ is applied to three times the mass, $3m$, resulting in an acceleration of $\frac{1}{3}\vec{a}$.



From this series of drawings, we can conclude that when the force is constant, the acceleration of the mass is inversely related to the mass: $a \alpha \frac{1}{m}$.

So an object will accelerate with the amount of acceleration depending on the net force (how hard it is being pushed overall) as well as on the object's mass (massive things are harder to accelerate).

Newton's Second Law: The **net force** of the **product** of **mass** and **acceleration**, or the **acceleration** is the **quotient** of the **net force** divided by the **mass**.

$$\vec{F}_{\text{NET}} = m\vec{a} \text{ or } \vec{a} = \frac{\vec{F}_{\text{NET}}}{m}$$

Quantity	Symbol	Unit
Net force	$\vec{F}_{\text{NET}}$	newton (N)
Mass	m	kilogram (kg)
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)

Note that this is a **vector equation**—the direction of the acceleration will always be the same as the direction of the net force.

Note that this is a vector equation—the direction of the acceleration will always be the same as the direction of the net force. You should be able to see from this equation that the best way to get a large acceleration is to give it a large push (big $\Sigma\vec{F}$), and to push on something that is not very massive (small m).

Definition of the Newton

Remember that we must use SI units, which means that mass must be in kg, and acceleration in m/s^2. But what unit is needed for force?

Well, notice that we could solve the equation for net force, resulting in $\vec{F}_{\text{NET}} = m\vec{a}$. The units would have to be the same on both sides of the equation, so the unit for force would have to be kg · m/s^2. (Note that we use a small multiplier dot between units.) This group of units is kind of clumsy, so we invent a new unit, which we call a **newton** (N) to represent exactly this.

A **newton** is defined as the force that causes a 1 kg mass to accelerate at 1 m/s^2 or 1 kg · m/s^2.

Perhaps a more familiar unit of force is the pound. A person that weighs 100 pounds for example, presses into the floor with 100 pounds of force. It may be helpful to know that a pound is the same thing as about 4.45 newtons (1 lb = 4.45 N). Helpful or not, we will not be using pounds anymore in this course.

Learning Activity 3.3

Newton's Second Law

1. According to Newton's Second Law, indicate how the acceleration will change if
   a) the mass of the object is doubled but the net force is kept constant.
   b) the net force on the object is tripled but the mass of the object is constant.
2. Calculate the net force acting on a 2.50 kg mass that causes an acceleration of 1.65 m/s^2 to the right.
3. What is the acceleration of a car of mass 1250 kg that is subjected to a net force of 2250 N [N]?
4. What is the mass of person who accelerates at 4.25 m/s^2 [S] under a net force of 265 N [S]?
5. A bicycle has a mass of 13.1 kg, and the rider has a mass of 81.7 kg. The rider is pumping hard, so that a horizontal net force of 9.78 N accelerates them. What is the acceleration?

Newton's Third Law

Try this activity. Hold your hand flat, palm down, and push on a table or desk. You should feel the table or desk push back on your hand. If you push harder with your hand, you feel the table or desk push back harder as well. This illustrates Newton's Third Law.

Newton's Third Law is popularly known as "for every action there is an equal and opposite reaction."

Newton's Third Law: For every action force on object B due to object A, there is a reaction force, equal in magnitude but opposite in direction due to object B acting back on object A.

$$\vec{F}_{\text{A ON B}} = -\vec{F}_{\text{B ON A}}$$

Here the term **"action" force** means the force that one body exerts on a second body, while **"reaction" force** means the force that the second body exerts on the first. There can be no force unless there are two bodies involved.

> **Note:** It should be remembered that action and reaction forces, though equal in magnitude and opposite in direction, can never neutralize each other for they always act on different objects. In order for two forces to neutralize each other, they must act on the same object.

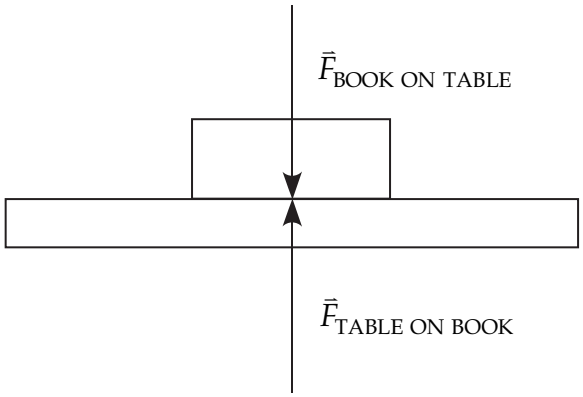
In the example of the book resting on a table in previous lessons, you will recall that the force of gravity on the book pulls the book downwards. The book exerted a force on the table that was equivalent to the force of gravity pulling down on the book.

At the same time, the table was pushing up on the book with a force that is called the normal force. As hard as the book is pushing on the table (action force), the table is pushing back up on the book (reaction force).

These two forces are equal in magnitude but opposite in direction. These two forces also act on different objects.

$$\vec{F}_{\text{BOOK ON TABLE}} = -\vec{F}_{\text{TABLE ON BOOK}}$$

Because the forces act on different objects, they do not cancel each other out.



Action-Reaction Pairs of Forces are All Around Us

When a baseball bat strikes a ball, the bat exerts a force on the ball while the two are in contact. During the same time, the ball exerts a force of the same magnitude but opposite in direction on the bat.

A freely falling body is accelerated by the net force (action force) with which the earth attracts the body. The earth in turn is accelerated by the opposite reaction force the body exerts on the earth. Because of the great mass of the earth, this acceleration is too small to be observed.

In throwing a light object, one has the feeling that he cannot put much effort into the throw, for he cannot exert any more force on the object than that object exerts in reaction against his hand. This reaction force is proportional to the mass of the object and to the acceleration of the object ($F = ma$). The thrower's arm must be accelerated along with the object thrown; hence the larger part of the effort exerted in throwing a light object is expended in "throwing" one's arm.

When one steps from a small boat to the shore, he observes that the boat is pushed away as he steps. The force he exerts on the boat is responsible for its motion. The force of reaction, exerted by the boat on him, is responsible for his motion toward the shore. The two forces are equal in magnitude and opposite in direction. The accelerations which they produce (in boat and passenger, respectively) are inversely proportional to the masses of the objects on which they act ($a = F/m$). Thus, a large boat will experience only a small acceleration when one steps from it to shore; a small boat experiences a much greater acceleration.

A rocket ship, coasting in space, suddenly fires its rockets. The rockets shoot a blast of gas backward with a force of 1000.0 newtons (action force) and the gas exerts an equal force (–1000.0 newtons) forward on the rocket ship (reaction force). This forward force causes the rocket ship to move forward.

A gun fires a bullet forward with a force of 50.0 N (action force) and the bullet exerts an equal force (–50.0 N) backward on the gun (reaction force). This backward force is normally called the ''kick" of the gun.

A skater standing on ice throws a large heavy ball with a force of 10.0 N (action force). The ball pushes back on the skater with a force of –10.0 N and the skater glides backwards.

A water skier pulls on a tow rope with a force of 1000 N (action force). The rope, in turn, pulls on the water skier with an equal but opposite force (reaction force) of –1000 N.

Using Newton's Laws

Knowing Newton's Laws is one thing. Using them to answer questions and solve problems is quite another.

Newton's First Law is useful in two ways:

1. If you are told that an object moves with **constant velocity**, then you may conclude that there is no net force on it.
2. If you are told that an object has **no net force** on it (or determine this on your own), then you may conclude that it is **not accelerating** (it moves with constant velocity or is not moving at all).

Newton's Third Law is useful in only one way: if you know the details of how one object exerts force on another, then you may conclude that the force acting on the first object from the second is the **same size**, but in the **opposite direction**.

Newton's Second Law will be the law that we find the most useful in problems. With knowledge of the forces acting on an object, we can add them (remember vectors!) to get the net force, which can then be used along with the mass of the object in Newton's Second Law to find the acceleration of the object. Of course, depending on what is given and what is asked for, there are other possibilities too. In particular, if you are given the mass and the acceleration of an object, then Newton's Second Law can be used to determine the net force. If you are also told all but one of the forces, you could then find the size and direction of the last force.

We will be doing much more with Newton's Second Law in an upcoming lesson.

Learning Activity 3.4

Newton's Laws

Once you have answered these questions, check your answers with the answer key at the end of this module.

1. If "action forces" and "reaction forces" are equal and opposite, why can they never balance or cancel?

2. In a car crash, a passenger's head collides with the window in the door. The passenger suffers a fractured skull. The window in the door is shattered. Account for this using Newton's Laws of Motion.

3. Using the appropriate law of motion, explain the following. Identify which law is being illustrated and then describe how the motion is explained by Newton's laws.

   a) A bullet is fired from a rifle. The rifle recoils.

   b) A karate expert attempts to break 10 boards piled on top of each other by striking them with one blow of his hand. In the process, he breaks a bone in his hand.

   c) The stationary car in which a passenger sits is struck from the rear by a second car. The passenger suffers whiplash.

   d) A curling rock slides along the ice and slowly comes to a stop.

   e) A rock is dropped from a bridge and accelerates towards the earth. The rock exerts a force on the earth. We do not notice the earth accelerating towards the rock.

Lesson Summary

Galileo Galilei first came up with the idea that force is not needed to keep an object going (inertia).

Sir Isaac Newton developed a set of three laws of motion (as well as other things). He lived approximately 300 years ago.

A **law** in physics is a statement that describes something that is always true, whenever we check. It does not explain why it is true.

Newton's First Law of Motion states that an object will maintain constant velocity (which includes being at rest as one possibility), unless acted on by a net force.

Inertia is the ability of an object to resist changes in its state of motion. Newton's First Law can be referred to as the law of inertia.

The unit of force is the **newton**. It is the net force needed to cause a mass of 1 kg to have an acceleration of 1 m/s^2. This unit is abbreviated as "N".

Newton's Second Law of Motion can be mathematically stated as $\vec{F}_{\text{NET}} = m\vec{a}$ or $\vec{a} = \frac{\vec{F}_{\text{NET}}}{m}$. Force is a vector, and the direction of the acceleration is in the same direction as the force.

Newton's Third Law of Motion states that whenever one object exerts force onto another object, it also experiences a force back from it. These two forces are equal in size and opposite in direction.

It is important to note now that a pair of action reaction forces do not cancel out since they act on different bodies.

NOTES

Lesson 3: Video Laboratory Activity: Dynamics (2.0 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe how the acceleration of a cart changes as the applied force varies while holding the mass of the object constant
- describe how the acceleration of a cart changes as the mass varies while holding the force applied to the object constant
- describe the overall relationship between the net force acting on an object, the mass of the object, and the acceleration of the object

Please note that this lesson contains only a video laboratory assignment.

Video Laboratory Activity: Dynamics

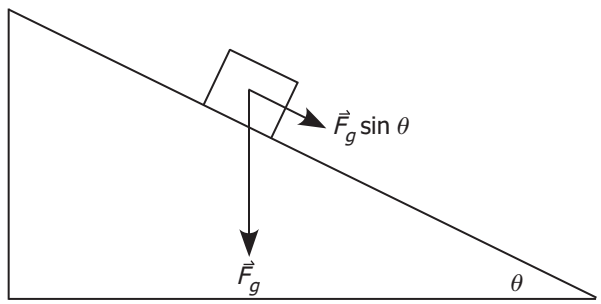
Notes to Students

In this lesson, you will view *Dynamics*, a short video laboratory activity found in the learning management system (LMS). You will collect some data from the video so you should begin by reading the introduction and answering the pre-lab questions.

When you have finished the lab activity, you will complete a Laboratory Report, which is found at the end of this and every other Laboratory Assignment. The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

Introduction

What happens when you apply a force to an object? We know from our experience that objects move if we apply enough force. To investigate the exact nature of this motion, we will roll a cart down an inclined plane. The applied force acting on the cart is a component of gravity, which is constant near the surface of the earth. The component of the force of gravity acting on the cart down the plane is $\vec{F}_g = \sin\theta$.



Since sin θ is proportional to the opposite side (h), and the applied force is proportional to sin θ, we can increase the force acting on our cart by raising the height of the plane. If we raise the height of the plane in equal increments, then our applied force will also increase in equal increments. That is, we can measure our applied force as 1, 2, 3, 4 and proportional units (blocks) as we increase the angle of the plane in the video.

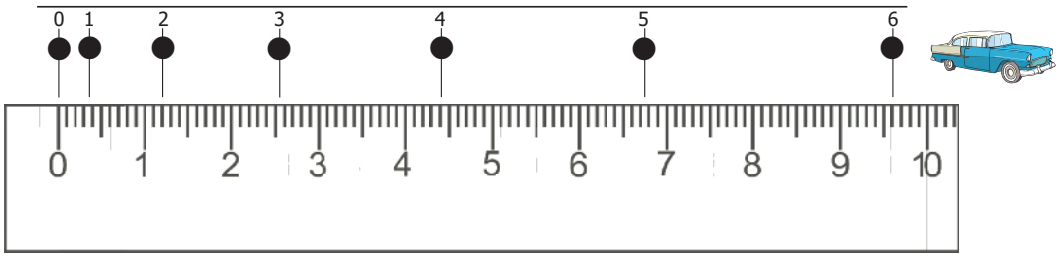
To measure the motion of the cart, we will use a "tickertape" timing device. To learn how to use the timer, consider the following problem.

Sample Problem

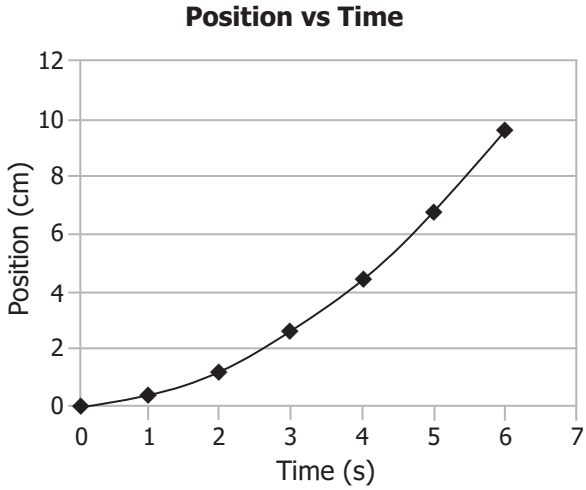
A car with a leaky engine accelerates from a stoplight and leaves oil drops on the road at regular one-second intervals. Using the oil drops, find the acceleration of the car.

1. To begin, mark and label the dots.

2. Now measure the position for each interval. Record your measurements in a data table and make a graph.



Position (cm)	Time (s)
0	0
0.35	1
1.20	2
2.55	3
4.40	4
6.75	5
9.60	6



3. Next, find the average velocity for each interval. Note that the average velocity for the interval very closely approximates the instantaneous velocity at the midpoint of the interval. Thus, when we plot velocity versus time, we will use the time midpoint.

Velocity v (cm/s)	Time (s)
0.35	0.5
0.85	1.5
1.35	2.5
1.85	3.5
2.35	4.5
2.85	5.5

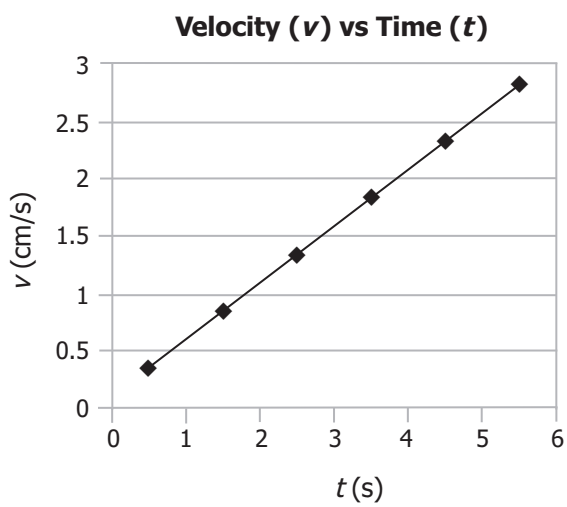
For example, to find the average velocity for the interval from t = 2 s to t = 3 s (e.g., t = 2.5 s).

$$v_{avg} = \frac{pos_2 - pos_1}{t_2 - t_1}$$

$$v_{avg} = \frac{2.55 - 1.20}{3 - 2}$$

$$v_{avg} = 1.35 \text{ cm/s}$$

4. Graph velocity versus time.



The acceleration is the slope of the line and is constant for all parts of the line.

$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

$$a = \frac{2.35 - 0.85}{4.5 - 1.5}$$

$$a = \frac{1.5}{3}$$

$$a = 0.5 \text{ cm/s}^2$$

Purpose

To determine the relationship between force and acceleration for a cart on an inclined plane

Apparatus

- dynamics cart
- inclined plane
- bricks
- tickertape timer

Procedure

1. Set up the apparatus and check the operation of the tickertape timer.
2. Connect the tickertape to the back of the cart.
3. Start the timer and release the cart.
4. Label the tape and lower the inclined plane.
5. Repeat for heights of the plane at 32, 27, 22, 17, and 12 cm.
6. Start with the 32 cm tape and mark off equal time intervals (six intervals for each time mark gives a time of 0.1 seconds). Copies of the tickertape are included on the following pages. Line up point A on the first section with point A on the second section. Point B on the second section lines up with point B on the third section. If you find it easier, cut out tapes. Your measurements will vary slightly from the measurements on the video because of the photocopying.
7. Measure each interval and complete a table for distance (cm) and time (seconds) for each tape. **Remember to add the changes in position together to get the total distance from the origin. For example, see the sample problem.**
8. For each tape, calculate velocity and record in a new table (see the sample problem and/or follow the procedure on the video for using Excel).
9. For each tape, make a graph of velocity versus time and calculate acceleration.
10. Complete the following acceleration and force table, and graph acceleration versus force.

Video Viewing

View the video *Dynamics*, which can be found in the learning management system (LMS).

Data and Calculations

Acceleration (cm/s^2)	Force (blocks)
	1
	2
	3
	4
	5

Discussion

Discuss possible sources of error in this experiment and how you could reduce the error.

Outline a procedure that could be used to determine the relationship between force and mass.

The net force is the sum of the applied force down the plane (in this case, gravity) plus the force of friction (in this case, the force of friction is opposite the motion). Thus, $\vec{F}_{\text{net}} = \vec{F}_A + \vec{F}_f$. What happens to the net force when the force of friction increases? What happens to the acceleration?

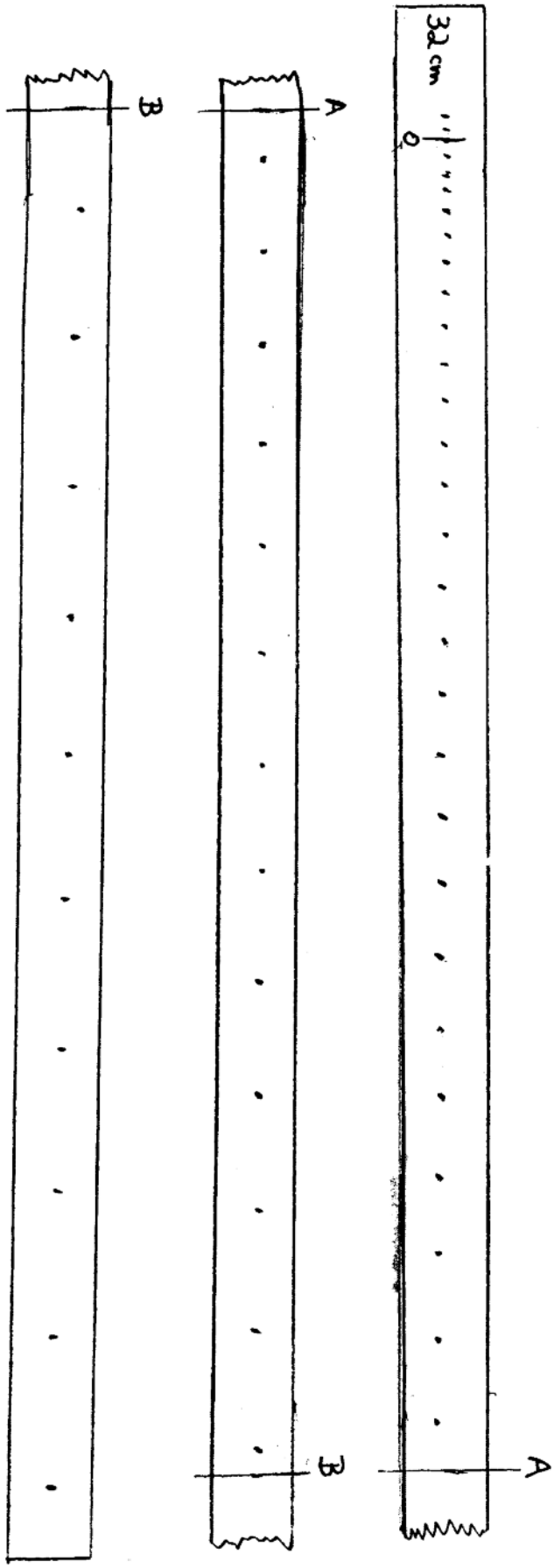
What would the distance-versus-time tickertape look like if there was no acceleration?

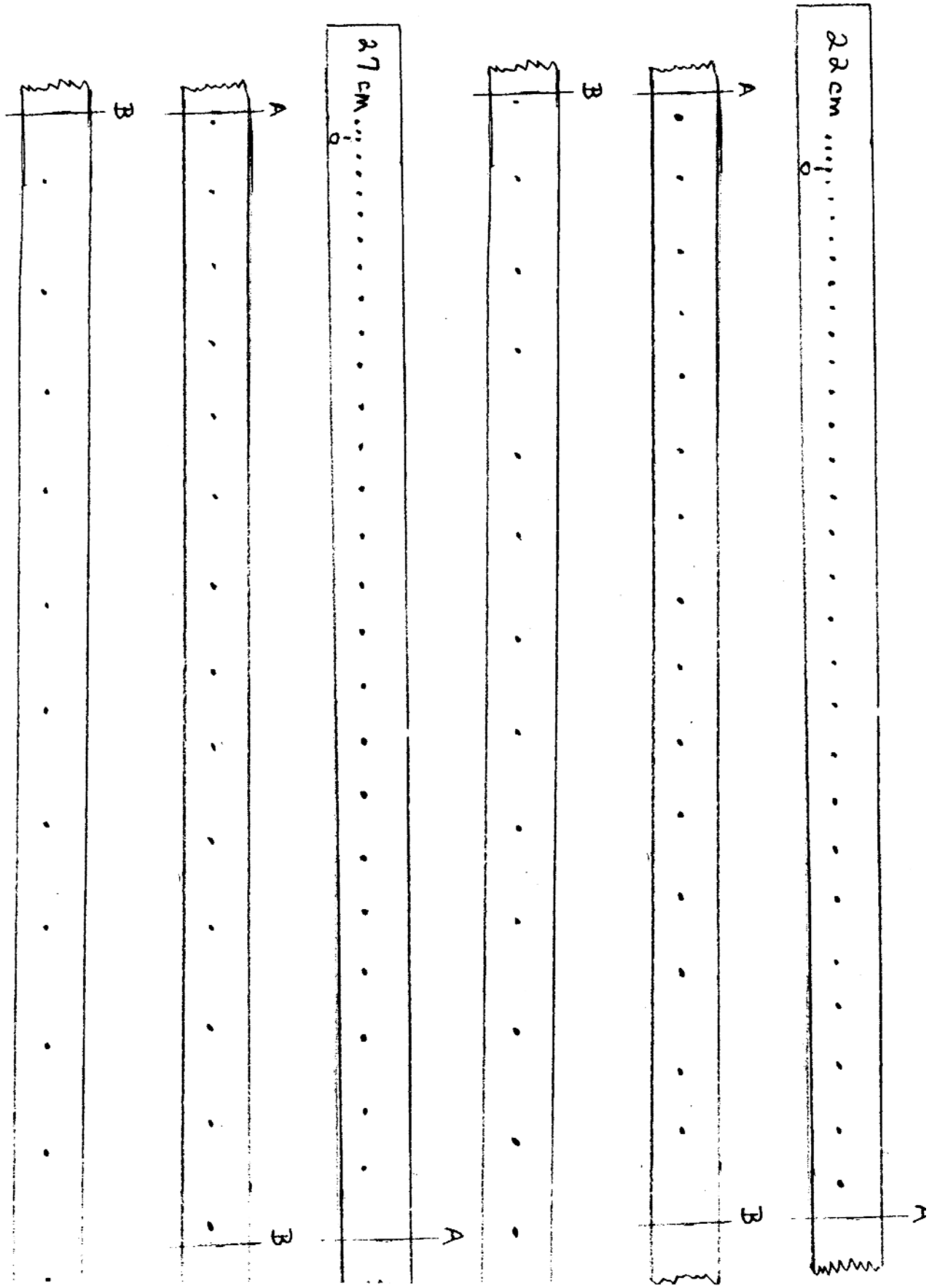
Conclusion

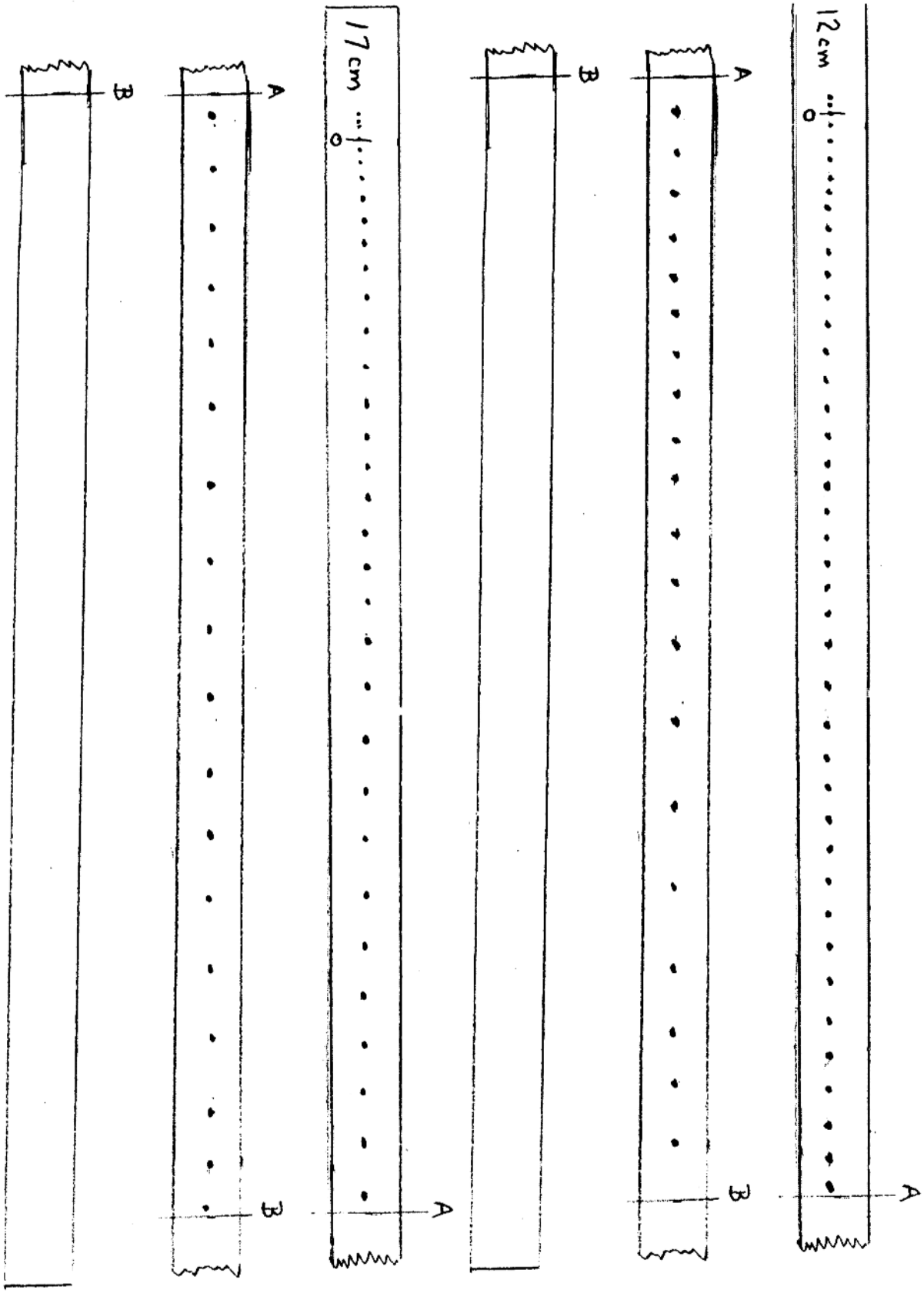
What is the relationship between acceleration and force?

Tapes

See samples of tapes on the following pages.


32 cm
0
A
B
A
B


22 cm
0
A
B
A
B
27 cm
0
A
B
A
B


12 cm
0
A
B
A
B
17 cm
0
A
B
A
B

NOTES

Assignment 3.1

Video Laboratory Activity: Dynamics (20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow those directions.

The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words, in a brief paragraph (do not use point form), how the experiment was performed.

(continued)

Assignment 3.1: Video Laboratory Activity: Dynamics (continued)

Data and Calculations:

- Include photocopies of your data measurements (e.g., tapes or tracks) if they were provided in the notes.
- Include the raw data for each part of the experiment in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data. For example, if you use a formula, write out the formula, and show your substitutions and calculations. This should be done for each different calculation (that is, whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be done.

(continued)

Assignment 3.1: Video Laboratory Activity: Dynamics (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce the error.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. Errors are always made when making measurements. In the error analysis, your job is to look critically at the procedure, identify possible sources of error (there may be several), and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 3.1: Video Laboratory Activity: Dynamics (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

_____

_____

_____

_____

_____

Marking Rubric for Assignment 3.1

Section of Report	Possible	Actual
Purpose	1	
Apparatus and Procedure	2	
Completed Position-Time Data Tables	4	
Sample Instantaneous Velocity Calculation	1	
Completed Velocity-Time Tables and Velocity-Time Graphs	4	
Sample Calculation of Average Acceleration	1	
Force-Acceleration Graph	2	
Discussion (Errors — 2 and Questions — 2)	4	
Conclusion	1	
Total	**20**	

LESSON 4: FREE-BODY DIAGRAMS (1.5 HOURS)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the terms "free-body diagram," "non-contact force," "contact force," "friction," "normal force"
- ❑ apply the strategy for drawing free-body diagrams for falling objects, objects on a flat surface, and objects on an inclined surface

Key Words

free-body diagram	non-contact force	contact force
normal force	friction	net force
applied force	air friction	balanced force
unbalanced force		

Introduction

When we do physics problems involving several forces acting on an object, it is important to understand exactly which forces are acting and in what directions they are acting. To help in this understanding, it is helpful to draw diagrams called "free-body diagrams." The focus of this lesson will be to learn how to draw these diagrams, and later to use this skill in problem solving.

Free-Body Diagrams Defined and Strategy for Drawing

A **free-body diagram** is a diagram that represents an object and all the forces acting on it.

In drawing a free-body diagram, the following strategy should be used.

1. Draw a sketch of the object completely removed from its physical surroundings. Often the force vectors are drawn from a dot at the centre of the object, that is, the tails of the vectors are placed on the dot representing the object.
2. Draw vectors representing the forces acting on the object. The vectors must show the direction of the force. It is also useful to approximate the magnitude of the force, so the length of the vector is important. But in first drawing the vectors, it is often not clear what the length should be, so an approximate length can be shown.
3. Free-body diagrams should look like a cross (+).
4. Do not include forces exerted on the surroundings by the object.
5. When finding the net force acting on an object from a free-body diagram, use the rules for vector addition.

We will now examine several situations in which free-body diagrams will be drawn.

Free-Body Diagram for Falling Objects

1. Free fall in a vacuum

In this case, there is only one force vector. That is the force due to gravity. The force vector is drawn straight down.

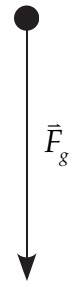
The force of gravity arises because of a gravitational attraction between the earth and the ball. The symbol for the force of gravity is $\vec{F}_G$.

Here at the Earth's surface, you know that objects with more mass have more weight (a larger force of gravity acts on them). For now, the value of the force of gravity will be supplied when it is needed. In the next module, you will discover a method of calculating the force of gravity if you know the mass of the object.

The earth and the ball are not actually in contact. This is an example of a "non-contact force."

The **non-contact force** can be defined as a force between two objects that arises when the objects are not in contact with each other.

Other examples of non-contact forces are the electrical forces and the magnetic forces to be studied later.



The **net force** is the vector sum of all the forces acting on an object.

We calculate the net force by adding all of the forces acting on the object as specified in the free-body diagram.

In this case, the sum of all forces acting on the object = the force of gravity: $\vec{F}_{\text{NET}} = \sum \vec{F} = \vec{F}_g$.

The force of gravity has no other force to oppose it in this case. There are no other forces to balance the force of gravity.

An **unbalanced force** occurs when a force in a given direction is not opposed by another force of the same magnitude but opposite direction acting on the same object.

In this case, the force of gravity is an **unbalanced force**.

Therefore, according to Newton's Second Law, the object will accelerate in the direction of the net force. The object will accelerate downwards as it falls.

If the net force acting on the object is 0 N $\left(\vec{F}_{\text{NET}} = 0\text{ N}\right)$, then we say that the forces are **balanced**.

Balanced forces that are acting on a given object are those forces whose sum is 0 N.

If the forces are balanced, then according to Newton's Second Law, $\vec{F}_{\text{NET}} = m\vec{a}$, the acceleration must also be 0 m/s^2.

This of course is Newton's First Law. If the object is at rest, it will remain at rest. If the object is in motion, it will remain in motion with a constant velocity.

2. Free fall with air friction

The force vector representing gravity is still present. There is also now the vector presenting air friction pointing straight up. Friction is an example of a "contact force."

> A **contact force** is defined as a force that arises when two objects are in contact.

One example of a contact force is the force of friction.

> **Friction** can be defined as a force opposing the relative motion of two objects that are in contact. The symbol for the force of friction is $\vec{F}_F$.

In this case, friction arises because of air pushing against the ball as it falls. Usually, friction is a force that acts in a direction **opposite** to the motion of the object on which it acts. So if the object is falling **downwards**, friction acts **upwards**.

The net force $\left(\vec{F}_{\text{NET}}\right)$ is the sum of all forces acting on the object.

$F_{\text{NET}} = \Sigma\vec{F} = \vec{F}_g + \vec{F}_F$

The object will accelerate in the direction of the net force—downwards.

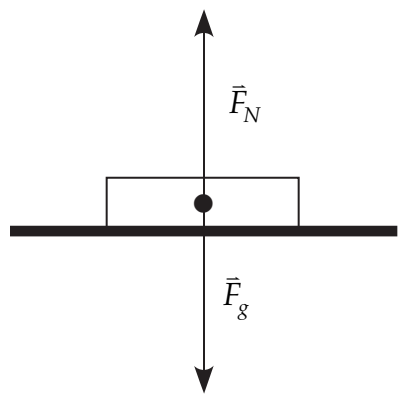
Free-Body Diagram for Objects on a Flat Surface

3. An object resting on top of a table

When an object such as a book rests on a tabletop, the table pushes back on the book with an equal and opposite force (Newton's Third Law). The force that the table exerts on the book is referred to as a "normal force."

> A **normal force** is a force that acts perpendicular to the surface of contact. The symbol for the normal force is $\vec{F}_N$.

In this situation, the book is at rest. This is an example of an equilibrium situation.



The normal force is a little strange in that it has no fixed value. You experience a normal force when you sit on a chair. If you alone are sitting on the chair, you feel a normal force of a certain value. However, if you are seated on the same chair but are holding a stack of 10 physics textbooks (these are always the largest books), you will feel a larger normal force pushing up on you.

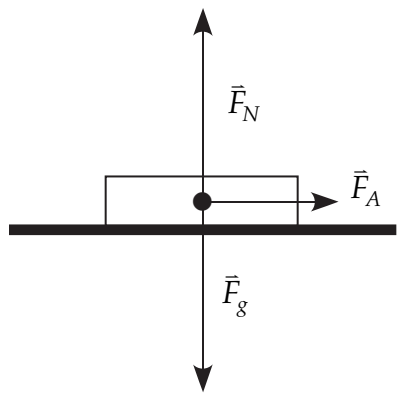
The net force is $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_g + \vec{F}_N$.

In this case, the net force is 0 N as the two forces are equal but opposite and, therefore, cancel out.

4. An object on a frictionless table being pulled to the right

When the book mentioned earlier is pulled to the right, the gravitational force and the normal force are still acting. The pull to the right is an applied force.

> An **applied force** is a force applied to an object by an external agent. It is the external agent pushing or pulling on the object. The symbol for the applied force is $\vec{F}_A$.



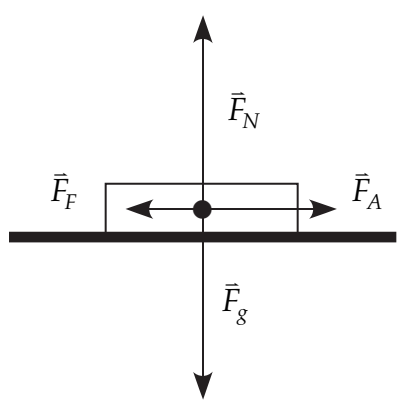
The net force is $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_g + \vec{F}_N + \vec{F}_A$.

Since the force of gravity and the normal force cancel out, the net force is just the applied force: $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_A$.

The object will accelerate in the direction of the net force—to the right.

5. An object pulled to the right on a surface with friction. Assume that the pull to the right is larger than the force of friction.

For the book described above, the force of friction is opposite to the applied force, and is, therefore, to the left. This friction vector is shorter than the applied force vector.



The net force is $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_g + \vec{F}_N + \vec{F}_A + \vec{F}_F$.

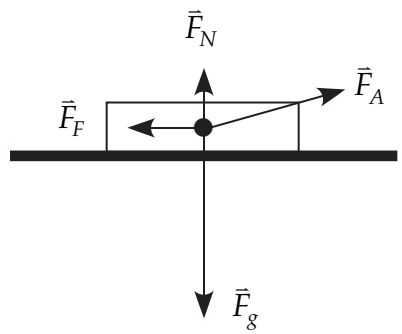
Since the force of gravity and the normal force cancel out, the net force is given by the sum of the applied force and the force of friction.

$$\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_A + \vec{F}_F.$$

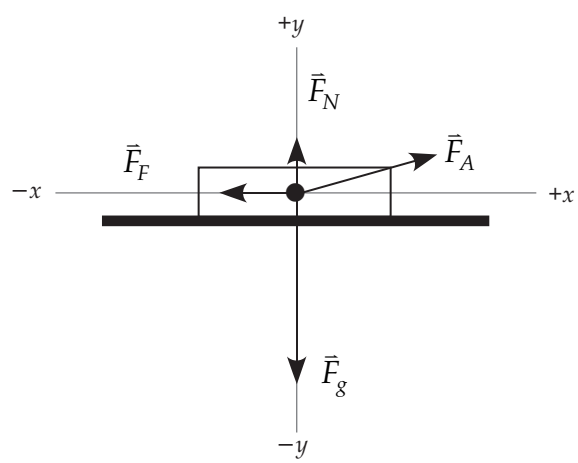
The object will accelerate in the direction of the net force (that is, to the right).

6. An object pulled to the right with an applied force at an angle to the horizontal.

When the applied force is at an angle above the horizontal surface, the normal force is decreased. This effect will be discussed in more detail later in this course.



In order for us to find the sum of these forces, we will require the **components** (x-component and y-component) of all of the forces. In this case, let's superimpose an x–y coordinate system on the diagram above.

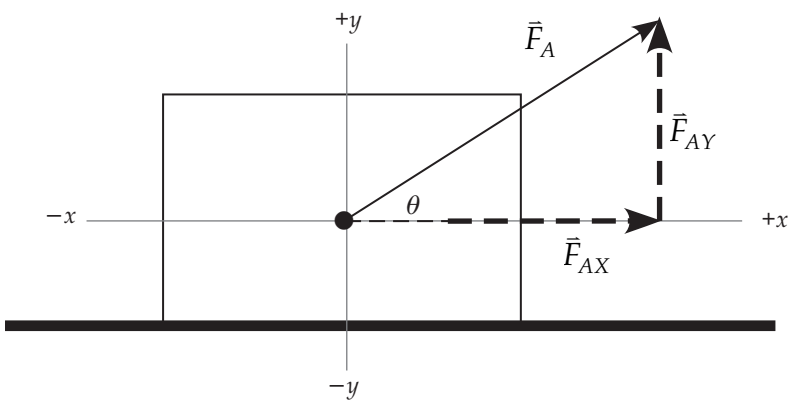


You can see that all of the forces nicely fit along the x-axis and the y-axis except for the applied force.

Free-body diagrams should look like a cross (+) with all of the forces pointing along one of the major axes.

So, in this case, we have a little extra work to do. Specifically, we must resolve the vector $\vec{F}_A$ into its components, an x-component and a y-component.

Let's magnify the applied force. We will call the angle between the horizontal and the vector θ.

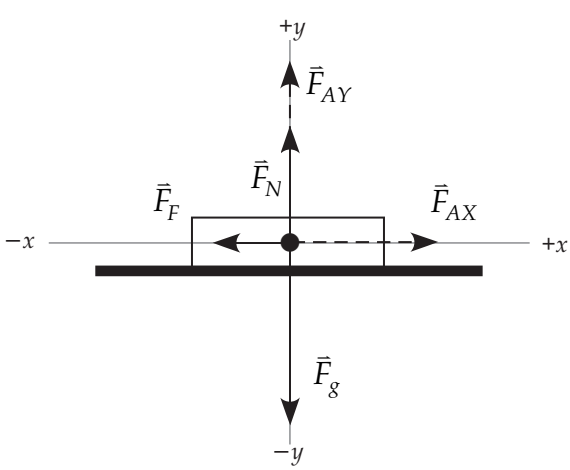


Using trigonometry, we see that

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{F}_{AY}}{\vec{F}_A} \text{ and } \vec{F}_{AY} = (\sin\theta)\vec{F}_A.$$

$$\text{Similarly, } \cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{F}_{AX}}{\vec{F}_A} \text{ and } \vec{F}_{AX} = (\cos\theta)\vec{F}_A.$$

So we can now replace the applied force with its two components and have a free-body diagram with all the forces pointing along a major axis. This diagram has the shape of a cross (+).



The net force is given by $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_g + \vec{F}_N + \vec{F}_{AY} + \vec{F}_F + \vec{F}_{AX}$.

In this case, the force of gravity, the normal force, and the y-component of the applied force all add up to 0 N.

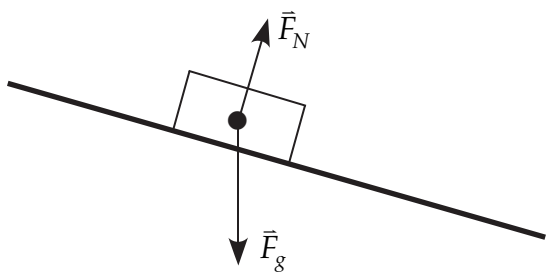
Therefore, $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_{AX} + \vec{F}_F$.

The object will accelerate in the direction of the net force (that is, to the right).

Free-Body Diagram for Objects on an Inclined Surface

7. An object on a frictionless incline

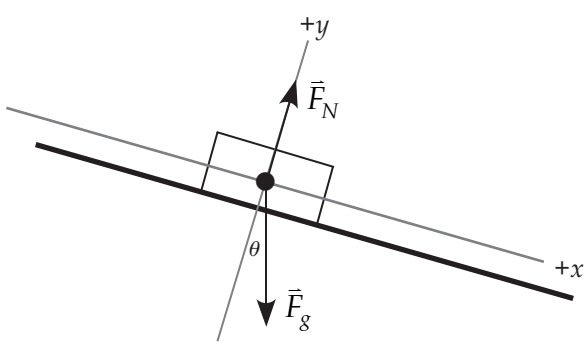
In this case, there are only two forces acting on the object. Gravity acts on the object downwards. The normal force is perpendicular to the surface of contact. Note that we continue our convention of drawing the normal forces from one point (in this case, the centre of the box).



Again, the free-body diagram does not look like a cross.

In this case, we will have to take components of one of the forces to obtain the cross shape. The question is which force to use?

Here is what we do. We establish a coordinate system at an angle so that the x-axis runs **parallel to the surface** and the ***y*-axis runs perpendicular** to the surface of the inclined plane.



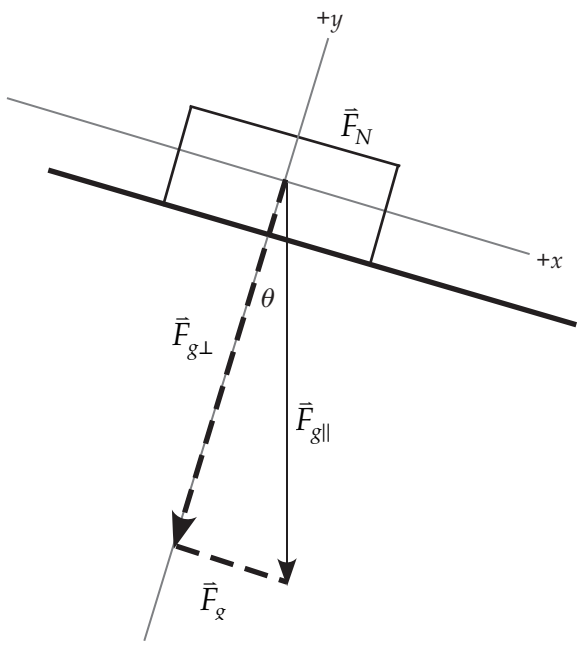
You can see that the force of gravity does not fit along a major axis. Therefore, we must resolve the force of gravity into its components:

- $\vec{F}_{g\parallel}$ = the component of the force of gravity **parallel** to the surface (the x-component)

  and,

- $\vec{F}_{g\perp}$ = the component of the force of gravity **perpendicular** to the surface (the y-component).

Here is a larger version of the triangle.

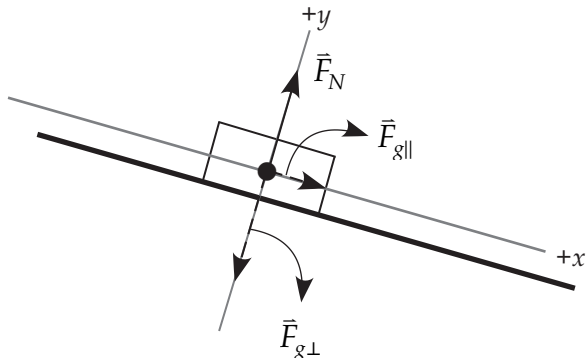


Using trigonometry, we see that

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{F}_{g\parallel}}{\vec{F}_g} \text{ and } \vec{F}_{g\parallel} = (\sin\theta)\vec{F}_g.$$

$$\text{Similarly, } \cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{F}_{g\parallel}}{\vec{F}_g} \text{ and } \vec{F}_{g\perp} = (\cos\theta)\vec{F}_g.$$

So, finally, here is the free-body diagram with the components of the force of gravity giving us the necessary cross shape (+).



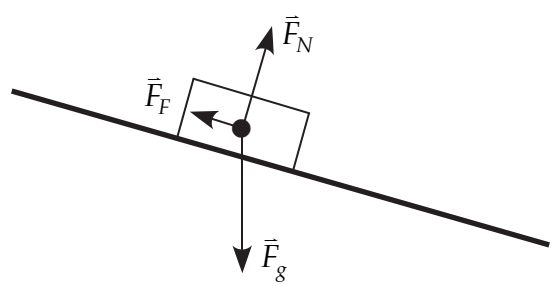
You can see here that the normal force and the perpendicular component of the force of gravity cancel, leaving a net force of the parallel component of the force of gravity.

$$\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_{g\parallel}$$

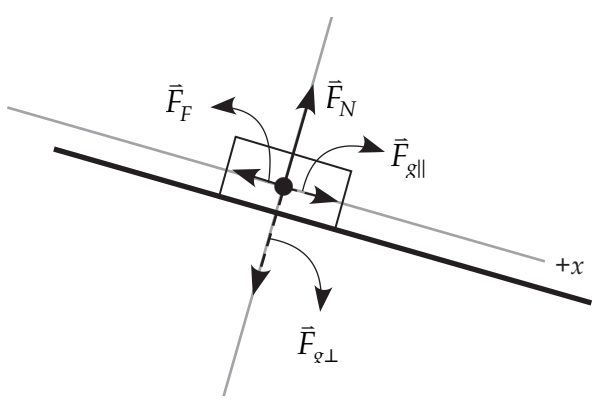
The object accelerates in the direction of this net force—down the incline.

8. An object on an incline with friction

The forces in the previous diagram are still at work. If the object is sliding down the incline, then the force of friction is opposite to the direction of motion. The force of friction is therefore up the incline and parallel to it.



After resolving the force of gravity into its components, the free-body diagram is as follows:



You can see here that the normal force and the perpendicular component of the force of gravity cancel, leaving a net force of the parallel component of the force of gravity and the force of friction.

$$\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_{g\parallel} + \vec{F}_F$$

The object accelerates in the direction of this net force—down the incline.

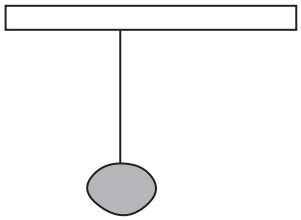
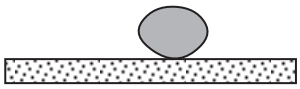
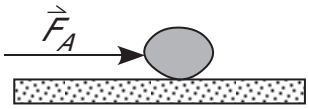
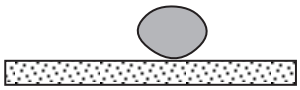
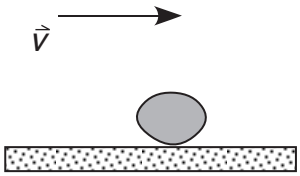
Learning Activity 3.5

Free-Body Diagrams

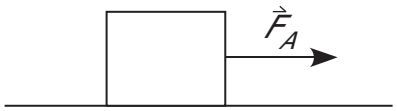
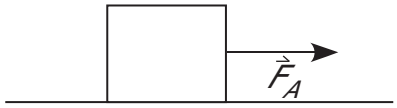
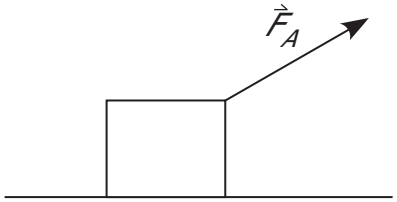
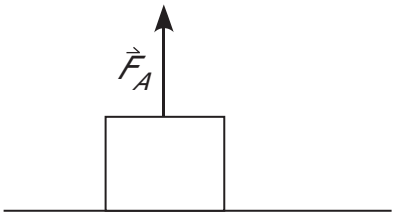
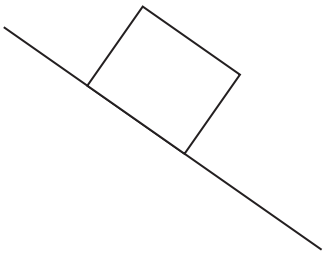
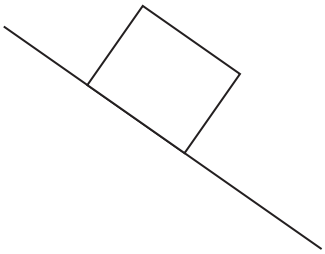
There are 15 questions in this Learning Activity. In each case, the rock is acted upon by one or more forces. All drawings are in the vertical plane, and friction is negligible except where noted. Draw accurate free-body diagrams showing all forces acting on the rock. Draw all forces as though they were acting on the centre of mass, even though forces like friction and the normal force act on the surface, at the point of contact. Please use a ruler and do it in pencil so that you can correct errors. Label the forces using $\vec{F}_g$ for the weight or force of gravity, T for tension, $\vec{F}_F$ for force of friction, $\vec{F}_N$ for normal force, and $\vec{F}_A$ for applied force.

For each question, indicate whether the forces are **balanced** or **unbalanced**.

Part 1:

1. Equilibrium 	2. Equilibrium 	3. Rock is pushed but remains motionless. Friction acts. 
4. Rock is falling, no friction.	5. Rock is sliding at constant speed on a frictionless surface. 	6. Rock is falling at a constant (terminal) velocity.
7. Rock is decelerating because of kinetic friction. 	8. Rock is rising. No friction.	9. Rock is at the top of its flight, momentarily motionless.

Part 2:

1. The object is pulled horizontally. No friction.  	2. The object is pulled horizontally at constant velocity. Kinetic friction acts. 
3. The object is pulled by a force acting in the direction shown. Static friction acts. The object is motionless.  	4. The object is pulled straight upwards. It is motionless. 
5. The object is resting on the plane. No friction acts. 	6. The object remains motionless. Static friction acts. 

Lesson Summary

A **free-body diagram** is a diagram that represents an object and all the forces acting on it.

The following is a brief summary of the strategy to be used in drawing a free-body diagram.

- Draw a sketch of the object completely removed from its physical surroundings. Often the force vectors are drawn from a dot at the centre of the object.
- Draw vectors representing the forces acting on the object. The vectors show the direction of the force and the approximate magnitude of the force.
- Free-body diagrams should look like a cross (+).
- Do not include forces exerted on the surroundings by the object.
- When finding the net force acting on an object from a free-body diagram, use the rules for vector addition.

The **non-contact force** can be defined as a force between two objects that arises when the objects are not in contact with each other.

A **contact force** is defined as a force that arises when two objects are in contact.

Friction can be defined as a force opposing the relative motion of two objects that are in contact.

A **normal force** is a force that acts perpendicular to the surface of contact.

An **unbalanced force** occurs when a force in a given direction is not opposed by another force of the same magnitude but opposite direction acting on the same object. Objects accelerate in the direction of a net unbalanced force.

Balanced forces that are acting on a given object are those forces whose sum is 0 N.

If the forces are balanced, then according to Newton's Second Law, $\vec{F}_{\text{NET}} = m\vec{a}$, the acceleration must also be 0 m/s^2.

This, of course, is Newton's First Law. If the object is at rest, it will remain at rest. If the object is in motion, it will remain in motion with a constant velocity.

NOTES

Assignment 3.2, Part A

Free-Body Diagrams (5 MARKS)

Be sure to show all your work and explain the method of arriving at your answer.

Draw a free-body diagram showing all the forces involved. Label each of the forces with the appropriate symbol. Be sure to draw the forces of appropriate size.

1. A steel ball is falling through water. Assume that the gravitational force is larger that the frictional force of the water.

2. A rectangular box is pulled to the left with a horizontal force. There is friction between the box and the flat, horizontal surface. The force to the left is larger than the frictional force.

(continued)

Assignment 3.2, Part A: Free-Body Diagrams (continued)

3. An inclined surface is slanting down and to the right. An object is sliding down the incline. There is friction between the object and the surface of the incline.

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for Question 1
- 2 marks for Question 2
- 2 marks for Question 3

Lesson 5: Linking Newton's Second Law and Kinematics (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe how Newton's Second Law of Motion applies in various situations
- draw free-body diagrams to aid in the analysis of problems involving forces
- solve problems involving the forces acting on an object (dynamics) and the motion of the object (kinematics)

Key Words

newton of force
Newton's Second Law
free-body diagram

Introduction

In this lesson, you will synthesize all of the ideas about forces and Newton's laws with the ideas of kinematics. You will look at the dynamics information that is presented, and analyze this information to give the net force acting on the object. If you know the net force and the mass, you can use Newton's Second Law to determine the acceleration of the object. Finally, knowing the acceleration allows you to solve problems concerning the motion (kinematics) of the situation.

As you progress through the study of physics, you will use this process of taking the concepts that you know and analyzing them from a new angle. Then you will synthesize these new concepts into what you already know, so as you study physics you are always trying to link concepts together.

A Short Review

Newton's First Law, the law of inertia, dealt with the motion of objects when the net force acting on them was 0 N. Objects that were at rest remained at rest (inertia of rest), and objects that were in motion remained in motion with the same speed and direction of motion (inertia of motion).

Newton's Second Law deals with what happens when the net force is not zero newtons.

To see the basic ideas expressed by the Second Law, consider a hockey puck. When a player strikes a stationary puck, he causes the velocity of the puck to change. In other words, he makes the puck accelerate. The **cause** of the acceleration is the force that the hockey stick applies to the puck. As long as this force acts, the velocity increases and the puck accelerates.

If the net force acting on an object is not 0 N, then an **unbalanced force** is acting on the object. An **unbalanced force** acting on an object **causes** the object to **accelerate in the direction of the force**.

Here is the mathematical statement of Newton's Second Law.

Newton's Second Law of Motion: The effect of a net force applied to a body is to cause the body to accelerate in the direction of the force. The acceleration is in direct proportion to the net force and in inverse proportion to the mass of the body.

The mathematical statement of Newton's Second Law of Motion is:

$$\vec{F}_{\text{NET}} = m\vec{a}$$

Quantity	Symbol	SI Unit
Net force	$\vec{F}_{NET}$	newtons (N)
Mass	m	kilograms (kg)
Acceleration	$\vec{a}$	metres/second/second (m/s/s)

It is very important that you understand that the $\vec{F}_{\text{NET}}$ in the formula $\vec{F}_{\text{NET}} = m\vec{a}$ always means net force. Remember from Lesson 4 that net force is the vector sum of all of the forces acting on a body. Therefore, if more than one force is acting on a body, the vector sum of these forces must be determined.

Always include a free-body diagram when working through dynamics problems.

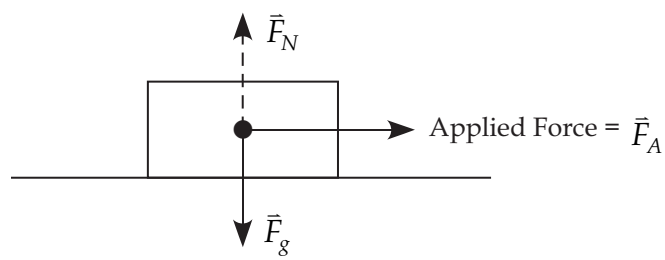
The free-body diagram helps you to keep track of forces and to reduce confusion when presented with many forces in a problem.

Let's consider the following simple example. Again, try to be systematic in your problem-solving approach. Draw diagrams of the situation, draw free-body diagrams, and use the GUESS method.

Example 1: Newton's Second Law

How many newtons of force must a boy exert horizontally against a 10.0 kg box resting on a smooth floor (negligible friction) to give the box an acceleration of 2.00 m/s^2?

Given: Free-body diagram



mass $m = 10.0$ kg

acceleration $\vec{a} = +2.00 \text{ m/s/s}$

Unknown: net force $\vec{F}_{\text{NET}} = ?$

Equation: $\vec{F}_{\text{NET}} = m\vec{a}$

Substitute: $\vec{F}_{\text{NET}} = (10.0 \text{ kg})(+2.00 \text{ m/s/s})$

Solve: $\vec{F}_{\text{NET}} = +20.0 \text{ N}$

Therefore, the force exerted by the boy is 20.0 N to the right.

Problems relating the net force, the mass, and acceleration in a given situation are quite simple.

Dynamics Problems with Friction

Let's consider a more challenging problem involving friction.

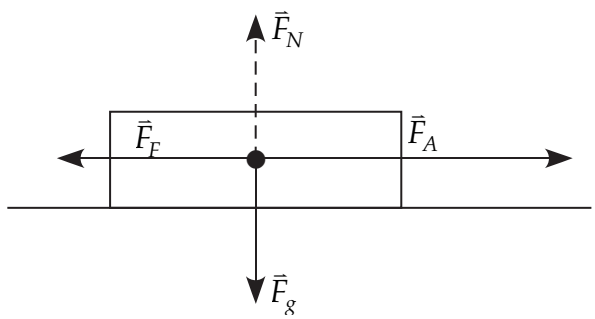
You should be able to solve a problem where you're given several forces that must be added to give the net force. Again, remember that a free-body diagram is very useful in keeping track of the forces acting on the body.

Example 2: Newton's Second law

A car of mass 1250 kg is pushed forward by its tires with a force of 2750 N. A force of friction of 1530 N also acts on the car. What is the acceleration of the car?

Given: Let right be the positive direction.

mass of the car	$m = 1250$ kg
applied force on the car	$\vec{F}_A = +2750$ N
force of friction on the car	$\vec{F}_F = -1530$ N



Unknown: acceleration of the car $\vec{a} = ?$

Equation: $\vec{F}_{\text{NET}} = m\vec{a}$

In this case, you do not know the net force. You must calculate this first.

$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F + \vec{F}_N + \vec{F}_g$

Note: The normal force and a force of gravity are equal but opposite. Since they are acting on the same body, these two forces are balanced and therefore cancel out. So, $\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F = (+2750\text{ N}) + (-1350\text{ N}) = +1220\text{ N}$.

Use $\vec{F}_{\text{NET}} = m\vec{a}$ and rearrange to get $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$.

Substitute and Solve: $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m} = \dfrac{+1220\text{ N}}{1250\text{ kg}} = +0.976\text{ m/s}^2$

Rounding the answer off to three significant digits, the acceleration of the car is 0.976 m/s/s [Right].

Learning Activity 3.6

Force of Friction

1. A wagon loaded with luggage has a mass of 525 kg. Two baggage handlers are pulling on the hitch of the wagon. The first person pulls with a force of 275 N and the second person pulls with a force of 175 N. Both people pull to the right. A force of friction of 225 N acts on the wagon. The force of gravity is 5140 N.

   a) Draw a free-body diagram labelling all of the forces.

   b) What is the normal force?

   c) What is the net force acting in the wagon?

   d) What is the acceleration of the wagon?

2. Suppose in Question #1 that when the two baggage handlers pulled on the wagon, the acceleration was 0.225 m/s^2 to the right. If everything else was the same, what would be the force of friction in this case? (Hint: Find the net force first using Newton's Second Law, then find the force of friction.)

Relating Dynamics Information to Kinematics Information

Many times in problems involving dynamics, kinematics information is also provided. Since **kinematics** is the **study of motion** and dynamics is a **study of the cause of the motion**, it is logical that these two should be linked together.

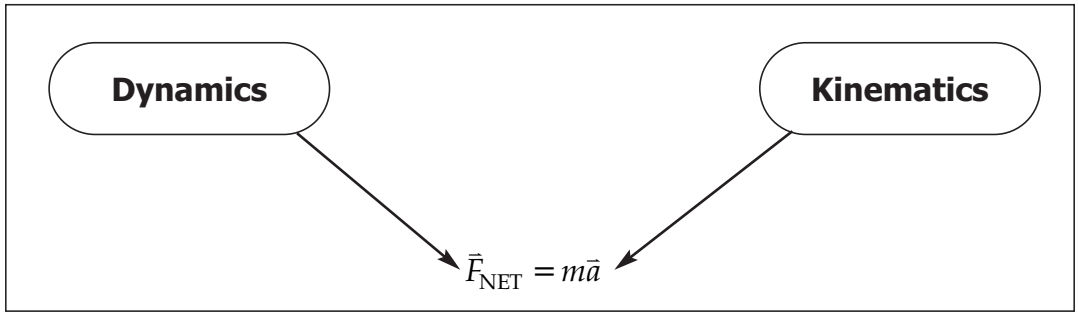
> The **link** between **kinematics** and **dynamics** happens to be Newton's Second Law.

The most efficient method for solving these kinds of problems is to take the information from the question and divide it into two categories: dynamics and kinematics.

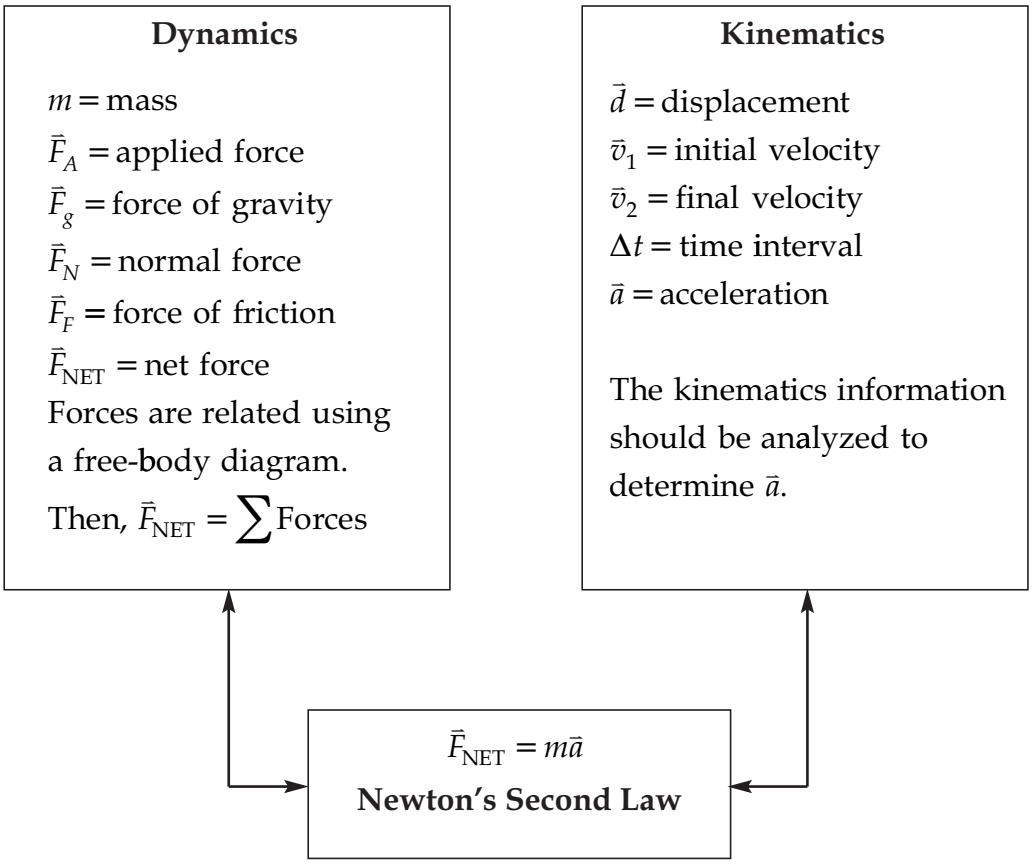
The work that can be done using the dynamics information depends on what exactly is given. When analyzing this information, you list the forces, draw a free-body diagram, and determine the net force.

The work that can be done using the kinematics information again depends exactly on what is given. In analyzing this information, you list the displacement, the velocities, and the time intervals. The goal is to determine the acceleration.

Since the dynamics information resulted in the net force and since the kinematics information resulted in the acceleration, the link between dynamics and kinematics is Newton's Second Law: $\vec{F}_{\text{NET}} = m\vec{a}$.



Here is the problem-solving strategy listing all the quantities.



Example 3: A Problem with Dynamics and Kinematics Starting with Kinematics

A car with a mass of 1175 kg is travelling at a velocity of 5.00 m/s [E]. During a time interval of 2.50 seconds, the car travels 19.2 m [E]. A force of friction of 2150 N acts on the car. What is the force that is driving the car forward?

The strategy in solving this problem involves using the kinematics information to determine the acceleration, then using Newton's Second Law to determine the net force, then working with this net force and the other dynamics information to determine the force that is driving the car forward. The solution to this problem really has three steps to it.

Dynamics

$m = \text{mass} = 1175\ kg$

$\vec{F}_A = \text{applied force} = ?$

$\vec{F}_F = \text{force of friction} = 2150\ \text{N [W]}$

$\vec{F}_{\text{NET}} = \text{net force} = ?$

Forces are related using a free-body diagram.

$\vec{F}_{\text{NET}} = \sum \text{Forces}$

Kinematics

$\vec{d} = \text{displacement} = 19.2\ \text{m [E]}$

$\vec{v}_1 = \text{initial velocity} = 5.00\ \text{m/s [E]}$

$\vec{v}_2 = \text{final velocity} = ?$

$\Delta t = \text{time interval} = 2.50\ \text{s}$

$\vec{a} = \text{acceleration} = ?$

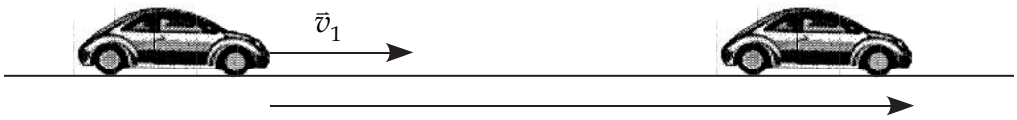
The kinematics information should be analyzed to determine $\vec{a}$.

$\vec{F}_{\text{NET}} = m\vec{a}$

Newton's Second Law

Step 1: Analyzing kinematics information to determine the acceleration

Given: Set east as the positive direction.



$\vec{v}_1 = +5.00 \text{ m/s}$ $\qquad$ $\vec{d} = +19.2 \text{ m}$

$\Delta t = 2.50 \text{ s}$

Unknown: acceleration $\quad \vec{a} = ?$

Equation: Kinematics equation number four can be used to calculate the acceleration.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve: for $\vec{a}$

$$+19.2 \text{ m} = (+5.00 \text{ m/s})(2.50 \text{ s}) + \frac{1}{2}\vec{a}(2.50 \text{ s})^2$$

$$+19.2 = 12.5 + 3.125\vec{a}$$

$$+6.7 = 3.125\vec{a}$$

$$\vec{a} = \frac{+6.7}{3.125} = 2.144$$

$$\vec{a} = 2.1 \text{ m/s}^2 \text{ [E]}$$

Two significant digits are necessary in this case.

Step 2: Use Newton's Second Law to determine the net force.

$m = 1175 \text{ kg}$

$\vec{a} = 2.1 \text{ m/s}^2 \text{ [E]}$

$\vec{F}_{\text{NET}} = m\vec{a}$

$\vec{F}_{\text{NET}} = (1175 \text{ kg})(2.1 \text{ m/s}^2 \text{ (E)}) = 2467.5 \text{ N [E]}$

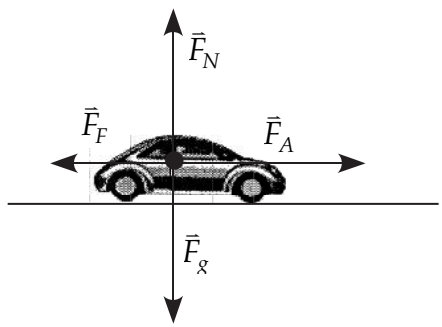
$\vec{F}_{\text{NET}} = 2500 \text{ N [E]}$

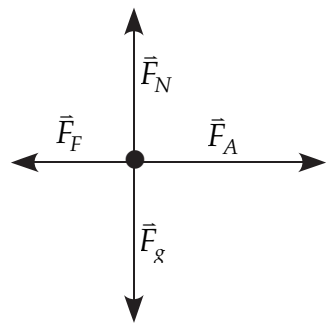
Step 3: Analyze the dynamics of the situation. Since you now know the net force, you can work backwards to determine the applied force driving the car forward.

Given:

Net force	$\vec{F}_{\text{NET}} = 2500\text{ N [E]} = +2500\text{ N}$
Force of friction	$\vec{F}_F = 2150\text{ N [W]} = -2150\text{ N}$
Normal force	$\vec{F}_N = ?$
Force of gravity	$\vec{F}_g = ?$

In this case, the normal force and the force of gravity cancel out.





Unknown: The applied force driving the car forward $\vec{F}_A = ?$

Equation:

$$\vec{F}_{\text{NET}} = \sum \text{Forces} = \vec{F}_A + \vec{F}_F + \vec{F}_N + \vec{F}_g \quad \left(\vec{F}_N + \vec{F}_g \text{ cancel}\right)$$

$$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$$

Substitute and solve:

$$+2500\text{ N} = \vec{F}_A + (-2150\text{ N})$$

$$\vec{F}_A = (+2500\text{ N}) - (-2150\text{ N}) = +4650\text{ N}$$

Rounding to significant digits, the applied force driving the car forwards is 4600 N [E].

Example 4: A Problem with Dynamics and Kinematics Starting with Dynamics

You are pushing a child on a sled over some level snow-covered ground. You exert a constant force of 35.0 N [E]. The snow exerts an opposing frictional force of 15.0 N. The mass of the child and sled is 22.0 kg. If the sled starts from rest, how far will it have travelled after 5.00 s?

The strategy in solving this problem involves using the dynamics information to determine the net force, then using Newton's Second Law to determine the acceleration, then working with this acceleration and the other kinematics information to determine the displacement. Again, the solution to the problem has three steps to it.

Given:

Dynamics

$m = 22.0$ kg

$\vec{F}_A$ = applied force = 35.0 N [E]

$\vec{F}_F$ = force of friction = 15.0 N [W]

$\vec{F}_{NET}$ = net force = ?

Then, free-body diagram and

$\vec{F}_{NET} = \sum$ Forces.

Kinematics

$\vec{d}$ = displacement = ?

$\vec{v}_1$ = initial velocity = 0 m/s

$\vec{v}_2$ = final velocity = ?

Δt = time interval = 5.00 s

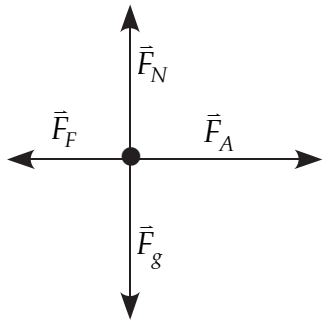
$\vec{a}$ = acceleration = ?

Start with the acceleration from Newton's Second Law.

$\vec{F}_{NET} = m\vec{a}$

Newton's Second Law

Step 1: Find the net force on the child and sled.



Unknown: The net force pushing the child and sled $\vec{F}_{\text{NET}} = ?$

Equation:

$$\vec{F}_{\text{NET}} = \sum \text{Forces} = \vec{F}_A + \vec{F}_F + \vec{F}_N + \vec{F}_g \quad \left(\vec{F}_N + \vec{F}_g \text{ cancel}\right)$$

$$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$$

Substitute and solve:

$$\vec{F}_{\text{NET}} = 35.0 \text{ N [E]} + 15.0 \text{ N [W]}$$

$$\vec{F}_{\text{NET}} = 20.0 \text{ N [E]}$$

Step 2: Use Newton's Second Law to find the acceleration.

$\vec{F}_{\text{NET}} = m\vec{a}$ rearranged to $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$.

$$\vec{a} = \frac{20.0N\,[E]}{22.0\,kg} = 0.909 \text{ m/s}^2 \text{ [E]}$$

Step 3: Use the acceleration and the kinematics equations to find the displacement.

Unknown: Displacement $\vec{d} = ?$

Equation: Kinematics equation 4 can be used to calculate the displacement.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve: for $\vec{d}$

$$\vec{d} = (0 \text{ m/s})(5.00 \text{ s}) + \frac{1}{2}(0.909 \text{ m/s}^2)(5.00 \text{ s})^2$$

$$\vec{d} = 11.3625 \text{ m} = 11.4 \text{ m}$$

The child and sled travels 11.4 m [E].

Learning Activity 3.7

Dynamics and Kinematics

1. Newton's Second Law indicates that when a net force acts on an object, it must accelerate. Does this mean that when two or more forces are applied to an object simultaneously, it must accelerate? Explain.

2. A person with a black belt in karate has a fist that has a mass of 0.70 kg. Starting from rest, this fist attains a velocity of 8.0 m/s in 0.15 s. What is the average force applied to the fist to achieve this level of performance?

3. A catapult on an aircraft carrier is capable of accelerating a plane from 0.0 to 56.0 m/s in a distance of 80.0 m. What is the average force that the catapult exerts on a 13 300 kg jet?

4. Two children are pulling on a wagon of mass 50.0 kg. One child is pulling to the right with a force of 200.0 N, while another child is pulling to the left with a force of magnitude 150.0 N.
   a) What is the net force on the wagon?
   b) What is the magnitude and direction of the acceleration of the wagon?
   c) How fast is the wagon moving after 3.25 s if the wagon starts from rest?

5. A crate of mass 30.0 kg rests on a level concrete floor. A man pushes the crate with a constant horizontal force of 75.0 N to the left. A constant force of friction of 40.0 N also acts on the crate. If the crate starts from rest, how far would it be pushed during 5.35 seconds?

6. A toboggan carrying a passenger is pulled by a person who exerts a force on a rope. The mass of a toboggan and passenger is 35.5 kg. A force of friction of 12 .0 N acts on the toboggan. At one point in time, the velocity of the toboggan is 1.00 m/s [E] and, after sliding 4.30 m [E], the velocity is 3.00 m/s [E]. If the person pulling the toboggan pulls horizontally towards the east, what force did he exert on the rope?

Lesson Summary

Newton's Second Law of Motion deals with the effect of forces applied to an object on the motion of the object.

The effect of a net force applied to a body is to cause the body to accelerate in the direction of the force. The **acceleration** is in **direct proportion to the net force** and in **inverse proportion to the mass** of the body.

The **mathematical statement** of Newton's Second Law of Motion is:

$$\vec{F}_{\text{NET}} = m\vec{a}$$

The **problem-solving strategy** that allows you to link dynamics information with kinematics information is given below.

Dynamics

m = mass
$\vec{F}_A$ = applied force
$\vec{F}_g$ = force of gravity
$\vec{F}_N$ = normal force
$\vec{F}_F$ = force of friction
$\vec{F}_{\text{NET}}$ = net force
Forces are related using a free-body diagram.
Then, $\vec{F}_{\text{NET}} = \sum \text{Forces}$

Kinematics

$\vec{d}$ = displacement
$\vec{v}_1$ = initial velocity
$\vec{v}_2$ = final velocity
Δt = time interval
$\vec{a}$ = acceleration

The kinematics information should be analyzed to determine $\vec{a}$.

$\vec{F}_{\text{NET}} = m\vec{a}$
Newton's Second Law

Note: You can start with dynamics information and proceed to kinematics, or you can start with kinematics information and proceed to dynamics.

NOTES

Assignment 3.2, Part B

Dynamics and Kinematics (5 MARKS)

A duck has a mass of 2.50 kg. As the duck paddles, a force of 0.100 N acts on it in a direction due east. In addition, the current of the water exerts a force of 0.200 N east.

a) Determine the net force on the duck.

b) Determine the acceleration of the duck.

(continued)

Assignment 3.2, Part B: Dynamics and Kinematics (continued)

c) Determine the displacement after 4.00 s if the duck is swimming initially at 1.25 m/s east.

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 2 marks for determining the net force in part (a)
- 1 mark for determining the acceleration in part (b)
- 2 marks for determining the displacement in part (c)

Lesson 6: The Vector Nature of Newton's Second Law (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ draw and use free-body diagrams to solve problems involving Newton's Second Law
- ❑ apply Newton's Second Law to a situation where two vectors act on an object at right angles to each other
- ❑ apply Newton's Second Law to a situation where a force is applied at an angle to the motion of the object

Introduction

Until now, the problems we have investigated for the application of Newton's Second Law have all had the applied force or forces acting along the direction of motion. You know that life is more complicated than that! So we are going to investigate further the vector nature of Newton's Second Law by considering situations where applied forces act other than along the direction of motion, and where more than one applied force is employed. This last lesson ties together all of the ideas of dynamics for which you are responsible.

Applied Forces Acting at an Angle to the Motion

Think back to the times you played in the snow with a toboggan. When you pulled on the rope of the toboggan, you did not hold the rope parallel to the ground so that you would exert a horizontal force. Instead, you held the rope so that it made an angle with the horizontal.

Now, the toboggan did not start floating off into the air in the direction of the force you exerted along the rope. Instead, the toboggan accelerated along the snow in a horizontal direction. You should recognize, therefore, that the toboggan accelerates in the direction of the net force. Once all of the forces acting on the toboggan are taken into account, the net force points horizontally along the ground!

This bit of reasoning forms the basis of the analysis of this situation where an applied force is exerted at some angle to the horizontal when the object is moving horizontally.

The second point to consider is how to draw the free-body diagram. In this situation, we will take a frame of reference from the side so that you see right-left as the x-axis and up-down as the y-axis.

The new part of analyzing this type of problem is that the applied force does not point along one of the axes. Therefore, you must resolve the applied force into its components. This will yield the free-body diagram in the required shape of a cross (+).

So let's consider a problem.

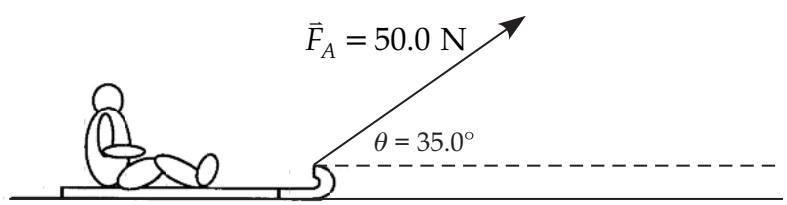
Example 1: Applied Force at an Angle to the Motion

You are pulling on the rope of your toboggan with a force of 50.0 N at an angle of 35.0° from the horizontal. The toboggan and passenger have a mass of 42.6 kg. The toboggan is pulled along a level surface where the force of friction is 18.0 N.

a) Draw a diagram of this situation.
b) Draw a free-body diagram so that the forces all point along a major axis.
c) Determine the x-component and the y-component of the applied force.
d) Determine the net force acting on the toboggan.
e) Determine the acceleration of the toboggan and passenger.

Solutions

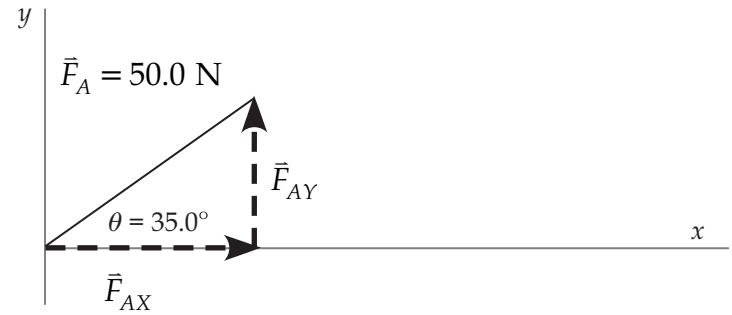
a) Draw a diagram of this situation.



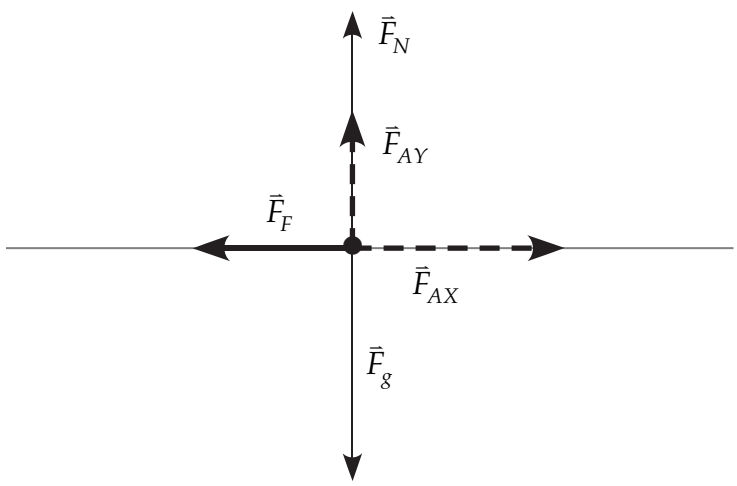
In this diagram, the toboggan will move in the horizontal direction along the ground.

b) To make the free-body diagram look like a cross, you must resolve the applied force into its components: an x-component and a y-component.

Let's find the components of the applied force, $\vec{F}_A$.



Here is the free-body diagram using the component of the applied force instead of the applied force itself.



Note that the normal force is not equal in magnitude to the force of gravity.

We know that the forces along the y-axis are balanced, since the toboggan does not move in the y direction. So the normal force has to be **just large enough** so that the **normal force plus the y-component of the applied force** will just **balance the force of gravity**.

Again, notice that the shape of the diagram is a cross (+).

c) To find the x-component, use cosine:

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{F}_{AX}}{\vec{F}_A}$$

$$\vec{F}_{AX} = (\cos\theta)(\vec{F}_A)$$

$$\vec{F}_{AX} = (\cos 35.0°)(50.0\text{ N}) = +41.0\text{ N}$$

To find the y-component, use sine:

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\vec{F}_{AY}}{\vec{F}_A}$$

$$\vec{F}_{AY} = (\sin\theta)(\vec{F}_A)$$

$$\vec{F}_{AY} = (\sin 35.0°)(50.0\text{ N}) = +28.7\text{ N}$$

d) To find the net force, use:

$\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_N + \vec{F}_{AY} + \vec{F}_{AX} + \vec{F}_F$ but $\vec{F}_g$ is cancelled by the sum of $\vec{F}_N + \vec{F}_{AY}$.

$$\vec{F}_{\text{NET}} = \vec{F}_{AX} + \vec{F}_F$$

$$\vec{F}_{\text{NET}} = (+41.0\text{ N}) + (-18.0\text{ N}) = +23.0\text{ N}$$

The net force is 23.0 N [right].

e) Since you know the net force and the mass (42.6 kg), you can calculate the acceleration using Newton's Second Law.

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{42.6\text{ kg}} = \frac{+23.0\text{ N}}{42.6\text{ kg}} = +0.540\text{ m/s}^2$$

The acceleration of the toboggan and passenger is +0.540 m/s^2 [right].

Two Applied Forces and Newton's Second Law

It is almost certain you have, together with another person, pulled on the same object. It may have been that you both were pulling in different directions with ropes on a toboggan or sled. You now should be able to reason that the sled accelerated along the direction of the net force, which was somewhere between the two forces that you and your friend exerted on the toboggan or sled.

In this situation, we will consider two applied forces that are exerted on an object so that there is 90° between the directions of the forces. Secondly, we will assume that the two forces are acting in the horizontal plane. Thirdly, we will assume that the object is moving in the horizontal plane. Inclined planes will be considered in Grade 12 Physics.

You may have seen an air hockey game in an arcade. The hockey puck floats on a layer of air so that the situation is frictionless. Once the puck is in motion, it moves with constant velocity (Newton's First Law).

Let's consider a device called a dry-ice puck similar to the air hockey puck. The dry-ice puck is a disk with a hole in the centre. On top of the disk is a container into which dry-ice (solid carbon dioxide) is placed. The solid carbon dioxide sublimes or changes directly into a gas. The gas is forced out of the hole and the whole apparatus then floats on a thin layer of gaseous carbon dioxide just like the air hockey puck floats on a layer of air.

Example 2: Two Applied Forces and Newton's Second Law

A dry-ice puck has a mass of 2.65 kg. It is pulled by two elastics. The first elastic exerts a force of 12.5 N [S] and the second elastic exerts a force of 15.8 N [W]. Both forces are exerted in the horizontal plane.

a) Draw a free-body diagram.

b) What is the net force acting on the dry-ice puck?

c) Determine the velocity after the forces act for 2.60 s if the dry-ice puck was initially at rest.

Solution

a) The key to the free-body diagram is choosing the correct frame of reference. Since we are given the north-south and east-west directions, we should use that frame of reference (that of looking at a map from above).

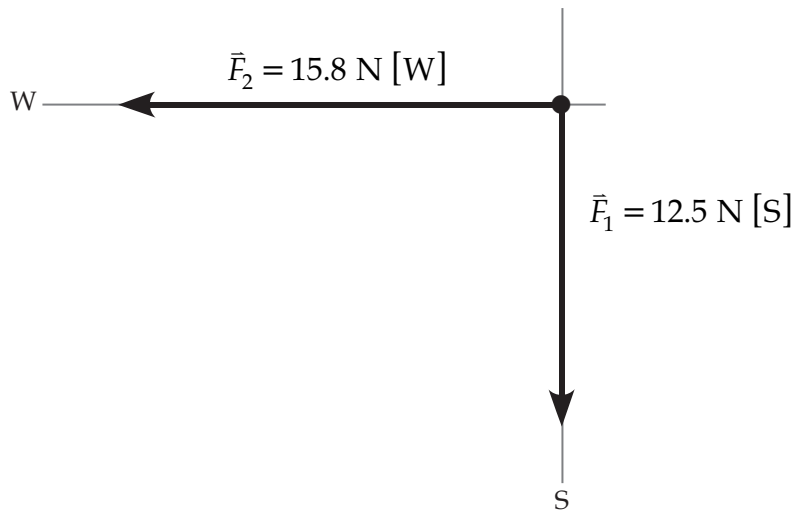
   The second factor is that since both forces lie in the horizontal plane, if we tried to draw the situation from a side view we could not correctly draw these forces on the diagram. They would simply overlap each other.

   Thirdly, you should know that since the two forces are pulling on the dry-ice puck in the horizontal plane, the force of gravity and the normal force should cancel out!

Given: Force 1: $\vec{F}_1 = 12.5\text{ N [S]}$

Force 2: $\vec{F}_2 = 15.8\text{ N [W]}$

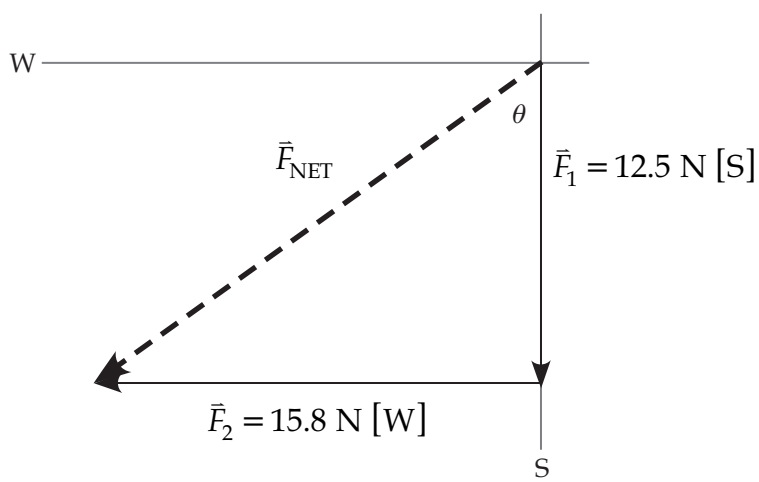
Top view:



b) The net force is the vector sum of the two forces, $\vec{F}_1$ and $\vec{F}_2$.

Let us use the component method to add these vectors.

Remember, we first sketch the vectors using the tip-to-tail method and draw in the resultant.



Determine the magnitude of the resultant, $\vec{F}_{NET}$, using the theorem of Pythagoras.

$$\vec{F}_{NET}{}^2 = \vec{F}_1{}^2 + \vec{F}_2{}^2$$

$$\vec{F}_{NET}{}^2 = (12.5\text{ N})^2 + (15.8\text{ N})^2 = 405.89\text{ N}^2$$

$$\vec{F}_{NET} = \sqrt{405.89\text{ N}^2} = 20.1\text{ N}$$

Determine the angle at the tail of the resultant using tangent.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{15.8}{12.5}$$

$$\theta = \tan^{-1}\frac{15.8}{12.5} = 51.6°$$

The net force is 20.1 N [51.6° W of S].

c) This question asks for the final velocity, a kinematics quantity. To link dynamics to kinematics, use Newton's Second Law to find the acceleration.

Given:

Mass	m = 2.65 kg
Net force	$\vec{F}_{NET}$ = 20.1 N [51.6° W of S]

Find acceleration using Newton's Second Law

$$\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{20.1 \text{ N [51.6° W of S]}}{2.65 \text{ kg}} = 7.58 \text{ m/s}^2 \text{ [51.6° W of S]}$$

Initial velocity	$\vec{v}_1 = 0$ m/s
Time interval	Δt = 2.60 s
Unknown: Final velocity	$\vec{v}_2 = ?$
Equation:	Use kinematics equation 2.
	$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ rearranged to $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$
Substitute and solve:	$\vec{v}_2 = 0$ m/s + (7.58 m/s^2 [51.6° W of S])(2.60 s)
	$=$19.7 m/s [51.6° W of S]

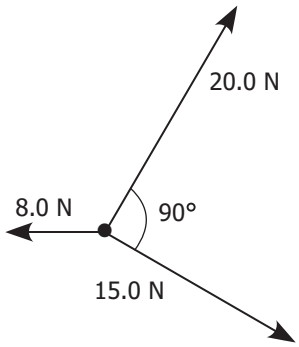
The final velocity is 19.7 m/s [51.6° W of S].

You can see that the dry-ice puck moves in a direction somewhere between the directions of the two applied forces.

Learning Activity 3.8

The Vector Nature of Newton's Second Law

1. A wagon carries a child. Together, the mass is 28.5 kg. You pull on the handle of the wagon with a force of 35.0 N at an angle of 40.0° from the horizontal. The wagon travels over a level horizontal sidewalk. A force of friction of 12.0 N acts on the wagon.
   a) What is the net force acting on the wagon?
   b) What is the acceleration of the wagon?
2. A crate of mass 50.0 kg is pulled across a level concrete floor by a force of 300.0 N acting 30.0° above the horizontal. The crate moves at a constant velocity of 0.962 m/s. What is the force of friction acting on the crate?
3. A person is stranded on a raft. The mass of the raft and the person is 1500 kg. By paddling, the man exerts an average force of 25 N in a direction due east (the $+x$-direction). The wind also exerts a force on the raft. The force of the wind has a magnitude of 15 N and points north. Determine the magnitude and direction of the acceleration of the raft and person.
4. Two children are trying to pull a 20.0 kg toboggan out of a deep snow drift that provides an opposing force of 8.0 N. They are using ropes attached to the toboggan and parallel to the ground. The forces exerted by the children and the direction in which they pull on the ropes are shown below. Determine the net force and the magnitude and acceleration of the mass.



Lesson Summary

Many times an applied **force** is exerted **at some angle** to the horizontal but the object moves horizontally (pushing a lawnmower or shopping cart, pulling the handle of a wagon). If these objects accelerate, the **net force acts in the horizontal direction**.

The second point to consider is how to draw the **free-body diagram**. In this situation, we will take a frame of reference from the side so that you see right-left as the x-axis and up-down as the y-axis.

The new part of analyzing this type of problem is that the applied force does not point along one of the axes. Therefore, you must **resolve the applied force into its components** (x-component and y-component). This will yield the free-body diagram in the required shape of a cross (+).

The second situation consists of an object accelerating horizontally when **2 or more forces are exerted** on the object in the **horizontal direction**.

In this situation, we considered two or more applied forces that are exerted on an object so that there is **90° between the directions of the forces**. Secondly, we assumed that the **two forces** are **acting** in the **horizontal plane**. Thirdly, we assumed that the object is moving in the horizontal plane.

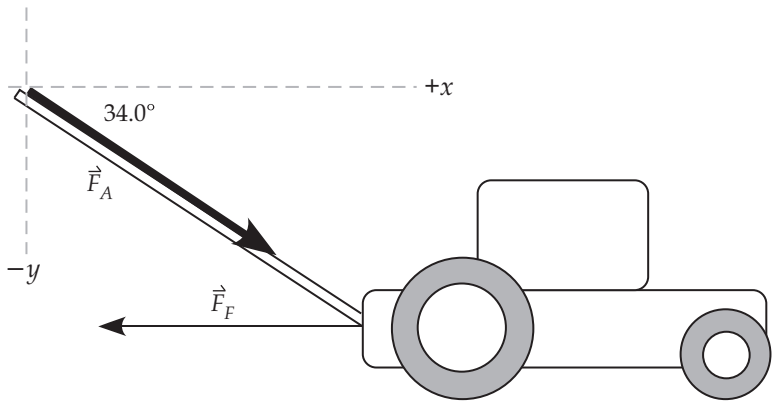
In this case, you must **view the situation from the top**. You can do this because the **force of gravity** and the **normal force** will **cancel out**, leaving the applied forces and the force of friction that act in the horizontal plane. This will yield the free-body diagram in the required shape of a cross (+).

NOTES

Assignment 3.2, Part C

The Vector Nature of Newton's Second Law (8 MARKS)

A lawnmower of mass 15.2 kg is pushed along by a force exerted on the handle. A force of 30.0 N is exerted directly along the handle, which makes an angle of 34.0° with the horizontal. A force of friction of 22.5 N acts on the lawnmower.



a) Calculate the horizontal and vertical components of the force exerted on the lawnmower.

(continued)

Assignment 3.2, Part C: The Vector Nature of Newton's Second Law (continued)

b) Draw a free-body diagram labelling all of the forces acting on the lawnmower.

c) Determine the net force acting on the lawnmower.

(continued)

Assignment 3.2, Part C: The Vector Nature of Newton's Second Law (continued)

d) Determine the acceleration of the lawnmower.

_____

_____

_____

_____

Method of Assessment

The total of eight marks for this assignment will be determined as follows:

- 2 marks for determining the components of the applied force in part (a)
- 3 marks for drawing the coordinate system and for drawing and labelling correctly the forces in part (b)
- 2 marks for determining the net force in part (c)
- 1 mark for determining the acceleration in part (d)

NOTES

Module 3 Summary

Congratulations on completing Module 3.

Submitting Your Assignments

You will not submit your Module 3 assignments to the Distance Learning Unit at this time. Instead, you will submit them, along with the Module 4 assignments, **when you have completed Module 4**.

You are now ready to start Module 4.

NOTES

Grade 11 Physics (30S)

Module 3: Dynamics

Learning Activity Answer Keys

Module 3: Dynamics

Learning Activity 3.1: Fundamental Forces

1. For each of the following situations, which of the four fundamental forces is acting?
   a) In radioactivity, a proton may change into a neutron.

      Answer: Weak nuclear

   b) An electron will repel another electron.

      Answer: Electromagnetic

   c) The protons in a nucleus are held together so that they do not push each other apart.

      Answer: Strong nuclear

   d) An attractive force exists between two neutrons that are not charged, but are attracted because they have mass.

      Answer: Gravitational

2. Complete the following table about the properties of the four fundamental forces.

   Answer:

Property	Fundamental Force
Acts between charged particles	electromagnetic
Acts in the nucleus	strong nuclear, weak nuclear
Has the shortest range of all of the forces	weak nuclear
Has unlimited range	electromagnetic, gravitational
The weakest force	gravitational
Acts between protons	strong nuclear, electromagnetic, gravitational
Due to the fact objects have mass	gravitational
Can be attractive or repulsive	electromagnetic
Is only attractive	strong nuclear, weak nuclear, gravitational

3. Identify to which of the four fundamental forces each of the following forces belongs.

   Answer:

Force	Category of Force
Weight	gravitational
Spring pulling a book	electromagnetic
Occurs between neutrons	strong nuclear
Occurs between particles smaller than protons	weak nuclear
Allows a balloon to "stick" to a wall	electromagnetic
Friction	electromagnetic
Bat hitting a ball	electromagnetic

Learning Activity 3.2: Newton's First Law

1. Why is it particularly dangerous to drive on an icy highway? (Hint: Consider the inertia of the vehicle and the low frictional force between the wheels and the icy surface.)

   Answer:

   A car has a considerable mass and, therefore, it has a large amount of inertia. If the car should hit a little bump, it could start into a skid in an undesirable direction. The only force available to correct the skidding car is the force of friction between the tires and the road surface. This frictional force is usually sufficient when the road conditions are normal. Under icy conditions, however, since the force of friction is less than it is under normal conditions, the force may not be sufficiently large to change the direction of motion of the car. The result is that the skid cannot be corrected and the car ends up in the ditch, or worse.

2. Why do you lunge forward when your car suddenly comes to a halt? Why are you "thrown backward" when your car rapidly accelerates?

   Answer:

   The car and your body are travelling at a certain velocity. The velocity of the car is decreased suddenly. Your body, because of inertia, will continue on at the same velocity unless it is restrained by a seatbelt.

   When the car accelerates rapidly, you're not really "thrown backward." What really happens is that your body, being at rest, wants to remain at rest. The car begins to move. The seat and headrest move forward, pressing against your back and head and accelerating you forward at the same rate as the car, making it appear that you are "thrown backwards."

3. Why is your body pressed against the left side of the seat when the roller-coaster car in which you are riding suddenly veers to the right?

   Answer:

   The mass of your body provides a considerable amount of inertia. When the roller-coaster car veers to the right, your body will tend to continue in the same straight-line motion it had prior to the change in direction of the car. Frictional force between your clothing and the seat may not produce sufficient force to cause you to change direction with the car, and you will slip left against the side of the seat. It is the force applied by the left side of the seat that will bring about the required change in the direction of your motion.

Learning Activity 3.3: Newton's Second Law

1. According to Newton's Second Law, indicate how the acceleration will change if

   a) the mass of the object is doubled but the net force is kept constant.

   Answer:

   Mass is doubled but force is kept constant.

   Acceleration is inversely proportional to mass $\left(\vec{a}\ \alpha\ \frac{1}{m}\right)$, so as mass increases, acceleration decreases.

   So the acceleration will be one-half as large as before.

   b) the net force on the object is tripled but the mass of the object is constant.

   Answer:

   The net force is tripled but the mass is kept constant.

   Acceleration is directly proportional to the net force $\left(\vec{a}\ \alpha\ \vec{F}_{NET}\right)$, so as net force increases so does the acceleration.

   Therefore, the acceleration will be three times as large as before.

2. Calculate the net force acting on a 2.50 kg mass that causes an acceleration of 1.65 m/s^2 to the right.

   Answer:

Given:	Mass	m = 2.50 kg
	Acceleration	$\vec{a}$ = 1.65 m/s^2 [right]
Unknown:	Net force	$\vec{F}_{NET}$ = ?
Equation:		$\vec{F}_{NET} = m\vec{a}$
Substitute:		$\vec{F}_{NET}$ = (2.50 kg)(1.65 m/s^2 [right]
Solve:		$\vec{F}_{NET}$ = 4.12 N [right]

   The net force is 4.12 N to the right. The net force acts in the same direction as the acceleration.

3. What is the acceleration of a car of mass 1250 kg that is subjected to a net force of 2250 N [N]?

   Answer:

Given:	Mass	m = 1250 kg
	Net force	$\vec{F}_{NET}$ = 2250 N [N]
Unknown:	Acceleration	$\vec{a}$ = ?

Equation: $\vec{F}_{NET} = m\vec{a}$ rearranged to $\vec{a} = \frac{\vec{F}_{NET}}{m}$

Substitute: $\vec{a} = \frac{2250 \text{ N [N]}}{1250 \text{ kg}}$

Solve: $\vec{a} = 1.80 \text{ m/s}^2 \text{ [N]}$

The acceleration is 1.80 m/s^2 [N].

4. What is the mass of person who accelerates at 4.25 m/s^2 [S] under a net force of 265 N [S]?

   Answer:

   Given: Net force $\vec{F}_{NET} = 265 \text{ N [S]}$

   Acceleration $\vec{a} = 4.25 \text{ m/s}^2 \text{ [S]}$

   Unknown: Mass $m = ?$

   Equation: $\vec{F}_{NET} = m\vec{a}$ rearranged to $m = \frac{\vec{F}_{NET}}{\vec{a}}$

   Substitute: $m = \frac{\vec{F}_{NET}}{\vec{a}} = \frac{265 \text{ N [S]}}{4.25 \text{ m/s}^2 \text{ [S]}}$

   Solve: $m = 62.4 \text{ kg}$

   The mass of the person is 62.4 kg.

5. A bicycle has a mass of 13.1 kg, and the rider has a mass of 81.7 kg. The rider is pumping hard, so that a horizontal net force of 9.78 N accelerates them. What is the acceleration?

   Let the positive direction point to the right.

   Answer:

   Given: The total mass of the bicycle and rider is $m = 13.1 \text{ kg} + 81.7 \text{ kg} = 94.8 \text{ kg}$.

   Net force $\vec{F}_{NET} = +9.78 \text{ N}$

   Unknown: Acceleration $\vec{a} = ?$

   Equation: $\vec{F}_{NET} = m\vec{a}$ rearranged to $\vec{a} = \frac{\vec{F}_{NET}}{m}$

   Substitute and solve: $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{+9.78 \text{ N}}{94.8 \text{ kg}} = +0.103 \text{ m/s}^2$

   The acceleration of this pair is +0.103 m/s^2.

Learning Activity 3.4: Newton's Laws

1. If "action forces" and "reaction forces" are equal and opposite, why can they never balance or cancel?

   Answer:

   An "action force" is a force that object 1 exerts on object 2. A "reaction" force is the force that object 2 exerts on object 1. Since the two forces act on different objects, they cannot balance or cancel.

2. In a car crash, a passenger's head collides with the window in the door. The passenger suffers a fractured skull. The window in the door is shattered. Account for this using Newton's Laws of Motion.

   Answer:

   According to Newton's Third Law of Motion, the passenger's head exerts an action force on the windshield. This action force shatters the window. The reaction force is the force that the window exerts on the passenger's head. It is this reaction force that fractures the passenger's skull.

3. Using the appropriate law of motion, explain the following:

   a) A bullet is fired from a rifle. The rifle recoils.

      Answer:

      This involves Newton's Third Law of Motion.

      When a rifle is fired, a chemical reaction—literally an explosion—occurs. In this explosion, gases are produced and expanded rapidly. The expanding gases push the bullet forward down through the barrel of the rifle. This can be called an action force. The reaction force can be thought of as the gases pushing on the other end of the rifle barrel. This reaction force causes the rifle to move backwards or recoil.

   b) A karate expert attempts to break 10 boards piled on top of each other by striking them with one blow of his hand. In the process, he breaks a bone in his hand.

      Answer:

      This involves Newton's Third Law of Motion.

      The karate expert exerts an action force of his hand on the boards. The boards exert a reaction force on the karate expert's hand. This reaction force is large enough to break a bone in his hand.

c) The stationary car in which a passenger sits is struck from the rear by a second car. The passenger suffers whiplash.

Answer:

This example involves Newton's First and Second Laws of Motion.

The force of the second car striking the stationary car is an unbalanced force acting on the stationary car. Therefore, according to Newton's Second Law, the second car will accelerate in the direction of the force applied.

The passenger was motionless. Being at rest, according to Newton's First Law, the passenger would tend to remain at rest. The back of the seat is accelerated forward, pushing the body of the person forward as well. The body of the person is literally pushed out from underneath his head, which remains at rest. This stretches and damages ligaments and tendons and muscles, resulting in whiplash.

d) A curling rock slides along the ice and slowly comes to a stop

Answer:

This involves both the First and Second Laws of Motion.

A curling rock is in motion and it should continue in motion with a constant velocity, according to the First Law of Motion. There is a small force of friction between the curling rock and the ice. This force of friction acts as an unbalanced force on the curling rock. According to the Second Law of Motion, an unbalanced force causes an acceleration in the direction that the force acts. In this case, the unbalanced force acts opposite to the velocity, causing the rock to slow down and eventually stop.

e) A rock is dropped from a bridge and accelerates towards the earth. The rock exerts a force on the earth. We do not notice the earth accelerating towards the rock.

Answer:

This is an example of the Second Law of Motion.

The earth exerts a force of attraction on the rock. According to Newton's Second Law for a given force, if the mass is small acceleration must be large.

$$\vec{F}_{\text{NET}} = m\vec{a}$$
$$\vec{F}_{\text{NET}} = m_R\vec{a}_R$$

The rock exerts a force of attraction on the earth. According to Newton's Second Law, for a given force, if the mass is large the acceleration must be small.

$$\vec{F}_{\text{NET}} = m\vec{a}$$
$$\vec{F}_{\text{NET}} = m_E\vec{a}_E$$

This small acceleration occurs when the earth accelerates under this force. We notice the large acceleration of the rock but not the small acceleration of the earth.

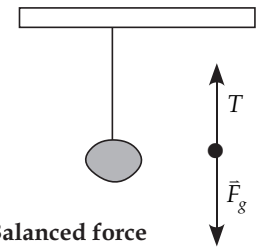
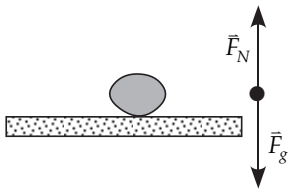
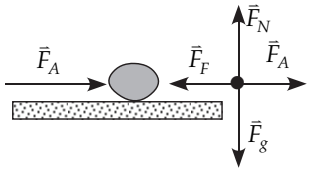
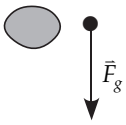
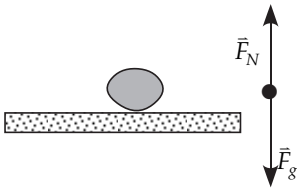
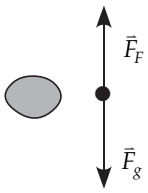
Learning Activity 3.5: Free-Body Diagrams

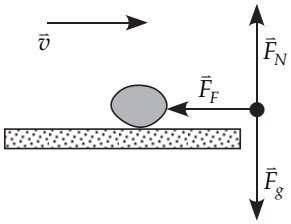
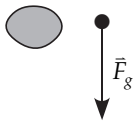
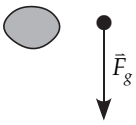
There are 15 questions in this learning activity. In each case, the rock is acted upon by one or more forces. All drawings are in the vertical plane, and friction is negligible except where noted. Draw accurate free-body diagrams showing all forces acting on the rock. Draw all forces as though they were acting on the centre of mass, even though forces like friction and normal force act on the surface at the point of contact. Please use a ruler and pencil so that you can correct errors. Label the forces using $\vec{F}_g$ for the weight or force of gravity, T for tension, $\vec{F}_F$ for force of friction, $\vec{F}_N$ for normal force, and $\vec{F}_A$ for applied force.

For each question, indicate whether the forces are **balanced** or **unbalanced**.

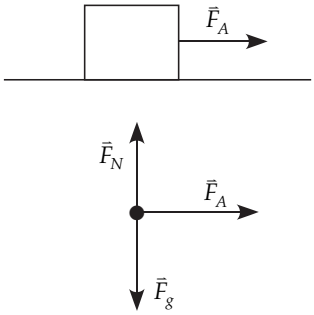
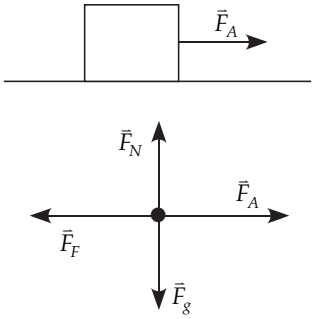
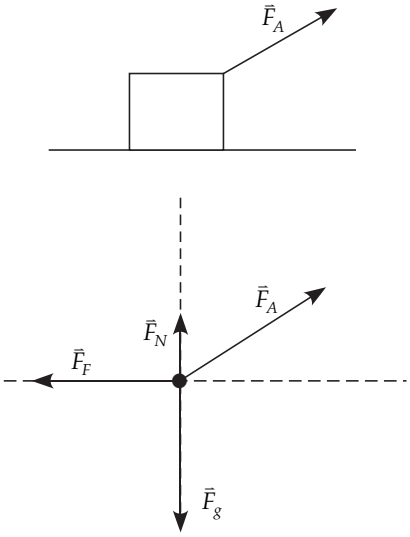
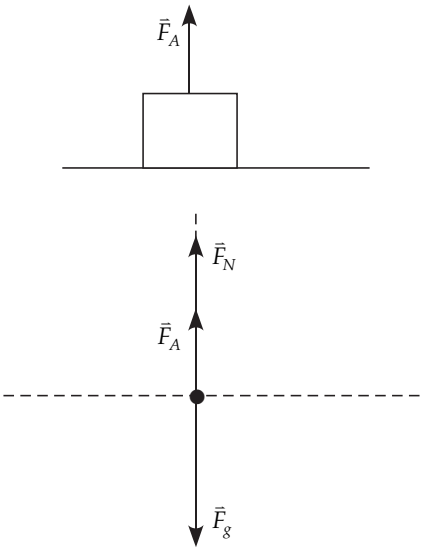
Answers:

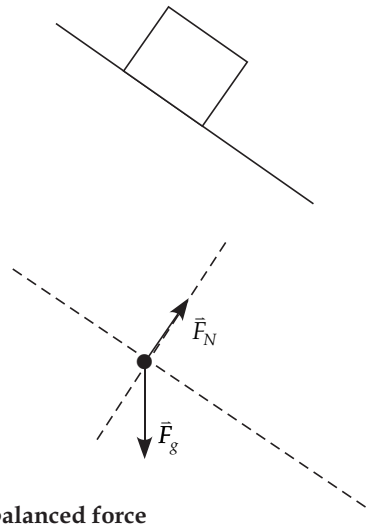
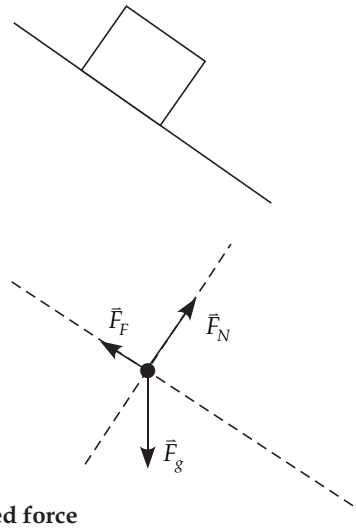
Part 1:

1. Equilibrium  **Balanced force**	2. Equilibrium  **Balanced force**	3. Rock is pushed but remains motionless. Friction acts.  **Balanced force**
4. Rock is falling, no friction.  **Unbalanced force**	5. Rock is sliding at constant speed on a frictionless surface.  **Balanced force**	6. Rock is falling at a constant (terminal) velocity.  **Balanced force**

7. Rock is decelerating because of kinetic friction.  **Unbalanced force**	8. Rock is rising. No friction.  **Unbalanced force**	9. Rock is at the top of its flight, momentarily motionless.  **Unbalanced force**

Part 2:

1. The object is pulled horizontally. No friction.  **Unbalanced force**	2. The object is pulled horizontally at constant velocity. Kinetic friction acts.  **Balanced force**
3. The object is pulled by a force acting in the direction shown. Static friction acts. The object is motionless.  **Balanced force**	4. The object is pulled straight upwards. It is motionless.  **Balanced force**

5. The object is resting on the plane. No friction acts.  **Unbalanced force**	6. The object remains motionless. Static friction acts.  **Balanced force**

Learning Activity 3.6: Force of Friction

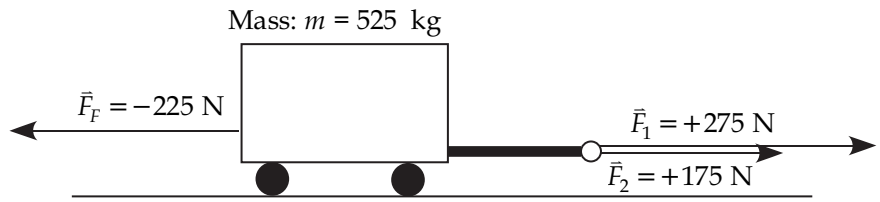
1. A wagon loaded with luggage has a mass of 525 kg. Two baggage handlers are pulling on the hitch of the wagon. The first person pulls with a force of 275 N and the second person pulls with a force of 175 N. Both people pull to the right. A force of friction of 225 N acts on the wagon. The force of gravity is 5140 N.

   a) Draw a free-body diagram labelling all the forces.

   Answer:

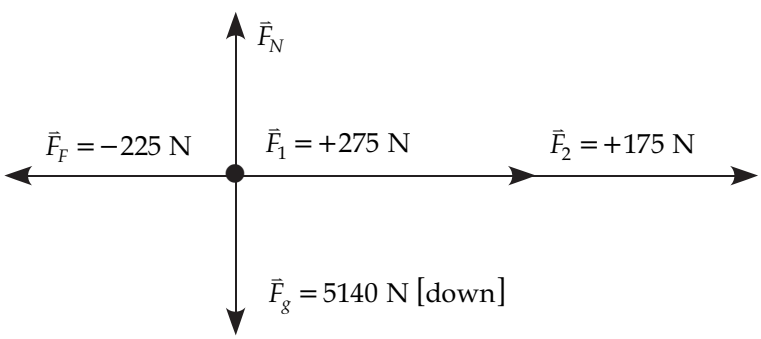
   Let to the right represent the positive direction.

   Given:



   Force of gravity: $\vec{F}_g$ = 5140 N [down]

   The free-body diagram should appear as follows. The vectors are not drawn to scale.



   b) What is the normal force?

   Answer:

   You can see that the normal force is just equal but opposite to the force of gravity.

   The normal force is 5140 N [up].

c) What is the net force acting in the wagon?

Answer:

The net force is the sum of all of the forces acting on the wagon.

$\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_N + \vec{F}_1 + \vec{F}_2 + \vec{F}_F$

You can see that $\vec{F}_g + \vec{F}_N$ cancel, so $\vec{F}_{\text{NET}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$.

$\vec{F}_{\text{NET}} = (+275\text{ N}) + (+175\text{ N}) + (-225\text{ N}) = +225\text{ N}$

d) What is the acceleration of the wagon?

Answer:

Using Newton's Second Law, $\vec{F}_{\text{NET}} = m\vec{a}$, and rearranging for acceleration $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$.

$\vec{a} = \dfrac{+225\text{ N}}{525\text{ kg}} = +0.428\text{ m/s}^2$

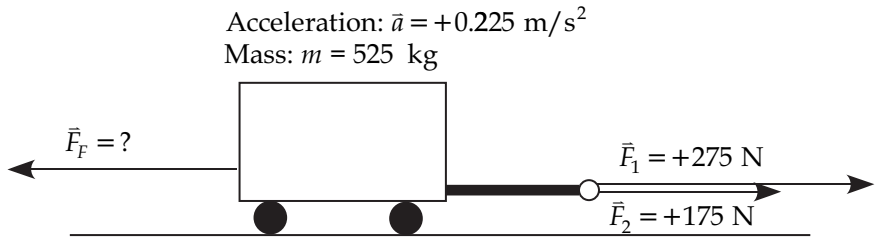
The acceleration of the wagon is 0.428 m/s^2 [right].

2. Suppose in Question #1 that the two baggage handlers pulled on the wagon but the acceleration was 0.225 m/s^2 to the right. If everything else was the same, what would be the force of friction in this case? (Hint: Find the net force first using Newton's Second Law, then find the force of friction.)

Answer:

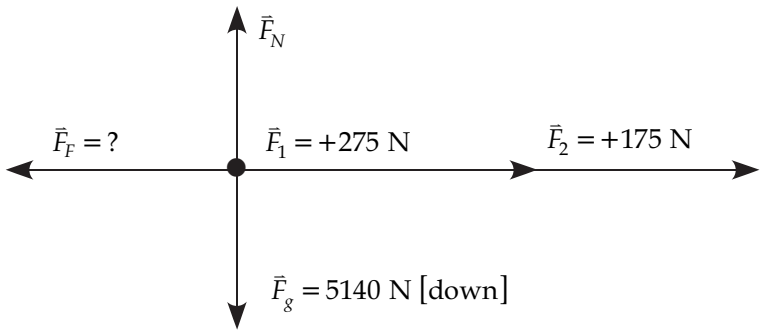
Let the right represent the positive direction.

Given:



Force of gravity $\vec{F}_g$ = 5140 N [down]

The free-body diagram should appear as follows. The vectors are not drawn to scale.



In this case, since you know the mass and the acceleration of the wagon, you can find the net force. Once you know the net force, you can find the force of friction.

Finding $\vec{F}_{\text{NET}}$ using $\vec{F}_{\text{NET}} = m\vec{a}$ gives

$$\vec{F}_{\text{NET}} = (525\text{ kg})(+0.225\text{ m/s}^2) = +118\text{ N}.$$

But we saw earlier that $\vec{F}_{\text{NET}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$.

Substitute and solve for the force of friction.

$$+118\text{ N} = (+275\text{ N}) + (+175\text{ N}) + \vec{F}_F$$

$$\vec{F}_F = -332\text{ N}$$

The force of friction is 332 N [left].

Learning Activity 3.7: Dynamics and Kinematics

1. Newton's Second Law indicates that when a net force acts on an object, it must accelerate. Does this mean that when two or more forces are applied to an object simultaneously, it must accelerate? Explain.

   Answer:

   An object will not necessarily accelerate when two or more forces are applied to it simultaneously. The applied forces may cancel, so the net force is zero; in such a case, the object will not accelerate. The resultant of all the forces that act on the object must be non-zero for the object to accelerate.

2. A person with a black belt in karate has a fist that has a mass of 0.70 kg. Starting from rest, this fist attains a velocity of 8.0 m/s in 0.15 s. What is the average force applied to the fist to achieve this level of performance?

   Answer:

   According to Newton's Second Law of Motion, the net force applied to the fist is equal to the mass of the fist multiplied by the acceleration.

   To determine the acceleration, we use kinematics.

   Let the positive direction be to the right.

   Given: Initial velocity $\vec{v}_1 = 0 \text{ m/s}$

   Time interval $\Delta t = 0.15 \text{ s}$

   Final velocity $\vec{v}_2 = +8.0 \text{ m/s}$

   Unknown: Acceleration $\vec{a} = ?$

   Equation: $$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$

   Substitute and solve: $$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{+8.0 \text{ m/s} - 0.0 \text{ m/s}}{0.15 \text{ s}} = +53 \text{ m/s}^2$$

   Using Newton's Second Law, determine the average force.

   Therefore, the average force is $\vec{F}_{\text{NET}} = m\vec{a} = (0.70 \text{ kg})(+53 \text{ m/s}^2) = +37 \text{ N}$.

3. A catapult on an aircraft carrier is capable of accelerating a plane from 0.0 to 56.0 m/s in a distance of 80.0 m. What is the average force that the catapult exerts on a 13,300 kg jet?

Answer:

We will first need to determine the acceleration of the aircraft using our information about velocities and distance.

To determine the acceleration, we use kinematics.

Let the positive direction be to the right.

Given:	Initial velocity	$\vec{v}_1 = 0 \text{ m/s}$
	Displacement	$\vec{d} = +80.0 \text{ m}$
	Final velocity	$\vec{v}_2 = +56.0 \text{ m/s}$
Unknown:	Acceleration	$\vec{a} = ?$

Equation: $v_2^2 - v_1^2 + 2ad$ rearranged to $a = \dfrac{v_2^2 - v_1^2}{2d}$

Substitute and solve:

$$a = \frac{v_2^2 - v_1^2}{2d} = \frac{(+56.0 \text{ m/s})^2 - (0.0 \text{ m/s})^2}{2(+80.0 \text{ m})}$$

$$= \frac{+3136}{+160} = +19.6 \text{ m/s}^2$$

Using Newton's Second Law, determine the average force. According to Newton's Second Law of Motion, the net force applied to the jet is equal to the mass of the jet multiplied by the acceleration.

The force acting on the aircraft is

$\vec{F}_{\text{NET}} = m\vec{a} = (13\ 300 \text{ kg})(+19.6 \text{ m/s}^2) = +2.61 \times 10^5 \text{ N}.$

4. Two children are pulling on a wagon of mass 50.0 kg. One child is pulling to the right with a force of 200.0 N, while another child is pulling to the left with a force of magnitude 150.0 N.

   a) What is the net force on the wagon?

   Answer:

   Use the dynamics information to find the net force.

   Let to the right be positive.

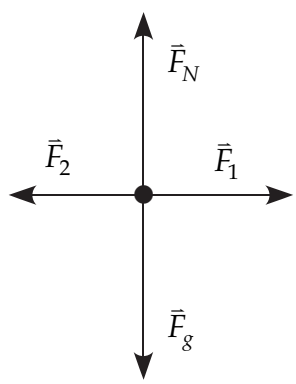
   Given: Mass $m = 50.0$ kg

   Force 1 $F_1 = +200.0$ N

   Force 2 $\vec{F}_2 = -150.0$ N

   Unknown: Net force $\vec{F}_{\text{NET}} = ?$

   The free-body diagram looks like this:



   Equation: $\vec{F}_{\text{NET}} = \sum \text{Forces} = \vec{F}_1 + \vec{F}_2 + \vec{F}_N + \vec{F}_g \left(\vec{F}_N + \vec{F}_g \text{ cancel}\right)$

   $\vec{F}_{\text{NET}} = \vec{F}_1 + \vec{F}_2$

   Substitute and solve: $\vec{F}_{\text{NET}} = (+200.0 \text{ N}) + (-150.0 \text{ N}) = +50.0 \text{ N}$

   The net force is 50.0 N [right].

   b) What is the magnitude and direction of the acceleration of the wagon?

   Answer:

   Knowing mass and net force, use Newton's Second Law.

   $$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{+50.0 \text{ N}}{50.0 \text{ kg}} = +1.00 \text{ m/s}^2$$

   The wagon accelerates at 1.00 m/s^2 [right].

c) How fast is the wagon moving after 3.25 s if the wagon starts from rest?

Answer:

Given: Initial velocity $\vec{v}_1 = 0 \text{ m/s}$

Acceleration $\vec{a} = +1.00 \text{ m/s}^2$

Time interval $\Delta t = 3.25 \text{ s}$

Unknown: Final velocity $\vec{v}_2 = ?$

Equation: Use kinematics equation 2.

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ rearranged to } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

Substitute and solve:

$$\vec{v}_2 = (0.0 \text{ m/s}) + (+1.00 \text{ m/s}^2)(3.25 \text{ s})$$
$$= +3.25 \text{ m/s}$$

The final velocity is 3.25 m/s [right].

5. A crate of mass 30.0 kg rests on a level concrete floor. A man pushes the crate with a constant horizontal force of 75.0 N to the left. A constant force of friction of 40.0 N also acts on the crate. If the crate starts from rest, how far would it be pushed during 5.35 seconds?

Answer:

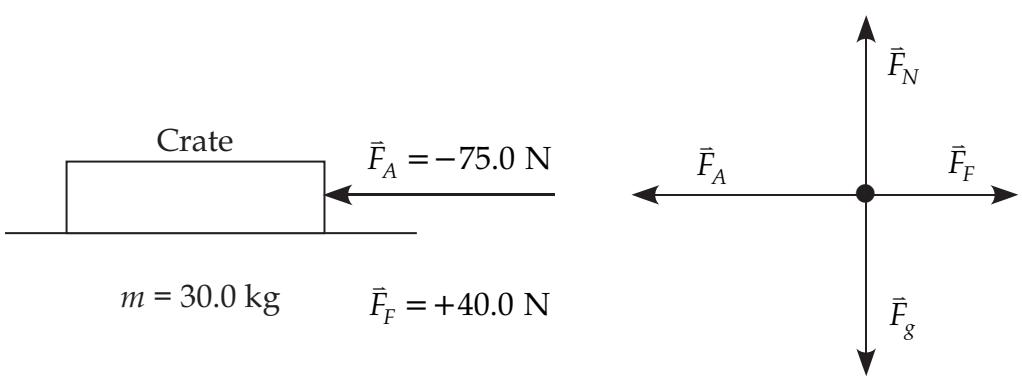
In this question, you are given enough dynamics information to determine the net force acting on the crate. Once you have the net force, you can use Newton's Second Law to determine the acceleration and then calculate the displacement of the crate.

Step 1:

Given:

In this case, let left be the negative direction and right be the positive direction.

You can start with the dynamics information.



Unknown: Net force $\vec{F}_{\text{NET}} = ?$

Equation: $\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F + \vec{F}_N + \vec{F}_g$

Since the normal force and the force of gravity cancel out, the equation becomes

$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$

Substitute and solve: $\vec{F}_{\text{NET}} = (-75.0\text{ N}) + (+40.0\text{ N}) = -35.0\text{ N}$

Step 2:

Use Newton's Second Law to calculate the acceleration.

$\vec{F}_{\text{NET}} = m\vec{a}$ rearranged to $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{-35.0\text{ N}}{30.0\text{ kg}} = -1.17\text{ m/s}^2$$

Step 3:

Now you can proceed to calculate the displacement using the kinematics information.

Given:

Acceleration	$\vec{a} = -1.17\text{ m/s}^2$
Initial velocity	$\vec{v}_1 = 0\text{ m/s}$
Time interval	$\Delta t = 5.35\text{ s}$

Unknown: Displacement $\vec{d} = ?$

Equation: You can use kinematics equation 4.

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve: $\vec{d} = (0\text{ m/s})(5.35\text{ s}) + \frac{1}{2}(-1.17\text{ m/s}^2)(5.35\text{ s})^2$

$\vec{d} = -16.7\text{ m}$

The crate is displaced –16.7 m or 16.7 m [left].

6. A toboggan carrying a passenger is pulled by a person who exerts a force on a rope. The mass of a toboggan and passenger is 35.5 kg. A force of friction of 12 .0 N acts on the toboggan. At one point in time, the velocity of the toboggan is 1.00 m/s [E] and, after sliding 4.30 m [E], the velocity is 3.00 m/s [E]. If the person pulling the toboggan pulls horizontally towards the east, what force did he exert on the rope?

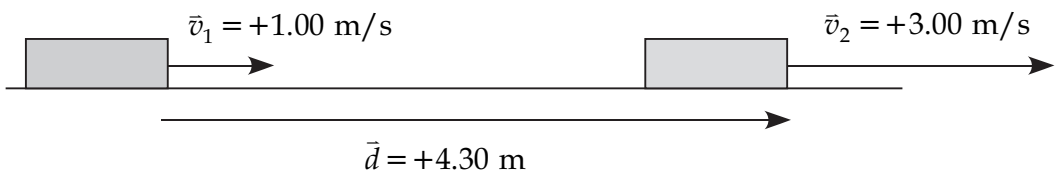
Answer:

In this case, you're given enough kinematics information to determine the acceleration. You can then find a net force using Newton's Second Law of Motion. Finally, you can use dynamics to determine the applied force.

Step 1:

Given:

Let east be the positive direction.



Unknown: Acceleration $\vec{a} = ?$

Equation: You can use kinematics equation 5:

$$v_2^2 = v_1^2 + 2ad$$

Substitute and solve:

$$(+3.00 \text{ m/s})^2 = (1.00 \text{ m/s})^2 + 2a(+4.30 \text{ m})$$

$$+9.00 = +1.00 + 8.60a$$

$$a = \frac{+8.00}{+8.60} = 0.930 \text{ m/s}^2$$

The acceleration is +0.930 m/s/s or 0.930 m/s/s [E].

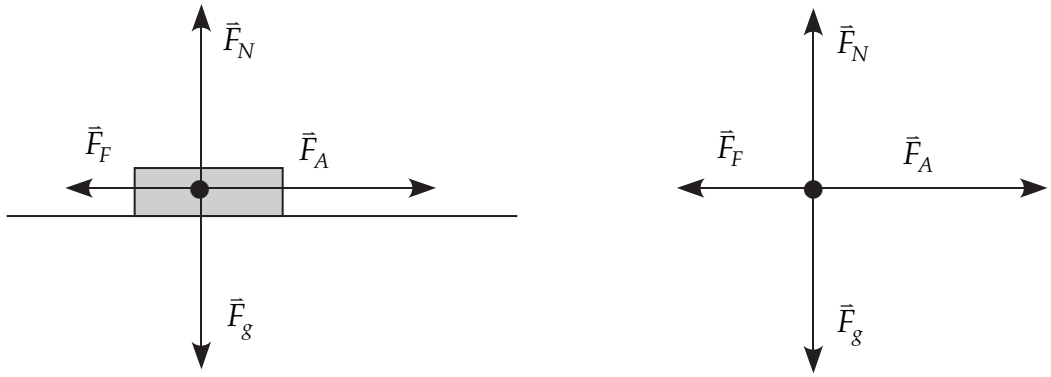
Step 2:

Find the net force using Newton's Second Law of Motion.

$$\vec{F}_{\text{NET}} = m\vec{a} = (35.5 \text{ kg})(+0.930 \text{ m/s}^2) = +33.0 \text{ N}$$

Step 3:

Now analyze the dynamics of the situation.



Given:

Net force	$\vec{F}_{\text{NET}} = +33.0\text{ N}$
Force of friction	$\vec{F}_F = 12.0\text{ N [W]} = -12.0\text{ N}$
Normal force	$\vec{F}_N = ?$
Force of gravity	$\vec{F}_g = ?$
	In this case, the normal force and the force of gravity cancel out.

Unknown: Applied force $\vec{F}_A = ?$

Equation: $\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F + \vec{F}_N + \vec{F}_g$

$\vec{F}_N + \vec{F}_g$ cancel out, so $\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$

Substitute and solve:

$$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$$
$$+33.0\text{ N} = \vec{F}_A + (-12.0\text{ N})$$
$$\vec{F}_A = +45.0\text{ N}$$

The person pulling the rope exerts a force of +45.0 N or 45.0 N [right].

Learning Activity 3.8: The Vector Nature of Newton's Second Law

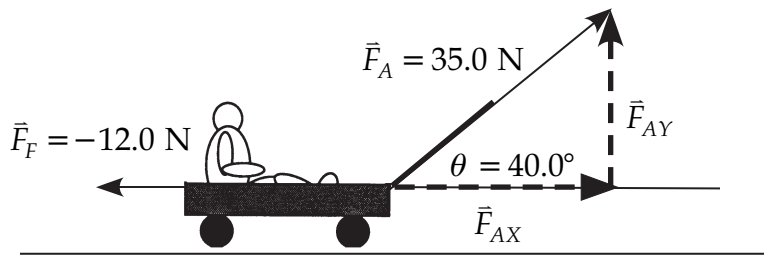
1. A wagon carries a child. Together, the mass is 28.5 kg. You pull on the handle of the wagon with a force of 35.0 N at an angle of 40.0° from the horizontal. The wagon travels over a level horizontal sidewalk. A force of friction of 12.0 N acts on the wagon.

   a) What is the net force acting on the wagon?

   b) What is the acceleration of the wagon?

   Answers:

   a) Let the positive direction be to the right. The wagon should move to the right.



Given:	Mass	$m = 28.5$ kg
	Force of friction	$\vec{F}_F = -12.0$ N
	Applied force	$\vec{F}_A = 35.0$ N [40.0° from the horizontal]
Unknown:	Net force	$\vec{F}_{NET} = ?$
Equation:		$\vec{F}_{NET} = \sum \vec{F}$

Here, you must draw a free-body diagram.

First, determine the horizontal (x) components of the applied force.

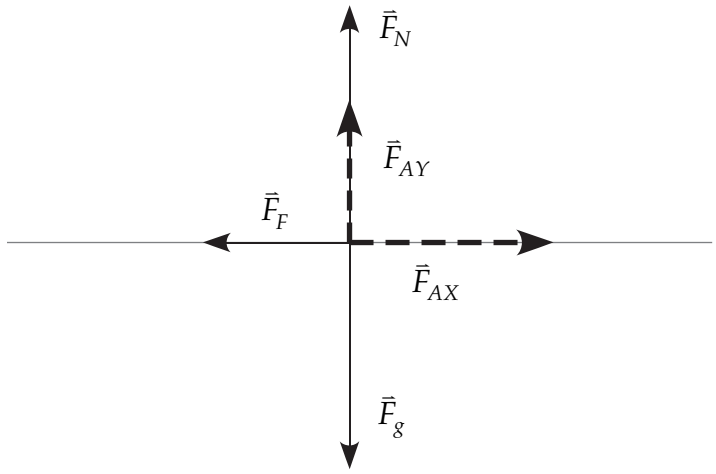
To find the x-component, use cosine.

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{F}_{AX}}{\vec{F}_A}$$

$$\vec{F}_{AX} = (\cos\theta)(\vec{F}_A)$$

$$\vec{F}_{AX} = (\cos 40.0°)(35.0\text{ N}) = +26.8\text{ N}$$

Since the y-component will be cancelled, you do not have to solve for it.



Substitute and solve: To find the net force, we use

$$\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_N + \vec{F}_{AY} + \vec{F}_{AX} + \vec{F}_F$$

but $\vec{F}_g$ is cancelled by the sum *of* $\vec{F}_N + \vec{F}_{AY}$.

$$\vec{F}_{\text{NET}} = \vec{F}_{AX} + \vec{F}_F$$

$$\vec{F}_{\text{NET}} = (+26.8\text{ N}) + (-12.0\text{ N}) = +14.8\text{ N}$$

The net force is 14.8 N [right].

b) Using Newton's Second Law, find the acceleration.

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{+14.8\text{ N}}{28.5\text{ kg}} = +0.519\text{ m/s}^2$$

The acceleration of the wagon and child is 0.519 m/s^2 [right].

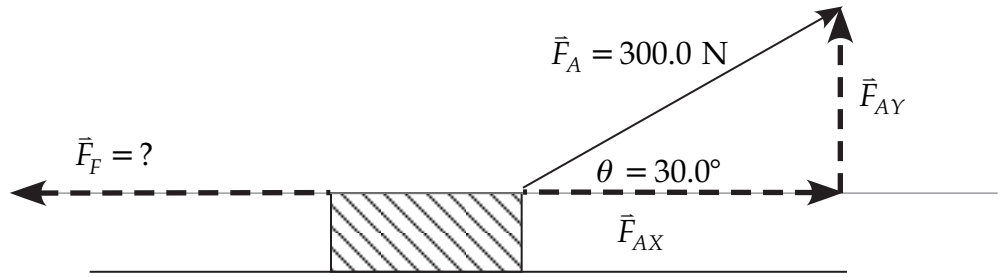
2. A crate of mass 50.0 kg is pulled across a level concrete floor by a force of 300.0 N acting 30.0° above the horizontal. The crate moves at a constant velocity of 0.962 m/s. What is the force of friction acting on the crate?

Answer:

Here, the velocity is constant, which indicates that acceleration is 0 m/s^2 and that the net force acting on the crate is 0 N.

Since the crate moves horizontally along the floor, the horizontal component of the applied force is pulling it forward (say, to the right). This component of the applied force must be balanced by the force of friction.

So the problem here is to just find the horizontal or x-component of the applied force.



First, determine the horizontal (x) components of the applied force.

To find the x-component, use cosine.

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{F}_{AX}}{\vec{F}_A}$$

$$\vec{F}_{AX} = (\cos\theta)(\vec{F}_A)$$

$$\vec{F}_{AX} = (\cos 30.0°)(300.0\text{ N}) = +259.8\text{ N}$$

The force of friction is –259.8 N or 259.8 N [left].

3. A person is stranded on a raft. The mass of the raft and the person is 1500 kg. By paddling, the man exerts an average force of 25 N in a direction due east (the +x-direction). The wind also exerts a force on the raft. The force of the wind has a magnitude of 15 N and points north. Determine the magnitude and direction of the acceleration of the raft and person.

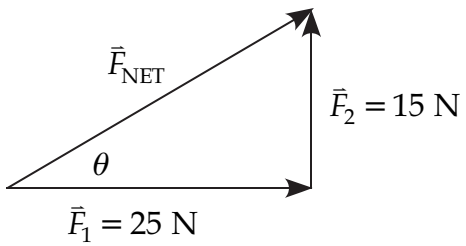
   Answer:

   Since you are given the applied forces acting on the raft, you can determine the net force on the raft. Since the man pushes the raft east and the wind pushes it north, you will have to add these vectors using the component method.

Given:	Mass	$m = 1500$ kg
	Force of man	$\vec{F}_1 = 25\text{ N [E]}$
	Force of wind	$\vec{F}_2 = 15\text{ N [E]}$
Unknown: Net force		$\vec{F}_{NET} = ?$
Equation:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2$
Substitute and solve:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2 = 25\text{ N [E]} + 15\text{ N [E]}$

   Add using the tip-to-tail method for the diagram and the component method to find the answer.

   The two force vectors form a right triangle.



The net force on the mass is $\vec{F}_{NET} = \sqrt{(25\text{ N})^2 + (15\text{ N})^2} = 29\text{ N}.$

The angle of the net force is $\theta = \tan^{1}\left(\frac{15\text{ N}}{25\text{ N}}\right) = 31°\text{ N of E}.$

The net force is 29 N [31° N of E].

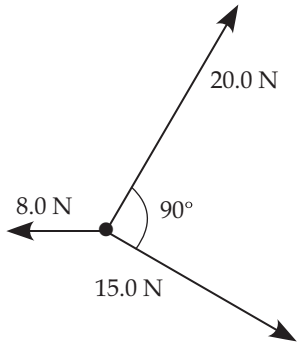
To find the acceleration, use Newton's Second Law.

The acceleration of the mass is $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{29\text{ N}}{1500\text{ kg}} = 0.019\text{ m/s}^2$

in the same direction as the net force.

The acceleration is 0.019 m/s^2 [31° N of E].

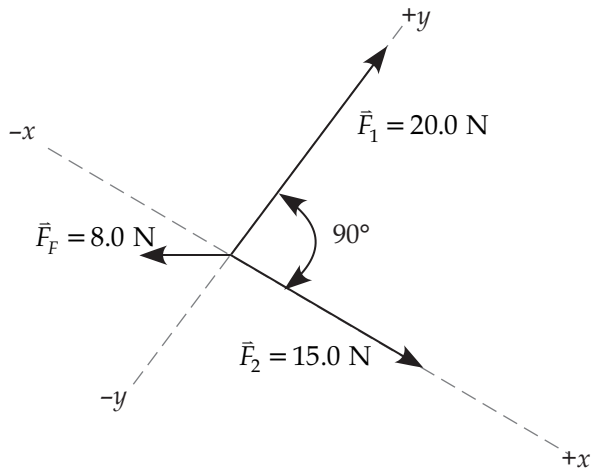
4. Two children are trying to pull a 20.0 kg toboggan out of a deep snow drift that provides an opposing force of 8.0 N. They are using ropes attached to the toboggan and parallel to the ground. The forces exerted by the children and the direction in which they pull on the ropes are shown below. Determine the net force and the magnitude and acceleration of the mass.



Answer:

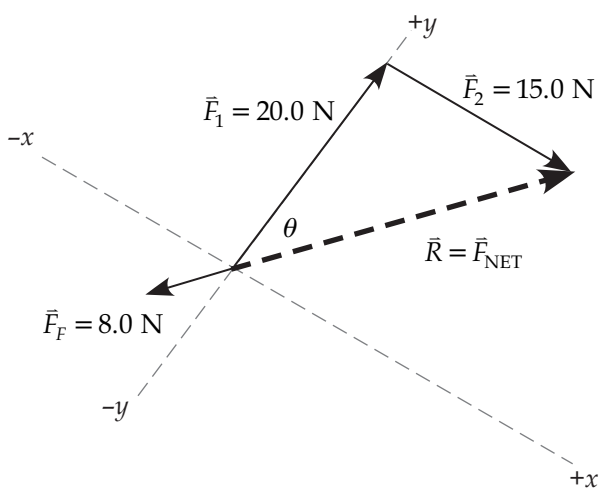
Since the actual directions are not given, you must specify a frame of reference to describe the motion. The simplest way to do this is to use the direction of one of the forces as the *x*-axis and then measure all other vectors in this frame of reference.

So let's draw in our coordinate system.



Given:	Force 1	$\vec{F}_1$ = 20.0 N [+y-direction]
	Force 2	$\vec{F}_2$ = 15.0 N [+x-direction]
	Force of friction	$\vec{F}_F$ = 8.0 N
	Mass	m = 20.0 kg
Unknown: Net force		$\vec{F}_{\text{NET}} = ?$
Equation:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$
Substitute and solve:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$

Find the sum of $\vec{F}_1 + \vec{F}_2$ first. Then add the force of friction unto that sum of $\vec{F}_1 + \vec{F}_2$. This is done since you do not know the direction of the force of friction but you do know that it must be opposite to the sum of the other two forces.



Using the theorem of Pythagoras,

$$\vec{R}^2 = \vec{F}_1^2 + \vec{F}_2^2$$

$$\vec{R}^2 = (20.0\text{ N})^2 + (15.0\text{ N})^2 = 625\text{ N}^2$$

$$\vec{R} = \sqrt{625\text{ N}^2} = 25.0\text{ N}$$

Find the angle using tangent.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{15.0}{20.0}$$

$$\theta = \tan^{-1}\frac{15.0}{20.0} = 36.9°$$

This angle can be stated as 36.9° clockwise from $+y$.

The sum of $\vec{F}_1 + \vec{F}_2$ is 25.0 N [36.9° clockwise from $+y$].

The net force will be the force of friction added to $\vec{R}$.

Friction will point opposite to the direction of $\vec{R}$.

These vectors point along the same line but in opposite directions, so you subtract the magnitudes and keep the direction of the larger vector.

$$\vec{F}_{\text{NET}} = \vec{R} + \vec{F}_F = 25.0\text{ N} - 8.0\text{ N} = 17.0\text{ N}$$

The net force is 17.0 N [36.9° clockwise from $+y$].

Using Newton's Second Law, find the acceleration.

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{17.0\text{ N}\left[36.9°\text{ clockwise from }+y\right]}{20.0\text{ kg}}$$

$$= 0.850\text{ m/s}^2\left[36.9°\text{ clockwise from }+y\right]$$

NOTES

Grade 11 Physics (30S)

Module 3: Dynamics

Learning Activity Answer Keys

Module 3: Dynamics

Learning Activity 3.1: Fundamental Forces

1. For each of the following situations, which of the four fundamental forces is acting?
   a) In radioactivity, a proton may change into a neutron.

      Answer: Weak nuclear

   b) An electron will repel another electron.

      Answer: Electromagnetic

   c) The protons in a nucleus are held together so that they do not push each other apart.

      Answer: Strong nuclear

   d) An attractive force exists between two neutrons that are not charged, but are attracted because they have mass.

      Answer: Gravitational

2. Complete the following table about the properties of the four fundamental forces.

   Answer:

Property	Fundamental Force
Acts between charged particles	electromagnetic
Acts in the nucleus	strong nuclear, weak nuclear
Has the shortest range of all of the forces	weak nuclear
Has unlimited range	electromagnetic, gravitational
The weakest force	gravitational
Acts between protons	strong nuclear, electromagnetic, gravitational
Due to the fact objects have mass	gravitational
Can be attractive or repulsive	electromagnetic
Is only attractive	strong nuclear, weak nuclear, gravitational

3. Identify to which of the four fundamental forces each of the following forces belongs.

   Answer:

Force	Category of Force
Weight	gravitational
Spring pulling a book	electromagnetic
Occurs between neutrons	strong nuclear
Occurs between particles smaller than protons	weak nuclear
Allows a balloon to "stick" to a wall	electromagnetic
Friction	electromagnetic
Bat hitting a ball	electromagnetic

Learning Activity 3.2: Newton's First Law

1. Why is it particularly dangerous to drive on an icy highway? (Hint: Consider the inertia of the vehicle and the low frictional force between the wheels and the icy surface.)

   Answer:

   A car has a considerable mass and, therefore, it has a large amount of inertia. If the car should hit a little bump, it could start into a skid in an undesirable direction. The only force available to correct the skidding car is the force of friction between the tires and the road surface. This frictional force is usually sufficient when the road conditions are normal. Under icy conditions, however, since the force of friction is less than it is under normal conditions, the force may not be sufficiently large to change the direction of motion of the car. The result is that the skid cannot be corrected and the car ends up in the ditch, or worse.

2. Why do you lunge forward when your car suddenly comes to a halt? Why are you "thrown backward" when your car rapidly accelerates?

   Answer:

   The car and your body are travelling at a certain velocity. The velocity of the car is decreased suddenly. Your body, because of inertia, will continue on at the same velocity unless it is restrained by a seatbelt.

   When the car accelerates rapidly, you're not really "thrown backward." What really happens is that your body, being at rest, wants to remain at rest. The car begins to move. The seat and headrest move forward, pressing against your back and head and accelerating you forward at the same rate as the car, making it appear that you are "thrown backwards."

3. Why is your body pressed against the left side of the seat when the roller-coaster car in which you are riding suddenly veers to the right?

   Answer:

   The mass of your body provides a considerable amount of inertia. When the roller-coaster car veers to the right, your body will tend to continue in the same straight-line motion it had prior to the change in direction of the car. Frictional force between your clothing and the seat may not produce sufficient force to cause you to change direction with the car, and you will slip left against the side of the seat. It is the force applied by the left side of the seat that will bring about the required change in the direction of your motion.

Learning Activity 3.3: Newton's Second Law

1. According to Newton's Second Law, indicate how the acceleration will change if

   a) the mass of the object is doubled but the net force is kept constant.

   Answer:

   Mass is doubled but force is kept constant.

   Acceleration is inversely proportional to mass $\left(\vec{a}\ \alpha\ \frac{1}{m}\right)$, so as mass increases, acceleration decreases.

   So the acceleration will be one-half as large as before.

   b) the net force on the object is tripled but the mass of the object is constant.

   Answer:

   The net force is tripled but the mass is kept constant.

   Acceleration is directly proportional to the net force $\left(\vec{a}\ \alpha\ \vec{F}_{NET}\right)$, so as net force increases so does the acceleration.

   Therefore, the acceleration will be three times as large as before.

2. Calculate the net force acting on a 2.50 kg mass that causes an acceleration of 1.65 m/s^2 to the right.

   Answer:

Given:	Mass	m = 2.50 kg
	Acceleration	$\vec{a}$ = 1.65 m/s^2 [right]
Unknown:	Net force	$\vec{F}_{NET}$ = ?
Equation:		$\vec{F}_{NET} = m\vec{a}$
Substitute:		$\vec{F}_{NET}$ = (2.50 kg)(1.65 m/s^2 [right]
Solve:		$\vec{F}_{NET}$ = 4.12 N [right]

   The net force is 4.12 N to the right. The net force acts in the same direction as the acceleration.

3. What is the acceleration of a car of mass 1250 kg that is subjected to a net force of 2250 N [N]?

   Answer:

Given:	Mass	m = 1250 kg
	Net force	$\vec{F}_{NET}$ = 2250 N [N]
Unknown:	Acceleration	$\vec{a}$ = ?

Equation: $\vec{F}_{NET} = m\vec{a}$ rearranged to $\vec{a} = \frac{\vec{F}_{NET}}{m}$

Substitute: $\vec{a} = \frac{2250 \text{ N [N]}}{1250 \text{ kg}}$

Solve: $\vec{a} = 1.80 \text{ m/s}^2 \text{ [N]}$

The acceleration is 1.80 m/s^2 [N].

4. What is the mass of person who accelerates at 4.25 m/s^2 [S] under a net force of 265 N [S]?

   Answer:

   Given: Net force $\vec{F}_{NET} = 265 \text{ N [S]}$

   Acceleration $\vec{a} = 4.25 \text{ m/s}^2 \text{ [S]}$

   Unknown: Mass $m = ?$

   Equation: $\vec{F}_{NET} = m\vec{a}$ rearranged to $m = \frac{\vec{F}_{NET}}{\vec{a}}$

   Substitute: $m = \frac{\vec{F}_{NET}}{\vec{a}} = \frac{265 \text{ N [S]}}{4.25 \text{ m/s}^2 \text{ [S]}}$

   Solve: $m = 62.4 \text{ kg}$

   The mass of the person is 62.4 kg.

5. A bicycle has a mass of 13.1 kg, and the rider has a mass of 81.7 kg. The rider is pumping hard, so that a horizontal net force of 9.78 N accelerates them. What is the acceleration?

   Let the positive direction point to the right.

   Answer:

   Given: The total mass of the bicycle and rider is $m = 13.1 \text{ kg} + 81.7 \text{ kg} = 94.8 \text{ kg}$.

   Net force $\vec{F}_{NET} = +9.78 \text{ N}$

   Unknown: Acceleration $\vec{a} = ?$

   Equation: $\vec{F}_{NET} = m\vec{a}$ rearranged to $\vec{a} = \frac{\vec{F}_{NET}}{m}$

   Substitute and solve: $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{+9.78 \text{ N}}{94.8 \text{ kg}} = +0.103 \text{ m/s}^2$

   The acceleration of this pair is +0.103 m/s^2.

Learning Activity 3.4: Newton's Laws

1. If "action forces" and "reaction forces" are equal and opposite, why can they never balance or cancel?

   Answer:

   An "action force" is a force that object 1 exerts on object 2. A "reaction" force is the force that object 2 exerts on object 1. Since the two forces act on different objects, they cannot balance or cancel.

2. In a car crash, a passenger's head collides with the window in the door. The passenger suffers a fractured skull. The window in the door is shattered. Account for this using Newton's Laws of Motion.

   Answer:

   According to Newton's Third Law of Motion, the passenger's head exerts an action force on the windshield. This action force shatters the window. The reaction force is the force that the window exerts on the passenger's head. It is this reaction force that fractures the passenger's skull.

3. Using the appropriate law of motion, explain the following:

   a) A bullet is fired from a rifle. The rifle recoils.

      Answer:

      This involves Newton's Third Law of Motion.

      When a rifle is fired, a chemical reaction—literally an explosion—occurs. In this explosion, gases are produced and expanded rapidly. The expanding gases push the bullet forward down through the barrel of the rifle. This can be called an action force. The reaction force can be thought of as the gases pushing on the other end of the rifle barrel. This reaction force causes the rifle to move backwards or recoil.

   b) A karate expert attempts to break 10 boards piled on top of each other by striking them with one blow of his hand. In the process, he breaks a bone in his hand.

      Answer:

      This involves Newton's Third Law of Motion.

      The karate expert exerts an action force of his hand on the boards. The boards exert a reaction force on the karate expert's hand. This reaction force is large enough to break a bone in his hand.

c) The stationary car in which a passenger sits is struck from the rear by a second car. The passenger suffers whiplash.

Answer:

This example involves Newton's First and Second Laws of Motion.

The force of the second car striking the stationary car is an unbalanced force acting on the stationary car. Therefore, according to Newton's Second Law, the second car will accelerate in the direction of the force applied.

The passenger was motionless. Being at rest, according to Newton's First Law, the passenger would tend to remain at rest. The back of the seat is accelerated forward, pushing the body of the person forward as well. The body of the person is literally pushed out from underneath his head, which remains at rest. This stretches and damages ligaments and tendons and muscles, resulting in whiplash.

d) A curling rock slides along the ice and slowly comes to a stop

Answer:

This involves both the First and Second Laws of Motion.

A curling rock is in motion and it should continue in motion with a constant velocity, according to the First Law of Motion. There is a small force of friction between the curling rock and the ice. This force of friction acts as an unbalanced force on the curling rock. According to the Second Law of Motion, an unbalanced force causes an acceleration in the direction that the force acts. In this case, the unbalanced force acts opposite to the velocity, causing the rock to slow down and eventually stop.

e) A rock is dropped from a bridge and accelerates towards the earth. The rock exerts a force on the earth. We do not notice the earth accelerating towards the rock.

Answer:

This is an example of the Second Law of Motion.

The earth exerts a force of attraction on the rock. According to Newton's Second Law for a given force, if the mass is small acceleration must be large.

$$\vec{F}_{\text{NET}} = m\vec{a}$$
$$\vec{F}_{\text{NET}} = m_R\vec{a}_R$$

The rock exerts a force of attraction on the earth. According to Newton's Second Law, for a given force, if the mass is large the acceleration must be small.

$$\vec{F}_{\text{NET}} = m\vec{a}$$
$$\vec{F}_{\text{NET}} = m_E\vec{a}_E$$

This small acceleration occurs when the earth accelerates under this force. We notice the large acceleration of the rock but not the small acceleration of the earth.

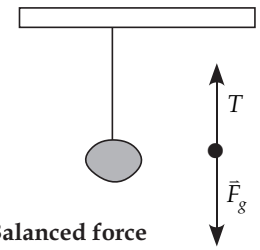
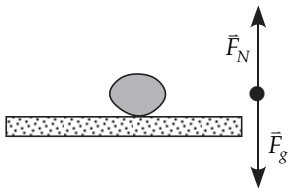
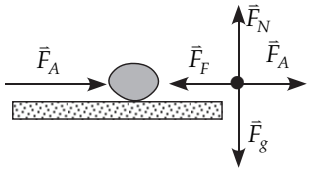
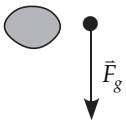
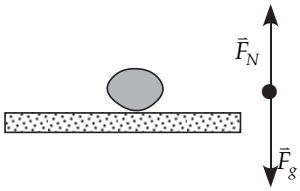
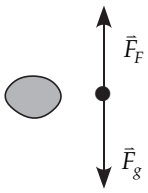
Learning Activity 3.5: Free-Body Diagrams

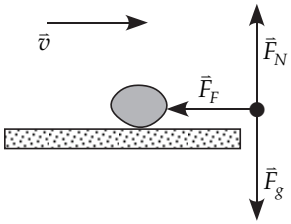
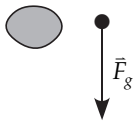
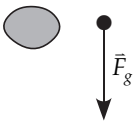
There are 15 questions in this learning activity. In each case, the rock is acted upon by one or more forces. All drawings are in the vertical plane, and friction is negligible except where noted. Draw accurate free-body diagrams showing all forces acting on the rock. Draw all forces as though they were acting on the centre of mass, even though forces like friction and normal force act on the surface at the point of contact. Please use a ruler and pencil so that you can correct errors. Label the forces using $\vec{F}_g$ for the weight or force of gravity, T for tension, $\vec{F}_F$ for force of friction, $\vec{F}_N$ for normal force, and $\vec{F}_A$ for applied force.

For each question, indicate whether the forces are **balanced** or **unbalanced**.

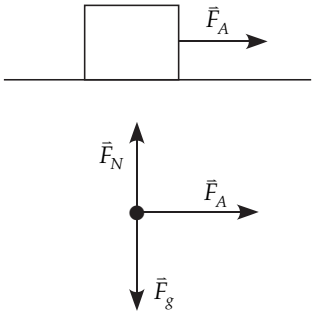
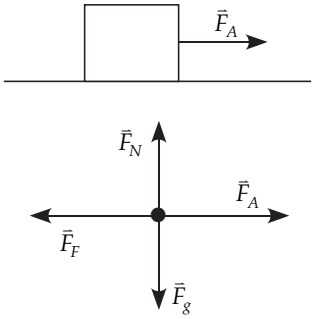
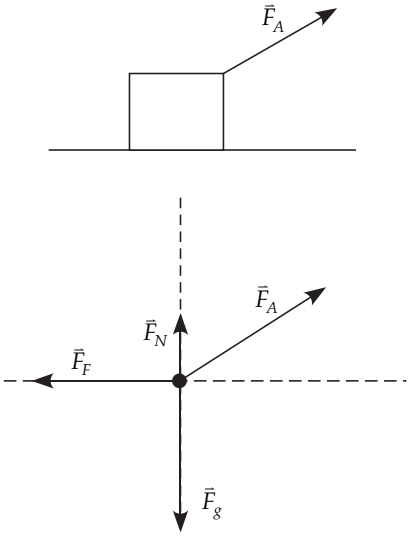
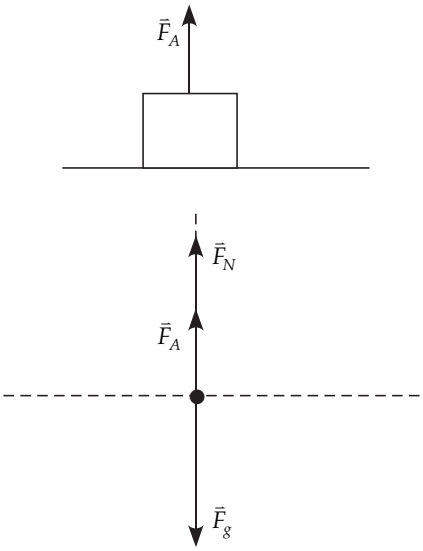
Answers:

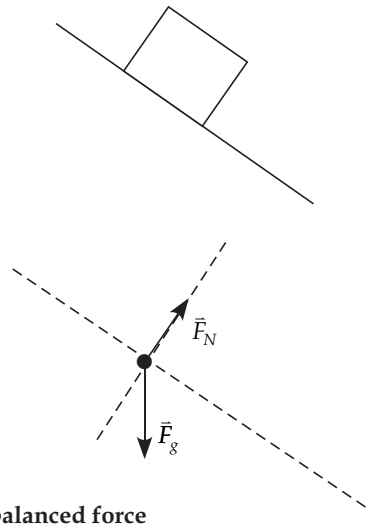
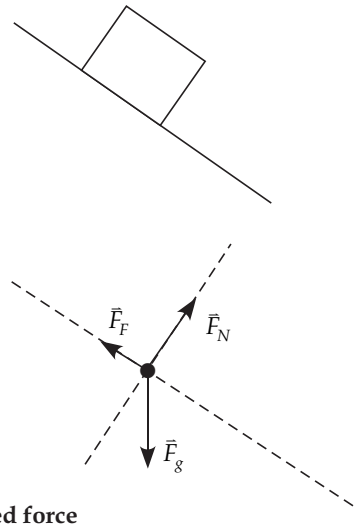
Part 1:

1. Equilibrium  **Balanced force**	2. Equilibrium  **Balanced force**	3. Rock is pushed but remains motionless. Friction acts.  **Balanced force**
4. Rock is falling, no friction.  **Unbalanced force**	5. Rock is sliding at constant speed on a frictionless surface.  **Balanced force**	6. Rock is falling at a constant (terminal) velocity.  **Balanced force**

7. Rock is decelerating because of kinetic friction.  **Unbalanced force**	8. Rock is rising. No friction.  **Unbalanced force**	9. Rock is at the top of its flight, momentarily motionless.  **Unbalanced force**

Part 2:

1. The object is pulled horizontally. No friction.  **Unbalanced force**	2. The object is pulled horizontally at constant velocity. Kinetic friction acts.  **Balanced force**
3. The object is pulled by a force acting in the direction shown. Static friction acts. The object is motionless.  **Balanced force**	4. The object is pulled straight upwards. It is motionless.  **Balanced force**

5. The object is resting on the plane. No friction acts.  **Unbalanced force**	6. The object remains motionless. Static friction acts.  **Balanced force**

Learning Activity 3.6: Force of Friction

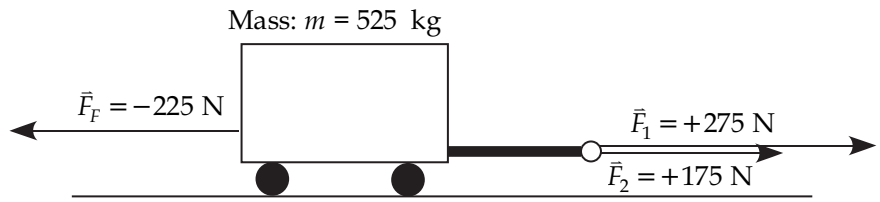
1. A wagon loaded with luggage has a mass of 525 kg. Two baggage handlers are pulling on the hitch of the wagon. The first person pulls with a force of 275 N and the second person pulls with a force of 175 N. Both people pull to the right. A force of friction of 225 N acts on the wagon. The force of gravity is 5140 N.

   a) Draw a free-body diagram labelling all the forces.

   Answer:

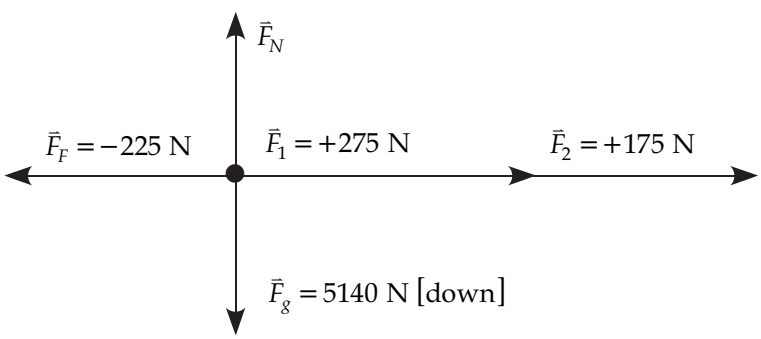
   Let to the right represent the positive direction.

   Given:



   Force of gravity: $\vec{F}_g$ = 5140 N [down]

   The free-body diagram should appear as follows. The vectors are not drawn to scale.



   b) What is the normal force?

   Answer:

   You can see that the normal force is just equal but opposite to the force of gravity.

   The normal force is 5140 N [up].

c) What is the net force acting in the wagon?

Answer:

The net force is the sum of all of the forces acting on the wagon.

$\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_N + \vec{F}_1 + \vec{F}_2 + \vec{F}_F$

You can see that $\vec{F}_g + \vec{F}_N$ cancel, so $\vec{F}_{\text{NET}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$.

$\vec{F}_{\text{NET}} = (+275\text{ N}) + (+175\text{ N}) + (-225\text{ N}) = +225\text{ N}$

d) What is the acceleration of the wagon?

Answer:

Using Newton's Second Law, $\vec{F}_{\text{NET}} = m\vec{a}$, and rearranging for acceleration $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$.

$\vec{a} = \dfrac{+225\text{ N}}{525\text{ kg}} = +0.428\text{ m/s}^2$

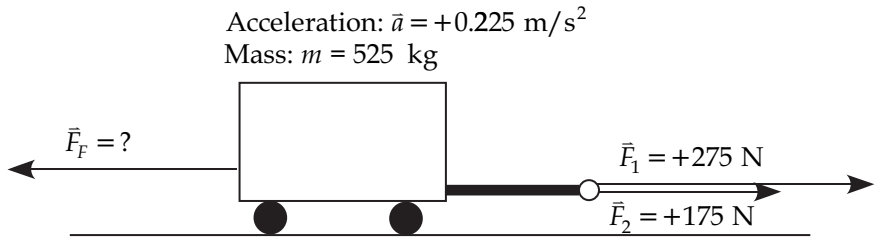
The acceleration of the wagon is 0.428 m/s^2 [right].

2. Suppose in Question #1 that the two baggage handlers pulled on the wagon but the acceleration was 0.225 m/s^2 to the right. If everything else was the same, what would be the force of friction in this case? (Hint: Find the net force first using Newton's Second Law, then find the force of friction.)

Answer:

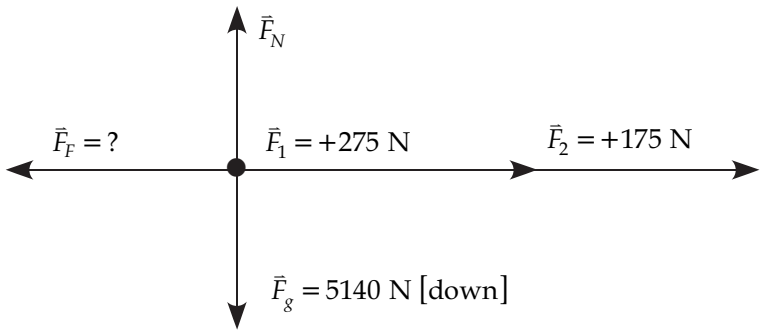
Let the right represent the positive direction.

Given:



Force of gravity $\vec{F}_g$ = 5140 N [down]

The free-body diagram should appear as follows. The vectors are not drawn to scale.



In this case, since you know the mass and the acceleration of the wagon, you can find the net force. Once you know the net force, you can find the force of friction.

Finding $\vec{F}_{\text{NET}}$ using $\vec{F}_{\text{NET}} = m\vec{a}$ gives

$$\vec{F}_{\text{NET}} = (525\text{ kg})(+0.225\text{ m/s}^2) = +118\text{ N}.$$

But we saw earlier that $\vec{F}_{\text{NET}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$.

Substitute and solve for the force of friction.

$$+118\text{ N} = (+275\text{ N}) + (+175\text{ N}) + \vec{F}_F$$

$$\vec{F}_F = -332\text{ N}$$

The force of friction is 332 N [left].

Learning Activity 3.7: Dynamics and Kinematics

1. Newton's Second Law indicates that when a net force acts on an object, it must accelerate. Does this mean that when two or more forces are applied to an object simultaneously, it must accelerate? Explain.

   Answer:

   An object will not necessarily accelerate when two or more forces are applied to it simultaneously. The applied forces may cancel, so the net force is zero; in such a case, the object will not accelerate. The resultant of all the forces that act on the object must be non-zero for the object to accelerate.

2. A person with a black belt in karate has a fist that has a mass of 0.70 kg. Starting from rest, this fist attains a velocity of 8.0 m/s in 0.15 s. What is the average force applied to the fist to achieve this level of performance?

   Answer:

   According to Newton's Second Law of Motion, the net force applied to the fist is equal to the mass of the fist multiplied by the acceleration.

   To determine the acceleration, we use kinematics.

   Let the positive direction be to the right.

   Given: Initial velocity $\vec{v}_1 = 0 \text{ m/s}$

   Time interval $\Delta t = 0.15 \text{ s}$

   Final velocity $\vec{v}_2 = +8.0 \text{ m/s}$

   Unknown: Acceleration $\vec{a} = ?$

   Equation: $$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$$

   Substitute and solve: $$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} = \frac{+8.0 \text{ m/s} - 0.0 \text{ m/s}}{0.15 \text{ s}} = +53 \text{ m/s}^2$$

   Using Newton's Second Law, determine the average force.

   Therefore, the average force is $\vec{F}_{\text{NET}} = m\vec{a} = (0.70 \text{ kg})(+53 \text{ m/s}^2) = +37 \text{ N}$.

3. A catapult on an aircraft carrier is capable of accelerating a plane from 0.0 to 56.0 m/s in a distance of 80.0 m. What is the average force that the catapult exerts on a 13,300 kg jet?

Answer:

We will first need to determine the acceleration of the aircraft using our information about velocities and distance.

To determine the acceleration, we use kinematics.

Let the positive direction be to the right.

Given:	Initial velocity	$\vec{v}_1 = 0 \text{ m/s}$
	Displacement	$\vec{d} = +80.0 \text{ m}$
	Final velocity	$\vec{v}_2 = +56.0 \text{ m/s}$
Unknown:	Acceleration	$\vec{a} = ?$

Equation: $v_2^2 - v_1^2 + 2ad$ rearranged to $a = \dfrac{v_2^2 - v_1^2}{2d}$

Substitute and solve:

$$a = \frac{v_2^2 - v_1^2}{2d} = \frac{(+56.0 \text{ m/s})^2 - (0.0 \text{ m/s})^2}{2(+80.0 \text{ m})}$$

$$= \frac{+3136}{+160} = +19.6 \text{ m/s}^2$$

Using Newton's Second Law, determine the average force. According to Newton's Second Law of Motion, the net force applied to the jet is equal to the mass of the jet multiplied by the acceleration.

The force acting on the aircraft is

$\vec{F}_{\text{NET}} = m\vec{a} = (13\ 300 \text{ kg})(+19.6 \text{ m/s}^2) = +2.61 \times 10^5 \text{ N}.$

4. Two children are pulling on a wagon of mass 50.0 kg. One child is pulling to the right with a force of 200.0 N, while another child is pulling to the left with a force of magnitude 150.0 N.

   a) What is the net force on the wagon?

   Answer:

   Use the dynamics information to find the net force.

   Let to the right be positive.

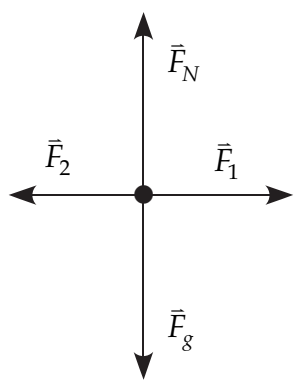
   Given: Mass $m = 50.0$ kg

   Force 1 $F_1 = +200.0$ N

   Force 2 $\vec{F}_2 = -150.0$ N

   Unknown: Net force $\vec{F}_{\text{NET}} = ?$

   The free-body diagram looks like this:



   Equation: $\vec{F}_{\text{NET}} = \sum \text{Forces} = \vec{F}_1 + \vec{F}_2 + \vec{F}_N + \vec{F}_g \left(\vec{F}_N + \vec{F}_g \text{ cancel}\right)$

   $\vec{F}_{\text{NET}} = \vec{F}_1 + \vec{F}_2$

   Substitute and solve: $\vec{F}_{\text{NET}} = (+200.0 \text{ N}) + (-150.0 \text{ N}) = +50.0 \text{ N}$

   The net force is 50.0 N [right].

   b) What is the magnitude and direction of the acceleration of the wagon?

   Answer:

   Knowing mass and net force, use Newton's Second Law.

   $$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{+50.0 \text{ N}}{50.0 \text{ kg}} = +1.00 \text{ m/s}^2$$

   The wagon accelerates at 1.00 m/s^2 [right].

c) How fast is the wagon moving after 3.25 s if the wagon starts from rest?

Answer:

Given: Initial velocity $\vec{v}_1 = 0 \text{ m/s}$

Acceleration $\vec{a} = +1.00 \text{ m/s}^2$

Time interval $\Delta t = 3.25 \text{ s}$

Unknown: Final velocity $\vec{v}_2 = ?$

Equation: Use kinematics equation 2.

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ rearranged to } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

Substitute and solve:

$$\vec{v}_2 = (0.0 \text{ m/s}) + (+1.00 \text{ m/s}^2)(3.25 \text{ s})$$
$$= +3.25 \text{ m/s}$$

The final velocity is 3.25 m/s [right].

5. A crate of mass 30.0 kg rests on a level concrete floor. A man pushes the crate with a constant horizontal force of 75.0 N to the left. A constant force of friction of 40.0 N also acts on the crate. If the crate starts from rest, how far would it be pushed during 5.35 seconds?

Answer:

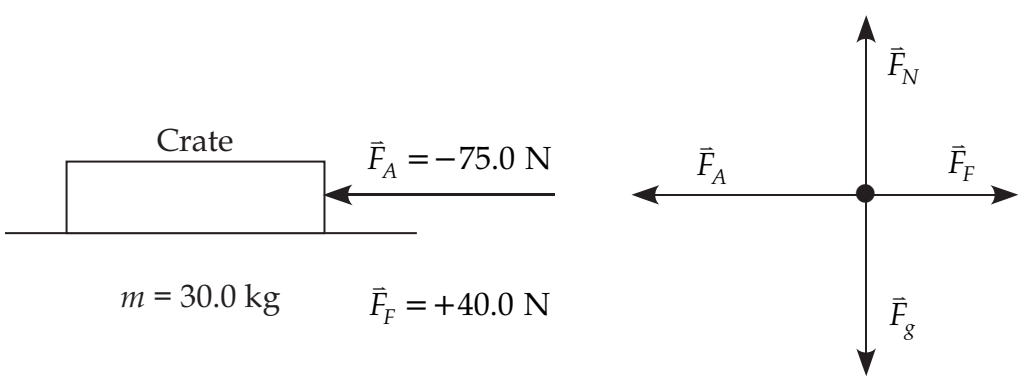
In this question, you are given enough dynamics information to determine the net force acting on the crate. Once you have the net force, you can use Newton's Second Law to determine the acceleration and then calculate the displacement of the crate.

Step 1:

Given:

In this case, let left be the negative direction and right be the positive direction.

You can start with the dynamics information.



Unknown: Net force $\vec{F}_{\text{NET}} = ?$

Equation: $\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F + \vec{F}_N + \vec{F}_g$

Since the normal force and the force of gravity cancel out, the equation becomes

$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$

Substitute and solve: $\vec{F}_{\text{NET}} = (-75.0\text{ N}) + (+40.0\text{ N}) = -35.0\text{ N}$

Step 2:

Use Newton's Second Law to calculate the acceleration.

$\vec{F}_{\text{NET}} = m\vec{a}$ rearranged to $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{-35.0\text{ N}}{30.0\text{ kg}} = -1.17\text{ m/s}^2$$

Step 3:

Now you can proceed to calculate the displacement using the kinematics information.

Given:

Acceleration	$\vec{a} = -1.17\text{ m/s}^2$
Initial velocity	$\vec{v}_1 = 0\text{ m/s}$
Time interval	$\Delta t = 5.35\text{ s}$

Unknown: Displacement $\vec{d} = ?$

Equation: You can use kinematics equation 4.

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve: $\vec{d} = (0\text{ m/s})(5.35\text{ s}) + \frac{1}{2}(-1.17\text{ m/s}^2)(5.35\text{ s})^2$

$\vec{d} = -16.7\text{ m}$

The crate is displaced –16.7 m or 16.7 m [left].

6. A toboggan carrying a passenger is pulled by a person who exerts a force on a rope. The mass of a toboggan and passenger is 35.5 kg. A force of friction of 12 .0 N acts on the toboggan. At one point in time, the velocity of the toboggan is 1.00 m/s [E] and, after sliding 4.30 m [E], the velocity is 3.00 m/s [E]. If the person pulling the toboggan pulls horizontally towards the east, what force did he exert on the rope?

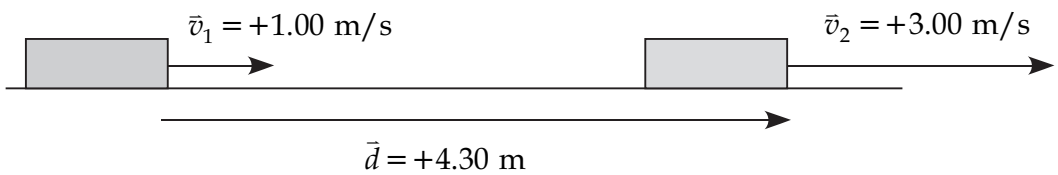
Answer:

In this case, you're given enough kinematics information to determine the acceleration. You can then find a net force using Newton's Second Law of Motion. Finally, you can use dynamics to determine the applied force.

Step 1:

Given:

Let east be the positive direction.



Unknown: Acceleration $\vec{a} = ?$

Equation: You can use kinematics equation 5:

$$v_2^2 = v_1^2 + 2ad$$

Substitute and solve:

$$(+3.00 \text{ m/s})^2 = (1.00 \text{ m/s})^2 + 2a(+4.30 \text{ m})$$

$$+9.00 = +1.00 + 8.60a$$

$$a = \frac{+8.00}{+8.60} = 0.930 \text{ m/s}^2$$

The acceleration is +0.930 m/s/s or 0.930 m/s/s [E].

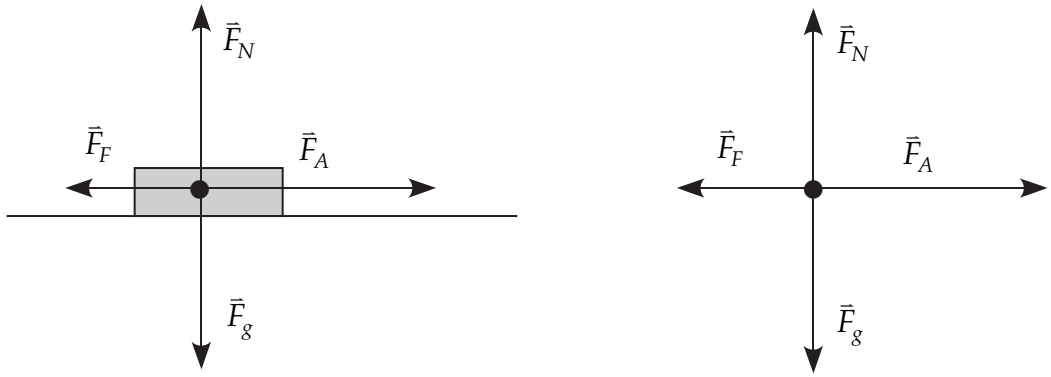
Step 2:

Find the net force using Newton's Second Law of Motion.

$$\vec{F}_{\text{NET}} = m\vec{a} = (35.5 \text{ kg})(+0.930 \text{ m/s}^2) = +33.0 \text{ N}$$

Step 3:

Now analyze the dynamics of the situation.



Given:

Net force	$\vec{F}_{\text{NET}} = +33.0\text{ N}$
Force of friction	$\vec{F}_F = 12.0\text{ N [W]} = -12.0\text{ N}$
Normal force	$\vec{F}_N = ?$
Force of gravity	$\vec{F}_g = ?$
	In this case, the normal force and the force of gravity cancel out.

Unknown: Applied force $\vec{F}_A = ?$

Equation: $\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F + \vec{F}_N + \vec{F}_g$

$\vec{F}_N + \vec{F}_g$ cancel out, so $\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$

Substitute and solve:

$$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_F$$
$$+33.0\text{ N} = \vec{F}_A + (-12.0\text{ N})$$
$$\vec{F}_A = +45.0\text{ N}$$

The person pulling the rope exerts a force of +45.0 N or 45.0 N [right].

Learning Activity 3.8: The Vector Nature of Newton's Second Law

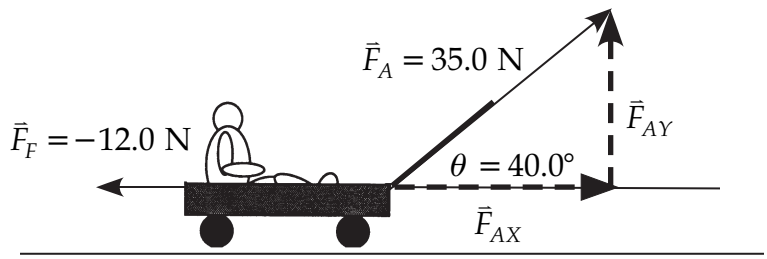
1. A wagon carries a child. Together, the mass is 28.5 kg. You pull on the handle of the wagon with a force of 35.0 N at an angle of 40.0° from the horizontal. The wagon travels over a level horizontal sidewalk. A force of friction of 12.0 N acts on the wagon.

   a) What is the net force acting on the wagon?

   b) What is the acceleration of the wagon?

   Answers:

   a) Let the positive direction be to the right. The wagon should move to the right.



Given:	Mass	$m = 28.5$ kg
	Force of friction	$\vec{F}_F = -12.0$ N
	Applied force	$\vec{F}_A = 35.0$ N [40.0° from the horizontal]
Unknown:	Net force	$\vec{F}_{NET} = ?$
Equation:		$\vec{F}_{NET} = \sum \vec{F}$

Here, you must draw a free-body diagram.

First, determine the horizontal (x) components of the applied force.

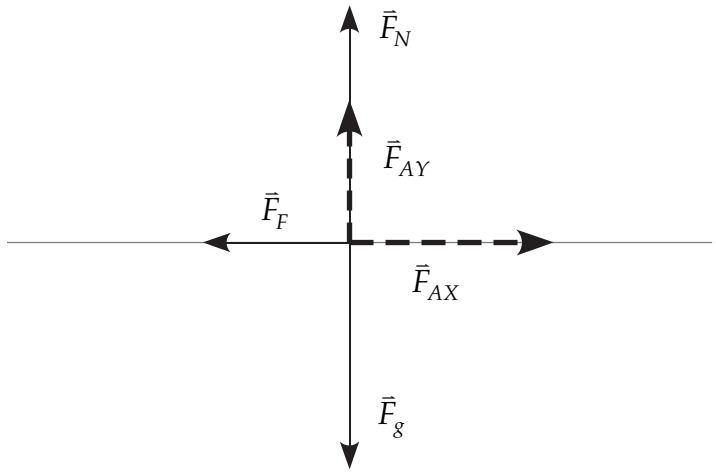
To find the x-component, use cosine.

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{F}_{AX}}{\vec{F}_A}$$

$$\vec{F}_{AX} = (\cos\theta)(\vec{F}_A)$$

$$\vec{F}_{AX} = (\cos 40.0°)(35.0\text{ N}) = +26.8\text{ N}$$

Since the y-component will be cancelled, you do not have to solve for it.



Substitute and solve: To find the net force, we use

$$\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_N + \vec{F}_{AY} + \vec{F}_{AX} + \vec{F}_F$$

but $\vec{F}_g$ is cancelled by the sum *of* $\vec{F}_N + \vec{F}_{AY}$.

$$\vec{F}_{\text{NET}} = \vec{F}_{AX} + \vec{F}_F$$

$$\vec{F}_{\text{NET}} = (+26.8\text{ N}) + (-12.0\text{ N}) = +14.8\text{ N}$$

The net force is 14.8 N [right].

b) Using Newton's Second Law, find the acceleration.

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{+14.8\text{ N}}{28.5\text{ kg}} = +0.519\text{ m/s}^2$$

The acceleration of the wagon and child is 0.519 m/s^2 [right].

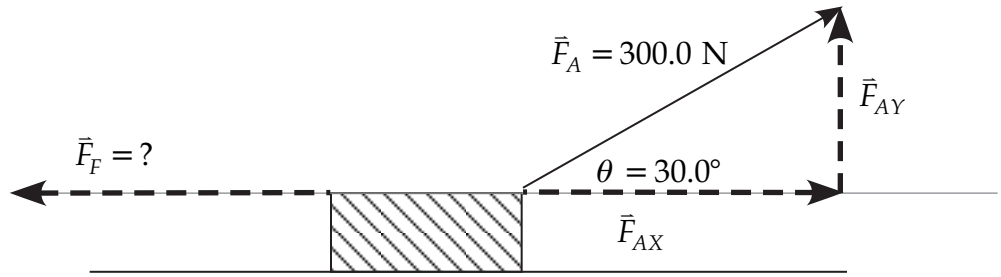
2. A crate of mass 50.0 kg is pulled across a level concrete floor by a force of 300.0 N acting 30.0° above the horizontal. The crate moves at a constant velocity of 0.962 m/s. What is the force of friction acting on the crate?

Answer:

Here, the velocity is constant, which indicates that acceleration is 0 m/s^2 and that the net force acting on the crate is 0 N.

Since the crate moves horizontally along the floor, the horizontal component of the applied force is pulling it forward (say, to the right). This component of the applied force must be balanced by the force of friction.

So the problem here is to just find the horizontal or x-component of the applied force.



First, determine the horizontal (x) components of the applied force.

To find the x-component, use cosine.

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} = \frac{\vec{F}_{AX}}{\vec{F}_A}$$

$$\vec{F}_{AX} = (\cos\theta)(\vec{F}_A)$$

$$\vec{F}_{AX} = (\cos 30.0°)(300.0\text{ N}) = +259.8\text{ N}$$

The force of friction is –259.8 N or 259.8 N [left].

3. A person is stranded on a raft. The mass of the raft and the person is 1500 kg. By paddling, the man exerts an average force of 25 N in a direction due east (the +x-direction). The wind also exerts a force on the raft. The force of the wind has a magnitude of 15 N and points north. Determine the magnitude and direction of the acceleration of the raft and person.

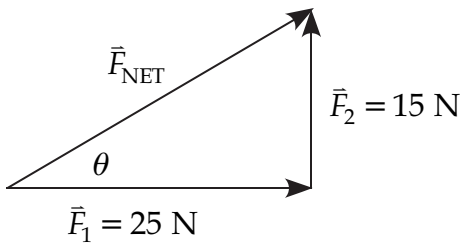
   Answer:

   Since you are given the applied forces acting on the raft, you can determine the net force on the raft. Since the man pushes the raft east and the wind pushes it north, you will have to add these vectors using the component method.

Given:	Mass	$m = 1500$ kg
	Force of man	$\vec{F}_1 = 25\text{ N [E]}$
	Force of wind	$\vec{F}_2 = 15\text{ N [E]}$
Unknown: Net force		$\vec{F}_{NET} = ?$
Equation:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2$
Substitute and solve:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2 = 25\text{ N [E]} + 15\text{ N [E]}$

   Add using the tip-to-tail method for the diagram and the component method to find the answer.

   The two force vectors form a right triangle.



The net force on the mass is $\vec{F}_{NET} = \sqrt{(25\text{ N})^2 + (15\text{ N})^2} = 29\text{ N}.$

The angle of the net force is $\theta = \tan^{1}\left(\frac{15\text{ N}}{25\text{ N}}\right) = 31°\text{ N of E}.$

The net force is 29 N [31° N of E].

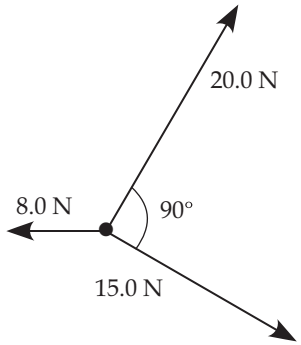
To find the acceleration, use Newton's Second Law.

The acceleration of the mass is $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{29\text{ N}}{1500\text{ kg}} = 0.019\text{ m/s}^2$

in the same direction as the net force.

The acceleration is 0.019 m/s^2 [31° N of E].

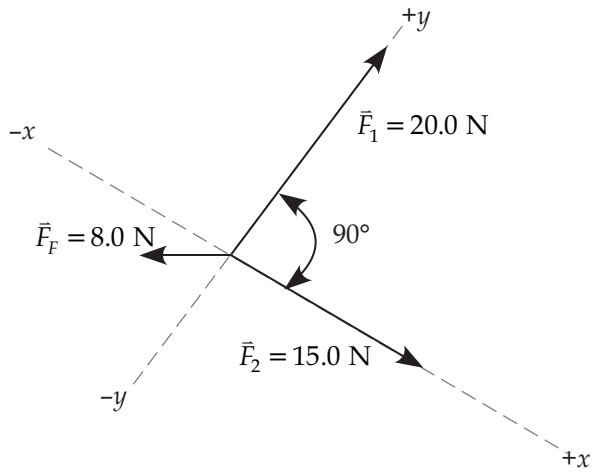
4. Two children are trying to pull a 20.0 kg toboggan out of a deep snow drift that provides an opposing force of 8.0 N. They are using ropes attached to the toboggan and parallel to the ground. The forces exerted by the children and the direction in which they pull on the ropes are shown below. Determine the net force and the magnitude and acceleration of the mass.



Answer:

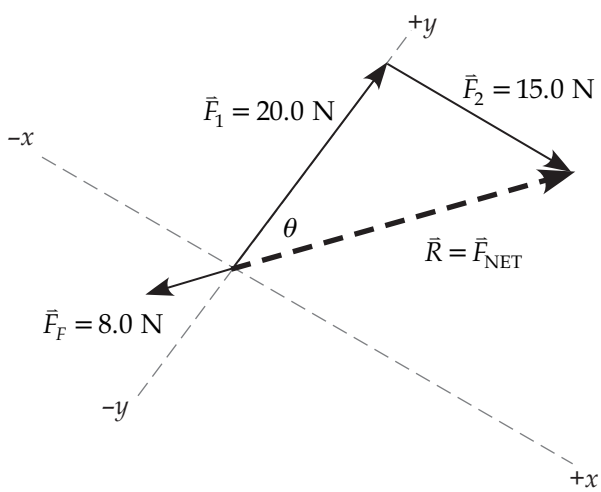
Since the actual directions are not given, you must specify a frame of reference to describe the motion. The simplest way to do this is to use the direction of one of the forces as the *x*-axis and then measure all other vectors in this frame of reference.

So let's draw in our coordinate system.



Given:	Force 1	$\vec{F}_1$ = 20.0 N [+y-direction]
	Force 2	$\vec{F}_2$ = 15.0 N [+x-direction]
	Force of friction	$\vec{F}_F$ = 8.0 N
	Mass	m = 20.0 kg
Unknown: Net force		$\vec{F}_{\text{NET}} = ?$
Equation:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$
Substitute and solve:		$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2 + \vec{F}_F$

Find the sum of $\vec{F}_1 + \vec{F}_2$ first. Then add the force of friction unto that sum of $\vec{F}_1 + \vec{F}_2$. This is done since you do not know the direction of the force of friction but you do know that it must be opposite to the sum of the other two forces.



Using the theorem of Pythagoras,

$$\vec{R}^2 = \vec{F}_1^2 + \vec{F}_2^2$$

$$\vec{R}^2 = (20.0\text{ N})^2 + (15.0\text{ N})^2 = 625\text{ N}^2$$

$$\vec{R} = \sqrt{625\text{ N}^2} = 25.0\text{ N}$$

Find the angle using tangent.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{15.0}{20.0}$$

$$\theta = \tan^{-1}\frac{15.0}{20.0} = 36.9°$$

This angle can be stated as 36.9° clockwise from $+y$.

The sum of $\vec{F}_1 + \vec{F}_2$ is 25.0 N [36.9° clockwise from $+y$].

The net force will be the force of friction added to $\vec{R}$.

Friction will point opposite to the direction of $\vec{R}$.

These vectors point along the same line but in opposite directions, so you subtract the magnitudes and keep the direction of the larger vector.

$$\vec{F}_{\text{NET}} = \vec{R} + \vec{F}_F = 25.0\text{ N} - 8.0\text{ N} = 17.0\text{ N}$$

The net force is 17.0 N [36.9° clockwise from $+y$].

Using Newton's Second Law, find the acceleration.

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{17.0\text{ N}\left[36.9°\text{ clockwise from }+y\right]}{20.0\text{ kg}}$$

$$= 0.850\text{ m/s}^2\left[36.9°\text{ clockwise from }+y\right]$$

NOTES

Topic 1 - Audio/Videos

Module 3

1. The four fundamental forces of nature - Michio Kaku
2. Strong Interaction: The Four Fundamental Forces of Physics #1a
3. Weak Interaction: The Four Fundamental Forces of Physics #2
4. Introduction to Newton's First Law of Motion
5. High School Physics - Newton's 1st Law of Motion
6. STEMonstrations: Newtons 2nd Law of Motion
7. STEMonstrations: Newton's Third Law of Motion
8. Newton's First Law of Motion - Second & Third - Physics Practice Problems & Examples
9. Newton's 3 Laws of Motion for Kids: Three Physical Laws of Mechanics for Children - FreeSchool
10. Dynamics: What are Forces?
11. Watch a Video for Assignment 3.1 - Go to Track 2
12. Introduction to Free Body Diagrams or Force Diagrams
13. Breaking the Force of Gravity into its Components on an Incline
14. Concept Builder - Free Body Diagrams
    a. Work through each of the 12 situations by drawing the correct free body diagram for the situation that is described.
15. Common Free-Fall Pitfalls
16. Free-Body Diagrams
17. Free Body Diagrams Physics Mechanics Problems, Tension, Friction, Inclined Planes, Net Force
18. Introduction to Newton's Second Law of Motion with Example Problem
19. Introductory Newton's 2nd Law Example Problem and Demonstration
    a. This video show how kinematics and dynamics are related through Newton's Second Law. This is a more complicated example of the Dynamics-Newton's Second Law-Kinematics relationship. A cart is placed on a track that is almost frictionless. The cart is accelerated from rest by a falling mass that is attached to the cart by a string. There are kinematics quantities (displacement, initial velocity, time) that are measured along with the applied force of the string pulling the cart. The question is to find the force of friction (a dynamics quantity). The analysis requires a list of the given quantities, a free body diagram, and finding the net force as the sum of the forces acting on the cart. From the kinematics side the measured quantities allow acceleration to be calculated. Then the link over to dynamics is Fnet = ma where the net force is calculated. In turn knowing the net force allows the force of friction to be calculated. See page 64 for a graphic illustrating the link between Dynamics <-> Newton's Second Law <-> Kinematics.
20. Kinematics (Part 9: Force and Acceleration Example)
21. Newton's Second Law of Motion - Science of NFL Football
22. Newton's second law of motion | Forces and Newton's laws of motion | Physics | Khan Academy
23. More on Newton's second law | Physics | Khan Academy

a. This video from Khan Academy shows that if several forces act on an object the analysis of the forces to determine the net force can be accomplished using the property of vectors that components of vectors are independent of each other or what happens in the x direction does not affect what happens in the y direction.
b. So we can find the sum of the horizontal or x components of the forces by themselves. Then we can add the vertical or y components of the forces by themselves.
c. Then the sum of the x-components plus the sum of the y components of the forces can be added using the component method to give the net force that is acting.
d. If a force is acting in neither the vertical direction nor the horizontal direction, that force must be resolved into its horizontal and vertical components which are then added with the forces in the x direction or in the y direction.

Grade 11 Physics (30S)

Topic 2: Fields

Topic 2: Fields

Introduction to Topic 2

In Modules 1 to 3, you learned about mechanics—the first topic in this course. The second topic in this course is fields. The knowledge of fields is useful in several areas in physics.

In Module 4, you learn about gravitational fields. A way of defining gravitational fields is to say that they are regions of space in which a mass experiences a force of gravity caused by one or more other masses. Module 5 looks at electric fields. Electric fields are created by electric charges, and the fields created by these charges cause other charges to be influenced by them. Module 6 deals with magnetic fields and electromagnetism. A magnetic field is the region of space around a magnet where another magnet will experience a force. Electromagnetism is the union of electricity and magnetism. Although electricity and magnetism appear to be two completely different things, they are actually two aspects of a single physical phenomenon.

NOTES

Grade 11 Physics (30S)

Module 4: Gravitational Fields

This module contains the following

- Introduction to Module 4
- Lesson 1: Gravitational Fields
- Lesson 2: Mass, Weight, and Weightlessness
- Lesson 3: Laboratory Activity: Determining Acceleration Due to Gravity
- Lesson 4: Free Fall and Vertical Motion at the Earth's Surface
- Lesson 5: Air Resistance and Terminal Velocity
- Lesson 6: Friction
- Module 4 Summary

Module 4: Gravitational Fields

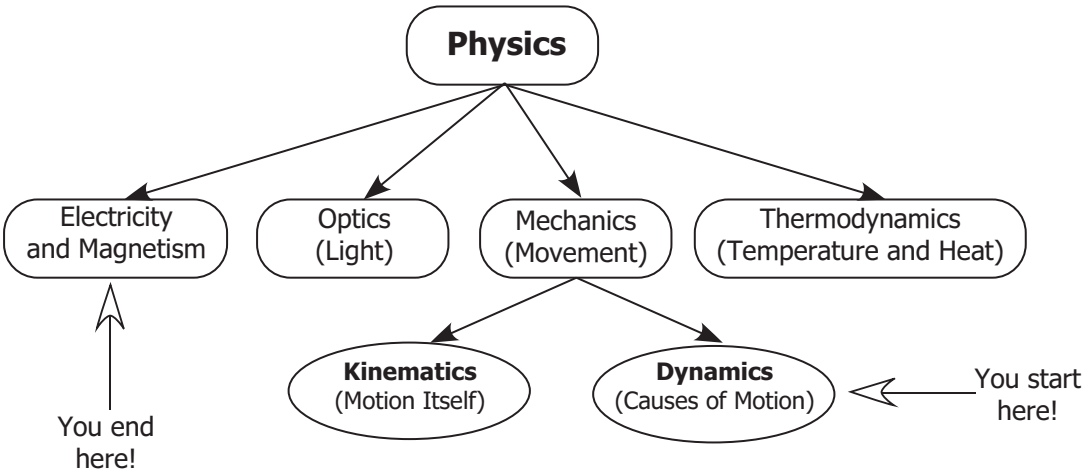
Introduction to Module 4

Welcome to Module 4. In Modules 1 to 3, you learned about the first topic in this course, mechanics. Modules 4 to 6 will deal with the second topic in the course, fields. In this module, you will learn about gravitational fields. In Module 5, you will learn about electric fields. Module 6 deals with magnetic fields and electromagnetism.

Each of the previous two modules focused on one of the two halves of mechanics: kinematics and dynamics. You might be thinking that we're all done with mechanics, but the topic of this module, fields (which will be explained shortly), is going to take us on an interesting ride that actually begins in dynamics. You'll notice that fields don't even show up in our navigational map that appears below. This is because fields are useful in several areas of physics.

In this module, we will learn what is meant by the term "field," diagram various kinds of fields, and work with them mathematically. We begin with a study of a familiar type of field: gravitational. The second type of field we will see is the electric field, which is created by electric charge. In particular, we will study electric fields caused by single charges, by combinations of more than one charge, as well as by electrically charged sheets. We will apply much of what we learned about vector addition, kinematics, and dynamics to electric fields. Finally, we will turn to magnetism and electromagnetism and learn the basics of what is meant by the "poles" of a magnet. We will also see what the magnetic field looks like for a single magnet and for combinations of magnets, and study the Domain Theory of Magnetism. The module ends with electromagnetism—the bringing together of the ideas of electric and magnetic effects. Here, we will discuss the fundamental connections between electricity and magnetism.

So while we will begin the study of fields in the area of mechanics (the study of the how and why things move in the earth's gravitational field), we will end up in the area of electricity and magnetism.



In our work in dynamics, we learned that the force of gravity is one of the four fundamental forces. We extend the knowledge of forces to fields.

- **Lesson 1: Gravitational Fields** will demonstrate what is meant by the term "field," and will diagram the earth's gravitational field using lines of force.
- **Lesson 2: Mass, Weight, and Weightlessness** will contrast the terms "mass" and "weight," and demonstrate how the apparent weight of an object changes as it moves up and down in moving systems like elevators.
- **Lesson 3: Laboratory Activity: Determining Acceleration Due to Gravity** involves an experiment where you will determine the value of the gravitational field intensity here on the surface of the earth.
- **Lesson 4: Free Fall and Vertical Motion at the Earth's Surface** will look at free fall and make connections between what you learned about Newton's laws and kinematics. You will see how to determine the gravitational fields' constant and the acceleration of objects due to the gravitational field of the earth. This will allow you to apply the kinematics equations you studied earlier to free-fall situations.
- **Lesson 5: Air Resistance and Terminal Velocity** shows how when an object falls through the air, it will eventually reach a point where it will no longer accelerate, but will fall at a constant velocity called "terminal velocity."
- **Lesson 6: Friction** will give you an opportunity to make use of your knowledge of the force of gravity to study friction and how it affects the motion of objects.

Assignments in Module 4

When you have completed the assignments for Module 4, submit your completed assignments for Module 3 and Module 4 to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 4.1, Part A	Gravitational Fields
2	Assignment 4.1, Part B	Mass, Weight, and Weightlessness
3	Assignment 4.2	Laboratory Activity: Determining Acceleration Due to Gravity
4	Assignment 4.3, Part A	Free Fall
5	There is no assignment for this lesson.	
6	Assignment 4.3, Part B	Friction

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

NOTES

Lesson 1: Gravitational Fields (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "gravitational field intensity"
- ❑ state that the value of $\vec{g}$ varies depending on where you are on the earth
- ❑ describe the factors that may determine why the gravitational field intensity varies from place to place on the earth
- ❑ define the term "gravitational field"
- ❑ describe the gravitational field around the earth
- ❑ diagram the earth's field using lines of force or vectors representing $\vec{g}$
- ❑ define the term "weight"
- ❑ calculate the weight of an object given its mass and the value of $\vec{g}$
- ❑ explain how weight can actually be measured

Key Words

gravity
weight
gravitational field
gravitational field constant
gravitational field intensity

Introduction

In this lesson, we will learn what is meant by the term "field" by beginning with a familiar example: gravitational fields. We will also learn how to diagram fields by learning how to diagram the earth's gravitational field.

The Gravitational Force

Gravity is the fundamental attractive force that exists between objects because they have mass.

You can measure the force of gravity using a **scale**. A more common name for the force of gravity is **weight**. We will have more to say about weight later.

Free Fall

You are familiar with the force of gravity and how it operates here at the surface of the earth. You know that if you drop an object, it falls down towards the ground. If you drop two dense heavy objects (a curling rock and a bowling ball) from the same height at the same time, they will accelerate and fall to the floor with both objects striking the floor simultaneously. The acceleration of these objects can be measured.

When an object is dropped, it accelerates downward at approximately 9.8 m/s^2, provided that air resistance is negligible, which we always assume unless instructed otherwise. We call this value "the acceleration due to gravity" and have seen that $\vec{g}$ = 9.8 m/s^2.

By Newton's Second Law, a net unbalanced force must be acting on a falling object since it is accelerating. The net force is calculated using $\vec{F}_{\text{NET}} = m\vec{a}$.

If we replace the acceleration $(\vec{a})$ with the acceleration of gravity $(\vec{g})$, then Newton's Second Law becomes $\vec{F}_{\text{NET}} = m\vec{g}$.

This net force is the **gravitational force** that the earth applies to the object.

$$\vec{F}_{\text{NET}} = \vec{F}_g$$

So we have this expression for the gravitational force acting on an object at the surface of the earth.

$$\vec{F}_g = m\vec{g}$$

An object having a mass of 1.0 kg will experience a gravitational force of 9.8 N at the earth's surface.

So, freely falling objects accelerate at 9.8 m/s^2 towards the earth at the earth's surface.

Field

All of this seems all right, but many early physicists had a problem with it—even Newton. They didn't have a problem understanding that all this does happen—that much is pretty clear. The problem was in making sense of *how* it happens. In particular, just how does the earth (down there) exert a force onto an object (up there) without touching it? It would seem somehow more comforting if the earth reached up, visibly grabbed the object with a rocky arm and then gave it a downward pull, but instead we have this somewhat spooky behaviour of the earth invisibly, mysteriously being able to reach up to objects no matter how high they are. In fact, early critics of Newton referred to his description of gravity as being "spooky action at a distance." What was needed was an explanation of how something in one place could affect something else without touching it.

Modern physics now has at least some of the answers to how this happens. We don't have all of the answers (and certainly not all of the details), but we do have answers that go a long way in explaining this phenomenon. Enter the concept of a **field**. No, we're not talking about large areas of open land; in fact, we are talking about something that is a little difficult to understand, so let's begin with an analogy.

A Field Analogy

Although not at all the real topic of discussion here, you are certainly familiar with the idea of temperature. Things can be hot or cold, and hot or cold can be measured by a thermometer, which indicates the temperature as a numerical value such as 20°C (the small "°" symbol stands for "degrees" and the "C" stands for "Celsius").

We sometimes say things like "the temperature in this room is 20°C" but realize that each point in the room has a temperature value of its own. If, for example, it is winter and the furnace is on, 20°C might be the average temperature of the air in the room, but the air near the window will probably have temperature values less than this, and the air coming out of the heat register will certainly have temperature values higher than this. You could imagine the room being filled with hundreds of thermometers all over the room, each reading a value for the temperature at that particular spot.

The point is that temperature is something measurable throughout the entire space of a room, and each point (even those that don't have thermometers sitting in them) has a value for temperature. Physicists use the word "field" as a shortcut for this idea. In fact, we could say that the room (the space) is filled with a "temperature field." So a **field** is a property of a space. Remember, we are using temperature only to get a better understanding of what the word "field" means. This is not a module on thermodynamics!

Measuring Gravitational Field using a Freely Falling Object

Thermometers are great for measuring temperature, but how can you measure how strong gravity is?

Clearly there is "more gravity" here on earth than on the moon—things are lighter on the moon than they are on the earth and, as a consequence, things fall with a greater acceleration on the earth than on the moon. Clearly, the acceleration of a freely falling object $(\vec{g})$ is itself an indication of the strength of gravity at that location. I don't know if you noticed it, but g just took on a whole new level of significance.

We have so far been using $\vec{g}$ as the acceleration of a falling object—it was the object that we were focusing our attention on. We are now talking about g being used to describe the space that the object is occupying—how strong gravity is there. The object is now merely a part of our measuring device for doing so (it is like a thermometer, but for gravity).

We can improve this significantly by taking advantage of our knowledge of dynamics.

To measure $\vec{g}$, we don't even have to drop anything! We know that $\vec{F}_g = m\vec{g}$, so if we solve for $\vec{g}$, we get $\vec{g} = \frac{\vec{F}_g}{m}$. All we have to do is determine the weight $(\vec{F}_g)$ of an object for which we already know the mass, and use this equation to determine $\vec{g}$—how strong gravity is at that spot. This could be done anywhere and everywhere, so each point in space will have a value for $\vec{g}$ … hence, the term **gravitational field**.

In fact, $\vec{g}$ is now being used to indicate the strength or intensity of this field, so $\vec{g}$ can be described as the strength of the gravitational field. Think of it as being a promotion—a new job title. $\vec{g}$ used to be merely **"acceleration due to gravity"** but is now called the **"gravitational field intensity."** Of course, $\vec{g}$ can be called either of these, depending on how it is being used.

> $\vec{g}$ has been called the "acceleration due to gravity," but can also be called the "gravitational field intensity."

The promotion to gravitational field intensity does earn $\vec{g}$ something interesting: a new unit.

When we thought of it as an acceleration, we naturally used m/s^2 as the unit for $\vec{g}$. Now that we are thinking of $\vec{g}$ as being the gravitational force per mass $\left(\vec{g} = \frac{\vec{F}_g}{m}\right)$, we actually will find it more natural to use the unit N/kg, as this is literally a force unit (newton) divided by ("per") mass unit (kilogram). Notice that the units N/kg and m/s^2 are actually equivalent to each other, since the newton is merely a convenient name for the group of units kg · m/s^2 , as we saw in the last module:

$$\frac{\text{N}}{\text{kg}} = \frac{\text{kg} \cdot \frac{m}{s^2}}{\text{kg}} = \frac{m}{s^2}$$

The units of $\vec{g}$ may be in m/s^2 or in N/kg, which are equivalent to each other.

Gravitational Field Intensity: We call the ratio of gravitational force to mass the **gravitational field intensity**, and represent it by the symbol "$\vec{g}$."

$$\vec{g} = \frac{\vec{F}_g}{m}$$

Quantity	**Symbol**	**Unit**
Gravitational field	$\vec{g}$	newton/kilogram (N/kg)
Force of gravity	$\vec{F}_g$	newton (N)
Mass	m	kilogram (kg)

Thus, the value of $\vec{g}$ is 9.80 N/kg at the earth's surface, with the gravitational force always acting towards the centre of the earth.

The gravitational field intensity is a vector.

The gravitational field intensity is fairly constant at the surface of the earth.

The value of the gravitational field intensity at the earth's surface of $\vec{g}$ = 9.8 N/kg or $\vec{g}$ = 9.8 m/s^2 is called the **gravitational field constant**.

Remember that **this value** of the gravitational field intensity **refers** only to **locations** at the **surface of the earth**!

Example: Force of Gravity on Mars

An astronaut has a mass of 75.0 kg.

a) What is his weight here on earth?

Weight of course is the force of gravity on an object. So to find weight we find the force of gravity.

Given: Mass $m = 75.0$ kg

Gravitational field strength $\vec{g} = 9.80$ N/kg [towards earth's centre]

Unknown: Weight (force of gravity) $\vec{F}_g = ?$

Equation: $\vec{F}_g = m\vec{g}$

Substitute and solve: $\vec{F}_g = m\vec{g} = (75.0\text{ kg})(9.80\text{ N/kg}) = 735\text{ N}$

On earth, the astronaut's weight is 735 N towards the centre of the earth.

b) What would be his weight on Mars, where the acceleration of gravity is 3.72 m/s^2 towards the centre of Mars?

Again, to find the weight, we find the force of gravity on Mars, where the gravitational field intensity is less than it is here on the earth.

Given: Mass $m = 75.0$ kg

Gravitational field strength $\vec{g} = 3.72$ N/kg [towards Mars centre]

Unknown: Weight (force of gravity) $\vec{F}_g = ?$

Equation: $\vec{F}_g = m\vec{g}$

Substitute and solve: $\vec{F}_g = m\vec{g} = (75.0\text{ kg})(3.72\text{ N/kg}) = 279\text{ N}$

On Mars, the weight of the astronaut is 279 N towards the centre of Mars.

Note that the mass of the astronaut did not change. His weight changed because the astronaut was in a gravitational field with a different intensity.

Learning Activity 4.1

Weight and Mass

There are three questions in this activity. Once you have completed the questions, you may check your answers against the answer key provided at the end of this module.

1. What is weight?
2. Would your weight be the same on the surface of every planet in our solar system? Explain your answer.
3. An astronaut has a mass of 85.2 kg. What is the gravitational field intensity on the surface of a planet where the weight of the astronaut is 542 N towards the centre of the planet?

The Gravitational Field Varies on the Surface of the Earth

Although we will use the value $\vec{g}$ = 9.8 N/kg as the value of the gravitational field, the actual value varies slightly from one place to another on the earth.

For example, the value of $\vec{g}$ at sea level at the North Pole is 9.8322 N/kg (latitude 90° N) while at the equator it is 9.7805 N/kg (latitude 0°). This is due partially to the fact that they are different distances from the centre of the earth. The North Pole is 6357 km from the centre and the equator is 6378 km when both are measured at sea level.

> For the same altitude, as latitude increases the gravitational field increases.

In Toronto (altitude 162 m, latitude 44°), the value of $\vec{g}$ is 9.8049 N/kg, while on Mt. Everest (altitude 8848 m, latitude 28°) the value of $\vec{g}$ is 9.7647 N/kg, and at the Dead Sea (altitude –397 m, latitude 32°) the value of g is 9.7962 N/kg. All three locations have roughly the same latitude but different altitude.

> For the same latitude, as altitude increases the gravitational field decreases.

Thus, the value of $\vec{g}$ is not a constant value everywhere on the earth. It varies with the distance from the centre of the earth and with other aspects of the earth's composition and motion. However, at a given location on the earth's surface, such as the province of Manitoba, we can usually get away with treating g as a constant—and can usually round it off to 9.8 N/kg.

On earth, $\vec{g}$ is approximately 9.8 N/kg everywhere.

Now, back to the matter at hand: just how does the earth (down there) exert a force onto an object (up there) without touching it?

The answer involves two steps:

Firstly, the **earth** affects the space around itself: it **creates a gravitational field "up there"** (and in all of the surrounding space).

Secondly, it is this **gravitational field** that is already up there that **acts on objects, causing the gravitational force of attraction.**

More generally, the field from one object acts on a second body at the location of the second body. In fact, another way of defining the gravitational field is simply to say that it is a region of space in which a mass experiences a force of gravity.

Gravitational Field Definition: A **gravitational field** is a region in space in which a mass experiences a force of gravity.

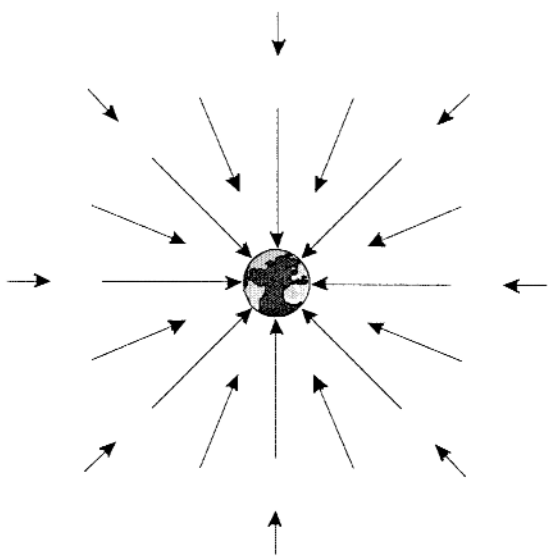
Gravitational fields cause gravitational forces on masses placed in them. More specifically, objects experience forces when in fields.

If you are still having some trouble with this, let's go back to our temperature analogy: How does the furnace "over there" warm you up when you are "over here?" The furnace warms up the air everywhere in your home, and you are in that warm air. The air is the in-between step. In the same way, earth creates a gravitational field that extends from itself and objects that are placed in that field feel the effects of this gravity (or gravitational force). It is the field that provides the force on objects.

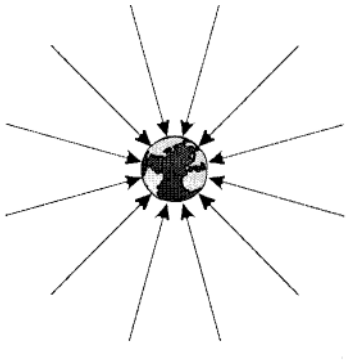
Visualizing the Gravitational Field

We know that the gravitational field near the earth is about 9.8 m/s^2 and that it gets weaker if you go farther from it (details of this will be provided in Grade 12 Physics). One way to show this would be to actually place the numerical values of the value of $\vec{g}$ at various places onto a picture, in much the same way that temperature values can be placed on a map to show the various temperature values at different places.

We can also represent the gravitational field of the earth as a collection of vectors surrounding the earth and pointing in the direction of the gravitational field (towards the centre of earth). This time, instead of showing numerical values, the stronger the field is, the longer the vector will be.



But the next way to visualize the gravitational field (as well as other types of fields) that we will most often prefer is with a **field line diagram**.



Field line diagrams are the preferred way to visualize fields.

There's a lot more to field line diagrams than you might at first guess. First off, those arrows are not vectors! They are field lines. Their lengths don't mean anything, and although they are straight in this case, we will soon see diagrams with curved field lines (and yes, we continue to call them field "lines" even when they curve!).

Interpreting Field Line Diagrams

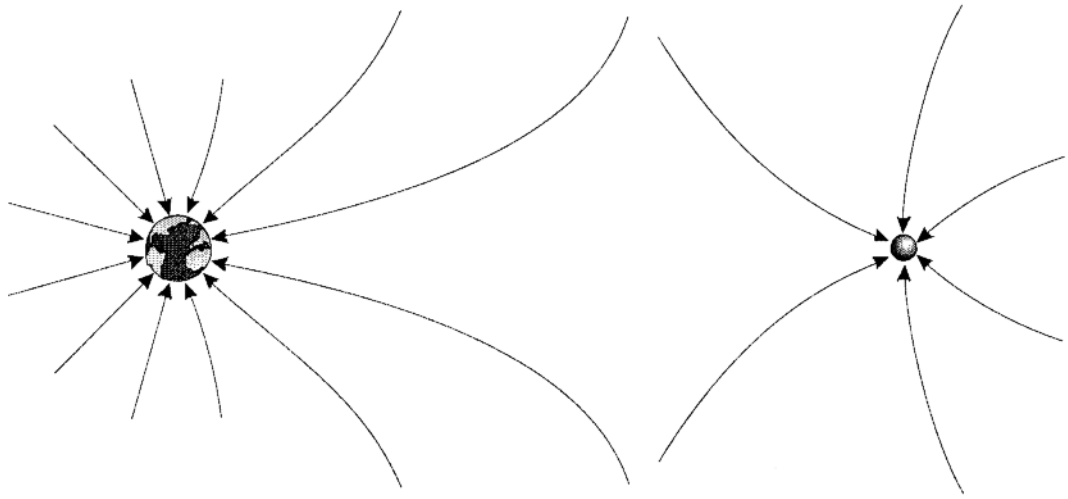
The directions of the field lines show the direction of the field at various points (towards the centre of the earth). Also, the spacing of the lines suggests the relative strength of the field. This means that where the field lines are closer together, the field is stronger. In the diagram, you can see that as we move away from the earth, the field lines are spaced farther apart.

The field lines show the direction of the field, as well as the relative strength of the field—more closely spaced field lines mean a stronger field.

Finally, although it is clear in this example, the direction of the field is the same direction as the field line at every point. This is not as obvious when there are curved field lines, in which case the direction of the field vectors are understood to be tangent to the field lines everywhere.

When field lines curve, the direction of the field at any point is in the direction of a tangent line to the curving field line.

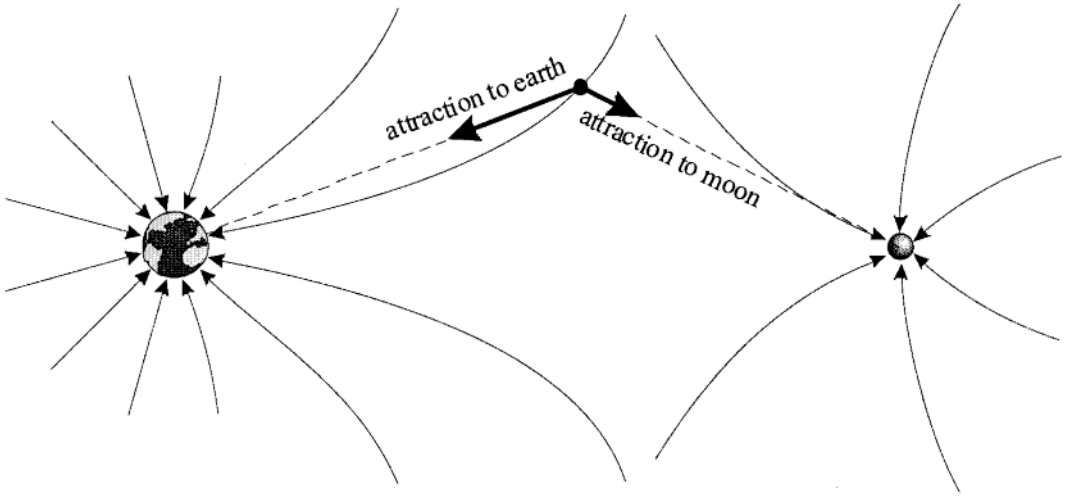
As an example, consider the gravitational field of the moon and the earth (ignoring all other objects). If the earth (or moon) was entirely by itself, the above diagrams would show their fields quite well. But since they exist together, they each provide contributions to the gravitational field. If we show both the moon and the earth in the same diagram, here is what the gravitational field line diagram would look like. (Note that this diagram is only approximate to get the general idea across.) The earth is shown on the left, and the moon is on the right.



Plotting the Gravitational Field around Two Masses

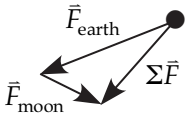
At first, this diagram probably doesn't make a whole lot of sense, so let's examine it. Realize that an object out in space would be attracted to both earth and the moon. If it was quite close to either one, then the nearer object's field would dominate. Notice that close to either body, the field lines are pretty much straight into the centre of that body, just like before. The moon has fewer field lines because it has less mass than the earth (the number of field lines produced by an object depends on the object—in this case, its mass, since we are looking at gravitational field lines).

As you move away from the objects, both contributions to the field need to be considered. Let's have a look at one particular point to discuss this further.

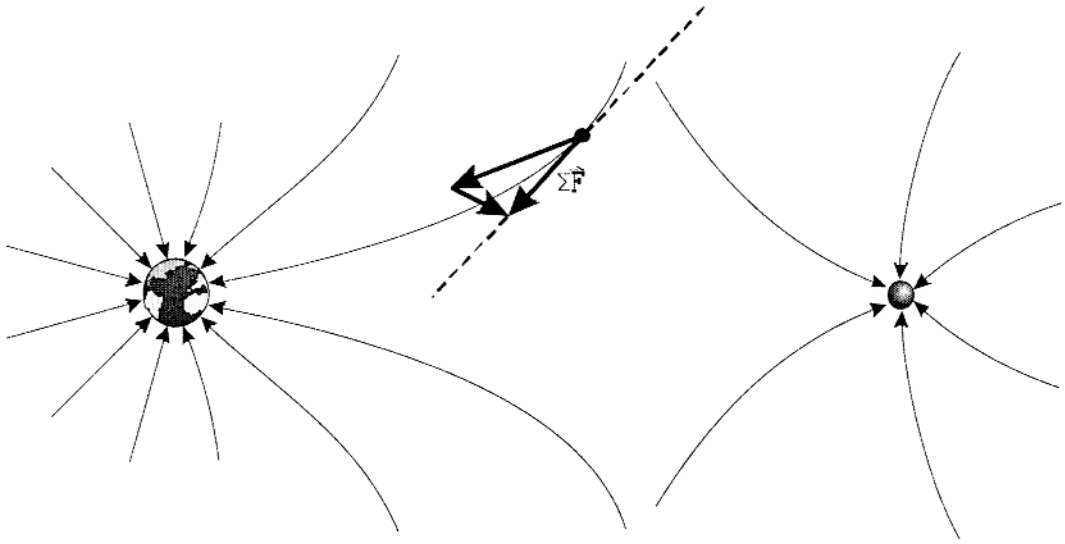


Choosing the point shown in the diagram, we can imagine what would happen if we were to place a small mass there to "test" the field. This "test mass" would be attracted to the earth and also to the moon. Because of the location we chose, the attraction to the earth would be stronger, as this particular point is similarly distant from both bodies, but the earth is more massive. These forces of attraction are both shown. Note that each of these attractions is, as expected, towards the centre of each body.

With both of these forces acting, the net gravitational force on the object could be found by adding these two forces as vectors, as shown here.



Placing this back onto our diagram, have a close look at the connection between the direction of the net force and the direction of the field line it is on.



You will notice that the net force is exactly tangent to the field line at that spot. This means that if the object was placed anywhere in the field and released, the net force would make it move in a direction that causes it to initially follow the field line.

Drawing field line diagrams when there is more than one object contributing to the field present can be complicated, and we won't normally do this for gravitational fields. We will see more diagrams similar to this later for electric and magnetic fields.

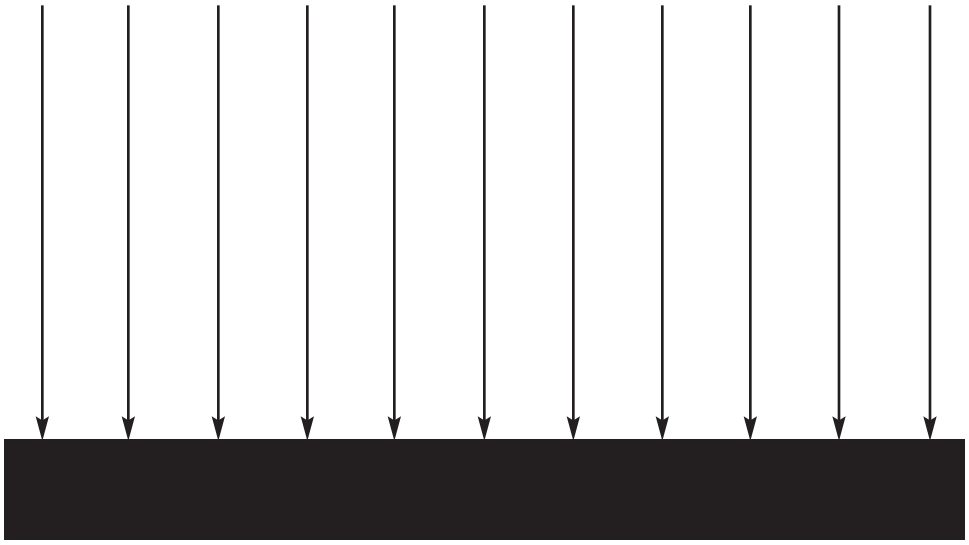
Gravitational Field Diagram at the Surface of the Earth

At the earth's surface, we have seen that the gravitational field is pretty well constant at 9.80 N/kg [towards the earth's centre].

It turns out that at the earth's surface pointing towards the centre of the earth also points in a direction that is perpendicular to the surface of the earth.

So if this is the case, then all of the gravitational field lines will point perpendicular to the surface of the earth. Secondly, since the gravitational field is constant at the earth's surface, the diagram for the gravitational field lines should illustrate this fact. A uniform field is illustrated by using lines that are parallel to each other and equally spaced.

Gravitational Field at the Surface of the Earth



Learning Activity 4.2

Gravitational Fields

Once you have completed these questions, you may check your answers against the answer key provided at the end of the module.

1. A vehicle is being designed to explore the moon's surface and is being tested on earth, where it weighs roughly six times more than it will on the moon. In one test, the acceleration of the vehicle is measured. To achieve the same acceleration on the moon, will the net force acting on the vehicle be greater than, less than, or the same as that required on earth?

2. The gravitational field constant on the surface of Pluto is 0.31 N/kg. What would the gravitational force be on a person of mass 50.0 kg on Pluto?

(continued)

Learning Activity 4.2: Gravitational Fields (continued)

3. A space traveller whose mass is 115 kg leaves earth. What are his weight and mass
   a) on earth and
   b) in interplanetary space where there are no nearby planetary objects?
4. Describe two methods by which the gravitational field intensity can be measured here at the surface of the earth.
5. What are two factors that affect the gravitational field intensity at the surface of the earth? How does each factor affect the value of the gravitational field intensity?
6. Distinguish between the terms: field, gravitational field, and gravitational field intensity.
7. State two facts about the gravitational field that are given by a diagram of gravitational field lines.

Lesson Summary

Falling objects at the earth's surface that are accelerated only by the force of gravity are said to be freely falling.

Objects that are freely falling at the surface of the earth accelerate at the rate of 9.8 m/s^2 toward the centre of the earth. We call this the **acceleration of gravity**.

We call the ratio of gravitational force to mass the **gravitational field intensity**, and represent it by the symbol "$\vec{g}$." The value of $\vec{g}$ is approximately 9.80 N/kg at the earth's surface, pointing towards the centre of the earth. The exact value of $\vec{g}$ varies from place to place on earth. It varies with the distance from the centre of the earth and with other aspects of the earth's composition and motion.

One can define the **gravitational field** by saying it is a region of space in which a mass experiences a force of gravity caused by one or more other masses.

The **gravitational field strength** at any location on a planet or at any place above the planet could be determined by finding the **ratio** of the **gravitational force** and a **mass** placed at that place—that is, $\vec{g} = \frac{\vec{F}_g}{m}$. The units of are N/kg (although m/s^2 is equivalent).

We can represent the gravitational field of the earth as a collection of vectors surrounding the earth and pointing towards it. The stronger the field is at any point, the longer the vector there would be.

We can also represent the gravitational field of the earth by the use of a **field line diagram**, which uses field lines instead of vectors. The direction of the field lines shows the direction of the field, and the strength of the field is suggested by the spacing of the field lines (the closer that the field lines are, the stronger the field is). This is the preferred way of visualizing fields.

Assignment 4.1, Part A

Gravitational Fields (4 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 3 and Module 4, after you have completed Module 4.

1. What is the gravitational field intensity at the surface of Mars if a 2.05-kilogram object experiences gravitational force of 7.58 N?

2. What is the weight of an object of mass 3.50 kg on the surface of Saturn where the gravitational field intensity is 10.4 N/kg?

(continued)

Assignment 4.1, Part A: Gravitational Fields (continued)

3. Describe two methods by which the gravitational field intensity at the surface of the earth can be measured.

4. Draw the pattern of gravitational field lines around the earth.

Method of Assessment

The total of four marks for this assignment will be determined as follows:

- 1 mark for the correct answer for the gravitational field in Question 1
- 1 mark for the correct way to the object in Question 2
- 1 mark for each description of the methods for determining the gravitational field intensity in Question 3
- 1 mark for the correct pattern of gravitational field lines in Question 4

Lesson 2: Mass, Weight, and Weightlessness (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "mass"
- ❑ define the term "weight"
- ❑ calculate the weight of an object given its mass and the value of $\vec{g}$
- ❑ explain how weight can actually be measured
- ❑ differentiate between real weightlessness and apparent weightlessness
- ❑ calculate apparent weight in accelerating frames of reference

Key Words

mass	weight	real weightlessness
apparent weight	normal force	apparent weightlessness

Introduction

In the first lesson, we began our discussion of gravity and gravitational fields. We discussed what is meant by terms such as "gravitational field intensity," "gravitational field," and "weight." This will lead into a discussion of two terms that are commonly confused, namely mass and weight. We will also discuss the differences between real weightlessness and apparent weightlessness. We have all seen pictures or video of astronauts in weightless environments, but are they really weightless? The lesson will conclude with an experience most of us are all familiar with—riding in an elevator—and this will help to clarify what we mean by weight and weightlessness.

Weight and Mass

Now is a good time to clear up an issue that is often poorly understood. To most people, the words "**mass**" and "**weight**" are thought to mean the same thing. This is simply not true.

Mass is "amount of matter" present in an object.

"Matter" is the scientific word for "stuff." You need to realize that the mass of an object will not change from location to location. The mass of an object is changed by adding more matter to it, or removing matter from it. This reflects the property that mass is additive (1 kg + 2 kg = 3 kg). You know from Grade 10 Science that mass is conserved during chemical and physical changes (the Law of Conservation of Mass). Mass is measured on an instrument called a balance in units of kilograms. Mass is a **scalar quantity**.

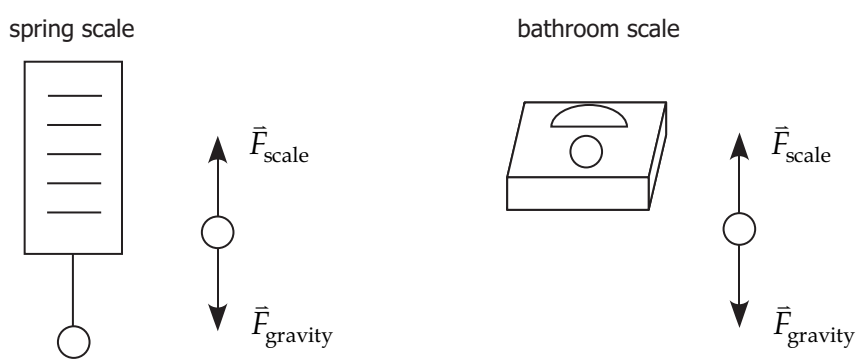
On the other hand, **weight** is a **force**: the force that gravity pulls on an object. In fact, the symbol for weight (which you might guess to be a W) is actually $\vec{F}_g$, which literally stands for the force of gravity (which we may call weight).

Weight is the force that gravity exerts on an object.

Since weight is a force, its units will be force units (i.e., newtons), and it will be a vector quantity.

$$\text{weight} = \vec{F}_g$$

Weight is often measured using a scale, such as a spring scale or a bathroom scale. The object whose weight is being measured is pulled down by the force of gravity until the upward force of the spring is equal to the gravitational force pulling down. The value of the force exerted by the spring, indicated by a pointer or dial, is a measure of the weight of the object.



Thus, the weight of a 60.0-kg person at the earth's surface will be the force of gravity on the 60.0-kg mass, or 588 N. As long as the force of gravity is present, an object has weight. Whether you are sitting, standing, flying, falling, or even orbiting the earth in a space vehicle, you have weight, since the force of gravity is present. If this 60.0-kg person moves off the earth's surface into space, the gravitational field strength is less, and the person would weigh less. But the mass of the person would not change.

It is generally true that the more massive an object is, the more it weighs, but isn't it also generally true that the taller a person is, the more he or she weighs? Can we consider height and weight to be the same thing? Certainly not! Besides, there are tall but light people, and there are short but heavy people: the connection between height and weight is not guaranteed. Similarly, the connection between mass and weight is not guaranteed, because weight also depends on how strong gravity is, which changes depending on where you are (especially if you leave earth).

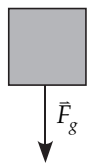
Calculating the Weight of an Object

Let's put everything we have learned so far together for review, and also to generate a very useful equation. We do this often in physics—that is, synthesize new concepts from the knowledge we already possess.

Consider an object that is falling. We saw in the last lesson that it will have an acceleration of "g" ($\vec{g}$ = 9.8 m/s^2 on earth), no matter what its mass is. Let's consider what each of Newton's Laws has to say about this scenario, saving Newton's Second Law for last.

- Newton's First Law: Since the object is accelerating, it must have a net force acting on it
- Newton's Third Law: Since there is a force acting, there must be two objects interacting with each other. These two objects would be the falling object, and the earth itself. Earth pulls the object down with a certain sized force (this is the "weight" of the object). Simultaneously, the object attracts the earth upwards with the exact same size force. Some people find this hard to believe as the earth does not seem to rise upwards. Remember that this is the same size **force** so the acceleration of the earth will be practically zero since its mass is so very large. Nonetheless, the earth is attracted upwards to the mass.
- Newton's Second Law states that the acceleration must be equal to the net force divided by the mass.

Consider a free body diagram:



The only force acting on the object is the downward force of gravity (remember that we are assuming no air resistance). This means that the net force (the sum of all forces acting) *is* the gravitational force. The acceleration is down, by an amount " $\vec{g}$."

$\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$ This is Newton's Second Law.

$\vec{g} = \dfrac{\vec{F}_g}{m}$ We know that the acceleration is of an amount equal to " $\vec{g}$ " and that the net force is the weight. Both vectors, $\vec{g}$ and $\vec{F}_g$, point towards the centre of the earth.

$\vec{F}_g = m\vec{g}$ The equation has been solved for the weight, $\vec{F}_g$ which is a downward force.

The bottom line: the force of gravity can be found by multiplying the mass by the value of $\vec{g}$. On earth the value of $\vec{g}$ is 9.8 m/s^2 towards the centre of the earth, which means that a one kilogram object weighs 9.8 newtons here.

On the moon the value of $\vec{g}$ is only 1.6 m/s^2, which means that a one kilogram object weighs 1.6 newtons there.

Example 1: Calculating Weights on the Earth and on the Moon

Consider two people: Isaac, who is 50.0 kg, and Albert, who is 100.0 kg. These numbers are the number of kilograms (amount of mass) that each one is. The kilogram is the SI unit for mass. Clearly Albert is twice the mass of Isaac. This means that he has twice the amount of matter making up his body.

Which one is heavier depends on where they are.

Suppose Isaac is on earth (where $\vec{g}$ = 9.8 m/s^2).

We can find his weight: $\vec{F}_g = m\vec{g}$ = (50.0 kg)(9.8 m/s^2) = 490 N towards the centre of the earth.

If Albert is on the moon (where $\vec{g}$ = 1.6 m/s^2), then his weight will be $\vec{F}_g = m\vec{g}$ = (100.0 kg)(1.6 m/s^2) = 160 N towards the centre of the moon.

In this example, the more massive person is lighter, but only because they are in a place where gravity is weaker.

True Weightlessness

According the relationship for weight that was just derived, $\vec{F}_g = m\vec{g}$, you can see that if an object is truly weightless the force of gravity on the object must be 0 N at that location.

> An object is **truly weightless** at a given location if the force of gravity on the object is 0 N.

Now according to this equation the force of gravity can be 0 N if one of two things happens.

1. If the mass of the object is 0 kg, the force of gravity which is the product of the mass and the gravitational field intensity will be 0 N. This is impossible because no object has a mass of 0 kg.
2. If the gravitational field intensity at that location is to 0 N/kg, the force of gravity which is the product of the mass and the gravitational field intensity will be 0 N. This is possible.

True weightlessness occurs where the force of gravity acting on an object is 0 N. This is due to the fact that the gravitational field intensity at that location is 0 N/kg.

Apparent Weight

You have probably noticed that while riding in an elevator at certain times your body feels a little heavier than it usually does, and at other points, your body feels a little lighter than usual. In fact, if you were to start at the ground floor and ride up in an elevator to the top floor of a tall building, here is what you would feel:

- When the elevator is stationary at the bottom floor, you would feel nothing unusual, in terms of your weight.
- When the doors close and the elevator begins to accelerate upwards, you would feel as if you were a little heavier than usual.
- Assuming that the building is sufficiently high, and that the elevator won't be stopping until it gets to the top, the elevator soon reaches its maximum speed, and so is not accelerating any more. At this point, you will again feel your usual weight.
- As the elevator nears the top floor, it begins to slow down, which is a downward acceleration. During this motion, you would feel as if you were lighter than usual.
- Eventually the elevator stops—both its motion and its acceleration. You feel your usual weight again.

For the return trip back to the ground level, here is what you would feel:

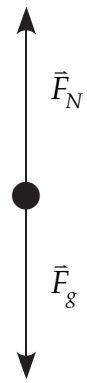
- When the elevator is stationary at the top floor, you would feel nothing unusual, in terms of your weight.
- When the doors close and the elevator begins to accelerate downwards, you would feel as if you were a little lighter than usual.
- Again assuming that the elevator won't be stopping until it gets to the ground floor, the elevator soon reaches its maximum speed, and so is not accelerating any more. At this point, you will again feel your usual weight.
- As the elevator nears the ground floor, it begins to slow down, which is an upward acceleration. During this motion, you would feel as if you were heavier than usual.
- Eventually the elevator stops—both its motion and its acceleration. You feel your usual weight again.

Notice that you only feel unusual when the elevator is accelerating—you feel heavier than usual when it accelerates upward, and lighter than usual when it accelerates downward. The fact is that your true weight $\left(\vec{F}_g\right)$ never changed throughout this motion. Your weight depends only on your mass and on the strength of gravity where you are: $\vec{F}_g = m\vec{g}$, neither of which changed. So why did your weight appear to change?

The answer to this question is surprisingly complicated, so we will have to simplify. The simplified answer is that in most situations, the force that you really feel is not your weight, but rather the **normal force**.

> The **normal force** is often referred to as "**apparent weight**."

If you are sitting in a chair right now, then there are two forces acting on your body: your weight (the downward force of gravity), and the normal force (the upward force of support from the chair). Since your body is not accelerating, then there must be no net force on your body by Newton's First Law. This means that in this situation, the normal force and your weight are the exact same size (although opposite in direction)—this is the only way that the forces can balance each other to produce no net force. Notice that in this situation, your apparent weight (the normal force) is the same size as your true weight (force of gravity).

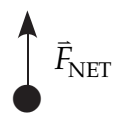


$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = 0 \text{ N}$$
$$\vec{F}_N + \vec{F}_g = 0 \text{ N}$$
$$\vec{F}_N = -\vec{F}_g$$

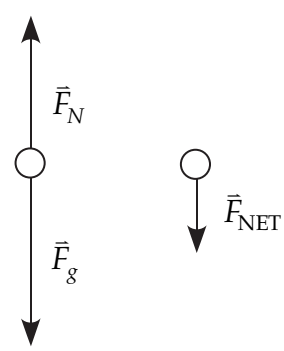
From the free-body diagram above you can see that the relationships represented in symbolic form.

Now suppose that you are standing in an elevator that is accelerating upwards. This would require a net upward force, which means that the normal force must now be larger than the force of gravity—this is the increase in the force that you feel—your "apparent weight."

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$
$$\vec{F}_N + \vec{F}_g = m\vec{a}$$
$$\vec{F}_N = m\vec{a} - \vec{F}_g$$

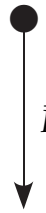


Now suppose that you are standing in an elevator that is accelerating downwards. This would require a net downward force, which means that the normal force must now be smaller than the force of gravity—this is the decrease in the force that you feel—your "apparent weight."



$\vec{F}_N = 0\ \text{N}$

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}}$$
$$0\ N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$
$$\vec{F}_g = m\vec{a}$$
$$\vec{F}_g = m\vec{g} = m\vec{a}$$
$$\vec{g} = \vec{a}$$



What if the elevator you were standing in had been tampered with, so that its cables break, and none of the safety devices work (don't worry about this—elevators are surprisingly well designed!) In particular, what would you feel inside of an elevator that all of a sudden drops completely unsupported? The answer is that you would feel as if you were weightless! With both your body and the floor dropping and accelerating at 9.8 m/s^2, the floor would be completely unable to support you. You would still have your full true weight acting on your body (which would be the reason that you fall), but you would be "normal force-less" with an apparent weight of zero.

To calculate the **normal force** or **apparent weight** of an object in an accelerating frame of reference use the following relationship: the sum of the normal force and the weight of the object equals the net force acting on the object.

By Newton's second law, net force equals mass times acceleration.

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$

Quantity	**Symbol**	**Unit**
Normal force (apparent weight)	$\vec{F}_N$	newton (N)
Force of gravity (weight)	$\vec{F}_g$	newton (N)
Net force	$\vec{F}_{\text{NET}}$	newton (N)
Mass	m	kilogram (kg)
Acceleration	$\vec{a}$	metres/second squared

At the earth's surface assume the acceleration of gravity to be 9.80 m/s^2 [down].

Example 2: Apparent Weight in an Elevator Accelerating Upwards

If your mass is 65.0 kg, what is your apparent weight in an elevator accelerating at 3.00 m/s^2 upwards?

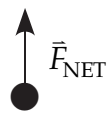
Let up be the positive direction and down be the negative direction.

Remember that the apparent weight is the normal force that is acting on you.

Given:

Mass	m = 65.0 kg
Acceleration	$\vec{a}$ = +3.00 m/s^2
Acceleration of gravity	$\vec{g}$ = –9.80 m/s^2

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$
$$\vec{F}_N + \vec{F}_g = m\vec{a}$$
$$\vec{F}_N = m\vec{a} - \vec{F}_g$$



Unknown: Apparent weight (normal force) $\vec{F}_N = ?$

Equation: $\vec{F}_N + \vec{F}_g = m\vec{a}$ rearranged to $\vec{F}_N = m\vec{a} - \vec{F}_g$

Substitute and solve:
$$\vec{F}_N = (65.0\text{ kg})(3.00\text{ m/s}^2) - (65.0\text{ kg})(-9.80\text{ m/s}^2)$$
$$\vec{F}_N = (+195\text{ N}) - (-637\text{ N}) = +832\text{ N}$$

The normal force or the apparent weight you would feel is 832 N upwards.

You will notice here that you need a force to overcome your weight and some extra force to make you accelerate.

Apparent Weightlessness

True weightlessness occurs at a location where the gravitational field intensity is 0 N/kg.

Apparent weightlessness can occur at any location, even at places where the gravitational field intensity is large. As you have just witnessed in the case for the elevator where the cable has snapped, the apparent weight of the object is 0 N. If you were standing on a scale in this elevator, the scale would read 0 N.

Again, think back to the videos you have seen of astronauts floating around in a spacecraft that is orbiting the earth. These astronauts appear to be truly weightless. However, they are still near to the surface of the earth (only a few hundred kilometres away), so the gravitational field intensity is still quite large (about 7 N/kg).

The spacecraft must be acting like the freely falling elevator. In fact, the spacecraft is accelerating and freely falling towards the earth, so these astronauts are only apparently weightless.

Learning Activity 4.3

Mass, Weight, and Weightlessness

There are five questions in this activity. Once you have completed the exercise, you may check your answers against the answer key at the end of the module.

1. What is true weightlessness? Under what conditions are objects truly weightless?
2. a) What is apparent weightlessness?
   b) When is the apparent weight equal to the true weight of an object?
   c) When is the apparent weight less than the true weight of an object?
   d) When is the apparent weight greater than the true weight of an object?
3. Distinguish between mass and weight.

(continued)

Learning Activity 4.3: Mass, Weight, and Weightlessness (continued)

4. A space traveller whose mass is 105 kg leaves earth. What are his weight and mass
   a) on earth
   b) in interplanetary space where there are no nearby planetary objects
   c) on the moon of a planet where the gravitational field intensity is 2.85 N/kg?
5. A 75.0-kg person stands in an elevator. What will be the force the elevator exerts on the person in each of the following situations? Give both the real weight and the apparent weight in each case.
   a) The elevator is at rest.
   b) The elevator is moving upward with a uniform acceleration of 2.00 m/s^2.
   c) The elevator is moving downward with a uniform acceleration of –2.00 m/s^2.
   d) The elevator is moving upward with a uniform velocity of 2.00 m/s.

Lesson Summary

Mass is the amount of matter contained in an object. You can think of mass as being an indication of how much "stuff" (i.e., protons, neutrons, and electrons) that an object contains. Note that the mass of an object will not change unless matter is added to or removed from the object. The SI unit of mass is the kilogram (kg), and the letter "m" is used to represent mass in physics equations. Mass is measured on a balance, is additive, and obeys the law of conservation of mass. Mass is a scalar quantity.

Weight is a word that is used to mean **gravitational force** acting on an object. This is a different interpretation of the word "weight" than what you are used to. The SI unit of weight is the same as the unit of force, the newton (N), since weight is a force. Weight is a vector and is measured on a scale.

In physics equations, "$\vec{F}_g$" is used to represent weight (remember that weight and gravitational force mean the same thing). The weight of an object does depend on its mass, but also on how strong gravity is. Identical masses will have different weights if one is on the moon and the other is on earth. In fact, the one on the moon would be lighter, since gravity is weaker there.

The **weight** of an object can be calculated from the mass of the object and the value of $\vec{g}$ where it is located: $\vec{F}_g = m\vec{g}$.

True weightlessness occurs only at locations where the gravitational field intensity is 0 N/kg.

In situations where objects are located in a **frame of reference** that is accelerating (like an elevator), objects have **apparent weights** that are different from their **true weight** at that location.

In such situations, the **apparent weight** is the same as the **normal force** that acts on the object. If you're standing in an elevator that accelerates upwards, you feel heavier than normal because the normal force is larger than your weight (the force of gravity).

The following relationship is used to calculate the normal force in an accelerating frame of reference:

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$

Assignment 4.1, Part B

Mass, Weight, and Weightlessness (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 3 and Module 4, after you have completed Module 4.

A bag of sugar has a mass of 20.0 kg. The bag of sugar is placed on a scale.

a) What will the scale read if the scale is resting on the floor?

b) What will a scale read if you lift the scale and the bag of sugar, accelerating them at 1.50 m/s^2 upwards?

(continued)

Assignment 4.1, Part B: Mass, Weight, and Weightlessness (continued)

c) What will the scale read if you lower the scale and the bag of sugar at a constant velocity of –1.00 m/s?

_____

_____

_____

_____

_____

d) Under what conditions would the scale read 0 N?

_____

_____

_____

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining the correct reading on the scale in part (a)
- 2 marks for determining the correct reading on the scale in part (b)
- 1 mark for determining the correct reading on the scale in part (c)
- 1 mark for stating the correct conditions in part (d)

Lesson 3: Laboratory Activity: Determining Acceleration Due to Gravity (1 hour)

Learning Outcomes

You will perform an experiment to measure the gravitational intensity at the surface of the earth.

Laboratory Activity: Determining the Acceleration Due to Gravity

Submit this assignment to the Distance Learning Unit along with all the other assignments from Module 3 and Module 4, after you have completed Module 4.

Introduction

The lesson consists of just one short, simple experiment, which you will conduct using ordinary household items. In this experiment, you will build a pendulum that you will use to calculate the gravitational field.

When you have finished the lab, you will complete a Laboratory Report, which is found at the end of this and every other Laboratory Assignment. The Laboratory Report is the only part of this assignment that you will hand in. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

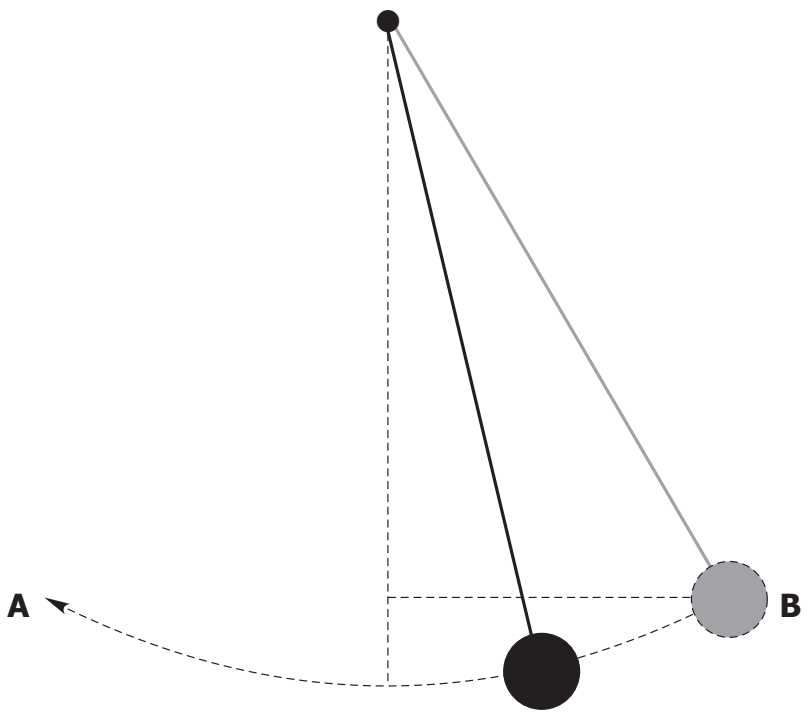
Purpose

To measure the gravitational field intensity at the surface of the earth

Apparatus

- **string:** a piece of thread, fishing line or thin string at least 2 m long
- **a weight:** a heavy coin like a toonie, or a fishing weight or other small, heavy object
- **a timer:** a clock or watch or stopwatch
- **some tape**
- **a doorway**

Here is a diagram that shows one oscillation.



From A to B and back to A is one oscillation.

Procedure

1. Tape one end of the thread or string at the top of the doorway, near the middle.
2. Tape the other end of the thread to the coin so that the coin is a few centimetres from the floor.
3. Measure the length of the string from the point at which the thread is taped to the doorway to the middle of the weight.
4. Pull the weight 10 cm from the rest position to one side and release it.
5. Record how long it takes to make 15 oscillations. One oscillation is counted as the weight starting at one end of its swing, travelling to the other end of the swing, and back to its original position. Repeat this three times.

6. Find the average time for one oscillation (the period).
7. Repeat the steps above using a length 0.5 m shorter than the previous length of the pendulum.

Data and Calculations

Part 1	**Length of Pendulum:**
Trial	Time for 15 oscillations (s)
1	
2	
3	
Period: Average time for 1 oscillation (s)	

Part 2	**Length of Pendulum:**
Trial	Time for 15 oscillations (s)
1	
2	
3	
Period: Average time for 1 oscillation (s)	

1. What is the length of the pendulum (in metres)? _____ m
2. How long did it take on average to make 15 oscillations (in seconds)? _____ s
3. What is the average time for one oscillation (the period)? _____ s

4. Calculate the acceleration due to gravity, "$\vec{g}$," by using the following equation:

$$T = 2\pi\sqrt{\frac{l}{\vec{g}}}$$

where T represents the period in seconds, l represents the length of the pendulum in metres, and $\vec{g}$ represents the acceleration due to gravity (a measure of the strength of the gravitational field). Solve for $\vec{g}$ after re-arranging the mathematical relationship above. Show each step of this re-arrangement in your solution. Your answer will be a measure of the gravitational acceleration at earth's surface (with units of m/sec^2).

5. Using a value of $\vec{g}$ = 9.80 N/kg, determine the percentage error for your measurement of $\vec{g}$. Use the equation:

$$\text{Percentage Error} = \frac{|\text{Accepted Value} - \text{Measured Value}|}{\text{Accepted Value}} \times 100\%$$

6. Repeat the calculations for your second trial.

Discussion

Discuss possible sources of error in this experiment, and how you could reduce the error.

Conclusion

The following questions do not have obvious right or wrong answers. Answer at least two of them. You will be assessed on how well you have thought out your answers.

1. Would the length of the pendulum change the result?
2. What would happen to the period if this experiment were conducted on a much smaller (less massive) earth?
3. How would the results differ if this experiment were conducted near a very dense neutron star?

Assignment 4.2

Laboratory Activity: Determining Acceleration Due to Gravity

(20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow those directions.

The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words in a brief paragraph (do not use point form) how the experiment was performed.

_____

_____

_____

_____

_____

(continued)

Assignment 4.2: Laboratory Activity: Determining Acceleration Due to Gravity (continued)

Data and Calculations:

- Include photocopies of your data measurements (e.g., tapes or tracks) if they were provided in the notes.
- Include the raw data for each part of the experiment that should be recorded in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data. For example, if you use a formula, write out the formula, and show your substitutions and calculations. This should be done for each different calculation (i.e., whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be done.

(continued)

Assignment 4.2: Laboratory Activity: Determining Acceleration Due to Gravity (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce the error.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. In making measurements, errors are always made. In the error analysis, your job is to critically look at the procedure, identify possible sources of error (there may be several), and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 4.2: Laboratory Activity: Determining Acceleration Due to Gravity (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

_____

_____

_____

_____

_____

Marking Rubric for Assignment 4.2

Section of Report	Possible	Actual
Purpose	1	
Apparatus and Procedure	4	
Completed Data Tables	2	
Calculation of the Period and Gravitational Field for Each Trial	8	
Discussion—Sources of Error	2	
Conclusion and Questions on page 42	3	
Total	**20**	

Lesson 4: Free Fall and Vertical Motion at the Earth's Surface (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain how the acceleration of a mass can be derived from Newton's Second Law
- ❑ describe one method to determine the value of $\vec{g}$ experimentally
- ❑ use the equations from our study of kinematics to solve problems dealing with free fall

Key Words

free fall
vertical motion

Introduction

Until now, in our problems with kinematics we only considered motion in the horizontal direction. In this lesson, we will apply the ideas of kinematics to motion in the vertical direction at the earth's surface. You know that if you hold an object at shoulder height and release it, it falls towards the ground. The object will accelerate (i.e., speed up) as it falls. So in this lesson, when we analyze motion in the vertical direction we must always keep in mind that this is accelerated motion.

Free Fall

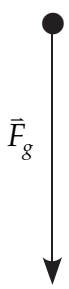
It was Galileo Galilei (1564–1642) who made important discoveries about falling bodies. Galileo discovered that all bodies fall with the same constant acceleration at the earth's surface. It does not matter if the object is a large rock or a small rock: both fall with the same acceleration due to the earth's gravity. This acceleration is given the special symbol $\vec{g}$ and has the value of $\vec{g} = 9.80\ \text{m/s}^2$.

An interesting consequence of this is that if air resistance could be eliminated, then a feather and a rock would fall at exactly the same rate of acceleration. You do not see this in normal circumstances because the force of air friction slows down the feather much more than the rock.

Since you probably don't have a rock and a feather but you probably do have a book and a sheet of paper, you can try this by dropping a book and a sheet of paper side by side from the same height. The book probably had a greater acceleration than a sheet of paper.

If you could eliminate or minimize the force of air friction acting on the sheet of paper, then the book and the paper should fall together accelerating at the same rate. To minimize the force of friction of the air acting on the paper, crumple a sheet of paper into a tight ball. If you release the book and a crumpled piece of paper at the same time from the same height, they should fall together, accelerating at the same rate.

You can approach this idea from Newton's Second Law of Motion as well. Here is the free-body diagram of an object that is released and falling towards the earth. Let's assume that the force of air friction is zero.



Recall Newton's Second Law of Motion:

$$\vec{F}_{\text{NET}} = m\vec{a}$$

Also, recall the force of gravity is given by:

$$\vec{F}_g = m\vec{g}$$

Since the force of gravity is the only force acting on the object, then the net force is equal to the force of gravity. So,

$$\vec{F}_{\text{NET}} = \vec{F}_g \text{ and}$$

$$m\vec{a} = m\vec{g}.$$

The mass, m, cancels giving

$$\vec{a} = \vec{g}.$$

In the idealized case where air resistance is neglected (such as in a vacuum chamber), you can assume that all objects at the same location on the earth fall with the acceleration due to gravity. This idealized situation is called **free fall**.

Free fall describes the situation in which the only force acting on the falling object is the force of gravity.

For freely falling objects, use the acceleration as the acceleration of gravity.

$$\vec{a} = \vec{g} = 9.80 \text{ m/s}^2 \text{ [down]}$$

However, if you could get to a place with little air resistance (for instance, the surface of the moon), we could attempt to demonstrate that two very different objects—say, a feather and a rock hammer—have similar behaviour when they fall freely under the influence of a gravity field.

In 1972, that's just what was done by David Scott, one of the two Apollo 15 astronauts who were on the surface of the moon that year. Here is a transcript of Commander Scott's playful demonstration as it was done on television from the lunar surface:

"In my left hand, I have a feather, in my right, a hammer. And I guess one of the reasons we got here today was because of a gentleman named Galileo, a long time ago, who made a rather significant discovery about falling objects in gravity fields. And we thought, 'where would be a better place to confirm his findings than on the moon?' And so we thought we'd try it here for you. The feather happens to be, appropriately, a falcon feather for our Falcon. And I'll drop the two of them here and hopefully they'll hit the ground at the same time."

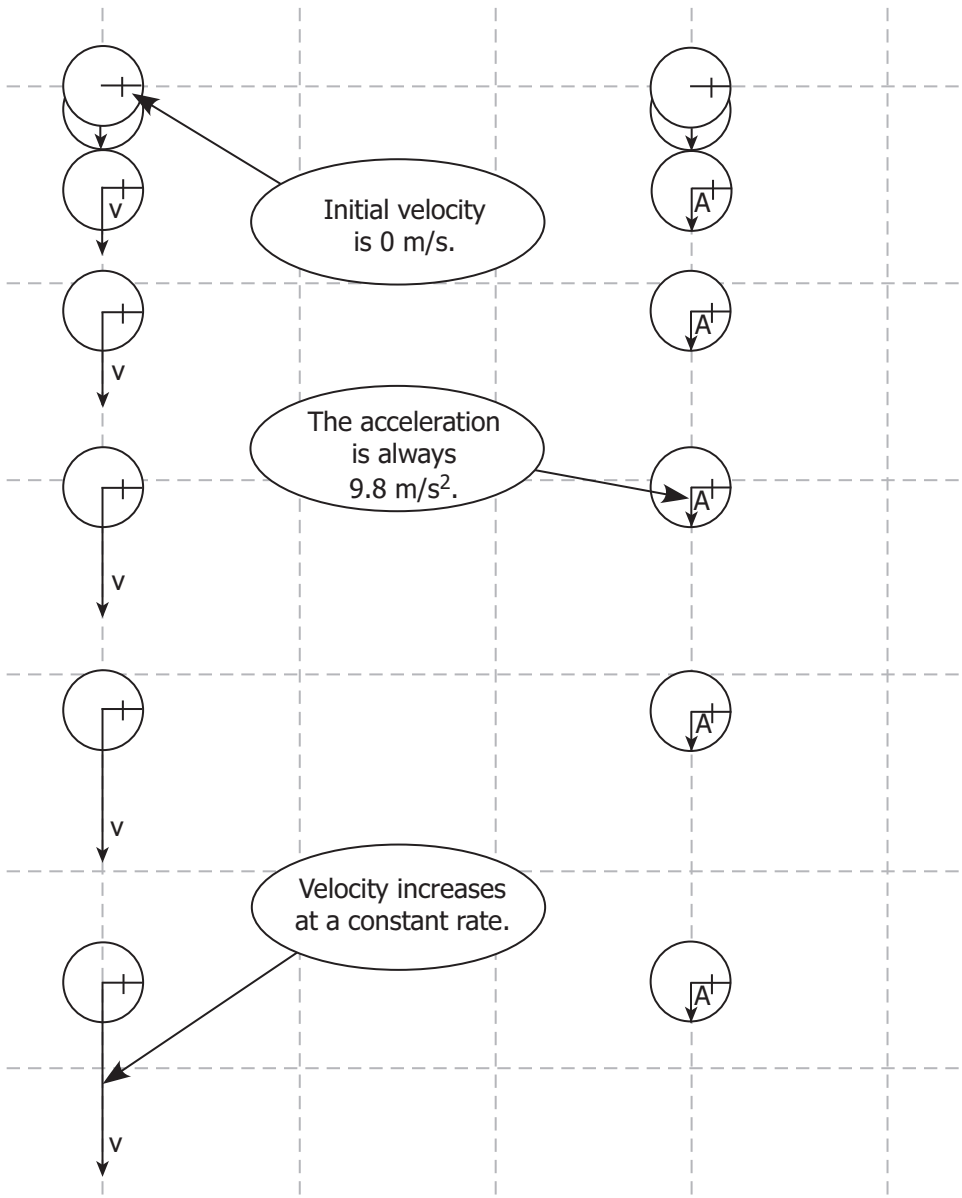
On a simultaneous release the feather and the hammer dropped to the ground together.

"Mr Galileo was correct in his findings." said Scott, as the backroom scientists applauded.

Here is the URL of the video clip if you are interested in viewing the event as it was broadcast on television (in mpeg format):
http://www.hq.nasa.gov/office/pao/History/alsj/a15/a15v_1672206.mpg

Below is a graphic illustrating the velocity and acceleration vectors during free fall.

Velocity and Acceleration Vectors for Freely Falling Objects



So, freely falling objects accelerate at 9.8 m/s^2 towards the earth at the earth's surface.

Determining "*g*" Experimentally

There are various ways in which one could experimentally determine the value of "$\vec{g}$," the acceleration due to gravity. One of the ways to do so is to simply drop a small, dense object, such as a small steel ball, and record its motion as it falls. This could be done using a strobe light and a camera. The data tables below show an ideal case.

In the first data table, the position of the ball from the point of release is recorded. The position is recorded every tenth of a second. Note that although the object is falling downwards, the position is recorded as a positive number. The velocity and acceleration will also be recorded as positive numbers.

Time (s)	0.00	0.10	0.20	0.30	0.40	0.50
Position (m)	0.00	0.049	0.196	0.441	0.784	1.225

A new data table can be created showing the average velocity of the ball for each of the time intervals. The average time must also be recorded.

Time (s)	0.00	0.050	0.15	0.25	0.35	0.45
Velocity (m/s)	0.00	0.49	1.47	2.45	3.43	4.41

Finally, a data table is created showing the average acceleration of the ball for each of the time intervals.

Time (s)	0.00	0.025	0.10	0.20	0.30	0.40
Accel. (m/s^2)	0.0	9.8	9.8	9.8	9.8	9.8

The acceleration of the ball is determined to be 9.8 m/s^2 for the data above. Note that this is the magnitude of the acceleration. Since the acceleration is downwards, we can properly say that the acceleration due to gravity is $\vec{g} = -9.8\ m/s^2$.

There are other ways to measure the acceleration due to gravity. In a way that is similar to the method above, a motion sensor could be connected to a computer and the data would then be analyzed. This would measure the value of "$\vec{g}$," directly at that location.

Vertical Motion at the Earth's Surface

Vertical motion at the earth's surface is still **straight-line motion**. Therefore, you can apply the **equations of kinematics** that were studied earlier to this straight-line vertical motion.

As you have seen, vertical motion is accelerated motion and the acceleration here at the earth's surface will be 9.80 m/s^2 downwards. Since the motion is accelerated, we will be able to use kinematics equations #2 through #5. At this point, you may want to review these equations.

Solving Vertical Motion Problems: In order to solve vertical motion problems in a systematic way, let us outline some common strategies to use.

1. Frame of Reference

Since the motion is vertical motion, our frame of reference will be the *y*-axis of the Cartesian coordinate system.

In our frame of reference, up will represent the positive direction and down will represent the negative direction.

2. Acceleration

We will assume in these questions that the acceleration of the object will be the acceleration of gravity:

$$\vec{a} = \vec{g} = 9.80 \text{ m/s}^2 \text{ [down]} = -9.80 \text{ m/s}^2$$

We will also assume that air friction does not play a role in these problems.

Example 1: Dropping an Object

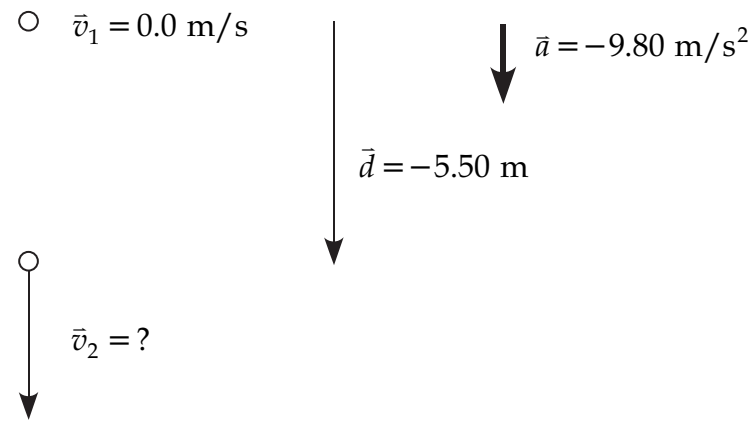
Against the advice of your parents, you have climbed up onto the roof of your house. The edge of the roof is a distance of 5.50 m above the ground.

a) If you were to step off the edge of this roof, what would be your velocity when you hit the ground below?

The frame of reference will have up as the positive direction and down as the negative direction.

Assume that the acceleration is –9.80 m/s^2.

Given:



Note that the displacement is negative.

Unknown: final velocity $\vec{v}_2 = ?$

Equation: Kinematics equation #5 relates the given variables to the final velocity.

$$v_2^2 = v_1^2 + 2ad$$

Substitute and solve:

$$v_2^2 = v_1^2 + 2ad$$

$$v_2^2 = (0 \text{ m/s})^2 + 2(-9.80 \text{ m/s}^2)(-5.50\ m)$$

$$= 107.8 \text{ m}^2/\text{s}^2$$

$$\vec{v}_2 = \sqrt{107.8 \text{ m}^2/\text{s}^2} = -10.4 \text{ m/s}$$

The velocity is negative, since you would be moving downwards.

Your velocity as you hit the ground is 10.4 m/s [down].

b) How long is the time interval between your stepping off the roof and your hitting the ground?

Given: Information above plus the final velocity: $\vec{v}_2 = -10.4$ m/s

Unknown: time interval $\Delta t = ?$

Equation: You have a choice of kinematics equations to use in this case. Let's use equation #2.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ rearranged to } \Delta t = \frac{\vec{v}_2 - \vec{v}_1}{\vec{a}}$$

Substitute and solve:

$$\Delta t = \frac{(-10.4 \text{ m/s}) - (0 \text{ m/s})}{(-9.80 \text{ m/s}^2)} = \frac{(-10.4 \text{ m/s})}{(-9.80 \text{ m/s}^2)}$$

$$= 1.06 \text{ s}$$

You hit the ground 1.06 s after stepping off the roof.

Example 2: Throwing an Object Downwards

Suppose you were in the observation deck of the CN Tower at a height of 342 m above the ground, and you threw a marble straight downwards with a velocity of 35.0 m/s. Assume there is no air friction.

a) Determine the velocity of the marble when it strikes the ground below.
b) Determine the time it takes the marble to reach the ground below the point from which it was released.
c) Where is the marble 3.00 seconds after being released?
d) What is the velocity of the marble 3.00 seconds after being released?

Solution

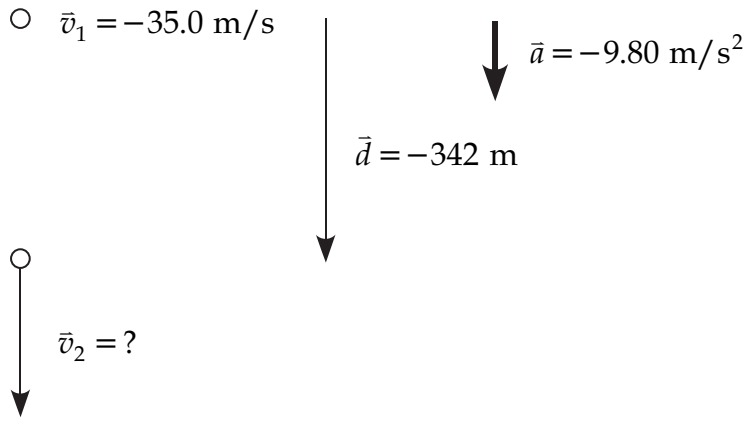
a) Determine the velocity of the marble when it strikes the ground below.

This problem is essentially the same as the previous problem except that the initial velocity is no longer 0 m/s.

The frame of reference will have up as the positive direction and down as the negative direction.

Assume that the acceleration is –9.80 m/s^2.

Given:



Note that the displacement is negative.

Unknown: Final velocity $\vec{v}_2 = ?$

Equation: Kinematics equation #5 relates the given variables to the final velocity.

$$v_2^2 = v_1^2 = 2ad$$

Substitute and solve:

$$v_2^2 = v_1^2 + 2ad$$

$$v_2^2 = (35.0\,\text{m/s})^2 + 2(-9.80\ \text{m/s}^2)(-342\ \text{m})$$

$$= 7928.2\ \text{m}^2/\text{s}^2$$

$$\vec{v}_2 = \sqrt{7928.2\ \text{m}^2/\text{s}^2} = -89.0\ \text{m/s}$$

The velocity is negative, since the marble would be moving downwards.

The marble's velocity as it hits the ground is 89.0 m/s [down].

b) Determine the time it takes the marble to reach the ground below the point from which it was released.

Given: Information above plus the final velocity: $\vec{v}_2 = -89.0 \text{ m/s}$

Unknown: Time interval $\Delta t = ?$

Equation: You have a choice of kinematics equations to use in this case. Let's use equation #2.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ rearranged to } \Delta t = \frac{\vec{v}_2 - \vec{v}_1}{\vec{a}}$$

Substitute and solve:

$$\Delta t = \frac{(-89.0 \text{ m/s}) - (-35.0 \text{ m/s})}{(-9.80 \text{ m/s}^2)} = \frac{(-54.0 \text{ m/s})}{(-9.80 \text{ m/s}^2)}$$

$$= 5.51 \text{ s}$$

The marble hits the ground 5.51 s after being released.

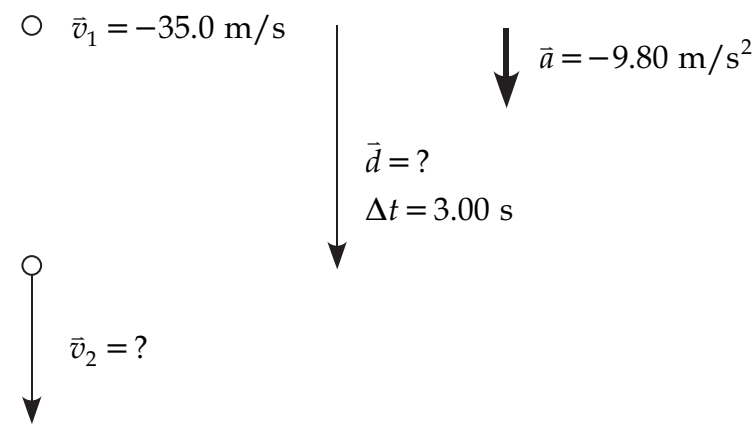
c) Where is the marble 3.00 seconds after being released?

This is a new situation, since the marble is still falling towards the earth. It has not yet reached the ground so its final velocity is not –89.0 m/s.

The frame of reference will have up as the positive direction and down as the negative direction.

Assume that the acceleration is –9.80 m/s^2.

Given:



Note that the displacement is negative.

Unknown: Displacement $\vec{d} = ?$

Equation: Kinematics equation #4 relates the given variables to the displacement.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve:

$$\vec{d} = (-35.0 \text{ m/s})(3.00 \text{ s}) + \frac{1}{2}(-9.80 \text{ m/s}^2)(3.00 \text{ s})^2$$

$$\vec{d} = -105 \text{ m} + -44.1 \text{ m} = -149.1 \text{ m} = -149 \text{ m}$$

The marble has fallen 149 m and is located 149 m below the point of release.

d) What is the velocity of the marble 3.00 seconds after being released?

This situation is still a continuation of part (c).

Unknown: Final velocity $\vec{v}_2 = ?$

Equation: Kinematics equation #2 relates the given variables to the final velocity.

$$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

Substitute and solve:

$$\vec{v}_2 = (-35.0 \text{ m/s}) + (-9.80 \text{ m/s}^2)(3.00 \text{ s})$$

$$\vec{v}_2 = (-35.0 \text{ m/s}) + (-29.4 \text{ m/s}) = -64.4 \text{ m/s}$$

The final velocity of the marble after three seconds is 64.4 m/s [down].

Learning Activity 4.4

Free Fall and Vertical Motion

Once you have completed the questions, you may check your answers against the answer key found at the end of the module.

1. If you were to take a 2.0 kg mass to Venus and use a force scale to find its weight, you would find that the weight is 17.8 N. If you were to lift this mass up from the surface of Venus and drop it, at what rate would it accelerate downwards?

For these questions 2, 3, and 4, use $\vec{a} = \vec{g}$ = 9.80 m/s^2 [down] and assume that air friction is negligible.

2. A stone is dropped from a bridge to the water below. If it takes 2.45 seconds for the stone to hit the water, calculate the distance that the stone fell.
3. A baseball is thrown straight upwards with a velocity of 32.0 m/s.
   a) What is the time interval from the moment the ball is released until it stops rising at the top of its flight?
   b) To what height above the point of release will the ball rise?
4. Food aid on a skid is dropped from an airplane flying horizontally at 125 m/s. The food skid falls for 18.6 seconds before it hits the ground.
   a) Assuming that the initial vertical velocity is 0 m/s, from what height was the food dropped?
   b) What is its vertical velocity when it strikes the ground?
   c) How fast is it travelling horizontally when it strikes the ground?
5. The gravitational field constant at the moon's surface is 1.60 N/kg. A moon rock is dropped and falls for a time of 2.00 s.
   a) After falling for this time, what will be the new velocity of the rock?
   b) What distance has the rock fallen?

Lesson Summary

Galileo, in one of his famous thought experiments, postulated that a rock and a feather when dropped together, would accelerate at the same rate.

When **astronauts** went to the **moon** where there is no atmosphere and, therefore, no air friction, they demonstrated that a hammer and a feather dropped from the same height at the same time struck the ground at the same time. The acceleration experienced by both objects was the same.

In a situation in which air friction could be eliminated at the earth's surface, all objects would accelerate at $-9.80\ \text{m/s}^2$ when allowed to fall freely.

Free fall describes the situation in which the only force acting on the falling object is the force of gravity.

For freely falling objects, use the acceleration as the acceleration of gravity.

$$\vec{a} = \vec{g} = 9.80\ \text{m/s}^2\ [\text{down}]$$

For **vertical motion** at the surface of the earth, we assume that the **force of gravity** is the only force acting on the object and that the force of air friction is negligible.

In these circumstances, we can treat vertical motion simply as straight-line motion along the y-axis. The acceleration during the motion is constant at $-9.80\ \text{m/s}^2$.

Assignment 4.3, Part A

Free Fall (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 3 and Module 4, after you have completed Module 4.

On Mars, the gravitational field constant is $\bar{g}$ = 3.70 N/kg [towards the centre of Mars].

a) How much would a 2.00 kg mass weigh on Mars?

b) If this object was allowed to fall for 4.00 s, what would be the new velocity of the rock, assuming no resistance with the atmosphere of Mars?

(continued)

Assignment 4.3, Part A: Free Fall (continued)

c) From the spot where the object is dropped from rest, what distance would the object fall, assuming no atmospheric resistance?

_____

_____

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining the correct weight is part (a)
- 2 marks for determining the second velocity in part (b)
- 2 marks for determining the displacement in part (c)

Lesson 5: Air Resistance and Terminal Velocity (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe the conditions under which "terminal velocity" is reached
- explain how the mass of an object determines what the terminal velocity of the mass becomes and how much time it takes to reach this velocity
- describe the shape of the velocity-time graph at various times as an object falls through an atmosphere

Key Words

air resistance
terminal velocity

Introduction

In the previous lesson, we saw how the gravitational field constant is related to the acceleration due to gravity. We were able to combine this value of acceleration with the equations we learned in kinematics to solve problems dealing with the free fall of objects. In the problems we considered, the air resistance was assumed to be negligible. When air resistance is considered, objects will eventually reach "terminal velocity," which is the speed at which they no longer accelerate. It is terminal velocity that allows a parachutist to survive a jump from an aircraft.

Terminal Velocity and Air Resistance

If a heavy book and a single flat sheet of paper are dropped simultaneously, the paper will fall more slowly than the book, and so hit the ground much later than the book. This, of course, means that our assumption that everything falls at the same rate regardless of weight is not true in this case. **Air resistance** (which we usually ignore) produces this difference.

> In general, whenever something moves through the air, the air exerts a force onto the object to oppose its motion—we call this force **air resistance** or **drag force** ($\vec{F}_d$).

The **size** of the **drag force** depends on many things, one of which is the **speed** of the object moving through the air. You have likely experienced this if you have ever stuck your hand out of a moving car. As the car moves faster, you feel your hand pushed more strongly backwards. When an objects falls, its speed increases, resulting in the drag force also increasing.

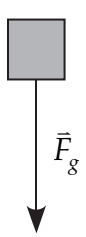
A second factor that influences the drag force is the **size** of the object. If you hold your hand flat out of the window of a moving car with the palm pointing in the direction of motion (the hand is held perpendicular to the ground), the drag of the air will be large. If you turn your hand so that the palm faces the ground, the drag of the air is reduced. The larger the area of an object, the greater the drag of air resistance, so a parachute experiences a large drag force because of its large area.

Terminal Velocity

Let us consider a falling object.

The net force causing the acceleration of the object is made up of two forces: the downward force of gravity $\vec{F}_g$, and the upwards drag force $\vec{F}_d$.

Diagram 1

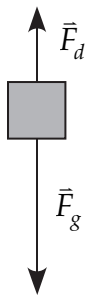


The object has just been released—since it is not yet moving, there is no drag force. The weight is the only force, and so it is the net force.

$$\vec{F}_{\text{NET}} = \vec{F}_g$$
$$\vec{a} = \vec{g}$$

As long as $\vec{F}_g > \vec{F}_d$, the net force will be downwards, and so downward acceleration will occur.

Diagram 2

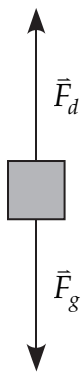


The object is now moving downwards, so there is an upwards drag force smaller than the weight. The net force is down because of this, but smaller than in the previous diagram.

$$\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_d$$
$$\vec{a} < \vec{g}$$

But as the force of air resistance increases due to the object speeding up, the magnitude of the net force will decrease, thus decreasing the acceleration.

Diagram 3



The object is now moving downwards at its terminal velocity. The net force is zero as the drag force balances the weight, making the net force zero.

$$\vec{F}_{NET} = 0 \text{ N}$$
$$\vec{a} = 0 \text{ m/s}^2$$

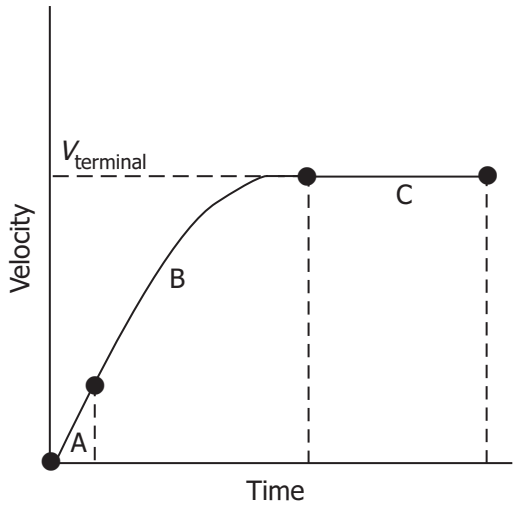
Eventually, the force of air resistance will be equal but opposite to the force of gravity, $\vec{F}_g = -\vec{F}_d$, the net force on the object will be zero, and the object will no longer be accelerating (though it is certainly still moving!).

We say that the object has reached **terminal velocity**. The value for the terminal velocity will vary, but in general it will be smaller for objects that are light compared to their size. It is therefore quite a bit slower for a flat piece of paper than it is for a book.

The **terminal velocity** is the constant velocity of a falling object at which the drag force of air resistance is equal in magnitude to the force of gravity. The net force on the object is 0 N and the acceleration is 0 m/s^2.

Terminal Velocity and a Parachutist

When a parachutist jumps from an airplane (with the parachute initially closed), a terminal velocity will also be reached. The graph below shows possible velocities at various times (down is being used as the positive direction).



In section A, air resistance is negligible (small enough to be safely ignored), making gravity the only force worth considering—the parachutist falls with an acceleration of 9.8 m/s^2 (constant) as we would predict. This results in a constant slope on the velocity-time graph (recall that the slope of such a graph represents acceleration).

In section B, air resistance is no longer negligible, and is increasing due to the increasing speed of the parachutist. This results in a decreasing net force and a decreasing acceleration. Thus, the graph is curved in this section, as the slope (acceleration) decreases. Notice, however, that the velocity continues to increase.

In section C, the air resistance has increased to the point where $\vec{F}_d = \vec{F}_g$ and the net force on the parachutist is zero. No acceleration occurs, so the slope of the velocity-time graph in this section is zero. The parachutist falls at a constant velocity—this is the **terminal velocity**.

A parachutist falling with a closed parachute has a pretty high terminal velocity—approximately 200 km/h. This is much too fast to land safely! Of course, the parachute can be opened, which effectively makes the falling person a much larger object. The downward force of gravity does not change, but the air resistance suddenly becomes much greater than it was (and it was the same size as the force of gravity). This means that the upward drag force will actually be larger than the downward force of gravity, producing an

upwards acceleration, so the parachutist slows down. The reverse of the above then happens: as the parachutist slows down, the drag force decreases until it eventually again matches the force of gravity. A new, much smaller terminal velocity will be reached (approximately 20 km/h)—slow enough for a safe landing (though it takes some skill to do so!).

Example: A Falling Object Experiencing a Drag Force of Air Resistance

A parachutist and his equipment have a mass of 108 kg. The parachutist is falling at 144 km/h or 40.0 m/s. When the parachute is opened, the drag of air resistance is 3020 N.

a) Calculate the net force on the parachutist.
b) Calculate the acceleration of the parachutist.
c) What distance would the parachutist fall while his velocity is reduced to his terminal velocity of 18.6 m/s?

Solution

Use down as the negative direction.

a) Given: Mass $m = 108\text{ kg}$

Initial velocity $\vec{v}_1 = -40.0\text{ m/s}$

Drag of air resistance $\vec{F}_d = +3020\text{ N}$

Final velocity $\vec{v}_2 = -18.6\text{ m/s}$

Unknown: Net force $\vec{F}_{\text{NET}} = ?$

Equation: $\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_d$

Substitute and solve: $\vec{F}_{\text{NET}} = m\vec{g} + \vec{F}_d$

$$\vec{F}_{\text{NET}} = (108\text{ kg})(-9.80\text{ m/s}^2) + (3020\text{ N})$$

$$\vec{F}_{\text{NET}} = (-1060\text{ N}) + (+3020\text{ N}) = +1960\text{ N}$$

The net force is 1960 N [up].

b) Use Newton's Second Law to find acceleration.

$\vec{F}_{\text{NET}} = m\vec{a}$ rearranged to $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$.

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{+1960\text{ N}}{108\text{ kg}} = +18.1\text{ m/s}^2$$

The parachutist accelerates at 18.1 m/s^2 [up].

c) This is kinematics now.

Given: Initial velocity $\vec{v}_1 = -40.0 \text{ m/s}$

Final velocity $\vec{v}_2 = -18.6 \text{ m/s}$

Acceleration $\vec{a} = +18.1 \text{ m/s}^2$

Unknown: Displacement $\vec{d} = ?$

Equation: $v_2^2 = v_1^2 + 2ad$

Rearranged to $\vec{d} = \dfrac{v_2^2 - v_1^2}{2a}$

Substitute and solve:

$$d = \frac{v_2^2 - v_1^2}{2a} = \frac{(-18.6 \text{ m/s})^2 - (-40.0 \text{ m/s})^2}{2(+18.1 \text{ m/s}^2)}$$

$$\vec{d} = \frac{-1254.04}{+36.2} = -34.6 \text{ m}$$

The parachutist falls 34.6 m [down].

Learning Activity 4.5

Air Resistance and Terminal Velocity

These questions will help you with the concepts from this section of the course. Once you have completed them, you may check your answers against the answer key provided at the end of the module.

1. What is terminal velocity?
2. What factors affect the drag of air resistance as an object falls through the air?
3. Which of the following objects would have a larger terminal velocity: a polystyrene ball or a billiard ball of the same size? Explain.
4. Which of the following objects would have the smaller terminal velocity: a paper coffee filter or the same coffee filter crumpled into a small ball?
5. A 1.00-kg ball is allowed to fall through the air. When its downward velocity is –10.3 m/s, the force of air resistance is 3.00 N upwards. What must be the net force on the ball at this moment and what must be the acceleration of the ball?

Lesson Summary

When an object is falling through the air, the force of air resistance (drag force = $\vec{F}_d$) will eventually equal the force of gravity, $\vec{F}_d = \vec{F}_g$, the net force on the object is zero, and the object is no longer accelerating. We say that the object has reached **terminal velocity**.

When free fall begins, there is no air resistance. As an object begins to fall, the drag force increases until terminal velocity, when the force of air resistance is equal to the gravitational force.

Note: There is no assignment for this lesson.

NOTES

LESSON 6: FRICTION (1.5 HOURS)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "static friction"
- ❑ draw a free-body diagram illustrating a case of static friction
- ❑ explain how the magnitude of the force of static friction can change, and at what point the maximum force of static friction is reached
- ❑ define the term "coefficient of static friction"
- ❑ determine the force of static friction in problem solving
- ❑ explain what kinds of physical factors affect the value of the coefficient of static friction, and therefore the force of friction
- ❑ define the terms "kinetic friction" and "coefficient of kinetic friction"
- ❑ describe the kinds of physical factors that affect the amount of kinetic friction between two surfaces

Key Words

friction
coefficient of static friction
coefficient of kinetic friction
kinetic friction

Introduction

The force of gravity has an effect on the amount of friction between two surfaces. For us, friction can be a problem or a benefit. In many situations, considerable effort is made to reduce friction. For example, oil is used in an automobile engine to reduce the friction that causes wear and tear in the pistons and cylinder walls. On the other hand, without friction, the tires of that car would not have the traction necessary to move the car. We will examine two different types of friction, static and kinetic, and put to use our knowledge of free-body diagrams from the previous module to solve problems involving friction.

Friction

To most people, friction is a force that tries to stop or slow things down. To be sure, friction can act to stop or slow things down (car brakes rely on friction!), but did you know that in most situations we need friction to get things going in the first place?

> In general, **friction** is a force that acts between two surfaces. More specifically, friction tries to prevent the surfaces from sliding past each other.

Friction: An Analogy

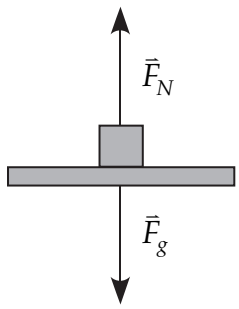
To help get a better understanding of friction, let's have a look at something that is probably familiar to you.

Velcro® is the brand name of a hook-and-loop fastening system that is used to hold all kinds of things together. It is often used instead of laces in shoes and instead of buckles on straps. If you have some nearby, go take a close look at it right now. You will find that one surface is made up of a tangle of soft plastic loops and the other surface is made up of harder plastic hooks. When they are brought together, the plastic hooks get caught into the loops. When you try to pull them apart, the hooks and loops stretch out, and, if pulled hard enough, the hooks will straighten enough to pull out of the loops without breaking anything (so that it can be reused).

Suppose that you have a table with the entire top surface made up of one of the materials (loops or hooks—either one). Now place on the table a small block that has the opposing material covering its lower surface so that some of the hooks of one surface catch into the loops of the other. Notice that, just sitting there, the hooks and loops are all relaxed—there is no "velcro force" at this time.

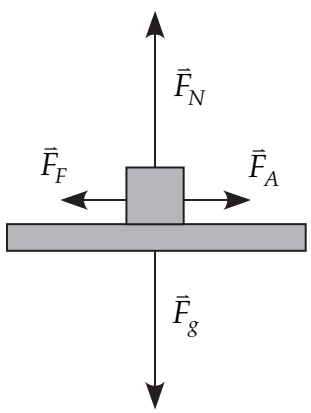
Friction and a Block on a Table

Now repeat this with an ordinary block on an ordinary table (no more Velcro®). Just sitting there, there are only two forces (gravity and normal—no friction force!).



Now try to slide the block across the table by pushing the block sideways. At first, your pushes might not succeed in moving the block at all—the hooks and loops would stretch out a bit, but hold.

If a small force is applied to the right, experience tells us that the block will not move in most situations where there is some friction between surfaces. The block does not move because the frictional force to the left just balances the applied force to the right.

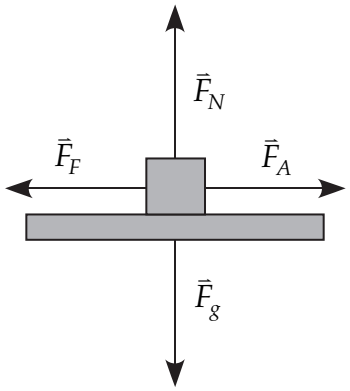


The friction present in this situation is static friction.

Static friction can be defined as a force that opposes the start of motion between two surfaces.

If the applied force increases slightly but not enough to cause the block to slide, the force of static friction increases by the same amount and the block does not move. The frictional force is still equal in magnitude to the applied force and opposite in direction.

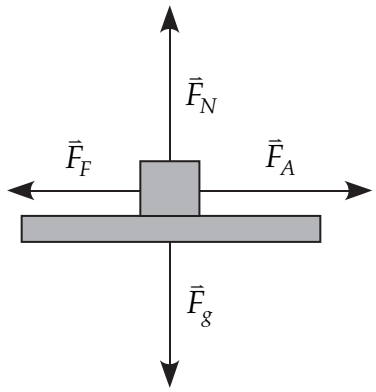
Larger friction to the left.



If the applied force continues to increase, there is a point where the block finally "breaks away" and starts to move. The force just before the breakaway represents the **maximum static frictional force** that the surface can exert on the block.

Back to the Velcro® analogy: You could push harder and harder, but still the hooks and loops hold (though stretch out even more). Eventually, if you push hard enough, (**maximum static frictional force**) you will reach the point that they have stretched out so much that they detach and the block moves … but not very far, before the hooks catch into different loops! In fact, sliding the block would require the continual "catch and release" of the hooks and loops.

If the applied force is greater than this frictional force, the resulting net force causes the block to accelerate to the right, and the type of friction force present changes to **kinetic friction**.



The **kinetic frictional force** is the frictional force that acts to slow the motion of an object. The kinetic frictional force is measured as the force required just to keep an object sliding over another object at a constant velocity.

Explaining Friction

If only gently pushed, the block will not slide at all. If pushed hard enough it will slide, but with some resistance. This is friction at work. Friction is similar to Velcro® in some, but definitely not all ways. Instead of hooks and loops doing all of the work (and you need one of each type), with friction, it is the attraction of the atoms of the two surfaces. Essentially the atoms of one surface "see" the atoms of the other surface and try to latch onto them, forming temporary bonds with them (a bit like a hook in a loop). If pulled to the side, they will hold a bit, but eventually will break free, only to form new temporary bonds with other atoms. A little more precisely, it is the positive and negative charges that make up the surfaces that are attracting each other. For this reason, the **force of friction** can be identified as being an example of the **electromagnetic fundamental force**.

Notice that there will be absolutely no force of friction acting on a block that has been merely placed onto a surface. In terms of Velcro®, it is not enough for the hooks to be caught in loops—it is the stretching of them that produces the force! For this reason, friction can be described as being a **responsive force**: it only exists when responding to a condition, such as the attempt to stretch or break the temporary bonds between the two surfaces.

Factors Affecting the Force of Friction

The available strength of the force of friction depends on two things:

- How slippery (or not) the types of surfaces involved are (e.g., "rubber on concrete" or "rubber on ice")
- How firmly these two surfaces are pressing into each other

Numerically, we use a value that is called the **coefficient of friction** to represent how "unslippery" the surfaces are. Note that we are saying "unslippery" here because the bigger this number is, the less slippery they are—a coefficient of friction of zero would be perfectly slippery (no friction at all). We use the symbol μ (the Greek letter "mu") to represent the coefficient of friction. As for the second point, we already have a name for "how firmly these two surfaces are pressing into each other": the normal force (F_N). This may not at first be obvious, but on thinking it through it should be clearer.

We usually think of the normal force as a "support force," but it is really more than just that. Try this to see if it helps: put your right hand in the air, palm up. Now place your left hand, palm down onto your right hand (so that the palms are together). Your left hand has two forces acting on it: the downward force of gravity (its weight) and the upward normal force (support from your right hand). Clearly, the normal force discussed here is the force that your right hand is applying to your left hand.

By Newton's Third Law, this means that your left hand is necessarily exerting the same size force onto your right hand. You can vary the size of these forces by actively pressing your hands together or relaxing them. You are in fact varying "how firmly these two surfaces are pressing into each other"—the normal force!

The Equation for Friction

The equation for the friction force is pretty easy, but there are complications that we will discuss shortly. Basically, the force of friction is the product of the coefficient of friction (μ) and the normal force (F_N):

Force of Friction: The magnitude of the **force of friction** acting at the surface between two objects is the product of the coefficient of friction for that surface and the magnitude of the normal force. The force of friction has a direction so as to prevent or oppose surfaces from slipping.

$$F_F = \mu F_N$$

Quantity	Symbol	SI Unit
Force of friction	F_S	N (newton)
Coefficient of friction	μ	none (coefficients of friction are unitless)
Normal force	F_N	N (newton)

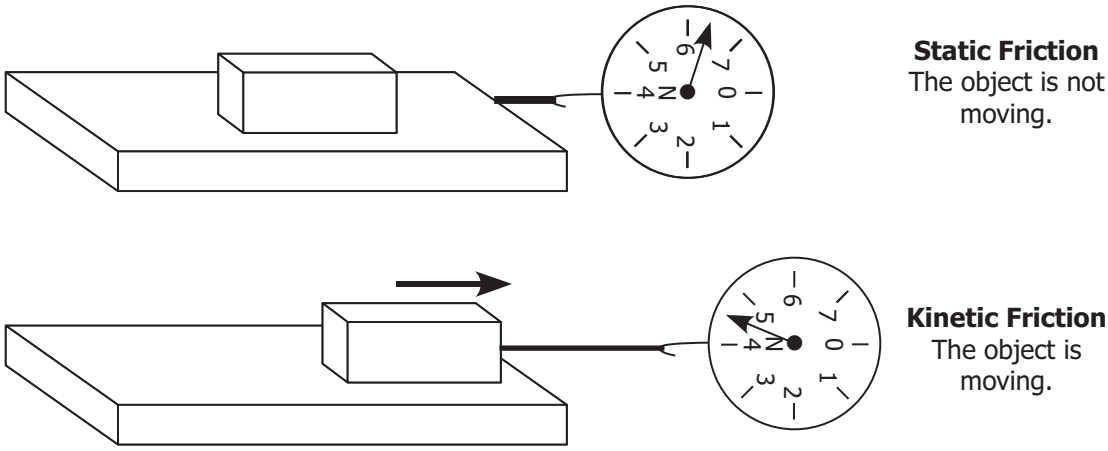
Note: The vector notations for the two forces are omitted, since the two forces act perpendicularly to each other.

First complication: The little vector arrows for force were not forgotten! They are not supposed to be in this equation, as it is an equation that only deals with magnitude. The force of friction is a vector (as all forces are), but the direction is something that you have to figure out based on the situation—not the equation. It isn't very hard, as the force of friction always acts to prevent or oppose surfaces from slipping.

Second complication: As discussed above, the force of friction is a responsive force: its size depends on what is happening (are the temporary bonds relaxed or stretched?). This means that the force of friction can be less than the value calculated from the equation. In fact, the equation is sometimes written $F_F^{max} = \mu F_N$ to remind us of this.

How do you know if the force of friction is less than the maximum value? Quite simply actually: remember that the force of friction will never cause surfaces to slide. If the value for the force of friction determined from the equation $F_F = \mu F_N$ suggests that an object will start sliding in the direction of the force of friction, then the friction force is less—only enough to hold it from sliding. You saw this in the example above for static friction.

Third and final complication: It can make a difference whether the surfaces are presently sliding across each other or not, so much so that we actually name the two possibilities. We use the term **static friction** when the surfaces are not sliding against each other, and **kinetic friction** for when they are.



For the same surfaces, static friction is larger than kinetic friction.

The reason for this distinction is that the available **strength of friction** depends on **whether or not sliding is happening**. Generally, **static friction is stronger than kinetic friction**, as there are a larger number of temporary bonds when they are held together than when the surfaces are sliding with the bonds coming and going. This means that for any pair of surfaces, there are actually t**wo different values** for the **coefficient of friction**: one for **static friction** (μ_s) and one for **kinetic friction** (μ_k). If given both values (μ_s and μ_k), you must choose which **one** to use in the equation, based on whether or not the surfaces are sliding (which you may actually have to determine first, calculating the maximum available static friction). When only one value for μ is given in a problem, we assume that the given value for μ represents both μ_s and μ_k.

The values for the coefficients of friction are determined experimentally.

Solving the above equation for the coefficient of friction, we get $\mu = \frac{F_f}{F_N}$.

> The **coefficient of friction** is the ratio of frictional force to the normal force between two object surfaces.

Actually measuring the sizes of these two forces would allow you to calculate the value for the coefficient of friction. The coefficient of friction does not have a unit, since it is a ratio of two forces (the unit would be N/N which cancels out). It does depend on the types of surface involved (wood on snow, rubber on asphalt, etc.), the condition of the surface (polished, lubricated, etc.), and other variables such as the temperature. Typical values of μ range from about 0.01 for slippery surfaces (0 for perfectly slippery or "frictionless") to about 1.5 for rough surfaces.

Coefficients of Friction		
Surfaces	**Static Friction**	**Kinetic Friction**
Steel on steel (dry)	0.6	0.4
Steel on steel (greasy)	0.1	0.05
Teflon on steel	0.041	0.04
Brake lining on cast iron	0.4	0.3
Rubber tires on dry pavement	0.9	0.8
Metal on ice	0.022	0.02
Rubber tip of crutch on rough wood	0.7	—

Factors Affecting the Magnitude of the Force of Friction

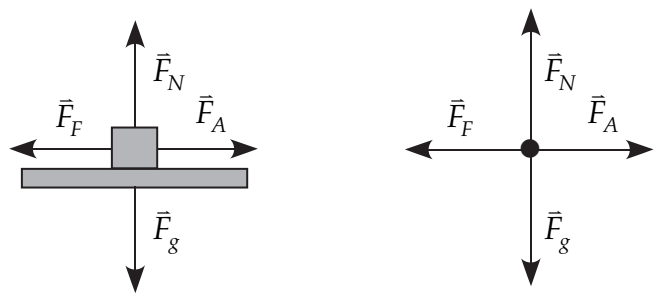
Experiments show that the maximum static frictional force between a pair of dry surfaces is **independent of the area of contact between the objects**. For instance, the maximum static frictional force that the surface of a table can exert on a block is the same whether the block is resting on its smallest side or its largest side (convince yourself of this, by simply trying to drag a book in these two ways). Similarly, the force of kinetic friction is **independent of the speed** at which the sliding takes place.

Example 1: Determining the Maximum Force of Static Friction

As an example of finding the maximum static frictional force, let us look at the example of a sled at rest on a horizontal spot of snow. A reasonable coefficient of static friction in this situation would be $\mu_s = 0.350$. Assume that the sled and the child have a total mass of 40.0 kg. Determine the horizontal force that a person would need to use to start the sled moving. Assume that this horizontal force is applied parallel to the surface of the ground.

In order to get the sled moving, a sufficient amount of force is needed to overcome the maximum force of static friction.

A free-body diagram for this situation might look as follows:



Notice in this situation that the applied force and the force of static friction are equal in magnitude but opposite in direction. Notice also that the gravitational force and the normal force are also equal in magnitude but opposite in direction.

Since the normal force in this case is equal in magnitude to the gravitational force, we can determine the value of the normal force:

$$\vec{F}_N = m\vec{g} = (40.0\text{ kg})(9.80\text{ N/kg}) = 392\text{ N}$$

Given:	Coefficient of static friction	$\mu_s = 0.350$
	Mass	$m = 40.0$ kg
	Gravitational field intensity	$\vec{g} = 9.80\text{ N/kg [down]}$
	Normal force	$\vec{F}_N = 392\text{ N [up]}$
Unknown:	Applied force	$\vec{F}_A = ?$
Equation:		Applied force is equal but opposite to the force of static friction. $\vec{F}_A = -\vec{F}_F$ $F_F = \mu_s F_N$

Substitute and solve:

$$F_F = \mu_s F_N$$
$$F_F = (0.350)(392\ \text{N})$$
$$F_F = 137\ \text{N}$$

The maximum force of static friction is 137 N. Therefore, you must exert an applied force of 137 N.

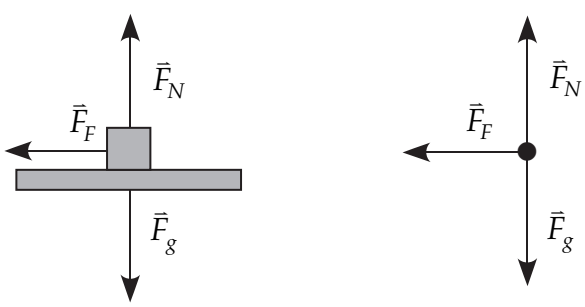
Example 2: Kinetic Friction

A sled with mass 40.0 kg is moving initially at 4.00 m/s to the right along a horizontal stretch of snow when all of a sudden the applied force is completely removed. The coefficient of kinetic friction is μ = 0.0500. Determine how far the sled will move before it stops.

To solve this problem, we need to realize that the reason the sled comes to a stop is that friction between the sled and the snow causes an acceleration in the opposite direction that it is moving in. Using Newton's Second Law, we can first determine the acceleration of the sled. Knowing the acceleration, we can then determine the distance the sled travels by using kinematics.

Dynamics

The free-body diagram for this situation might look like the following. Note that since the sled moves right, the force of friction must be to the left, opposing the slide.



Right is positive

Given:	Mass	$m = 40.0\ \text{kg}$
	Coefficient of kinetic friction	$\mu_k = 0.0500$
	Force of gravity	$\vec{F}_g = m\vec{g} = (40.0\ \text{kg})(9.80\ \text{N/kg})$
		$= 392\ \text{N}\ [\text{down}]$
	Normal force	$\vec{F}_N = 392\ \text{N}\ [\text{up}]$
Unknown:	Net force	$\vec{F}_{\text{NET}} = ?$
Equation:		$\vec{F}_{\text{NET}} = \vec{F}_F = \mu_k F_N$
Substitute and solve:		$\vec{F}_{\text{NET}} = \vec{F}_F = (0.0500)(392\ \text{N}) = 19.6\ [\text{left}]$

Newton's Second Law

$\vec{F}_{\text{NET}} = m\vec{a}$ rearranged to $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$

$$\vec{a} = \frac{-19.6\ \text{N}}{40.0\ \text{kg}} = -0.490\ \text{m/s}^2$$

Kinematics

Given:	Acceleration	$\vec{a} = -0.490\ \text{m/s}^2$
	Initial velocity	$\vec{v}_1 = +4.00\ \text{m/s}$
	Final velocity	$\vec{v}_2 = 0\ \text{m/s}$
Unknown:	Displacement	$\vec{d} = ?$
Equation:		$v_2^2 = v_1^2 + 2ad$ rearranged to $d = \dfrac{v_2^2 - v_1^2}{2a}$
Substitute and solve:		$d = \dfrac{v_2^2 - v_1^2}{2a} = \dfrac{(0\ \text{m/s})^2 - (+4.00\ \text{m/s})}{2(-0.490\ \text{m/s}^2)}$
		$= \dfrac{-16.0\ \text{m}^2/\text{s}^2}{-0.980\ \text{m/s}^2} = +16.3\ \text{m}$

The sled moves 16.3 m to the right before it comes to a stop.

Learning Activity 4.6

Friction

An answer key is available at the end of the module for you to check your answers after you have completed the practice questions.

1. Suppose that the coefficient of static friction is μ_s = 1.0 and the coefficient of kinetic friction is μ_k = 0.50 for a rectangular box at rest on a rough surface. Is it possible to say that the magnitude of the static frictional force for the box at rest is twice the magnitude of the kinetic frictional force acting on the moving crate?

2. In attempting to push a freezer, a person uses a force of 270 N. But the freezer does not move. What must be the force of static friction that the floor exerts on the freezer?

3. A block of weight 50.0 N rests on a horizontal surface. A horizontal force of 40.0 N is applied to the block. The coefficient of static friction is 0.650 and the coefficient of kinetic friction is 0.420. Explain whether or not the block moves. If it does move, what will its acceleration be?

4. Imagine being on an airplane in flight. You have a cup of tea on a table in front of you. The plane then starts to accelerate at the same altitude it initially had. The coefficient of static friction between the cup and the table is 0.250. What is the maximum acceleration of the plane before the cup begins to slide on the table?

Lesson Summary

Static friction can be defined as a force that opposes the start of motion between two surfaces.

The frictional force is equal in magnitude to the applied force and opposite in direction.

If the applied force increases again by a small amount, the force of static friction increases by the same amount and the block does not move. The frictional force is equal in magnitude to the applied force and opposite in direction.

If the applied force continues to increase, there is a point where the block finally "breaks away" and starts to move.

The maximum static frictional force is independent of the area of contact between the objects, provided that the surfaces are hard and non-deformable. The maximum static frictional force is proportional to the magnitude of the normal force $\left(\vec{F}_N\right)$. This in turn is dependent on the mass of the object.

We can define the **coefficient of static friction** as the ratio of the maximum static frictional force and the normal force.

$$\mu_s = \frac{\vec{F}_S^{\text{MAX}}}{\vec{F}_N}$$

Kinetic friction can be defined as a force that opposes the motion between two surfaces that are moving relative to each other.

The kinetic force of friction is independent of the area of contact between the surfaces of the materials (as was the case with static friction). The kinetic force of friction does not depend on the speed of the sliding motion if the speed is small. Lastly, the magnitude of the kinetic force of friction is proportional to the magnitude of the normal force (as was the case with static friction).

The **coefficient of kinetic friction** can be defined as the ratio of the kinetic frictional force and the normal force.

$$\mu_k = \frac{\vec{F}_F}{\vec{F}_N}$$

NOTES

Assignment 4.3, Part B

Friction (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 3 and Module 4, after you have completed Module 4.

A baseball player of mass 80.0 kg slides into home base. The coefficient of kinetic friction between the player and the ground is 0.610.

a) What is the magnitude of the frictional force? (In solving this part of the question, draw a free-body diagram with all of the forces labelled. Use a dot to represent the baseball player. Also, assume the player is moving to the right while sliding.)

(continued)

Assignment 4.3, Part B: Friction (continued)

b) If the player comes to rest after 1.50 s, what must have been the initial speed of the player?

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for vectors drawn in the correct directions
- 1 mark for labelling the vectors correctly
- 1 mark for determining the correct force of friction
- 1 mark for determining the acceleration
- 1 mark for determining the velocity

Module 4 Summary

Congratulations on completing Module 4.

Submitting Your Assignments

It is now time for you to submit Assignments 3.1 and 3.2 from Module 3 and Assignments 4.1 to 4.3 from Module 4 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 3 and Module 4 assignments and organize your material in the following order:

- Modules 3 and 4 Cover Sheet (found at the end of the course Introduction)
- Assignment 3.1: Video Laboratory Activity: Dynamics
- Assignment 3.2, Part A: Free-Body Diagrams
- Assignment 3.2, Part B: Dynamics and Kinematics
- Assignment 3.2, Part C: The Vector Nature of Newton's Second Law
- Assignment 4.1, Part A: Gravitational Fields
- Assignment 4.1, Part B: Mass, Weight, and Weightlessness
- Assignment 4.2: Laboratory Activity: Determining Acceleration Due to Gravity
- Assignment 4.3, Part A: Free Fall
- Assignment 4.3, Part B: Friction

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

You are now ready to start Module 5.

NOTES

Grade 11 Physics (30S)

Module 4: Gravitational Fields

Learning Activity Answer Keys

MODULE 4: GRAVITATIONAL FIELDS

Learning Activity 4.1: Weight and Mass

1. What is weight?

   Answer:

   Weight is the force of gravity acting on an object. Weight is measured using a scale in units of newton.

2. Would your weight be the same on the surface of every planet in our solar system? Explain your answer.

   Answer:

   Your weight would vary from the surface of one planet to the next in the solar system. The reason for this is that weight is calculated using "force of gravity equals mass times gravitational field intensity." The mass of an object does not change from location to location. However, at the surface of each planet, the gravitational field intensity will be different, resulting in a different weight.

3. An astronaut has a mass 85.2 kg. What is the gravitational field intensity on the surface of a planet where the weight of the astronaut is 542 N towards the centre of the planet?

   Answer:

   Given: Mass $m = 85.2$ kg

   Force of gravity $\vec{F}_g = 542$ N towards the centre of the planet

   Unknown: Gravitational field intensity $\vec{g} = ?$

   Equation: $$\vec{g} = \frac{\vec{F}_g}{m}$$

   Substitute and solve: $$\vec{g} = \frac{542\ \text{N}}{85.2\ \text{kg}} = 6.36\ \text{N/kg}$$

   The gravitational field intensity is 6.36 N/kg towards the centre of the planet.

Learning Activity 4.2: Gravitational Fields

1. A vehicle is being designed for use in exploring the moon's surface and is being tested on earth, where it weighs roughly six times more than it will on the moon. In one test, the acceleration of the vehicle is measured. To achieve the same acceleration on the moon, will the net force acting on the vehicle be greater than, less than, or the same as that required on earth?

   Answer:

   The net force required to accelerate the vehicle is specified by Newton's Second Law as $\vec{F}_{NET} = m\vec{a}$ where m is the vehicle's mass and a is the acceleration. For a given acceleration, the net force depends only on the mass. But the mass is an intrinsic property of the vehicle and is the same on the moon as it is on earth. Therefore, the same net force would be required for a given acceleration on the moon as on earth. Do not be misled by the fact that the vehicle weighs more on earth. The greater weight occurs only because the force of gravity is greater on the earth. Newton's Second Law states that the net force is proportional to the vehicle's mass, not its weight.

2. The gravitational field constant on the surface of Pluto is 0.31 N/kg. What would the gravitational force be on a person of mass 50.0 kg on Pluto?

   Answer:

   The gravitational force would be $\vec{F}_g = m\vec{g}$ = (50.0 kg)(0.31 N/kg) = 15.5 N or 16 N [towards the centre of Pluto].

3. A space traveller whose mass is 115 kg leaves earth. What are his weight and mass

   a) on earth and

      Answer:

      The mass on earth is m = 115 kg. The weight on earth is $\vec{F}_g = m\vec{g}$ = (115 kg)(9.80 m/s^2) = 1.13 x 10^3 N [towards the Earth's centre].

   b) in interplanetary space where there are no nearby planetary objects?

      Answer:

      In interplanetary space, there are no nearby planetary objects. There is virtually no force exerted on the space traveller, so $\vec{g} = 0$. There, the weight $\vec{F}_g = 0$. Since the mass is an intrinsic property of the object and is independent of the location in the universe, the mass of the space traveller is still 115 kg.

4. Describe two methods by which the gravitational field intensity can be measured here at the surface of the earth.

   Answer:

   1. Drop a heavy object such as a bowling ball. Measure the acceleration of the freely falling object. The falling objects must have no force of air friction acting on them. The acceleration of gravity that is measured will be equal to the gravitational field intensity.
   2. Take a known mass. Find the weight of this known mass on a scale. The gravitational field intensity is then just the force of gravity divided by the mass.

5. What are two factors that affect the gravitational field intensity at the surface of the earth? How does each factor affect the value of the gravitational field intensity?

   Answer:

   The two factors are latitude and altitude.

   If latitude is kept constant, then as altitude increases the gravitational field intensity decreases.

   If altitude is kept constant, then as latitude increases the gravitational field intensity increases.

6. Distinguish between the following terms: field, gravitational field, and gravitational field intensity.

   Answer:

   A field is a property of space. An object influences the space around it setting up the field. The field, in turn, exerts a force on other objects located within it.

   A gravitational field is the region in space around a mass where another mass experiences a gravitational force.

   Gravitational field intensity is a measure of the strength of the gravitational field. It is calculated as the force of gravity acting on the unit mass. It has units of N/kg.

7. State two facts about the gravitational field that are given by a diagram of gravitational field lines.

   Answer:

   1. Where the gravitational field lines are closer together, the gravitational field intensity is larger. Where the gravitational field lines are farther apart, the gravitational field intensity is smaller.
   2. At a given point on a gravitational field line, the direction of the gravitational field is tangent to the field line. If the gravitational field line is straight, the gravitational force points along the field line. If the gravitational field line is curved, the gravitational force acting on a mass placed at that point will be in the direction of the tangent line.

Learning Activity 4.3: Mass, Weight, and Weightlessness

1. What is true weightlessness? Under what conditions are objects truly weightless?

   Answer:

   An object is truly weightless when the force of gravity acting on the object at that location is 0 N. It is true that weightlessness occurs at locations where the gravitational field intensity is 0 N/kg.

2. a) What is apparent weightlessness?

   Answer:

   The apparent weight of an object is the same as the normal force acting on an object in a given frame of reference.

   b) When is the apparent weight equal to the true weight of an object?

   Answer:

   The apparent weight of an object equals its true weight when the object is located in a frame of reference that is not accelerating. In these situations, the frame of reference may be motionless or moving with a constant velocity.

   c) When is the apparent weight less than the true weight of an object?

   Answer:

   The apparent weight of an object is less than the true weight when the object is located in a frame of reference that is accelerating downwards.

   d) When is the apparent weight greater than the true weight of an object?

   Answer:

   The apparent weight of an object is the same as the normal force acting on an object in a given frame of reference. The apparent weight is more than the true weight of an object when the object is located in a frame of reference that is accelerating upwards.

3. Distinguish between mass and weight.

   Answer:

   Mass is the amount of matter in a given object. Mass is measured on a balance in units of newtons. Mass is a scalar quantity. Mass does not change when its location is changed. Mass is additive. Mass obeys the law of conservation of mass.

   Weight is the force of gravity acting on an object. Weight is measured on a scale in units of newtons. Weight is a vector quantity.

   Weight is calculated by multiplying the mass of an object by the gravitational field intensity at that location. Weight changes from location to location if the gravitational field intensity changes.

4. A space traveller whose mass is 105 kg leaves earth. What are his weight and mass

   a) on earth, and

      Answer:

      In all cases, let down be the negative direction.

      On earth the gravitational field intensity is –9.80 N/kg.

      The mass on earth is m = 105 kg.

      The weight on earth is $\vec{F}_g = m\vec{g}$ = (105 kg)(–9.80 N/kg) = -1.03×10^3 N.

   b) in interplanetary space where there are no nearby planetary objects?

      Answer:

      In interplanetary space, there are no nearby planetary objects. There is virtually no force exerted on the space traveller so $\vec{g}$ = 0 N/kg. There, the weight is $\vec{F}_g$ = 0 N. Since the mass is an intrinsic property of the object and is independent of the location in the universe, the mass of the space traveller is still 105 kg.

   c) on the moon of a planet where the gravitational field intensity is 2.85 N/kg?

      Answer:

      The mass on earth is m = 105 kg.

      The weight on this moon is $\vec{F}_g = m\vec{g}$ = (105 kg)(–2.85 N/kg) = –299 N.

5. A 75.0 kg person stands in an elevator. What will be the force the elevator exerts on the person in each of the following situations? Give both the real weight and the apparent weight in each case.

Answer:

In all cases, the real weight of the person does not change. It will always be $\vec{F}_g = m\vec{g}$ = (75.0 kg)(–9.80 N/kg) = –735 N. Note that the force of gravity acts downward so a negative sign is used. The magnitude of $\vec{F}_g$ is 735 N.

a) The elevator is at rest.

Answer:

The force the elevator will exert is the normal force.

The net force on the person is $\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$.

When the elevator is at rest, the acceleration is zero.

$\vec{F}_e + \vec{F}_g = 0$ so $\vec{F}_e = -\vec{F}_g = -(-735\text{ N}) = 735\text{ N}$.

In other words, the force of the elevator on the man is equal but opposite in direction to the force of gravity on the person. In this case, the apparent weight is the same as the real weight.

b) The elevator is moving upward with a uniform acceleration of 2.00 m/s^2.

Answer:

When the elevator is accelerating upwards,

$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$

$\vec{F}_N = m\vec{a} - \vec{F}_g = (75.0\text{ kg})(2.00\text{ m/s}^2) - (-735\text{ N}) = +885\text{ N}$.

This is also the apparent weight of the person. The weight appears to be greater because the elevator is accelerating upwards, causing the floor of the elevator to exert a greater upward force on the person.

c) The elevator is moving downward with a uniform acceleration of –2.00 m/s^2.

Answer:

When the elevator is accelerating downwards,

$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$

$\vec{F}_N = m\vec{a} - \vec{F}_g = (75.0\text{ kg})(-2.00\text{ m/s}^2) - (-735\text{ N}) = 585\text{ N}$.

This is also the apparent weight of the person. The weight appears to be less because the elevator is accelerating downwards, causing the floor of the elevator to exert less force on the person.

d) The elevator is moving upward with a uniform velocity of 2.00 m/s.

Answer:

When the elevator is moving at a uniform velocity, there is no acceleration and the net force will be zero. Therefore, the elevator floor will exert a force of 735 N on the person, the same as when the elevator is at rest. The real weight of the person is the same as the apparent weight.

Learning Activity 4.4: Free Fall and Vertical Motion

1. If you were to take a 2.0 kg mass to Venus and used a force scale to find its weight, you would find that the weight is 17.8 N. If you were to lift this mass up from the surface of Venus and drop it, at what rate would it accelerate downwards?

   Answer:

   The gravitational field constant is $\vec{g} = \frac{\vec{F}_g}{m} = \frac{17.8\text{ N}}{2.0\text{ kg}} = 8.9\text{ N/kg}.$

   The magnitude of the gravitational field constant is also equal to the acceleration of the mass due to gravity. This is 8.9 m/s^2. Since the acceleration due to gravity is downwards, we say that $\vec{g}$ = –8.9 m/s^2.

For questions 2, 3, and 4, use $\vec{a} = \vec{g} = 9.80\text{ m/s}^2$ [down] and assume that air friction is negligible.

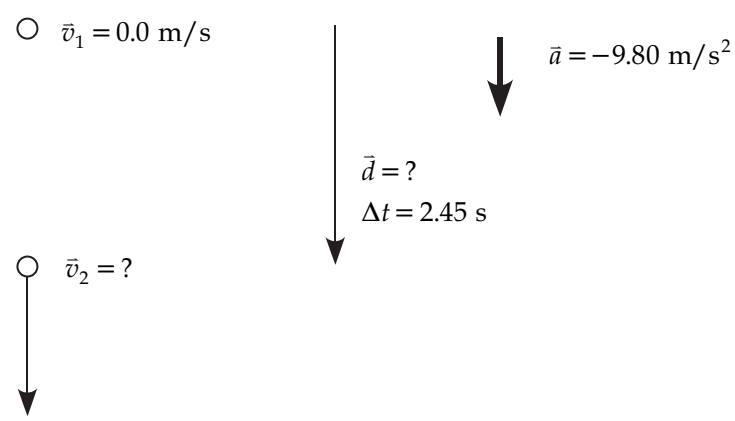
2. A stone is dropped from a bridge to the water below. If it takes 2.45 seconds for the stone to hit the water, calculate the distance that the stone fell.

   Answer:

   The frame of reference will have up as the positive direction and down as the negative direction.

   Assume that the acceleration is –9.80 m/s^2.

   Given:



   Note that the displacement is negative.

   Unknown: Displacement $\vec{d} = ?$

   Equation: Kinematics equation 4 relates the given variables to the displacement.

   $$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}t^2$$

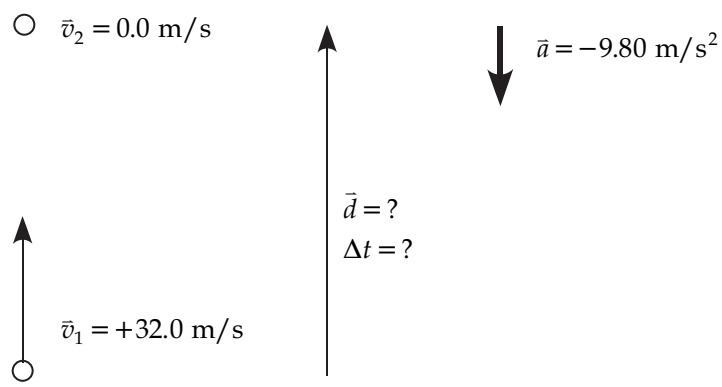
Substitute and solve: $\vec{d} = (0\ \text{m/s})(2.45\ \text{s}) + \frac{1}{2}(-9.80\ \text{m/s}^2)(2.45\ \text{s})^2$

$\vec{d} = -29.4\ \text{m}$

The stone fell –29.4 m.

3. A baseball is thrown straight upwards with a velocity of 32.0 m/s.
   a) What is the time interval from the moment the ball is released until it stops rising at the top of its flight?

   Answer:



The frame of reference will have up as the positive direction and down as the negative direction.

Assume that the acceleration is –9.80 m/s^2. The initial velocity will be positive.

Unknown: Time interval $\Delta t = ?$

Equation: Kinematics equation 2 relates the given information to the time interval.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ rearranged to } \Delta t = \frac{\vec{v}_2 - \vec{v}_1}{\vec{a}}$$

Substitute and solve: $\Delta t = \frac{(0\ \text{m/s}) - (+32.0\ \text{m/s})}{(-9.80\ \text{m/s}^2)}$

$$\Delta t = \frac{-32.0\ \text{m/s}}{(-9.80\ \text{m/s}^2)} = 3.26\ \text{s}$$

The ball reaches the top of its flight after 3.26 s.

b) To what height above the point of release will the ball rise?

The information given is the same as in part (a).

Unknown: Displacement $\vec{d} = ?$

Equation: Kinematics equation 4 relates the given variables to the displacement.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve: $\vec{d} = (+32.0 \text{ m/s})(3.26 \text{ s}) + \frac{1}{2}((-9.80 \text{ m/s}^2)(3.26 \text{ s})^2$

$$\vec{d} = +104 \text{ m} + -52.1 \text{ m} = +51.9 \text{ m} = +52 \text{ m}$$

The ball rises to a height of 52 m above the point of release.

4. Food aid on a skid is dropped from an airplane flying horizontally at 125 m/s. The food skid falls for 18.6 seconds before it hits the ground.

a) Assuming that the initial vertical velocity is 0 m/s, from what height was the food dropped?

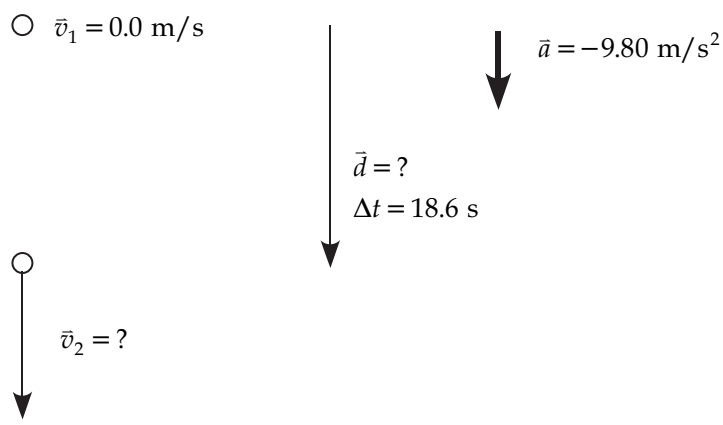
Answer:

This question requires us to use one of the properties of components of the vectors. Even though the food is travelling horizontally, we can treat the vertical motion completely separately. This uses the property of components that components are independent of each other.

The frame of reference will have up as the positive direction and down as the negative direction.

Assume that the acceleration is –9.80 m/s^2.

Given:



Note that the displacement is negative.

Unknown: Displacement $\vec{d} = ?$

Equation: Kinematics equation 4 relates the given variables to the displacement.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve:

$$\vec{d} = (0\ m/s)(18.6\ \text{s}) + \frac{1}{2}(-9.80\ \text{m/s}^2)(18.6\ \text{s})^2$$

$$\vec{d} = -1695\ \text{m}$$

Since the skid fell 1.70 x 10^3 m, the skid was released from a height of 1.70 x 10^3 m.

b) What is its vertical velocity when it strikes the ground?

Answer:

This question uses the same information as part (a).

Unknown: Final velocity $\vec{v}_2 = ?$

Equation: $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$

Substitute and solve:

$$\vec{v}_2 = (0\ \text{m/s}) + (-9.80\ \text{m/s}^2)(18.6\ \text{s})$$

$$\vec{v}_2 = -182\ \text{m/s}$$

The final vertical velocity of the skid is 182 m/s [down].

c) How fast is it travelling horizontally when it strikes the ground?

Answer:

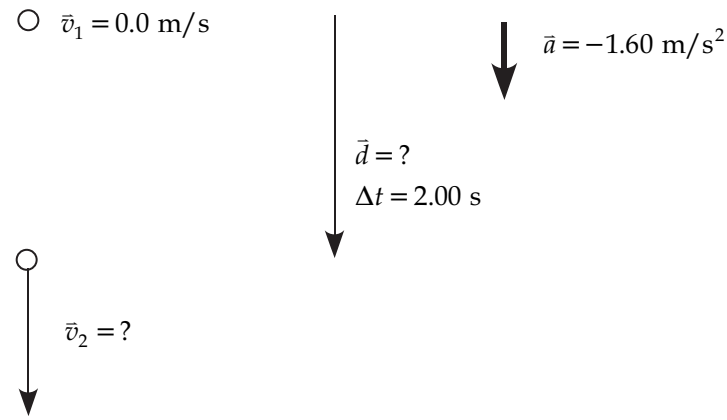
Since we are assuming there's no air friction here, there are no forces in the horizontal direction that will speed up or slow down the food skid. So, by Newton's First Law, the velocity of the food skid should remain constant in the horizontal direction at 125 m/s.

5. The gravitational field constant at the moon's surface is 1.60 N/kg. A moon rock is dropped and falls for a time of 2.00 s.

   a) After falling for this time, what will be the new velocity of the rock?

   Answer:

   Since the gravitational field intensity is 1.60 N/kg on the surface of the moon, the acceleration of gravity at that location will be 1.60 m/s^2 [down] or –1.60 m/s^2.



   Unknown: Final velocity $\vec{v}_2 = ?$

   Equation: $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$

   Substitute and solve: $\vec{v}_2 = (0 \text{ m/s}) + (-1.60 \text{ m/s}^2)(2.00 \text{ s})$

   $\vec{v}_2 = -3.20 \text{ m/s}$

   The final vertical velocity of the moon rock is 3.20 m/s [down].

   b) What distance has the rock fallen?

   Answer:

   The information given is the same as in part (a).

   Unknown: Displacement $\vec{d} = ?$

   Equation: Kinematics equation 3 relates the given variables to the displacement.

   $$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$$

   Substitute and solve: $$\vec{d} = \frac{((0 \text{ m/s}) + (-3.20 \text{ m/s}))}{2}(2.00 \text{ s}) = -3.20 \text{ m}$$

   The moon rock falls 3.20 m [down].

Learning Activity 4.5: Air Resistance and Terminal Velocity

1. What is terminal velocity?

   Answer:

   The terminal velocity of an object is the velocity of a falling object at which the force of air resistance is equal in magnitude to the force of gravity.

2. What factors affect the drag of air resistance as an object falls through the air?

   Answer:

   Factors that affect the drag of air resistance are:

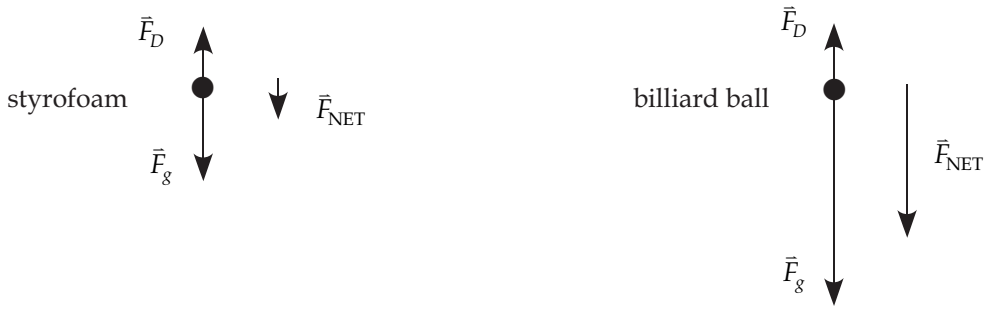
   1. The speed of the object—the faster the object goes, the larger the drag of the air resistance.
   2. The size of the object. If two objects have the same mass, the object with the larger surface area would experience a larger drag of air resistance.

3. Which of the following objects would have a larger terminal velocity: a styrofoam ball or a billiard ball of the same size? Explain.

   Answer:

   The Styrofoam ball and the billiard ball would experience the same drag of air resistance as they fall at the same velocity. Because the Styrofoam ball has a small force of gravity acting on it compared to the billiard ball, which has a larger mass, a smaller velocity is needed by the Styrofoam ball to experience a drag of air friction that will balance the force of gravity on the Styrofoam ball. So the billiard ball will have the larger terminal velocity.

   The diagram below shows both balls shortly after they have begun their fall.



4. Which of the following objects who would have the smaller terminal velocity: a paper coffee filter or the same coffee filter crumpled into a small ball?

   Answer:

   The two objects have the same mass, so they experienced the same force of gravity. The regular coffee filter has a larger surface area than the coffee filter that is crumpled. Therefore, the regular coffee filter will experience a larger drag of air resistance than the crumpled coffee filter at the same velocity. The balance between the force of gravity and the drag of their friction will be achieved at a lower velocity by the regular coffee filter than by the crumpled coffee filter.

   The regular coffee filter will have the smaller terminal velocity.

5. A 1.00 kg ball is allowed to fall through the air. When its downward velocity is –10.3 m/s, the force of air resistance is 3.00 N upwards. What must be the net force on the ball at this moment and what must be the acceleration of the ball?

   Answer:

   The gravitational force is $\vec{F}_g = m\vec{g}$ = (1.00 kg)(–9.80 N/kg) = –9.80 N.

   The net force must be $\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_d$ = 9.80 N + 3.00 N = –6.80 N.

   The acceleration of the ball at this moment is

   $$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{-6.80\ \text{N}}{1.00\ \text{kg}} = -6.80\ \text{m/s}^2.$$

Learning Activity 4.6: Friction

There are four practice questions in this assignment. An answer key is available at the end of the module for you to check your answers after you have completed the practice questions.

1. Suppose that the coefficient of static friction is $\mu_s = 1.0$ and the coefficient of kinetic friction is $\mu_k = 0.50$ for a rectangular box at rest on a rough surface. Is it possible to say that the magnitude of the static frictional force for the box at rest is twice the magnitude of the kinetic frictional force acting on the moving crate?

   Answer:

   We know that the maximum force of static friction is given by $\vec{F}_s^{MAX} = \mu_s\left(\vec{F}_N\right)$ and the force of kinetic friction is given by $\vec{F}_k = \mu_k F_N$.

   The normal force is the same value in both situations. We can conclude that the magnitude of the maximum static force of friction will always be twice that of the kinetic force of friction once the crate has begun moving. But the static frictional force may not always be at its maximum value. Thus, the magnitude of the static frictional force is not always twice the magnitude of the kinetic frictional force.

2. In attempting to push a freezer, a person uses a force of 270 N. But the freezer does not move. What must be the force of static friction that the floor exerts on the freezer?

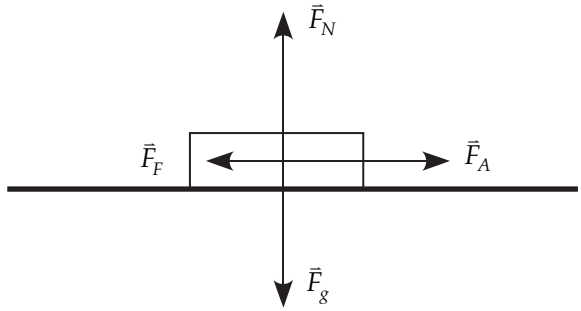
   Answer:

   Since the freezer does not move, the static force of friction must be the same as the applied force. The magnitude of this force is 270 N, but the direction is opposite to the applied force.

3. A block of weight 50.0 N rests on a horizontal surface. A horizontal force of 40.0 N is applied to the block. The coefficient of static friction is 0.650 and the coefficient of kinetic friction is 0.420. Explain whether or not the block moves. If it does move, what will its acceleration be?

   Answer:

   In drawing the free-body diagram, it is not clear at this point if the applied force is larger than the force of static friction. Let us assume for the moment that it is.



The magnitude of the normal force is equal to the weight of the block.

$\vec{F}_N = 50.0\ N$

The maximum value of the static force of friction is

$\vec{F}_S^{\text{MAX}} = \mu_s \vec{F}_N = (0.650)(50.0\ \text{N}) = 32.5\ \text{N}.$

The applied force is 40.0 N. This is greater than the maximum value of the static friction force, so the block does move.

The force of kinetic friction is

$\vec{F}_K = \mu_k F_N = (0.420)(50.0\ \text{N}) = 21.0\ \text{N}$ to the left.

The net force to the right is

$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_K = (40.0\ \text{N [right]}) + (21.0\ \text{N [left]}) = 19.0\ \text{N [right]}.$

To find the acceleration of the block, we need to know its mass.

Use $\vec{F}_g = m\vec{g}$ rearranged to $m = \dfrac{\vec{F}_g}{\vec{g}}$.

$$m = \frac{\vec{F}_G}{\vec{g}} = \frac{50.0\ \text{N}}{9.80\ \text{m/s}^2} = 5.10\ \text{kg}$$

Therefore, the acceleration of the block is

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m}$$

$$\vec{a} = \frac{19.0\ \text{N}\left[\text{right}\right]}{5.10\ \text{kg}} = 3.72\ \text{m/s}^2\ \left[\text{right}\right]$$

4. Imagine being on an airplane in flight. You have a cup of tea on a table in front of you. The plane then starts to accelerate at the same altitude it had initially. The coefficient of static friction between the cup and the table is 0.250. What is the maximum acceleration of the plane before the cup begins to slide on the table?

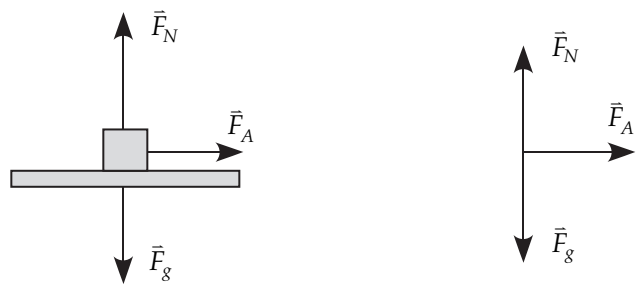
   Answer:

   In a question like this, it might seem that there is not enough information given. It would seem that we need to know the mass. However, in situations like this, an equation can be developed where the mass will cancel out and we can still obtain the answer!

   This force of static friction will be equal to the applied force that is present due to the accelerating airplane and has the value $\vec{F}_A = m\vec{a}$.

   The maximum force of static friction is equal to the applied force.

   The free-body diagram would look like this.



The maximum amount of static friction is $\vec{F}_S^{\text{MAX}} = \mu_s\left(\vec{F}_N\right) = \mu_s m\vec{g}$.

This is equal to the applied force due to the plane, $\vec{F}_A = m\vec{a}$.

$\vec{F}_S^{\text{MAX}} = \vec{F}_A$

$\mu_s m\vec{g} = m\vec{a}$

The mass cancels out.

So the maximum acceleration is $\vec{a} = \mu_s\vec{g} = (0.250)\left(9.80\ \text{m/s}^2\right)$

$= 2.45\ \text{m/s}^2\ [\text{right}]$.

Grade 11 Physics (30S)

Module 4: Gravitational Fields

Learning Activity Answer Keys

MODULE 4: GRAVITATIONAL FIELDS

Learning Activity 4.1: Weight and Mass

1. What is weight?

   Answer:

   Weight is the force of gravity acting on an object. Weight is measured using a scale in units of newton.

2. Would your weight be the same on the surface of every planet in our solar system? Explain your answer.

   Answer:

   Your weight would vary from the surface of one planet to the next in the solar system. The reason for this is that weight is calculated using "force of gravity equals mass times gravitational field intensity." The mass of an object does not change from location to location. However, at the surface of each planet, the gravitational field intensity will be different, resulting in a different weight.

3. An astronaut has a mass 85.2 kg. What is the gravitational field intensity on the surface of a planet where the weight of the astronaut is 542 N towards the centre of the planet?

   Answer:

   Given: Mass $m = 85.2$ kg

   Force of gravity $\vec{F}_g = 542$ N towards the centre of the planet

   Unknown: Gravitational field intensity $\vec{g} = ?$

   Equation: $$\vec{g} = \frac{\vec{F}_g}{m}$$

   Substitute and solve: $$\vec{g} = \frac{542\ \text{N}}{85.2\ \text{kg}} = 6.36\ \text{N/kg}$$

   The gravitational field intensity is 6.36 N/kg towards the centre of the planet.

Learning Activity 4.2: Gravitational Fields

1. A vehicle is being designed for use in exploring the moon's surface and is being tested on earth, where it weighs roughly six times more than it will on the moon. In one test, the acceleration of the vehicle is measured. To achieve the same acceleration on the moon, will the net force acting on the vehicle be greater than, less than, or the same as that required on earth?

   Answer:

   The net force required to accelerate the vehicle is specified by Newton's Second Law as $\vec{F}_{NET} = m\vec{a}$ where m is the vehicle's mass and a is the acceleration. For a given acceleration, the net force depends only on the mass. But the mass is an intrinsic property of the vehicle and is the same on the moon as it is on earth. Therefore, the same net force would be required for a given acceleration on the moon as on earth. Do not be misled by the fact that the vehicle weighs more on earth. The greater weight occurs only because the force of gravity is greater on the earth. Newton's Second Law states that the net force is proportional to the vehicle's mass, not its weight.

2. The gravitational field constant on the surface of Pluto is 0.31 N/kg. What would the gravitational force be on a person of mass 50.0 kg on Pluto?

   Answer:

   The gravitational force would be $\vec{F}_g = m\vec{g}$ = (50.0 kg)(0.31 N/kg) = 15.5 N or 16 N [towards the centre of Pluto].

3. A space traveller whose mass is 115 kg leaves earth. What are his weight and mass

   a) on earth and

      Answer:

      The mass on earth is m = 115 kg. The weight on earth is $\vec{F}_g = m\vec{g}$ = (115 kg)(9.80 m/s^2) = 1.13 x 10^3 N [towards the Earth's centre].

   b) in interplanetary space where there are no nearby planetary objects?

      Answer:

      In interplanetary space, there are no nearby planetary objects. There is virtually no force exerted on the space traveller, so $\vec{g} = 0$. There, the weight $\vec{F}_g = 0$. Since the mass is an intrinsic property of the object and is independent of the location in the universe, the mass of the space traveller is still 115 kg.

4. Describe two methods by which the gravitational field intensity can be measured here at the surface of the earth.

   Answer:

   1. Drop a heavy object such as a bowling ball. Measure the acceleration of the freely falling object. The falling objects must have no force of air friction acting on them. The acceleration of gravity that is measured will be equal to the gravitational field intensity.
   2. Take a known mass. Find the weight of this known mass on a scale. The gravitational field intensity is then just the force of gravity divided by the mass.

5. What are two factors that affect the gravitational field intensity at the surface of the earth? How does each factor affect the value of the gravitational field intensity?

   Answer:

   The two factors are latitude and altitude.

   If latitude is kept constant, then as altitude increases the gravitational field intensity decreases.

   If altitude is kept constant, then as latitude increases the gravitational field intensity increases.

6. Distinguish between the following terms: field, gravitational field, and gravitational field intensity.

   Answer:

   A field is a property of space. An object influences the space around it setting up the field. The field, in turn, exerts a force on other objects located within it.

   A gravitational field is the region in space around a mass where another mass experiences a gravitational force.

   Gravitational field intensity is a measure of the strength of the gravitational field. It is calculated as the force of gravity acting on the unit mass. It has units of N/kg.

7. State two facts about the gravitational field that are given by a diagram of gravitational field lines.

   Answer:

   1. Where the gravitational field lines are closer together, the gravitational field intensity is larger. Where the gravitational field lines are farther apart, the gravitational field intensity is smaller.
   2. At a given point on a gravitational field line, the direction of the gravitational field is tangent to the field line. If the gravitational field line is straight, the gravitational force points along the field line. If the gravitational field line is curved, the gravitational force acting on a mass placed at that point will be in the direction of the tangent line.

Learning Activity 4.3: Mass, Weight, and Weightlessness

1. What is true weightlessness? Under what conditions are objects truly weightless?

   Answer:

   An object is truly weightless when the force of gravity acting on the object at that location is 0 N. It is true that weightlessness occurs at locations where the gravitational field intensity is 0 N/kg.

2. a) What is apparent weightlessness?

   Answer:

   The apparent weight of an object is the same as the normal force acting on an object in a given frame of reference.

   b) When is the apparent weight equal to the true weight of an object?

   Answer:

   The apparent weight of an object equals its true weight when the object is located in a frame of reference that is not accelerating. In these situations, the frame of reference may be motionless or moving with a constant velocity.

   c) When is the apparent weight less than the true weight of an object?

   Answer:

   The apparent weight of an object is less than the true weight when the object is located in a frame of reference that is accelerating downwards.

   d) When is the apparent weight greater than the true weight of an object?

   Answer:

   The apparent weight of an object is the same as the normal force acting on an object in a given frame of reference. The apparent weight is more than the true weight of an object when the object is located in a frame of reference that is accelerating upwards.

3. Distinguish between mass and weight.

   Answer:

   Mass is the amount of matter in a given object. Mass is measured on a balance in units of newtons. Mass is a scalar quantity. Mass does not change when its location is changed. Mass is additive. Mass obeys the law of conservation of mass.

   Weight is the force of gravity acting on an object. Weight is measured on a scale in units of newtons. Weight is a vector quantity.

   Weight is calculated by multiplying the mass of an object by the gravitational field intensity at that location. Weight changes from location to location if the gravitational field intensity changes.

4. A space traveller whose mass is 105 kg leaves earth. What are his weight and mass

   a) on earth, and

      Answer:

      In all cases, let down be the negative direction.

      On earth the gravitational field intensity is –9.80 N/kg.

      The mass on earth is m = 105 kg.

      The weight on earth is $\vec{F}_g = m\vec{g}$ = (105 kg)(–9.80 N/kg) = -1.03×10^3 N.

   b) in interplanetary space where there are no nearby planetary objects?

      Answer:

      In interplanetary space, there are no nearby planetary objects. There is virtually no force exerted on the space traveller so $\vec{g}$ = 0 N/kg. There, the weight is $\vec{F}_g$ = 0 N. Since the mass is an intrinsic property of the object and is independent of the location in the universe, the mass of the space traveller is still 105 kg.

   c) on the moon of a planet where the gravitational field intensity is 2.85 N/kg?

      Answer:

      The mass on earth is m = 105 kg.

      The weight on this moon is $\vec{F}_g = m\vec{g}$ = (105 kg)(–2.85 N/kg) = –299 N.

5. A 75.0 kg person stands in an elevator. What will be the force the elevator exerts on the person in each of the following situations? Give both the real weight and the apparent weight in each case.

Answer:

In all cases, the real weight of the person does not change. It will always be $\vec{F}_g = m\vec{g}$ = (75.0 kg)(–9.80 N/kg) = –735 N. Note that the force of gravity acts downward so a negative sign is used. The magnitude of $\vec{F}_g$ is 735 N.

a) The elevator is at rest.

Answer:

The force the elevator will exert is the normal force.

The net force on the person is $\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$.

When the elevator is at rest, the acceleration is zero.

$\vec{F}_e + \vec{F}_g = 0$ so $\vec{F}_e = -\vec{F}_g = -(-735\text{ N}) = 735\text{ N}$.

In other words, the force of the elevator on the man is equal but opposite in direction to the force of gravity on the person. In this case, the apparent weight is the same as the real weight.

b) The elevator is moving upward with a uniform acceleration of 2.00 m/s^2.

Answer:

When the elevator is accelerating upwards,

$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$

$\vec{F}_N = m\vec{a} - \vec{F}_g = (75.0\text{ kg})(2.00\text{ m/s}^2) - (-735\text{ N}) = +885\text{ N}$.

This is also the apparent weight of the person. The weight appears to be greater because the elevator is accelerating upwards, causing the floor of the elevator to exert a greater upward force on the person.

c) The elevator is moving downward with a uniform acceleration of –2.00 m/s^2.

Answer:

When the elevator is accelerating downwards,

$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$

$\vec{F}_N = m\vec{a} - \vec{F}_g = (75.0\text{ kg})(-2.00\text{ m/s}^2) - (-735\text{ N}) = 585\text{ N}$.

This is also the apparent weight of the person. The weight appears to be less because the elevator is accelerating downwards, causing the floor of the elevator to exert less force on the person.

d) The elevator is moving upward with a uniform velocity of 2.00 m/s.

Answer:

When the elevator is moving at a uniform velocity, there is no acceleration and the net force will be zero. Therefore, the elevator floor will exert a force of 735 N on the person, the same as when the elevator is at rest. The real weight of the person is the same as the apparent weight.

Learning Activity 4.4: Free Fall and Vertical Motion

1. If you were to take a 2.0 kg mass to Venus and used a force scale to find its weight, you would find that the weight is 17.8 N. If you were to lift this mass up from the surface of Venus and drop it, at what rate would it accelerate downwards?

   Answer:

   The gravitational field constant is $\vec{g} = \frac{\vec{F}_g}{m} = \frac{17.8\text{ N}}{2.0\text{ kg}} = 8.9\text{ N/kg}.$

   The magnitude of the gravitational field constant is also equal to the acceleration of the mass due to gravity. This is 8.9 m/s^2. Since the acceleration due to gravity is downwards, we say that $\vec{g}$ = –8.9 m/s^2.

For questions 2, 3, and 4, use $\vec{a} = \vec{g} = 9.80\text{ m/s}^2$ [down] and assume that air friction is negligible.

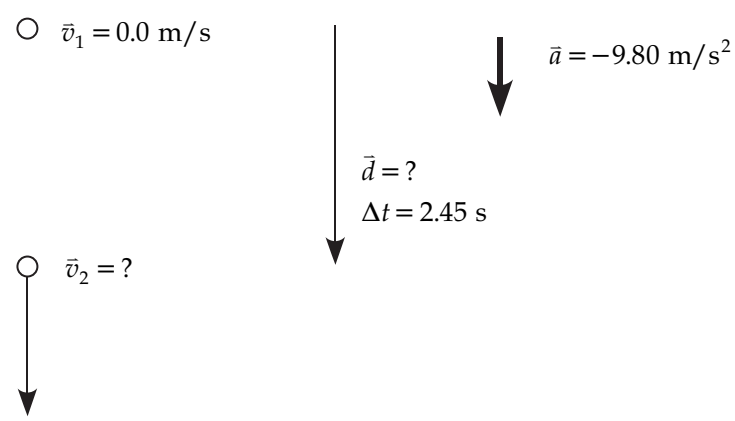
2. A stone is dropped from a bridge to the water below. If it takes 2.45 seconds for the stone to hit the water, calculate the distance that the stone fell.

   Answer:

   The frame of reference will have up as the positive direction and down as the negative direction.

   Assume that the acceleration is –9.80 m/s^2.

   Given:



   Note that the displacement is negative.

   Unknown: Displacement $\vec{d} = ?$

   Equation: Kinematics equation 4 relates the given variables to the displacement.

   $$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}t^2$$

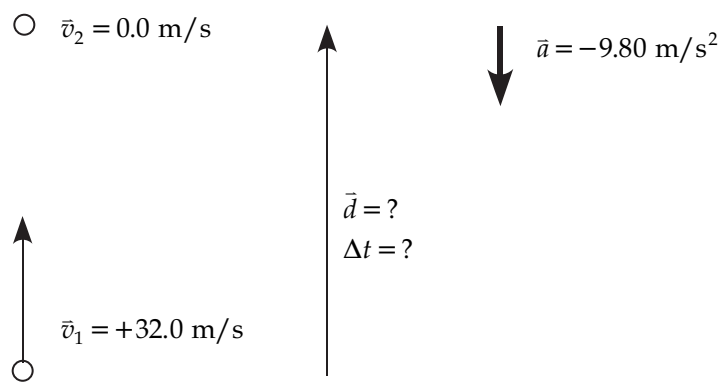
Substitute and solve: $\vec{d} = (0\ \text{m/s})(2.45\ \text{s}) + \frac{1}{2}(-9.80\ \text{m/s}^2)(2.45\ \text{s})^2$

$\vec{d} = -29.4\ \text{m}$

The stone fell –29.4 m.

3. A baseball is thrown straight upwards with a velocity of 32.0 m/s.
   a) What is the time interval from the moment the ball is released until it stops rising at the top of its flight?

   Answer:



The frame of reference will have up as the positive direction and down as the negative direction.

Assume that the acceleration is –9.80 m/s^2. The initial velocity will be positive.

Unknown: Time interval $\Delta t = ?$

Equation: Kinematics equation 2 relates the given information to the time interval.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ rearranged to } \Delta t = \frac{\vec{v}_2 - \vec{v}_1}{\vec{a}}$$

Substitute and solve: $\Delta t = \frac{(0\ \text{m/s}) - (+32.0\ \text{m/s})}{(-9.80\ \text{m/s}^2)}$

$$\Delta t = \frac{-32.0\ \text{m/s}}{(-9.80\ \text{m/s}^2)} = 3.26\ \text{s}$$

The ball reaches the top of its flight after 3.26 s.

b) To what height above the point of release will the ball rise?

The information given is the same as in part (a).

Unknown: Displacement $\vec{d} = ?$

Equation: Kinematics equation 4 relates the given variables to the displacement.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve: $\vec{d} = (+32.0 \text{ m/s})(3.26 \text{ s}) + \frac{1}{2}((-9.80 \text{ m/s}^2)(3.26 \text{ s})^2$

$$\vec{d} = +104 \text{ m} + -52.1 \text{ m} = +51.9 \text{ m} = +52 \text{ m}$$

The ball rises to a height of 52 m above the point of release.

4. Food aid on a skid is dropped from an airplane flying horizontally at 125 m/s. The food skid falls for 18.6 seconds before it hits the ground.

a) Assuming that the initial vertical velocity is 0 m/s, from what height was the food dropped?

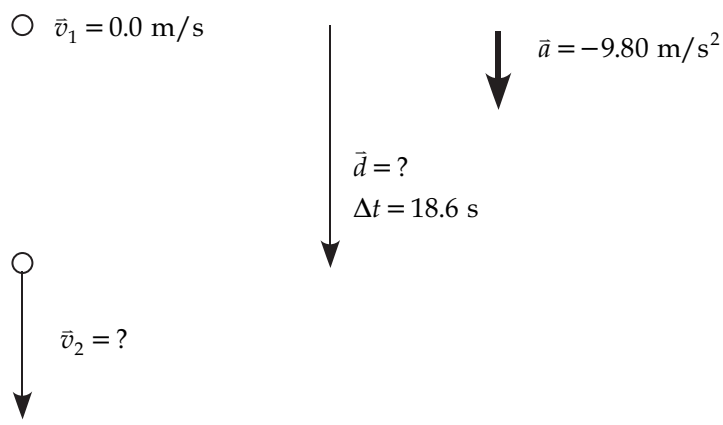
Answer:

This question requires us to use one of the properties of components of the vectors. Even though the food is travelling horizontally, we can treat the vertical motion completely separately. This uses the property of components that components are independent of each other.

The frame of reference will have up as the positive direction and down as the negative direction.

Assume that the acceleration is –9.80 m/s^2.

Given:



Note that the displacement is negative.

Unknown: Displacement $\vec{d} = ?$

Equation: Kinematics equation 4 relates the given variables to the displacement.

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

Substitute and solve:

$$\vec{d} = (0\ m/s)(18.6\ \text{s}) + \frac{1}{2}(-9.80\ \text{m/s}^2)(18.6\ \text{s})^2$$

$$\vec{d} = -1695\ \text{m}$$

Since the skid fell 1.70 x 10^3 m, the skid was released from a height of 1.70 x 10^3 m.

b) What is its vertical velocity when it strikes the ground?

Answer:

This question uses the same information as part (a).

Unknown: Final velocity $\vec{v}_2 = ?$

Equation: $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$

Substitute and solve:

$$\vec{v}_2 = (0\ \text{m/s}) + (-9.80\ \text{m/s}^2)(18.6\ \text{s})$$

$$\vec{v}_2 = -182\ \text{m/s}$$

The final vertical velocity of the skid is 182 m/s [down].

c) How fast is it travelling horizontally when it strikes the ground?

Answer:

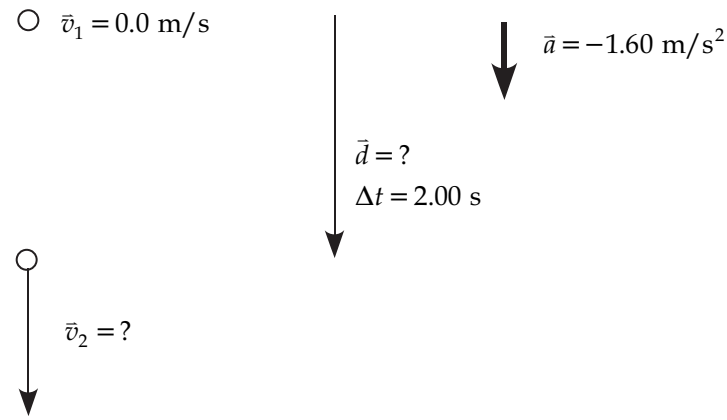
Since we are assuming there's no air friction here, there are no forces in the horizontal direction that will speed up or slow down the food skid. So, by Newton's First Law, the velocity of the food skid should remain constant in the horizontal direction at 125 m/s.

5. The gravitational field constant at the moon's surface is 1.60 N/kg. A moon rock is dropped and falls for a time of 2.00 s.

   a) After falling for this time, what will be the new velocity of the rock?

   Answer:

   Since the gravitational field intensity is 1.60 N/kg on the surface of the moon, the acceleration of gravity at that location will be 1.60 m/s^2 [down] or –1.60 m/s^2.



   Unknown: Final velocity $\vec{v}_2 = ?$

   Equation: $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$

   Substitute and solve: $\vec{v}_2 = (0 \text{ m/s}) + (-1.60 \text{ m/s}^2)(2.00 \text{ s})$

   $\vec{v}_2 = -3.20 \text{ m/s}$

   The final vertical velocity of the moon rock is 3.20 m/s [down].

   b) What distance has the rock fallen?

   Answer:

   The information given is the same as in part (a).

   Unknown: Displacement $\vec{d} = ?$

   Equation: Kinematics equation 3 relates the given variables to the displacement.

   $$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$$

   Substitute and solve: $$\vec{d} = \frac{((0 \text{ m/s}) + (-3.20 \text{ m/s}))}{2}(2.00 \text{ s}) = -3.20 \text{ m}$$

   The moon rock falls 3.20 m [down].

Learning Activity 4.5: Air Resistance and Terminal Velocity

1. What is terminal velocity?

   Answer:

   The terminal velocity of an object is the velocity of a falling object at which the force of air resistance is equal in magnitude to the force of gravity.

2. What factors affect the drag of air resistance as an object falls through the air?

   Answer:

   Factors that affect the drag of air resistance are:

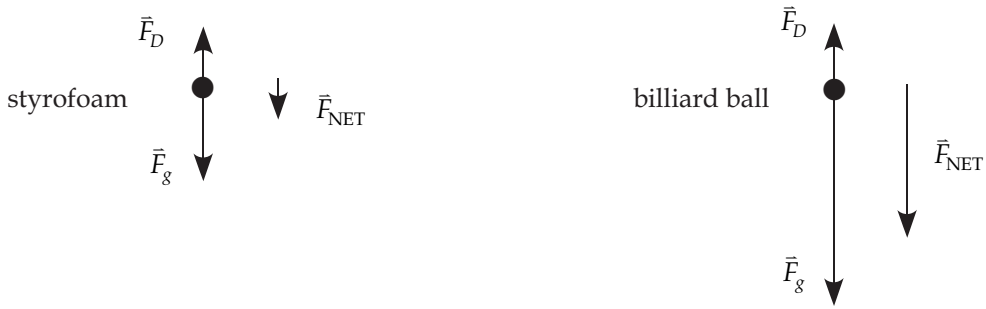
   1. The speed of the object—the faster the object goes, the larger the drag of the air resistance.
   2. The size of the object. If two objects have the same mass, the object with the larger surface area would experience a larger drag of air resistance.

3. Which of the following objects would have a larger terminal velocity: a styrofoam ball or a billiard ball of the same size? Explain.

   Answer:

   The Styrofoam ball and the billiard ball would experience the same drag of air resistance as they fall at the same velocity. Because the Styrofoam ball has a small force of gravity acting on it compared to the billiard ball, which has a larger mass, a smaller velocity is needed by the Styrofoam ball to experience a drag of air friction that will balance the force of gravity on the Styrofoam ball. So the billiard ball will have the larger terminal velocity.

   The diagram below shows both balls shortly after they have begun their fall.



4. Which of the following objects who would have the smaller terminal velocity: a paper coffee filter or the same coffee filter crumpled into a small ball?

   Answer:

   The two objects have the same mass, so they experienced the same force of gravity. The regular coffee filter has a larger surface area than the coffee filter that is crumpled. Therefore, the regular coffee filter will experience a larger drag of air resistance than the crumpled coffee filter at the same velocity. The balance between the force of gravity and the drag of their friction will be achieved at a lower velocity by the regular coffee filter than by the crumpled coffee filter.

   The regular coffee filter will have the smaller terminal velocity.

5. A 1.00 kg ball is allowed to fall through the air. When its downward velocity is –10.3 m/s, the force of air resistance is 3.00 N upwards. What must be the net force on the ball at this moment and what must be the acceleration of the ball?

   Answer:

   The gravitational force is $\vec{F}_g = m\vec{g}$ = (1.00 kg)(–9.80 N/kg) = –9.80 N.

   The net force must be $\vec{F}_{\text{NET}} = \vec{F}_g + \vec{F}_d$ = 9.80 N + 3.00 N = –6.80 N.

   The acceleration of the ball at this moment is

   $$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{-6.80\ \text{N}}{1.00\ \text{kg}} = -6.80\ \text{m/s}^2.$$

Learning Activity 4.6: Friction

There are four practice questions in this assignment. An answer key is available at the end of the module for you to check your answers after you have completed the practice questions.

1. Suppose that the coefficient of static friction is $\mu_s = 1.0$ and the coefficient of kinetic friction is $\mu_k = 0.50$ for a rectangular box at rest on a rough surface. Is it possible to say that the magnitude of the static frictional force for the box at rest is twice the magnitude of the kinetic frictional force acting on the moving crate?

   Answer:

   We know that the maximum force of static friction is given by $\vec{F}_s^{MAX} = \mu_s\left(\vec{F}_N\right)$ and the force of kinetic friction is given by $\vec{F}_k = \mu_k F_N$.

   The normal force is the same value in both situations. We can conclude that the magnitude of the maximum static force of friction will always be twice that of the kinetic force of friction once the crate has begun moving. But the static frictional force may not always be at its maximum value. Thus, the magnitude of the static frictional force is not always twice the magnitude of the kinetic frictional force.

2. In attempting to push a freezer, a person uses a force of 270 N. But the freezer does not move. What must be the force of static friction that the floor exerts on the freezer?

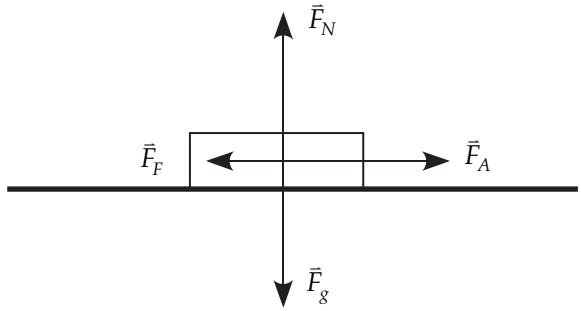
   Answer:

   Since the freezer does not move, the static force of friction must be the same as the applied force. The magnitude of this force is 270 N, but the direction is opposite to the applied force.

3. A block of weight 50.0 N rests on a horizontal surface. A horizontal force of 40.0 N is applied to the block. The coefficient of static friction is 0.650 and the coefficient of kinetic friction is 0.420. Explain whether or not the block moves. If it does move, what will its acceleration be?

   Answer:

   In drawing the free-body diagram, it is not clear at this point if the applied force is larger than the force of static friction. Let us assume for the moment that it is.



The magnitude of the normal force is equal to the weight of the block.

$\vec{F}_N = 50.0\ N$

The maximum value of the static force of friction is

$\vec{F}_S^{\text{MAX}} = \mu_s \vec{F}_N = (0.650)(50.0\ \text{N}) = 32.5\ \text{N}.$

The applied force is 40.0 N. This is greater than the maximum value of the static friction force, so the block does move.

The force of kinetic friction is

$\vec{F}_K = \mu_k F_N = (0.420)(50.0\ \text{N}) = 21.0\ \text{N}$ to the left.

The net force to the right is

$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_K = (40.0\ \text{N [right]}) + (21.0\ \text{N [left]}) = 19.0\ \text{N [right]}.$

To find the acceleration of the block, we need to know its mass.

Use $\vec{F}_g = m\vec{g}$ rearranged to $m = \dfrac{\vec{F}_g}{\vec{g}}$.

$$m = \frac{\vec{F}_G}{\vec{g}} = \frac{50.0\ \text{N}}{9.80\ \text{m/s}^2} = 5.10\ \text{kg}$$

Therefore, the acceleration of the block is

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m}$$

$$\vec{a} = \frac{19.0\ \text{N}\left[\text{right}\right]}{5.10\ \text{kg}} = 3.72\ \text{m/s}^2\ \left[\text{right}\right]$$

4. Imagine being on an airplane in flight. You have a cup of tea on a table in front of you. The plane then starts to accelerate at the same altitude it had initially. The coefficient of static friction between the cup and the table is 0.250. What is the maximum acceleration of the plane before the cup begins to slide on the table?

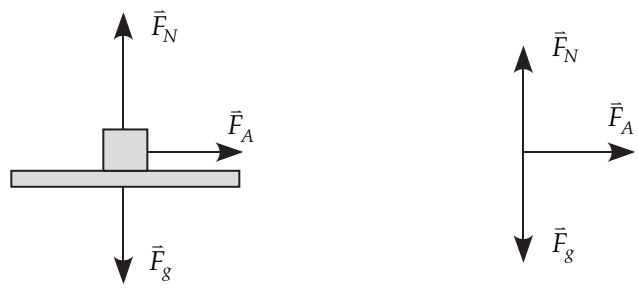
   Answer:

   In a question like this, it might seem that there is not enough information given. It would seem that we need to know the mass. However, in situations like this, an equation can be developed where the mass will cancel out and we can still obtain the answer!

   This force of static friction will be equal to the applied force that is present due to the accelerating airplane and has the value $\vec{F}_A = m\vec{a}$.

   The maximum force of static friction is equal to the applied force.

   The free-body diagram would look like this.



The maximum amount of static friction is $\vec{F}_S^{\text{MAX}} = \mu_s\left(\vec{F}_N\right) = \mu_s m\vec{g}$.

This is equal to the applied force due to the plane, $\vec{F}_A = m\vec{a}$.

$\vec{F}_S^{\text{MAX}} = \vec{F}_A$

$\mu_s m\vec{g} = m\vec{a}$

The mass cancels out.

So the maximum acceleration is $\vec{a} = \mu_s\vec{g} = (0.250)\left(9.80\ \text{m/s}^2\right)$

$= 2.45\ \text{m/s}^2\ [\text{right}]$.

Topic 2 - Audio/Videos

Module 4

1. Gravitational Field Introduction
    a. This video uses the concept that the force of gravity acting on an object is given by
    b. Force of gravity = (mass of the object)(gravitational field intensity) or
    c. Fg = mo g.
    d. Then gravitational field intensity = (Force of gravity) / (mass of the object) or g = Fg / mo.
    e. Gravitational field lines are introduced to represent the concept of the strength and direction of a constant gravitational field at the Earth's surface and the strength and direction of a non-constant gravitational field far from the Earth's surface.
2. Weight and Mass are Not the Same
3. Would you weigh less in an elevator? - Carol Hedden
4. Do You Feel Your Weight?
    a. Weight is introduced as the force of gravity. Weight though is measured by standing on a scale. What we feel as our weight is the normal force of the scale (or whatever we are standing on).
    b. Our weight does not change. What we feel as our weight can change (heavier than normal or lighter than normal). If we stand on a scale in an elevator we can feel heavier than normal when the elevator accelerates upwards, lighter than normal when the elevator accelerates downwards, or normal when the elevator is not accelerating.
    c. What we feel as our weight (the apparent weight) is the normal force of the scale pushing up on us.
5. Elevator Ride
    a. This interactive activity illustrates when a person riding in an elevator experiences having a normal weight or feel lighter than normal or feels heavier than normal.
    b. A free body diagram located by the passenger shows the force of gravity and the normal force acting on the passenger. Using the values for these forces determine the net force when the passenger experiences having a normal weight or feel lighter than normal or feels heavier than normal.
6. Video 222 - Calculating Gravity using a Pendulum
    a. Watch this video from 8:56 to 10:51.
    b. This part of the video illustrates how to isolate the gravitational field intensity (g) from the equation for the period of a pendulum.
7. O Level Physics Notes
    a. This website provides a method of measuring the period of a pendulum with increased accuracy. A method to calculate the period is outlined.

8. Dropping Dictionaries Doesn't Defy Gravity, Duh!
9. Introduction to Free-Fall and the Acceleration due to Gravity
10. Dropping a Ball from 2.0 Meters - An Introductory Free-Fall Acceleration Problem
    a. This video solves a problem using the equations of motion for the motion of a medicine ball that is dropped from rest over a distance of 2.0 metres.
    b. Note in this video that the subscript “y” is added to the symbols of velocity and acceleration and that displacement in the vertical direction is referred to as delta y (Δy).
    c. Pay attention to some of the common errors made with vector directions.
11. Free Fall
    a. Click on the link Launch Concept Builder.
    b. Attempt each of the 3 activities- Describing Free Fall, Speedometer, It’s About Time.
    c. This simulation uses a value of 10.0 m/s/s [down] for the acceleration of gravity.
    d. The simulation relates the sizes and directions of the velocities and acceleration during different parts of the journey of an object thrown straight up into the air.
12. GCSE Physics Revision: Forces on a skydiver
    a. As a skydiver falls to the Earth the force of gravity and the force of air friction both act on the skydiver. The two forces will add to produce the net force on the skydiver at a given instant in time. The skydiver will accelerate in the direction of the net force. This video describes how the forces change to create the net force and enable for you to predict the acceleration of the skydiver and the accompanying change in velocity.
13. Physics Ch.2.1 Part 2 Air resistance and terminal velocity
14. Brian Cox visits the world's biggest vacuum chamber - Human Universe: Episode 4 Preview - BBC Two
    a. This video shows a visit to a large vacuum chamber. The structure and operation of the vacuum chamber is reviewed. A large ball and some feathers are dropped from the same height simultaneously when the chamber is filled with air to observe the effect of air resistance. The feathers accelerate from rest picking up speed as they fall. The rate of acceleration for the feather slows until the feathers fall at a constant velocity, the terminal velocity. The ball accelerates constantly increasing its speed s it falls.
    b. The air is then evacuated from the chamber leaving a vacuum inside the chamber. The ball and the feathers are dropped again. How do the motions of the ball and feather compare when they fall without air resistance?
15. Introduction to Static and Kinetic Friction by Bobby
16. Introduction to the Coefficient of Friction
17. Understanding the Force of Friction Equation
    a. This video examines the force of friction equation. The application of the equation for kinetic friction results in a constant value as long as the object is moving.

   b. However for the force of static friction the value of the force of static friction varies according to the external force applied to the object force. The force of static friction will have the same magnitude as the applied force acting on the objet.
   c. Once the applied force exceeds the maximum force of static friction, the object begins to move and the force of kinetic friction appears. The force of static friction then drops to 0 N.
18. Does the Book Move? An Introductory Friction Problem
   a. A book rests on a level horizontal table. A horizontal force is applied to the book. The question is will the book move? If the book moves what will be its acceleration?
   b. The approach to this problem follows the Dynamics – Newton's Second Law – Kinematics approach with the new factor of the forces of kinetic friction and static friction.
19. Static Friction and Kinetic Friction Physics Problems With Free Body Diagrams
20. Physics - What is Friction?

GRADE 11 PHYSICS (30S)

Module 5: Electric Fields

This module contains the following

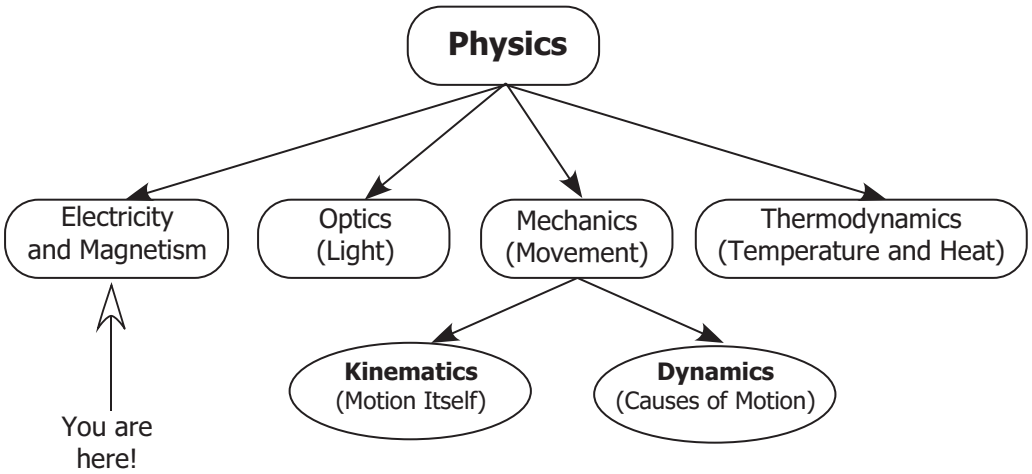
- Introduction to Module 5
- Lesson 1: Electric Fields
- Lesson 2: Calculating Electric Field and Electric Force
- Lesson 3: The Parallel Plate Apparatus
- Lesson 4: The Millikan Experiment
- Module 5 Summary

Module 5: Electric Fields

Introduction to Module 5

In Module 4, we began our study of fields by looking at gravitational fields. In this module, we study electric fields. Electric fields are created by electric charges, and the fields created by these charges cause other charges to be influenced by them.

- **Lesson 1: Electric Fields** examines electric fields caused by single charges, by combinations of more than one charge, and by electrically charged plates.
- **Lesson 2: Calculating Electric Field and Electric Force** applies some of what we learned about vector addition to determine the total electric field at any point, as well as the net force exerted on a charge by one or more fields. This lesson will also apply some of what we learned in kinematics to analyze the motion of a charged particle in an electric field.
- **Lesson 3: The Parallel Plate Apparatus** is an introduction to the parallel plate apparatus, a device that is used to produce a constant electric field.
- **Lesson 4: The Millikan Experiment** examines the Millikan experiment and how Millikan was able to determine that there exists a minimum electric charge. Finally, we will be able to convert between a quantity of charge called the coulomb and the number of elementary charges in the coulomb.



Assignments in Module 5

When you complete Module 6, you will submit your Module 5 assignments, along with your Module 6 assignments, to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 5.1	Electric Fields
2	Assignment 5.2, Part A	Calculating Electric Field and Electric Force
3	Assignment 5.2, Part B	The Parallel Plate Apparatus
4	Assignment 5.2, Part C	The Millikan Drop Experiment

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Lesson 1: Electric Fields (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the terms "electric field," "electric field lines," and "lines of force"
- ❑ draw an electric field line pattern for an isolated positive point charge or an isolated negative point charge
- ❑ explain what the length of an electric field line and the direction of an electric field line represent
- ❑ explain what the density of electric field lines represent
- ❑ compare gravitational field lines to electric field lines
- ❑ define the term "electric dipole" and draw the electric field line pattern for the dipole
- ❑ draw a vector representing the direction and strength of the electric field at any given point in an electric field line pattern
- ❑ draw an electric field line pattern for two charges of the same sign and magnitude
- ❑ draw an electric field line pattern between two oppositely charged parallel plates
- ❑ draw an electric field line pattern for the charge between two plates or near one plate

Key Words

electric field
electric field lines
test charge
electric dipole

Introduction

In the previous module, we studied gravitational fields. In this lesson, we move to a study of electric fields. In this study, you will see how electric fields are similar to and different from gravitational fields. We will diagram electric fields using lines of force. These lines of force will be applied to single charges, double charges, and charged plates.

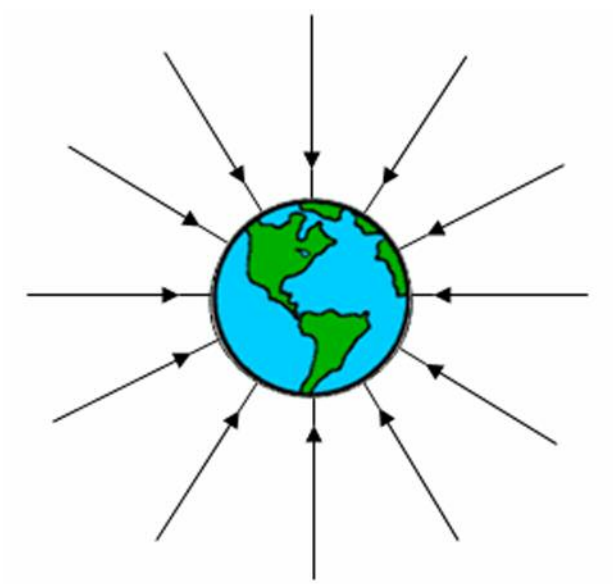
A Review of Gravitational Fields

In our work with gravitational fields, one of the ways to define the gravitational field was to simply say that it is a region of space in which a mass experiences a force of gravity. More exactly, we use the equation $\vec{g} = \frac{\vec{F}_g}{m}$ to calculate the strength of the gravitational field. In this equation, "m" is the mass of an object in the gravitational field, and $\vec{F}_g$ is the strength of the gravitational force it experiences as a result. In essence, this object is being used to "test" the gravitational field being produced by some other mass (such as the earth) or group of masses, as was discussed in the previous lesson.

The units of gravitational field are newtons/kilogram (N/kg). Gravitational field is a vector quantity.

The pattern of gravitational field lines is given in the diagram below.

Earth's Gravitational Field



Electric Field

In a similar way, we can define the **electric field** as a region of space around a charge where an electric charge experiences a force caused by one or more other charges.

More exactly, if we use an uppercase "E" to represent electric field, and a lowercase "q" to represent charge (yes, this is a strange choice of letter for charge, but it is the "official" letter nonetheless!), then we can calculate the **electric field intensity** as the **"electric force per amount of charge."**

An electric field is a region in which a charge experiences an electric force. We symbolize electric fields as "E."

The **electric field** at a point in space is calculated as the quotient of the **electric force** on an amount of charge and the **magnitude of the charge** located at that point.

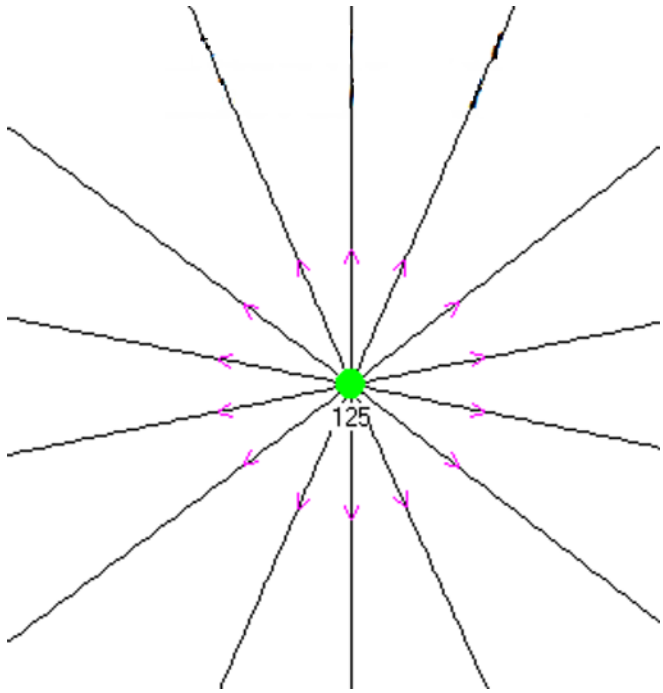
$$\vec{E} = \frac{\vec{F}_E}{|q|}$$

Quantity	**Symbol**	**Unit**
Electric field	$\vec{E}$	newtons/coulomb (N/C)
Electric force	$\vec{F}_E$	newtons (N)
Magnitude of the electric charge	$\lvert q \rvert$	coulombs (C)

To measure the electric field, we place a charge, q, at a given point in space and measure the electric force acting on this charge. Then we can calculate the electric field, $\vec{E}$, using the relationship, $\vec{E} = \frac{\vec{F}_E}{|q|}$.

The electric field around the point charge varied with the distance from the centre of the charge. The farther away from the charges's centre, the weaker the electric field. We can illustrate the electric field using a diagram showing the pattern of electric field lines.

2D Electric Field Pattern Around a Positive Charge



Test Charges and the Directions of Electric Force and Electric Field

Our discussion until now has been following the similarities between gravitational fields around point masses and electric fields around point charges. Now let's consider an important difference between how we measure electric fields compared to gravitational fields.

There is only one kind of mass. Here on earth, one kilogram of matter is one kilogram regardless of the material present. In terms of mass, one kilogram of water is the same as one kilogram of salt is the same as one kilogram of you!

However, with electrical charge, one unit is not necessarily one unit!

> With electric fields and forces, it is important to keep in mind the following. There are two kinds of charge: positive and negative.

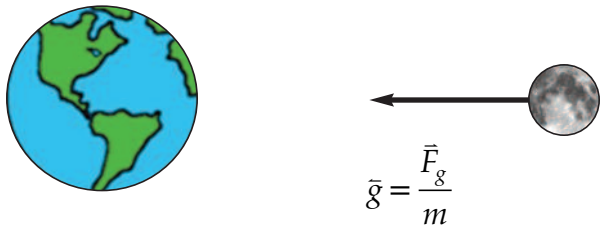
The equation $\vec{E} = \frac{\vec{F}_E}{|q|}$ only deals with the **amount** of charge, which is why there are absolute value bars around the charge "q."

To try to keep things as simple as possible, physicists tend to think of **positive** charge as being the "official" kind of charge. By this, what we mean is that we make rules and generalizations about electric fields and forces while thinking about positive charges. We then have the responsibility to recognize that if we, in fact, have a negative charge instead, we must "reverse" the rule.

For example, recall that gravitational fields point in the direction that masses get pushed with gravitational forces. We can similarly say that electric fields point in the direction that positive charges get pushed. We don't really need a new rule for negative charges, but it is certainly the case that negative charges get pushed in the exact opposite direction. So if a room was filled with an electric field that pointed to the west, positive charges in the room would get pushed west while negative charges in the room would get pushed east.

> The **direction** of the **electric field** is the **direction** that **positive charges** experience electric forces. Negative charges would have electric forces in the opposite direction.

You will recall this is what happened when you measured the gravitational field at a point near the earth.

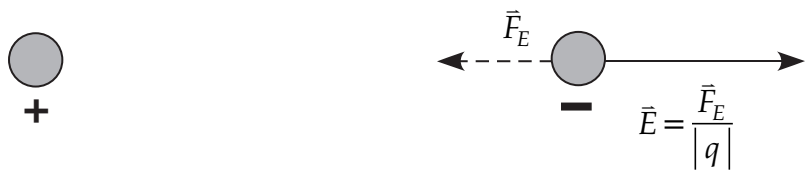


The force of gravity is attractive and pulls the object (the moon) towards the earth. The gravitational field points towards the earth as well.

Here is what happens if we place a positive test charge next to a positive point charge.

The **electric force** on the **positive** charge on the right pushed the positive charge to the **right**. The direction of **the electric field** is to the **right** also.

Here is what happens if we place a negative test charge next to a positive point charge.



The **electric force** on the **negative** charge on the right pulled the negative charge to the **left**. The direction of the **electric field** is still to the **right**.

Properties of Test Charges

To determine the direction (and strength) of the electric field, we just have to "test" it by placing a small charge into the region being tested and measure the direction and strength of the electric force it produces onto our "test charge." Think of a "test charge" as being a bit like a thermometer. It is the thing that we stick into a region to make a measurement for that spot. Unlike a thermometer, which senses the temperature of the place it is put, test charges, being charges, experience an electric force in the electric field where they are put.

It is important that the test charge be small so that it does not disturb the arrangement of charge creating the electric field that we are trying to measure. This is a very important idea in all of science: if you want to measure something, be careful not to significantly change it in the act of measuring it. To understand this principle better, suppose you wanted to measure the temperature of boiling water in a teaspoon. If you put the end of a large glass thermometer into the water to measure its temperature, the water would immediately cool and the temperature indicated by the thermometer would be much less than the temperature the water *used to be*. It would have been better to use a tiny thermometer (perhaps a tiny electronic thermometer attached to a large display) to measure the temperature. Being tiny, this thermometer wouldn't change the temperature of the water much, so the indicated value would be much closer to what you were really after.

If a large charge is used to test the electric field being made by surrounding charges, the test charge would inadvertently cause those surrounding charges to move around, making their electric field different than it was before the test charge was introduced. By using a small test charge, we mostly prevent this from happening.

Test charges should be a small amount of charge, so as not to disrupt the charges creating the electric field being investigated.

The test charge should be **positive** for convenience, but a negative test charge would be fine as long as you remember that positive charges are still the "official" kind of charge. This means that if a negative test charge experiences an electric force to the south, we would conclude that the electric field points north (since that is the way positive charge *would have* been pushed—the exact opposite direction from the negative charge).

Point Charges

Now that you know what a "test charge" is, let's discuss "point charge"—another term that we will use fairly often. Real charged objects come in all shapes and sizes. Dealing with this can be very complicated, so we will usually find it necessary to simplify. A point charge then is a charged object that is imagined to have zero size—literally a "point." This is not realistic, but does a very good job for charged objects that are at least somewhat small.

> **Point charges** are charged objects that are very small—so small that their size may be safely ignored.

Putting these two ideas together, we find that a good test charge should be small as well as small. You did read that correctly! Here, "small" is being used in two different ways. Firstly, it should be small *in the amount of charge* that it has so it does not change the electric field it is trying to test or measure. Secondly, it should be *physically* small to be close to the idea of a point charge.

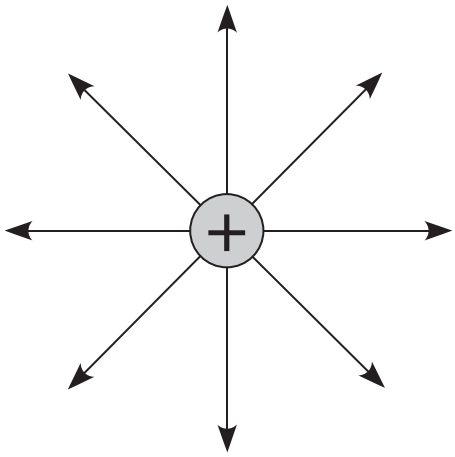
Electric Field Line Diagrams

Electric field lines are lines representing the direction of the electric field. Since electric field is defined as the electric force per amount of charge, the electric field lines are sometimes called **lines of force**.

Electric field lines are drawn in a similar manner to the method used to draw gravitational field lines of force. You can refer back to the previous module to review the process. The important difference is that we use our "official" test charge, which is positive, to determine the correct direction for the electric field lines.

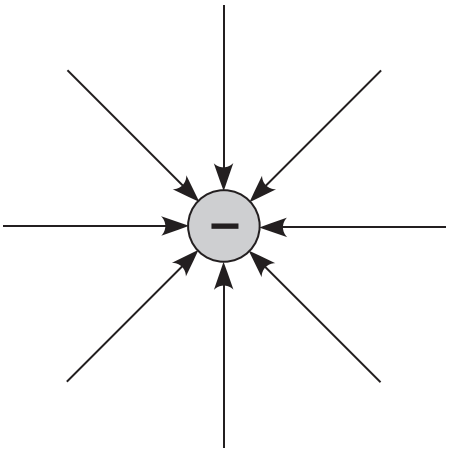
Electric Field Line Diagram for a Positive Charge

In much the same way that we draw the gravitational field produced by massive objects, we can draw the electric field made by charged objects. The diagram below shows a positive charge, "+." The arrows show that if a positive test charge was placed in the space around this charge, the test charge would experience a force outward from the centre of this charge. Remember that when we speak of these directions, we are assuming the "official" kind of charge is being used: positive charge. If a negative test charge was used instead, it would be pushed in the direction opposite of the drawn arrows.



Electric Field Line Diagram for a Negative Charge

If the charge is negative, then the positive test charge would be attracted towards it. In this case, the field lines would point inward towards the negative charge.

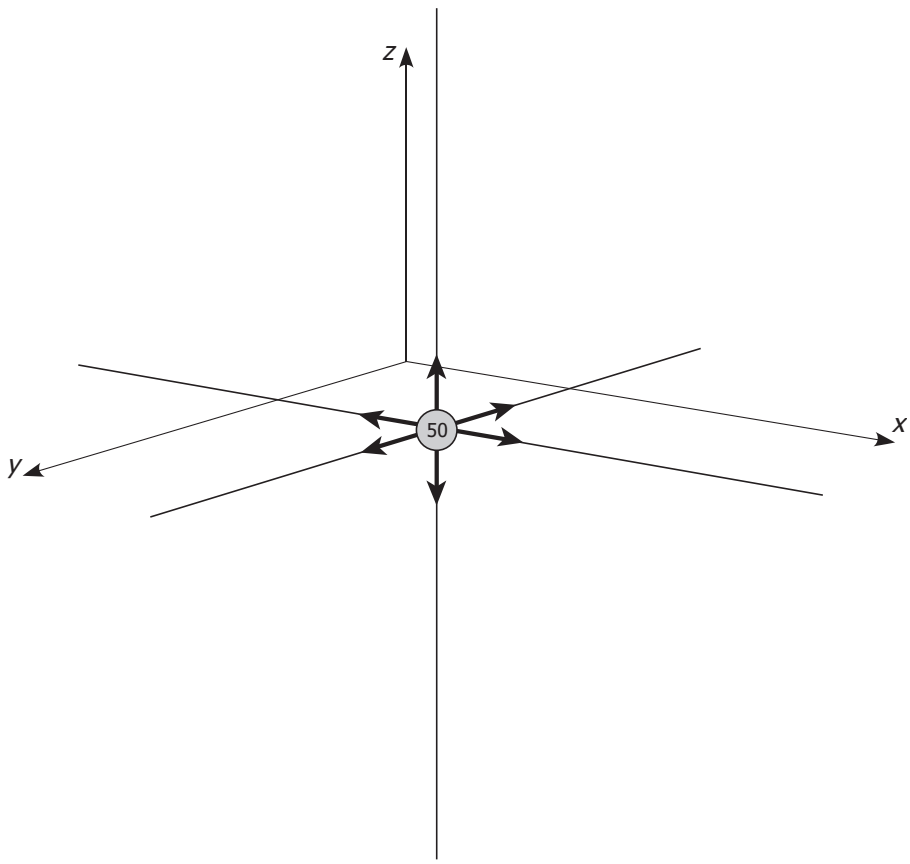


The examples above show that electric field lines point away from positive charges and towards negative charges. In both cases, the field lines point away from or toward the exact centre of the charge.

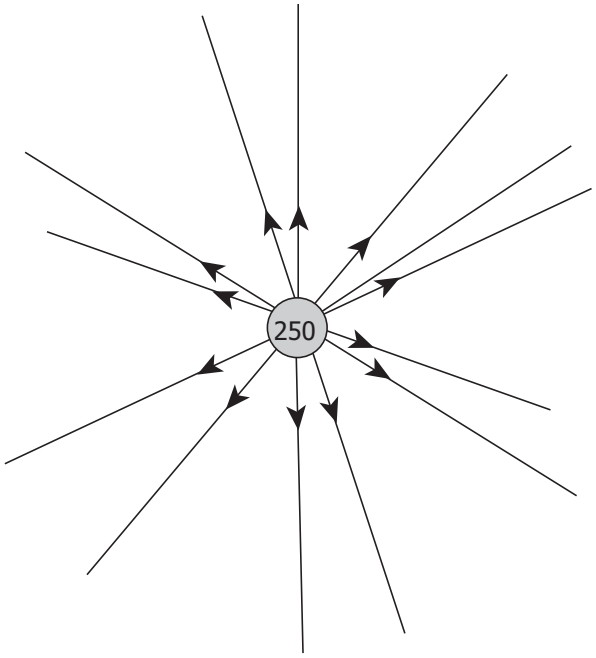
As a matter of convenience, electric field lines are drawn in only two dimensions ("flat" on our pages). Field lines actually radiate from the charges in three dimensions and an infinite number of lines could potentially be drawn.

Here are a couple of diagrams showing the three-dimensional nature of the electric field.

This is the pattern around a positive point charge of magnitude 50.



This is the pattern around a positive point charge of magnitude 250. All of the lines of force point away from the positive charge.



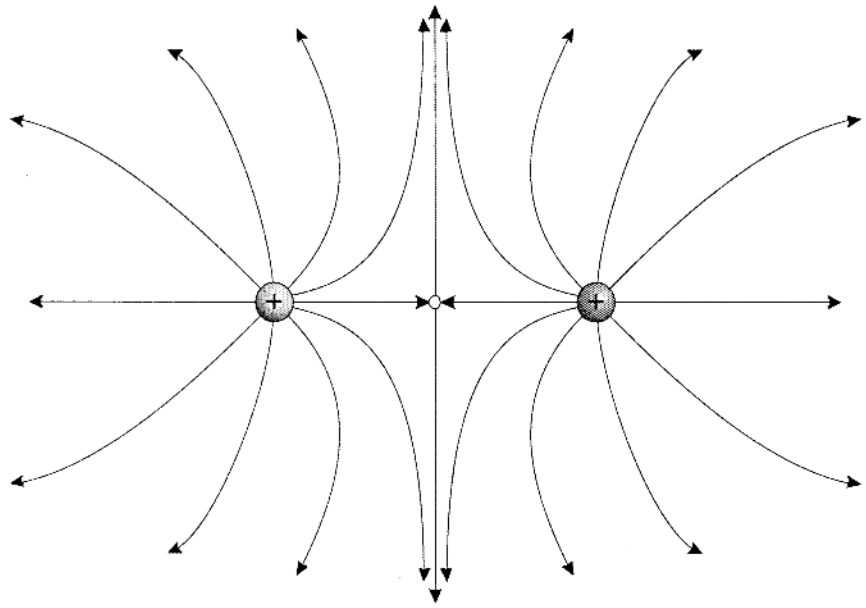
For practical reasons, only a small number are drawn in pictures. The number of lines drawn should be enough that the overall pattern is clear but the actual number is not important. Note, however, that if a second charged object is to be drawn in the same diagram, or even a separate diagram that is to be compared to the first, then the number of lines drawn for the charges would have to be proportional to the amount of charge. So, for example, a charge of +250 would have five times the number of lines that a +50 charge would have. This is shown in the previous diagrams.

Just like gravitational field lines, the electric field lines also provide information about the strength of the field. **Near the charges** where the electric field is **strongest**, the lines are **closest together**. At distances far from the charges, the electric field is **weaker**, which is seen as the lines being **farther apart**.

> In general, the electric field is strongest in regions where the field lines are closer together.

Electric Field Line Diagram for a Pair of Like Charges

In very much the same way that we earlier diagrammed the gravitational field for the earth and the moon, we can show the electric field line diagram for a pair of "like" charges (meaning two charges with the same kind of charge). In the example below, there are two positive charges of equal amounts. If two negative charges were used instead, the picture would look exactly the same, but the arrows showing the direction of the field lines would all be pointing towards the negative charges.

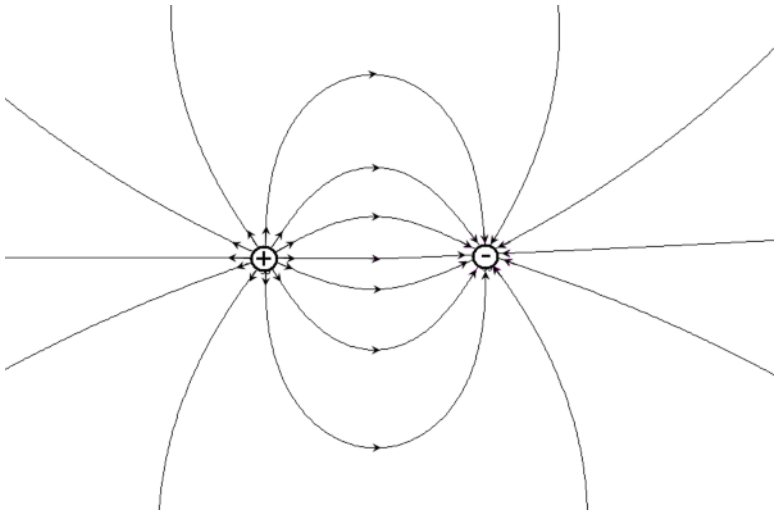


One interesting feature of this diagram is the point exactly between the two charges. At that spot, there is a "hole" in the electric field. This means that a test charge could be placed there and it would experience no net electric force at all. This should make sense as the test charge (assumed to be positive) would be repelled from both of the positive charges equally. These two forces would exactly cancel at that spot.

Electric Field Line Diagram for an Electric Dipole

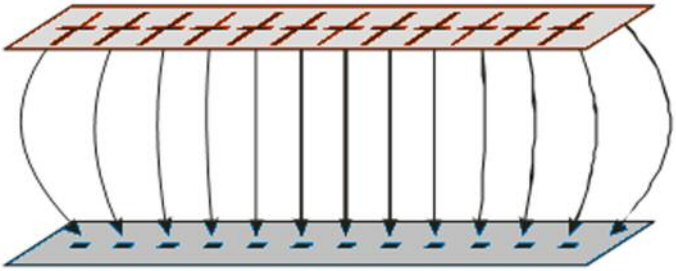
When two charged objects have the same amount of charge but one is positive and the other is negative, we may call the pair an **electrode dipole**.

Here is the electric field line diagram for a dipole:

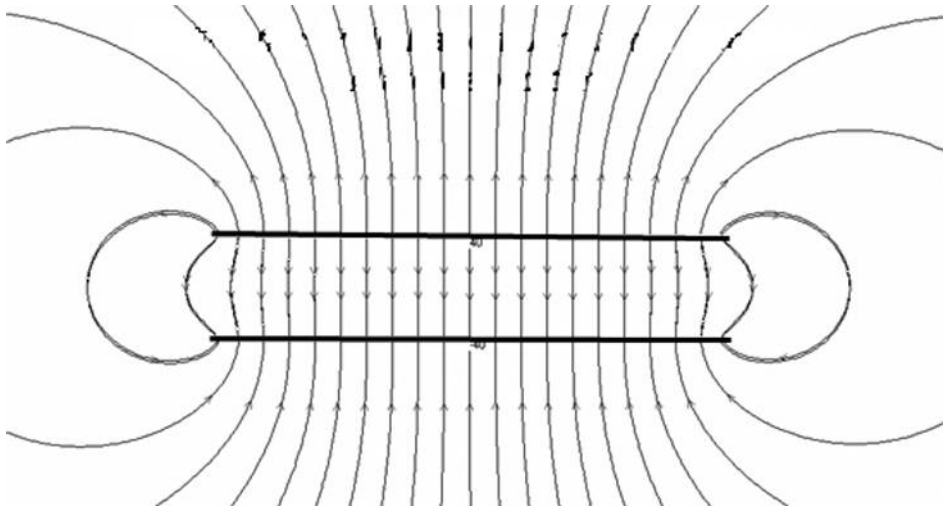


The Electric Field Line Diagram for a Pair of Oppositely Charged Plates

Let's now examine the electric field pattern between two parallel plates with opposite charges. The electric field lines point away from the positive plate towards the negative plate. There is a slight bulge near the edges of the plates. This is called an "edge effect." Within the plates but not near the edges, the electric field lines are equally spaced and point directly toward the negative plate. This is because a positive test charge placed in this region would be repelled from the positive plate and attracted to the negative plate.



2D Electric Field Pattern
Around a Parallel Plate Capacitor

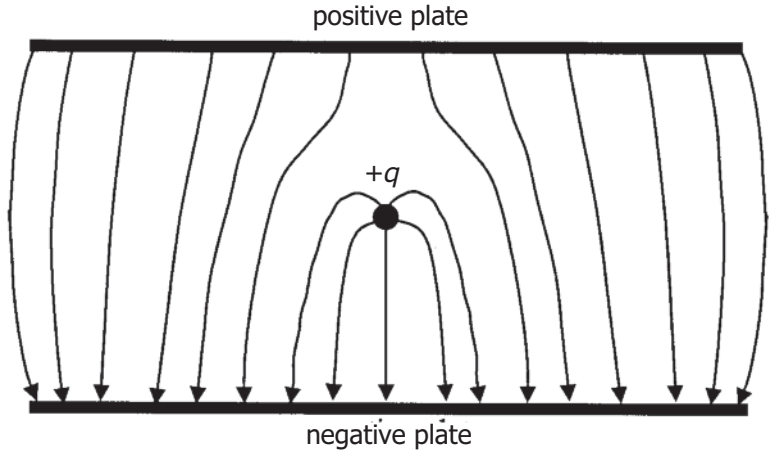


Parallel plates are a very handy way of generating a region of uniform (or constant) electric field—the electric field between the plates is the same strength and in the same direction (towards the negative plate) everywhere between the plates, except near the edges. This is very similar to the uniform gravitational field that we experience near the surface of the earth.

> The electric field is constant between oppositely charged parallel plates (except for the edges).

Electric Field Lines for Two Plates and a Positive Charge

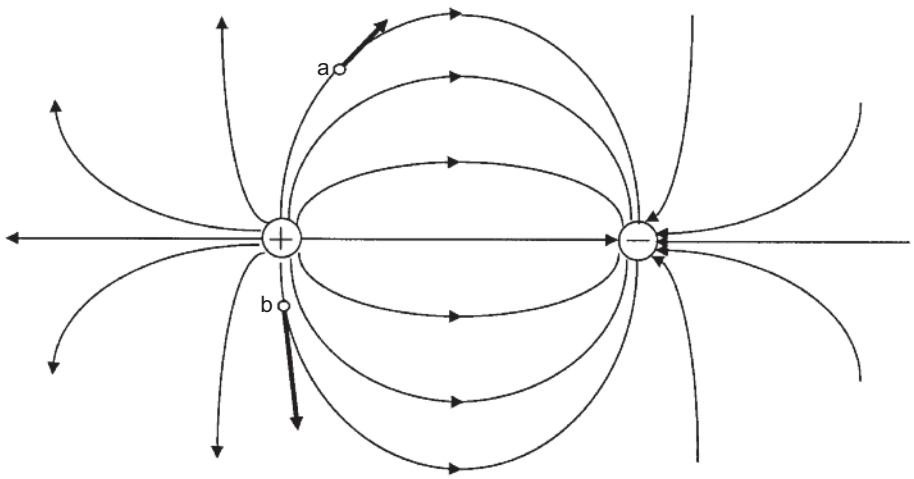
The following diagram shows the electric field line pattern between a single positive charge and two charged plates when the charge is between the plates. Note that the electric field lines move away from the positive charge and the positive plate and towards the negative plate.



Now that we have seen a few different examples of electric field line diagrams, let's point out a few of their general characteristics:

1. Electric field lines generally begin on a positive charge and end on a negative charge.
2. The number of lines associated with a charge is proportional to the amount of charge. (Stronger charges have more field lines.)
3. In general, the more closely spaced lines there are in a given location, the stronger the field is in that region. For example, the lines are very close together near a charge, indicating that the electric field is strong there. The field lines farther away from the charge are spaced farther apart, indicating a weaker field strength in that region.
4. The direction of the electric field at any given point is tangential to the electric field line at that point.
5. The field lines are drawn perpendicular (90°) to the surface of the charge. This causes the lines to bend when the charged objects are points or spheres.

These points will be clearer with the help of an example:



At position "a" in the diagram above, notice that the electric field vector is drawn **tangent** to the field line. The direction is along the line pointing away from the positive charge. The electric field vector at position "b" is also drawn away from the positive charge tangent to the field line. The vector at "b" is longer than the one at "a" because there are more field lines per unit area at that location showing that the electric field strength at that location is also stronger.

In drawing these field lines, note that they show how a positive test charge would be forced to follow the field lines. If a negative charge were to be placed at these points, it would be forced in the opposite direction but still along the same lines.

Learning Activity 5.1

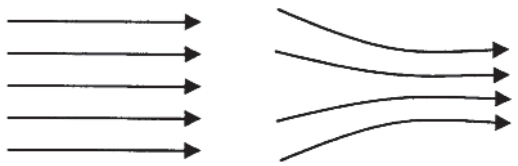
Electric Fields

1. a) How are a gravitational field and an electric field similar?
   b) How are a gravitational field and an electric field different?
2. Why is an electric field considered to be a vector quantity?
3. a) What are electric field lines?
   b) How does the direction of an electric field line compare with the direction of the force that acts on a positive test charge in the same region?
4. How is the strength of an electric field indicated with field lines?
5. How do the electric field lines appear when the field has the same strength as all points in a region?
6. The vectors for the gravitational field of earth point toward earth; the vectors for the electric field of a proton point away from the proton. Explain.
7. Draw two points indicating negative charges. The points should be separated by a short distance. Add to your diagram the following:
   a) Draw the electric field line pattern for the two negative point charges.
   b) Place an "x" at a point about two centimetres away from the right negative charge. Place the "x" on a field line at about 60° north of east of this charge. Draw a possible vector representing the electric field strength at this point.
   c) In a similar way, place the letter "y" on an electric field line about one centimetre away from the left negative charge at a direction of about 45° south of west of the charge. Draw a vector representing the strength of the electric field at this point. Be sure that the length and the direction of this vector show how the field strength at "y" is different from the field strength at "x."

(continued)

Learning Activity 5.1: Electric Fields (continued)

8. Diagrams 1 and 2 show two examples of electric field lines.



1 2

Decide which of the following statements are true and which are false, defending your choice in each case.

a) In both 1 and 2, the electric field is the same everywhere.

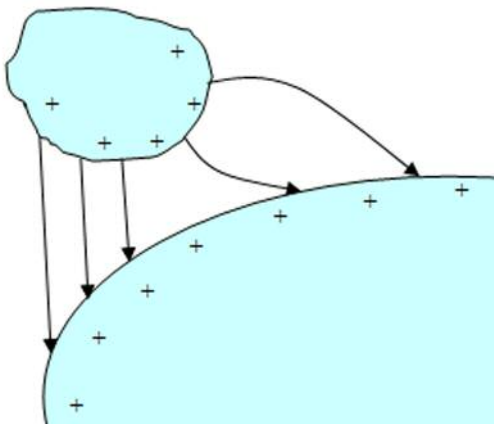
b) As you move from the left to right in each case, the electric field becomes stronger.

c) The electric field in 1 is the same everywhere but the electric field in 2 becomes stronger as you move from left to right.

d) The electric fields in both 1 and 2 are created by negative charges located somewhere on the left and positive charges located somewhere on the right.

e) Both 1 and 2 arise from a single positive point charge located somewhere to the left.

9. The drawing below is supposed to show the electric field lines in the region between the two charged metal conductors. Give two reasons why this drawing is incorrect.



Lesson Summary

The **electric field** is the region of space around a charge or system of charges where another charge experiences a force caused by the charge or system of charges.

We define a **positive test charge** as a positive charge so small that the force it exerts does not significantly alter the distribution of the other charges (the ones that cause the field being measured).

We can define a **point charge** as an idealized charged particle with no real size or spatial extent.

Electric field lines are lines representing the direction of the electric field. Since electric field is defined to be the electric force per unit charge, the electric field lines are sometimes called **lines of force**.

The electric field lines for a positive charge point away from the charge. The electric field lines for a negative charge point towards the charge.

The number of lines is proportional to the charge.

Near the charges where the electric field is strongest, the lines are close together. At distances far from the charges, the electric field is weaker so the lines are farther apart. In general, the electric field is strongest in regions where the field lines are closer together.

An **electric dipole** consists of two point charges that are opposite in sign but equal in magnitude.

In drawing electric field lines, the following important points should be kept in mind:

1. Electric field lines always begin on a positive charge and end on a negative charge, and do not start or stop in the region between.
2. The number of lines leaving a positive charge or entering a negative charge is proportional to the magnitude of the charge.
3. In general, the more lines there are in a given location, the stronger the field is in that region.
4. The direction of the electric field at any given point is the vector drawn tangent to the electric field line at that point. The longer the electric field vector, the stronger the electric field is at that point.
5. The field lines are drawn coming out perpendicular, 90°, to the positive surface and going in perpendicular to the negative surface. This causes the lines to bend when the charged objects are points or spheres.

NOTES

Assignment 5.1

Electric Fields (5 MARKS)

The question below refers to two point charges separated by a distance of about 4 cm. The charge on the right side is a positive charge and the one on the left is a negative charge. In the example used in this lesson, there were 12 field lines leaving each charge. For this question, assume that the charges have **half** the magnitude of what they did in the lesson.

a) Draw the electric field line pattern for this situation.

b) Draw a vector at two locations where the direction of the vector representing the electric field at that point is about 45° south of east.

c) Place an "X" at two spots showing where an electron would be forced directly west.

d) Without actually drawing it on the diagram, describe the line where one could put a positive charge so that it experiences a force directly to the west—that is, anywhere on this line, a positive charge would experience the force to the left.

(continued)

Assignment 5.1: Electric Fields (continued)

Method of Evaluation

The total of five marks for this assignment will be determined as follows:

- 1 mark for showing the correct direction of the lines for part (a)
- 1 mark for showing the correct number of lines for part (a)
- 1 mark for drawing the two electric field vectors for part (b)
- 1 mark for showing the two spots for part (c)
- 1 mark for describing the line for part (d)

Lesson 2: Calculating Electric Field and Electric Force (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ state what a "coulomb" is
- ❑ convert between a number of elementary electric charges and coulombs
- ❑ calculate the magnitude and direction of the electric force, $\vec{F}_E$, acting on a test charge, q, in an electric field, $\vec{E}$
- ❑ compare the direction of the electric field vector and the electric force vector when the test charge is positive or negative
- ❑ determine the total electric field at a given point when two or more electric fields, in one or two dimensions, act at this point

Key Words

proton	electric field
elementary charge	Coulomb
electron	electric force

Introduction

In the previous lesson, we discussed how to draw electric field lines. In this lesson, we discuss how charge is measured. We also calculate the total electric field in a region where more than one electric field exists at a given point. We will then be able to calculate magnitude and direction of the total force exerted on a charge at a point where one or more electric fields exist. Since electric field has magnitude and direction, we must apply the rules of vector addition to add together two or more electric field vectors.

The Elementary Charge and the Coulomb

So far, we know that there are two **kinds** of charge: positive and negative. We now turn our attention to **how much** charge that an object has.

If you were able to study protons in detail, you would find that they are all identical to each other in every way. They are all the same amount of mass, and they are all positively charged. In fact, they all have the same amount of charge too. Since protons are so readily available and are all identical to each other, we can think of them as containing an amount of charge that we can give a name to, and use as a unit for charge. This is exactly the idea of the **"elementary charge"** that can be defined as the amount of charge on a single proton. We often abbreviate elementary charge down to the symbol "*e*."

Mind you, if you looked closely at electrons, you would find that they are also all identical to each other. Furthermore, while they are not at all like protons in terms of mass (protons are much more massive), they surprisingly have the exact same amount of charge as protons do—but the other kind of charge, which we call negative. This means that electrons too each have an amount of charge that we call an elementary charge.

The elementary charge (e) is the amount of charge on a single proton or electron.

Remember that the symbol "*e*" stands for elementary charge, not electron! Now, just as we use the letter "*m*" to stand for mass, we will use the letter "*q*" to stand for charge. This may seem to be a strange choice, but it is the "official" letter, and after using it like this for a while it won't seem strange at all. As an example, here is how we could summarize the masses and charges of protons and electrons:

Each proton has a mass: $m = 1.68 \times 10^{-27}$ kg and a charge: $q = 1\ e$

Each electron has a mass: $m = 9.11 \times 10^{-31}$ kg and a charge: $q = -1\ e$

While the above information is correct, there is one problem. The problem is that while the elementary charge is fine for dealing with individual or even small numbers of protons and electrons, it is a very inconvenient unit when there are very many of them. For this reason, elementary charges are not the SI unit for charge. Remember that in physics we choose one unit of those available to be the "official" unit that we use all of the time.

The SI unit for charge is called the **coulomb** (abbreviated "**C**").

This unit of charge is named in honour of Charles Coulomb (1736–1806), who discovered what has come to be known as Coulomb's Law, which will be covered in Grade 12 Physics.

Essentially, a coulomb of charge is the amount of charge contained in a "package" consisting of a very specific number of protons (or electrons). This can be compared to the idea of a "dozen," which is also a "package" of a very specific number. A dozen refers to 12, and a coulomb refers to 6.24×10^{18}. While a coulomb indicates a much bigger number than a dozen, both terms indicate a particular value.

If you go to a doughnut shop and ask for a dozen doughnuts, you should receive a package of 12. If you go to a doughnut shop and ask for a "coulomb of doughnuts," you should receive the reply "Sorry, we don't have that many doughnuts. In fact, there aren't that many doughnuts in the whole world. Even if you added up all the doughnuts that have ever been made, it wouldn't be anywhere near that many." Well, at least that's the response you would get if the person working in the doughnut shop has some idea what a coulomb is. But although it's true that the coulomb indicates a very large number (i.e., the amount of charge contained in a group of 6.24×10^{18} protons or electrons, which is a very big number that exceeds the number of doughnuts in the world), the coulomb only measures charge and nothing else. A dozen, on the other hand, can be used to measure anything from doughnuts to eggs to hotdog buns.

A coulomb can be described in the following way:

> 1 coulomb = 6.24×10^{18} elementary charges ... 1 C = $6.24 \times 10^{18}\ e$

Knowing how coulombs compare to elementary charges enables us to convert between these two units. (You can check the section on unit conversion in the appendix.) Of particular interest would be the charge of a single proton or electron expressed in coulombs. This can be found by the following conversion:

$$1\ e\left(\frac{1\ \text{C}}{6.24 \times 10^{18}\ e}\right) = 1.60 \times 10^{-19}\ \text{C}$$

This means that we now know the charge of protons and electrons in the preferred, SI unit for charge:

> Each proton has a charge $q = +1.60 \times 10^{-19}$ C and each electron has a charge $q = -1.60 \times 10^{-19}$ C

To determine the amount of charge in coulombs, multiply the number of elementary charges (protons and electrons) by the magnitude of the elementary charge.

$$q = Ne$$

Quantity	Symbol	Unit
Amount of charge	q	coulomb (C)
Number of elementary charges	N	integer (no unit)
Elementary charge	e	coulomb (C)

Example 1: The Charge on a Balloon

When the number of electrons and protons is the same in an object, that object is said to be electrically neutral. When there is an excess of protons in an object, that object is said to be positively charged. When there is an excess of electrons in an object, that object is said to be negatively charged.

When you rub a balloon against the hair on your head, electrons are transferred from your hair to the balloon. If 7.2×10^{10} electrons are transferred from your hair to the balloon,

a) what is the charge on the balloon expressed in coulombs?

b) what is the sign of the charge on the balloon?

Solution

a) Given: Number of elementary charges $N = 7.2 \times 10^{10}$

Elementary charge $e = 1.60 \times 10^{-19}$ C

Unknown: Charge $q = ?$

Equation: $q = Ne$

Substitute and solve: $q = (7.2 \times 10^{10})(1.60 \times 10^{-19}\ \text{C})$
$= 1.152 \times 10^{-8}$ C

The charge on the balloon is 1.2×10^{-8} C.

b) Since the balloon contains an excess of electrons, it is negatively charged.

The Electric Field and Force

Earlier, we defined the electric field $\vec{E}$ to be the ratio of the electric force, $\vec{F}_E$, to the amount of charge q experiencing the electric force: $\vec{E} = \frac{\vec{F}_E}{|q|}$. Now that we know that the coulomb is the SI unit for charge, it should be clear that electric field has the units of "unit of force" divided by "unit of charge." This means that the unit for electric field is the newton per coulomb (N/C), in much the same way that the unit for gravitational field was the N/kg.

The **electric field** at a point in space is calculated as the quotient of the **electric force** or an amount of charge and the **magnitude of the charge** located at that point.

$$\vec{E} = \frac{\vec{F}_E}{|q|}$$

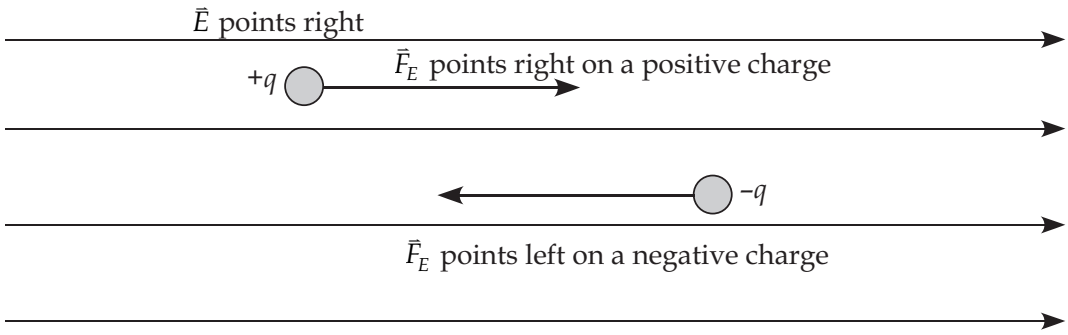
Quantity	**Symbol**	**Unit**
Electric field	$\vec{E}$	newtons/coulomb (N/C)
Electric force	$\vec{F}_E$	newtons (N)
Magnitude of the electric charge	$\lvert q \rvert$	coulombs (C)

If a point charge q is placed into an electric field of known strength, then the electric force, $\vec{F}_E$, acting on the charge can be calculated using the same equation solved for electric force: $\vec{F}_E = |q|\vec{E}$.

Note that this equation for electric force is very similar to the equation for the force of gravity: $\vec{F}_g = mg$. This is because gravitational fields "$\vec{g}$" exert gravitational forces "$\vec{F}_g$" on masses placed in them, in the same way that electric fields "$\vec{E}$" exert electric forces "$\vec{F}_E$" onto charges "q" placed in them.

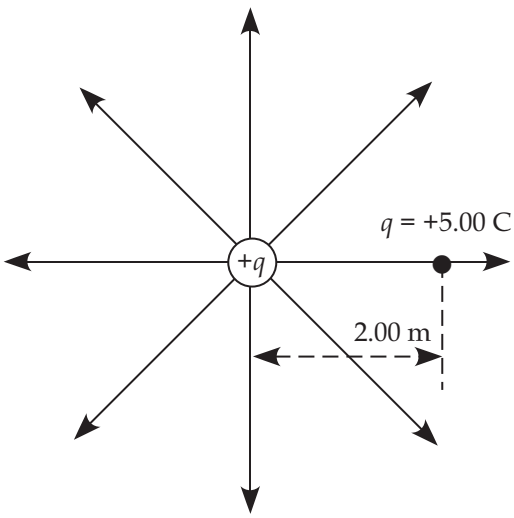
The electric field $\vec{E}$ and the electric force $\vec{F}_E$ are both vectors, which means that they both have direction that needs to be tracked. The rule for this is straight forward, and comes from the way that we tend to think of positive charge as being the "official" kind of charge:

> The electric force and electric field are in the same direction for positive charges; they are in opposite directions for negative charges.



When determining the electric force, both the magnitude (size), and the direction of the force should be stated. The electric field line pattern for a positive point charge and a negative point charge was discussed earlier.

Example 2: Electric Fields and Electric Force

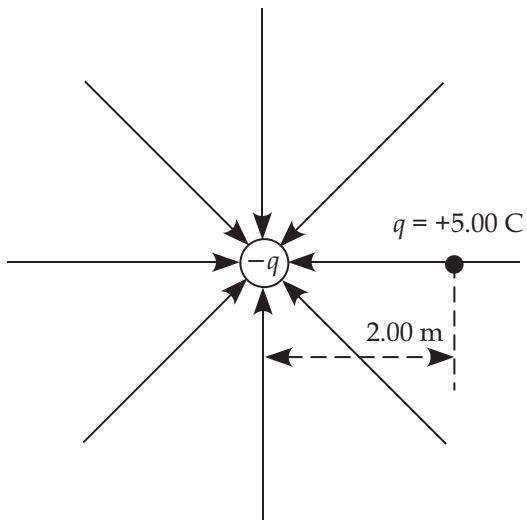


A test charge of +5.00 C is placed a distance of 2.00 m to the right of the point charge +q. The strength of the electric field produced by this charge is 10.0 N/C at the location of the charge q. What is the electric force acting on the charge q?

Given:	Charge	$q = +5.00\ \text{C}$
	Electric field intensity	$\vec{E} = 10.0\ \text{N/C}\ [\text{E}]$
Unknown:	Electric force	$\vec{F}_E = ?$
Equation:		$\vec{E} = \dfrac{\vec{F}_E}{\lvert q \rvert}$ rearranged to $\vec{F}_E = \lvert q \rvert \vec{E}$
Substitute and solve:		$\vec{F}_E = (5.00\ \text{C})(10.0\ \text{N/C}) = 50.0\ \text{N}$

The charge test charge, q, and the point charge producing the electric field, +q, are both positive, so that charges repel each other. The direction of the force is to the right (or east).

Example 3: Electric Fields and Electric Force



A test charge of +5.00 C is placed a distance of 2.00 m to the right of the point charge –q. The strength of the electric field produced by this charge is 10.0 N/C at the location of the charge q.

What is the electric force acting on the charge q?

Given:	Charge	$q = +5.00\ \text{C}$
	Electric field intensity	$\vec{E} = 10.0\ \text{N/C}\ [\text{E}]$
Unknown:	Electric force	$\vec{F}_E = ?$
Equation:		$\vec{E} = \dfrac{\vec{F}_E}{\lvert q \rvert}$ rearranged to $\vec{F}_E = \lvert q \rvert \vec{E}$
Substitute and solve:		$\vec{F}_E = (5.00\ \text{C})(10.0\ \text{N/C}) = 50.0\ \text{N}$

The charge test charge, q, and the point charge producing the electric field, –q, are opposite in charge, so that charges attract each other. The direction of the force is to the left (or west).

Example 4: Electric Fields and Electric Force

A charge of –5.0 μC is placed in an electric field that is 250 N/C to the east. Determine the amount and direction of the electric force that the charge experiences there.

Given:	Charge	$q = -5.0\ \mu\text{C} = -0.0050\ \text{C}$
	Electric field intensity	$\vec{E} = 250\ \text{N/C}\ [\text{E}]$
Unknown:	Electric force	$\vec{F}_E = ?$
Equation:		$\vec{E} = \dfrac{\vec{F}_E}{\lvert q \rvert}$ rearranged to $\vec{F}_E = \lvert q \rvert \vec{E}$
Substitute and solve:		$\vec{F}_E = (0.0050\ \text{C})(250\ \text{N/C}) = 1.25\ \text{N} = 1.2\ \text{N}$

Since the charge was **negative**, the electric force and electric field must be in **opposite** directions, so the final answer is $\vec{F}_E$ = 1.2 N [W].

Electric Field and Force in One Dimension

In our work in dynamics, we reviewed how to add vectors.

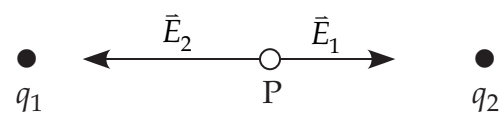
If there are two point charges located near each other, the electric field at a point around these charges will be the **vector sum** of the electric field due to the first charge, $\vec{E}_1$, and the electric field due to the second charge, $\vec{E}_2$.

$$\vec{E}_{\text{TOTAL}} = \vec{E}_1 + \vec{E}_2$$

Example 5: Electric Field and Force in One Dimension

In the situation below, there are two charges. The positive charge, q_1, on the left creates an electric field, $\vec{E}_1$, of 10.0 N/C to the right at position P. The positive charge on the right, q_2, creates an electric field, $\vec{E}_2$, of 15.0 N/C to the left at position P.

What is the total electric field at point P?



Since the two vectors are antiparallel, remember that the vector sum will be found by finding the difference between the magnitudes of $\vec{E}_1$ and $\vec{E}_2$, and then attaching the direction of the larger vector.

Let the positive direction be to the right.

The total electric field at position P is

$$\vec{E}_{\text{TOTAL}} = \vec{E}_1 + \vec{E}_2 = 10.0 \text{ N/C} + (-15.0 \text{ N/C}) = -5.0 \text{ N/C}$$
or 5.0N/C [left].

If a charge of 2.0 C is placed at position P, what electric force would the charge experience?

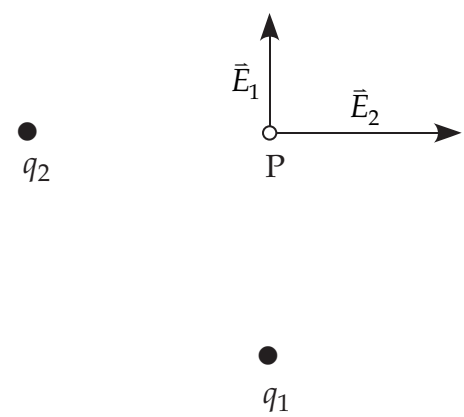
Given:	Charge	$q = 2.0$ C
	Electric field intensity	$\vec{E} = 5.0$ N/C [left]
Unknown:	Electric force	$\vec{F}_E = ?$
Equation:		$\vec{E} = \dfrac{\vec{F}_E}{\lvert q \rvert}$ rearranged to $\vec{F}_E = \lvert q \rvert \vec{E}$
Substitute and solve:		$\vec{F}_E = (2.0 \text{ C})(5.0 \text{ N/C}) = 10 \text{ N} = 1.0 \times 10^1 \text{ N}$

Since the charge was **positive**, the electric force and electric field must be in **the same** direction, so the final answer is $\vec{F}_E = 1.0 \times 10^1$ N [left].

Similarly, if a charge of –2.0 C is placed at P, then the force on this charge would be 1.0 x 10^1 N but the direction of the force would be opposite to the direction of the electric field, which is right.

Electric Field and Force in Two Dimensions

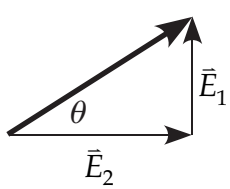
In the next situation, the two electric fields are at right angles relative to each other. The positive charge, q_1, creates an electric field of 10.0 N/C [north] while the charge, q_2, creates and electric field of 15.0 N/C [east].



The total electric field is the vector sum of the two given electric fields:

$$\vec{E}_{\text{TOTAL}} = \vec{E}_1 + \vec{E}_2 = 10.0 \text{ N/C [north]} + 15.0 \text{ N/C [east]}$$

In adding together the two electric field vectors, we attach them tip to tail.



The magnitude of the total electric field vector is

$$\vec{E}_{\text{T}} = \sqrt{(10.0 \text{ N/C})^2 + (15.0 \text{ N/C})^2} = 18.0 \text{ N/C}$$

The direction of this vector is

$$\theta = \tan^{-1}\left(\frac{10.0 \text{ N/C}}{15.0 \text{ N/C}}\right) = 33.7° \text{ N of E}$$

If a charge of 2.0 C is placed at position P, then the force on this charge is $\vec{F}_E = |q|\vec{E} = (2.0\text{ C})(18.0\text{ N/C}) = 36\text{ N}.$

The direction of this force is in the same direction as the electric field vector—that is, 33.7° N of E .

Similarly, if a charge of –2.0 C is placed at P, then the force on this charge would be 36 N. But the direction of the force would be opposite to the direction of the electric field, which is 33.7° S of W.

Learning Activity 5.2

Calculating Electric Fields and Electric Force

1. a) How many electrons are found in a charge of -1.25×10^{-7} C?

   b) What is the charge on an object with an excess of 4.85×10^{13} protons? (Include the sign of this charge.)

2. A positive point charge creates an electric field of 5.0×10^{4} N/C at a point P directly south of the charge. If a test charge of –2.0 C is placed at that place, then what is the magnitude and direction of the force on that charge?

3. A positive point charge, q_1, produces a field $\vec{E}_1$, of size 5.0 N/C at a location "P." A negative point charge, $-q_2$, produces an electric field $\vec{E}_2$ of size 10.0 N/C at the same location "P."

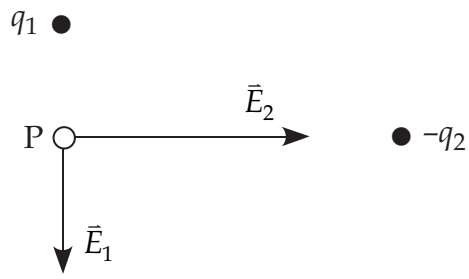
   a) Determine the magnitude and direction of the total electric field at "P."

   b) If a 4.5 C charge is placed at P, what is the magnitude and the direction of the force on this charge?

(continued)

Learning Activity 5.2: Calculating Electric Fields and Electric Forces (continued)

4. A positive point charge, q_1, produces a field, $\vec{E}_1$, of size 5.0 N/C at a location P. A negative point charge, $-q_2$, produces an electric field, $\vec{E}_2$, of size 10.0 N/C at the same location P.



a) Determine the magnitude and direction of the total electric field at P.

b) If a 4.0 C charge is placed at P, what are the magnitude and the direction of the force on this charge?

Lesson Summary

A **coulomb** is the internationally accepted SI unit of charge, q.

To determine the amount of **charge** in coulombs, multiply the number of elementary charges (protons or electrons) by the **magnitude of the elementary charge**.

$q = Ne$

The **electric field** at a point in space is calculated as the quotient of the **electric force** on an amount of charge and the **magnitude of the charge** located at that point.

$$\vec{E} = \frac{\vec{F}_E}{|q|}$$

This equation can be rearranged to solve for the electric force.

The amount of electric force, $\vec{F}_E$, acting on a test charge q in an electric field $\vec{E}$ is determined by $\vec{F}_E = |q|\vec{E}$.

The direction of the electric force and the electric field is the **same** for **positive charges** and opposite for **negative charges**.

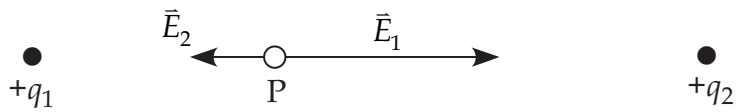
If there are two point charges located near each other, the electric field at a point around these charges will be the **vector sum** of the electric field due to the first charge, $\vec{E}_1$, and the electric field due to the second charge, $\vec{E}_2$.

$$\vec{E}_{\text{TOTAL}} = \vec{E}_1 + \vec{E}_2$$

Assignment 5.2, Part A

Calculating Electric Field and Electric Force (5 MARKS)

The $+q_1$ charge produces an electric field at the location of point P. The magnitude of this electric field is 3.60×10^{10} N/C. Another charge $+q_2$ to the right of point P produces an electric field of magnitude 1.60×10^{10} N/C at point P.



a) What is the total electric field strength at point P?

b) What force would a +5.00 C charge experience at this point P?

(continued)

Assignment 5.2, Part A: Calculating Electric Field and Electric Force (continued)

c) The charge q_1 is now removed. It is replaced by a charge $-q_3$. This charge is directly south of the point P and it produces an electric field of magnitude 2.60×10^{10} N/C. Draw a diagram representing the two electric fields. Then determine the magnitude and direction of the total electric field at P.

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Method of Evaluation

The total of five marks for this assignment will be determined as follows:

- 0.5 marks for determining the magnitude of the electric field for part (a)
- 0.5 marks for determining the direction of the electric field for part (a)
- 0.5 marks for determining the magnitude of the electric force for part (b)
- 0.5 marks for determining the direction of the electric force for part (b)
- 1 mark for drawing the electric field vectors in the correct direction for part (c)
- 1 mark for determining the correct magnitude of the electric field for part (c)
- 1 mark for determining the correct direction of the electric field for part (c)

Lesson 3: The Parallel Plate Apparatus (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- determine the electric force and the gravitational force on a charged particle and the acceleration of the particle between two charged parallel plates
- apply the equations for the motion of an object as discussed in kinematics

Key Words

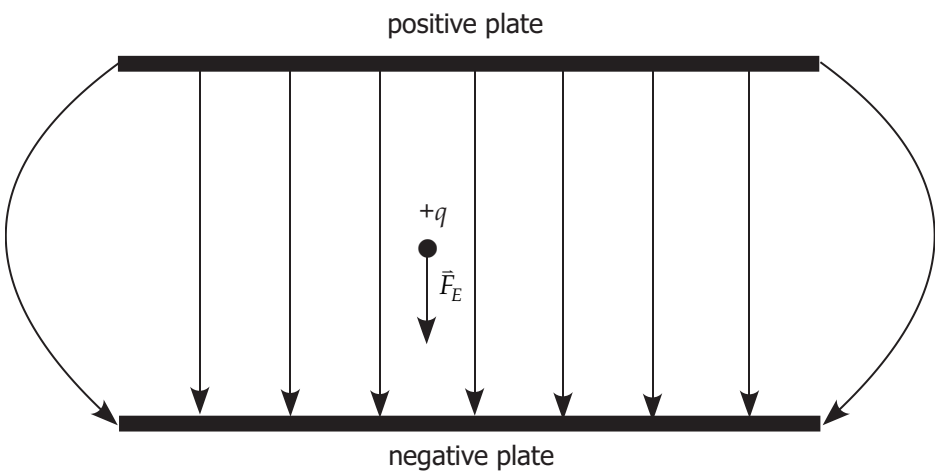
electric force	charge
elementary charge	gravitational force
electric field	parallel plate apparatus

Introduction

We conclude our discussion of electric fields with a discussion of a ground-breaking experiment performed by Millikan in the early 1900s. His work made it possible to calculate the charge in coulombs on an elementary charge, such as an electron or a proton. In order to understand this work better, we must first review the behaviour of a charged particle between two charged parallel plates separated from each other by a short distance. We will also show how Newton's Second Law and the equations describing the motion of a particle apply to a charged particle in an electric field created by two charged plates.

Charged Parallel Plates and Force

We have already studied the electric field line pattern between two charged parallel plates. The electric field lines point away from the positive plate towards the negative plate. There is a slight bulge at each edge of the plates.



In the region between the plates, the electric field lines are parallel and evenly spaced. This indicates that the electric field has the same magnitude and direction at all points.

If a positive point charge is placed between the plates, the net force on the charge will be in the same direction as the electric field lines. A negative point charge will be forced in a direction opposite to the electric field line direction.

The amount of the electric force on the charged particle can be determined by $\vec{F}_E = q\vec{E}$.

If the electric force is the only force acting on the charged object, then $\vec{F}_{\text{NET}} = \vec{F}_E$ and the acceleration of the object can be determined from Newton's Second Law: $\vec{F}_{\text{NET}} = m\vec{a}$.

Example 1: The Dynamics of a Charged Particle between Charged Parallel Plates

If the electric field strength between the charged plates is 10.0 N/C, and the object has a charge of q = +2.00 C and a mass of m = 4.00 x 10^{-4} kg, calculate the acceleration of the particle.

Given:	Electric field intensity	$\vec{E} = 10.0\ \text{N/C [down]}$
	Charge	q = +2.00 C
	Mass	m = 4.00 x 10^{-4} kg
Unknown:	Acceleration	$\vec{a} = ?$
Equation:		The net force on the particle is the electric force. Once we know the electric force, we can use Newton's Second Law to determine the acceleration. $\vec{F}_{\text{NET}} = \vec{F}_E = q\vec{E}$ Then use $\vec{F}_{\text{NET}} = m\vec{a}$ to find acceleration.
Substitute and solve:		$\vec{F}_{\text{NET}} = \vec{F}_E = q\vec{E} = (2.00\ \text{C})(10.0\ \text{N/C}) = 20.0\ \text{N}$ The electric force is down so the net force points down also. $\vec{F}_{\text{NET}} = m\vec{a}$ rearranged to $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m}$ $\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m} = \dfrac{20.0\ \text{N}}{4.00 \times 10^{-4}\ \text{kg}} = 5.00 \times 10^{4}\ \text{m/s}^2$

The direction of the acceleration is in the same direction as the force. For the diagram above, the charge would accelerate in the downward direction.

So what about the force of gravity?

If the charged plates are oriented in the direction as shown above, then the particle also experiences a force of gravity $\vec{F}_g$ acting downwards. The magnitude of this force is

$$\vec{F}_g = m\vec{g} = (4.00 \times 10^{-4}\ \text{kg})(9.80\ \text{N/kg}) = 3.92 \times 10^{-3}\ \text{N}.$$

Since both the electrical force and the force of gravity are acting downwards, the net force is

$$\vec{F}_{\text{NET}} = \vec{F}_E + \vec{F}_g = q\vec{E} + m\vec{g}$$
$$= (2.00\ \text{C})(10.0\ \text{N/C}) + (4.00 \times 10^{-4}\ \text{kg})(9.80\ \text{N/kg}) = 20.0\ \text{N}$$

The effect of the gravitational force is negligible compared to the electric force.

So in this case the acceleration of the particle is caused almost completely by the electric force.

Charged Parallel Plates and Kinematics

You should recognize that we have been analyzing the dynamics of this situation in order to find the net force. We then used Newton's Second Law to determine the acceleration. The next logical step is to consider the kinematics of the situation.

Since this is accelerated motion, we can use kinematics equations #2 through #5 to solve kinematics problems.

Here are the equations:

Kinematics Equation 2: $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ or $\vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$

Kinematics Equation 3: $\vec{d} = \frac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$

Kinematics Equation 4: $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$

Kinematics Equation 5: $v_2^2 = v_1^2 + 2ad$

Quantity	Symbol	Unit
Displacement	$\vec{d}$	metres (m)
Velocity	$\vec{v}$	metres/second (m/s)
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)
Time interval	Δt	seconds (s)
Initial velocity	$\vec{v}_1$	metres/second (m/s)
Final velocity	$\vec{v}_2$	metres/second (m/s)

Example 2: The Kinematics of a Charged Particle between Charged Parallel Plates

In the dynamics section of this example, we saw that a charge of +2.00 C accelerated downwards at a rate of 5.00×10^4 m/s^2 downwards, or -5.00×10^4 m/s^2.

Calculate

a) the change in velocity during 6.00 μs (6.00 x 10^{-6} s) of acceleration

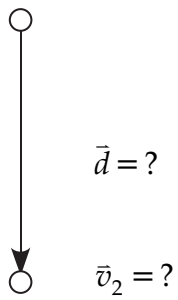
b) the final velocity if the particle started from rest

c) the displacement during this time interval

Solution

We are now working with kinematics. Let downward be the negative direction.

Given:



$\vec{v}_1 = 0 \text{ m/s}$

$\vec{a} = -5.00 \times 10^4 \text{ m/s}$

$\Delta t = 6.00 \times 10^{-6} \text{ s}$

a) Unknown: Change in velocity $\Delta\vec{v} = ?$

Equation: Use equation #2.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ rearranged to } \Delta\vec{v} = \vec{a}\Delta t$$

Substitute and solve:

$$\Delta\vec{v} = \vec{a}\Delta t = \left(-5.00 \times 10^4 \text{ m/s}\right)\left(6.00 \times 10^{-6} \text{ s}\right)$$
$$= -0.300 \text{ m/s}$$

The velocity of the particle changes by 0.300 m/s [down].

b) Unknown: Final velocity $\vec{v}_2 = ?$

Equation: Again, use equation #2 but rearranged to $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$.

Substitute and solve:

$$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t = 0 \text{ m/s} + \left(-0.300 \text{ m/s}\right)$$
$$= -0.300 \text{ m/s}$$

The final velocity of the particle is –0.300 m/s.

c) Unknown: Displacement $\vec{d} = ?$

Equation: You may use any of the three remaining kinematics equations. Let us use #3.

$$\vec{d} = \frac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$$

Substitute and solve:

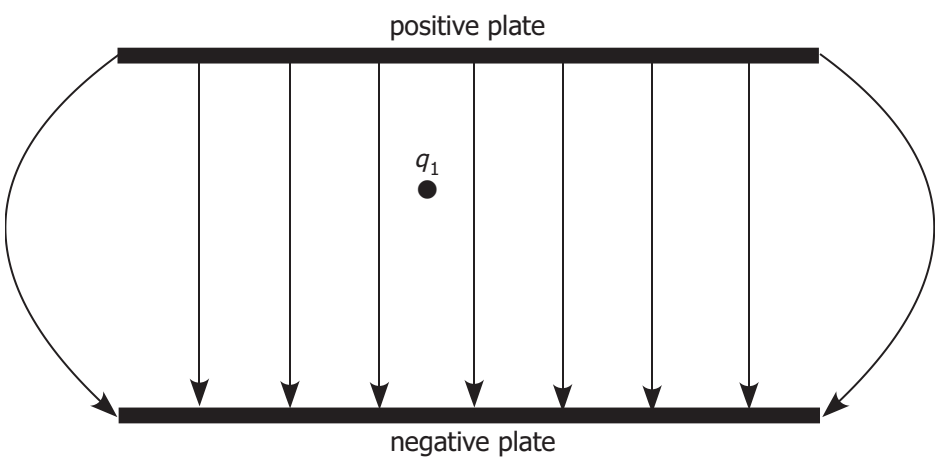
$$\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$$
$$= \frac{(0\ \text{m/s}) + (-0.300\ \text{m/s})}{2}(6.00 \times 10^{-6}\ \text{s})$$
$$= -9.00 \times 10^{-7}\ \text{m}$$

The particle moves –9.00 x 10^{-7} m or 9.00 x 10^{-7} m [down].

Learning Activity 5.3

The Parallel Plate Apparatus

1. A charge, q_1 = +5.00 C, is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 4.00 N/C. The mass of the charged particle is m = 2.00 x 10–4 kg.



a) Determine the magnitude and direction of the electric force on the charged particle between the plates.

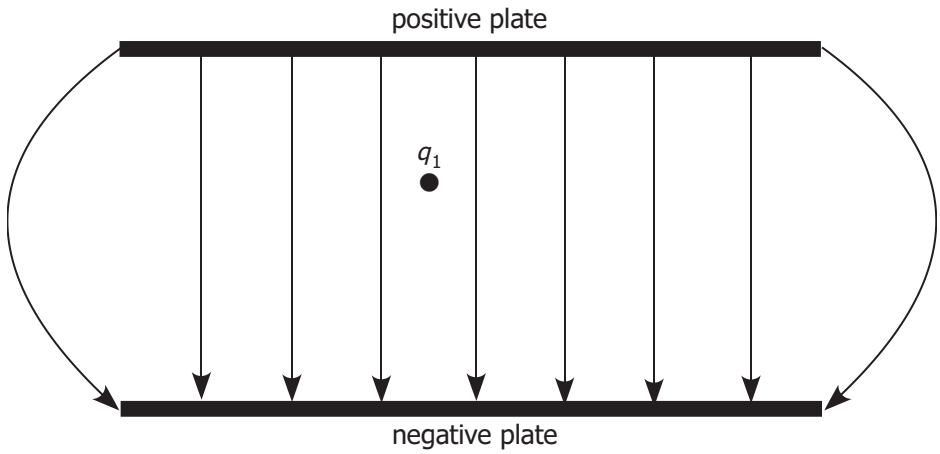
b) Determine the magnitude and direction of the acceleration on the charged particle between the plates.

c) If the particle is released from rest, what will be the displacement of the particle after a time of 8.00 ms (8.00 x 10^{-3} s)?

(continued)

Learning Activity 5.3: The Parallel Plate Apparatus (continued)

2. A charge, q_1 = –2.00 C, is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 6.00 N/C. The mass of the charged particle is m = 5.00 x 10^{-4} kg.



a) Determine the magnitude and direction of the electric force on the charged particle between the plates.

b) Determine the magnitude and direction of the acceleration on the charged particle between the plates.

c) If the particle is released from rest, what will be the final velocity of the particle after a time of 4.00 ms (4.00 x 10^{-3} s)?

Lesson Summary

The analysis of the motion of a charged particle between two charged parallel plates allows us to use the dynamics-Newton's Second Law-kinematics method.

Here is the **dynamics** portion of the situation.

For a charged particle between two charged plates, the net force on the particle is the sum of the electrical force and the gravitational force on the particle: $\vec{F}_{\text{NET}} = \vec{F}_E + \vec{F}_g$.

The electrical force is $\vec{F}_E = |q|\vec{E}$ and the gravitational force is $\vec{F}_g = m\vec{g}$.

Now link **dynamics** and **kinematics** using Newton's Second Law.

The acceleration of the particle is found using Newton's Second Law: $\vec{F}_{\text{NET}} = m\vec{a}$.

Lastly, analyze the **kinematics**.

To analyze the motion of a charged object in an electric field, we can apply the kinematic equations.

Here are the equations:

Kinematics Equation 2: $\vec{a} = \dfrac{\Delta\vec{v}}{\Delta t}$ or $\vec{a} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$

Kinematics Equation 3: $\vec{d} = \dfrac{1}{2}\left(\vec{v}_1 + \vec{v}_2\right)\Delta t$

Kinematics Equation 4: $\vec{d} = \vec{v}_1\Delta t + \dfrac{1}{2}\vec{a}\Delta t^2$

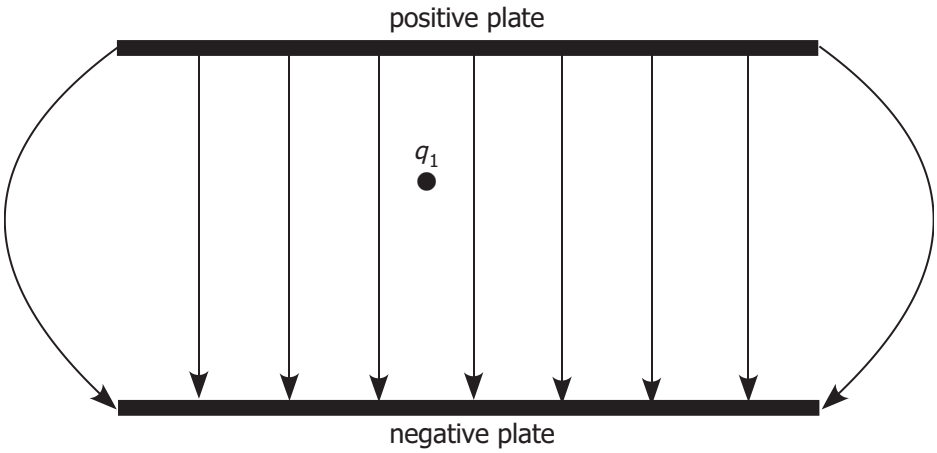
Kinematics Equation 5: $v_2^2 = v_1^2 + 2ad$

Quantity	**Symbol**	**Unit**
Displacement	$\vec{d}$	metres (m)
Velocity	$\vec{v}$	metres/second (m/s)
Acceleration	$\vec{a}$	metres/second^2 (m/s^2)
Time interval	Δt	seconds (s)
Initial velocity	$\vec{v}_1$	metres/second (m/s)
Final velocity	$\vec{v}_2$	metres/second (m/s)

Assignment 5.2, Part B

The Parallel Plate Apparatus (5 MARKS)

A charge, q_1 = –4.00 C is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 4.00 N/C. The mass of the charged particle is m = 2.50 x 10^{-4} kg.



a) Determine the magnitude and direction of the electric force on the charged particle between the plates.

(continued)

Assignment 5.2, Part B: The Parallel Plate Apparatus (continued)

b) Determine the magnitude and direction of the acceleration of the charged particle between the plates.

c) If the particle is released from rest, what will be the displacement of the particle after a time of 5.00 ms (5.00×10^{-3} s)?

Method of Evaluation

The total of five marks for this assignment will be determined as follows:

- 1 mark for the correct direction of the electric force in part (a)
- 1 mark for the correct magnitude of the electric force in part (a)
- 1 mark for the correct acceleration in part (b)
- 2 marks for the correct displacement in part (c)

Lesson 4: The Millikan Experiment (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ determine the electric force and the gravitational force on a charged particle and the acceleration of the particle between two charged parallel plates
- ❑ explain what Millikan attempted to determine in his experiment, and how he determined it
- ❑ state the value of an elementary charge in coulombs
- ❑ convert between a charge in coulombs and the number of elementary particles in the charge

Key Words

electric force
elementary charge
Millikan experiment
electric field
charge
force of gravity
coulomb

Introduction

Earlier, we stated that there are two units for electric charge: the elementary charge, which by definition is the amount of charge on a single proton or electron; and the coulomb, which is the SI unit of charge. We have also shown how these two units compare: $1\ e = 1.6 \times 10^{-19}$ C. In this lesson, you will learn how a famous experiment performed by Robert Millikan in the early 1900s used the same physics we have seen so far to determine this.

Determining the Mass of a Paperclip

Suppose you have been given the task to determine the mass of a paperclip from a collection of paperclips (all of which are the same mass). You are to determine this mass by making measurements and by following one important rule: you may not at any point look at, touch, or in any way directly interact with a paperclip. You have to determine the mass yourself; you may not, for example, "look it up" or ask somebody.

This rule may give you the impression that it won't be possible to measure the mass of a paperclip, but don't worry. It is entirely possible, especially considering that you will be allowed to do the following: you may use a container of which you know the mass, and I will place a random number of paperclips from my collection into your container. Remember that you can't see the paperclips, so the container has to be sealed and not see-through. You could then put your container (with an unknown number of paperclips in it) on a scale and subtract the mass of the container in order to calculate the mass of the paperclips.

Would this tell you the mass of a single paperclip? Of course not! You have no idea how many paperclips are in your container (and you have no way of finding out according to the rule). But you may return your container to have it filled with a new (possibly different) random number of paperclips in it as many times as you like. Each of these "rounds" is a new "trial."

Trial 1: Suppose you determine the mass of the paperclips to be 40 grams. Can you conclude anything? Remember, you don't know how many paperclips are in there. You may be tempted to say that you can't conclude anything, but you can: You can confidently state that the paperclips have a mass of "no more than 40 grams." In other words, using "m_c" for the mass of a single paperclip, you can conclude $m_c \leq 40$ g (the "≤" symbol stands for "less than or equal"). This means that a single paperclip may be 40 grams (which would mean that there was a single paperclip in the container), but it could be less (there may be two or more in the container).

Trial 2: Suppose you determine the mass of the paperclips in this trial to be 20 grams. Using similar logic, you can conclude that $m_c \leq 20$ g.

Trial 3: In this trial, let's suppose the mass of the paperclips is found to be 30 grams. At first, you might be disappointed and tempted to say that we haven't learned anything we didn't already know from the first two trials. But this trial has given us new information! With a mass of 30 grams found, we now know that there is no way that a paperclip could be 20 grams, which was our previous conclusion based on trial 2. The "trick" here is not to look at the value of any one trial by itself, but rather all of the trials completed so

far. We need to think of a mass for a paperclip that could explain the first trial (40 g), the second trial (20 g), and this trial of 30 grams. There are many possibilities: maybe the paperclips are 2 grams each (this would be true if there had been 20 paperclips in the first trial, 10 in the second trial, and now 15 in this trial). Then again, maybe the paperclips are 1 gram each (40, 20, and 30 paperclips).

While we don't know, we can at least find the "biggest possible" mass for a paperclip that could work. In essence, we are looking for the largest value that can "explain" all of our trials. In this case, this value is 10 grams. There is no larger value that could lead to the data we have found so far. This means that our new conclusion is $m_c \leq 10$ g.

To summarize, we can record our findings and conclusions in a chart:

Trial #	Mass of Paperclip(s)	Conclusion So Far
1	40 g	$m_c \leq 40$ g
2	20 g	$m_c \leq 20$ g
3	30 g	$m_c \leq 10$ g

Now suppose that a few more trials are conducted, as summarized here:

Trial #	Mass of Paperclip(s)	Conclusion So Far
4	50 g	$m_c \leq 10$ g
5	20 g	$m_c \leq 10$ g
6	35 g	$m_c \leq 5$ g

Notice that trials 4 and 5 didn't really reveal any new knowledge. Thinking of a single paperclip being "no more than 10 grams," we can easily explain the 50-gram trial as well as the 20-gram trial. However, in the 6th trial we learn something new: with an observed mass of 35 grams, there is no way for the paperclips to be 10 grams each. The conclusion of $m_c \leq 5$ g was again reached by thinking of the largest mass that explains all of the trials so far.

Now for the really important part: suppose that *hundreds* of trials are completed. Suppose that there are many trials that contained a mass of 15 grams, many that contained a mass of 25 grams, many with 30 grams, many with 35 grams (etc.), BUT never once was there a trial with a mass of 22 grams or a mass of 38 grams or a mass of 17.5 grams. In other words, suppose that ALL of the trials are whole-number multiples of 5 grams.

This would mean that the final column of our chart would have been reading "$m_c \leq 5$ g" for a very long time. At this point, we are prepared to make a "logical jump" to a new conclusion: the mass of a single paper clip *is* 5 grams: $m_c = 5$ g, which explains all of the trials. Note that it is still mathematically possible for the mass to be something else. After all, a paperclip mass of 2.5 grams would also explain all of the trials. Our conclusion that $m_c = 5$ g comes from the following reasoning:

Since the number of paperclips in each trial was *random*, then in order for the mass to be anything other than 5 gram multiples—such as 2.5 grams, or 17.5 grams—it would have required the extraordinarily unlikely coincidence that each and every trial contained an even number of paperclips. When we only have a few trials, we are not willing to rule this out. Given a large number of trials, we are.

It is sort of like flipping a coin. If a coin is tossed and comes up "heads," we don't really think much of it. Even if it comes up heads 3 or 4 times in a row, we should not think much of it. If a coin was tossed hundreds of times, and came up heads *every single time*, we would be right to be suspicious of the coin. Strictly speaking, it is possible for a regular coin to come up heads hundreds of times in a row, but this is so unlikely that we tend to think of it as being practically impossible.

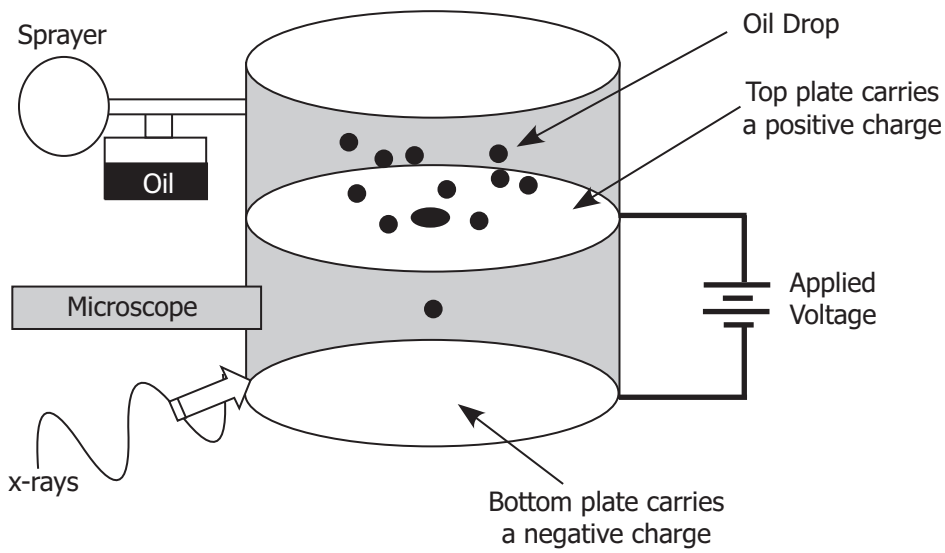
The Millikan Experiment

At the turn of the last century, when the understanding of electric forces was beginning to increase, two fundamental questions arose regarding the nature of electric charge.

1. Does there exist in nature a smallest unit of electric charge of which all other units are multiples?
2. If so, what is this elementary charge, and what is its magnitude in coulombs?

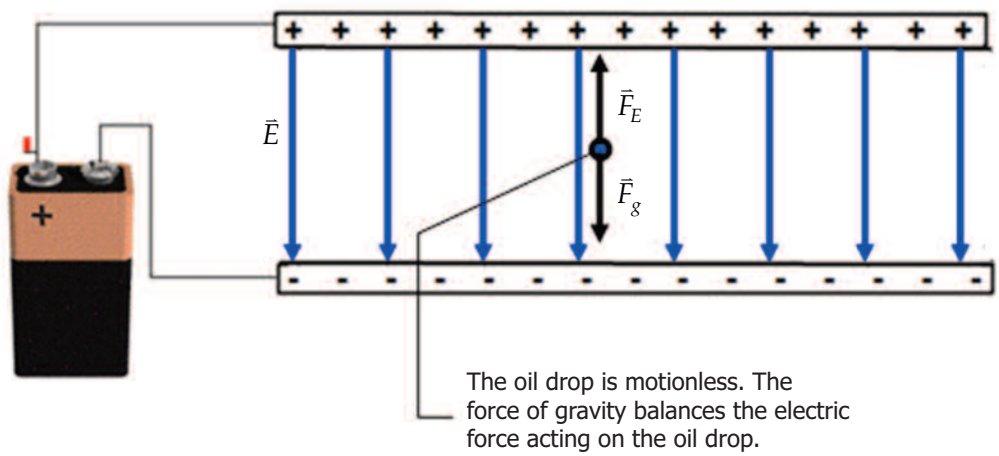
In determining the amount of charge on a single proton or electron, we are faced with the problem that individual electrons and protons are far too small to be seen or to directly interact with (sound familiar?) In spite of this, Millikan devised an ingenious way to measure their charge.

Millikan did this by obtaining a small neutral "package" onto which a random number of excess elementary charges could be placed (which means that it would no longer be neutral). Millikan could get a random charge on the package by a brief exposure to radiation, but he simply could not tell how many elementary charges were in the package. He did however come up with a clever way of determining the charge of the whole package, and did so for many trials. After many such trials, he was able to come up with a conclusion, which was the amount of charge for a single elementary charge.



He started with a set of horizontal parallel plates. Parallel plates can have a voltage applied to them (for example, by connecting a battery to them). This will charge the plates (top plate positive and bottom plate negative), and create a constant electric field between them (more on this in Grade 12 Physics). Millikan could control the electric field easily—and knew how strong it was. In between these plates, he placed a "charge package."

This charged object would have two forces acting: $\vec{F}_g$ would be downward, and $\vec{F}_E$ could be made to be upward. If the mass of the object is known, then the force of gravity could be easily calculated $\left(\vec{F}_g = m\vec{g}\right)$. By adjusting the electric field, he could find the electric field that would result in the object remaining motionless, suspended in mid-air—levitating.



With the charged object suspended motionless, it should be clear that there is no net force (otherwise it would have to be accelerating). This means that the upward electric force $\vec{F}_E$ must exactly match the size of the downward gravitational force $\vec{F}_g$. If $\vec{F}_g$ is known, then $\vec{F}_E$ is known too (it's the same size). Knowing $\vec{F}_E$ and the electric field strength $\vec{E}$, it is quite easy to find the charge q.

Here is a summary in case you had trouble following all of these details:

- Millikan knew the mass of his charged object, and so could calculate the downward force of gravity: $\vec{F}_g = m\vec{g}$
- Millikan knew that the package was charged (q) but didn't know how much charge it had, and didn't know how many individual protons or electrons (elementary charges) were causing this charge.
- He used parallel plates for which he knew and controlled the electric field $(\vec{E})$ in order to produce an electric force to exactly balance the force of gravity (the package was stationary): $\vec{F}_E = \vec{F}_g$
- Since the force of gravity is known, he automatically knew the electric force.
- Since he knew the electric force and the electric field, he could calculate the amount of charge (q) on the package: $\vec{F}_E = |q|\vec{E} \rightarrow |q| = \frac{\vec{F}_E}{\vec{E}}$

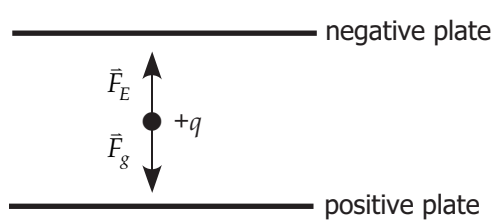
Millikan could find the charge of the "package" in the way described, but that is not what he was really interested in. He was trying to find the charge of individual protons (and electrons). He knew that the charged object was charged because it had a certain number of excess protons (or electrons) giving it its charge. Ordinary objects that are charged have very many excess protons (or electrons) giving it a charge, so Millikan did something very clever: he chose a very small object! A small object can only hold a small charge, so the number of excess elementary charges on it would be small. In

fact, the smaller the object is, the better. Millikan chose the smallest object that he could produce and still see: a tiny drop of oil—one that came from an atomizer (like that found on a perfume or Windex bottle). By the way, oil has the advantage that it won't evaporate.

Fine, Millikan can find the charge on a tiny drop of oil, but he still doesn't know the charge of an individual elementary charge (because he doesn't know how many were on the oil drop). This is exactly the same problem we had when discussing the mass of a paperclip. For the same reasons, he found the charge of the oil drops over and over and over! He then analyzed the charges of all the drops, looking for a pattern. He found what he was looking for: every drop had a charge that was a multiple of a common number, the modern value of which is 1.6×10^{-19} C. Since he (and nobody ever since) has found an object with a charge that is not a multiple of this number, he made the conclusion that 1.6×10^{-19} C is the charge of a single elementary charge.

Calculating the Charge on an Oil Drop

Here is a diagram showing these ideas with a small, positively charged oil drop. Note that the parallel plates would produce an upward electric field (from positive plate to negative plate) that produces an upward electric force on the oil drop.



When the oil droplet is in balance, then $\vec{F}_E = \vec{F}_g$, and $q\vec{E} = m\vec{g}$. The charge of the oil drop can then be determined by $q = \frac{m\vec{g}}{\vec{E}}$.

Example: The Charge on an Oil Drop

An oil drop of mass 1.22×10^{-14} kg is held motionless between the plates of the parallel plate apparatus. The electric field between the plates is 1.50×10^{5} N/C. The top plate is negatively charged.

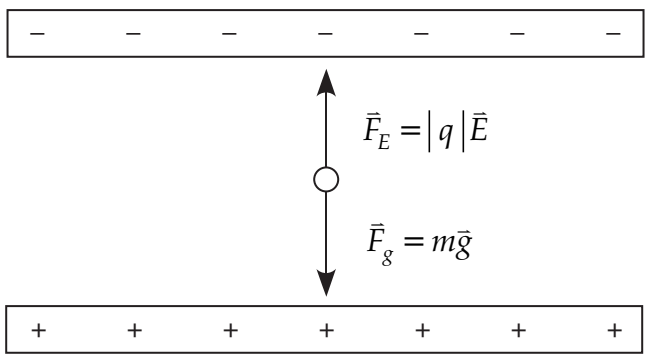
a) Draw a free-body diagram of this situation.

b) Determine the charge on the oil drop in coulombs.

c) Determine the number and type of excess elementary charges on the oil drop.

Solution

a)



b) Given: Mass $m = 1.22 \times 10^{-14}$ kg

Electric field $\vec{E} = 1.50 \times 10^5$ N/C

Gravitational field intensity $\vec{g} = 9.80$ N/kg

Unknown: Charge $q = ?$

Equation: The electric force and the force of gravity balance, so

$\vec{F}_E = \vec{F}_g$ and

$q\vec{E} = m\vec{g}$ so $q = \dfrac{m\vec{g}}{\vec{E}}$

Substitute and solve:

$$q = \frac{m\vec{g}}{\vec{E}} = \frac{(1.22 \times 10^{-14}\ \text{kg})(9.80\ \text{N/kg})}{1.50 \times 10^5\ \text{N/C}}$$

$$= 7.97 \times 10^{-19}\ \text{C}$$

The charge on the oil drop is 7.97×10^{-19} C.

c) To determine the number of elementary charges, use the equation $q = \text{N}e$.

Given: Charge $q = 7.97 \times 10^{-19}$ C

Elementary charge $e = 1.60 \times 10^{-19}$ C

Unknown: Number of charges N = ?

Equation: $q = \text{N}e$ rearranged to $\text{N} = \dfrac{q}{e}$

Substitute and solve:

$$\text{N} = \frac{q}{e} = \frac{7.97 \times 10^{-19}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}/e} = 5$$

There is an excess of five elementary charges on the oil drop. Since the oil drop is attracted to the negatively charged top plate, the oil drop carries an excess positive charge. Therefore, the oil drop has an excess of five protons.

Learning Activity 5.4

The Millikan Drop Experiment

1. Most experiments in atomic physics are performed in a vacuum. Describe how performing it in a vacuum would affect the Millikan oil drop experiment.
2. How many electrons must be removed from an electrically neutral silver dollar to give it a charge of +2.4 μC?
3. What is the charge on an electroscope that has a deficit of 4.0×10^{11} electrons?
4. Small charges are measured in microcoulombs (μC). A shock of 1.1 μC is passed from one student to another in a dry physics classroom. How many electrons were transferred?
5. An oil drop, whose mass is found to be 4.95×10^{-15} kg, is balanced between two large horizontal plates with the upper plate positive. The electric field strength between the plates is $\vec{E} = 5.10 \times 10^{4}$ N/C. What is the charge on the oil drop, both in coulombs and in elementary charges, and is it an excess or deficit in electrons?
6. An oil drop having a charge of 6.40×10^{-19} C is suspended between two charged parallel plates where the electric field is 1.50×10^{5} N/C. What is the mass of the oil drop?
7. In a Millikan oil drop experiment, a drop of oil was found to have a mass of 1.94×10^{-15} kg. When the electric field is 4.00×10^{4} N/C pointing down, the drop is held motionless.
   a) What is the charge on the drop?
   b) Did the drop have an excess or deficit of electrons? How many electrons were in excess or deficit?

Lesson Summary

In his experiment, Millikan attempted to determine the answer to two questions:

1. Does there exist in nature a smallest unit of electric charge of which all other units are multiples?
2. If so, what is this elementary charge, and what is its magnitude, in coulombs?

Using a charged oil droplet between two charged plates, Millikan was able to suspend the particle between the two plates. This meant that the upward electrical force equaled the downward pull of gravity.

$\vec{F}_E = \vec{F}_g$ and $q\vec{E} = m\vec{g}$

The charge on the charged particle can then be determined by $q = \frac{m\vec{g}}{\vec{E}}$.

The currently accepted value for the elementary charge is $1.602\,177\,33 \times 10^{-19}$ C. Thus, the total charge, q, on any object is a whole number multiple, N, of this elementary charge, e.

$q = \mathrm{N}e$

The number of elementary charges in 1 C is

$$\mathrm{N} = \frac{1}{1.60217733 \times 10^{-19}\ \mathrm{C}/e} = 6.24 \times 10^{18}\ e.$$

Assignment 5.2, Part C

The Millikan Drop Experiment (6 MARKS)

In a Millikan-type experiment, two horizontal plates are separated by a distance of 2.50 cm, and the upper plate is positive. The voltage to the plates is adjusted so that a 1.50×10^{-15} kg sphere remains stationary.

a) Draw a free-body diagram showing the forces acting on the charged sphere *q*. Label the force vectors with appropriate symbols identifying the forces involved.

b) Is the sphere charged negatively or positively? Explain.

c) If the electric field intensity is 1.84×10^{4} N/C, what must be the charge on the sphere?

(continued)

Assignment 5.2, Part C: The Millikan Drop Experiment (continued)

d) How many elementary charges does this correspond to?

e) If the electric field is turned off, and the charged sphere begins to fall, what will its displacement be after a time of 1.00 ms? Assume that air resistance over this short time is negligible.

Method of Evaluation

The total of six marks for this assignment will be determined as follows:

- 1 mark for each of the four parts (a), (b), (c), and (d)
- 0.5 marks for the correct acceleration in part (e)
- 0.5 marks for the correct conversion of the time in part (e)
- 1 mark for determining the displacement in part (e)

Module 5 Summary

Congratulations on completing Module 5.

Submitting Your Assignments

You will not submit your Module 5 assignments to the Distance Learning Unit at this time. Instead, you will submit them, along with the Module 6 assignments, **when you have completed Module 6**.

You are now ready to start Module 6.

NOTES

Grade 11 Physics (30S)

Module 5: Electric Fields

Learning Activity Answer Keys

Module 5: Electric Fields

Learning Activity 5.1: Electric Fields

1. a) How are a gravitational field and an electric field similar?

   Answer:

   They both exert forces.

   b) How are a gravitational field and an electric field different?

   Answer:

   A gravitational field interacts with mass while an electric field interacts with charge. A gravitational field only exerts attractive forces while an electric field can exert attractive forces and repulsive forces.

2. Why is an electric field considered a vector quantity?

   Answer:

   An electric field has both magnitude and direction.

3. a) What are electric field lines?

   Answer:

   These are lines that depict the electric field showing its direction and relative strength at a given point.

   b) How does the direction of an electric field line compare with the direction of the force that acts on a positive test charge in the same region?

   Answer:

   The directions are the same.

4. How is the strength of an electric field indicated with field lines?

   Answer:

   The closer the lines of an electric field, the stronger the field is.

5. How do the electric field lines appear when the field has the same strength as all points in a region?

   Answer:

   The electric field lines will be parallel and equally spaced.

6. The vectors for the gravitational field of earth point toward earth; the vectors for the electric field of a proton point away from the proton. Explain.

   Answer:

   The force of gravity on any mass above the earth's surface will point towards the earth. Therefore, the gravitational field of the earth points towards the earth.

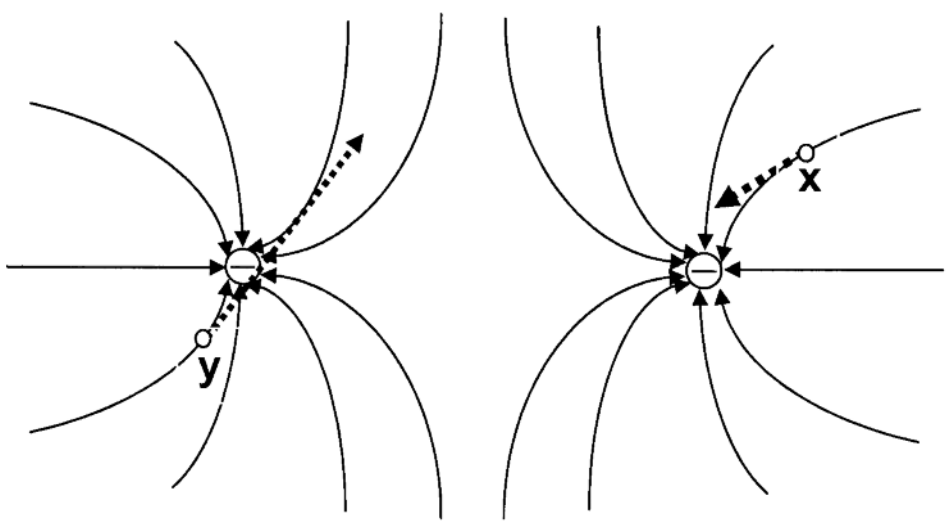
   By convention, the direction of the electric field is given by the direction of the force acting on a positive test charge. A proton (positive charge) will repel the positive test charge, resulting in an electric field line that points away from the proton.

7. Draw two points indicating negative charges. The points should be separated by a short distance. Add to your diagram the following:

   a) Draw the electric field line pattern for the two negative point charges.

      Answer:

      The diagram below shows a possible field line pattern. It is identical to the pattern for two positive charges, but the direction of the lines is reversed.



   b) Place an "x" at a point about two centimetres away from the right negative charge. Place the "x" on a field line at about 60° north of east of this charge. Draw a possible vector representing the electric field strength at this point.

      Answer:

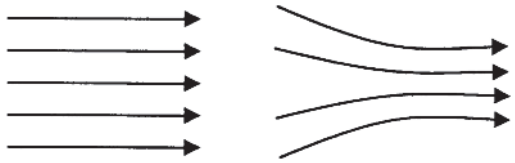
      The approximate location of the "x" is shown above. The vector representing the direction of the electric field at that point is shown tangent to the line.

c) In a similar way, place the letter "y" on an electric field line about one centimetre away from the left negative charge at a direction of about 45° south of west of the charge. Draw a vector representing the strength of the electric field at this point. Be sure that the length and the direction of this vector show how the field strength at "y" is different from the field strength at "x."

Answer:

The approximate location of "y" is shown above. The length of this vector is longer than the one at "x" because it is closer to the charge and the electric field is stronger at this point. The direction is tangent to the field line.

8. Diagrams 1 and 2 show two examples of electric field lines.



1 2

Decide which of the following statements are true and which are false, defending your choice in each case.

a) In both 1 and 2, the electric field is the same everywhere.

Answer:

False. In 1, the electric field is the same everywhere. In 2, the electric field increases as you go to the right.

b) As you move from the left to the right in each case, electric field becomes stronger.

Answer:

False. The electric field becomes stronger in 2 but remains constant in 1.

c) The electric field in 1 is the same everywhere but the electric field in 2 becomes stronger as you move from left to right.

Answer:

True. The equally spaced lines in 1 indicate a uniform electric field, but in 2 the lines coming closer together indicate an increasing electric field.

d) The electric fields in both 1 and 2 are created by negative charges located somewhere on the left and positive charges located somewhere on the right.

Answer:

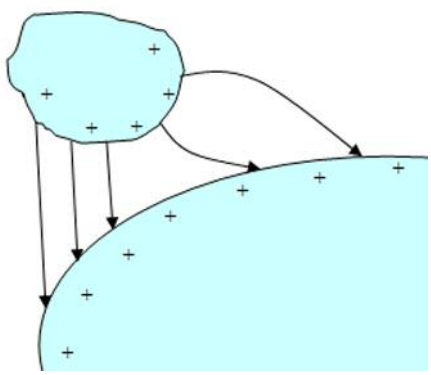
False. Since the electric field lines point to the right, the negative charges must be on the right side.

e) Both 1 and 2 arise from a single positive point charge located somewhere to the left.

Answer:

False. The electric field around a point charge looks like the spokes on a bicycle wheel—they radiate outwards from the point charge, getting farther and farther apart. Neither 1 nor 2 fit this pattern.

9. The drawing below is supposed to show the electric field lines in the region between the two charged metal conductors. Give two reasons why this drawing is incorrect.



Answer:

Reason 1: Electric field lines point from positive charge towards negative charge. Here, the field lines point towards a positive charge.

Reason 2: The lines of the electric field should meet the surface of a conductor at a 90° angle. This does not occur for any of the lines.

Learning Activity 5.2: Calculating Electric Field and Electric Force

1. a) How many electrons are found in a charge of -1.25×10^{-7} C?

Answer:

Given: Charge $q = -1.25 \times 10^{-7}$ C

Elementary charge $e = 1.60 \times 10^{-19}$ C

Unknown: Number of elementary charges N = ?

Equation: $q = Ne$ rearranged to $N = \frac{q}{e}$

Substitute and solve: $N = \frac{q}{e} = \frac{1.25 \times 10^{-7}}{1.60 \times 10^{-19}} = 7.81 \times 10^{11}$

The number of electrons is 7.81×10^{11}.

b) What is the charge on an object with an excess of 4.85×10^{13} protons? (Include the sign of this charge.)

Answer:

Given: Number of elementary charges $N = 4.85 \times 10^{13}$

Elementary charge $e = 1.60 \times 10^{-19}$ C

Unknown: Charge q = ?

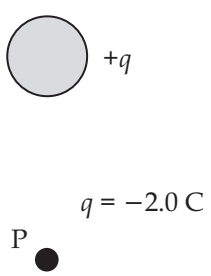
Equation: $q = Ne$

Substitute and solve: $q = (4.85 \times 10^{13})(1.60 \times 10^{-19}\ \text{C})$
$= 7.76 \times 10^{-6}$ C

The charge is $+7.76 \times 10^{-6}$ C.

2. A positive point charge creates an electric field of 5.0×10^{4} N/C at a point P directly south of the charge. If a test charge of –2.0 C is placed at that place, then what is the magnitude and direction of the force on that charge?

Answer:



One way to approach this problem is to disregard the sign of the test charge to calculate the magnitude of the force. Then the direction of the force will be added from our understanding of the forces between unlike charges, or from our knowledge of the relationship between the direction of the electric field and the sign of the test charge.

The magnitude of the force on the charge is
$\vec{F}_e = q\vec{E} = (2.0\ \text{C})(5.0 \times 10^{4}\ \text{N/C}) = 1.0 \times 10^{5}$ N.

Since the point charge is positive, the direction of the electric field is south.

Since the test charge is negative, the direction of the electric force will be opposite to the direction of the field—that is, north.

3. A positive point charge, q_1, produces a field $\vec{E}_1$, of size 5.0 N/C at a location "P." A negative point charge, $-q_2$, produces an electric field $\vec{E}_2$, of size 10.0 N/C at the same location "P."

a) Determine the magnitude and direction of the total electric field at "P."

Answer:

Let to the right or east be the positive direction.

The total electric field at position P is $\vec{E}_{\text{TOTAL}} = \vec{E}_1 + \vec{E}_2$ = –5.0 N/C or 5.0 N/C west.

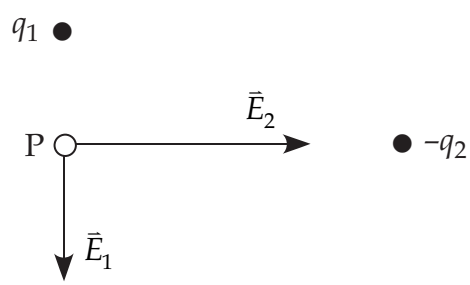
b) If a 4.5 C charge is placed at P, what is the magnitude and the direction of the force on this charge?

Answer:

The magnitude of the force is $\vec{F} = q\vec{E}_{\text{T}} = (4.5\text{ C})(5.0\text{ N/C}) = 22\text{ N}$.

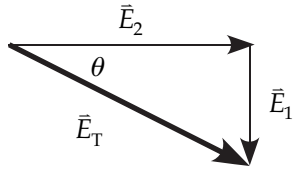
The direction of this force is in the same direction as the electric field vector—that is, west.

4. A positive point charge, q_1, produces a field, $\vec{E}_1$, of size 5.0 N/C at a location P. A negative point charge, $-q_2$, produces an electric field, $\vec{E}_2$, of size 10.0 N/C at the same location P.



a) Determine the magnitude and direction of the total electric field at P.

Answer:



In adding together the two electric field vectors, we attach them tip to tail.

The magnitude of the total electric field vector is

$$\vec{E}_T = \sqrt{(5.0\ \text{N/C})^2 + (10.0\ \text{N/C})^2} = 11.18\ \text{N/C or } 11\ \text{N/C}.$$

The direction of this vector is

$$\theta = \tan^{-1}\left(\frac{5.0\ \text{N/C}}{10.0\ \text{N/C}}\right) = 26.57°\ \text{S of E or } 27°\ \text{S of E}.$$

b) If a 4.0 C charge is placed at P, what is the magnitude and the direction of the force on this charge?

Answer:

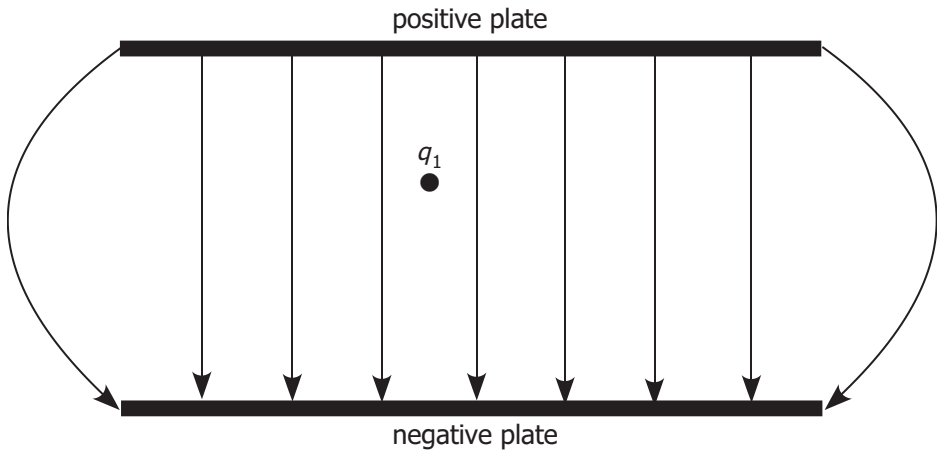
The magnitude of the force is $\vec{F} = q\vec{E}_T = (4.0\ \text{C})(11\ \text{N/C}) = 44\ \text{N}$.

The direction of this force is in the same direction as the electric field vector—that is, 27° S of E.

Learning Activity 5.3: The Parallel Plate Apparatus

There are two practice questions in this assignment. An answer key is available at the end of the module for you to check your answers after you have completed the practice questions.

1. A charge, q_1 = +5.00 C, is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 4.00 N/C. The mass of the charged particle is m = 2.00 x 10^{-4} kg.



a) Determine the magnitude and direction of the electric force on the charged particle between the plates.

Answer:

Given:	Charge	q_1 = +5.00 C
	Electric field	$\vec{E} = 4.00$ N/C
	Initial velocity	$\vec{v}_1 = 0$ m/s
	Mass	m = 2.00 x 10^{-4} kg.
Unknown: Electric force		$\vec{F}_E = ?$
Equation:		To find the magnitude of the electric force use $\vec{F}_E = q\vec{E}$.
Substitute and solve:		$\vec{F}_E = q\vec{E} = (5.00\text{ C})(4.00\text{ N/C}) = 20.0\text{ N}$

Since the sign of the charge is positive, the directions of the electric force and the electric field are the same.

The electric force is 20.0 N [down].

You should also know that a positive charge will be attracted to the negative plate of this apparatus.

b) Determine the magnitude and direction of the acceleration on the charged particle between the plates.

Answer:

Let down be negative.

Unknown: Acceleration $\vec{a} = ?$

Equation: Use Newton's Second Law. The net force is the electric force.

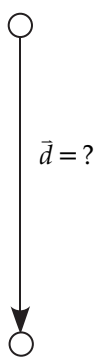
$$\vec{F}_{NET} = m\vec{a} \text{ rearranged to } \vec{a} = \frac{\vec{F}_{NET}}{m}$$

Substitute and solve: $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{-20.0 \text{ N}}{2.00 \times 10^{-4} \text{ kg}} = -1.00 \times 10^{5} \text{ m/s}^2$

The acceleration of the particle is -1.00×10^5 m/s^2.

c) If the particle is released from rest, what will be the displacement of the particle after a time of 8.00 ms (8.00×10^{-3} s)?

Answer:



$\vec{v}_1 = 0$ m/s

$\vec{a} = -1.00 \times 10^5$ m/s^2

$\Delta t = 8.00 \times 10^{-3}$ s

Equation: Use equation #4:

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

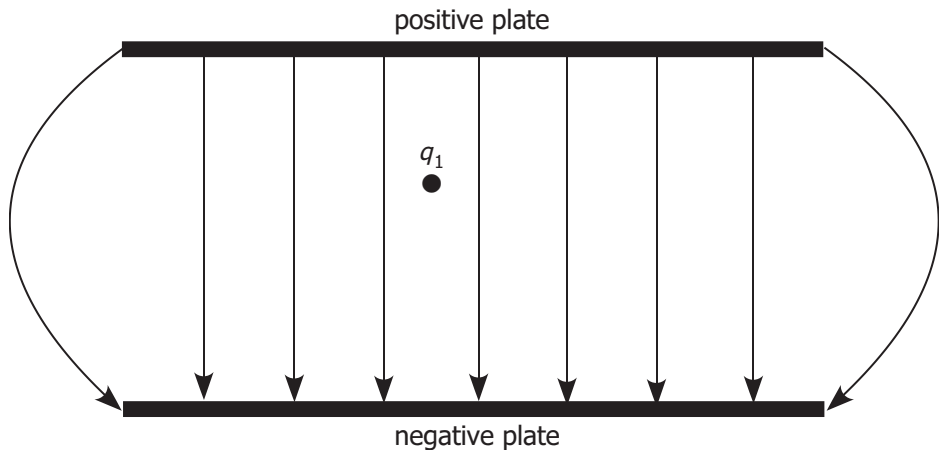
Substitute and solve:

$$\vec{d} = (0 \text{ m/s})(8.00 \times 10^{-3} \text{ s}) + \frac{1}{2}(-1.00 \times 10^{5} \text{ m/s})(8.00 \times 10^{-3} \text{ s})^2$$

$$\vec{d} = 0 \text{ m} + (-3.20 \text{ m}) = -3.20 \text{ m}$$

The particle's displacement is 3.20 m [down].

2. A charge, q_1 = –2.00 C is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 6.00 N/C. The mass of the charged particle is m = 5.00 x 10^{-4} kg.



a) Determine the magnitude and direction of the electric force on the charged particle between the plates.

Answer:

This time the particle carries a negative charge so it will be attracted to the positive plate. The electric force will point up!

Given:	Charge	q_1 = –2.00 C
	Electric field	$\vec{E} = 6.00\ \text{N/C}$
	Initial velocity	$\vec{v}_1 = 0\ \text{m/s}$
	Mass	m = 5.00 x 10^{-4} kg
Unknown:	Electric force	$\vec{F}_E = ?$
Equation:		To find the magnitude of the electric force, use $\vec{F}_E = q\vec{E}$.
Substitute and solve:		$\vec{F}_E = q\vec{E} = (2.00\ \text{C})(6.00\ \text{N/C}) = 12.0\ \text{N}$

Since the sign of the charge is negative, the directions of the electric force and the electric field are the opposite.

The electric force is 12.0 N [up].

b) Determine the magnitude and direction of the acceleration on the charged particle between the plates.

Answer:

Let up be positive.

Unknown: Acceleration $\vec{a} = ?$

Equation: Use Newton's Second Law. The net force is the electric force.

$$\vec{F}_{NET} = m\vec{a} \text{ rearranged to } \vec{a} = \frac{\vec{F}_{NET}}{m}$$

Substitute and solve: $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{+12.0 \text{ N}}{5.00 \times 10^{-4} \text{ kg}} = +2.40 \times 10^{4} \text{ m/s}^2$

The acceleration of the particle is $+2.40 \times 10^4$ m/s^2.

c) If the particle is released from rest, what will be the final velocity of the particle after a time of 4.00 ms (4.00×10^{-3} s)?

Answer:

Given:

$\vec{v}_1 = 0 \text{ m/s}$

$\vec{a} = +2.40 \times 10^4 \text{ m/s}^2$

$\Delta t = 4.00 \times 10^{-3} \text{ s}$

Equation: Use equation #2:

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ rearranged to } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

Substitute and solve:

$$\begin{aligned}\vec{v}_2 &= \vec{v}_1 + \vec{a}\Delta t \\ &= (0 \text{ m/s}) + (+2.40 \times 10^4 \text{ m/s})(4.00 \times 10^{-3} \text{ s}) \\ &= +96.0 \text{ m/s}\end{aligned}$$

The final velocity of the particle is 96.0 m/s [up].

Learning Activity 5.4: The Millikan Drop Experiment

1. Most experiments in atomic physics are performed in a vacuum. Describe the effect on the Millikan oil drop experiment of performing it in a vacuum.

   Answer:

   The Millikan experiment would not work in a vacuum. The net force on the drop could be balanced, but when the balancing electric field is removed, the particle would accelerate under gravity. Since there is no air, the drag of air friction would not be present to act on the oil drop. It would not be possible to determine its terminal velocity and, hence, to calculate its mass. Also, the oil drops would move very quickly, making them difficult to balance, and they would evaporate.

2. How many electrons must be removed from an electrically neutral silver dollar to give it a charge of +2.4 μC?

   Answer:

   The number of electrons is $N = \frac{q}{e} = \frac{2.4 \times 10^{-6}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}/e} = 1.5 \times 10^{13}$ electrons.

3. What is the charge on an electroscope that has a deficit of 4.0×10^{11} electrons?

   Answer:

   Using $q = Ne$,

   $q = (4.0 \times 10^{11})(1.60 \times 10^{-19}\ \text{C}/e) = 6.4 \times 10^{-8}$ C.

4. Small charges are measured in microcoulombs (μC). A shock of 1.1 μC is passed from one student to another in a dry physics classroom. How many electrons are transferred?

   Answer:

   $q = 1.1\ \mu\text{C}$

   Since micro means 10^{-6}

   $q = 1.1 \times 10^{-6}$ C

   $e = 1.60 \times 10^{-19}$ C/e

   Using $q = Ne$ rearranged to $N = \frac{q}{e}$ gives

   $$N = \frac{q}{e} = \frac{1.1 \times 10^{-6}\ \text{C}}{1.60 \times 10^{-19}\text{C}/e} = 6.9 \times 10^{12}$$

   The number of electrons transferred is 6.9×10^{12} electrons.

5. An oil drop, whose mass is found to be 4.95×10^{-15} kg, is balanced between two large horizontal plates with the upper plate positive. The electric field strength between the plates is $\vec{E} = 5.10 \times 10^4$ N/C. What is the charge on the oil drop, both in coulombs and in elementary charges, and is it an excess or deficit in electrons?

Answer:

Given:	Mass	$m = 4.95 \times 10^{-15}$ kg
	Electric field	$\vec{E} = 5.10 \times 10^4$ N/C
	Gravitational field intensity	$\vec{g} = 9.80$ N/kg
Unknown:	Charge	$q = ?$
Equation:		The electric force and the force of gravity balance, so $\vec{F}_E = \vec{F}_g$ and $q\vec{E} = m\vec{g}$ so $q = \dfrac{m\vec{g}}{\vec{E}}$
Substitute and solve:		$q = \dfrac{m\vec{g}}{\vec{E}} = \dfrac{(4.95 \times 10^{-13}\ \text{kg})(9.80\ \text{N/kg})}{5.10 \times 10^4\ \text{N/C}} = 9.51 \times 10^{-19}\ \text{C}$

The number of elementary charges is $\text{N} = \dfrac{q}{\vec{E}} = \dfrac{9.51 \times 10^{-19}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}/e} = 5.94$ or 6 e.

The upper plate is positive, so for the electrical force to be up, the oil droplet must be negatively charged. Therefore, it must have gained six electrons. There is an excess of electrons.

6. An oil drop having a charge of 6.40×10^{-19} C is suspended between two charged parallel plates where the electric field is 1.50×10^{5} N/C. What is the mass of the oil drop?

Answer:

Given: Charge $q = 6.40 \times 10^{-19}$ C

Electric field $\vec{E} = 1.50 \times 10^{5}$ N/C

Gravitational field intensity $\vec{g} = 9.80$ N/kg

Unknown: Mass $m = ?$

Equation: The electric force and the force of gravity balance, so

$\vec{F}_E = \vec{F}_g$ and

$$q\vec{E} = m\vec{g} \text{ so } m = \frac{q\vec{E}}{\vec{g}}$$

Substitute and solve:

$$m = \frac{q\vec{E}}{\vec{g}} = \frac{\left(6.40 \times 10^{-19}\ \text{C}\right)\left(1.50 \times 10^{5}\ \text{N/C}\right)}{9.80\ \text{N/kg}}$$

$$= 9.80 \times 10^{-15}\ \text{kg}$$

The mass of the oil drop is 9.80×10^{-15} kg.

7. In a Millikan oil drop experiment, a drop of oil was found to have a mass of 1.94×10^{-15} kg. When the electric field is 4.00×10^{4} N/C pointing down, the drop is held motionless.

a) What is the charge on the drop?

Answer:

Given: Mass $m = 1.94 \times 10^{-15}$ kg

Electric field $\vec{E} = 4.00 \times 10^{4}$ N/C

Gravitational field intensity $\vec{g} = 9.80$ N/kg

Unknown: Charge $q = ?$

Equation: The electric force and the force of gravity balance, so

$\vec{F}_E = \vec{F}_g$ and

$$q\vec{E} = m\vec{g} \text{ so } q = \frac{m\vec{g}}{\vec{E}}$$

Substitute and solve:

$$q = \frac{m\vec{g}}{\vec{E}} = \frac{\left(1.94 \times 10^{-15}\ \text{kg}\right)\left(9.80\ \text{N/kg}\right)}{4.00 \times 10^{4}\ \text{N/C}}$$

$$= 4.75 \times 10^{-19}\ \text{C}$$

The charge on the drop is 4.75×10^{-19} C. Since the electric field points down and the electric force points up, the charge on the drop is negative.

b) Did the drop have an excess or deficit of electrons? How many electrons were in excess or deficit?

Answer:

Since the charge on the drop is negative, it had an excess of electrons.

The number of electrons is $N = \frac{q}{\vec{E}} = \frac{4.75 \times 10^{-19}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}/e} = 2.97$

or 3 electrons.

NOTES

Grade 11 Physics (30S)

Module 5: Electric Fields

Learning Activity Answer Keys

Module 5: Electric Fields

Learning Activity 5.1: Electric Fields

1. a) How are a gravitational field and an electric field similar?

   Answer:

   They both exert forces.

   b) How are a gravitational field and an electric field different?

   Answer:

   A gravitational field interacts with mass while an electric field interacts with charge. A gravitational field only exerts attractive forces while an electric field can exert attractive forces and repulsive forces.

2. Why is an electric field considered a vector quantity?

   Answer:

   An electric field has both magnitude and direction.

3. a) What are electric field lines?

   Answer:

   These are lines that depict the electric field showing its direction and relative strength at a given point.

   b) How does the direction of an electric field line compare with the direction of the force that acts on a positive test charge in the same region?

   Answer:

   The directions are the same.

4. How is the strength of an electric field indicated with field lines?

   Answer:

   The closer the lines of an electric field, the stronger the field is.

5. How do the electric field lines appear when the field has the same strength as all points in a region?

   Answer:

   The electric field lines will be parallel and equally spaced.

6. The vectors for the gravitational field of earth point toward earth; the vectors for the electric field of a proton point away from the proton. Explain.

   Answer:

   The force of gravity on any mass above the earth's surface will point towards the earth. Therefore, the gravitational field of the earth points towards the earth.

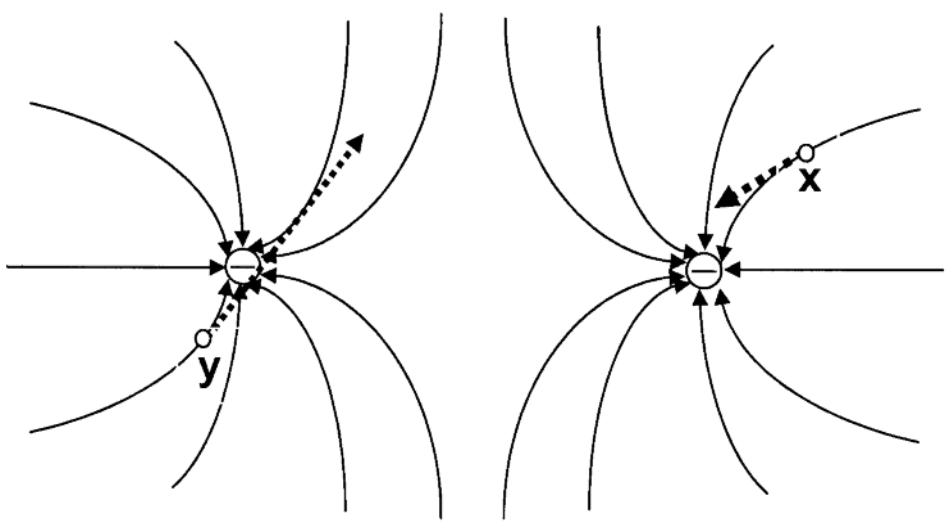
   By convention, the direction of the electric field is given by the direction of the force acting on a positive test charge. A proton (positive charge) will repel the positive test charge, resulting in an electric field line that points away from the proton.

7. Draw two points indicating negative charges. The points should be separated by a short distance. Add to your diagram the following:

   a) Draw the electric field line pattern for the two negative point charges.

      Answer:

      The diagram below shows a possible field line pattern. It is identical to the pattern for two positive charges, but the direction of the lines is reversed.



   b) Place an "x" at a point about two centimetres away from the right negative charge. Place the "x" on a field line at about 60° north of east of this charge. Draw a possible vector representing the electric field strength at this point.

      Answer:

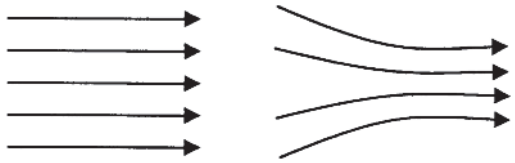
      The approximate location of the "x" is shown above. The vector representing the direction of the electric field at that point is shown tangent to the line.

c) In a similar way, place the letter "y" on an electric field line about one centimetre away from the left negative charge at a direction of about 45° south of west of the charge. Draw a vector representing the strength of the electric field at this point. Be sure that the length and the direction of this vector show how the field strength at "y" is different from the field strength at "x."

Answer:

The approximate location of "y" is shown above. The length of this vector is longer than the one at "x" because it is closer to the charge and the electric field is stronger at this point. The direction is tangent to the field line.

8. Diagrams 1 and 2 show two examples of electric field lines.



1 2

Decide which of the following statements are true and which are false, defending your choice in each case.

a) In both 1 and 2, the electric field is the same everywhere.

Answer:

False. In 1, the electric field is the same everywhere. In 2, the electric field increases as you go to the right.

b) As you move from the left to the right in each case, electric field becomes stronger.

Answer:

False. The electric field becomes stronger in 2 but remains constant in 1.

c) The electric field in 1 is the same everywhere but the electric field in 2 becomes stronger as you move from left to right.

Answer:

True. The equally spaced lines in 1 indicate a uniform electric field, but in 2 the lines coming closer together indicate an increasing electric field.

d) The electric fields in both 1 and 2 are created by negative charges located somewhere on the left and positive charges located somewhere on the right.

Answer:

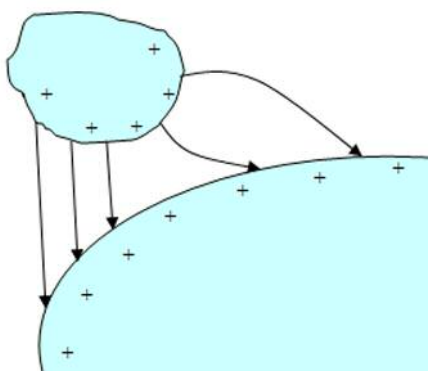
False. Since the electric field lines point to the right, the negative charges must be on the right side.

e) Both 1 and 2 arise from a single positive point charge located somewhere to the left.

Answer:

False. The electric field around a point charge looks like the spokes on a bicycle wheel—they radiate outwards from the point charge, getting farther and farther apart. Neither 1 nor 2 fit this pattern.

9. The drawing below is supposed to show the electric field lines in the region between the two charged metal conductors. Give two reasons why this drawing is incorrect.



Answer:

Reason 1: Electric field lines point from positive charge towards negative charge. Here, the field lines point towards a positive charge.

Reason 2: The lines of the electric field should meet the surface of a conductor at a 90° angle. This does not occur for any of the lines.

Learning Activity 5.2: Calculating Electric Field and Electric Force

1. a) How many electrons are found in a charge of -1.25×10^{-7} C?

Answer:

Given: Charge $q = -1.25 \times 10^{-7}$ C

Elementary charge $e = 1.60 \times 10^{-19}$ C

Unknown: Number of elementary charges N = ?

Equation: $q = Ne$ rearranged to $N = \frac{q}{e}$

Substitute and solve: $N = \frac{q}{e} = \frac{1.25 \times 10^{-7}}{1.60 \times 10^{-19}} = 7.81 \times 10^{11}$

The number of electrons is 7.81×10^{11}.

b) What is the charge on an object with an excess of 4.85×10^{13} protons? (Include the sign of this charge.)

Answer:

Given: Number of elementary charges $N = 4.85 \times 10^{13}$

Elementary charge $e = 1.60 \times 10^{-19}$ C

Unknown: Charge q = ?

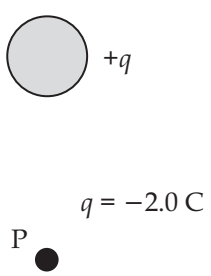
Equation: $q = Ne$

Substitute and solve: $q = (4.85 \times 10^{13})(1.60 \times 10^{-19}\ \text{C})$
$= 7.76 \times 10^{-6}$ C

The charge is $+7.76 \times 10^{-6}$ C.

2. A positive point charge creates an electric field of 5.0×10^{4} N/C at a point P directly south of the charge. If a test charge of –2.0 C is placed at that place, then what is the magnitude and direction of the force on that charge?

Answer:



One way to approach this problem is to disregard the sign of the test charge to calculate the magnitude of the force. Then the direction of the force will be added from our understanding of the forces between unlike charges, or from our knowledge of the relationship between the direction of the electric field and the sign of the test charge.

The magnitude of the force on the charge is
$\vec{F}_e = q\vec{E} = (2.0\ \text{C})(5.0 \times 10^{4}\ \text{N/C}) = 1.0 \times 10^{5}$ N.

Since the point charge is positive, the direction of the electric field is south.

Since the test charge is negative, the direction of the electric force will be opposite to the direction of the field—that is, north.

3. A positive point charge, q_1, produces a field $\vec{E}_1$, of size 5.0 N/C at a location "P." A negative point charge, $-q_2$, produces an electric field $\vec{E}_2$, of size 10.0 N/C at the same location "P."

a) Determine the magnitude and direction of the total electric field at "P."

Answer:

Let to the right or east be the positive direction.

The total electric field at position P is $\vec{E}_{\text{TOTAL}} = \vec{E}_1 + \vec{E}_2$ = –5.0 N/C or 5.0 N/C west.

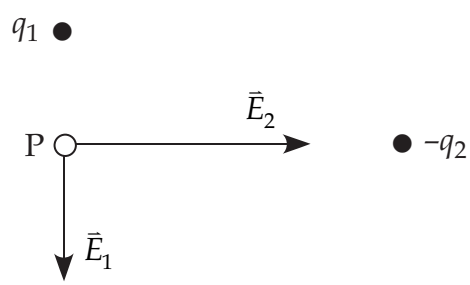
b) If a 4.5 C charge is placed at P, what is the magnitude and the direction of the force on this charge?

Answer:

The magnitude of the force is $\vec{F} = q\vec{E}_{\text{T}} = (4.5\text{ C})(5.0\text{ N/C}) = 22\text{ N}$.

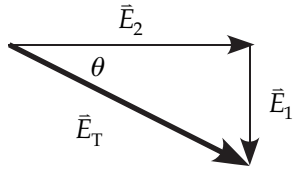
The direction of this force is in the same direction as the electric field vector—that is, west.

4. A positive point charge, q_1, produces a field, $\vec{E}_1$, of size 5.0 N/C at a location P. A negative point charge, $-q_2$, produces an electric field, $\vec{E}_2$, of size 10.0 N/C at the same location P.



a) Determine the magnitude and direction of the total electric field at P.

Answer:



In adding together the two electric field vectors, we attach them tip to tail.

The magnitude of the total electric field vector is

$$\vec{E}_T = \sqrt{(5.0\ \text{N/C})^2 + (10.0\ \text{N/C})^2} = 11.18\ \text{N/C or } 11\ \text{N/C}.$$

The direction of this vector is

$$\theta = \tan^{-1}\left(\frac{5.0\ \text{N/C}}{10.0\ \text{N/C}}\right) = 26.57°\ \text{S of E or } 27°\ \text{S of E}.$$

b) If a 4.0 C charge is placed at P, what is the magnitude and the direction of the force on this charge?

Answer:

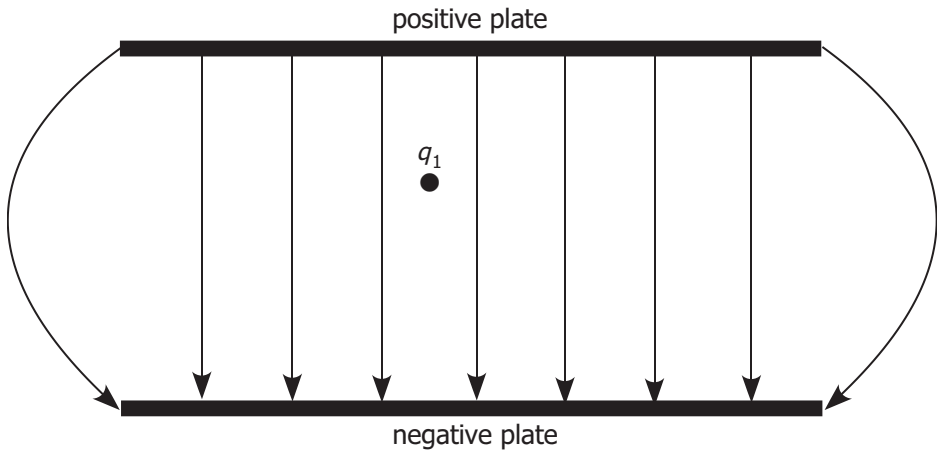
The magnitude of the force is $\vec{F} = q\vec{E}_T = (4.0\ \text{C})(11\ \text{N/C}) = 44\ \text{N}$.

The direction of this force is in the same direction as the electric field vector—that is, 27° S of E.

Learning Activity 5.3: The Parallel Plate Apparatus

There are two practice questions in this assignment. An answer key is available at the end of the module for you to check your answers after you have completed the practice questions.

1. A charge, q_1 = +5.00 C, is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 4.00 N/C. The mass of the charged particle is m = 2.00 x 10^{-4} kg.



a) Determine the magnitude and direction of the electric force on the charged particle between the plates.

Answer:

Given:	Charge	q_1 = +5.00 C
	Electric field	$\vec{E} = 4.00$ N/C
	Initial velocity	$\vec{v}_1 = 0$ m/s
	Mass	m = 2.00 x 10^{-4} kg.
Unknown: Electric force		$\vec{F}_E = ?$
Equation:		To find the magnitude of the electric force use $\vec{F}_E = q\vec{E}$.
Substitute and solve:		$\vec{F}_E = q\vec{E} = (5.00\text{ C})(4.00\text{ N/C}) = 20.0\text{ N}$

Since the sign of the charge is positive, the directions of the electric force and the electric field are the same.

The electric force is 20.0 N [down].

You should also know that a positive charge will be attracted to the negative plate of this apparatus.

b) Determine the magnitude and direction of the acceleration on the charged particle between the plates.

Answer:

Let down be negative.

Unknown: Acceleration $\vec{a} = ?$

Equation: Use Newton's Second Law. The net force is the electric force.

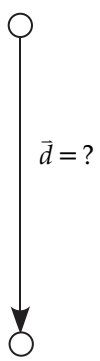
$$\vec{F}_{NET} = m\vec{a} \text{ rearranged to } \vec{a} = \frac{\vec{F}_{NET}}{m}$$

Substitute and solve: $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{-20.0 \text{ N}}{2.00 \times 10^{-4} \text{ kg}} = -1.00 \times 10^{5} \text{ m/s}^2$

The acceleration of the particle is -1.00×10^5 m/s^2.

c) If the particle is released from rest, what will be the displacement of the particle after a time of 8.00 ms (8.00×10^{-3} s)?

Answer:



$\vec{v}_1 = 0$ m/s

$\vec{a} = -1.00 \times 10^5$ m/s^2

$\Delta t = 8.00 \times 10^{-3}$ s

Equation: Use equation #4:

$$\vec{d} = \vec{v}_1 \Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

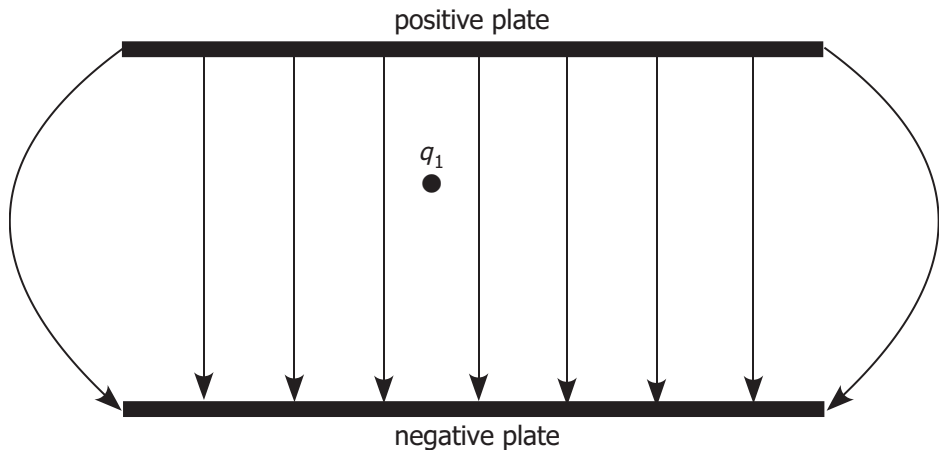
Substitute and solve:

$$\vec{d} = (0 \text{ m/s})(8.00 \times 10^{-3} \text{ s}) + \frac{1}{2}(-1.00 \times 10^{5} \text{ m/s})(8.00 \times 10^{-3} \text{ s})^2$$

$$\vec{d} = 0 \text{ m} + (-3.20 \text{ m}) = -3.20 \text{ m}$$

The particle's displacement is 3.20 m [down].

2. A charge, q_1 = –2.00 C is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 6.00 N/C. The mass of the charged particle is m = 5.00 x 10^{-4} kg.



a) Determine the magnitude and direction of the electric force on the charged particle between the plates.

Answer:

This time the particle carries a negative charge so it will be attracted to the positive plate. The electric force will point up!

Given:	Charge	q_1 = –2.00 C
	Electric field	$\vec{E} = 6.00\ \text{N/C}$
	Initial velocity	$\vec{v}_1 = 0\ \text{m/s}$
	Mass	m = 5.00 x 10^{-4} kg
Unknown:	Electric force	$\vec{F}_E = ?$
Equation:		To find the magnitude of the electric force, use $\vec{F}_E = q\vec{E}$.
Substitute and solve:		$\vec{F}_E = q\vec{E} = (2.00\ \text{C})(6.00\ \text{N/C}) = 12.0\ \text{N}$

Since the sign of the charge is negative, the directions of the electric force and the electric field are the opposite.

The electric force is 12.0 N [up].

b) Determine the magnitude and direction of the acceleration on the charged particle between the plates.

Answer:

Let up be positive.

Unknown: Acceleration $\vec{a} = ?$

Equation: Use Newton's Second Law. The net force is the electric force.

$$\vec{F}_{NET} = m\vec{a} \text{ rearranged to } \vec{a} = \frac{\vec{F}_{NET}}{m}$$

Substitute and solve: $\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{+12.0 \text{ N}}{5.00 \times 10^{-4} \text{ kg}} = +2.40 \times 10^{4} \text{ m/s}^2$

The acceleration of the particle is $+2.40 \times 10^4$ m/s^2.

c) If the particle is released from rest, what will be the final velocity of the particle after a time of 4.00 ms (4.00×10^{-3} s)?

Answer:

Given:

$\vec{v}_1 = 0 \text{ m/s}$

$\vec{a} = +2.40 \times 10^4 \text{ m/s}^2$

$\Delta t = 4.00 \times 10^{-3} \text{ s}$

Equation: Use equation #2:

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ rearranged to } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

Substitute and solve:

$$\begin{aligned}\vec{v}_2 &= \vec{v}_1 + \vec{a}\Delta t \\ &= (0 \text{ m/s}) + (+2.40 \times 10^4 \text{ m/s})(4.00 \times 10^{-3} \text{ s}) \\ &= +96.0 \text{ m/s}\end{aligned}$$

The final velocity of the particle is 96.0 m/s [up].

Learning Activity 5.4: The Millikan Drop Experiment

1. Most experiments in atomic physics are performed in a vacuum. Describe the effect on the Millikan oil drop experiment of performing it in a vacuum.

   Answer:

   The Millikan experiment would not work in a vacuum. The net force on the drop could be balanced, but when the balancing electric field is removed, the particle would accelerate under gravity. Since there is no air, the drag of air friction would not be present to act on the oil drop. It would not be possible to determine its terminal velocity and, hence, to calculate its mass. Also, the oil drops would move very quickly, making them difficult to balance, and they would evaporate.

2. How many electrons must be removed from an electrically neutral silver dollar to give it a charge of +2.4 μC?

   Answer:

   The number of electrons is $N = \frac{q}{e} = \frac{2.4 \times 10^{-6}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}/e} = 1.5 \times 10^{13}$ electrons.

3. What is the charge on an electroscope that has a deficit of 4.0×10^{11} electrons?

   Answer:

   Using $q = Ne$,

   $q = (4.0 \times 10^{11})(1.60 \times 10^{-19}\ \text{C}/e) = 6.4 \times 10^{-8}$ C.

4. Small charges are measured in microcoulombs (μC). A shock of 1.1 μC is passed from one student to another in a dry physics classroom. How many electrons are transferred?

   Answer:

   $q = 1.1\ \mu\text{C}$

   Since micro means 10^{-6}

   $q = 1.1 \times 10^{-6}$ C

   $e = 1.60 \times 10^{-19}$ C/e

   Using $q = Ne$ rearranged to $N = \frac{q}{e}$ gives

   $$N = \frac{q}{e} = \frac{1.1 \times 10^{-6}\ \text{C}}{1.60 \times 10^{-19}\text{C}/e} = 6.9 \times 10^{12}$$

   The number of electrons transferred is 6.9×10^{12} electrons.

5. An oil drop, whose mass is found to be 4.95×10^{-15} kg, is balanced between two large horizontal plates with the upper plate positive. The electric field strength between the plates is $\vec{E} = 5.10 \times 10^4$ N/C. What is the charge on the oil drop, both in coulombs and in elementary charges, and is it an excess or deficit in electrons?

Answer:

Given:	Mass	$m = 4.95 \times 10^{-15}$ kg
	Electric field	$\vec{E} = 5.10 \times 10^4$ N/C
	Gravitational field intensity	$\vec{g} = 9.80$ N/kg
Unknown:	Charge	$q = ?$
Equation:		The electric force and the force of gravity balance, so $\vec{F}_E = \vec{F}_g$ and $q\vec{E} = m\vec{g}$ so $q = \dfrac{m\vec{g}}{\vec{E}}$
Substitute and solve:		$q = \dfrac{m\vec{g}}{\vec{E}} = \dfrac{(4.95 \times 10^{-13}\ \text{kg})(9.80\ \text{N/kg})}{5.10 \times 10^4\ \text{N/C}} = 9.51 \times 10^{-19}\ \text{C}$

The number of elementary charges is $\text{N} = \dfrac{q}{\vec{E}} = \dfrac{9.51 \times 10^{-19}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}/e} = 5.94$ or 6 e.

The upper plate is positive, so for the electrical force to be up, the oil droplet must be negatively charged. Therefore, it must have gained six electrons. There is an excess of electrons.

6. An oil drop having a charge of 6.40×10^{-19} C is suspended between two charged parallel plates where the electric field is 1.50×10^{5} N/C. What is the mass of the oil drop?

Answer:

Given: Charge $q = 6.40 \times 10^{-19}$ C

Electric field $\vec{E} = 1.50 \times 10^{5}$ N/C

Gravitational field intensity $\vec{g} = 9.80$ N/kg

Unknown: Mass $m = ?$

Equation: The electric force and the force of gravity balance, so

$\vec{F}_E = \vec{F}_g$ and

$$q\vec{E} = m\vec{g} \text{ so } m = \frac{q\vec{E}}{\vec{g}}$$

Substitute and solve:

$$m = \frac{q\vec{E}}{\vec{g}} = \frac{\left(6.40 \times 10^{-19}\ \text{C}\right)\left(1.50 \times 10^{5}\ \text{N/C}\right)}{9.80\ \text{N/kg}}$$

$$= 9.80 \times 10^{-15}\ \text{kg}$$

The mass of the oil drop is 9.80×10^{-15} kg.

7. In a Millikan oil drop experiment, a drop of oil was found to have a mass of 1.94×10^{-15} kg. When the electric field is 4.00×10^{4} N/C pointing down, the drop is held motionless.

a) What is the charge on the drop?

Answer:

Given: Mass $m = 1.94 \times 10^{-15}$ kg

Electric field $\vec{E} = 4.00 \times 10^{4}$ N/C

Gravitational field intensity $\vec{g} = 9.80$ N/kg

Unknown: Charge $q = ?$

Equation: The electric force and the force of gravity balance, so

$\vec{F}_E = \vec{F}_g$ and

$$q\vec{E} = m\vec{g} \text{ so } q = \frac{m\vec{g}}{\vec{E}}$$

Substitute and solve:

$$q = \frac{m\vec{g}}{\vec{E}} = \frac{\left(1.94 \times 10^{-15}\ \text{kg}\right)\left(9.80\ \text{N/kg}\right)}{4.00 \times 10^{4}\ \text{N/C}}$$

$$= 4.75 \times 10^{-19}\ \text{C}$$

The charge on the drop is 4.75×10^{-19} C. Since the electric field points down and the electric force points up, the charge on the drop is negative.

b) Did the drop have an excess or deficit of electrons? How many electrons were in excess or deficit?

Answer:

Since the charge on the drop is negative, it had an excess of electrons.

The number of electrons is $N = \frac{q}{\vec{E}} = \frac{4.75 \times 10^{-19}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}/e} = 2.97$

or 3 electrons.

NOTES

Topic 2 - Audio/Videos

Module 5

1. Electric Charge and Electric Fields
2. Electric Fields: Crash Course Physics #26
3. Electric Field Due to a Point Charge - Physics Practice Problems
4. Electric Field Physics Problems - Point Charges, Tension Force, Conductors, Square & Triangle
5. Capacitor Lab: Basics
    a. This is an interactive animation of the charged parallel plate apparatus or capacitor.
    b. There is a window with 4 variables that can be displayed. Be sure that Plate Charge and Electric Field are checked.
    c. You can also change the area of the plates and the separation of the plates by dragging on the green arrows.
    d. The voltage can be measured using the meter marked voltage. Place the point of the red probe on the wire at the top of the battery and the black probe on the wire just below the battery.
    e. Finally you can drag the yellow rectangle on the battery to change the voltage. You can change the size of the voltage and the polarity which changes which plate is positive and which plate is negative.
    f. Select a voltage of 1.00 volts, an area of 400 mm2, and a plate separation of 5.00 mm. The electric field intensity will be displayed as the density of the electric field lines.
    g. Adjust the apparatus changing voltage only and observe the effect on the electric field.
    h. Adjust the apparatus changing area of the plates only and observe the effect on the electric field.
    i. Adjust the apparatus changing separation of plates only and observe the effect on the electric field.
6. Parallel Plate Apparatus
    a. This video describes through aanimation how a parallel plate apparatus works. The importance of this apparatus is that the electric field between the plates of of the apparatus is uniform, both in magnitude and direction.
    b. This electric field can be calculated by the ratio of the potential difference between the plates measured in volts divided by the separation of the plates in metres. The electric field between the charged plates will always point from the positive plate to the negative plate.
    c. Between the charged plates the electric force on a charged particle is found by multiplying the electric field by the electric charge on the particle. The direction of the electric force is found by determining to which plate the charge on the particle will be attracted.
7. Electric Field of Parallel Plates

    a. This video illustrates the electric field between two charged parallel plates. It illustrates how the electric field is calculated. We will use the electric field between charged parallel plates is the ratio of the potential difference between the plates expressed in volts divided by the separation of the plates expressed with units of metres.
    b. Again the electric force on a charges particle between the charged plates is found using the electric charge on the particle expressed in Coulombs divided by the separation of the plates expressed in metres.
    c. Charged particles are shot into the space between the plates traveling in a direction parallel to to the charged plates. These particles follow a path much like a ball thrown horizontally at the surface of the Earth.
8. Electric Field Strength Parallel Plates Example - Physics
    a. This video solves a problem about charges particles within the electric field between two charge parallel plates and the force on an electron between the plates and also the force on a proton between the plates.
    b. The electric field between the plates is calculated from the voltage across the plates and the separation between the plates using
    c. Electric Field = Voltage/ Separation of the plates.
    d. Once electric field is found in part a, this value is used to calculate the electric force on an electron in part b and the electric force on a proton in part c.
    e. Note you must include directions with the electric field and the electric force.
9. Uniform Electric Field (1 of 9) Motion of Charged Particles Parallel to the Field
10. Millikan Oil Drop Experiment Animation
    a. When the oil drop is motionless the force of gravity downwards is balanced by the electric force upwards and the net force on the droplet is 0N.
    b. So in the vertical or y direction Fnet = Fe – Fg = 0N
    c. And Fe = Fg.
    d. But Fe = qE and Fg = mg so
    e. qE = mg and
    f. q = mg/E.
    g. The final result was that there was a smallest charge that q could have called the unit elementary charge e.
11. Millikan's Oil Drop Experiment
12. Elementary Charge
    a. In this video animation of the Millikan Experiment is used to describe how Millikan's experiment worked. Millikan was able to isolate oil drops as they fell between charged parallel plates where the electric field was controlled by the voltage. Millikan was able to observe an oil droplet with a microscope. The oil drops where exposed to X-rays which ionized molecules to produce a net charge on the droplets. The droplets fell with a terminal velocity which depends on the size of the droplet. Oil droplets

falling with the same terminal velocity would have the same size and mass. Millikan selected oil droplets that fell with the same terminal velocity which ensured that the drops had the same mass and force of gravity acting on each droplet.

b. Millikan then changed the charge by exposing the oil droplets to X-rays. Millikan then adjusted the voltage to hold an oil droplet motionless. Knowing the size of the oil drop and the density of oil, the mass of the oil drop (m) could be calculated.
c. Then the force of gravity on the oil drop is found using Fg = mg.
d. When the oil drop is motionless the force of gravity downwards is balanced by the electric force upwards and the net force on the droplet is 0N.
e. So in the vertical or y direction Fnet = Fe – Fg = 0N
f. And Fe = Fg.
g. But Fe = qE and Fg = mg so
h. qE = mg and
i. q = mg/E.
j. The final result was that there was a smallest charge that q could have called the unit elementary charge e.
k. The charge on a given oil drop was always found to be a multiple of e.
l. All the values of q were found to be
m. Charge on the oil droplet = (integer)(unit elementary charge)
n. Or q = Ne.
o. In other words charge is quantized, that is, it comes in discrete units or packages with a smallest possible amount of e = 1.602 x 10-19 Coulombs.

13. Millikan's oil drop calculation
    a. This video solves a typical problem based on Millikan's Oil Drop Experiment.
    b. The force of gravity on the oil drop is found using Fg = mg.
    c. When the oil drop is motionless the force of gravity downwards is balanced by the electric force upwards and the net force on the droplet is 0N.
    d. So in the vertical or y direction Fnet = Fe – Fg = 0N
    e. And Fe = Fg.
    f. But Fe = qE and Fg = mg so
    g. qE = mg.
    h. So you can solve for any of these variables using qE = mg or E = Voltage/ Plate Separation or E = V/d.

Grade 11 Physics (30S)

Module 6: Magnetic Fields and Electromagnetism

This module contains the following

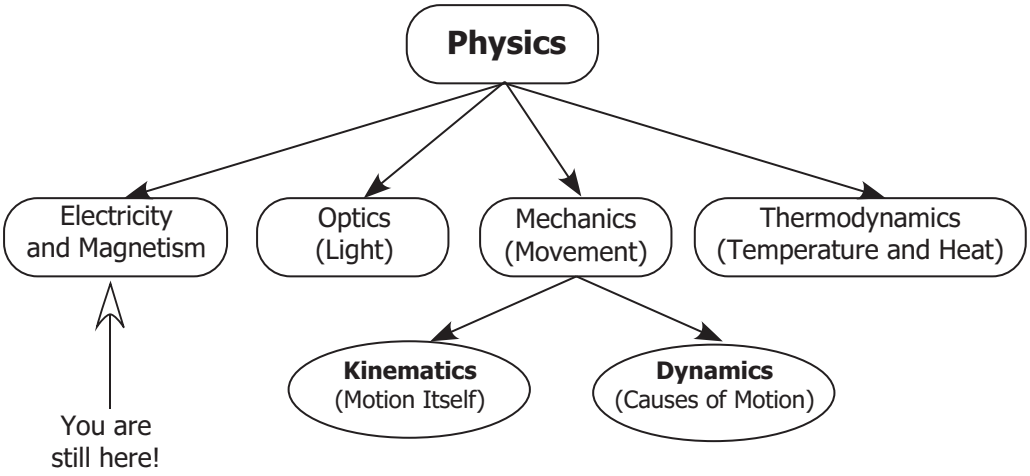
- Introduction to Module 6
- Lesson 1: Magnetic Fields
- Lesson 2: Domain Theory and the Earth's Magnetic Field
- Lesson 3: Electromagnetism
- Lesson 4: Video Laboratory Activity: The Tangent Galvanometer
- Lesson 5: Forces on Currents in a Magnetic Field
- Lesson 6: Fields: A Summary
- Module 6 Summary

Module 6: Magnetic Fields and Electromagnetism

Introduction to Module 6

In the previous two modules, we studied gravitational and electric fields. In this module, we study magnetic fields. Magnetic effects have been known to man since ancient times when natural magnets called lodestones were found to cling to iron tools. Lodestone has iron ore in it and it occurs in many parts of the world. The word "magnet" comes from the Greek word "magnes" which probably derives from the ancient colony of Magnesia where the ore was mined 2500 years ago.

- **Lesson 1: Magnetic Fields** discusses the basics of what is meant by the "poles" of a magnet. We will explain how to determine what the magnetic field looks like for a single magnet or a combination of magnets. The magnetic field line patterns resemble electric field line patterns.
- **Lesson 2: Domain Theory and the Earth's Magnetic Field** explains why magnetic fields exist by illustrating the Domain Theory of Magnetism. This theory helps to explain many common magnetic effects. The lesson will conclude with the study of the magnetic fields of our own earth, and what causes the beautiful auroral displays that can be seen in both the northern and southern skies.
- **Lesson 3: Electromagnetism** discusses how a current-carrying wire produces a magnetic field. The wire can be a straight wire or it can be arranged in circular coils as in a solenoid. This will lead to a study of electromagnets, how they work, and their many uses.
- **Lesson 4: Video Laboratory: The Tangent Galvanometer** involves an experiment in which we vary an electric current to determine the effect of current on magnetic field strength.
- **Lesson 5: Forces on Currents in a Magnetic Field** shows that current-carrying wires that are in magnetic fields experience forces acting on them and we will study these forces.
- **Lesson 6: Fields: A Summary** explains the characteristics of the three fields that you have studied: gravitational fields, electric fields, and magnetic fields.



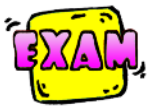
Assignments

When you have completed the assignments for Module 6, submit your completed assignments for Module 5 and Module 6 to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 6.1, Part A	Magnetic Fields
2	Assignment 6.1, Part B	The Earth's Magnetic Field
3	Assignment 6.1, Part C	Electromagnetism
4	Assignment 6.2	Video Laboratory Activity: The Tangent Galvanometer
5	Assignment 6.3	Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance)
5	Assignment 6.4	Forces on Currents in a Magnetic Field
6	There are no assignments in Lesson 6.	

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Writing Your Midterm Examination



You will write the midterm examination when you have completed Module 6 of this course. The midterm examination is based on Modules 1 to 6, and is worth 20 percent of your final mark in the course. To do well on the midterm examination, you should review all the work you complete in Modules 1 to 6, including all the learning activities and assignments. You will write the midterm examination under supervision.

NOTES

Lesson 1: Magnetic Fields (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the terms pole, north pole, and south pole
- ❑ explain the Law of Magnetic Poles
- ❑ explain how electric charges are different from magnetic poles in terms of our ability to isolate them
- ❑ explain how a compass can be used to depict the magnetic field around a bar magnet
- ❑ draw a magnetic field line pattern for a bar magnet
- ❑ draw the direction of the magnetic field at any point on a magnetic field line
- ❑ explain how to determine the relative strength of the magnetic field at different places given a magnetic field line pattern
- ❑ compare a magnetic field line pattern to an electric field line pattern
- ❑ draw a magnetic field line pattern for a horseshoe magnet, and for two bar magnets placed so that opposite poles or like poles face each other

Key Words

pole	North Pole	South Pole
law of magnetic poles	compass	magnetic field
bar magnet	horseshoe magnet	

Introduction

We begin our discussion of magnetic fields by a discussion of what is meant by the poles of a magnet and how these poles interact with each other when they are near each other. In many ways magnetic effects resemble the electric effects we discussed in the previous unit, but there are also important differences. A compass or iron filings can be used to determine what the magnetic field lines for a magnet or combination of magnets looks like. Once we know what the magnetic field line pattern is, we can draw the magnetic field much as we did in our study of electric fields. We will conclude the lesson by drawing magnetic fields for combinations of magnets placed near each other.

Magnetic Poles

The effects of magnetism have been known for centuries. Even before 600 BCE, the Greeks had discovered that lodestone, a type of ore containing iron, was able to exert forces of attraction on small iron objects. Also, when allowed to rotate freely, a needle-shaped piece of lodestone would tend to rotate in order to point approximately in a north-south position, a fact that led to its widespread use in navigation in the form of a compass. Since this type of iron ore was first found near a region in Asia Minor called Magnesia, its effects became known as magnetism.

Today, lodestone is rarely used for its magnetic properties as they are quite weak magnets. Modern magnets are made from various alloys of iron, nickel, cobalt, gadolinium and other "rare earths" such as neodymium. When a bar magnet is dipped in iron filings (literally small scrapings of iron resembling a coarse powder), the filings are attracted to it and accumulate most noticeably around regions at each end of the magnet, called **poles**. When a bar magnet is allowed to rotate freely, the pole that tends to point in the northerly direction is called the **north magnetic pole**, or simply the N-pole. The opposite end is called the **south magnetic pole**, or the S-pole.

Magnets can exert forces on each other. By observing how magnets interact with each other, we can state the two points of the Law of Magnetic Poles as:

1. opposite magnetic poles attract
2. similar magnetic poles repel

Another way of saying this is that "like poles" repel each other, and "unlike poles" attract. This behaviour is similar to that of like and unlike electric charges. However, it is important to keep one important difference in mind: while it is possible to separate positive from negative charges and produce isolated charges of either kind, it seems not to be possible to do so for magnetism. In other words, we cannot have a north pole (or a south pole) by itself. The idea of a single magnetic pole has been given the name "magnetic monopole"—but it does not actually exist. Any attempt to separate north and south poles by cutting a bar magnet in half fails, because each piece will become a smaller magnet with its own complete set of north and south poles.

Another important thing to note is that while electric charges exert forces on each other and magnetic poles exert forces on each other, magnetic poles and electric charges do not exert forces on each other—at least not in a direct way. We will soon see details of how they do interact, but it is not a simple attraction or repulsion.

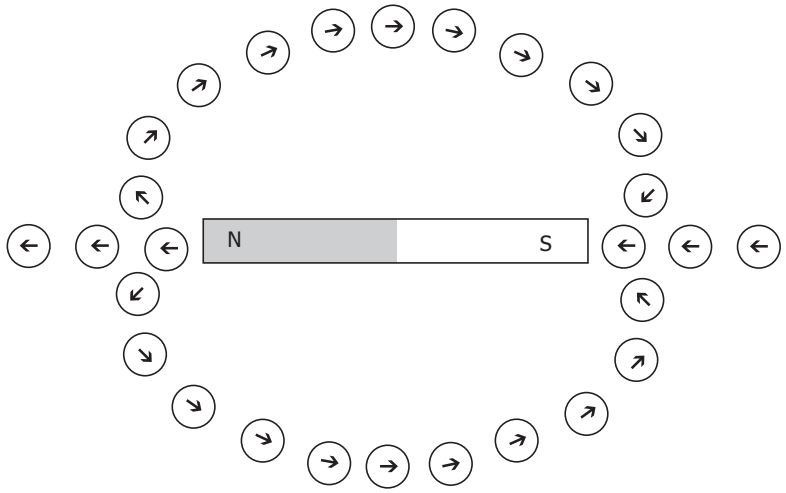
Magnetic Field Line Determination using a Compass or Iron Filings

Magnetic forces act at a distance, just like gravitational and electrical forces do. The explanation of how this happens should be familiar: magnets create magnetic fields (just as masses create gravitational fields and electric charges create electric fields), and this field exerts forces onto other magnets placed in the field.

A magnetic field is a region in which a magnetic pole experiences a magnetic force. We symbolize magnetic fields as "*B*."

A magnetic field is a region in which a magnetic pole experiences a magnetic force. We symbolize magnetic fields as "*B*."

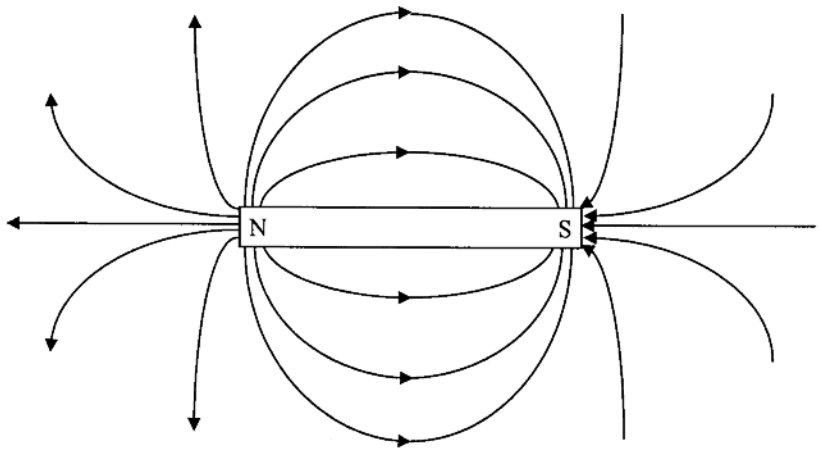
A magnetic field can be detected by its effect on a small compass (magnetized needle). The magnetic field is visually shown by drawing magnetic field lines that show the direction in which the north pole of the "test compass" points. An arrow, the head of the arrow being the north pole, symbolizes the compass needle. The diagram shows how compasses can be used to map out the magnetic field in the space surrounding the bar magnet. Since like poles repel and unlike poles attract, the needle of each compass becomes aligned relative to the bar magnet in the manner shown in the picture. The compass needle provides a visual picture of the magnetic field that the bar magnet creates in the surrounding space.



Another way to create a visual image of the magnetic field lines is to sprinkle finely ground iron filings on a piece of paper that covers the magnet. Iron filings behave like tiny compasses and align themselves along the magnetic field lines, revealing the shape of the magnetic field.

Magnetic Field Line Pattern for a Bar Magnet

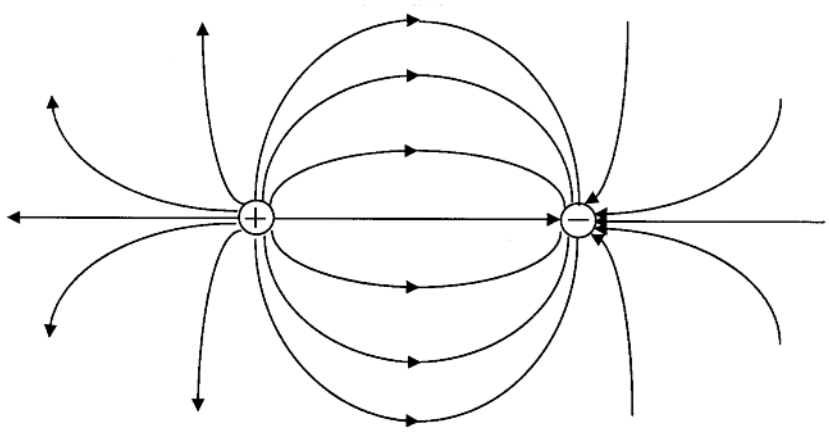
If we now remove the compasses from the diagram in the previous section and draw in the magnetic field lines, the diagram would look as follows. Additional field lines have been added to give a more complete picture.

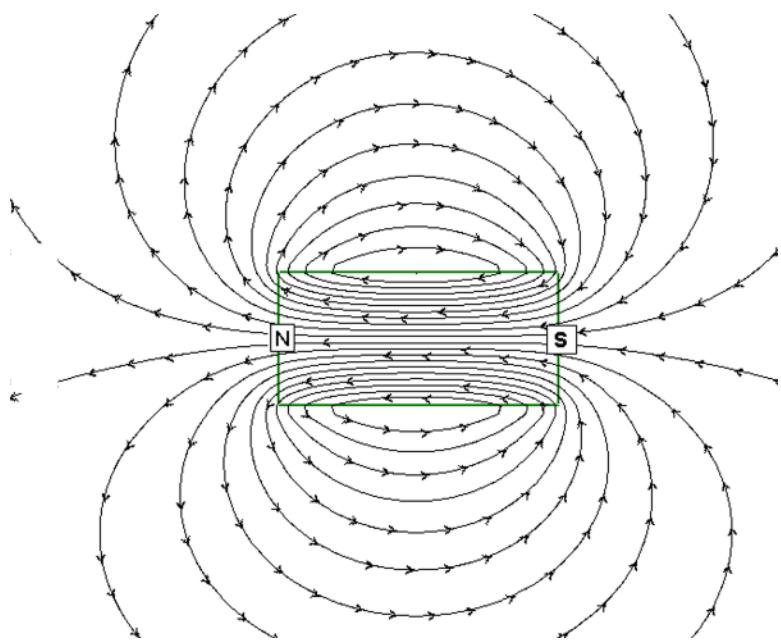


Notice **around the magnet** that the lines **begin** at the **north pole** and end at the **south pole**. (Think of using a magnetic north pole to test the magnetic field.)

As is the case with electric field lines, the **direction** of the magnetic field at any point is **tangent** to the magnetic field line at any point.

Furthermore, the **strength** of the magnetic field is shown by the **spacing** of the **field lines**. Thus, the magnetic field is stronger in regions where the field lines are relatively close together and weaker where they are relatively far apart. For instance, the lines are closer together near the north and south poles, reflecting the fact that the strength of the magnetic field is greatest in these regions. Away from the poles, the magnetic field becomes weaker. Compare the magnetic field line pattern above with the electric field line pattern below and notice how similar they are.





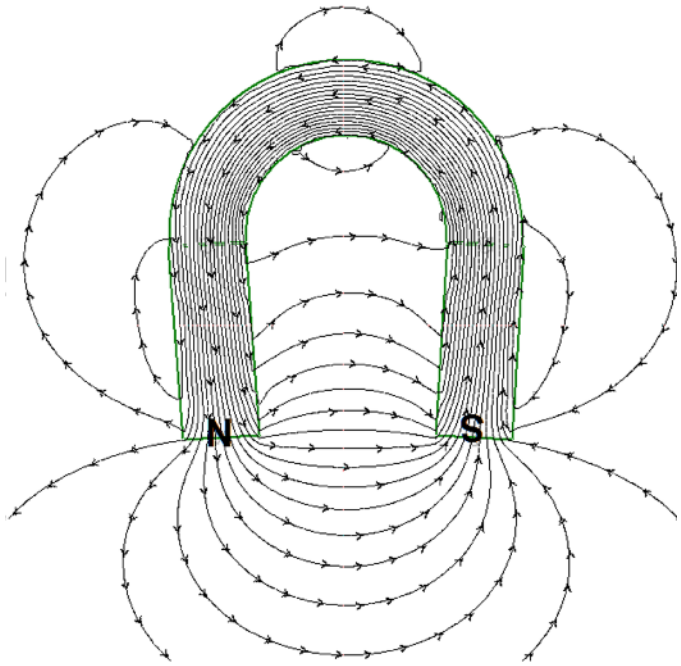
There are two other differences worth noting about lines of magnetic field. You will notice two features in the more detailed diagram of the magnetic field around a bar magnet pictured above.

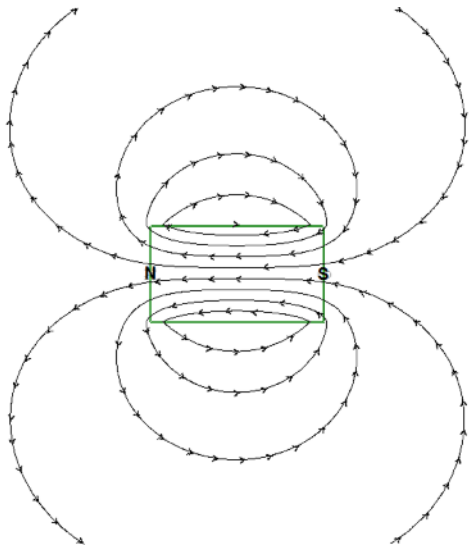
1. Magnet field lines are **complete loops**.
2. Magnet field lines actually pass through the magnet. Inside the magnet, the field lines point from the south pole to the north pole.

So if you are asked to draw the magnet field around a bar magnet, try to make it look like the diagram above. Again, you need draw in only enough of the lines to indicate how the pattern appears.

Magnetic Field and the Horseshoe Magnet

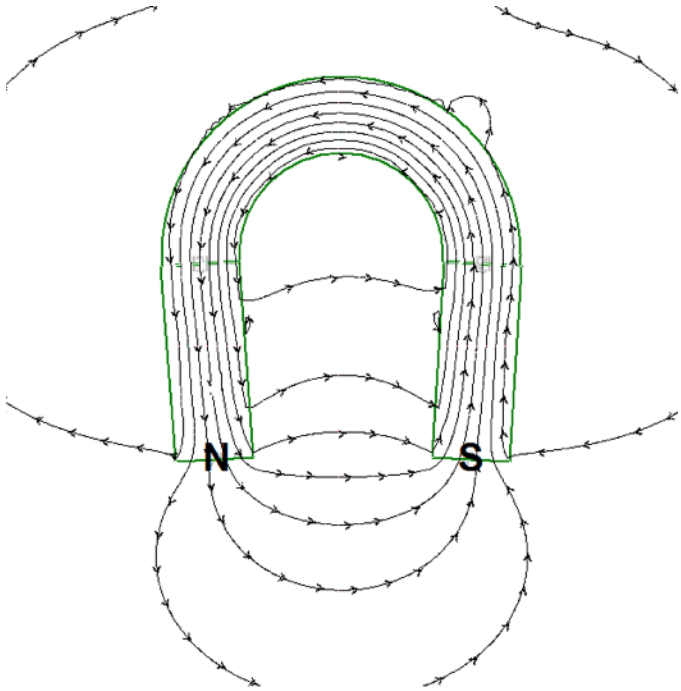
In a horseshoe magnet, the magnetic field lines are concentrated in the immediate region between the poles. Again, note that the magnetic field lines are complete loops and that part of each loop passes through the magnet itself.





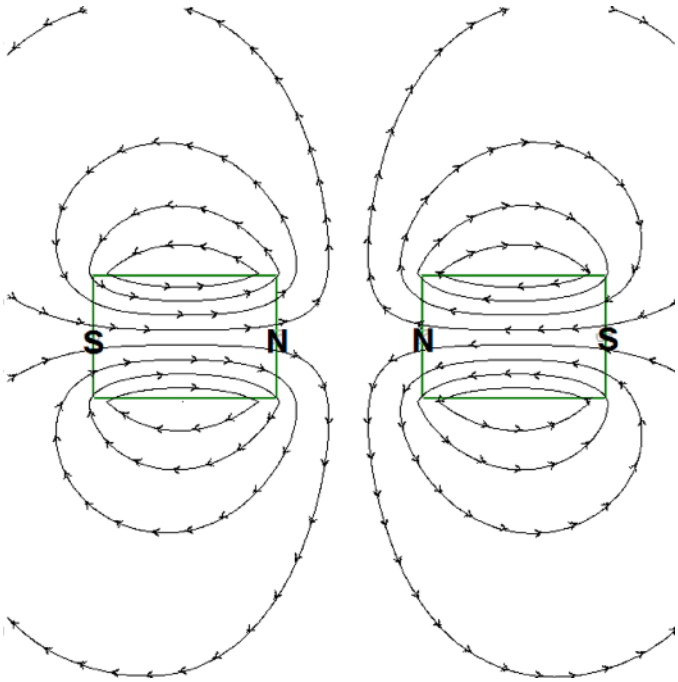
Note how the magnetic field lines for the horseshoe magnet compare to those of the bar magnet in the diagram above.

Again, your drawing of this field around the horseshoe magnet should contain fewer lines of magnetic field.



Magnet Field and Two Bar Magnets—Like Poles Together

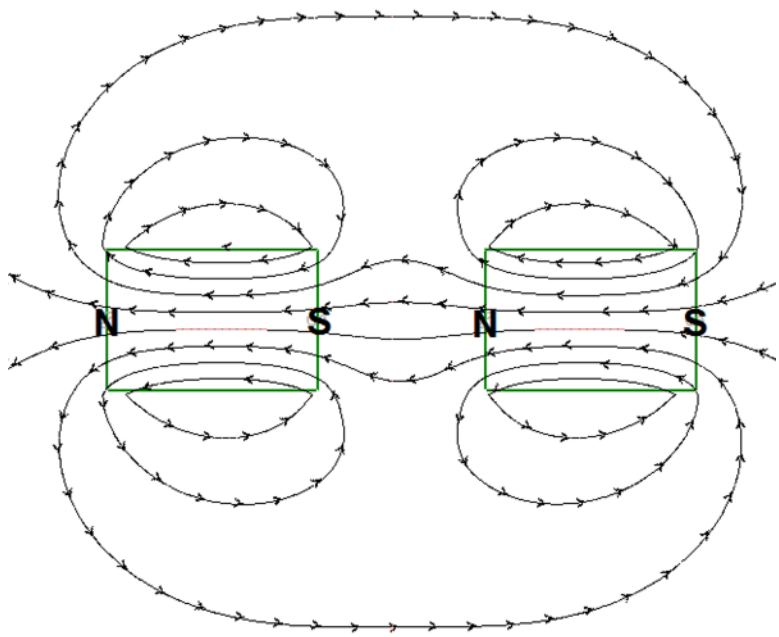
The magnetic field lines between the magnets repel when two magnets are placed near each other so that like poles face each other. The diagram below shows two bar magnets with north poles facing each other. Notice how the magnetic field lines between the poles seem to repel each other. These lines do not join up or cross.



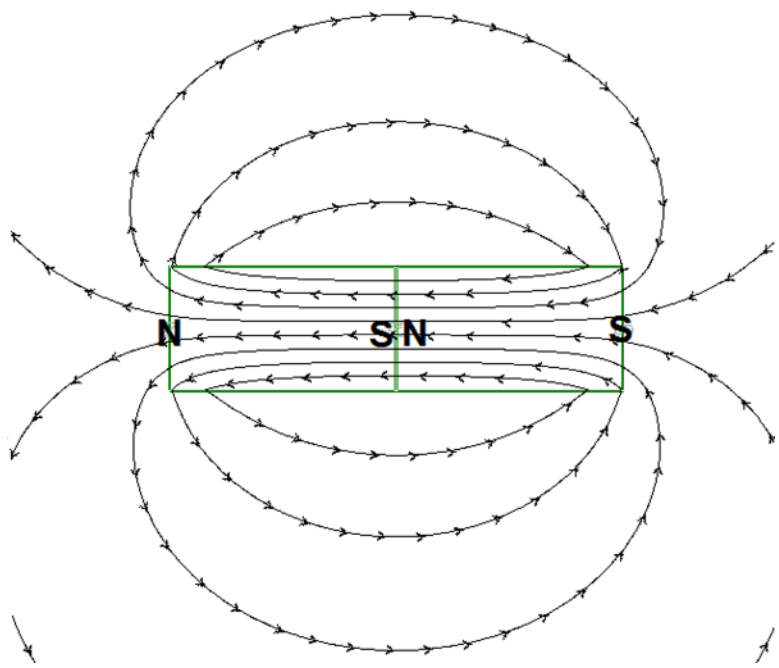
Magnet Field and Two Bar Magnets—Unlike Poles Together

The following diagram shows a possible field line pattern for opposite poles of bar magnets facing each other.

Notice how the magnetic field lines between the poles join together to form a loop that extends through both of the magnets!



What would happen if the magnets were placed with the north pole touching the south pole?

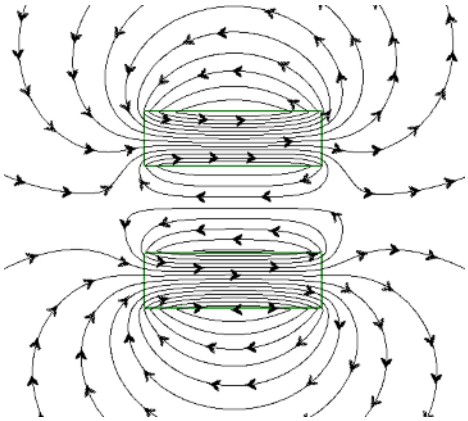


You see that the two bar magnets in this case just seem to combine to make a single bar magnet! Keep this in mind for later.

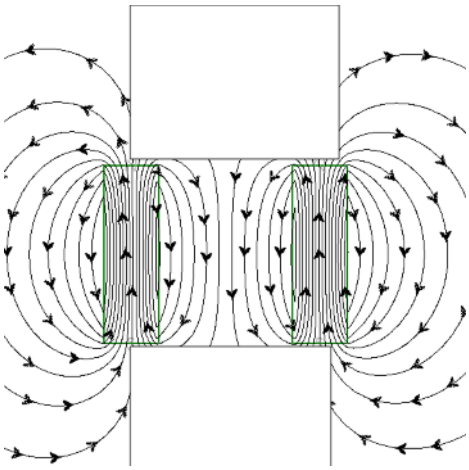
Learning Activity 6.1

Magnetic Fields

1. The following diagram shows two bar magnets near each other. Part of the magnetic field lines is shown.
   a) From the direction in which the field lines are drawn, indicate which poles are located at each pole of the bar magnet.



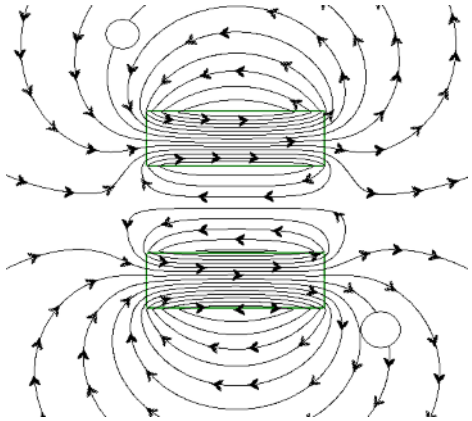
   b) The following diagram shows two rectangular regions. Add additional field lines in these areas to show how they would interact with each other.



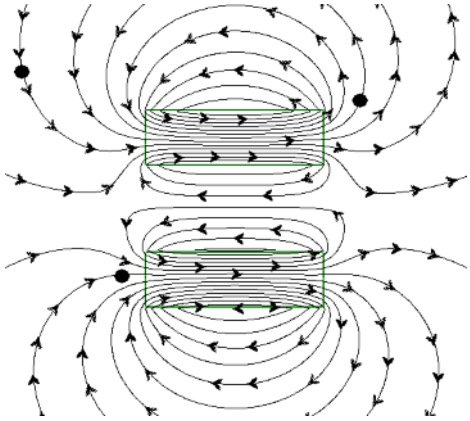
(continued)

Learning Activity 6.1: Magnetic Fields (continued)

c) The diagram below shows two compasses placed in the magnetic field of this combination of magnets. Indicate the direction in which the compass needle would point at these locations.



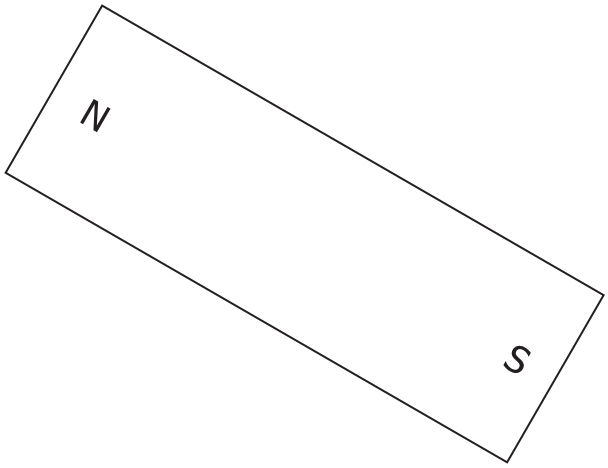
d) The diagram below shows three solid circles. From these circles, draw possible magnetic field vectors. In your drawing, draw the vectors with a length indicating the relative strength of the magnetic field at that point.



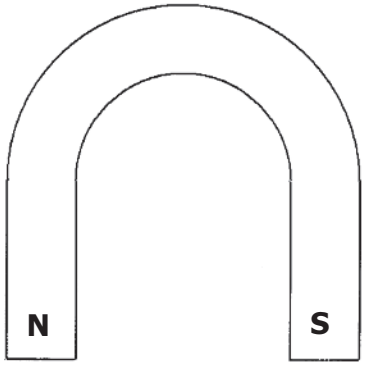
(continued)

Learning Activity 6.1: Magnetic Fields (continued)

2. Draw the magnetic field around the following bar magnet. Include eight lines in the diagram.



3. Draw the magnetic field around a horseshoe magnet.



Lesson Summary

Poles are the regions at each end of the magnet where magnetic fields are most concentrated (where iron filings are attracted and accumulate most noticeably).

The **north magnetic pole** (N-pole) is the pole that tends to seek the northerly direction.

The **south magnetic pole** (S-pole) is the pole that tends to seek the southerly direction.

The **Law of Magnetic Poles** states that unlike poles attract each other, and like poles repel.

While it may be possible to separate positive from negative charges, it is not possible to form single magnetic poles (monopoles).

A magnetic field is visually shown by drawing magnetic field lines that show the direction in which the north pole of the test compass points. The north end of a compass points away from the north pole and towards the south pole **in the space outside the magnet**.

The direction of the magnetic field at any point is tangent to the magnetic field line at any point. Just like electric field lines, magnetic field lines do not cross each other.

The strength of the magnetic field is proportional to the number of field lines per unit area that passes through a surface oriented perpendicular to the lines.

The shape of the magnetic field line pattern is very similar to the electric field line pattern for a dipole.

There are two major differences between magnetic field line patterns and electric field line patterns:

1. Magnet field lines are complete loops.
2. Magnet field lines actually pass through the magnet. Inside the magnet the field lines point from the south pole to the north pole

When drawing magnetic field line patterns for bar magnets, horseshoe magnets, or combinations of magnets, the magnetic field lines are drawn so that they point away from the north pole and towards the south pole.

NOTES

Assignment 6.1, Part A

Magnetic Fields (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 5 and Module 6, after you have completed Module 6.

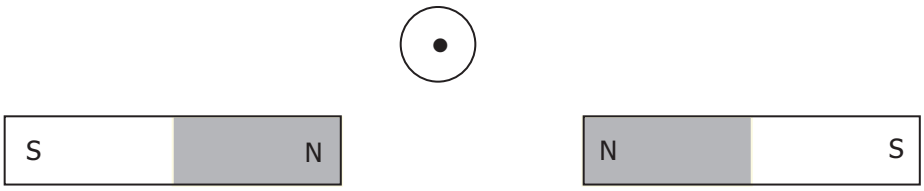
The diagram below shows two bar magnets with the north poles facing each other.

a) Draw a possible magnetic field line pattern for this situation.

(continued)

Assignment 6.1, Part A: Magnetic Fields (continued)

b) On the diagram you completed in part a, place a compass in the position shown below. Show how the needle would point.



c) On your diagram, draw an arrow indicating two possible places where a magnetic field vector would point at 45° north of east. Place the two vectors at different distances from the bar magnets, and show how the relative field strength would vary by arrow lengths.

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining the correct pattern or shape of the magnetic field in part (a)
- 1 mark for showing the correct arrow direction in all parts of the diagram in part (a)
- 1 mark for showing the correct compass direction in part (b)
- 1 mark for the correct positioning of two possible vectors in part (c)
- 1 mark for the correct relative length of vectors in part (c)

Lesson 2: Domain Theory and the Earth's Magnetic Field (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "ferromagnetic" and state which materials are ferromagnetic
- ❑ explain what makes materials magnetic or not using the Domain Theory of Magnetism
- ❑ explain various common magnetic effects using the Domain Theory of Magnetism (e.g., needles can be magnetized, breaking a bar magnet produces two new bar magnets, some magnets demagnetize instantaneously while others do not, magnets can reverse their field direction, physical structures such as ship hulls and beams in buildings can be magnetized)
- ❑ define the terms "north magnetic pole" and "south magnetic pole"
- ❑ explain the magnetic effects caused by the earth's magnetic field by comparing it to a bar magnet
- ❑ state where the north magnetic pole and the south magnetic pole are in relation to the earth's geographic north and south poles
- ❑ define the terms "magnetic declination" and "magnetic inclination" or "angle of dip"
- ❑ explain what is meant by the terms "magnetosphere," "solar wind," and "aurora"

Key Words

Domain theory of magnetism
north magnetic pole
magnetic inclination
solar wind
south magnetic pole
angle of dip
aurora
ferromagnetic
magnetic declination
magnetosphere

Introduction

In this second lesson of magnetic fields, we examine a theory that explains why certain materials are magnetic, while others are not. The Domain Theory of Magnetism helps to explain several common magnetic effects, such as how a nail may become magnetized. We then turn our attention to the earth itself and learn about magnetic properties of, and effects caused by, the earth. The earth behaves approximately as if it is has a huge bar magnet stuck inside of it, and this is what causes a compass to point towards a magnetic pole and why a magnetized needle that is able to rotate in a vertical direction usually tilts up or down. The magnetic field of the earth gives rise to a sort of magnetic atmosphere above and beyond the surface of the earth known as the magnetosphere. It is in the magnetosphere where charged particles from the sun become trapped and produce the beautiful auroras, or the Northern Lights that we are able to observe on occasion.

Ferromagnetism and the Domain Theory of Magnetism

Some materials, such as iron, nickel, and cobalt, are not normally magnetized, but under certain circumstances they can become magnetized. Such materials are called **ferromagnetic**. Ferromagnetic materials are strongly attracted to magnets. Ferromagnetic substances are commonly referred to as "magnetic substances."

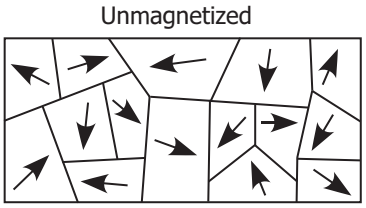
> **Ferromagnetic** materials readily show strong attractions to nearby magnets, and may become magnetized.

Some alloys (mixtures of different metals) such as "alnico" have extraordinary ferromagnetic properties. Alnico consists of the elements aluminum, nickel, cobalt, and iron. These magnets can support a weight of over 1000 times that of the magnets themselves. Certain alloys containing "rare earth" elements such as neodymium can be made to have even stronger magnetic properties.

Why ferromagnetic materials have these magnetic properties may be explained using the **Domain Theory of Magnetism**. Ferromagnetic substances are composed of a large number of tiny regions (typically less than 1 mm in size) called "**magnetic domains**." Each domain behaves like a tiny bar magnet, with its own north and south poles, due to the nature of the atoms within the domain. When the material is in an unmagnetized state, these domains are oriented at random, so that their magnetic fields mostly cancel out. In the diagram below, the arrows represent the orientation of the

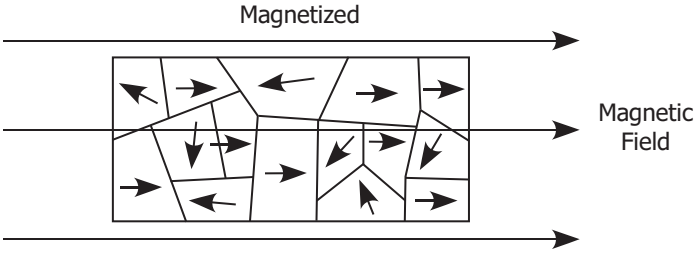
magnetic fields produced by each domain in a small piece of unmagnetized iron. Remember the tip of the arrow represents the north pole of the magnetic domain.

According to the Domain Theory of Magnetism, ferromagnetic materials are made up of "miniature magnetic regions" known as **domains**.



However, if this piece of ferromagnetic material is placed in a strong enough magnetic field, some domains actually rotate slightly to align with the external field. The net result is that there is a preferred orientation of the domains in the same direction as the external field, causing the material to behave like a magnet. It now produces its own magnetic field as the individual domain fields now reinforce each other instead of cancelling out.

When the external field is removed, this orientation may remain for a long time (we call these materials "**magnetically hard**"), or may disappear almost immediately (we call these materials "**magnetically soft**"), depending on the material. Note that "hard" and "soft" here do not have their usual meaning. They refer only to the magnetic properties of the material. Permanent magnets are made out of "hard" materials that tend to maintain this domain order.



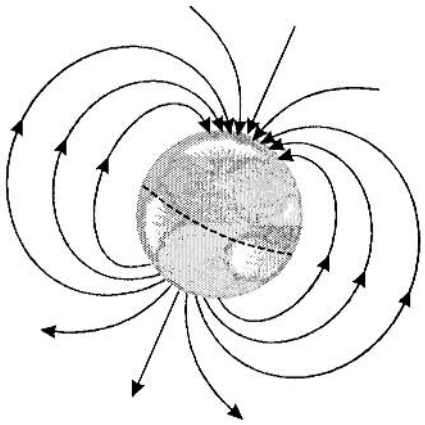
Domain Model Explanation of Magnetic Effects

The domain model provides simple explanations for many common properties of magnets.

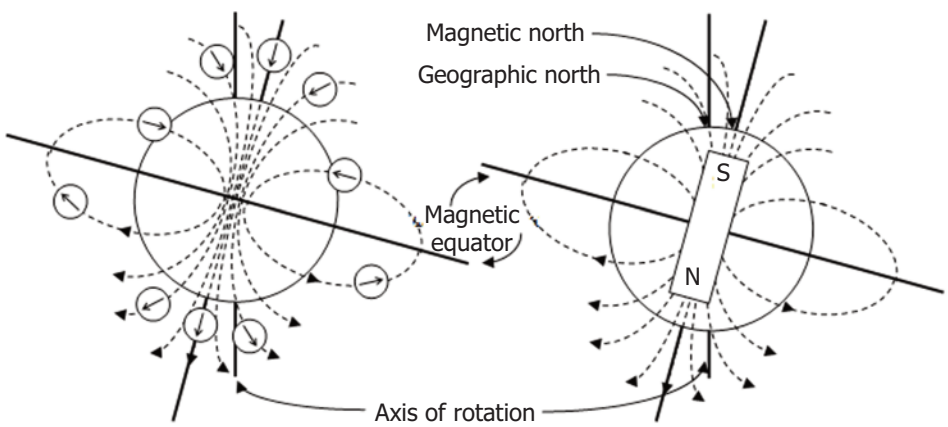
1. Touching a strong permanent magnet to a ferromagnetic (but unmagnetized) object will align the domains in the object and therefore magnetize it. The object is now itself a magnet, either a temporary one or a permanent one, depending on the material. In fact, touching is not strictly required. As long as the ferromagnetic material is placed in a sufficiently strong magnetic field (such as *near to* a strong magnet), the result will be the same.
2. When a bar magnet is broken in two, rather than producing separate north and south poles, two smaller magnets are produced, each with its own north and south poles. The original magnet contained many aligned domains, each with a north and south pole. Breaking it produced two pieces, each still containing aligned domains with north and south poles. (Recall in the previous lesson that placing two magnets together, one after the other, north pole of one touching the south pole of the other, produced one large magnet. Breaking a large magnet into two smaller magnets is simply like separating the two magnets mentioned above!)
3. Some materials lose their magnetism easily. These are called temporary magnets and are often used in electromagnets designed to lift ferromagnetic materials. Other magnets that are made of hard steel or alloys remain magnetized for a long time. These kinds of "permanent magnets" have many applications, such as door catches in fridges. Impurities or irregularities in the alloys help to "lock" the domains—once aligned—in place and prevent them from relaxing to a random orientation.
4. Heating or dropping a magnet may cause it to lose some or all of its magnetization. The domains are physically jostled (in the case of dropping) or jostling (in the case of heating, as heating increases the atomic motion), which tends to make them move and become "scrambled" so that the domain fields tend to cancel each other out. If you heat a magnetized material to a certain temperature called the Curie temperature, the material will become "unmagnetized." The Curie temperature is different for different materials.
5. A very strong magnetic field can reverse the magnetism in bar magnets so that the pole marked S points north. This occurs when the domains reverse their direction of orientation by 180° due to the influence of a strong magnetic field in the opposite direction.
6. Ferromagnetic materials, which mostly remain fixed in position (steel table legs, columns and beams in buildings, etc.), are often found to be slightly magnetized due to the effects of the earth's magnetic field. With time, the earth's magnetic field tends to align the domains within these objects.

The Magnetic Field of the Earth

Compasses work because the earth itself behaves like a magnet. Ancient sailors believed that somewhere in the north was a magnetic mountain that was the source of attraction for their compasses. It was not until the 1600s when Sir William Gilbert compared the earth to a large spherical lodestone. He maintained that the compass needle was drawn to the planet's magnetic pole. It was simply a matter of one magnet (earth) pulling on another (the compass). In simple terms, Gilbert's model was that the earth's magnetic field was similar to that of a large bar magnet with its south pole in the northern hemisphere (which is why the north pole of a compass points that way).



In the adjacent diagram, the magnetic field produced by the earth is shown. Note that this magnetic field comes out of the South Pole of the earth, which is the north pole of the earth's magnetism. Similarly, the magnetic field goes into the North Pole of the earth, which is therefore the south pole of earth's magnetism. It may seem a little strange that there is a "magnetic south pole in the north," but remember that this is why the north pole of a compass is attracted to the north. At the magnetic poles, the magnetic field lines point perpendicularly into the earth at the north magnetic pole and perpendicularly out of the earth at the south magnetic pole. A compass placed at a magnetic pole would rotate freely.

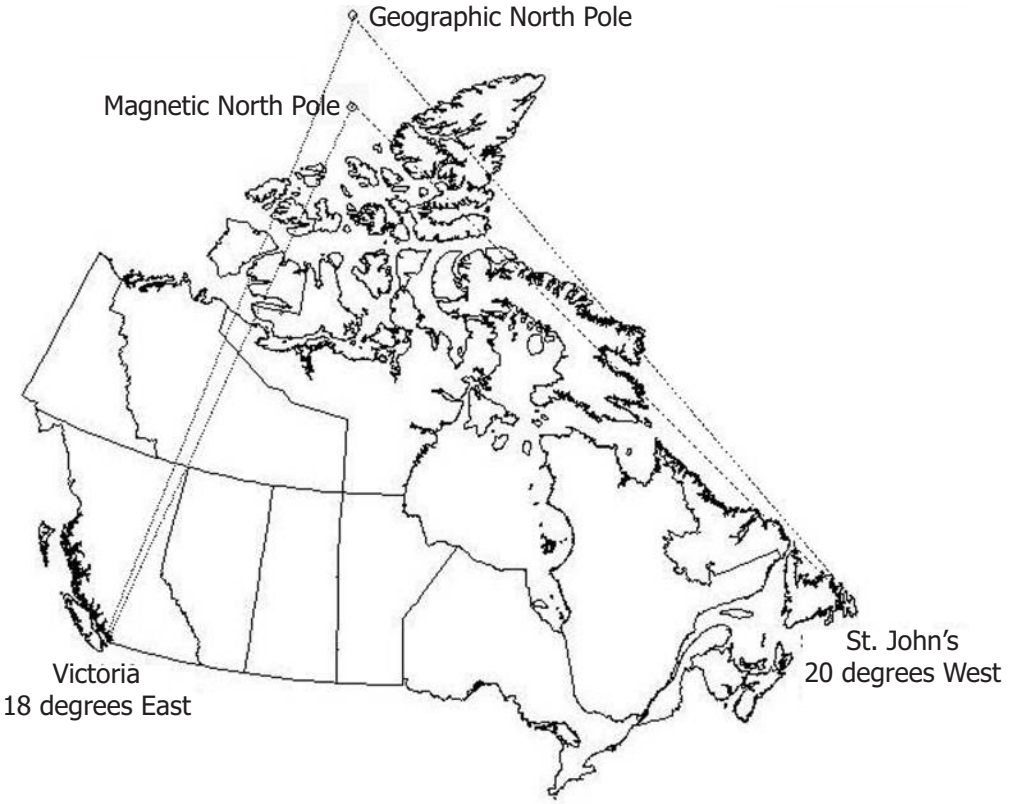


Magnetic Declination

The above description is not quite true. The reality is that the geographic poles of the earth are not quite at the same location as the magnetic poles. The geographical poles are the points about which the earth completes its daily rotation, and it is these points that define where north and south "really" are.

However, the magnetic poles are not quite at these geographic poles - the magnetic south pole (which is where the north pole of a compass will point) is about 1500 km away from the geographic North Pole. The position of the magnetic north pole moves about 40 km/year.

"Magnetic declination" is a measure of the angular difference between the true north direction and the direction that a compass points and can vary from 0° to about 25° for most of Canada, depending on your location. For example, the magnetic declination for Victoria B.C. is 18° east, but in St. John's, Newfoundland it is 20° west. This means that a compass needle in Victoria points 18° east of true north and a compass needle in St. John's points 20° west of true north.



In order to navigate by compass, the angle of declination for a particular location must be known to permit calculation of true north. According to the National Geomagnetism Program, the north magnetic pole is a feature unique to Canada and monitoring its position and motion is of prime importance to Canadian cartography.

> **Magnetic declination** is the measured angle between the direction to true north (the location of the north geographical pole) and the direction that a compass will point (towards the magnetic north pole—the south pole of earth's magnetism).

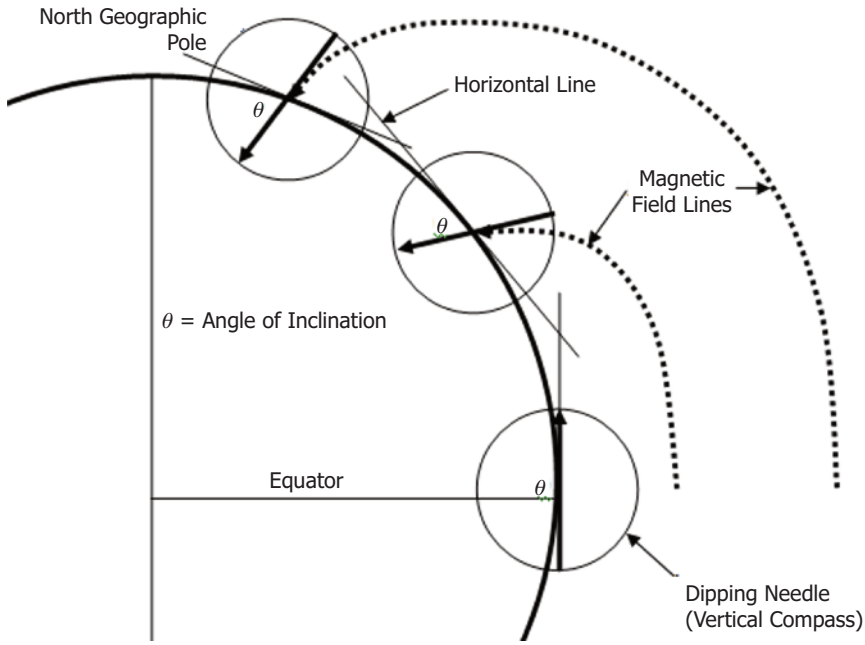
Magnetic Inclination

As well, the earth's magnetic field is three dimensional, with both a horizontal and a vertical component. A magnetic compass on a horizontal surface reveals only the horizontal component.

> The angle between the earth's magnetic field at any point and the horizontal is called the **magnetic inclination** or **angle of dip** and it is measured with a "magnetic dipping needle."

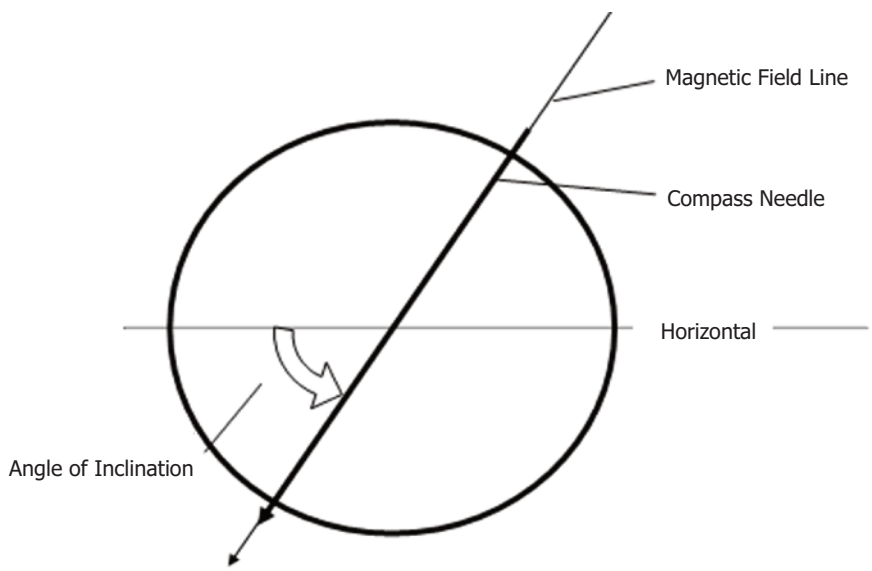
A dipping needle is a compass pivoted at the centre that is free to rotate vertically (normal compasses are free to rotate horizontally). When aligned with a horizontal compass pointing north, it will point in the direction of the earth's magnetic field, and the angle of inclination can be read directly from the attached protractor. At each location on the earth, the magnetic field lines intersect the earth's surface at a specific angle of inclination. Near the equator, the field lines are approximately parallel to the earth's surface, and the angle of inclination in this region is close to 0°. At the magnetic pole, the field lines are directed almost straight down into the earth and the angle of inclination is 90°. Thus, the angle of inclination varies with latitude. It has been suggested that some animals have the ability to distinguish between magnetic inclination angles, and therefore "sense" the latitude.

Angle of Inclination



Here is a magnified view of a dipping needle (vertical compass) measuring the angle of inclination.

Vertical Compass

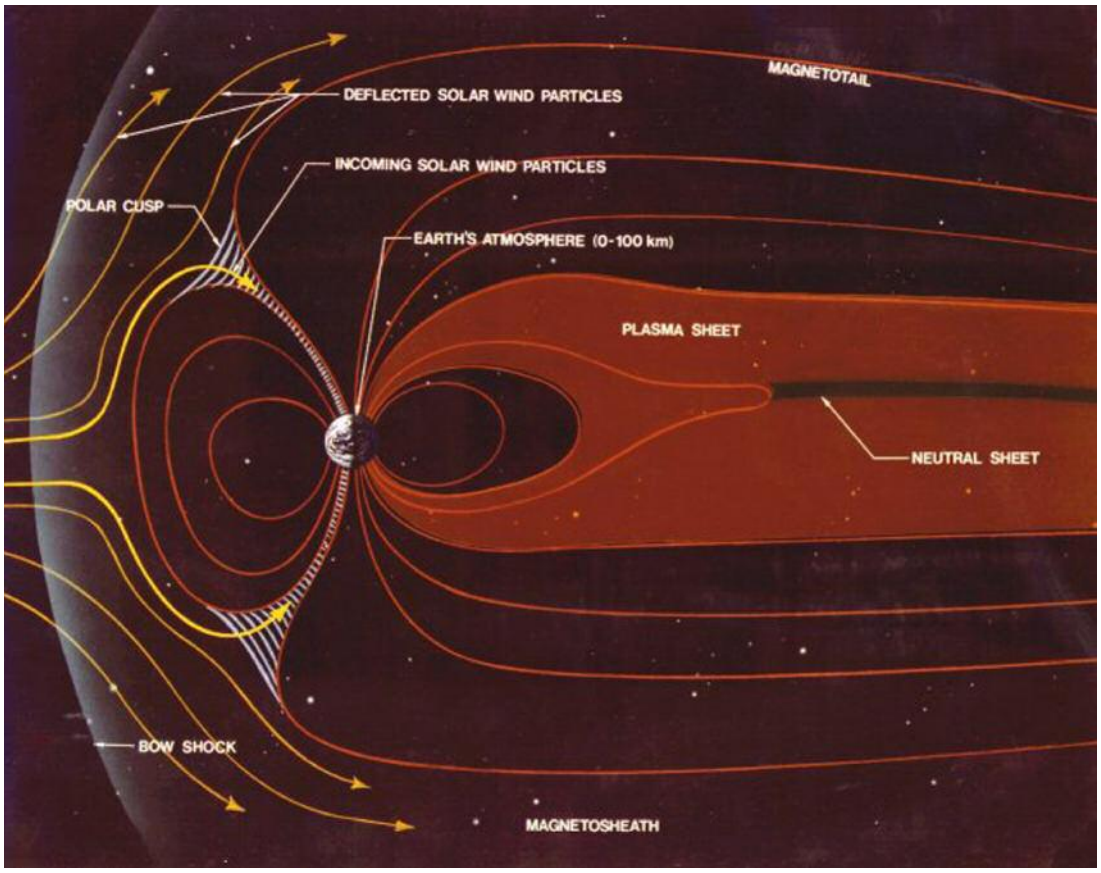


Magnetic inclination (also known as "angle of dip") is the angle that the earth's magnetic field makes to the horizontal at the surface of the earth.

Inclination and declination charts must be revised from time to time because the earth's magnetic field seems to be slowly changing. It is believed that these changes result from the earth's magnetic field rotating about the earth's axis, taking about 1000 years to make a complete rotation.

The Magnetosphere and the Auroras

The **magnetosphere** is a region of the upper atmosphere beyond approximately 200 km in which the motion of charged particles from space is governed by the magnetic field of the earth. The magnetosphere on the side facing the sun extends beyond the earth's surface approximately 57,000 km (about 10 times the earth's radius). On the side away from the sun, the magnetosphere extends outward considerably farther. The elongated shape results from the influence of the onrushing **solar wind**. The solar wind consists mainly of protons and electrons emitted by the sun, which compresses the magnetosphere on the side nearest the sun and "blows it away" from the earth on the other side.



Source: http://science.nasa.gov/newhome/headlines/guntersville98/images/mag_sketch_633.jpg. Public Domain.

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Schematic of magnetosphere.

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In 1958, regions of intense radiation were discovered within the magnetosphere by a team of physicists headed by Dr. J. Van Allen. These regions are now known as the Van Allen radiation belts, and contain energetic protons and electrons trapped by the earth's magnetic field. Those trapped in the inner belts probably originate in the earth's atmosphere, while those trapped in the outer belts probably have their origin in the sun.

Auroras, commonly called the northern or southern lights, are caused by high-energy particles from the solar wind that are trapped in the Van Allen belts of the earth's magnetic field. As these particles oscillate along the magnetic field lines, they enter the atmosphere near the north and south magnetic poles. Energetic electrons collide with the oxygen and nitrogen molecules in the atmosphere. These collisions excite the molecules. When they escape from their excited states, they emit the light we see in the auroras. This forms a curtain of light that may hang down to an altitude of 100 km. Green light is emitted by oxygen, and pink light by nitrogen, but often the light is so dim that the colour can't be perceived, and so it appears to be a faint white.

An auroral display extends in an arc above the earth. Although the display is long, it is less than 1 km thick (north to south).

Learning Activity 6.2

The Earth's Magnetic Field

1. What would you do to magnetize a steel nail, and then demagnetize the same nail? Explain why these effects occur.
2. In a TV commercial that advertises a soda pop, a strong electromagnet picks up a delivery truck carrying cans of the soft drink. The picture switches to the interior of the truck, where cans are seen to fly upward and stick to the roof just beneath the electromagnet. Are the cans made of aluminum? Justify your answer.
3. Suppose you have two bars, one of which is a permanent magnet and one which is not a magnet but is made from a ferromagnetic material like iron. The two bars look exactly alike. Using a third bar, which is known to be a magnet, how can you determine which of the look-alike bars is the permanent magnet and which is not?
4. Why would it be dangerous for life on earth if the Van Allen belts produced by the earth's magnetic field were not present?

Lesson Summary

Ferromagnetic materials, such as iron, nickel, cobalt, and gadolinium, are not normally magnetized, but under certain circumstances they can become magnetized. Ferromagnetic materials are strongly attracted by magnets. They are commonly referred to as "magnetic substances."

The **Domain Theory of Magnetism** states that

- ferromagnetic substances are composed of a large number of tiny regions (less than 1 mm long or wide) called "magnetic domains."
- each domain behaves like a tiny bar magnet, with its own north and south poles.
- when the material is in an unmagnetized state, these millions of domains are oriented at random, so their magnetic effects cancel out.
- if a piece of this material is placed in a strong enough magnetic field, some domains rotate slightly to align with the external field.
- the net result is that there is a preferred orientation of the domains in the same direction as the external field, causing the material to behave like a magnet.

The domain theory can be used to explain many common magnetic effects.

- A ferromagnetic object can be magnetized by stroking it in one direction with a strong permanent magnet.
- When a bar magnet is broken in two, two smaller magnets are produced, each with its own north and south poles.
- Magnetically "soft" materials lose their magnetization relatively easily.
- Magnetically "hard" materials, once magnetized, remain magnetized indefinitely.
- Heating or dropping a magnet may cause it to lose its magnetization (as the domains randomize).
- A strong magnetic field can reverse the magnetism.
- Ships' hulls, columns, beams in buildings, and many other ferromagnetic structures are often found to be magnetized by the effects of the earth's magnetic field.

Sir William Gilbert's model of the earth's magnetic field suggested that it was similar to that of a large bar magnet, inclined at a slight angle to the earth's axis and with its south pole in the northern hemisphere.

The **north magnetic pole** is the pole that is found in the northern hemisphere. The **south magnetic pole** is the pole that is in the southern hemisphere. At the poles, a magnetic compass would just rotate freely.

The north magnetic pole does not coincide with the north geographic pole, but instead lies some 1300 km to the south. The south magnetic pole is located in Antarctica near the Ross Sea.

Magnetic declination is the angle between magnetic north and geographic north that varies from position to position on the earth's surface.

Magnetic inclination or **angle of dip** is the angle between the earth's magnetic field at any point and the horizontal, and it is measured with a magnetic dipping needle.

At each location on the earth, the magnetic field lines intersect the earth's surface at a specific angle of inclination. Near the equator, the field lines are approximately parallel to the earth's surface, and the angle of inclination in this region is close to 0°. At the magnetic pole, the field lines are directed almost straight down into the earth and the angle of inclination is 90°.

The magnetosphere

- is a region of the upper atmosphere beyond approximately 200 km in which the motion of charged particles from space is governed by the magnetic field of the earth
- extends beyond the earth's surface approximately 57,000 km or about 10 earth radii on the side facing the sun
- probably extends outward for hundreds of earth radii on the side away from the sun
- is elongated in shape as a result of the influence of the onrushing solar wind

The **solar wind** consists mainly of protons and electrons emitted by the sun, and this compresses the magnetosphere on the side nearest the sun.

The Van Allen radiation belts contain energetic protons and electrons trapped by the earth's magnetic field. Those trapped in the inner belts probably originate in the earth's atmosphere, while those trapped in the outer belts probably have their origin in the sun.

Auroras, commonly called the northern or southern lights, are caused by high-energy particles from the solar wind that are trapped in the Van Allen belts of the earth's magnetic field. The lights in the auroras are caused by molecules escaping from their excited states.

NOTES

Assignment 6.1, Part B

The Earth's Magnetic Field (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 5 and Module 6, after you have completed Module 6.

1. Suppose you have two bars, one of which is a permanent magnet and the other is not a magnet but is made from a ferromagnetic material such as iron. The two bars look exactly alike. Explain how you can distinguish the look-alike bars with the aid of a third bar that is not a magnet, but is made from a ferromagnetic material.

_____

_____

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_____

_____

2. Describe the action of a magnetic compass and a magnetic dipping needle at
   a) the north magnetic pole

   _____

   _____

   b) the south magnetic pole

   _____

   _____

(continued)

c) the equator

_____

_____

3. Iron pipes, steel beams, and other steel structures that remain stationary are often found to be magnetized with a distinct polarity. Explain how this can happen.

_____

_____

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for a correct explanation in question 1
- 1 mark for correctly explaining how the compass and dipping needle behave at the north pole and part 2(a)
- 1 mark for correctly explaining how the compass and dipping needle behave at the south pole in part 2(b)
- 1 mark for correctly explaining how the compass and dipping needle behave at the equator in part 2(c)
- 1 mark for the correct explanation in question 3

LESSON 3: ELECTROMAGNETISM (1.25 HOURS)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain the principle of electromagnetism as discovered by Oersted
- ❑ use the right-hand rule to determine the direction of the magnetic field produced by a straight conductor carrying a current
- ❑ explain how the intensity of the field varies as one moves away from the wire
- ❑ determine the magnetic field line pattern for a loop of wire
- ❑ define the term "solenoid"
- ❑ state where the magnetic field of a solenoid is strongest
- ❑ determine the direction of the magnetic field in and around a solenoid using the right-hand rule for a solenoid
- ❑ define the term "electromagnet"
- ❑ list the factors that affect the magnetic field strength of an electromagnet
- ❑ list various applications of the use of an electromagnet

Key Words

electromagnetism
electromagnets
right-hand rule
conventional current

Introduction

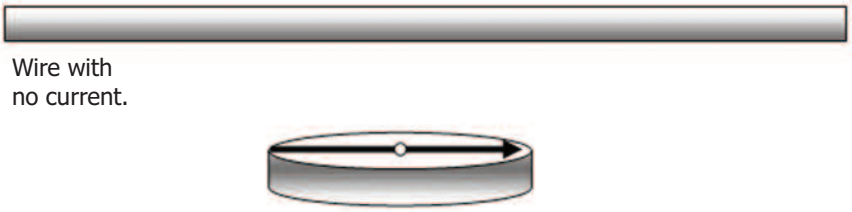
In the late 1700s, a man by the name of Alessandro Volta invented the battery. Soon after this, there were renewed attempts to discover the relationship between electricity and magnetism. Evidence that a connection existed had been at hand for decades. In 1735, the *Philosophical Transactions of the Royal Society of London* carried a paper entitled "Of an Extraordinary Effect of Lightning in Communicating Magnetism." It contained a report of a bolt of lightning that struck a tradesman's house, blasting apart a box full of knives and forks, hurling them "all over the room ... but what was most remarkable…" was that they were all strongly magnetic afterward.

So far we have studied electric fields as well as magnetic fields. In this lesson, we bring together electric and magnetic fields into the study of electromagnetism. We begin with the early work done by the Dutch scientist Hans Christian Oersted (pronounced "Er-Sted") in the 1800s. His work led to an understanding of how an electric current produces a magnetic field around the conductor. The principles learned in magnetic field patterns for a single straight wire are extended first into a single loop of wire, and then into many loops of wire in a device called a solenoid. We end the lesson with a discussion of electromagnets, the factors that increase or decrease the strength of electromagnets, and the various applications of electromagnets.

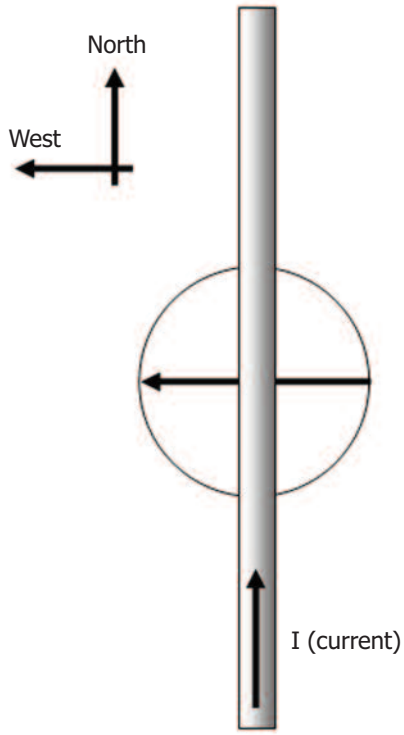
Oersted's Discovery

Prior to the nineteenth century, electricity and magnetism were generally thought to be very separate phenomena. We have actually emphasized this point earlier, stating that a magnet does not attract or repel a charged object (which is true). On July 21, 1820, Hans Christian Oersted, professor of physics at Copenhagen University, made an accidental discovery of the utmost importance. Oersted was teaching a class on electricity when, by chance, a wire leading to a battery was nearly parallel to and above a magnetic compass that happened to be on a table along with some other objects.

Oersted's Apparatus



When the electric current was turned on, the needle of the compass swung around to be almost perpendicular to the electric current-carrying wire as if gripped by a powerful magnet.



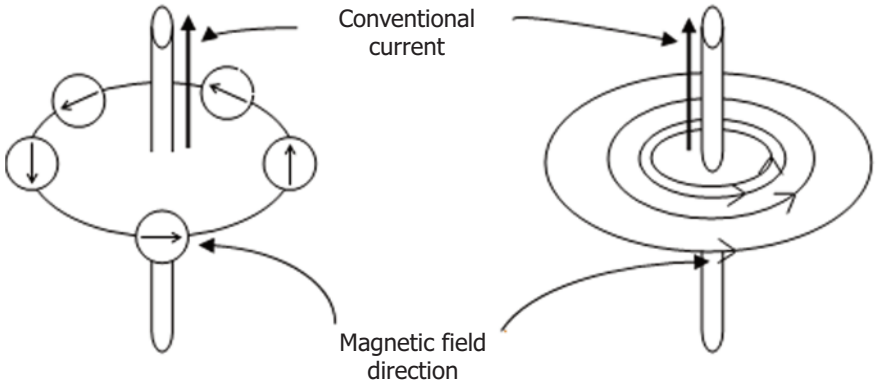
The diagram above shows the results of this experiment when it is viewed from above the wire. The needle is deflected to the west, indicating that the magnetic field is pointing west at that point.

From this lucky observation, Oersted was able to determine the basic **principle of electromagnetism**:

> Electric currents (moving electric charges—physics symbol "*I*") produce a magnetic field (physics symbol "*B*").

The news of Oersted's discovery reached Paris on September 4th of that same year, when it was reported to a sceptical gathering at the Paris Academy of Sciences. A young professor, Andre Marie Ampere, attended the talk and within two weeks he completed a series of experiments of his own. Ampere showed that the magnetic force experienced by a compass needle in the vicinity of a current-carrying wire acted at right angles to the current along a series of circles, all centred on the wire.

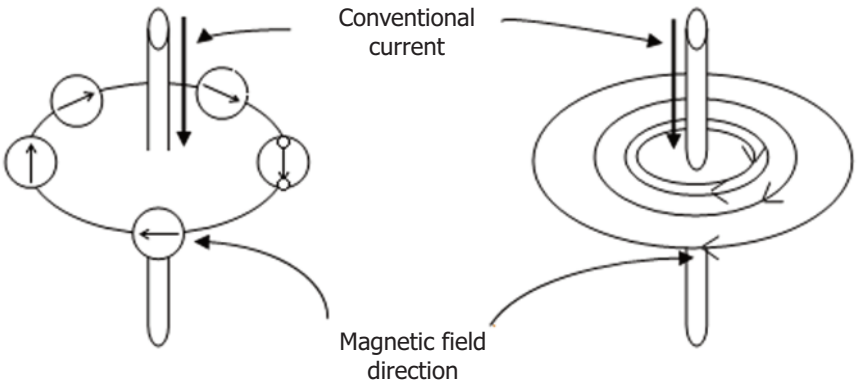
Magnetic Field around a Straight Current-Carrying Wire



The diagrams above illustrate Oersted's discovery and Ampere's work with a long straight wire. When an electric current is present, a compass needle is observed to point in a circular pattern around the wire (the north pole of the compass needle points in the direction of the field at that location, tangential to this circular pattern). The pattern indicates that in general the magnetic field lines produced by a current are circles centred on the wire.

If the direction of the current is reversed, the magnetic field it produces also reverses direction. As you move farther away from the wire, the strength of the magnetic field decreases.

When the direction of the current is reversed the direction of the magnetic field is reversed also.



Magnetic fields circle around current-carrying wires.

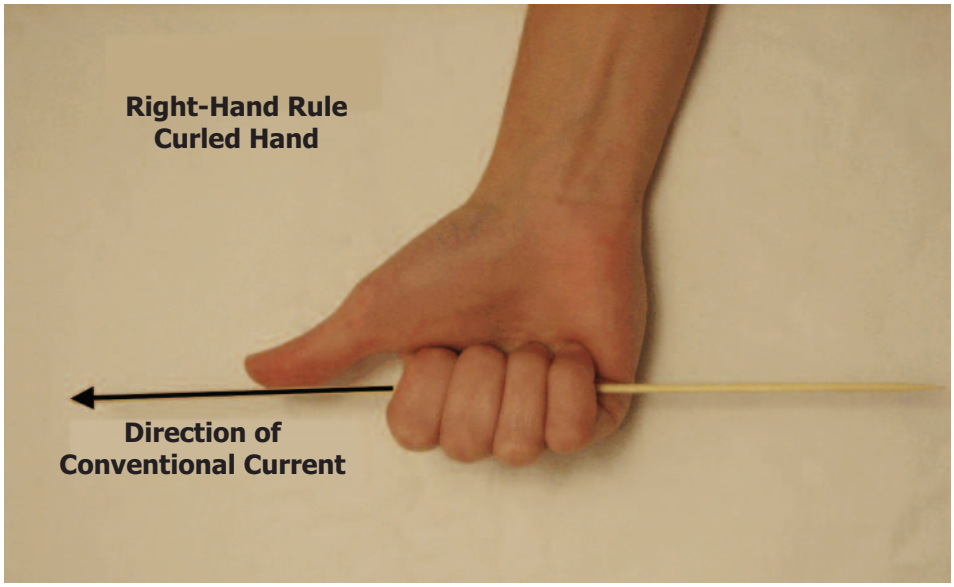
A current is considered to be the flow of positive particles. This flow of positive particles is called "conventional current" to distinguish it from the flow of negative electrons. Due to their opposite natures, a flow of negative particles in one direction is equivalent to a flow of positive particles going the exact opposite way. When the word "current" is used, it automatically implies the flow of positive (and not negative) charge.

> "**Current**" is the flow of positive charge.

Right-Hand Rule #1: Curled Hand

The direction of the magnetic field can be determined by using what we call "**the first right-hand rule**" (there are two more right-hand rules, which we will discuss shortly). Before actually stating this rule, you should be aware that this rule (as well as the other hand rules) is really just a little trick to help us remember something important. This first rule helps us remember the direction of the circulating magnetic field around the current that creates it.

If you were to use your right hand to "grab the wire" that is carrying the current, and to point your thumb in the direction of the current, then your fingers would "curl around" the current in the same direction as the magnetic field circulating around the current.



To find the direction of the magnetic field at a given point, place the tips of your fingers at the point where you need to determine the direction of the magnetic field. The direction of the magnetic field is determined by the direction that your fingertips point.

Diagramming Magnetic Fields

As you can see, it is difficult to draw magnetic fields and wires in three dimensions. So we try to simplify matters by limiting our drawings to only two dimensions, like the piece of paper on which these words are printed.

What we do is draw the current in the wire either travelling into the page or out of the page. The wire is represented by a circle. If the current is flowing out of the page, we put a dot in the middle of the circle. This is like the tip of an arrow coming towards you. If the current is flowing into the page, we put an "X." This is like the tail of an arrow travelling away from you.

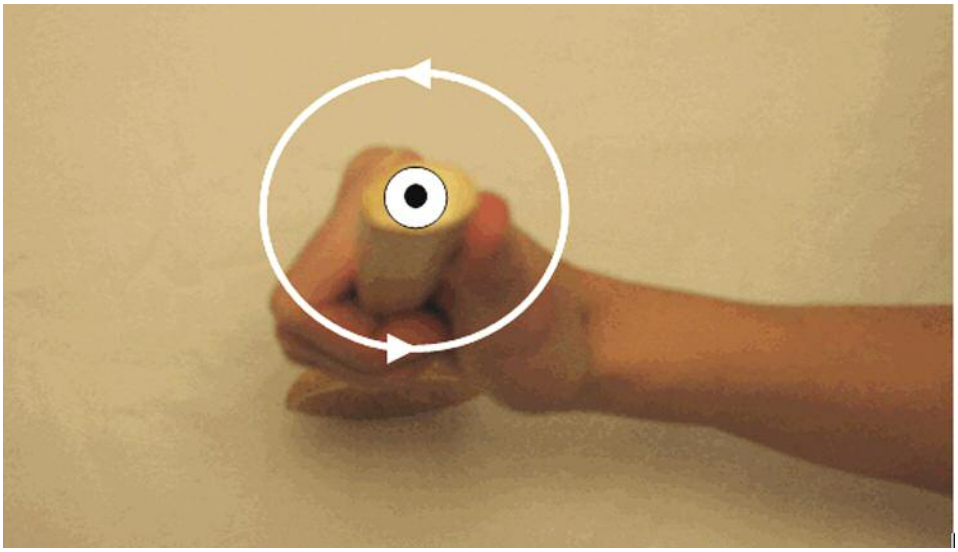
Current I travelling **OUT** of the page.

Current I travelling **INTO** the page.

If you stand your pen or pencil perpendicular to the page, it can represent the wire. If the current is travelling out of the page, place the thumb of your right hand along the pen or pencil pointing up away from the page. If the current is travelling into the page, place the thumb of the right hand along the pen or pencil pointing down towards the page.

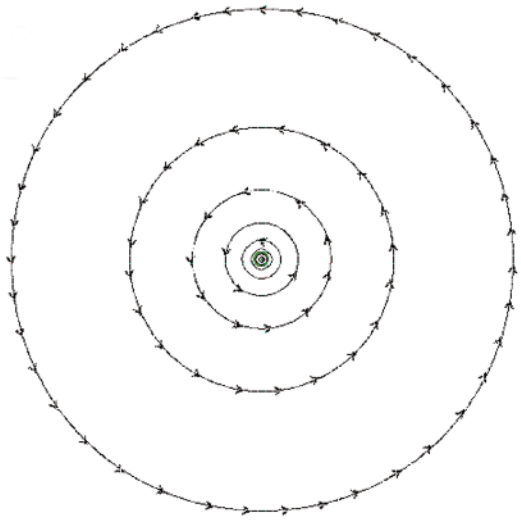
Now, in either case, if you curl your right hand, **your fingers will curl around the current in the same direction as the magnetic field**.

The current is up out of the page. The magnetic field is counterclockwise around the current.

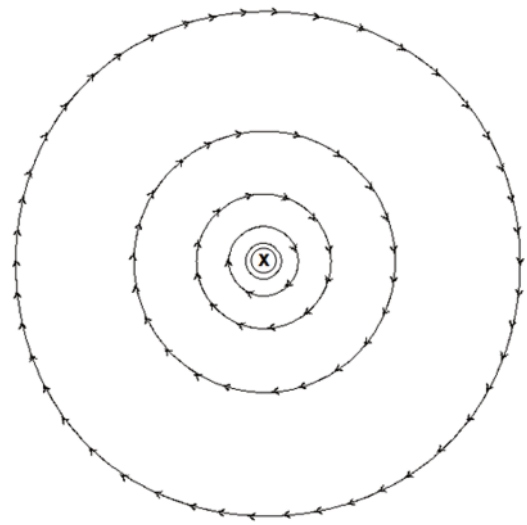


To complete the diagram for the magnetic field, you must draw concentric circles around the current. As you go farther from the current, the magnetic field decreases so lines of magnetic field must be spaced farther apart.

Magnetic Field around a Wire Carrying a Current **OUT** of the Page

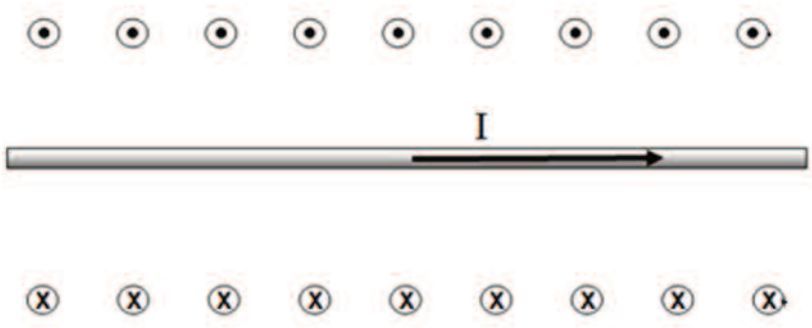


Magnetic Field around a Wire Carrying a Current **INTO** the Page



Magnetic Field of a Loop

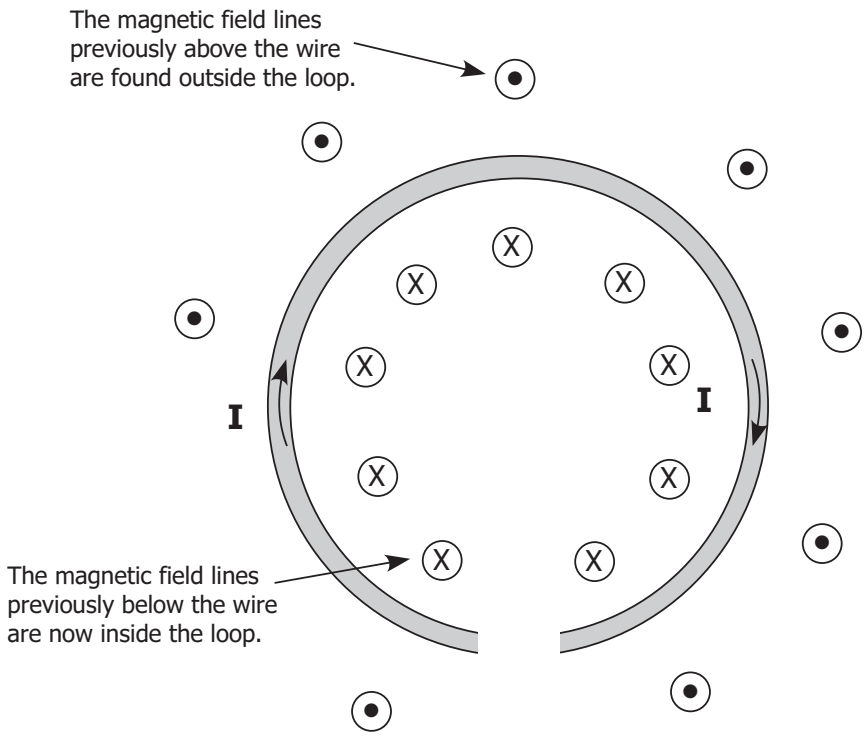
Before we can diagram the magnetic field around the loop of wire, let us consider what the magnetic field around a straight wire looks like if we view it in cross-section. To do this, just imagine taking a flat piece of paper and running the long edge through the length of the wire.



Magnetic field lines point out of the page.

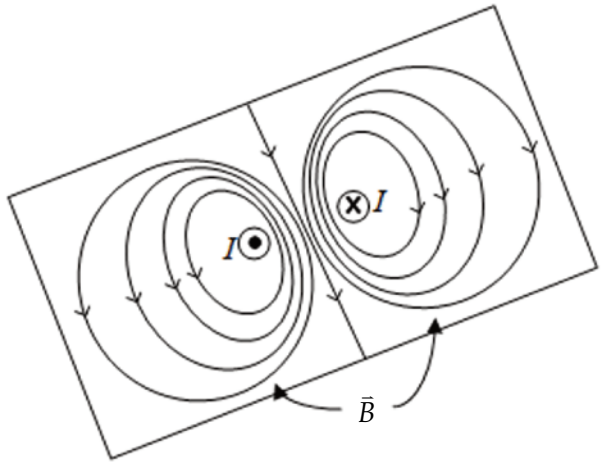
Magnetic field lines point into the page.

When a straight wire is bent into the shape of a circular loop, its magnetic field will appear as shown in the following diagrams:



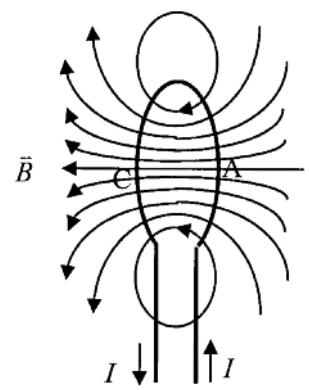
You can see that magnetic field lines become concentrated inside the loop and decrease in density outside of the loop.

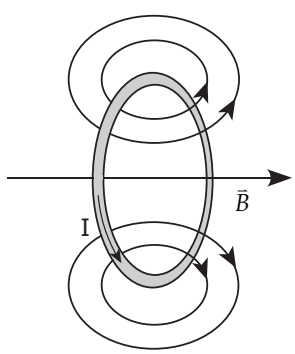
The next diagram shows the top part of a loop above the surface of a plane. The direction of the current through the loop is shown. The current is passing into the plane on the right side. If the thumb points in the direction of the current on this part of the loop, then the magnetic field appears clockwise on the plane surface. As the current in the wire comes up through the surface on the left side, the magnetic field is found to be counter-clockwise in this region. The field lines inside the loop are closer together, indicating a stronger magnetic field than on the outside of the loop.



You can see in the previous diagram that, compared to the magnetic field outside the loop, the magnetic field at the centre of a current-carrying loop of wire is concentrated. Since the field lines are parallel in the plane of the loop, this suggests that the magnetic field is fairly constant inside the loop. Finally, you see that the directions of the magnetic field and the currents are consistent with the first right-hand rule.

The diagram on the right shows a loop in the vertical position, slightly turned, so that we are seeing it from an angle. As you look at the diagram, imagine that the right side of the loop (A) is closer to you and that the left side (C) is farther from you. On the right side of the loop, as the current moves upwards, the magnetic field passes through the interior of the loop in the direction shown.



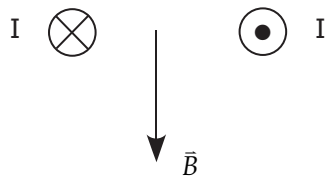


Here is another diagram to show this point. In this diagram, only the loop of current (I) is shown, as well as a few loops of magnetic field. Note that there are not enough field lines shown to illustrate the entire pattern seen above, but enough to see the three-dimensional nature of the field-current relationship.

Second Right-Hand Rule—Curled Hand

To help us find the magnetic field of a current loop, we can use the second right-hand rule: if the fingers of the right hand are "wrapped around" the loop in the same direction as the current flows, then the thumb (when extended out) will point in the direction of the magnetic field within the loop.

Another way to show this effect is to use special symbols to represent vectors (such as magnetic fields). We use a circle with the cross to show a vector going "into" the plane of the paper. Similarly, a circle with a dot inside represents a vector coming "out of" the plane of the paper. Thus, we can imagine a loop passing into the page and then out of the page. Applying the right-hand rule, we can see that the magnetic field direction will be down, as shown.



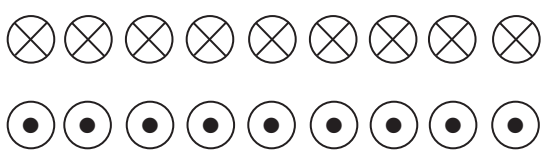
Magnetic Field of a Solenoid

If a long wire is wound into a spiral with many loops (such as along the length of a pencil), we have what may be called a **solenoid**.

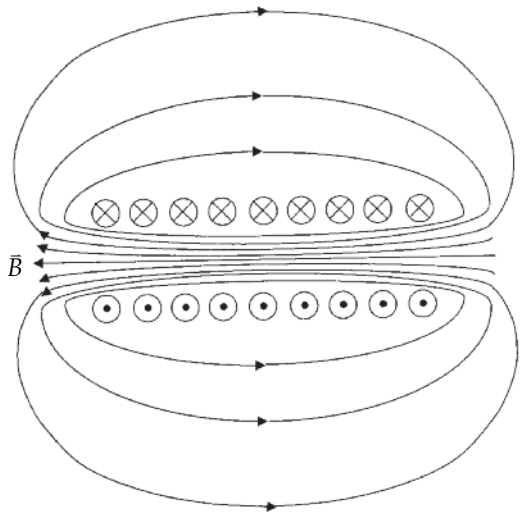
Picture of Solenoid

The magnetic field of a solenoid is the sum of the magnetic fields of all of its loops. As a result, the field inside the coil can be very strong, consisting of field lines that are nearly straight and very close together, as shown. To determine the direction of the magnetic field inside of the solenoid, use the second right-hand rule—curled hand, as was used with the straight wire and the loop.

The easiest way to represent the magnetic field around a solenoid is to imagine a plane cutting through the centre of the solenoid. The result is a cross-section of a solenoid. This cross-section will cut across the wires of the solenoid, yielding two lines of wires—one for each side of the solenoid.



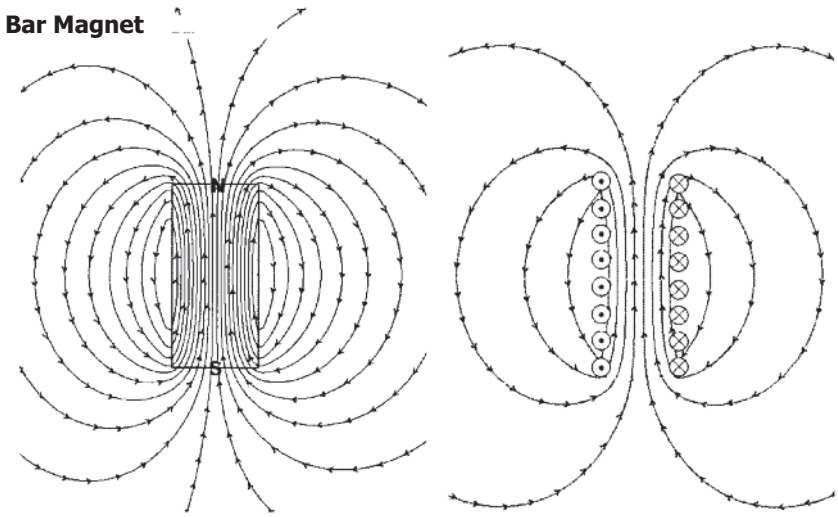
The current moves into the page along the top edge of the solenoid and out of the plane along the bottom edge. The magnetic field points to the left within this solenoid, as seen in the diagram below.



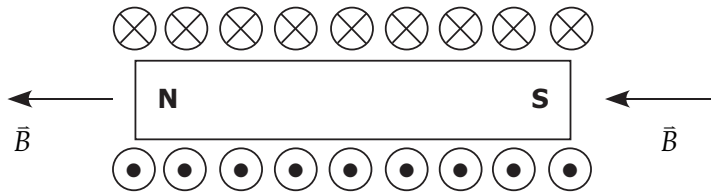
The right-hand rule for loops that you learned earlier can be applied to a solenoid to determine the direction of the magnetic field. Note that a solenoid has a magnetic field very similar to that of a bar magnet. In fact, a solenoid acts in many ways like a bar magnet, with the exception that the magnetic field *can be turned on and off* by turning the current on and off. This leads us right into the idea of …

The Electromagnet

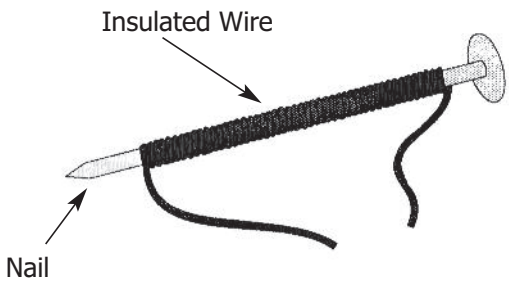
A solenoid is an example of an electromagnet. When carrying a current, it will produce a magnetic field much like a bar magnet.



The end of the solenoid, which has the magnetic field coming out of it, would be the north pole, and the end with magnetic field entering it would be the south pole.



A nail wound with a coil of insulated wire forms an electromagnet when a current flows through the wire.



There are several factors that affect the strength of the magnetic field inside an electromagnet:

- The type of material in the coil's centre is important. So far we have assumed that there was empty space (or air) inside of the solenoid. The strength of the electromagnet can be greatly increased if a ferromagnetic material is placed inside (preferably a "soft" ferromagnetic material—one in which the domains are easily randomized). When the solenoid is on, the current in it will produce a magnetic field, as described above. Additionally, the domains of the ferromagnetic material will tend to align in this field, and so produce an additional magnetic field that adds to the current's field. When the current is shut off, these domains will randomize (if a magnetically soft material was used) and so the magnetism will be lost.
- If the number of coils (turns of wire) in a given length of solenoid is increased (so that the coils are packed closer together), then the magnetic field of the coil will also increase.
- If the amount of electrical current flowing through the coil is increased, then the magnetic field will also be stronger.

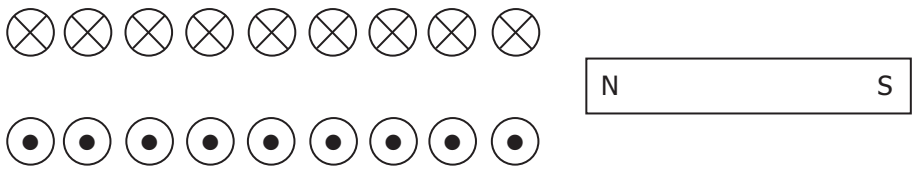
As mentioned above, placing a magnetically soft material in the coils of an electromagnet creates a powerful magnet that can be turned on and off easily. The practical importance of this is stunning. Electromagnets are used in all sorts of devices. Here are just a very few of these applications:

- Lifting electromagnets are able to lift large ferromagnetic materials, such as at a car-crushing plant. An electromagnet is used to lift and carry wrecked cars. Shutting the magnet off allows the car to be dropped.
- Some doors are actually kept locked (prevented from being opened) by powerful electromagnets. Instead of a regular key, a computer turns the electromagnet off to allow the door to be opened only at certain times, or by the entry of a code into a keypunch pad near the door.
- A device called a "relay" uses an electromagnet to attract a ferromagnetic metal to a contact point, and thus acts like a switch for large currents. This means that a small current (fed into the electromagnet windings) can trigger a much larger current to flow. Such a switch is used to turn on high-current circuits such as banks of lighting at sports complexes.
- In a typical doorbell, an electromagnet gets switched on when the button is pressed. This pulls a nearby ferromagnetic material towards the electromagnet, making it strike a bar, which produces a sound ("ding"). The ferromagnetic material is also attached to a spring, which at this point would be stretched out. Releasing the doorbell button shuts the electromagnet off, releasing the ferromagnetic material. The spring then pulls it to strike another bar, making another (different) sound ("dong").
- In a typical speaker, a current is rapidly turned on and off (and even reversed) in a coil of wire that is near a permanent magnet. The coil acts as an electromagnet and is attached to a speaker cone that moves back and forth as it is attracted to and repelled from the nearby magnet (as its poles reverse with when the current reverses). The now vibrating speaker cone produces the sound.

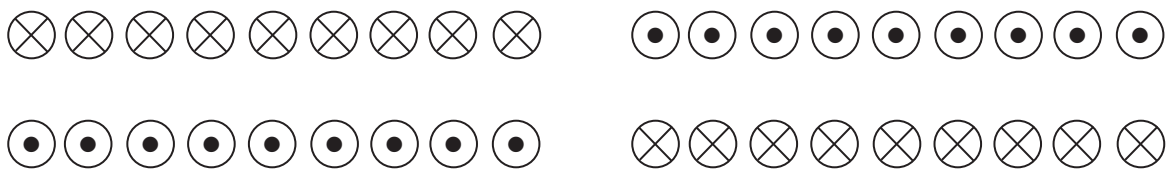
Learning Activity 6.3

Electromagnetism

1. A solenoid is shown below near a bar magnet. Draw the magnetic field line pattern for the solenoid. Will the solenoid and the bar magnet attract or repel each other? Justify your answer.



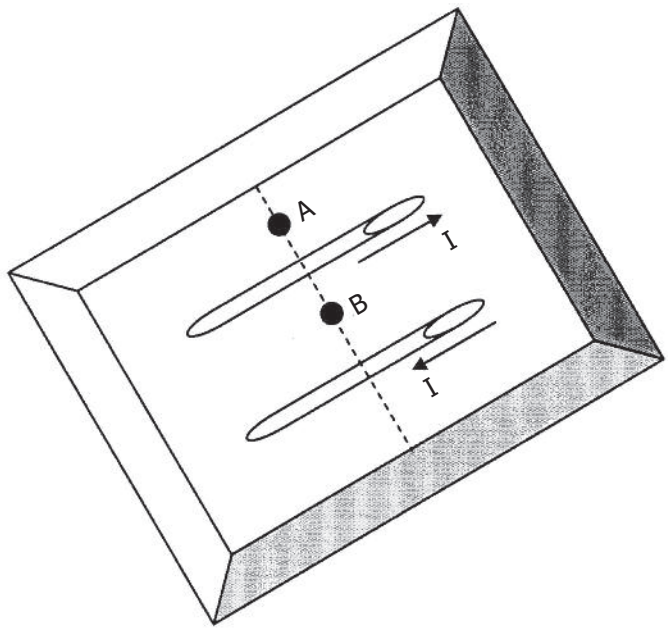
2. Two solenoids are placed side by side as shown below. Will the solenoids attract or repel each other? Justify your answer.



(continued)

Learning Activity 6.3: Electromagnetism (continued)

3. Two current-carrying wires are shown below. The currents are flowing in opposite directions. Both wires are carrying the same amount of current. Point A is to the left of one of the wires, and point B is midway between the wires. The directions of the currents are as shown.

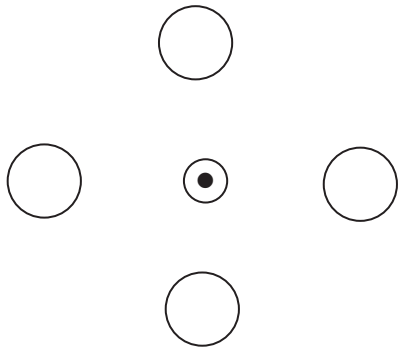


Determine the direction of the net magnetic field at each of points A and B.

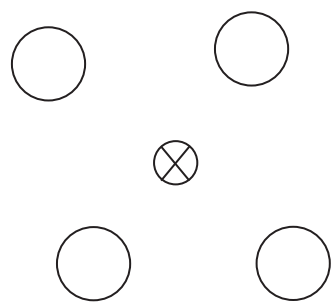
4. The following are ways in which the operation of an electromagnet can be changed. Indicate whether the change will produce a stronger magnetic field or a weaker field.
   a) Replacing an iron core with an aluminum core
   b) Increasing the number of coils of wire
   c) Decreasing the strength of the current

5. A wire is arranged so that it is straight and comes out of the page. The wire is at the centre of the diagram and each circle around the wire represents a compass. Indicate the direction of the compass needle in each circle.

a)



b)



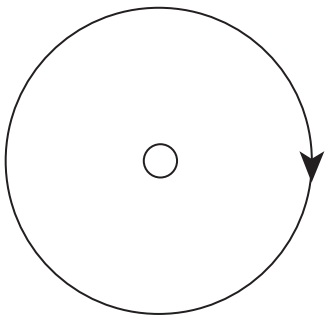
(continued)

Learning Activity 6.3: Electromagnetism (continued)

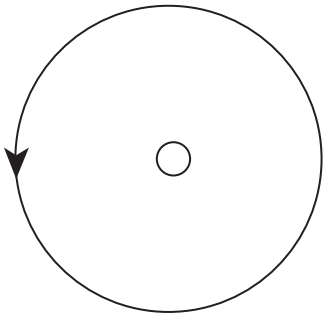
6. A current is travelling south in a straight horizontal conductor. What is the direction of the magnetic field
   a) below the conductor?
   b) above the conductor?
   c) east of the conductor?
   d) west of the conductor?

7. Each empty circle represents a conductor surrounded by a magnetic field. State whether a dot or an "x" should be placed in the circle.

a)

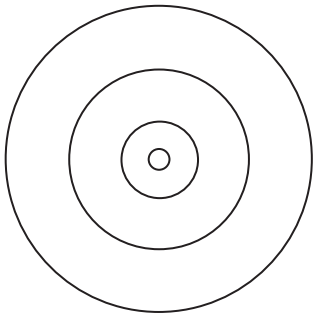


b)

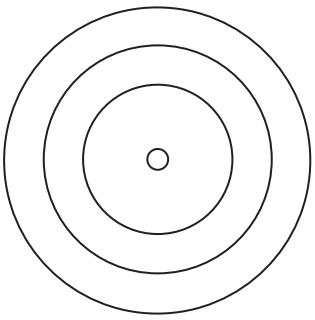


8. Choose the diagram that best illustrates the magnetic field surrounding a straight current-carrying conductor. Explain your choice.

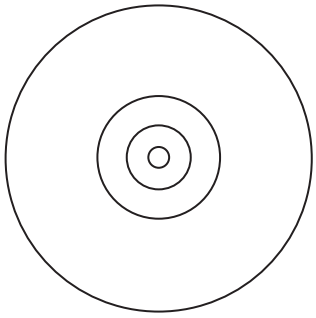
a)



b)



c)



Lesson Summary

In his experiments with magnets and a current-carrying wire, Oersted formulated the basic **principle of electromagnetism** that moving electric charges produce a magnetic field.

When an electric current is present in a straight wire,

- the compass needles are observed to point in a circular pattern around the wire
- the pattern indicates that the magnetic field lines produced by the current are circles centred on the wire
- if the direction of the current is reversed, the needles also reverse direction, indicating that the direction of the magnetic field has also reversed
- as you move farther away from the wire, the intensity of the magnetic field decreases

The direction of the magnetic field around a current-carrying wire can be determined by the **first right-hand rule**—curled hand.

1. Point the thumb in the direction of the conventional current.
2. Curl the fingers of the right hand into the shape of a half-circle. The tips of the fingers will point in the direction of the magnetic field at that point.

The right-hand rule for a wire can also be used to determine the direction of the magnetic field inside a current loop.

A **solenoid** is a spiral coil along the length of a cylinder with many loops of wire.

- The magnetic field of a solenoid is the sum of the magnetic fields of all of its loops. As a result, the field inside the coil can be very strong, consisting of field lines that are straight and very close together.
- To determine the direction of the magnetic field, use the right-hand rule as was used with the straight wire and the loop.

The direction of the magnetic field for a solenoid can be determined using the **right-hand rule** for a solenoid.

1. Grasp the solenoid in the right hand, with the fingers curled in the direction of the conventional electric current.
2. The thumb will point in the direction of the magnetic field lines in its core.

An **electromagnet** is a current-carrying, coiled conductor.

There are several factors that can affect the strength of the magnetic field inside an electromagnet.

- The type of material in the coil's centre is important.
- If a piece of ferromagnetic material is placed in the core of a solenoid, the magnetic field becomes much stronger. The domains in the iron are aligned by the magnetic field in the coil, and total magnetic field is the sum of the field due to the coil and that due to the magnetized core material.
- The ratio of the magnetic field strength with a particular core material to the magnetic field strength without it is called the permeability of the core material.
- If the number of coils or turns of wire is increased, then the magnetic field of the coil will also increase.
- If the amount of electrical current flowing through the coil is increased, then the magnetic field will also be stronger.

The ferromagnetic material used in an electromagnet is usually of a type called "soft." This type of material demagnetizes quickly when the current in the solenoid is shut off, as the domains of the material quickly randomize when the magnetic field that was keeping them in alignment drops to zero.

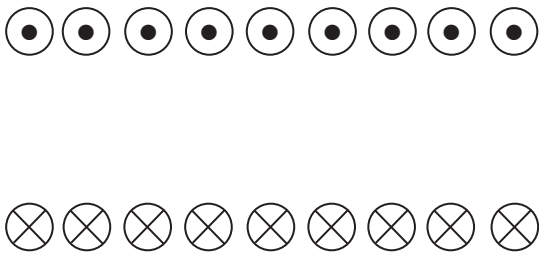
A very common material that exhibits these properties is iron. An iron core solenoid has many applications related to its ability to be a strong magnet that can be turned on and off.

- Lifting electromagnets are able to lift large ferromagnetic materials.
- In a relay, the electromagnet can attract a ferromagnetic metal to a contact point, and thus acts like a switch. Such a switch can be used to turn on high-current circuits such as the bank of lighting in a stadium.
- In an electric bell, an electromagnet oscillates on and off, causing a bell to ring.
- In magnetic speakers, a current is varied in a coil of wire in a magnetic field. The coil is attached to a speaker cone which moves back and forth producing the sound.

Assignment 6.1, Part C

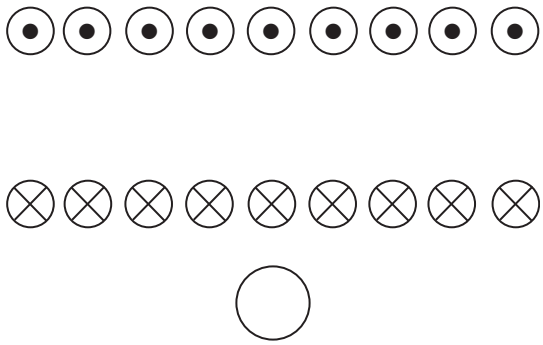
Electromagnetism (5 MARKS)

The coils of a wire in a solenoid are arranged as shown below.



a) Draw the magnetic field line pattern for this arrangement of current. Use at least six loops in the pattern.

b) A compass is placed below the solenoid as shown by the open circle below. How would the compass needle point?



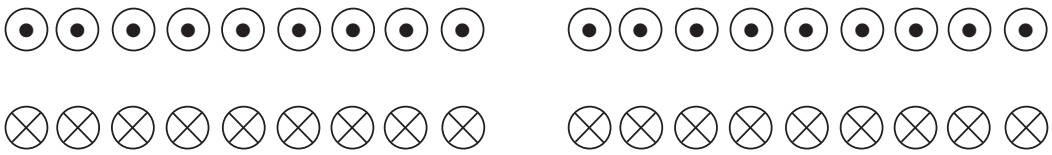
(continued)

Assignment 6.1, Part C: Electromagnetism (continued)

c) Describe the location where the magnetic field strength of the solenoid is the strongest. Why is the magnetic field strongest at this location?

d) What could you add to the interior of the solenoid to create a stronger magnetic field? Explain, using the domain theory, why this is effective?

e) A second solenoid is placed to the right of the previous solenoid. The currents in the solenoid coils are arranged as shown below.



Would the coils attract or repel each other? Explain your reasoning.

(continued)

Assignment 6.1, Part C: Electromagnetism (continued)

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for drawing the correct magnetic field line pattern for part (a)
- 1 mark for indicating the correct direction in which the compass needle will face in part (b)
- 0.5 marks for describing the location of the strongest magnetic field in part (c)
- 0.5 marks for the correct reasoning in part (c)
- 0.5 marks for indicating the type of material in part (d)
- 0.5 marks for the correct reasoning in part (d)
- 0.5 marks for correctly indicating if the solenoids attract or repel each other in part (e)
- 0.5 marks for correct reasoning in part (e)

NOTES

Lesson 4: Video Laboratory Activity: The Tangent Galvanometer (1.25 hours)

Learning Outcomes

When you have completed this lesson, you should be able to describe the effect on the magnetic field produced by a solenoid of:

- ❑ changing the current through the solenoid
- ❑ changing the type of material inside the solenoid
- ❑ changing the number of turns per metre for the solenoid

Video Laboratory Activity: The Tangent Galvanometer

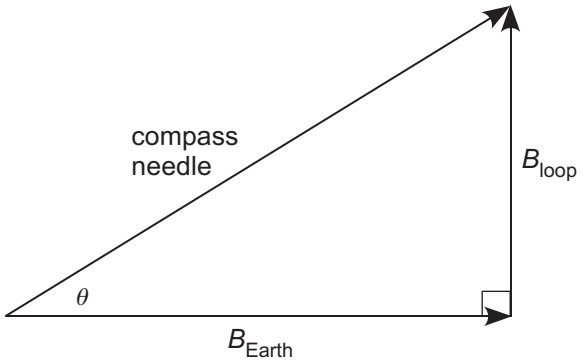
Notes to Student

In this lesson, you will view *The Tangent Galvanometer*, a short video laboratory activity found in the learning management system (LMS). You will collect some data from the video so you should begin by reading the introduction and answering the pre-lab questions.

When you have finished the lab, you will complete a Laboratory Report, which is found at the end of this and every other Laboratory Assignment. The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit for assessment. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

Introduction

An **electromagnet** can be defined as a coiled conductor that carries an electric current. In this experiment, we will vary an electric current to determine the effect of current on magnetic field strength (B). We can easily vary the electric current by increasing the number of loops (coils) of our electromagnet. In order to detect a magnetic field we use a compass and to measure the field we use a tangent galvanometer. The deflection of a compass needle inside of a current-carrying loop is the vector sum of the earth's magnetic field and the magnetic field of the loop.



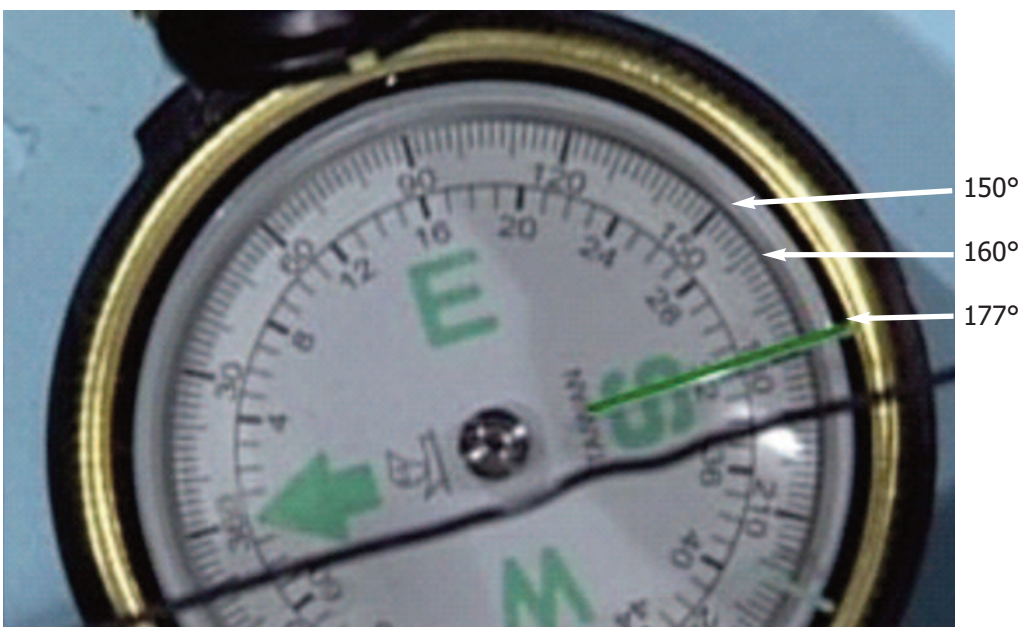
If B_{loop} and B_{Earth} are perpendicular (as shown in the above diagram)

$$\tan\theta = \frac{B_{loop}}{B_{Earth}} \text{ and } \tan\theta \ \alpha \ B_{loop}.$$

Therefore, $\tan\theta$ can be used as a measure of the magnetic field of the loop.

Sample Problem: Reading the Compass

On our compass we will measure the angles from the green line. Always record the angles from the same side of the line. Here is an example of how to read the compass.



No field in the loop—initial reading

Each division on the compass is 2 degrees. Record the deflection to an accuracy of one degree (halfway between marks). Always read the compass from the top edge of the green line.

Purpose

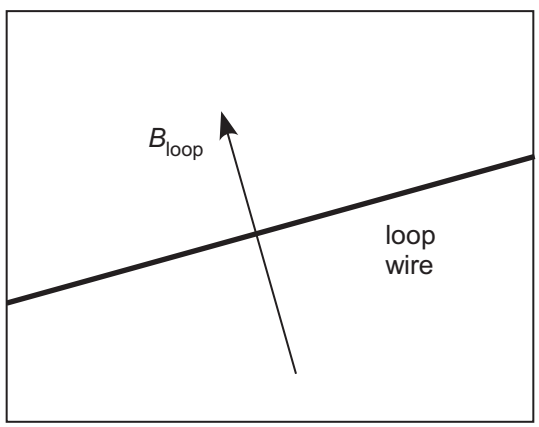
To find the relationship between the magnetic field of a loop (B_{loop}) and the current in the loop (I).

Apparatus

- tangent galvanometer
- compass
- wire
- power source
- magnifying glass

Procedure

1. Set up the tangent galvanometer as shown with one loop and set the current to about 0.6 A. If necessary, place a resistor between the power source and the tangent galvanometer to reduce the current. Excessive current will cause overheating in the wires.
2. Align the tangent galvanometer such that the loop points North-South (and the field through the loop is East-West).



3. Record the initial angle value (see the following pages for close-up pictures of the compass although you may find it easier to pause the video to read the angle).
4. Turn on the power supply and record the final angle value. Calculate the angle of deflection (final – initial).
5. Wrap another loop around the apparatus and turn on the power supply. Record the final angle and calculate the angle of deflection.
6. Repeat step #5 two more times.

Video Viewing

View the video *The Tangent Galvanometer*, which can be found in the learning management system (LMS).

Data and Calculations

Initial Angle	Final Angle	Angle of Deflection	Tan θ	Current (loops)

Make a hypothesis about what you think will happen to the magnetic field strength as the current is increased.

Graph B_{loop} (tan θ) vs Current (number of loops) and draw a line of best fit.

Discussion and Observations

Discuss possible sources of error in this experiment and how you could reduce the error.

What would happen to the direction of the magnetic field inside a solenoid if the current running through the wires in the solenoid is reversed?

As the current in the solenoid increases, what happens to the strength of the magnetic field?

Conclusion

What is the relationship between the magnetic field of a loop (B_{loop}) and the current in the loop (I)?

One Loop—Final

Two Loops—Final

Three Loops—Final

Four Loops—Final

Assignment 6.2

Video Laboratory Activity: The Tangent Galvanometer (20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow those directions.

The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words, in a brief paragraph (do not use point form), how the experiment was performed.

_____

_____

_____

_____

_____

(continued)

Assignment 6.2: Video Laboratory Activity: The Tangent Galvanometer (continued)

Data and Calculations:

- Include photocopies of your data measurements (eg. tapes or tracks) if they were provided in the notes.
- Include the raw data for each part of the experiment should be recorded in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data. For example, if you use a formula, write out the formula, show your substitutions and calculations. This should be done for each different calculation (that is, whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be done.

(continued)

Assignment 6.2: Video Laboratory Activity: The Tangent Galvanometer (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce the error.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. In making measurements errors are always made. In the error analysis your job is to look critically at the procedure, identify possible sources of error (there may be several) and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 6.2: Video Laboratory Activity: The Tangent Galvanometer (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

_____

_____

_____

_____

_____

Marking Rubric for Assignment 6.2

Section of Report	Possible	Actual
Purpose	1	
Apparatus and Procedure	2	
Completed Data Tables and Calculations	8	
Graph	4	
Discussion—Sources of Error and Questions on page 64	4	
Conclusion	1	
Total	**20**	

Lesson 5: Forces on Currents in a Magnetic Field (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ use the right-hand rule (flat hand) for current-carrying wires in a magnetic field to determine the direction of the force on the wire
- ❑ use the equation $\vec{F}_B = \vec{B}IL$ in problem solving
- ❑ define the unit "tesla" in terms of how it is measured using the force on a current-carrying wire in a magnetic field

Key Words

right-hand rule (flat hand)	magnetic field
Tesla	magnetic force

Introduction

In the previous lesson, we discussed how current-carrying wires produce magnetic fields. We stressed how the presence of a current can result in a force on a nearby magnet (such as the movement of a compass when near a current-carrying wire). In this lesson, we discuss how current-carrying wires that are in magnetic fields experience forces caused by those fields. We will be able to determine the magnitude and also the direction of this force using another right-hand rule. The lesson will conclude with an example showing how these principles apply. This lesson concludes our work on electromagnetism and on fields in general.

In the previous lesson, we saw that an electric current exerts a force on a magnet such as a compass needle. In our study of dynamics, we learned that if one object exerts a force on a second object, then the second object must exert an equal and opposite force back on the first (Newton's Third Law). So we should expect that a magnet exerts a force on a current-carrying wire. This is indeed the case and this was also discovered by Oersted.

Definition of Magnetic Field

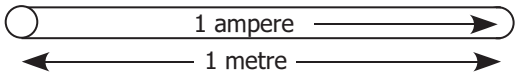
You will notice that up until now we have not defined magnetic field. We have looked at the patterns for the magnetic fields around permanent magnets and current-carrying wires, but we have not specifically defined magnetic field.

> The **magnetic field** is the region around a magnet or current-carrying wire where another magnet or current-carrying wire experiences a force.

You will recall we calculated gravitational field intensity as the force of gravity acting on a unit mass (1 kilogram). We also calculated the electric field as the electric force acting on a unit charge (+1 coulomb).

In this case for magnetic fields, we cannot physically have a unit north pole or a unit south pole. However, we still need a unit quantity in order to define magnetic fields. Since a magnet will exert a force on a current-carrying wire, we can define a unit of current (1 ampere) flowing through a unit length of wire (1 metre). This is the unit current element.

Unit Current Element: The **unit current element** consists of a straight wire of length 1 metre carrying a current of 1 ampere (1 A).



The **magnetic field, (T),** is defined as the magnetic force acting on a unit current element. The magnetic field is calculated as the magnetic force acting on a current carrying wire divided by the product of the current through the wire and the length of the wire. The field strength can be expressed in terms of force $\left(\vec{F}_B\right)$, current (I), and length of wire (L).

$$\vec{B}_{\perp} = \frac{\vec{F}_B}{IL}$$

Quantity	Symbol	Unit
Magnetic force	$\vec{F}_B$	newtons (N)
Current	I	amperes (A)
Length of wire	L	metres (m)
Magnetic field	$\vec{B}$	newtons per ampere x metre or tesla (T)

Note: There are some special directions in which these quantities must be oriented. For now, consider the **magnitudes** only.

Again, the magnetic force can be attractive or repulsive.

In this equation, the units of magnetic field can be seen to be equal to the units of force divided by the units for current as well as length. This means that magnetic field has the units "newton per ampere-metre" or "N/A·m". This is a very awkward group of units, so physicists have a special name for exactly this group of units: the **tesla (T)**.

> The unit for magnetic field is called the **tesla**: 1 tesla = 1 T = 1 N/A · m.

Example 1: Calculating the Magnetic Field

A wire of length 1.55 m experiences a magnetic force of 0.375 N when a current of 5.00 A flows through the wire. What is the magnetic field strength at the location of the wire?

Again, we are concerned only with the magnitude of the magnetic field.

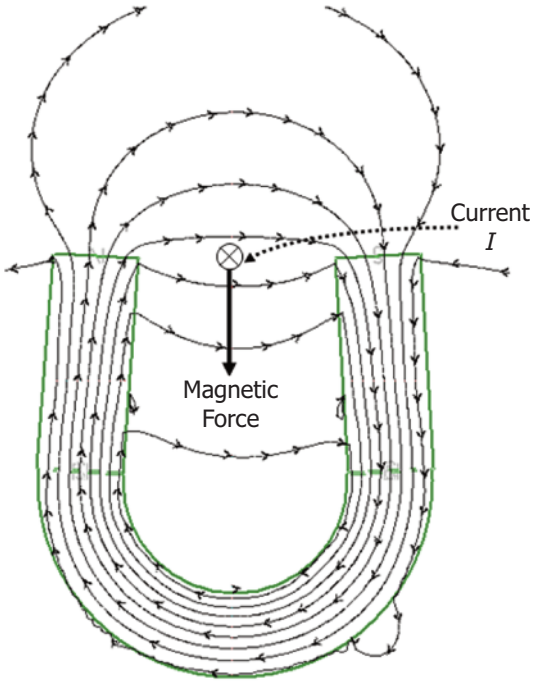
Given:	Length of wire	$L = 1.55\ \text{m}$
	Magnetic force	$\vec{F}_B = 0.375\ \text{N}$
	Current	$5.00\ \text{A}$
Unknown:	Magnetic field intensity	$\vec{B} = ?$
Equation:		$\vec{B} = \dfrac{\vec{F}_B}{IL}$
Substitute and solve:		$\vec{B} = \dfrac{\vec{F}_B}{IL} = \dfrac{(0.375\ \text{N})}{(5.00\ \text{A})(1.55\ \text{m})} = 0.0484\ \text{T}$

The magnetic field intensity is 0.0484 tesla.

The Direction of Force on a Current-Carrying Wire in a Magnetic Field

Now let's address the question of the directions of magnetic field, current, and magnetic force.

The following diagram shows a horseshoe magnet and its magnetic field. A wire is placed between the poles of a magnet, perpendicular to the page, and carries a current so that the current is directed into the page (represented by the cross in a circle).



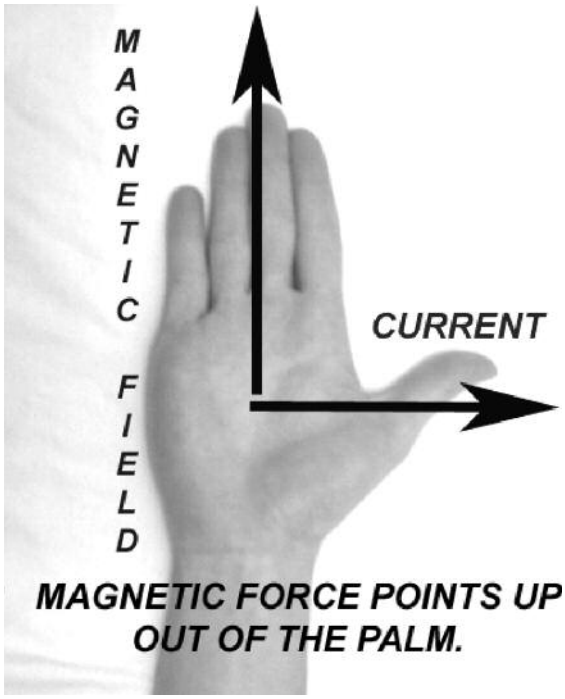
When the current flows through this wire, a force is exerted on the wire. However, this force is not directed toward either of the poles of the magnet. Instead, the force is directed at right angles to the magnetic field direction. In this case, the wire will be forced downwards (as shown in the diagram). If the current was reversed in direction, the force would also be reversed in the opposite direction. Similarly, reversing the magnetic field (by turning the magnet around) would also reverse the magnetic force felt by the current.

Notice that the force is perpendicular to the magnetic field, and also perpendicular to the direction of the current. This means that we need to work with all three dimensions. Experimentally, the relationship between these three (current, magnetic field, and magnetic force) can be found by another right-hand rule. This **third right-hand rule** lets you find the direction of any one of these items, provided that you know the direction of the other two items:

- Unlike the first right-hand rule, which uses curled fingers, this rule requires you to keep your fingers straight (so that your hand is flat). Similarly, your thumb must be straight and perpendicular to your fingers.
- Each of the three items (current, magnetic field, and magnetic force) have a direction that is associated with a part of your hand: your thumb represents the direction of the current; the fingers point in the direction of the magnetic field; and the palm of your hand "pushes" in the direction of the magnetic force.

- Orient your hand according to the above instructions (using the two known directions matched to the two parts of your hand).
- Observe the orientation of the third part of your hand to determine the direction of the third item.

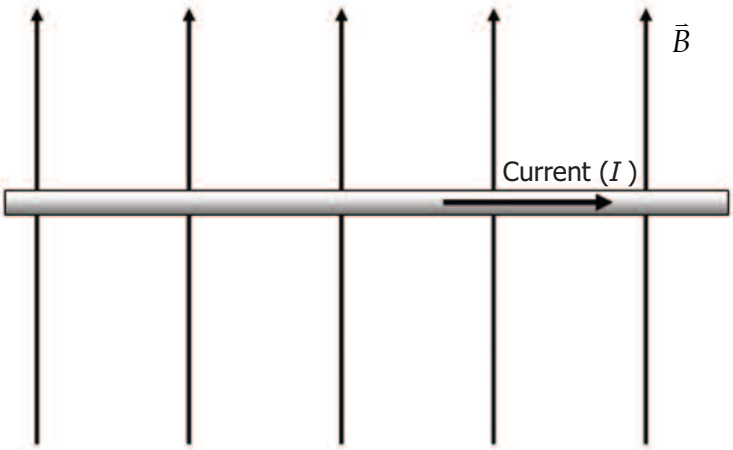
In the following picture, the thumb is aligned with the direction of the current and the straight fingers point in the direction of the magnetic field. In this case, you have to imagine an arrow pointing out of the palm straight at you. This is the direction of the magnetic force on the current-carrying wire.



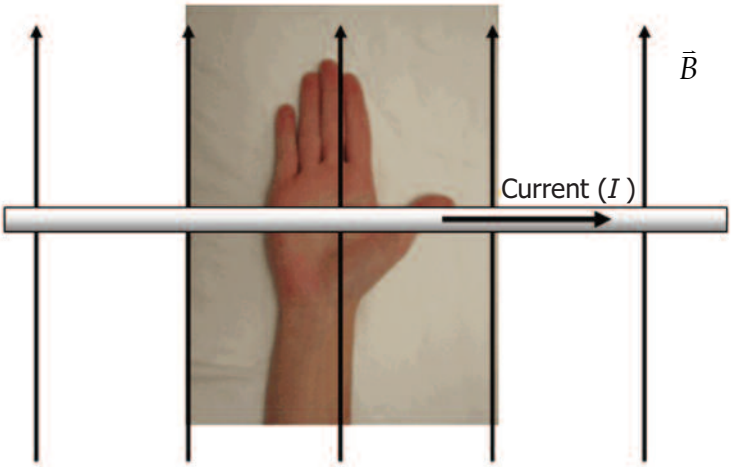
Example 2: Right-Hand Rule—Flat Hand

As an example, suppose that a current flows to your right, while in a magnetic field which points away from you. We can use this right-hand rule to determine the direction of the magnetic force this current would experience.

Draw a little sketch to help you visualize the situation. You are looking at the situation from the bottom of the sketch.



- Make sure that your right hand is formed in the correct shape: fingers stretch out straight, and your thumb at right angles to them. Do not change this throughout the rest of these steps!
- We know that the current is to your right, so orient your hand so that your thumb points to your right.
- Keeping your thumb pointing to your right, rotate your hand so that your fingers point in the direction of the magnetic field, away from you in this example.

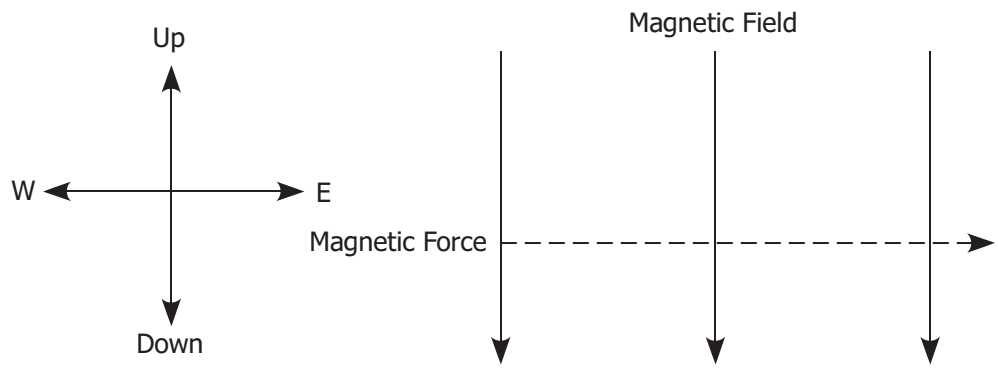


- Observe the direction that your palm is now facing. It is poised to "push upward." This reveals that the magnetic force this current would experience is upward, out of the page.

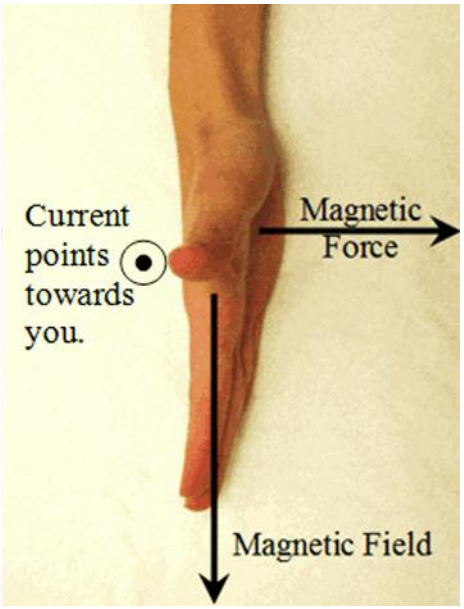
Example 3: Right-Hand Rule—Flat Hand

What is the direction of a current that would experience a magnetic force to the east in a magnetic field that points down?

Here is the sketch.



- Regardless of where you are and which direction you are really facing, we will assume that you are facing north.
- Start by straightening your fingers and sticking your thumb at right angles to them, as before.
- We know that the magnetic force is to the east. Position your hand so that your palm is poised to push to your right (which is where east is assumed to be). Note that this does require a bit of flexibility!
- We also know that the magnetic field is down, so while keeping your palm pointing to your east, ensure that your fingers are pointing down. This requires a bit more flexibility!
- Observe your thumb, which should be pointing at yourself, but more importantly, in the direction of south—which is the answer. A current to the south (thumb) will feel a magnetic force to the east (palm) in a downward magnetic field (fingers).



The Magnitude of the Force on a Current-Carrying Wire

Experiments can be done to study the factors affecting the magnitude of the magnetic force $\left(\vec{F}_B\right)$ on a current-carrying conductor in a magnetic field. It has been found that the magnitude of the force is directly proportional to three things:

- the strength of the magnetic field $\left(\vec{B}\right)$: $\vec{F}_B \ \alpha \ \vec{B}$
- the length (L) of the conductor in the magnetic field: $\vec{F}_B \ \alpha \ L$
- the current (I) flowing through the conductor: $\vec{F}_B \ \alpha \ I$

The orientation of these things is also important, but we will assume that the conductor passes through the magnetic field at right angles to it, in which case the magnitude of the force on the wire can be found by the equation: $\vec{F}_B = \vec{B}IL$.

The **magnetic force** on a current-carrying wire is the product of the strength of the magnetic field, the current through the wire, and the length of the wire.

$$\vec{F}_B = \vec{B}IL$$

Quantity	**Symbol**	**Unit**
Magnetic force	$\vec{F}_B$	newton (N)
Magnetic field	$\vec{B}$	newton per ampere-metre (n/A · m)
Current	I	amperes (A)
Length	L	metres (m)

Note: Three of these quantities have a direction. To simplify matters, work with this equation without the vector notation and use the second right-hand rule (flat hand) to relate the directions together.

We can rearrange this equation and solve for the magnetic field strength: $\vec{B} = \dfrac{\vec{F}_B}{IL}$.

You should recognize this is the equation for calculating magnetic field intensity.

Example 4: Magnetic Force on a Current-Carrying Wire Oriented Perpendicularly to a Magnetic Field

A straight wire of length 1.25 m carries a current of 3.25 A flowing north. The wire is immersed in a magnetic field of 0.465 T pointing upwards. What is the magnitude and direction of the magnetic force acting on this wire?

Since the wire and the magnetic field are perpendicular to each other, we can calculate the magnitude of the magnetic force using $\vec{F}_B = \vec{B}IL$.

Given: Length of wire	$L = 1.25$ m
Magnetic Field intensity	$\vec{B} = 0.465$ T
Current	$I = 3.25$ A
Unknown: Magnetic force	$\vec{F}_B = ?$
Equation:	$\vec{F}_B = \vec{B}IL$
Substitute and solve:	$\vec{F}_B = \vec{B}IL = (0.465\text{ T})(3.25\text{ A})(1.25\text{ m})$
	$= 1.89$ N

The magnitude of the magnetic force is 1.89 N.

To obtain the direction of the magnetic force we use the right-hand rule—flat hand.

Using a flat hand,
fingertips point upwards with the magnetic field,
thumb points north in the direction of the current,
then the palm faces east.

The magnetic force is 1.89 N [East].

Magnetic Force on a Current-Carrying Wire that is NOT Perpendicular to the Magnetic Field

Note that for this equation $(\vec{F}_B = \vec{B}IL)$ to work, the current must be perpendicular to the magnetic field.

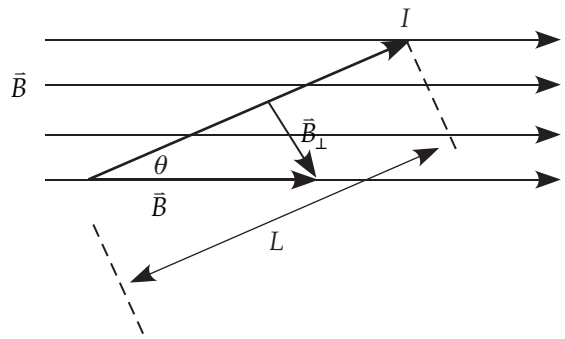
If the current was in the same or opposite direction as the magnetic field, then there would be no magnetic force on it at all!

If there was some other angle between the **current** and the **magnetic field**, we can resolve the **magnetic field** to find the **component** that is **perpendicular** to the **current**, and use that component in the above equation.

So we will add a final part to our equation to include the directions other than the perpendicular orientation between the current and magnetic field.

The direction of the current and the direction of the magnetic field form an angle where these directions cross. That angle is designated as theta (θ).

The situation below shows the current in the wire to be at some angle θ to the magnetic field.



The component of the field that is perpendicular to the current is $\vec{B}\sin\theta$. Therefore, the force on this wire is

$$\vec{F} = \vec{B}IL\sin\theta.$$

Also note that while the equation tells us the size of the magnetic force, it does not tell us the direction of this force—we need to use the right-hand rule—flat hand, to determine the direction.

The force on a current-carrying wire in a magnetic field is found by the product of the magnetic field (B), the current (I), the length of the current-carrying wire (L), and the sine of the angle between the magnetic field and the current-carrying wire ($\sin\theta$).

$$\vec{F}_B = \vec{B}IL\sin\theta$$

Quantity	**Symbol**	**Unit**
Magnetic force	$\vec{F}_B$	newtons (N)
Magnetic field	$\vec{B}$	tesla (T)
Current	I	amperes (A)
Length of current-carrying wire	L	metres (m)
Angle between direction of magnetic field and the current-carrying wire	θ	

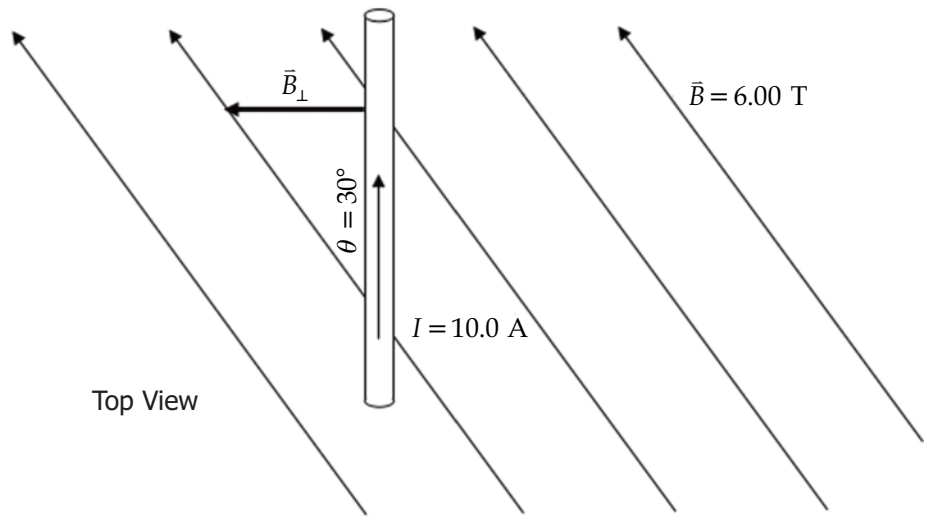
The directions of the magnetic force, a magnetic field, and the current are related using the right-hand rule with the flat right hand. When the magnetic field and the current-carrying wire are not perpendicular to each other, then your fingers must point in the direction of the component of the magnetic field that is perpendicular to the current.

Example 5: Magnetic Force on a Current-Carrying Wire

If a current of 10.0 A flows north through a 2.00 m length of wire in a magnetic field of 6.00 T that points at an angle of 30.0° west of north, what is the force on the wire?

Viewing the situation from the top allows you to see the direction of the current and the direction of the magnetic field drawn on the plane of the page.

Given:



Unknown: Magnetic force on the wire $\vec{F}_B = ?$

Equation: $\vec{F}_B = \vec{B}IL \sin\theta$

Substitute and solve:

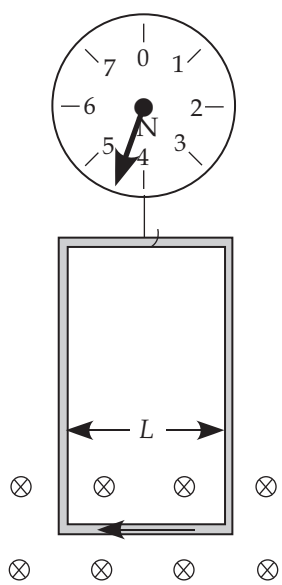
$$\vec{F}_B = (6.00\text{ T})(10.0\text{ A})(2.00\text{ m})(\sin 30.0°)$$
$$= 60.0\text{ N}$$

To determine the direction of the magnetic force on the current-carrying wire, point your fingers in the direction of the component of the magnetic field perpendicular to the wire $(\vec{B}_\perp)$, and point your thumb in the direction of the current.

Your right hand should be flat on the paper with the palm pointing up out of the paper. Therefore, the direction of this magnetic force is up out of the paper.

Example 6: Determination of Magnetic Field Strength by Measuring Force on a Wire

One of the ways to determine the magnetic field strength is to use a device that can measure the force on a current-carrying wire of known length, and with a known current in it. To illustrate this, consider a rectangular loop of wire that hangs vertically, as shown in the figure below. A magnetic field $\vec{B}$ is directed horizontally, perpendicular to the wire and points into the page at all points represented by the symbol showing an "X" inside of a circle. Let us assume that the magnetic field $\vec{B}$ that we are investigating is uniform along the lower horizontal portion of the loop. The top portion of the wire loop is not inside of the magnetic field at all. Notice that the current moves to the left through the lower horizontal wire, which is of length L. By using the second right-hand rule, we can see that the magnetic force it experiences will be straight down. If the loop hangs from a scale, we could measure the downward force that the magnetic field causes onto the wire, by observing the measurement indicated on the scale (taking the weight of the loop into account). We can now determine the magnetic field strength of the magnetic field.



Suppose that the length L is 0.300 m, the current I is 8.00 A and the loop itself weighs 3.00 N, but the scale is showing a force of 4.50 N. Clearly the magnetic force is pulling the loop down with a force of 1.50 N. The magnetic field strength can then be found:

$$\vec{B} = \frac{\vec{F}_B}{IL} = \frac{1.50\text{ N}}{(8.00\text{ A})(0.300\text{ m})} = 0.625\text{ N/A}\cdot\text{m} = 0.625\text{ T}$$

Video Laboratory Activity: The Magnetic Field of A Solenoid (Current Balance)

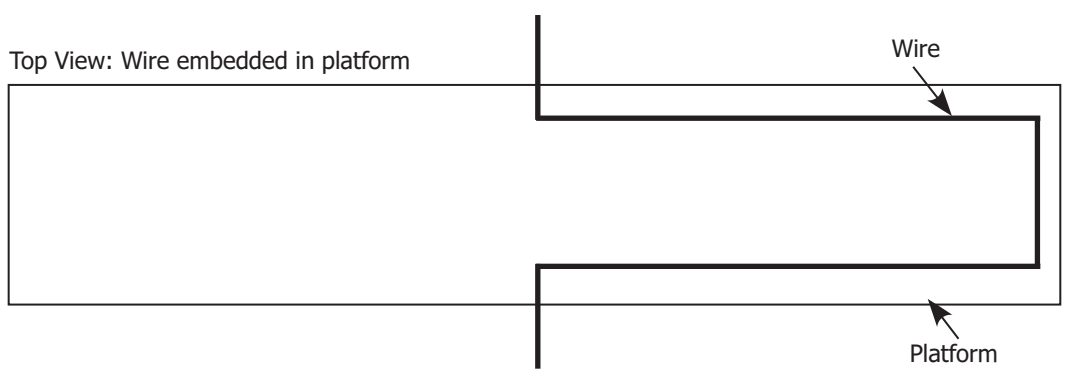
Notes to Student

For this lab activity, you will view *The Magnetic Field of a Solenoid (Current Balance)*, a short video laboratory activity found in the learning management system (LMS). You will collect some data from the video so you should begin by reading the introduction and answering the pre-lab questions.

When you have finished the lab, you will complete a Laboratory Report, which is found at the end of this and every other Laboratory Assignment. The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit for assessment. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

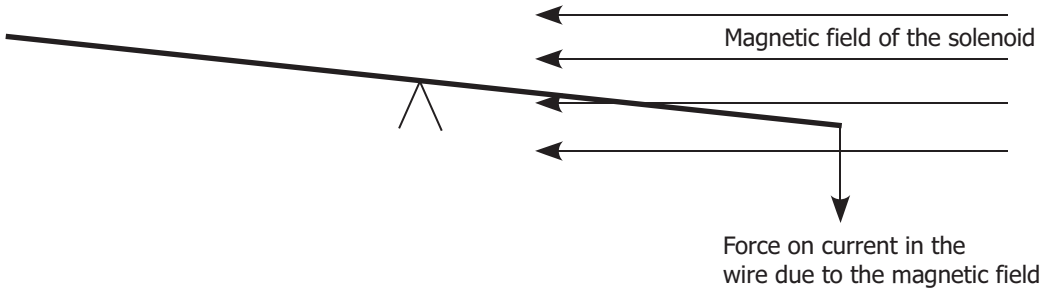
Introduction

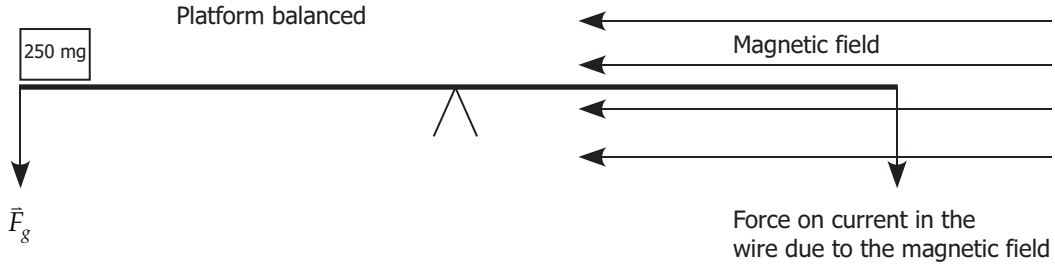
In the previous example, we suspended a wire vertically in a magnetic field and calculated the field strength using $\vec{F} = \vec{B}IL$. In this lab, we will balance a wire horizontally in the magnetic field of a solenoid. The wire is embedded in a platform and, when a current flows in the wire, the magnetic field of the solenoid will cause the platform to tip. We can re-balance the platform using the force of gravity $\left(\vec{F}_g = m\vec{g}\right)$ and calculate the magnetic field of the solenoid.



Sample Problem

A magnetic field causes a wire 6.0 cm in length to deflect downward. Find the magnetic field if the current in the wire is 2.0 A and a mass of 250 mg balances the platform. See Appendix for instructions on converting units.





$$\vec{F} = \vec{B}IL$$

$$\vec{B} = \frac{\vec{F}_g}{IL} = \frac{m\vec{g}}{IL}$$

$$\vec{B} = \frac{250 \times 10^{-6} \times 9.8}{2.0 \times 6.0 \times 10^{-2}}$$

$$\vec{B} = 2.0 \times 10^{-2}\ \text{T (left)}$$

Purpose

To determine the magnetic field of a solenoid from the deflection of a current-carrying wire.

Apparatus

- power supply
- wires
- solenoid
- current balance
- masses

Procedure

1. Set up the current balance apparatus.
2. Record the current and length of the wire embedded in the platform (only the portion perpendicular to the field).
3. Record the mass on the end of the platform when it is balanced.
4. Using $\vec{F} = \vec{B}IL$, calculate the magnetic field of the solenoid (use g = 9.80 N/kg).

Video Viewing

View the video *The Magnetic Field of a Solenoid (Current Balance)*, which can be found in the learning management system (LMS).

Data and Calculations

Current (A)	Length of Wire (m)	Mass (kg)

Force (N)	Magnetic Field (T)

Discussion and Observations

Discuss possible sources of error and how you could reduce the error.

Which is better, a platform that swings freely or one that does not? Why?

How might the current balance be used as a practical device?

Conclusion

Answer the purpose.

Assignment 6.3

Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance) (20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow those directions.

The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words, in a brief paragraph (do not use point form), how the experiment was performed.

_____

_____

_____

_____

_____

(continued)

Assignment 6.3: Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance) (continued)

Data and Calculations:

- Include photocopies of your data measurements (e.g., tapes or tracks) if they were provided in the notes.
- Include the raw data for each part of the experiment should be recorded in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data. For example, if you use a formula, write out the formula, show your substitutions and calculations. This should be done for each different calculation (that is, whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be done.

(continued)

Assignment 6.3: Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance) (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce the error.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. In making measurements errors are always made. In the error analysis your job is to look critically at the procedure, identify possible sources of error (there may be several) and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 6.3: Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance) (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

_____

_____

_____

_____

_____

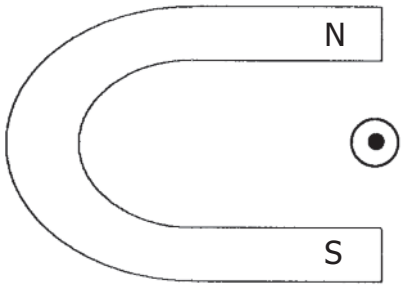
Marking Rubric for Assignment 6.3

Section of Report	Possible	Actual
Purpose	1	
Apparatus and Procedure	2	
Completed Data Tables	6	
Calculations of Magnetic Field	6	
Discussion—Sources of Error and Questions on page 86	4	
Conclusion	1	
Total	**20**	

Learning Activity 6.4

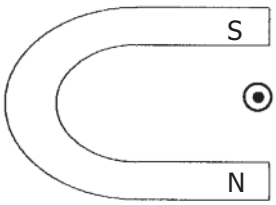
Forces on Currents in a Magnetic Field

1. a) Draw the magnetic field of the permanent horseshoe magnet.
   b) What is the direction of the force acting on the conductor?

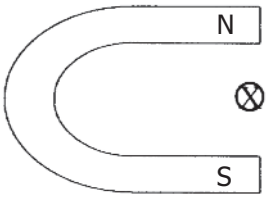


2. Give the direction of the magnetic force acting on each conductor in the diagrams below.

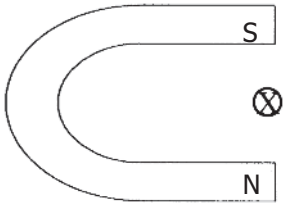
a)



b)



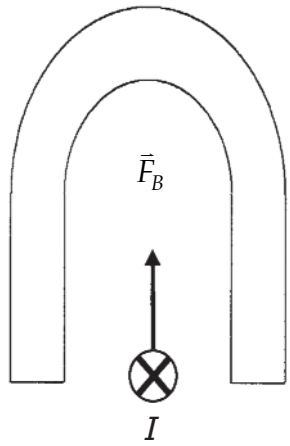
c)



(continued)

Learning Activity 6.4: Forces on Currents in a Magnetic Field (continued)

3. The drawing shows a current-carrying wire that passes through the gap in a horseshoe magnet. The magnetic force F exerted on the wire is directed upward. Which end of the magnet is the north pole and which is the south pole? Justify your answers.



4. An electric power line carries a current of 1400 A in a location where the earth's magnetic field is 5.0×10^{-5} T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120 m length of wire.

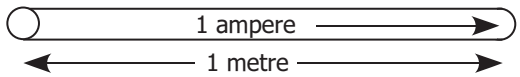
5. Near the equator in South America the earth's magnetic field has a strength of 3.2×10^{-5} T. The field at this location is parallel to the surface of the earth and points due north. A straight wire, 46 m in length, has an east-west orientation and experiences a magnetic force of 0.058 N, directed vertically down (toward the earth). What is the magnitude and direction of the current in the wire?

6. At New York City, the earth's magnetic field has a vertical (downward) component of 5.20×10^{-5} T. What is the magnitude and direction of the magnetic force on a long, straight wire, 6.00 m in length, that carries a 28.0 A current due east?

Lesson Summary

The **magnetic field** is that region around a magnetic or current-carrying wire where another magnet or current-carrying wire experiences a force.

The **unit current element** consists of a straight wire of length 1 metre carrying a current of 1 ampere (1 A).



The magnetic field is calculated as the magnetic force acting on a current-carrying wire divided by the product of the current through the wire and the length of the wire.

$$\vec{B}_{\perp} = \frac{\vec{F}_B}{IL} \text{ where}$$

- $\vec{F}_B$ is the magnetic force on the conductor in newtons (N)
- $\vec{B}$ is the magnetic field strength in teslas (T)
- I is the current in the wire in amperes (A)
- L is the length of the conductor in the magnetic field in metres (m)

This relationship allows us to relate these quantities together **only if the current-carrying wire is arranged perpendicularly to the magnetic field direction.**

To relate the direction of the magnetic force on a current-carrying wire, the direction of the current and the direction of the magnetic field we use another **right-hand rule** but with a **FLAT HAND**.

This right-hand rule for determining the force on a current-carrying wire in a magnetic field can be described by following:

- Thumb and fingers must be at right angles to each other, with your hand flat
- Thumb points in the direction of the current
- Fingers point in the direction of the magnetic field
- Palm "pushes" in the direction of the magnetic force

The force on a current-carrying wire in a magnetic field is found by the product of the magnetic field (B), the current (I), the length of the current-carrying wire (L), and the sine of the angle between the magnetic field and the current-carrying wire (sin θ).

$$\vec{F}_B = \vec{B}IL \sin\theta$$

Quantity	Symbol	Unit
Magnetic force	$\vec{F}_B$	newtons (N)
Magnetic field	$\vec{B}$	tesla (T)
Current	I	amperes (A)
Length of current-carrying wire	L	metres (m)
Angle between direction of magnetic field and the current-carrying wire	θ	

The directions of the magnetic force, a magnetic field, and the current are related using the right-hand rule with the flat right hand. When the magnetic field and the current-carrying wire are not perpendicular to each other, then your fingers must point in the direction of the component of the magnetic field that is perpendicular to the current.

The SI unit of magnetic field strength is the tesla (T). A unit of 1 **tesla (T)** is defined to be the magnetic field strength when a conductor with a current of 1 ampere (A) and a length of 1 metre (m) at an angle of 90° to the magnetic field, experiences a force of 1 newton (N).

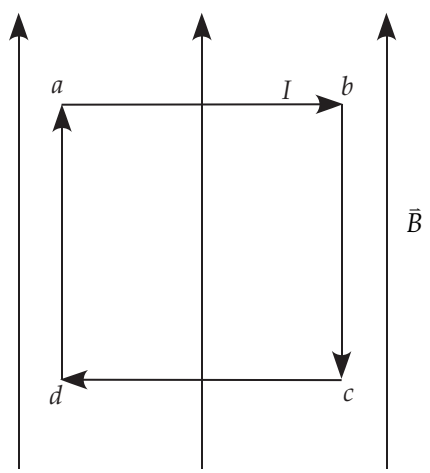
If the current-carrying wire crosses the magnetic field at some angle, then we must use the component of the magnetic field that is perpendicular to the current. Note that if the current is parallel to the magnetic field, then there will be no force on the wire at all.

Assignment 6.4

Forces on Currents in a Magnetic Field (5 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 5 and Module 6, after you have completed Module 6.

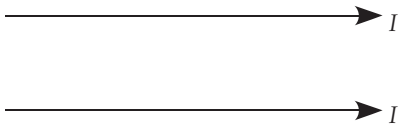
1. A square coil of wire containing a single turn is placed in a uniform 0.25 T magnetic field, as the drawing shows. Each side has a length of 0.32 m, and the current in the coil is 12 A. The direction of the current is clockwise. Determine the magnitude and direction of the magnetic force on each of the four sides.



(continued)

Assignment 6.4: Forces on Currents in a Magnetic Field (continued)

2. Two wires are running parallel to each other. Each wire carries a current of 4.0 A and each wire is 50.0 cm long. The magnetic field strength that the top wire produces at the location of the bottom wire is 8.0 T.



a) Determine the direction of the magnetic field at the location of the bottom wire caused by the top wire.

_____

_____

_____

_____

b) Determine the magnitude and direction of the force on the bottom wire.

_____

_____

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_____

(continued)

Assignment 6.4: Forces on Currents in a Magnetic Field (continued)

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 0.5 marks for determining the correct magnitude of the force for the line segment *ab* for 1
- 0.5 marks for determining the correct direction of the force for the line segment *ab* for 1
- 0.5 marks for determining the correct magnitude and direction for the line segment *bc* for 1
- 0.5 marks for determining the correct magnitude of the force for the line segment *cd* for 1
- 0.5 marks for determining the correct direction of the force for the line segment *cd* for 1
- 0.5 marks for determining the correct magnitude and direction for the line segment *da* for 1
- 0.5 marks for determining the correct direction of the magnetic field in part 2(a)
- 1.0 mark for determining the correct direction of the force in part 2(b)
- 0.5 marks for determining the correct magnitude of the force in part 2(b)

NOTES

LESSON 6: FIELDS: A SUMMARY (0.5 HOUR)

This last lesson is a brief wrap-up of the concepts of fields. Hopefully, this summary will solidify all of the ideas about fields and perhaps it will clarify some lingering misconceptions.

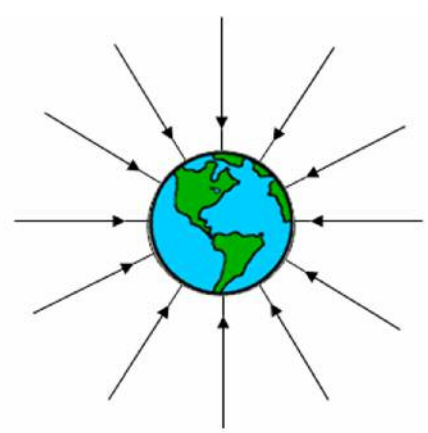
In general, the concept of fields occurs for forces that act at a distance. Gravitational fields occur around a mass where another mass experiences a gravitational force. Electric fields occur around an electric charge where another electric charge experiences an electric force. A magnetic field occurs around a magnet or current-carrying wire where another magnet or current-carrying wire would experience a magnetic force.

In all cases, the field is determined by the **force acting on a unit quantity**.

Gravitational Fields

The **gravitational field** at a particular point in space is determined by the force of gravity, which is an attractive force, acting on a unit mass, 1 kilogram. You are already familiar with the equation $\vec{F}_g = m\vec{g}$, which represents the force of gravity acting on an object at the surface of the earth or at any other point where the gravitational field is known. If you rearrange the equation, you arrive at the relationship by which you can calculate the gravitational field. We calculate the gravitational field using $\vec{g} = \frac{\vec{F}_g}{m}$. The units for gravitational field, $\vec{g}$, are newtons per kilogram (N/kg). As well, you recall that fields are vector quantities since they are specified using both a magnitude and a direction. Because gravitational fields vary in a regular way in the space around a given mass, a pattern of gravitational field lines can be used to help you visualize the strength and direction of the field at a particular point.

Earth's Gravitational Field



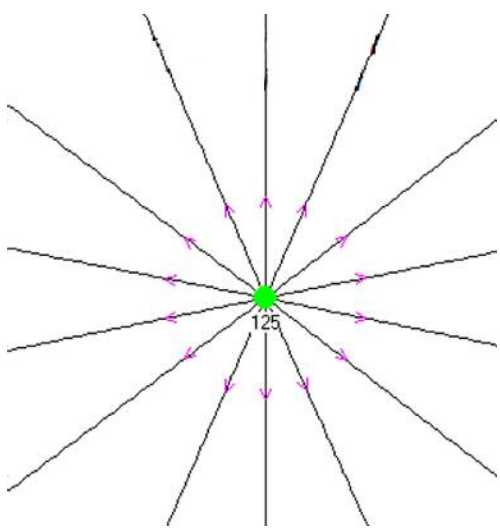
Electric Fields

In a similar way, we can define electric field as the electric force acting on a unit charge. In the case of electric forces, the forces can be attractive or repulsive. The **unit charge** is defined as a **positive** charge with a size of one coulomb. The coulomb is the charge carried by 6.24×10^{18} electrons or 6.24×10^{18} protons.

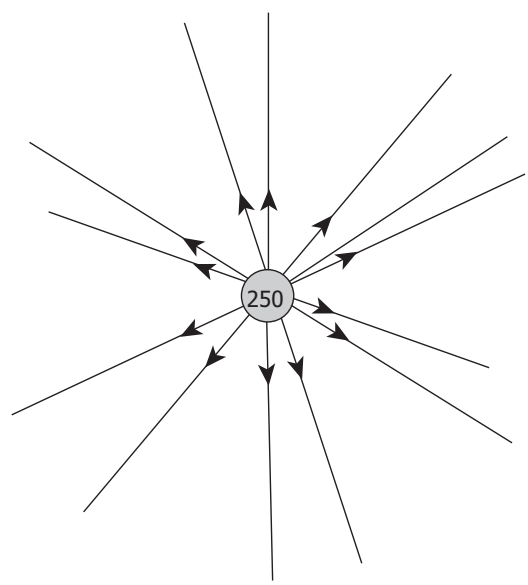
We calculate the electric field using electric field equals electric force over charge, $\vec{E} = \frac{\vec{F}_E}{q}$. The correct direction for the electric field is found by placing a positive charge at a given point and determining the direction of the electric force acting on the positive charge. The units for electric field are newtons per coulomb (N/C).

The graphic below illustrates a two-dimensional electric field pattern around the positive charge. However, field patterns extend into space—that is, into three dimensions. So while you may draw an electric field pattern in two dimensions on your page, you must realize that field patterns extend into three dimensions.

2D Electric Field Pattern Around a Positive Charge



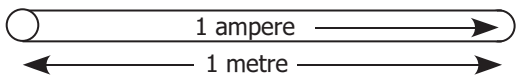
3D Electric Field Pattern Around a Positive Point Charge



Magnetic Fields

Finally, there is the magnetic field, which is the region around a magnet or current-carrying wire where another magnet or current-carrying wire experiences a force. In this case for magnetic fields, we cannot physically have a unit North Pole or a unit South Pole. However, we still need a unit quantity in order to define magnetic fields. Since a magnet will exert a force on a current-carrying wire, we can define a unit of current (1 Ampere) flowing through a unit length of wire (1 metre). Recall that this is the unit current element.

Unit Current Element



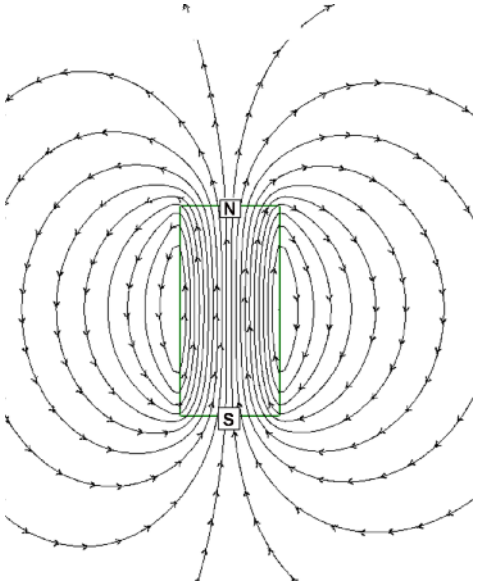
The magnetic field is defined as the magnetic force acting on a unit current element. The equation we use is $\vec{B}_{\perp} = \frac{\vec{F}_B}{IL}$. The magnetic force again can be attractive or repulsive.

The unit of magnetic field can be expressed as newtons over (Amperes x metres), N/A · m. This unit is also called the Tesla:
1 Tesla = 1 T = 1 N/A · m.

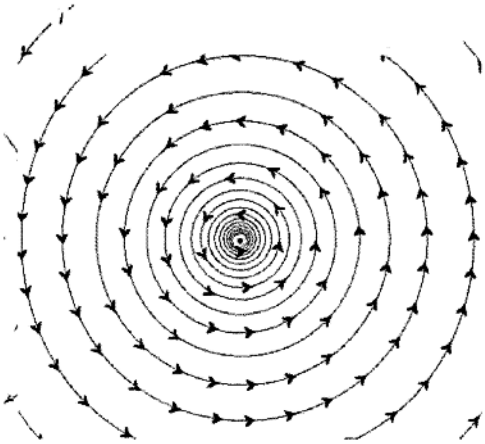
If you're talking about the magnetic field around a permanent magnet, you can determine the direction of the field by imagining the magnetic force acting on a magnetic north pole. If you're talking about the magnetic field in the space around current-carrying wires you will recall that you must use a right-hand rule. This right-hand rule requires a right hand with curled fingers and with the thumb held perpendicular to the fingers. The thumb is aligned with the direction of the current in the wire and the tips of the finger when placed at a particular point in space would point in the direction of the magnetic field at that point.

The magnetic field lines form the following patterns around a bar magnet and around a straight wire carrying a current up out of the page.

Magnetic Field around a Bar Magnet



Magnetic Field around a Straight Current-Carrying Wire



Hopefully, you are able to recognize the similarities in the way fields are defined, whether the field is gravitational, electrical, or magnetic.

Notice that in all of the field patterns some general rules are followed. The direction of the field at a particular point in space is given by the tangent to the field line at that point. The magnitude of the field is given by the relative spacing of the field lines. The closer the field lines are, the weaker the field.

There are also some differences in the patterns of field lines. Gravitational field lines start on the mass and extend outwards towards infinity. Electric field lines start on the surface of positive charge and end on the surface of negative charge. On the other hand, magnetic field lines have no beginning or end but rather are complete loops.

This concludes Module 6: Magnetic Fields and Electromagnetism.

Module 6 Summary

Congratulations on completing Module 6.

Submitting Your Assignments

It is now time for you to submit Assignments 5.1 and 5.2 from Module 5 and Assignments 6.1 to 6.3 from Module 6 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 5 and Module 6 assignments and organize your material in the following order:

- Modules 5 and 6 Cover Sheet (found at the end of the course Introduction)
- Assignment 5.1: Electric Fields
- Assignment 5.2, Part A: Calculating Electric Field and Electric Force
- Assignment 5.2, Part B: The Parallel Plate Apparatus
- Assignment 5.2, Part C: The Millikan Drop Experiment
- Assignment 6.1, Part A: Magnetic Fields
- Assignment 6.1, Part B: The Earth's Magnetic Field
- Assignment 6.1, Part C: Electromagnetism
- Assignment 6.2: Video Laboratory Activity: The Tangent Galvanometer
- Assignment 6.3: Video Laboratory Activity: The Magnetic Field of a Solenoid (Current Balance)
- Assignment 6.4: Forces on Currents in a Magnetic Field

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

You are now ready to start Module 7.

Midterm Examination

Congratulations, you have finished Module 6 in the course. The midterm examination is out of 100 marks and worth 20% of your final mark. In order to do well on this examination, you should review all of your learning activities and assignments from Modules 1 to 6.

You will complete this examination while being supervised by a proctor. You should already have made arrangements to have the examination sent to the proctor from the Distance Learning Unit. If you have not yet made arrangements to write it, then do so now. The instructions for doing so are provided in the Introduction to this module.

You will be allowed to use a calculator to write your examination. The calculator that you bring with you should be a graphing or scientific calculator. In addition, you will be supplied with an equation sheet and any constants that may be required.

A maximum of 2.5 hours is available to complete your midterm examination. When you have completed it, the proctor will then forward it for assessment. Good luck!

Midterm Practice Examination and Answer Key

To help you succeed in your examination, a practice examination can be found in the learning management system (LMS). The midterm practice examination is very similar to the actual examination that you will be writing. The answer key is also included so that, when you have finished writing the practice examination, you can check your answers. This will give you the confidence that you need to do well on your examination. If you do not have access to the Internet, contact the Distance Learning Unit at 1-800-465-9915 to get a copy of the practice examination and the answer key.

Grade 11 Physics (30S)

Module 6: Magnetic Fields and Electromagnetism

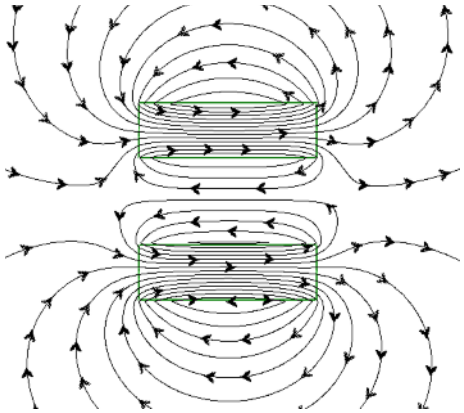
Learning Activity Answer Keys

Module 6: Magnetic Fields and Electromagnetism

Learning Activity 6.1: Magnetic Fields

1. The following diagram shows two bar magnets near each other. Part of the magnetic field lines is shown.

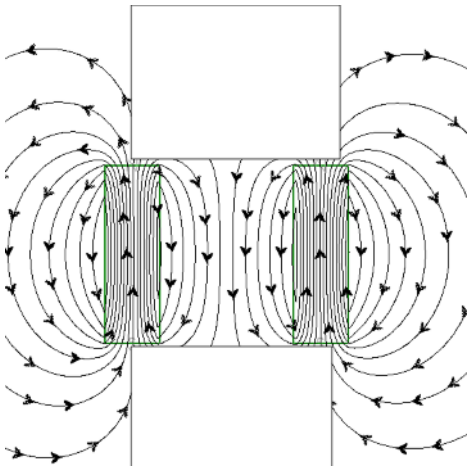
   a) From the direction in which the field lines are drawn, indicate which poles are located at each pole of the bar magnet.



   Answer:

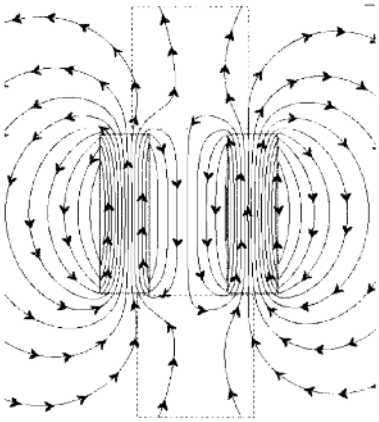
   On the left side of the diagram, the magnetic field lines are moving away from the poles. Both of these poles are north poles. Similarly, the field lines are moving towards the poles on the right side. These are south poles.

   b) The following diagram shows two rectangular regions. Add additional field lines in these areas, showing how they would interact with each other.

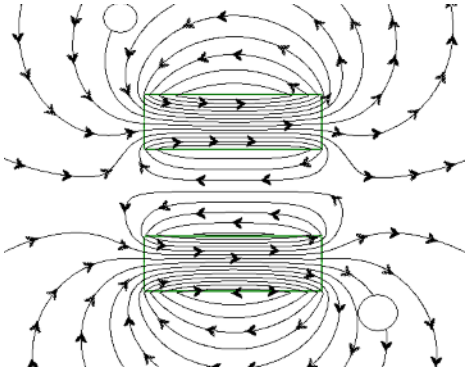


Answer:

In the rectangular regions, the field lines will repel each other. The diagram below shows this effect.

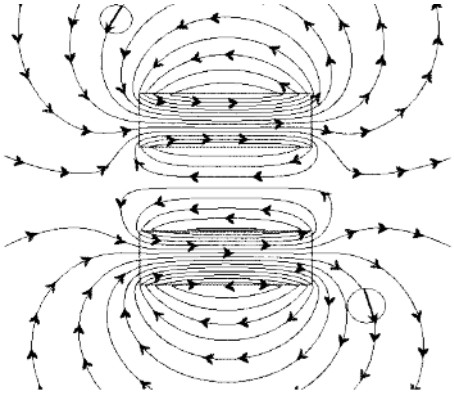


c) The diagram below shows two compasses placed in the magnetic field of this combination of magnets. Indicate the direction in which the compass needle would point at these locations.

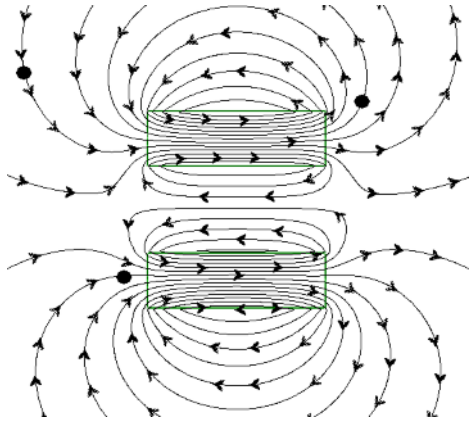


Answer:

The compass needle would point in the direction of the magnetic field, away from north and towards south.

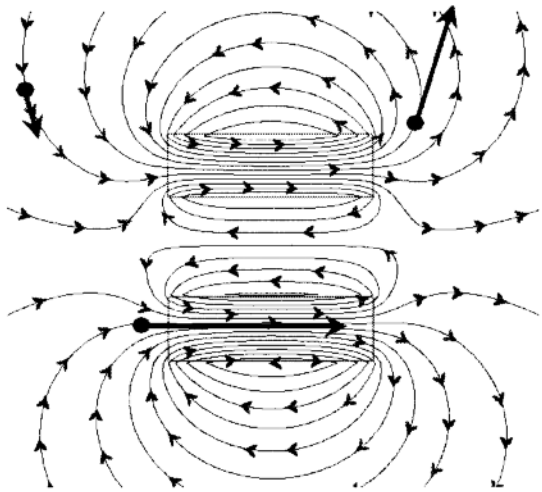


d) The diagram below shows three solid circles. From these circles, draw possible magnetic field vectors. In your drawing, draw the vectors with a length indicating the relative strength of the magnetic field at that point.



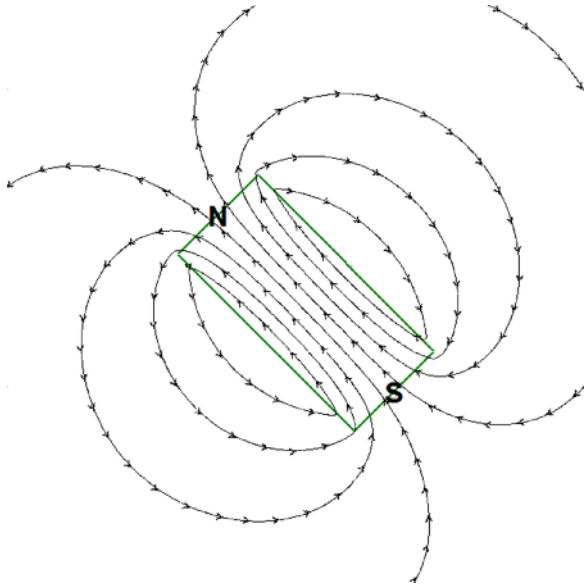
Answer:

The direction of the vectors is tangent to the field lines. The vector in the upper part of the diagram is closer to the pole than the lower vector. When the vector is closer to the pole, the field strength is greater. This is also indicated by the greater density of field lines in this area. Therefore, the vector is longer.



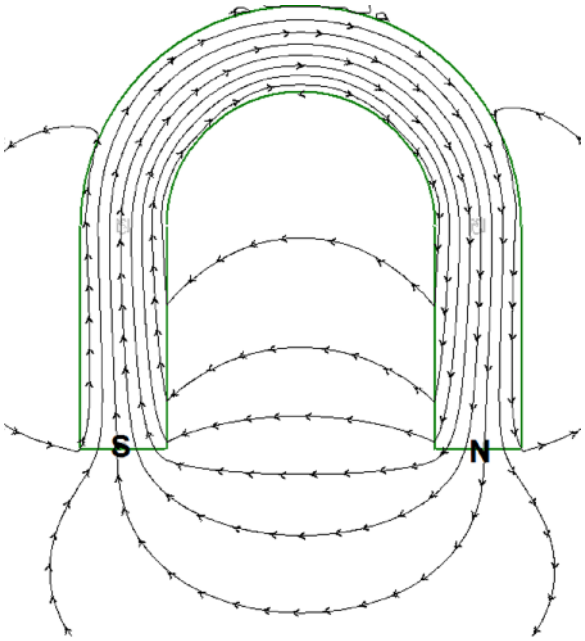
2. Draw the magnetic field around the following bar magnet. Include eight lines in the diagram.

   Answer:



3. Draw the magnetic field around a horseshoe magnet.

   Answer:



Learning Activity 6.2: The Earth's Magnetic Field

1. What would you do to magnetize a steel nail, and then demagnetize the same nail? Explain why these effects occur.

   Answer:

   To magnetize the nail, it would be necessary to place it in a strong magnetic field, or stroke it in one direction with one pole of a magnet. This works because it causes the domains to line up. To demagnetize the nail, you could drop it or strike it. This would cause the domains to point in different directions.

2. In a TV commercial that advertises a brand of soda pop, a strong electromagnet picks up a delivery truck carrying cans of the soft drink. The picture switches to the interior of the truck, where cans are seen to fly upward and stick to the roof just beneath the electromagnet. Are the cans made of aluminum? Justify your answer.

   Answer:

   If the electromagnet is able to attract the cans, they must at least in part be made from a ferromagnetic material. Since aluminum is a nonferromagnetic material, we know that the cans are not entirely made of aluminum.

3. Suppose you have two bars: one is a permanent magnet, and the other is not a magnet but is made from a ferromagnetic material like iron. The two bars look exactly alike. Using a third bar, which is known to be a magnet, how can you determine which of the look-alike bars is the permanent magnet and which is not?

   Answer:

   The third bar, which we can call the test bar, is known to be a magnet, so it has a north pole and a south pole. Bring one end of each of the two unknowns near the magnet. The unknown bar that is a permanent magnet will be attracted to the test bar when opposite poles are brought together, but it will be repelled from the test bar when like poles are brought together. Both ends of the unknown bar, which is a ferromagnetic bar, will be attracted to the test bar. The magnetic field of the test bar will always induce a pole that is opposite in polarity to the pole of the magnet. Ferromagnetism always results in attraction.

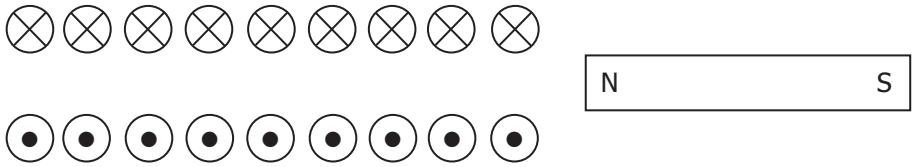
4. Why would it be dangerous for life on earth if the Van Allen belts produced by the earth's magnetic field were not present?

   Answer:

   The Van Allen belts deflect the solar radiation from the sun. This radiation could harm life on earth.

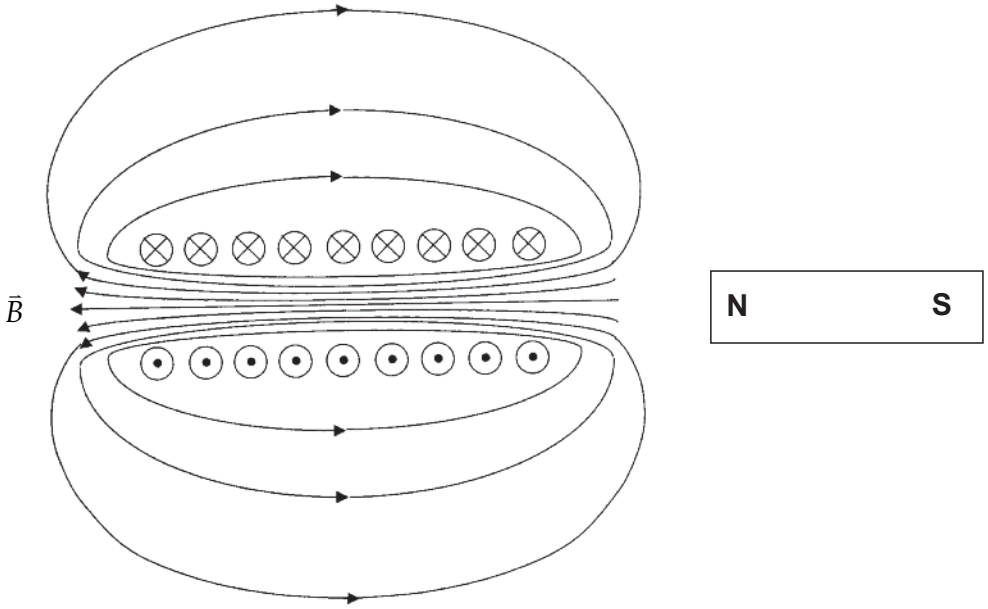
Learning Activity 6.3: Electromagnetism

1. A solenoid is shown below near a bar magnet. Draw the magnetic field line pattern for the solenoid. Will the solenoid and the bar magnet attract or repel each other? Justify your answer.



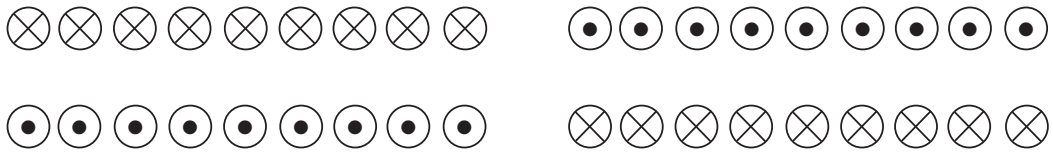
Answer:

The magnetic field lines of the solenoid are shown near the bar magnet.



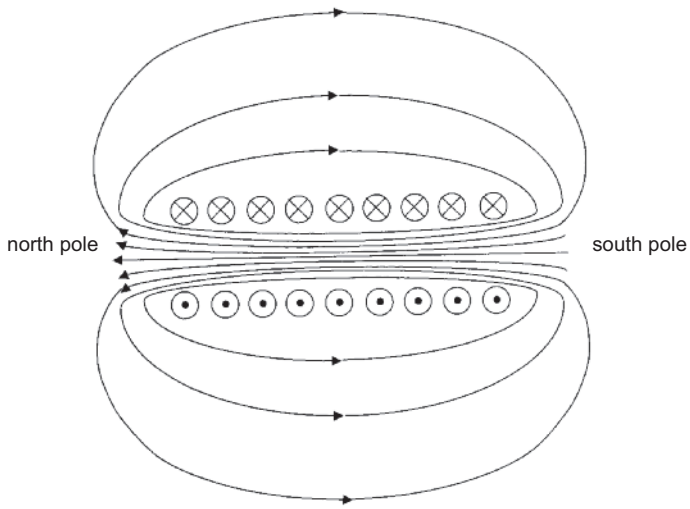
For the solenoid, the magnetic field lines are pointing towards the right side. The south end is, therefore, on the right side. This end faces the north side of the bar magnet. There will, therefore, be an attraction.

2. Two solenoids are placed side by side, as shown below. Will the solenoids attract or repel each other? Justify your answer.

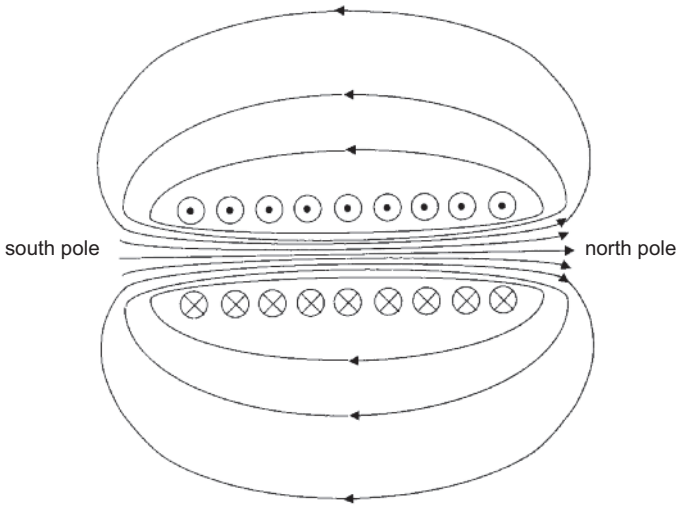


Answer:

The solenoid on the left will produce the magnetic field line pattern shown below.

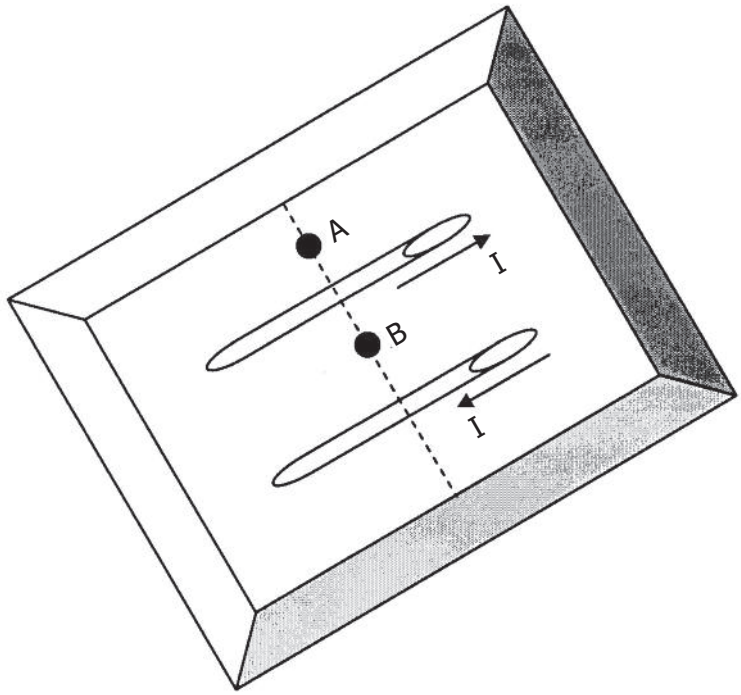


The solenoid on the right will produce the magnetic field line pattern shown below.



The ends that face each other have like poles. Similar poles repel each other.

3. Two current-carrying wires are shown below. The currents are flowing in opposite directions. Both wires are carrying the same amount of current. Point A is to the left of one of the wires, and point B is midway between the wires. The directions of the currents are as shown.



Determine the direction of the net magnetic field at each of points A and B.

Answer:

Using the right-hand rule for a wire, we can determine the direction of the magnetic field at each of the points A and B.

At point A, the direction of the magnetic field caused by the near wire is up out of the plane. The direction of the magnetic field caused by the farther wire is into the plane. However, the field due to the near wire is stronger because it is closer to point A. The result is that the direction of the net magnetic field will be up out of the page.

At point B, the direction of the magnetic field due to both wires is down into the plane. Therefore, the net magnetic field is into the plane. (Furthermore, we can say that the net magnetic field strength at B is twice the magnetic field strength caused by one of the wires since both point in the same direction and both wires have the same current.)

4. The following are ways in which the operation of an electromagnet can be changed. Indicate whether the change will produce a stronger magnetic field or a weaker field.

   a) Replacing an iron core with an aluminum core.

      Answer:

      Aluminum is not a ferromagnetic material. The field will be weaker.

   b) Increasing the number of coils of wire.

      Answer:

      Increasing the number of coils of wire will produce a stronger field.

   c) Decreasing the strength of the current.

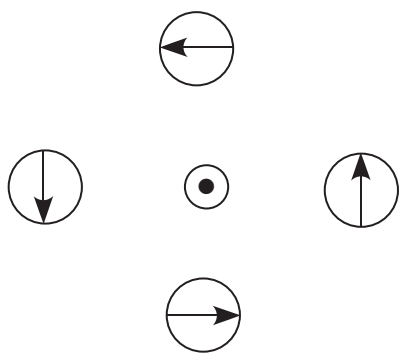
      Answer:

      Decreasing the strength of the current will produce a weaker field.

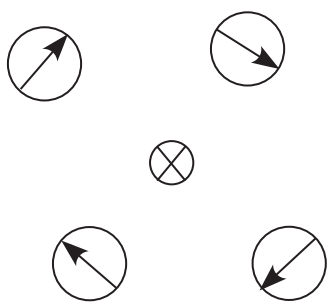
5. A wire is arranged so that it is straight and comes out of the page. The wire is at the centre of the diagram and each circle around the wire represents a compass. Indicate the direction of the compass needle in each circle.

   Answer:

   a)



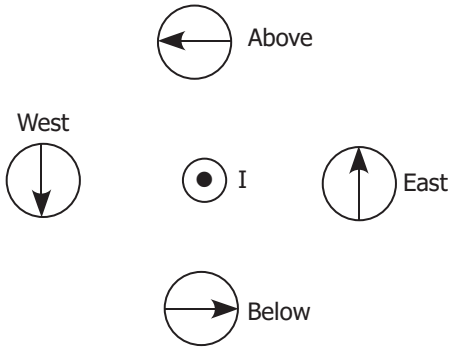
   b)



6. A current is travelling south in a straight horizontal conductor. What is the direction of the magnetic field…

   Answer:

   Look toward north along the wire. The current will be travelling towards you and appears as a dot.



   a) below the conductor?

      Answer: The magnetic field points east.

   b) above the conductor?

      Answer: The magnetic field points west.

   c) east of the conductor?

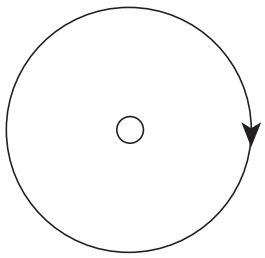
      Answer: The magnetic field points up.

   d) west of the conductor?

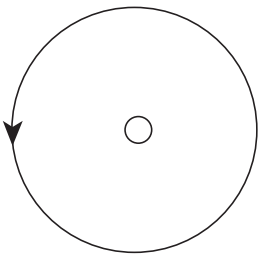
      Answer: The magnetic field points down.

7. Each empty circle represents a conductor surrounded by a magnetic field. State whether a dot or an "X" should be placed in the circle.

   a)



   b)



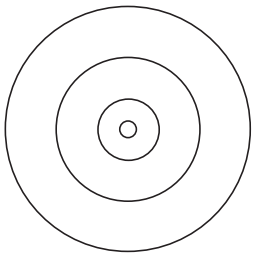
   Use the first right-hand rule (curled hand). Place your fingertips at the position of the arrow (the direction of the magnetic field). Your thumb will point in the direction that the current flows.

   In (a), the current flows into the page. Put an "X" in the circle at the centre.

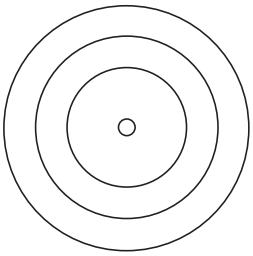
   In(b), the current flows out of the page. Put a dot in the circle at the centre.

8. Choose the diagram that best illustrates the magnetic field surrounding a straight current-carrying conductor. Explain your choice.

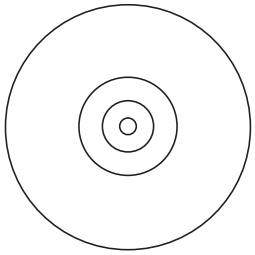
a)



b)



c)



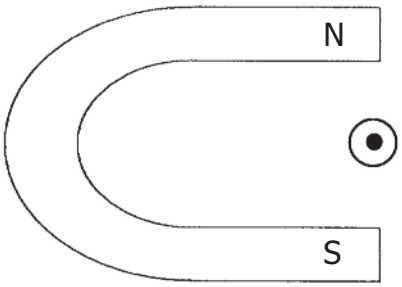
Answer:

The diagram that best illustrates the magnetic field surrounding a straight current-carrying conductor is that in part c.

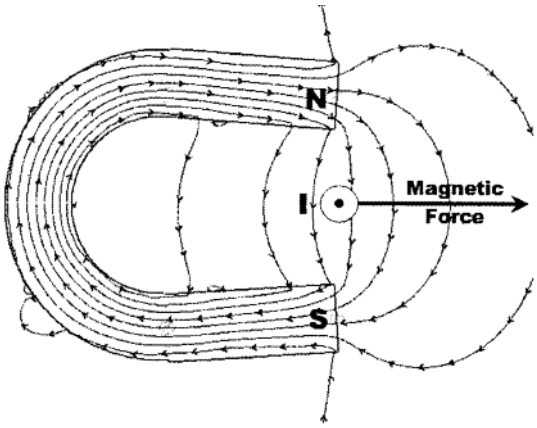
The magnetic field decreases as the distance from the current increases.

Learning Activity 6.4: Forces on Currents in a Magnetic Field

1. a) Draw the magnetic field of the permanent horseshoe magnet.
   b) What is the direction of the force acting on the conductor?



Answer:



Using the third right-hand rule (flat hand):

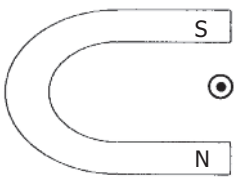
Fingertips point down the page.

Thumb points towards you.

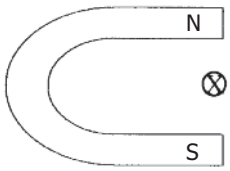
Palm faces to the right.

2. Give the direction of the magnetic force acting on each conductor in the diagrams below.

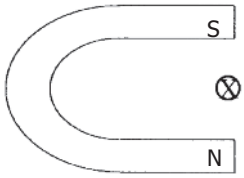
a)



b)



c)



a) The magnetic field lines point from N to S (up the page).

Answer:

Using the third right-hand rule (flat hand):

Fingertips point up the page.

Thumb points towards you.

Palm faces to the left.

The magnetic force is to the left.

b) The magnetic field lines point from N to S (down the page).

Answer:

Using the third right-hand rule (flat hand):

Fingertips point down the page

Thumb points away from you.

Palm faces to the left.

The magnetic force is to the left.

c) The magnetic field lines point from N to S (up the page).

Answer:

Using the third right-hand rule (flat hand):

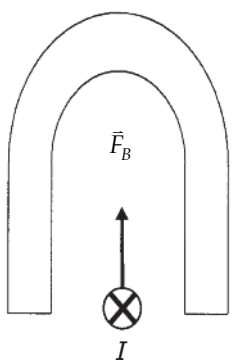
Fingertips point up the page.

Thumb points away from you.

Palm faces to the right.

The magnetic force is to the right.

3. The drawing shows a current-carrying wire that passes through the gap in a horseshoe magnet. The magnetic force $\vec{F}$ exerted on the wire is directed upward. Which end of the magnet is the north pole and which is the south pole? Justify your answers.



Answer:

According to the right-hand rule, point your thumb in the direction of the current. The current goes through the magnetic field from the front of the magnet to behind it. The direction of the force is up, so this is the direction in which the palm would face. The fingertips point to the left. Thus, in order for the wire to be forced up, the magnetic field must point from the right to the left. The north pole of the magnet is on the right side and the south pole is on the left side.

4. An electric power line carries a current of 1400 A in a location where the earth's magnetic field is 5.0×10^{-5} T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120 m length of wire.

   Answer:

   Since the wire and the magnetic field are not perpendicular to each other, we can calculate the magnitude of the magnetic force using $\vec{F}_B = \vec{B}IL \sin\theta$.

   Given: Length of wire $L = 120$ m

   Magnetic field intensity $\vec{B} = 5.0 \times 10^{-5}$ T

   Current $I = 1400$ A

   Angle $\theta = 75°$

   Unknown: Magnetic force $\vec{F}_B = ?$

   Equation: $\vec{F}_B = \vec{B}IL \sin\theta$

   Substitute and solve: $\vec{F}_B = \vec{B}IL = (5.0 \times 10^{-5}\ \text{T})(1400\ \text{A})(120\ \text{m})(\sin 75°)$

   $= 8.1$ N

   The magnitude of the magnetic force is 8.1 N.

5. Near the equator in South America, the earth's magnetic field has a strength of 3.2×10^{-5} T. The field at this location is parallel to the surface of the earth and points due north. A straight wire, 46 m in length, has an east-west orientation and experiences a magnetic force of 0.058 N, directed vertically down (toward the earth). What is the magnitude and direction of the current in the wire?

   Answer:

   The direction of the force is given by the right-hand rule. If the force on the wire is down and the direction of the magnetic field is north, then the current must be running from east to west.

   The magnitude of the force is $\vec{F} = \vec{B}IL$.

   Given: Length of wire $L = 46$ m

   Magnetic field intensity $\vec{B} = 3.2 \times 10^{-5}$ T

   Magnetic force $\vec{F}_B = 0.058$ N

   Angle $\theta = 90°$

   Unknown: Current $I = ?$

   Equation: $\vec{F}_B = \vec{B}IL$ solved for I gives

   $$I = \frac{\vec{F}_B}{\vec{B}L \sin\theta}$$

Substitute and solve: $I = \dfrac{\vec{F}_B}{\vec{B}L \sin\theta} = \dfrac{0.058 \text{ N}}{(3.2 \times 10^{-5} \text{ T})(46 \text{ m})(\sin 90°)} = 39 \text{ A}$

The current is 39 A flowing from east to west.

6. At New York City, the earth's magnetic field has a vertical (downward) component of 5.20×10^{-5} T. What is the magnitude and direction of the magnetic force on a long, straight wire, 6.00 m in length, that carries a 28.0 A current due east?

Answer:

The horizontal component of the magnetic field is at right angles to the current, so the angle between the direction of the current and the direction of the magnetic field is 90°.

Given:	Length of wire	$L = 6.00$ m
	Magnetic field intensity	$\vec{B} = 5.20 \times 10^{-5}$ T
	Current	$I = 28.0$ A
	Angle	$\theta = 90°$
Unknown:	Magnetic force	$\vec{F}_B = ?$
Equation:		$\vec{F}_B = \vec{B}IL \sin\theta$

Substitute and solve:

$$\vec{F}_B = \vec{B}IL = (5.20 \times 10^{-5} \text{ T})(28.0 \text{ A})(6.00 \text{ m})(\sin 90°)$$
$$= 8.74 \times 10^{-3} \text{ N}$$

The magnitude of the magnetic force is 8.74×10^{-3} N.

The magnetic field lines are down.

Using the third right-hand rule (flat hand) and facing north:

Fingertips point down.

Thumb points east (to your right).

Palm faces away from you to the north.

The magnetic force is to the north.

The magnitude of the magnetic force is 8.74×10^{-3} N [N].

NOTES

Grade 11 Physics (30S)

Module 6: Magnetic Fields and Electromagnetism

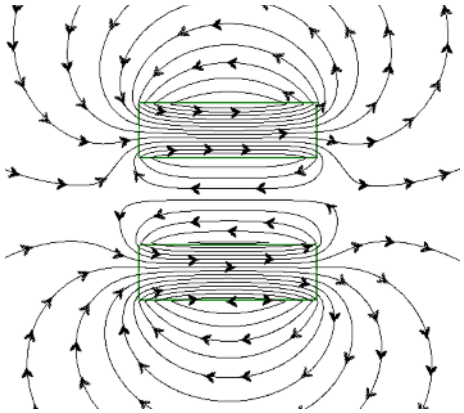
Learning Activity Answer Keys

Module 6: Magnetic Fields and Electromagnetism

Learning Activity 6.1: Magnetic Fields

1. The following diagram shows two bar magnets near each other. Part of the magnetic field lines is shown.

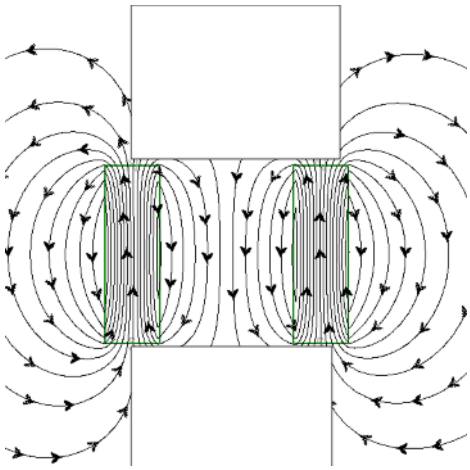
   a) From the direction in which the field lines are drawn, indicate which poles are located at each pole of the bar magnet.



   Answer:

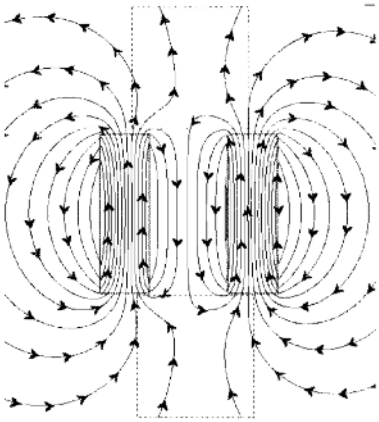
   On the left side of the diagram, the magnetic field lines are moving away from the poles. Both of these poles are north poles. Similarly, the field lines are moving towards the poles on the right side. These are south poles.

   b) The following diagram shows two rectangular regions. Add additional field lines in these areas, showing how they would interact with each other.

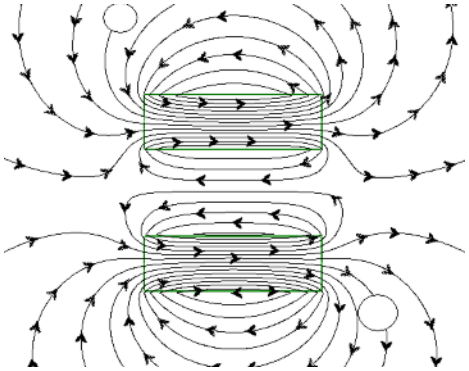


Answer:

In the rectangular regions, the field lines will repel each other. The diagram below shows this effect.

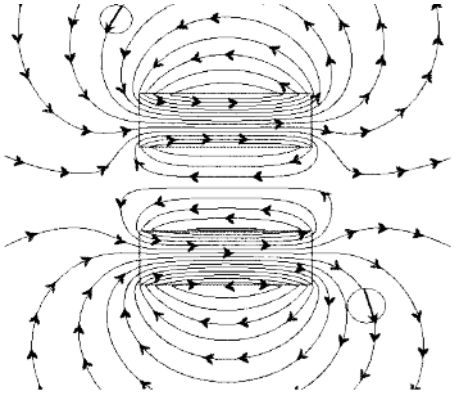


c) The diagram below shows two compasses placed in the magnetic field of this combination of magnets. Indicate the direction in which the compass needle would point at these locations.

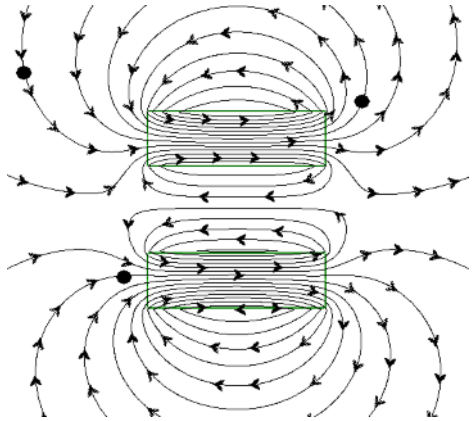


Answer:

The compass needle would point in the direction of the magnetic field, away from north and towards south.

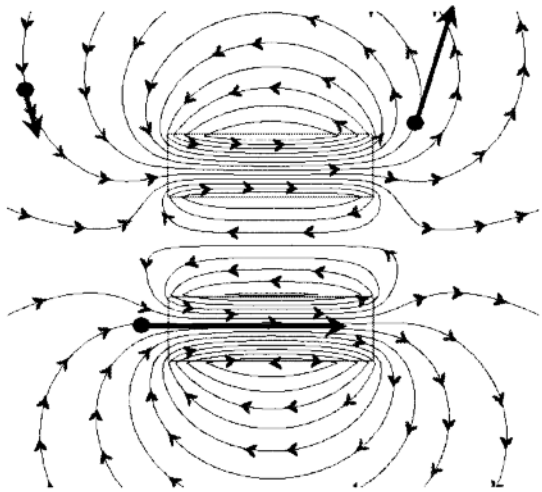


d) The diagram below shows three solid circles. From these circles, draw possible magnetic field vectors. In your drawing, draw the vectors with a length indicating the relative strength of the magnetic field at that point.



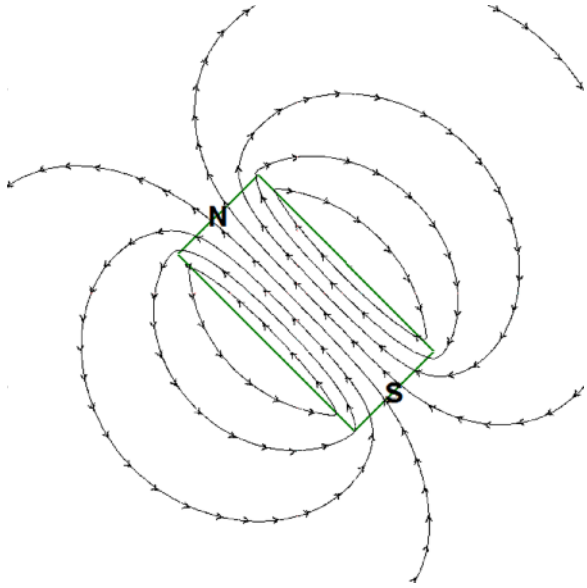
Answer:

The direction of the vectors is tangent to the field lines. The vector in the upper part of the diagram is closer to the pole than the lower vector. When the vector is closer to the pole, the field strength is greater. This is also indicated by the greater density of field lines in this area. Therefore, the vector is longer.



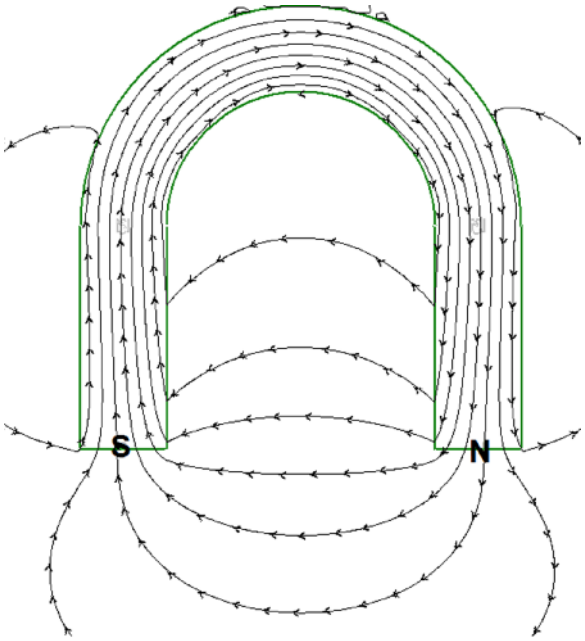
2. Draw the magnetic field around the following bar magnet. Include eight lines in the diagram.

   Answer:



3. Draw the magnetic field around a horseshoe magnet.

   Answer:



Learning Activity 6.2: The Earth's Magnetic Field

1. What would you do to magnetize a steel nail, and then demagnetize the same nail? Explain why these effects occur.

   Answer:

   To magnetize the nail, it would be necessary to place it in a strong magnetic field, or stroke it in one direction with one pole of a magnet. This works because it causes the domains to line up. To demagnetize the nail, you could drop it or strike it. This would cause the domains to point in different directions.

2. In a TV commercial that advertises a brand of soda pop, a strong electromagnet picks up a delivery truck carrying cans of the soft drink. The picture switches to the interior of the truck, where cans are seen to fly upward and stick to the roof just beneath the electromagnet. Are the cans made of aluminum? Justify your answer.

   Answer:

   If the electromagnet is able to attract the cans, they must at least in part be made from a ferromagnetic material. Since aluminum is a nonferromagnetic material, we know that the cans are not entirely made of aluminum.

3. Suppose you have two bars: one is a permanent magnet, and the other is not a magnet but is made from a ferromagnetic material like iron. The two bars look exactly alike. Using a third bar, which is known to be a magnet, how can you determine which of the look-alike bars is the permanent magnet and which is not?

   Answer:

   The third bar, which we can call the test bar, is known to be a magnet, so it has a north pole and a south pole. Bring one end of each of the two unknowns near the magnet. The unknown bar that is a permanent magnet will be attracted to the test bar when opposite poles are brought together, but it will be repelled from the test bar when like poles are brought together. Both ends of the unknown bar, which is a ferromagnetic bar, will be attracted to the test bar. The magnetic field of the test bar will always induce a pole that is opposite in polarity to the pole of the magnet. Ferromagnetism always results in attraction.

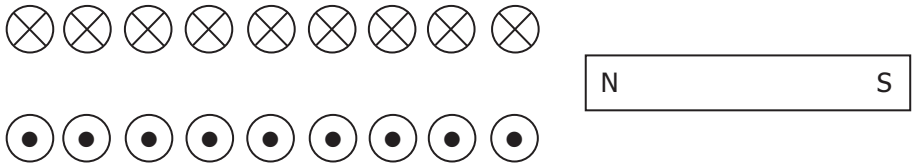
4. Why would it be dangerous for life on earth if the Van Allen belts produced by the earth's magnetic field were not present?

   Answer:

   The Van Allen belts deflect the solar radiation from the sun. This radiation could harm life on earth.

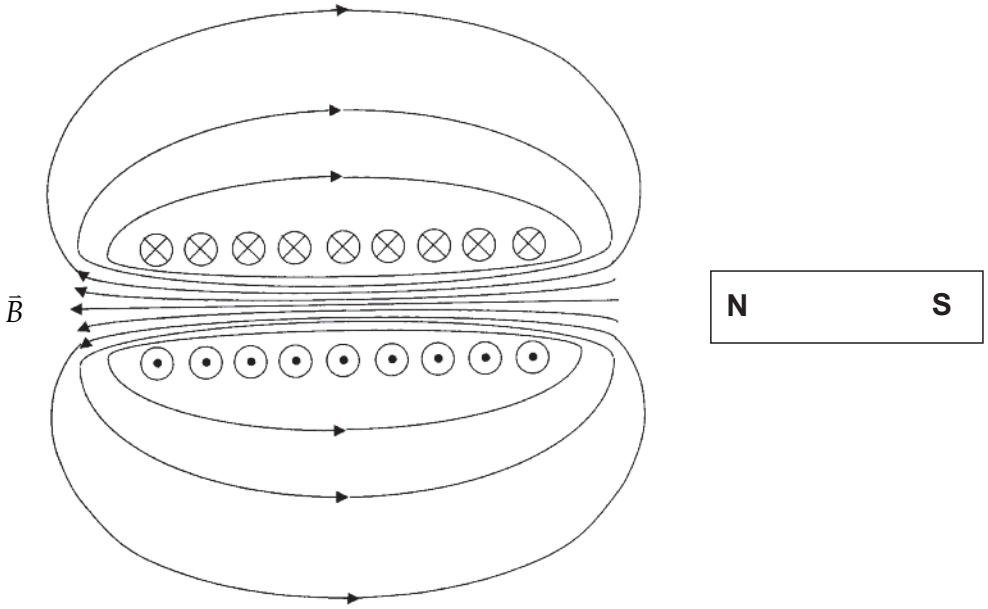
Learning Activity 6.3: Electromagnetism

1. A solenoid is shown below near a bar magnet. Draw the magnetic field line pattern for the solenoid. Will the solenoid and the bar magnet attract or repel each other? Justify your answer.



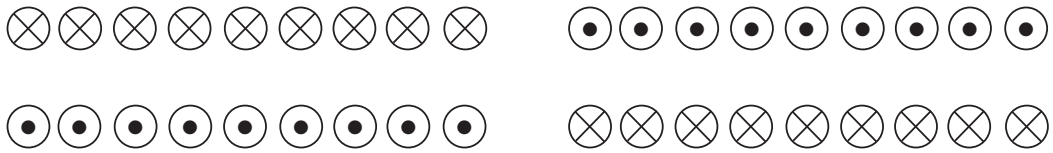
Answer:

The magnetic field lines of the solenoid are shown near the bar magnet.



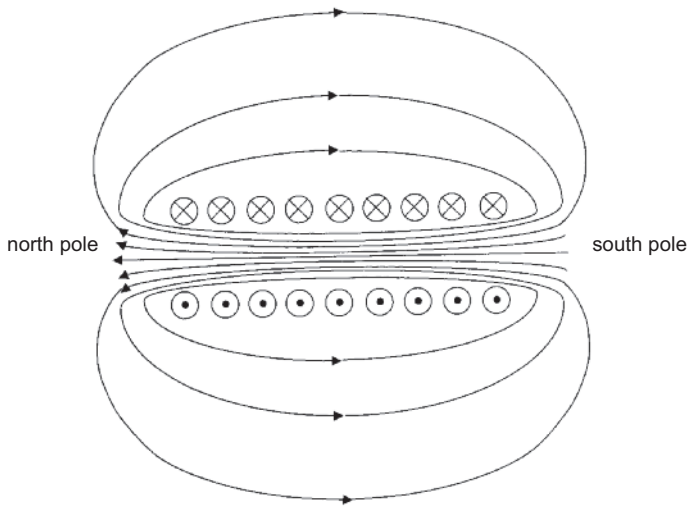
For the solenoid, the magnetic field lines are pointing towards the right side. The south end is, therefore, on the right side. This end faces the north side of the bar magnet. There will, therefore, be an attraction.

2. Two solenoids are placed side by side, as shown below. Will the solenoids attract or repel each other? Justify your answer.

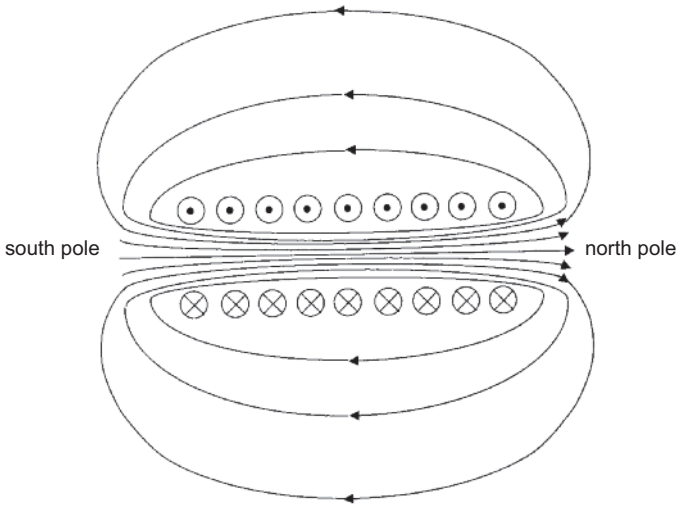


Answer:

The solenoid on the left will produce the magnetic field line pattern shown below.

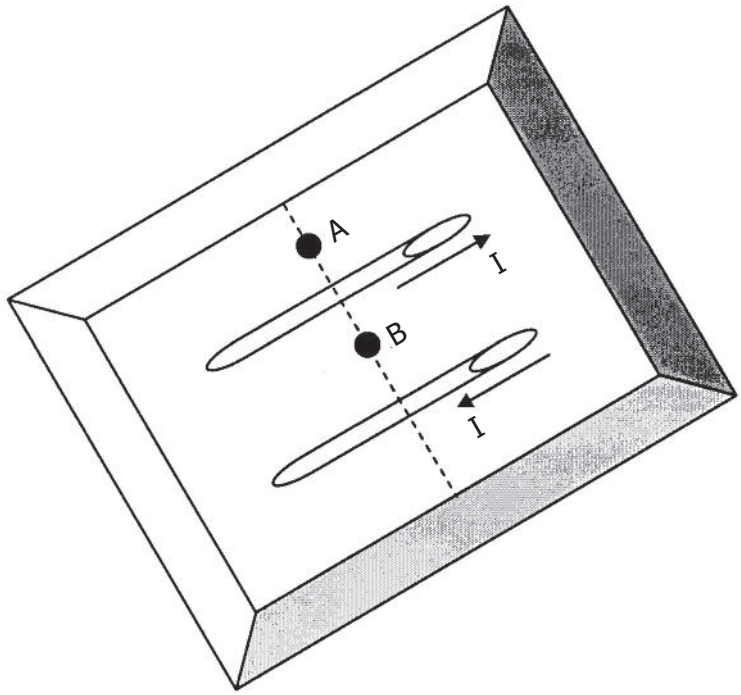


The solenoid on the right will produce the magnetic field line pattern shown below.



The ends that face each other have like poles. Similar poles repel each other.

3. Two current-carrying wires are shown below. The currents are flowing in opposite directions. Both wires are carrying the same amount of current. Point A is to the left of one of the wires, and point B is midway between the wires. The directions of the currents are as shown.



Determine the direction of the net magnetic field at each of points A and B.

Answer:

Using the right-hand rule for a wire, we can determine the direction of the magnetic field at each of the points A and B.

At point A, the direction of the magnetic field caused by the near wire is up out of the plane. The direction of the magnetic field caused by the farther wire is into the plane. However, the field due to the near wire is stronger because it is closer to point A. The result is that the direction of the net magnetic field will be up out of the page.

At point B, the direction of the magnetic field due to both wires is down into the plane. Therefore, the net magnetic field is into the plane. (Furthermore, we can say that the net magnetic field strength at B is twice the magnetic field strength caused by one of the wires since both point in the same direction and both wires have the same current.)

4. The following are ways in which the operation of an electromagnet can be changed. Indicate whether the change will produce a stronger magnetic field or a weaker field.

   a) Replacing an iron core with an aluminum core.

      Answer:

      Aluminum is not a ferromagnetic material. The field will be weaker.

   b) Increasing the number of coils of wire.

      Answer:

      Increasing the number of coils of wire will produce a stronger field.

   c) Decreasing the strength of the current.

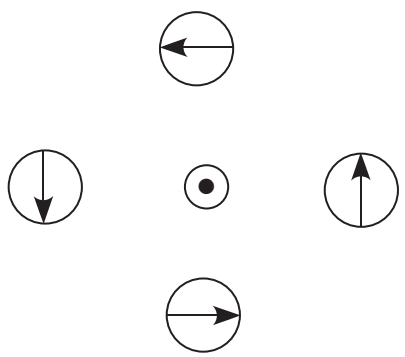
      Answer:

      Decreasing the strength of the current will produce a weaker field.

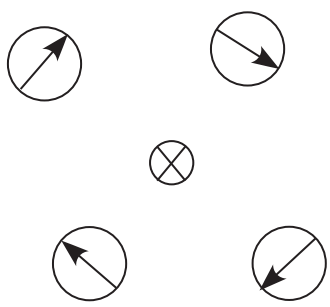
5. A wire is arranged so that it is straight and comes out of the page. The wire is at the centre of the diagram and each circle around the wire represents a compass. Indicate the direction of the compass needle in each circle.

   Answer:

   a)



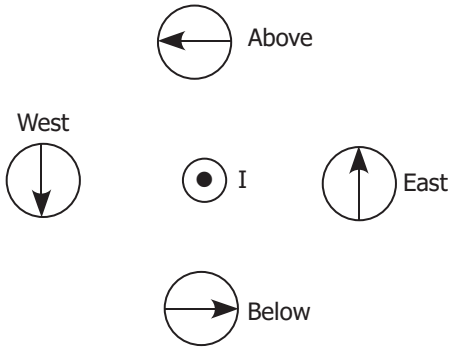
   b)



6. A current is travelling south in a straight horizontal conductor. What is the direction of the magnetic field…

   Answer:

   Look toward north along the wire. The current will be travelling towards you and appears as a dot.



   a) below the conductor?

      Answer: The magnetic field points east.

   b) above the conductor?

      Answer: The magnetic field points west.

   c) east of the conductor?

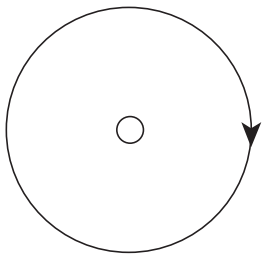
      Answer: The magnetic field points up.

   d) west of the conductor?

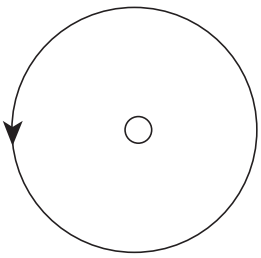
      Answer: The magnetic field points down.

7. Each empty circle represents a conductor surrounded by a magnetic field. State whether a dot or an "X" should be placed in the circle.

   a)



   b)



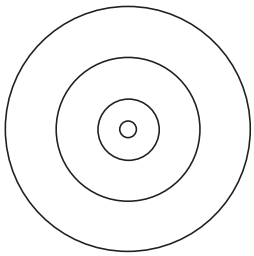
   Use the first right-hand rule (curled hand). Place your fingertips at the position of the arrow (the direction of the magnetic field). Your thumb will point in the direction that the current flows.

   In (a), the current flows into the page. Put an "X" in the circle at the centre.

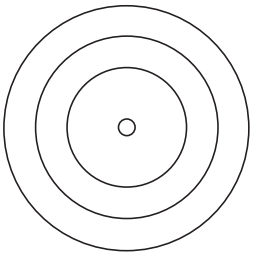
   In(b), the current flows out of the page. Put a dot in the circle at the centre.

8. Choose the diagram that best illustrates the magnetic field surrounding a straight current-carrying conductor. Explain your choice.

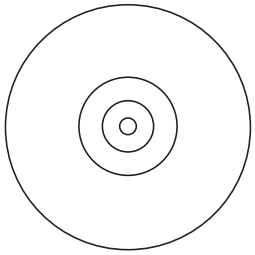
a)



b)



c)



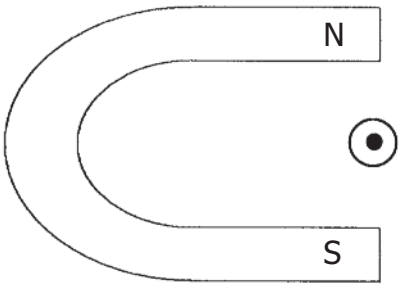
Answer:

The diagram that best illustrates the magnetic field surrounding a straight current-carrying conductor is that in part c.

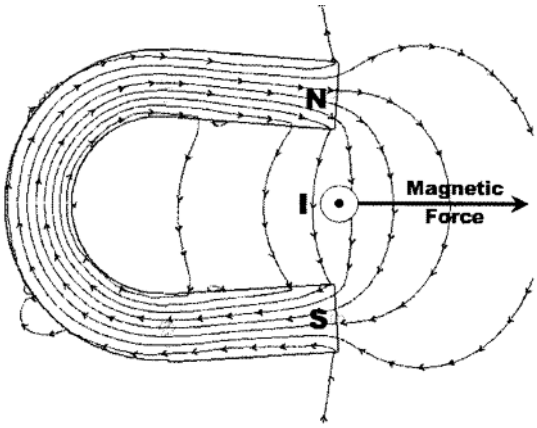
The magnetic field decreases as the distance from the current increases.

Learning Activity 6.4: Forces on Currents in a Magnetic Field

1. a) Draw the magnetic field of the permanent horseshoe magnet.
   b) What is the direction of the force acting on the conductor?



Answer:



Using the third right-hand rule (flat hand):

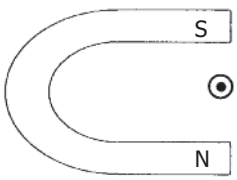
Fingertips point down the page.

Thumb points towards you.

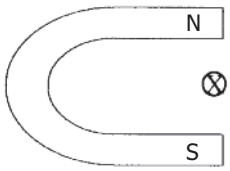
Palm faces to the right.

2. Give the direction of the magnetic force acting on each conductor in the diagrams below.

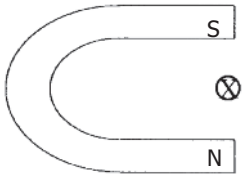
a)



b)



c)



a) The magnetic field lines point from N to S (up the page).

Answer:

Using the third right-hand rule (flat hand):

Fingertips point up the page.

Thumb points towards you.

Palm faces to the left.

The magnetic force is to the left.

b) The magnetic field lines point from N to S (down the page).

Answer:

Using the third right-hand rule (flat hand):

Fingertips point down the page

Thumb points away from you.

Palm faces to the left.

The magnetic force is to the left.

c) The magnetic field lines point from N to S (up the page).

Answer:

Using the third right-hand rule (flat hand):

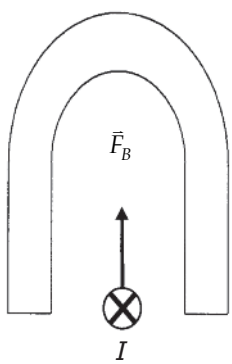
Fingertips point up the page.

Thumb points away from you.

Palm faces to the right.

The magnetic force is to the right.

3. The drawing shows a current-carrying wire that passes through the gap in a horseshoe magnet. The magnetic force $\vec{F}$ exerted on the wire is directed upward. Which end of the magnet is the north pole and which is the south pole? Justify your answers.



Answer:

According to the right-hand rule, point your thumb in the direction of the current. The current goes through the magnetic field from the front of the magnet to behind it. The direction of the force is up, so this is the direction in which the palm would face. The fingertips point to the left. Thus, in order for the wire to be forced up, the magnetic field must point from the right to the left. The north pole of the magnet is on the right side and the south pole is on the left side.

4. An electric power line carries a current of 1400 A in a location where the earth's magnetic field is 5.0×10^{-5} T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120 m length of wire.

   Answer:

   Since the wire and the magnetic field are not perpendicular to each other, we can calculate the magnitude of the magnetic force using $\vec{F}_B = \vec{B}IL \sin\theta$.

   Given: Length of wire $L = 120$ m

   Magnetic field intensity $\vec{B} = 5.0 \times 10^{-5}$ T

   Current $I = 1400$ A

   Angle $\theta = 75°$

   Unknown: Magnetic force $\vec{F}_B = ?$

   Equation: $\vec{F}_B = \vec{B}IL \sin\theta$

   Substitute and solve: $\vec{F}_B = \vec{B}IL = (5.0 \times 10^{-5}\ \text{T})(1400\ \text{A})(120\ \text{m})(\sin 75°)$

   $= 8.1$ N

   The magnitude of the magnetic force is 8.1 N.

5. Near the equator in South America, the earth's magnetic field has a strength of 3.2×10^{-5} T. The field at this location is parallel to the surface of the earth and points due north. A straight wire, 46 m in length, has an east-west orientation and experiences a magnetic force of 0.058 N, directed vertically down (toward the earth). What is the magnitude and direction of the current in the wire?

   Answer:

   The direction of the force is given by the right-hand rule. If the force on the wire is down and the direction of the magnetic field is north, then the current must be running from east to west.

   The magnitude of the force is $\vec{F} = \vec{B}IL$.

   Given: Length of wire $L = 46$ m

   Magnetic field intensity $\vec{B} = 3.2 \times 10^{-5}$ T

   Magnetic force $\vec{F}_B = 0.058$ N

   Angle $\theta = 90°$

   Unknown: Current $I = ?$

   Equation: $\vec{F}_B = \vec{B}IL$ solved for I gives

   $$I = \frac{\vec{F}_B}{\vec{B}L \sin\theta}$$

Substitute and solve: $I = \dfrac{\vec{F}_B}{\vec{B}L \sin\theta} = \dfrac{0.058 \text{ N}}{(3.2 \times 10^{-5} \text{ T})(46 \text{ m})(\sin 90°)} = 39 \text{ A}$

The current is 39 A flowing from east to west.

6. At New York City, the earth's magnetic field has a vertical (downward) component of 5.20×10^{-5} T. What is the magnitude and direction of the magnetic force on a long, straight wire, 6.00 m in length, that carries a 28.0 A current due east?

Answer:

The horizontal component of the magnetic field is at right angles to the current, so the angle between the direction of the current and the direction of the magnetic field is 90°.

Given:	Length of wire	$L = 6.00$ m
	Magnetic field intensity	$\vec{B} = 5.20 \times 10^{-5}$ T
	Current	$I = 28.0$ A
	Angle	$\theta = 90°$
Unknown:	Magnetic force	$\vec{F}_B = ?$
Equation:		$\vec{F}_B = \vec{B}IL \sin\theta$

Substitute and solve:

$$\vec{F}_B = \vec{B}IL = (5.20 \times 10^{-5} \text{ T})(28.0 \text{ A})(6.00 \text{ m})(\sin 90°)$$
$$= 8.74 \times 10^{-3} \text{ N}$$

The magnitude of the magnetic force is 8.74×10^{-3} N.

The magnetic field lines are down.

Using the third right-hand rule (flat hand) and facing north:

Fingertips point down.

Thumb points east (to your right).

Palm faces away from you to the north.

The magnetic force is to the north.

The magnitude of the magnetic force is 8.74×10^{-3} N [N].

NOTES

Topic 2 - Audio/Videos

Module 6

1. Introduction to magnetism | Physics | Khan Academy
2. Magnetic Field | #aumsum #kids #education #science #learn
3. Magnetic lines of force - edutree(full HD)
4. Magnets and Magnetic Fields
5. Magnetic Domains
6. Physics & Electromagnetism : The Domain Theory of Magnetism
7. Electromagnetism - Magnetic Force: The Four Fundamental Forces of Physics #4b
8. Oersted's Experiment
9. Physics-Magnetic Field Due a Current Carrying Wire
10. GCSE Science Physics (9-1) Electromagnets
    a. A current in a wire produces a magnet field around the wire which can be detected using a compass. A wire can be wound into a coil to create a solenoid. The solenoid also produces a magnetic field that has the same shape as the magnetic field for a bar magnet and which is strongest inside the core of the solenoid. Introducing an iron core into the core of the solenoid constructs an electromagnet. The strength of the electromagnet is affected by the size of the current, the number of turns in the coil and the insertion of a ferromagnetic coil into the core of the solenoid.
11. Three Right Hand Rules of Electromagnetism - Magnetic Force
    a. This video illustrates the 3 Right Hand Rules for the directions of current, magnetic field and magnetic force.
    b. The first rule (curled right hand) relates the direction of motion of the current in a wire (positive charge motion) and the direction of the magnetic field given by the direction that the curled fingers point around the wire.
    c. The second rule (flat right hand) relates the direction of the magnetic field given by direction the fingers point, the direction of the current or the direction of motion of a positively charged particle given by the direction the thumb points and the direction of the magnetic force on the wire or charged particle given by the direction the palm points.
    d. The third right hand rule relates the direction the current flows in the wires of a solenoid to the direction of the magnetic field inside the solenoid. The rule given in the course materials is a bit different. The thumb points along a wire in the direction the current is flowing. The curled fingers are placed inside the solenoid. The fingers then point towards the end of the solenoid where the North pole is found.
    e. Note that there are variations of the Right Hand Rules. Please use the one presented in the course materials.
12. Tangent Galvanometer
13. Grade 11 Physics Track 3 Tangent Galvanometer Mod 6 A6.2
14. Force on a current carrying conductor in a magnetic field - Physics
15. Force on a Current Carrying Wire in a Magnetic field

16. Magnetic Force on a Current-Carrying Conductor
    a. This webpage addresses the concept of how to determine the magnetic force (both magnitude and direction) on a current-carrying conductor in a magnetic field.
    b. The direction of the magnetic force on the current carrying wire is found using the flat right hand rule.
    c. For the magnitude of the magnetic force the equation used is $F_B = ILB\sin\Theta$.
    d. An explanation of the theory is presented in the first section of the webpage.
    e. In a colored text box the calculation is done for the magnitude. The right hand rule (flat hand) is used to determine the direction of the magnetic force.
    f. Scroll down to Problems and Exercises.
    g. Do the first 3 questions relating the directions of the magnetic force, current and magnetic field. Diagrams and answers are provided.
17. Finding Magnetic Force on a Current Carrying Wire
18. Grade 11 Physics Track 4 Magnetic Field and Solenoid Mod 6 A6.3

Grade 11 Physics (30S)

Midterm Practice Exam

Grade 11 Physics (30S)

Midterm Practice Exam

Instructions

The midterm exam will be weighted as follows:

Modules 1–6	100%

The format of the examination will be as follows:

Part A: Multiple Choice	40 x 1 = 40 marks
Part B: Fill-in-the-Blanks	12 x 0.5 = 6 marks
Part C: Short Explanations and Diagrams	5 x 3 = 15 marks
Part D: Problems	39 marks

The following instructions are meant to assist you when you are writing your midterm examination.

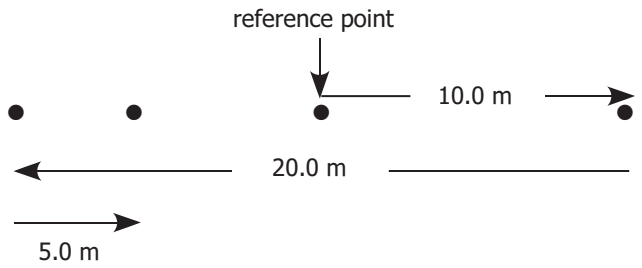
- Show your work for the problems.
- Include directions with all vector answers.
- Round off answers to the correct number of significant digits.

Part A: Multiple Choice (40 x 1 = 40 Marks)

Circle the letter of the choice that best completes each statement.

1. Those two quantities that are vectors are
   a) distance and position
   b) position and displacement
   c) displacement and speed
   d) speed and velocity

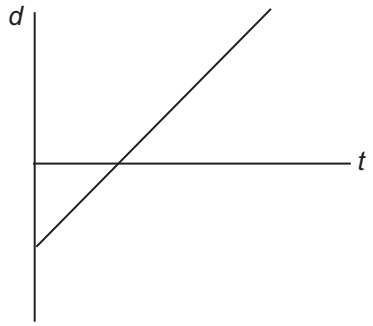
2. An object moves to the right 10.0 m from the starting point in a time of 1.0 s, then to the left 20.0 m in a time of 3.0 s, and then to the right 5.0 m in a time of 1.0 s. The diagram below represents this motion.



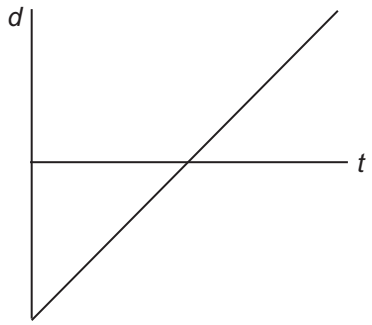
   The average velocity of the object over the whole time interval is best written as
   a) –1.0 m/s
   b) 0.8 m/s
   c) 1.2 m/s
   d) 7.0 m/s

3. Of the position-time graphs below, the one that shows the highest speed in the negative direction is

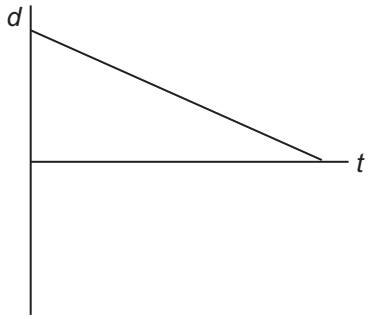
a)



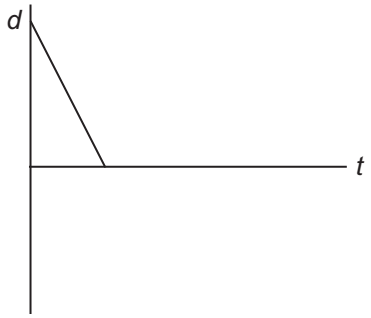
b)



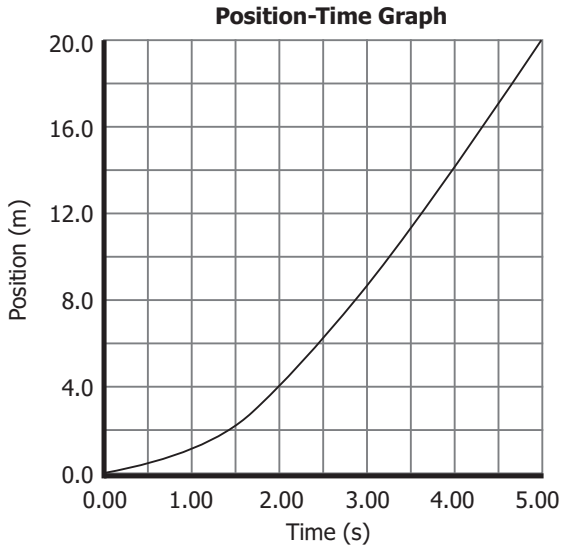
c)



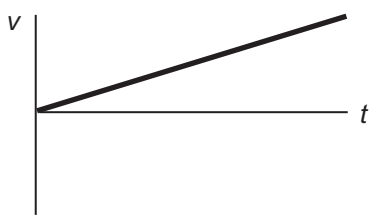
d)

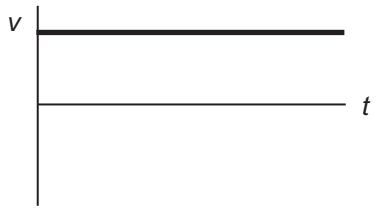


4. The following is a position-time graph.

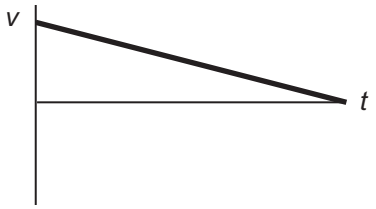


The shape of the velocity-time graph that would best correspond with this position-time graph is

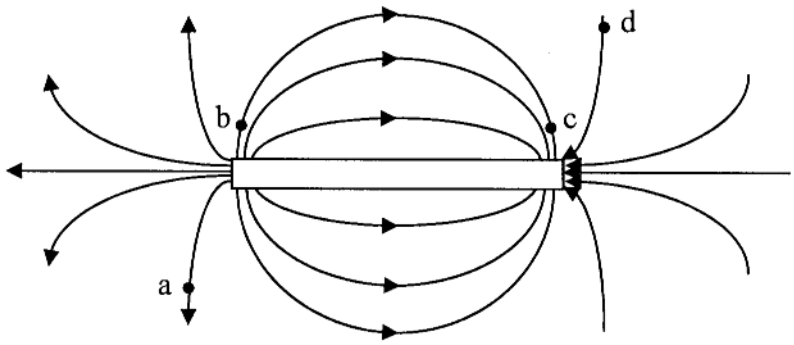
a) 

b) 

c)

d) 

5. The following diagram shows a possible magnetic field line pattern between two poles of a bar magnet. Four positions *a*, *b*, *c*, and *d*, are indicated on the diagram.



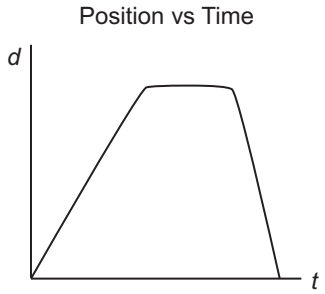
The positions that would most show the magnetic field vector pointing in the same direction are

a) *a* and *b*
b) *a* and *d*
c) *b* and *c*
d) *b* and *d*

6. The term "uniform motion" means
   a) acceleration is constant
   b) speed is constant
   c) velocity is constant
   d) displacement is constant

7. The magnetic pole found in the northern hemisphere of our earth acts like the
   a) north pole of a bar magnet and the north pole of a compass needle would point towards it
   b) north pole of a bar magnet and the south pole of a compass needle would point towards it
   c) south pole of a bar magnet and the north pole of a compass needle would point towards it
   d) south pole of a bar magnet and the south pole of a compass needle would point towards it

8. Study the position-time graph pictured below and select the statement that is true.



a) The object's speed is greatest during the last segment.
b) The object's acceleration is greatest during the last segment.
c) The object's average acceleration is zero.
d) The object travels a greater distance in the first segment than in the last segment.

9. Contact forces such as the force of friction and the force of a glove on a punching bag are examples of
a) gravitational force
b) electromagnetic force
c) strong nuclear force
d) weak nuclear force

10. If an object is already moving and the sum of all the vector forces on a mass is zero, then the object will
a) move at a constant speed in a straight line
b) accelerate at a constant rate in a straight line
c) come to rest
d) increase its amount of inertia

11. A net force acts on a mass of 8.00 kg causing it to move from rest to a speed of 10.0 m/s in a time of 5.00 s. The net force must have a magnitude of
a) 8.00 N
b) 16.0 N
c) 40.0 N
d) 80.0 N

12. Two forces are acting on a mass of 20.0 kg. One force is to the right at 400.0 N while the other force is to the left at a magnitude of 600.0 N. The acceleration of the wagon is

a) $-50.0\ m/s^2$

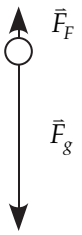
b) $-10.0\ m/s^2$

c) $10.0\ m/s^2$

d) $50.0\ m/s^2$

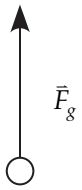
13. A free-body diagram for a ball in free fall in a vacuum is

a)

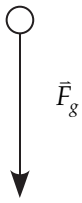


b)

c)

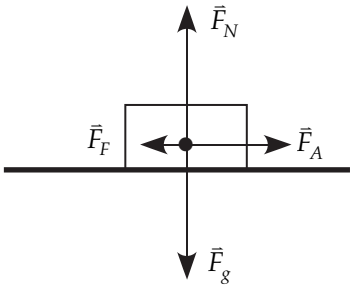


d)

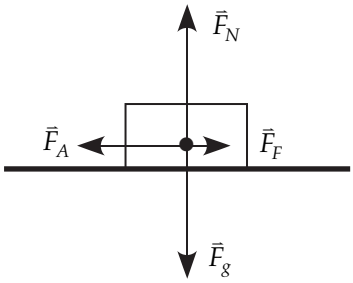


14. An object is being pulled to the right. The object is accelerating to the right, and friction is present. The correct free-body diagram for this situation is

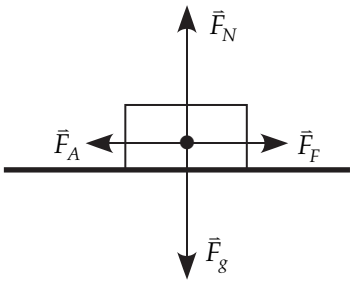
a)



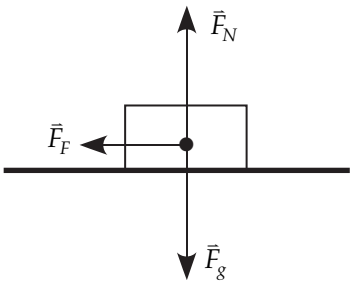
b)



c)

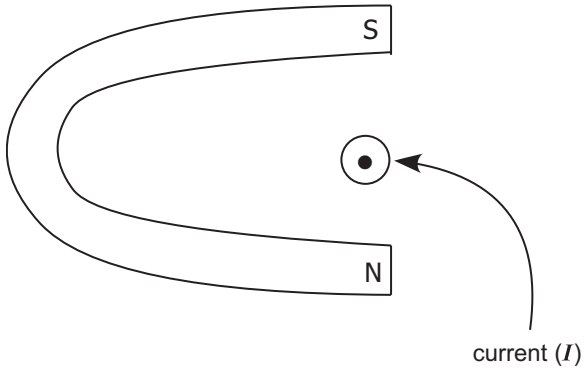


d)



15. Which of the following fundamental forces is the strongest?
    a) strong nuclear
    b) electrostatic
    c) weak nuclear
    d) They are equally strong.

16. The diagram below shows a horseshoe magnet with the north pole and south pole as indicated. A wire is placed between the poles and the current moves as shown.



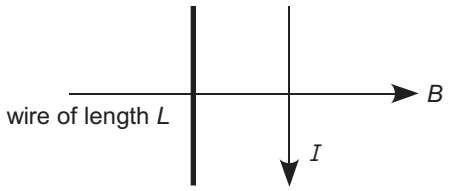
The direction of the force on the wire is

a) up out of the page
b) down into the page
c) towards the interior of the magnet (west)
d) towards the outside of the magnet (east)

17. The gravitational field can be defined as the

a) region of space around a mass where another mass experiences a force
b) acceleration due to gravity which is equal to approximately 9.80 m/s^2 for our Earth
c) force divided by the mass for an object in free fall
d) the amount of the contact force between a mass at rest on the surface of the Earth and the Earth

18. A straight wire has a current of 2.0 A passing through it. The wire is 10.0 cm long. The wire, which is oriented so that it is perpendicular to a magnetic field, is 5.0 T.



The magnitude of the force on the wire is

a) 0.0 N
b) 1.0 N
c) 1.0×10^1 N
d) 1.0×10^2 N

19. The value of the acceleration due to gravity, $\vec{g}$, can be determined experimentally by recording and analyzing the time and position of a ball while it is

a) rolling freely across a horizontal table
b) pulled across a horizontal table by a constant force
c) dropped in free fall
d) pushed upwards by a constant force

20. When an object has reached terminal velocity, the shape of the line in a velocity-time graph is

a) horizontal
b) straight and oblique with a positive slope
c) straight and oblique with a negative slope
d) curving upwards

21. The coefficient of friction can be defined as the ratio of the

a) force of gravity over the force of friction
b) force of friction over the normal force
c) normal force over the force of gravity
d) force of gravity over the applied force

22. How much would a 60.0 kg person weigh on the moon where the gravitational field strength has a magnitude of 1.60 N/kg?
    a) 60.0 kg
    b) 96.0 N
    c) 98.0 kg
    d) 98.0 N

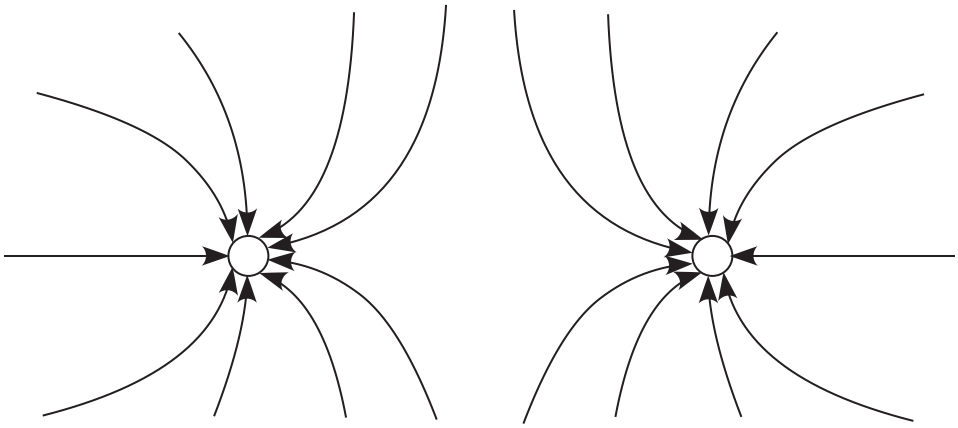
23. Two magnetic fields are acting on a 2.0 m long wire carrying a current of 8.0 A to the east. One of the magnetic fields is acting vertically downward into the paper. It has a magnitude of 5.0×10^{-5} T. A second magnetic field is acting at 4.0×10^{-5} T to the south. The magnitude of the net force on the wire is
    a) 1.0×10^{-6} N
    b) 4.8×10^{-4} N
    c) 1.0×10^{-3} N
    d) 3.8×10^{-2} N

24. Objects onboard an orbiting space station appear to be "floating" because
    a) they're in the vacuum of space
    b) they're weightless
    c) they're outside Earth's gravitational pull
    d) they're falling together with the space station

25. If a positive charge A is twice as large as a positive charge B, we could show this by drawing
    a) the field lines in the opposite direction for one of the charges
    b) the same number of field lines as B but shorter
    c) twice as many field lines for charge A
    d) half as many field lines for charge A

26. If we were to compare the field lines for the gravitational situation to the electric situation, we would find that the electric field line pattern that is identical to the gravitational pattern around the Earth occurs when there is
    a) a neutral charge
    b) a combination of positive and negative charges
    c) one positive charge
    d) one negative charge

27. The diagram below shows an electric field line pattern for two charges.

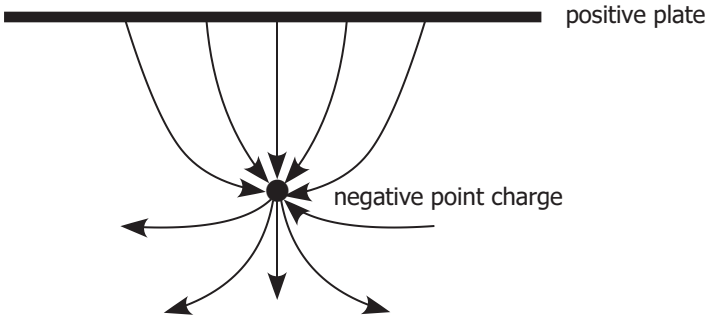


This is an electric field line pattern for two

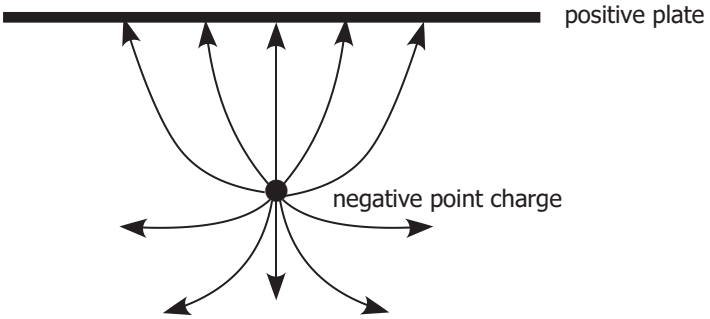
a) negative charges
b) positive charges
c) neutral charges
d) opposite charges

28. The diagrams below show a positively charged plate and a negative point charge. The electric field line pattern for this situation is best shown by

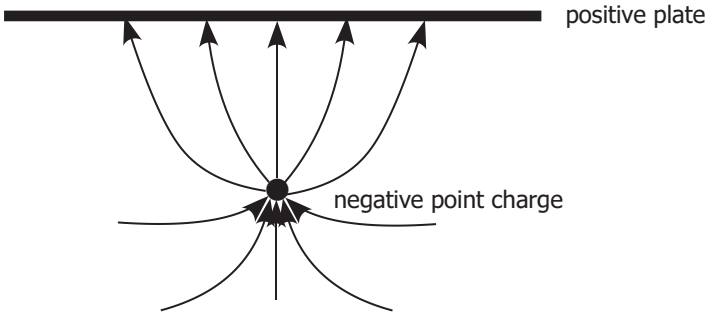
a)



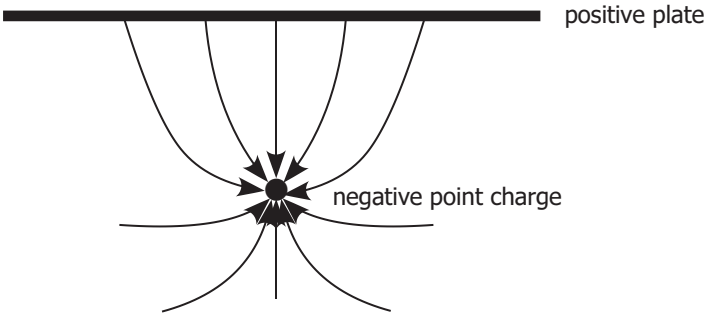
b)



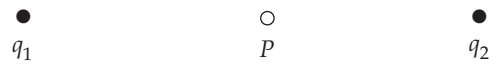
c)



d)



29. The negative charge, $-q_1$, to the left of point P, creates an electric field, $\vec{E}_1$, of magnitude 10.0 N/C at position P. The positive charge to the right of point P, q_2, creates an electric field, $\vec{E}_2$, of magnitude 25.0 N/C at position P.



The directions of the electric fields at position P are

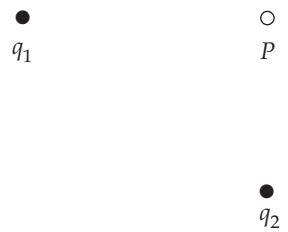
a) both to the west

b) both to the east

c) $\vec{E}_1$ to the east and $\vec{E}_2$ to the west

d) $\vec{E}_1$ to the west and $\vec{E}_2$ to the east

30. The negative charge, $-q_1$, to the west of point P, creates an electric field, $\vec{E}_1$, of magnitude 10.0 N/C at position P. The positive charge, q_2, to the south of point P, creates an electric field, $\vec{E}_2$, of magnitude 25.0 N/C at position P.



The direction of the total electric field at position P is

a) 68.2° S of W

b) 68.2° N of W

c) 21.8° S of W

d) 21.8° N of W

31. In a Millikan apparatus, a sphere of mass 4.0×10^{-15} kg is stationary in an electric field whose intensity is 2.00×10^{4} N/C. The top plate is positive. The magnitude of the charge on the sphere must be

a) 2.0×10^{-18} C

b) 1.3×10^{4} C

c) 5.1×10^{17} C

d) 3.2×10^{36} C

32. A ferromagnetic material is placed in a strong magnetic field that points from the left to the right.

The domains in the material point

a) in the up direction
b) in the down direction
c) to the right
d) to the left

33. State the number of significant digits in 0.0089076500

a) 8
b) 9
c) 10
d) 11

34. The correct answer for the product of 6.9530 x 0.07843 is

a) 0.5453
b) 0.54532
c) 0.545323
d) 0.5453238

35. The correct answer for the sum of 18.3 + 6.92 + 2.0084 is

a) 27.2282
b) 27.22
c) 27.2
d) 27.228

36. Which of the following is NOT a mode of representation used in physics?

a) visual mode
b) graphical mode
c) diagram mode
d) symbolic mode

37. The slope of a chord on a position-time graph represents which of the following quantities?
    a) average acceleration
    b) average velocity
    c) average displacement
    d) average distance

38. Which of the following is not a characteristic of the components of a vector?
    a) The components are parallel to each other.
    b) The components add to give the vector.
    c) The components are independent of each other.
    d) The magnitudes of the components can be added using the Theorem of Pythagoras.

39. What is the displacement of a cyclist who starts at highway marker +3 km and ends at marker –7 km? Consider positive numbers as representing positions east of the centre of town.
    a) l0 km [W]
    b) 10 km [E]
    c) 4 km [W]
    d) 4 km [E]

40. What is the magnitude of the net force acting on an object if the following forces are each pulling horizontally on the object: force one = 5.2 N [E] and force two = 6.8 N [S]?
    a) 12.0 N
    b) 1.6 N
    c) 8.6 N
    d) 73 N

Part B: Fill-in-the-Blanks (12 x 0.5 = 6 Marks)

Using a term from the word bank provided below, complete each of the following statements. Some of the terms will not be used and some of the terms may be used more than once.

distance	inertia	positive
balanced	mass	resultant
chord	negative	tangent
external	normal	velocity
free fall	position	weight
gravitational field intensity		

1. The _____ is the quotient of the gravitational force and the magnitude of the test mass at a given point in the field.
2. Any force exerted by an object that is not part of the system on an object within the system is known as a(n) _____.
3. _____ is amount of matter present in an object.
4. The length of a path travelled by an object is called the _____.
5. The _____ is the vector representing the sum of two or more vectors.
6. The rate of change of position is known as _____.
7. The _____ force is a force that acts in a direction perpendicular to the common contact surface between two objects.
8. The location of an object as measured from the origin of a frame of reference is known as _____.
9. The tendency of an object to resist changes in its state of motion is called _____.
10. The direction of the electric field at a given point in space is determined by the direction of the electric force acting on a charge with a _____ sign.
11. A(n) _____ is a line that intersects a curve at only one particular point.
12. _____ describes the situation in which the only force acting on an object is the force of gravity.

Part C: Short Explanations and Diagrams (5 x 3 = 15 Marks)

Answer any five (5) of the following questions. Be sure to indicate clearly which five questions are to be marked.

Outcome S3P-3-01

1. Distinguish between vectors and scalars. Give an example of each.

_____

_____

_____

_____

_____

Outcome S3P-3-04

2. Indicate whether you would use slope or area to convert between the following graphs:
   a) velocity to position _____
   b) velocity to acceleration _____
   c) position to velocity _____

Outcome S3P-3-13

3. Using Newton's Laws of Motion, explain the following:
   a) A child is sitting on a motionless toboggan. The rope of the toboggan is given a sharp tug forward. The child falls off the back of the toboggan.

   _____

   _____

   _____

   _____

   b) A person kicks a football. The person breaks his toe while kicking the ball.

   _____

   _____

   _____

Outcome S3P-1-21

4. Using the Domain Theory of Magnetism, explain the following.

   a) When placed in a strong magnetic field, a bar of iron becomes a bar magnet. When the field is removed, the piece of iron is no longer a bar magnet.

   b) Over a period of years, the steel girders in a building become magnetized.

Outcome S3P-4-03

5. Describe two methods of measuring the gravitational field at the Earth's surface.

Outcome S3P-4-05

6. An astronaut circling the Earth in a space shuttle at an altitude of 400 km is weightless. Do you agree or disagree with this statement? Justify your choice.

Outcome S3P-4-15

7. Give three bits of information given by a pattern of electric force field lines.

Outcome S3P-4-15

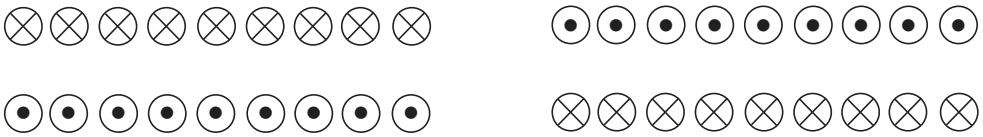
8. Draw the electric field around

   a) a negative point charge. *(1 mark)*

   b) a dipole made of a positive point charge and a negative point charge. *(2 marks)*

Outcome S3P-4-27

9. Will the two solenoids given below attract each other or repel each other? Explain your answer.

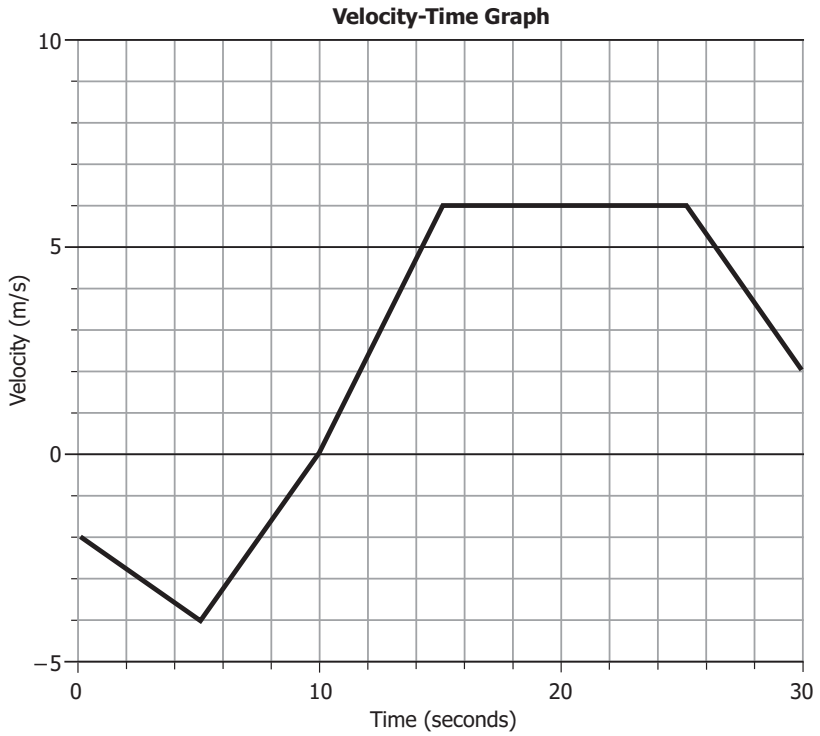


Part D: Problems (39 Marks)

Answer Question 1 plus any five (5) other problems.

Outcome S3P-3-04, S3P-3-05

1. Use the velocity-time graph below to answer the questions that follow.



a) Fill in the table for position-time data, assuming the object starts at +5.0 m. Graph these data on a sheet of graph paper. *(5 + 2 marks)*

Time Interval (seconds)	Displacement (m) Find area	Position at End of the Interval (m) $Pos_2 = Pos_1 + \vec{d}$

b) Calculate the average velocity. *(1 mark)*

c) Calculate the average acceleration. *(1 mark)*

Answer any five (5) of the remaining questions. Be sure to indicate clearly which questions you are submitting for evaluation.

2. A car travelling at 24.2 m/s decelerates at the rate of 2.10 m/s^2. Calculate

   Outcome S3P-3-06

   a) the time required by the car to stop. *(2 marks)*

   Outcome S3P-3-06

   b) the distance the car travels before it comes to a stop *(2 marks)*

Outcome S3P-3-06

c) how far the car travels from the time it starts decelerating until the speed is 12.00 m/s. *(2 marks)*

3. A crate has a mass of 35.0 kg. The crate is pulled along a level concrete floor by a force of 95.0 Newtons [east] acting in the horizontal direction. The crate accelerates at 1.20 m/s^2 [east].

Outcome S3P-4-03

a) Calculate the force of gravity acting on the crate. *(1.5 marks)*

Outcome S3P-3-13

b) Calculate the net force acting on the cart. *(1.5 marks)*

Outcome S3P-3-12

c) Draw a free-body diagram of this situation. Label each force and give its size. *(2 marks)*

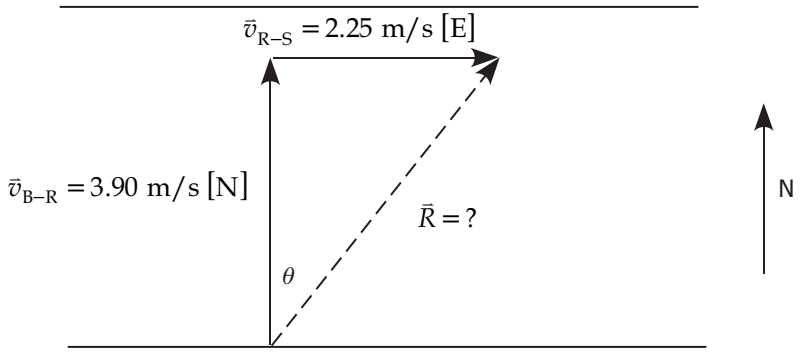
Outcome S3P-4-13

d) Calculate the force of friction acting on the cart. *(1 mark)*

4. A boat can be paddled at 3.90 m/s in still water. If the boat is aimed straight across a river flowing at 2.25 m/s and the river is 72.0 m wide,

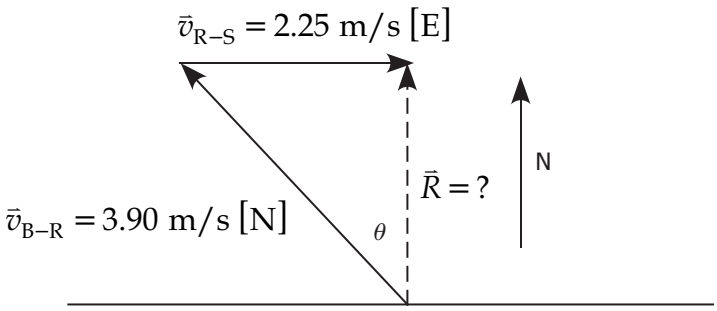
Outcome S3P-0-2h

a) what is the velocity of the boat as observed from the shore? *(4 marks)*



Outcome S3P-0-2h

b) what heading must the boat take to land on the opposite shore directly opposite the starting point? *(2 marks)*



5. A stone is thrown upwards at 8.75 m/s from the top of a building that is 55.0 m high.
Outcome S3P-4-08

a) Calculate the stone's velocity 2.15 s after being thrown. *(3 marks)*

Outcome S3P-4-08

b) Calculate the final velocity of the stone as it strikes the sidewalk at the base of the building. *(3 marks)*

Outcome S3P-0-2h

6. Given the vectors $\vec{A}$ = 350 km [W], $\vec{B}$ = 475 km [N], and $\vec{C}$ = 425 km [E],

   a) find the sum of $\vec{A}$, $\vec{B}$, and $\vec{C}$. *(5 marks)*

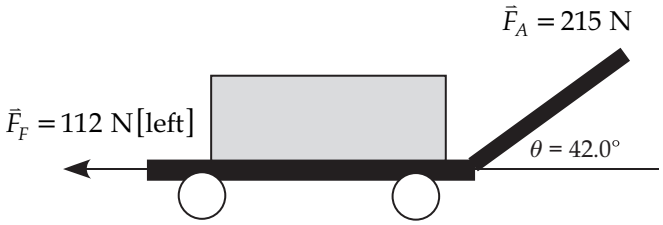
   b) find $\vec{A} - \vec{C}$. *(1 mark)*

7. A crate is pulled along a level floor. The crate rests on a dolly, which has a handle attached to it. The total mass of the crate and dolly is 255 kg. The handle is pulled by a person exerting a force of 215 Newtons at an angle of 42.0° from the horizontal, and the force of friction is 112 newtons.

Outcome S3P-3-13

a) Determine the net force acting on the crate. *(3 marks)*

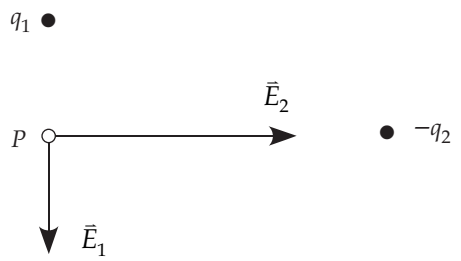
Dynamics



Outcome S3P-3-13

b) How far would the crate travel during 3.75 seconds if it started from rest? *(3 marks)*

8. A positive point charge, q_1, produces a field, $\vec{E}_1$, of size 5.00 N/C at a location P. A negative point charge, $-q_2$, produces an electric field, $\vec{E}_2$, of size 10.0 N/C at the same location P.



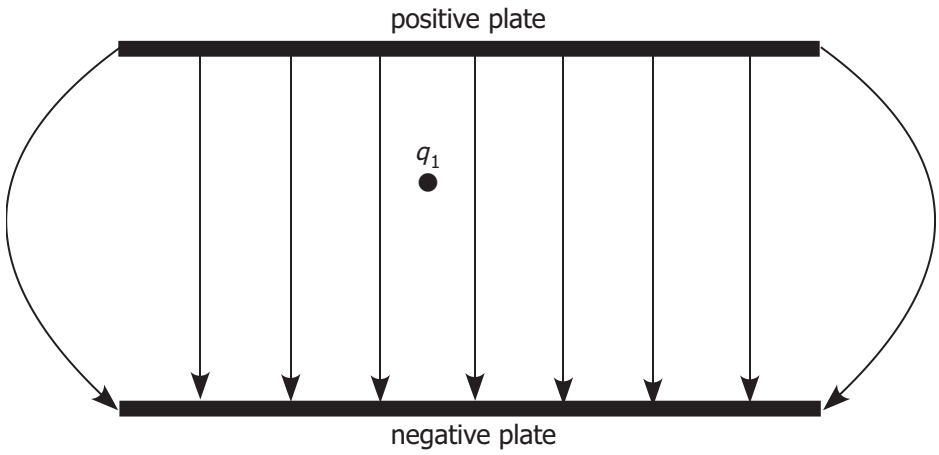
Outcome S3P-4-16

a) Determine the magnitude and direction of the total electric field at P. *(4 marks)*

Outcome S3P-4-16

b) If a 4.00 C charge is placed at P, what is the magnitude and the direction of the force on this charge? *(2 marks)*

9. A charge, q_1 = –2.00 C is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 6.00 N/C. The mass of the charged particle is $m = 5.00 \times 10^{-4}$ kg.



Outcome S3P-4-16

a) Determine the magnitude and direction of the electric force on the charged particle between the plates. *(2 marks)*

Outcome S3P-3-13

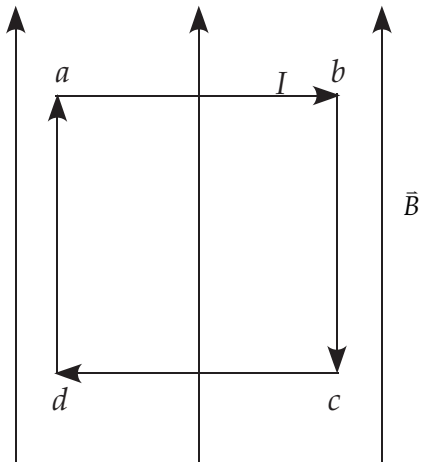
b) Determine the magnitude and direction of the acceleration of the charged particle between the plates. *(2 marks)*

Outcome S3P-3-13

c) If the particle is released from rest, what will be the final velocity of the particle after a time of 4.00 ms (4.00×10^{-3} s)? *(2 marks)*

Outcome S3P-4-30, S3P 4-32

10. A square coil of wire containing a single turn is placed in a uniform 0.25 T magnetic field, as the drawing shows. Each side has a length of 0.32 m, and the current in the coil is 12 A. The direction of the current is clockwise.



Determine the magnitude and direction of the magnetic force on

a) *ab* *(2 marks)*

b) *bc* *(2 marks)*

c) *cd* *(2 marks)*

NOTES

Grade 11 Physics
Formula Sheet

Mathematics

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\text{hypotenuse}^2 = (\text{Leg 1})^2 + (\text{Leg 2})^2$$

Kinematics

$$v = \frac{d}{\Delta t}$$

$$\Delta = \text{second value} - \text{first value}$$

$$\vec{d} = \text{pos}_2 - \text{pos}_1$$

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{\text{pos}_2 - \text{pos}_1}{\Delta t}$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ or } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

Waves

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{1-2}$$

$$PLD = |PS_1 - PS_2| = \left(n - \frac{1}{2}\right)\lambda$$

$$f = \frac{1}{T}$$

$$T = \frac{1}{f}$$

$$v = f\lambda$$

Light

$$\text{PLD} = |\text{PS}_1 - \text{PS}_2|$$

$$\frac{\Delta x}{L} = \frac{\lambda}{d}$$

Sound

$$v = 332 + 0.6\text{ T}$$

Closed-pipe resonant length

$$L_n = \left(\frac{(2n-1)}{4}\right)\lambda$$

Open-pipe resonant length

$$L_n = \left(\frac{n}{2}\right)\lambda$$

$$f_B = |f_2 - f_1|$$

Dynamics

$$\vec{F}_{\text{NET}} = m\vec{a}$$

$$\vec{F}_{\text{NET}} = \sum \text{Forces}$$

$$F_F = \mu F_N$$

Gravity

$$\vec{F}_g = m\vec{g}$$

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$

Electricity

$$\vec{E} = \frac{\vec{F}_E}{q}$$

$$q = \text{N}e$$

$$E = \frac{V}{d}$$

Magnetism

$$\vec{F}_B = BIL\sin\theta$$

Grade 11 Physics (30S)

Midterm Practice Exam

Answer Key

Grade 11 Physics (30S)

Midterm Practice Exam
Answer Key

Instructions

The midterm exam will be weighted as follows:

Modules 1–6	100%

The format of the examination will be as follows:

Part A: Multiple Choice	40 x 1 = 40 marks
Part B: Fill-in-the-Blanks	12 x 0.5 = 6 marks
Part C: Short Explanations and Diagrams	5 x 3 = 15 marks
Part D: Problems	39 marks

The following instructions are meant to assist you when you are writing your midterm examination. Please note the following instructions:

- Show your work for the problems.
- Include directions with all vector answers.
- Round off answers to the correct number of significant digits.

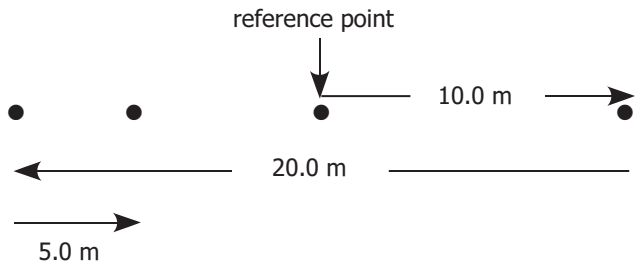
Part A: Multiple Choice (40 x 1 = 40 Marks)

Circle the letter of the choice that best completes each statement.

1. Those two quantities that are vectors are
   a) distance and position
   b) position and displacement
   c) displacement and speed
   d) speed and velocity

Answer (b)
Outcome S3P.3.01

2. An object moves to the right 10.0 m from the starting point in a time of 1.0 s, then to the left 20.0 m in a time of 3.0 s, and then to the right 5.0 m in a time of 1.0 s. The diagram below represents this motion.

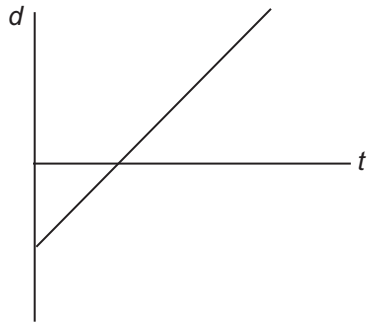


The average velocity of the object over the whole time interval is best written as
   a) –1.0 m/s
   b) 0.8 m/s
   c) 1.2 m/s
   d) 7.0 m/s

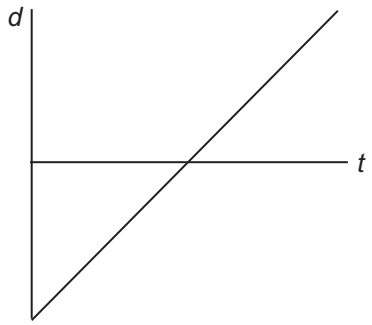
Answer (a)
Outcome S3P-3-01

3. Of the position-time graphs below, the one that shows the highest speed in the negative direction is

a)



b)



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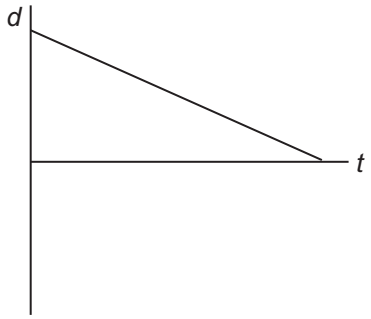
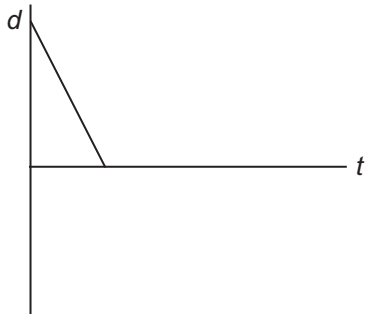


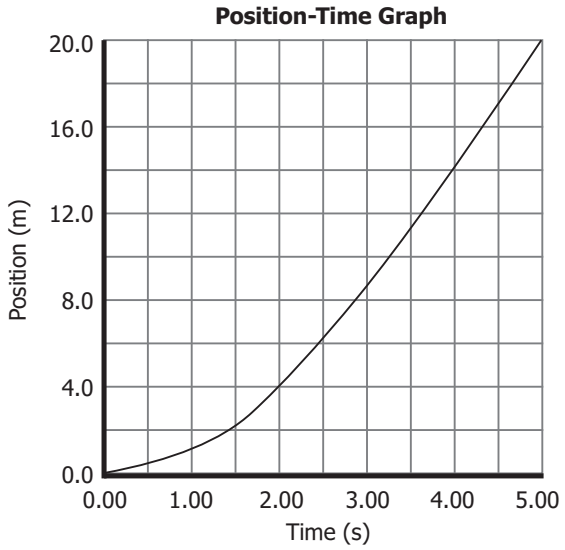
d)



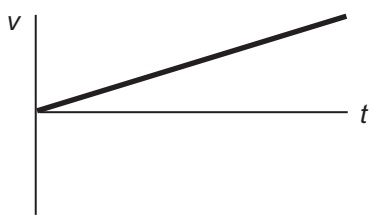
Answer (d)

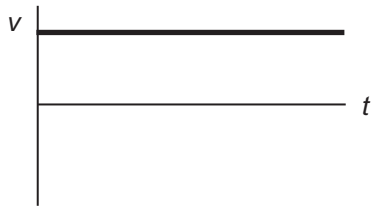
Outcome S3P-3-04

4. The following is a position-time graph.

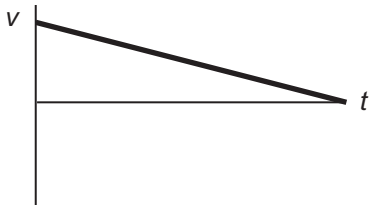


The shape of the velocity-time graph that would best correspond with this position-time graph is

a) 

b) 

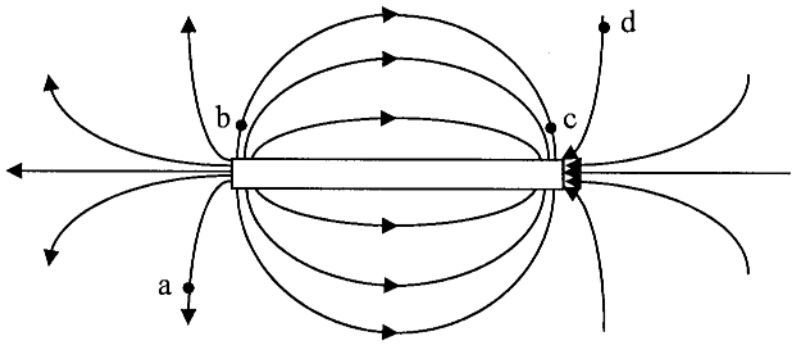
c)

d) 

Answer (a)

Outcome S3P-3-04

5. The following diagram shows a possible magnetic field line pattern between two poles of a bar magnet. Four positions *a*, *b*, *c*, and *d*, are indicated on the diagram.



The positions that would most show the magnetic field vector pointing in the same direction are

a) *a* and *b*

b) *a* and *d*

c) *b* and *c*

d) *b* and *d*

Answer (b)

Outcome S3P-4-17

6. The term "uniform motion" means

a) acceleration is constant

b) speed is constant

c) velocity is constant

d) displacement is constant

Answer (c)

Outcome S3P-3-04

7. The magnetic pole found in the northern hemisphere of our earth acts like the

a) north pole of a bar magnet and the north pole of a compass needle would point towards it

b) north pole of a bar magnet and the south pole of a compass needle would point towards it

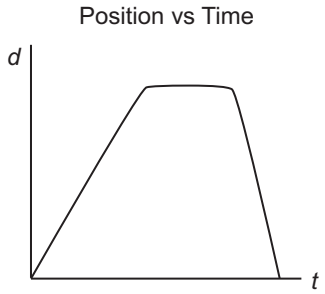
c) south pole of a bar magnet and the north pole of a compass needle would point towards it

d) south pole of a bar magnet and the south pole of a compass needle would point towards it

Answer (c)

Outcome S3P-4-20

8. Study the position-time graph pictured below and select the statement that is true.



a) The object's speed is greatest during the last segment.
b) The object's acceleration is greatest during the last segment.
c) The object's average acceleration is zero.
d) The object travels a greater distance in the first segment than in the last segment.

Answer (a)
Outcome S3P-3-04

9. Contact forces such as the force of friction and the force of a glove on a punching bag are examples of
a) gravitational force
b) electromagnetic force
c) strong nuclear force
d) weak nuclear force

Answer (b)
Outcome S3P-3-08

10. If an object is already moving and the sum of all the vector forces on a mass is zero, then the object will
a) move at a constant speed in a straight line
b) accelerate at a constant rate in a straight line
c) come to rest
d) increase its amount of inertia

Answer (a)
Outcome S3P-3-11

11. A net force acts on a mass of 8.00 kg causing it to move from rest to a speed of 10.0 m/s in a time of 5.00 s. The net force must have a magnitude of
a) 8.00 N
b) 16.0 N
c) 40.0 N
d) 80.0 N

Answer (b)
Outcome S3P-3-13

12. Two forces are acting on a mass of 20.0 kg. One force is to the right at 400.0 N while the other force is to the left at a magnitude of 600.0 N. The acceleration of the wagon is

a) –50.0 m/s^2

b) –10.0 m/s^2

c) 10.0 m/s^2

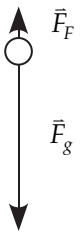
d) 50.0 m/s^2

Answer (b)

Outcome S3P-3-11

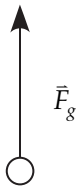
13. A free-body diagram for a ball in free fall in a vacuum is

a)

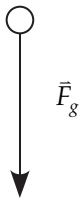


b)

c)



d)

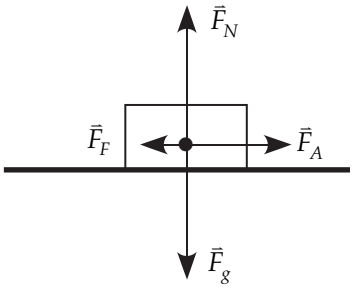


Answer (d)

Outcome S3P-3-12

14. An object is being pulled to the right. The object is accelerating to the right, and friction is present. The correct free-body diagram for this situation is

a)



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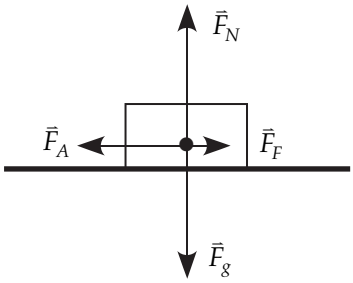
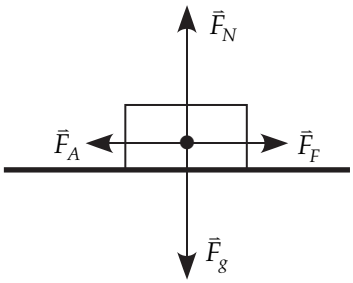
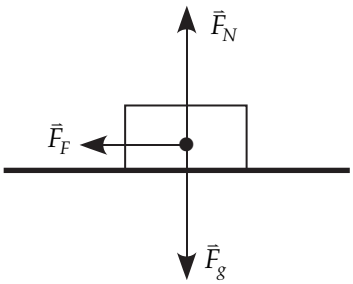


c)



d)



Answer (a)

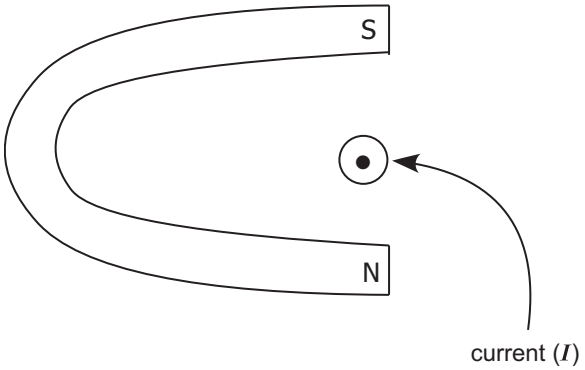
Outcome S3P-3-12

15. Which of the following fundamental forces is the strongest?
    a) strong nuclear
    b) electrostatic
    c) weak nuclear
    d) They are equally strong.

Answer (a)

Outcome S3P-3-08

16. The diagram below shows a horseshoe magnet with the north pole and south pole as indicated. A wire is placed between the poles and the current moves as shown.



The direction of the force on the wire is

a) up out of the page
b) down into the page
c) towards the interior of the magnet (west)
d) towards the outside of the magnet (east)

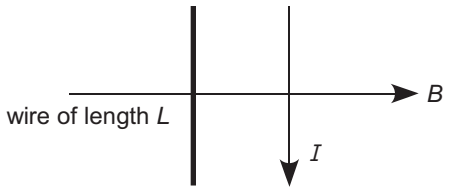
Answer (c)
Outcome S3P-3-08

17. The gravitational field can be defined as the

a) region of space around a mass where another mass experiences a force
b) acceleration due to gravity which is equal to approximately 9.80 m/s^2 for our Earth
c) force divided by the mass for an object in free fall
d) the amount of the contact force between a mass at rest on the surface of the Earth and the Earth

Answer (a)
Outcome S3P-4-01

18. A straight wire has a current of 2.0 A passing through it. The wire is 10.0 cm long. The wire, which is oriented so that it is perpendicular to a magnetic field, is 5.0 T.



The magnitude of the force on the wire is

a) 0.0 N
b) 1.0 N
c) 1.0×10^1 N
d) 1.0×10^2 N

Answer (b)
Outcome S3P-4-28

19. The value of the acceleration due to gravity, $\vec{g}$, can be determined experimentally by recording and analyzing the time and position of a ball while it is

a) rolling freely across a horizontal table
b) pulled across a horizontal table by a constant force
c) dropped in free fall
d) pushed upwards by a constant force

Answer (c)
Outcome S3P-4-07

20. When an object has reached terminal velocity, the shape of the line in a velocity-time graph is

a) horizontal
b) straight and oblique with a positive slope
c) straight and oblique with a negative slope
d) curving upwards

Answer (a)
Outcome S3P-4-09

21. The coefficient of friction can be defined as the ratio of the

a) force of gravity over the force of friction
b) force of friction over the normal force
c) normal force over the force of gravity
d) force of gravity over the applied force

Answer (b)
Outcome S3P-4-10

22. How much would a 60.0 kg person weigh on the moon where the gravitational field strength has a magnitude of 1.60 N/kg?

a) 60.0 kg
b) 96.0 N
c) 98.0 kg
d) 98.0 N

Answer (b)
Outcome S3P-4-04

23. Two magnetic fields are acting on a 2.0 m long wire carrying a current of 8.0 A to the east. One of the magnetic fields is acting vertically downward into the paper. It has a magnitude of 5.0×10^{-5} T. A second magnetic field is acting at 4.0×10^{-5} T to the south. The magnitude of the net force on the wire is

a) 1.0×10^{-6} N
b) 4.8×10^{-4} N
c) 1.0×10^{-3} N
d) 3.8×10^{-2} N

Answer (c)
Outcome S3P-4-28, S3P-2h

24. Objects onboard an orbiting space station appear to be "floating" because

a) they're in the vacuum of space
b) they're weightless
c) they're outside Earth's gravitational pull
d) they're falling together with the space station

Answer (d)
Outcome S3P-4-05

25. If a positive charge A is twice as large as a positive charge B, we could show this by drawing

a) the field lines in the opposite direction for one of the charges
b) the same number of field lines as B but shorter
c) twice as many field lines for charge A
d) half as many field lines for charge A

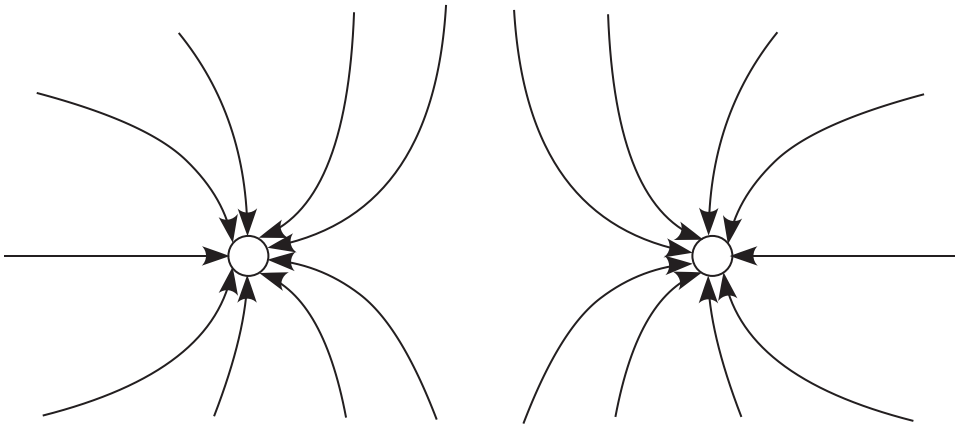
Answer (c)
Outcome S3P-4-15

26. If we were to compare the field lines for the gravitational situation to the electric situation, we would find that the electric field line pattern that is identical to the gravitational pattern around the Earth occurs when there is

a) a neutral charge
b) a combination of positive and negative charges
c) one positive charge
d) one negative charge

Answer (d)
Outcome S3P-4-15

27. The diagram below shows an electric field line pattern for two charges.



This is an electric field line pattern for two

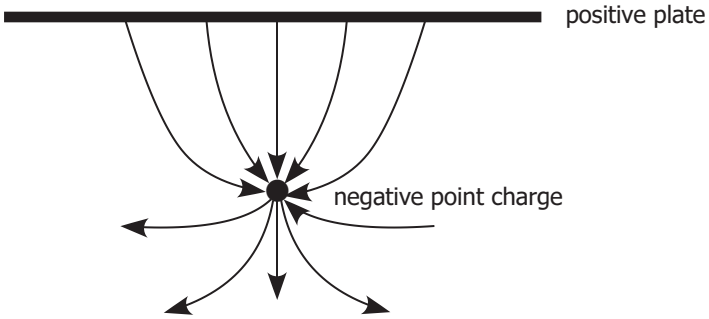
a) negative charges
b) positive charges
c) neutral charges
d) opposite charges

Answer (a)

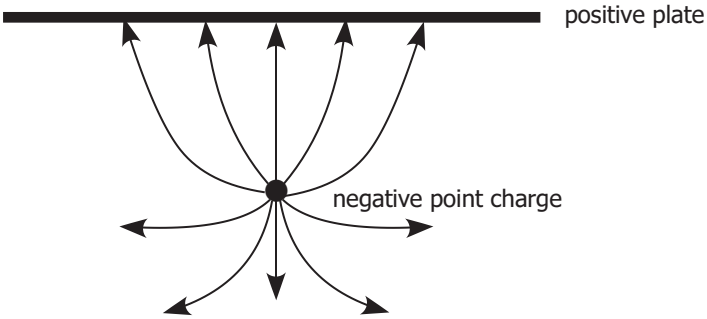
Outcome S3P-4-15

28. The diagrams below show a positively charged plate and a negative point charge. The electric field line pattern for this situation is best shown by

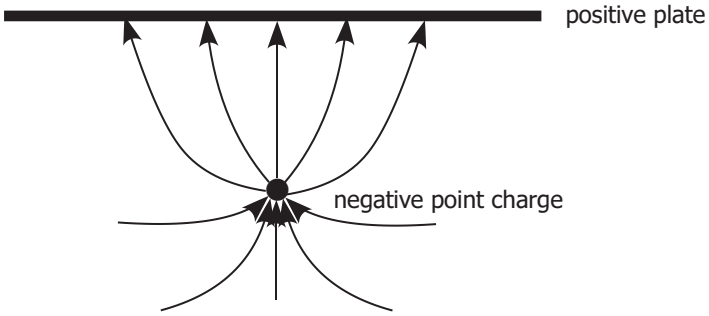
a)



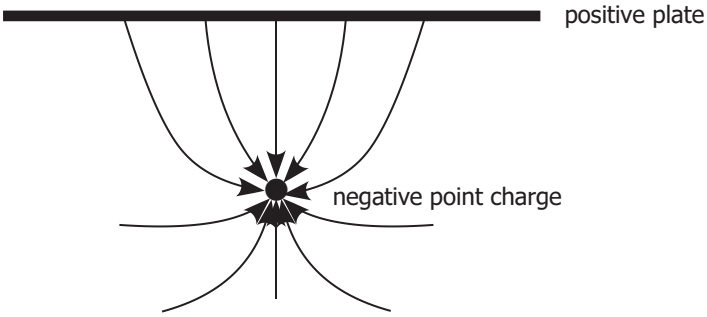
b)



c)



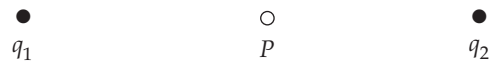
d)



Answer (d)

Outcome S3P-4-15

29. The negative charge, $-q_1$, to the left of point P, creates an electric field, $\vec{E}_1$, of magnitude 10.0 N/C at position P. The positive charge to the right of point P, q_2, creates an electric field, $\vec{E}_2$, of magnitude 25.0 N/C at position P.



The directions of the electric fields at position P are

a) both to the west

b) both to the east

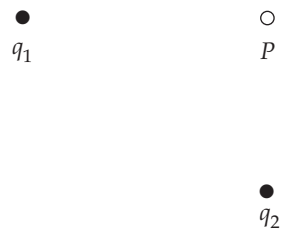
c) $\vec{E}_1$ to the east and $\vec{E}_2$ to the west

d) $\vec{E}_1$ to the west and $\vec{E}_2$ to the east

Answer (a)

Outcome S3P-4-16

30. The negative charge, $-q_1$, to the west of point P, creates an electric field, $\vec{E}_1$, of magnitude 10.0 N/C at position P. The positive charge, q_2, to the south of point P, creates an electric field, $\vec{E}_2$, of magnitude 25.0 N/C at position P.



The direction of the total electric field at position P is

a) 68.2° S of W

b) 68.2° N of W

c) 21.8° S of W

d) 21.8° N of W

Answer (b)

Outcome S3P-4-16, S3P-0-2h

31. In a Millikan apparatus, a sphere of mass 4.0×10^{-15} kg is stationary in an electric field whose intensity is 2.00×10^{4} N/C. The top plate is positive. The magnitude of the charge on the sphere must be

a) 2.0×10^{-18} C

b) 1.3×10^{4} C

c) 5.1×10^{17} C

d) 3.2×10^{36} C

Answer (a)

Outcome S3P-4-18

32. A ferromagnetic material is placed in a strong magnetic field that points from the left to the right.

The domains in the material point

a) in the up direction
b) in the down direction
c) to the right
d) to the left

Answer (c)
Outcome S3P-4-19

33. State the number of significant digits in 0.0089076500

a) 8
b) 9
c) 10
d) 11

Answer (a)
Outcome S3P-0-2d

34. The correct answer for the product of 6.9530 x 0.07843 is

a) 0.5453
b) 0.54532
c) 0.545323
d) 0.5453238

Answer (a)
Outcome S3P-0-2d

35. The correct answer for the sum of 18.3 + 6.92 + 2.0084 is

a) 27.2282
b) 27.22
c) 27.2
d) 27.228

Answer (c)
Outcome S3P-0-2d

36. Which of the following is NOT a mode of representation used in physics?

a) visual mode
b) graphical mode
c) diagram mode
d) symbolic mode

Answer (c)
Outcome S3P-2-02

37. The slope of a chord on a position-time graph represents which of the following quantities?
   a) average acceleration
   b) average velocity
   c) average displacement
   d) average distance

Answer (b)
Outcome S3P-3-05

38. Which of the following is not a characteristic of the components of a vector?
   a) The components are parallel to each other.
   b) The components add to give the vector.
   c) The components are independent of each other.
   d) The magnitudes of the components can be added using the Theorem of Pythagoras.

Answer (a)
Outcome S3P-0-2h

39. What is the displacement of a cyclist who starts at highway marker +3 km and ends at marker –7 km? Consider positive numbers as representing positions east of the centre of town.
   a) l0 km [W]
   b) 10 km [E]
   c) 4 km [W]
   d) 4 km [E]

Answer (a)
Outcome S3P-3-02

40. What is the magnitude of the net force acting on an object if the following forces are each pulling horizontally on the object: force one = 5.2 N [E] and force two = 6.8 N [S]?
   a) 12.0 N
   b) 1.6 N
   c) 8.6 N
   d) 73 N

Answer (c)
Outcomes S3P-0-2h, S3P-3-12

Part B: Fill-in-the-Blanks (12 x 0.5 = 6 Marks)

Using a term from the word bank provided below, complete each of the following statements. Some of the terms will not be used and some of the terms may be used more than once.

distance	inertia	positive
balanced	mass	resultant
chord	negative	tangent
external	normal	velocity
free fall	position	weight
gravitational field intensity		

1. The ***gravitational field intensity*** is the quotient of the gravitational force and the magnitude of the test mass at a given point in the field.
2. Any force exerted by an object that is not part of the system on an object within the system is known as a(n) ***external force***.
3. ***Mass*** is amount of matter present in an object.
4. The length of a path travelled by an object is called the ***distance***.
5. The ***resultant*** is the vector representing the sum of two or more vectors.
6. The rate of change of position is known as ***velocity***.
7. The ***normal*** force is a force that acts in a direction perpendicular to the common contact surface between two objects.
8. The location of an object as measured from the origin of a frame of reference is known as ***position***.
9. The tendency of an object to resist changes in its state of motion is called ***inertia***.
10. The direction of the electric field at a given point in space is determined by the direction of the electric force acting on a charge with a ***positive*** sign.
11. A(n) ***tangent*** is a line that intersects a curve at only one particular point.
12. ***Free fall*** describes the situation in which the only force acting on an object is the force of gravity.

Part C: Short Explanations and Diagrams (5 x 3 = 15 Marks)

Answer any five (5) of the following questions. Be sure to indicate clearly which five questions are to be marked.

Outcome S3P-3-01

1. Distinguish between vectors and scalars. Give an example of each.

   Answer:

   The scalar is a quantity with magnitude only. An example would be a time interval (5 s). The vector is a quantity with magnitude and direction. An example would be displacement or velocity (5 m/s [east]).

Outcome S3P-3-04

2. Indicate whether you would use slope or area to convert between the following graphs:
   a) velocity to position
   b) velocity to acceleration
   c) position to velocity

   Answer:

   a) uses area
   b) uses slope
   c) uses slope

Outcome S3P-3-13

3. Using Newton's Laws of Motion, explain the following:
   a) A child is sitting on a motionless toboggan. The rope of the toboggan is given a sharp tug forward. The child falls off the back of the toboggan.

      Answer:

      The child sitting at rest has inertia of rest. This is Newton's First Law: Objects at rest remain at rest. The toboggan is pulled out from under the child by the force. This is Newton's Second Law: An object accelerates in the direction of the unbalanced force.

   b) A person kicks a football. The person breaks his toe while kicking the ball.

      Answer:

      This is Newton's Third Law: For every action force, there is an equal but opposite reaction force. The action force is the foot kicking the ball. The reaction force is exerted by the ball on the foot. This force breaks the toe.

Outcome S3P-1-21

4. Using the Domain Theory of Magnetism, explain the following.

   a) When placed in a strong magnetic field, a bar of iron becomes a bar magnet. When the field is removed, the piece of iron is no longer a bar magnet.

      Answer:

      When the bar of iron is placed in a strong magnetic field, the magnetic domains within the piece of iron align themselves with the magnetic field. The bar of iron then acts like a bar magnet. When the magnetic field is removed, the magnetic domains return to their original random arrangement. The piece of iron is no longer a bar magnet.

   b) Over a period of years, the steel girders in a building become magnetized.

      Answer:

      Over a period of years, the magnetic domains within the steel girders align themselves with the Earth's magnetic field, thus becoming magnetized.

Outcome S3P-4-03

5. Describe two methods of measuring the gravitational field at the Earth's surface.

   Answer:

   The first method involves using a scale to find the weight of an object of known mass. Then the gravitational field is calculated as the ratio of the force of gravity over the mass.

   The second method involves allowing a dense, heavy object to fall freely. The acceleration of this object is measured and equals the gravitational field at that point.

Outcome S3P-4-05

6. An astronaut circling the Earth in a space shuttle at an altitude of 400 km is weightless. Do you agree or disagree with this statement? Justify your choice.

   Answer:

   This astronaut is not truly weightless but only apparently weightless. To be truly weightless, the gravitational field at that point must be 0 N/kg. At 400 km altitude, the gravitational field is still quite large so the astronaut still has weight. He appears to be weightless because he is really falling along with his surroundings.

Outcome S3P-4-15

7. Give three bits of information given by a pattern of electric force field lines.

   Answer:

   The pattern of force field lines has the lines closer together where the force field is stronger.

   The direction of the field at any point points in a direction that is tangent to the force field line.

   Electric force field lines begin on negative charge and end on positive charge.

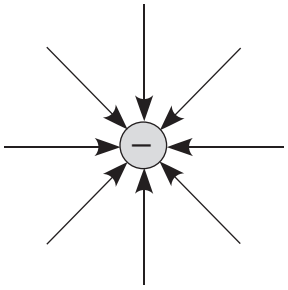
   Electric field lines meet the surface of a conductor at a 90° angle.

Outcome S3P-4-15

8. Draw the electric field around

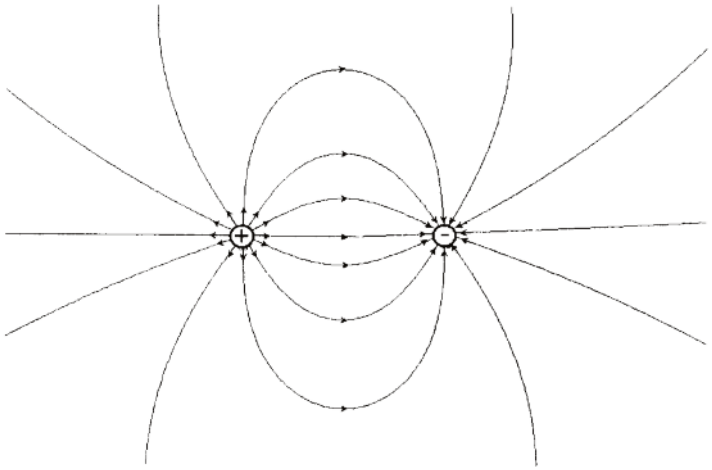
a) a negative point charge. *(1 mark)*

Answer:



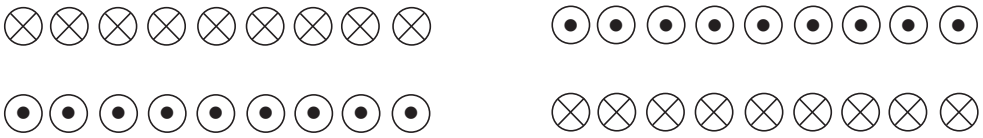
b) a dipole made of a positive point charge and a negative point charge. *(2 marks)*

Answer:



Outcome S3P-4-27

9. Will the two solenoids given below attract each other or repel each other? Explain your answer.



Answer:

The solenoid on the left will have the north end of the phantom bar magnet on the left and the south pole on the right (near the centre).

The solenoid on the right will have the south end of the phantom magnet on the left side (near the centre).

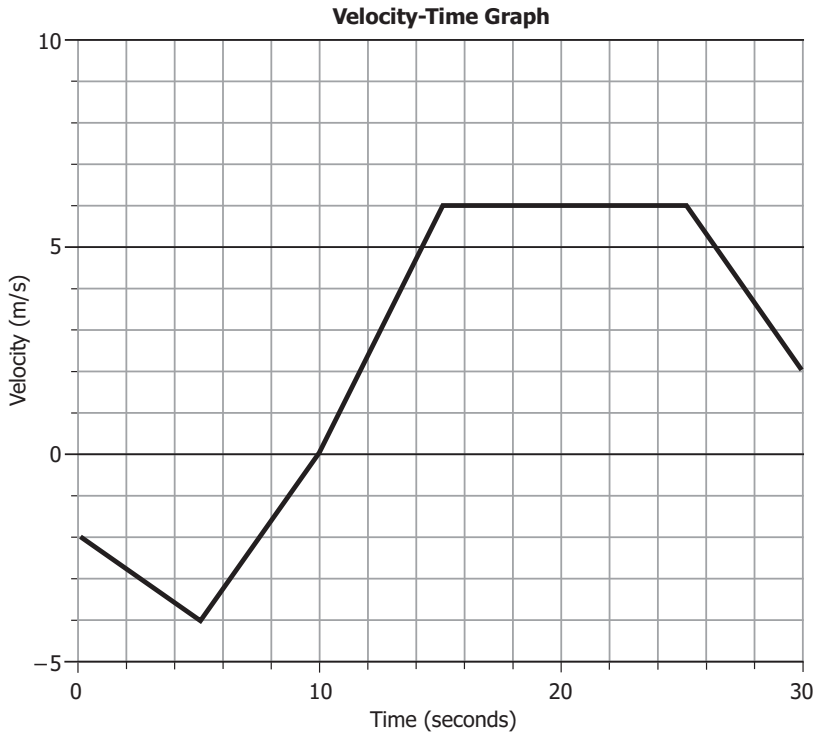
Since the two south poles are closest together, the solenoids will repel each other.

Part D: Problems (39 Marks)

Answer Question 1 plus any five (5) other problems.

Outcome S3P-3-04, S3P-3-05

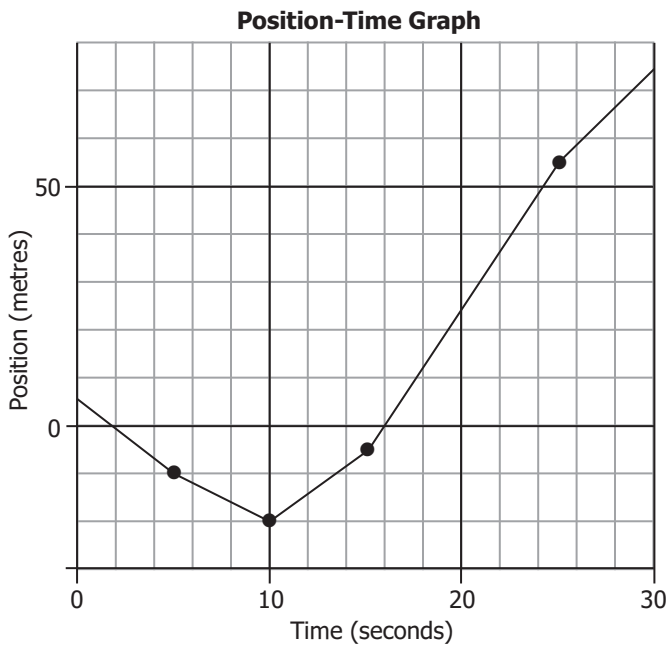
1. Use the velocity-time graph below to answer the questions that follow.



a) Fill in the table for position-time data, assuming the object starts at +5.0 m. Graph these data on a sheet of graph paper. *(5 + 2 marks)*

Answer:

Time Interval (seconds)	Displacement (m) Find area	Position at End of the Interval (m) $Pos_2 = Pos_1 + \vec{d}$
0		+5.0
0—5	$\frac{1}{2}(a + b)h =$ $\frac{1}{2}(-2 + (-4))(5) = -15$	(+5.0) + (–15) = –10
5–10	$\frac{1}{2}bh = \frac{1}{2}(5)(-4) = -10$	(–10) + (–10) = –20
10–15	$\frac{1}{2}bh = \frac{1}{2}(5)(+6) = +15$	(–20) + (+15) = –5
15—25	$lw = (10)(+6) = +60$	(–5) + (+60) = +55
25–30	$\frac{1}{2}(a + b)h =$ $\frac{1}{2}(+6 - (+2))(5) = +20$	(+55) + (+20) = +75



b) Calculate the average velocity. *(1 mark)*

Answer:

The average velocity is the slope of the chord on a position-time graph joining the initial position (0 s, 5 m) to the final position (30 s, 75 m).

$$\vec{v}_{avg} = \frac{\text{rise}}{\text{run}} = \frac{75\text{ m} - 5\text{ m}}{30\text{ s} - 0\text{ s}} = \frac{70\text{ m}}{30\text{ s}} = +2.3\text{ m/s}$$

c) Calculate the average acceleration. *(1 mark)*

Answer:

The average acceleration is the slope of the chord on a velocity-time graph joining the initial velocity (0 s, –2 m/s) to the final position (30 s, +2 m/s).

$$\vec{a}_{avg} = \frac{\text{rise}}{\text{run}} = \frac{+2\text{ m/s} - (-2\text{ m/s})}{30\text{ s} - 0\text{ s}} = \frac{+4\text{ m/s}}{30\text{ s}} = +0.13\text{ m/s}^2$$

Answer any five (5) of the remaining questions. Be sure to indicate clearly which questions you are submitting for evaluation.

2. A car travelling at 24.2 m/s decelerates at the rate of 2.10 m/s^2. Calculate

Outcome S3P-3-06

a) the time required by the car to stop. *(2 marks)*

Answer:

Let to the right be positive.

Given: Initial velocity $\vec{v}_1 = +24.2 \text{ m/s}$

Acceleration $\vec{a} = -2.10 \text{ m/s/s}$

Final velocity $\vec{v}_2 = 0 \text{ m/s}$

Unknown: Time interval $\Delta t = ?$

Equation: $\vec{a} = \dfrac{\Delta \vec{v}}{\Delta t} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ rearranged to $\Delta t = \dfrac{\vec{v}_2 - \vec{v}_1}{\vec{a}}$

Substitute and solve: $\Delta t = \dfrac{\vec{v}_2 - \vec{v}_1}{\vec{a}} = \dfrac{0 \text{ m/s} - (+24.2 \text{ m/s})}{-2.10 \text{ m/s/s}} = 11.5 \text{ s}$

The time required to stop is 11.5 s.

Outcome S3P-3-06

b) the distance the car travels before it comes to a stop. *(2 marks)*

Answer:

Unknown: Displacement $\vec{d} = ?$

Equation: $\vec{d} = \dfrac{(\vec{v}_1 + \vec{v}_2)}{2} \Delta t$

Substitute and solve: $\vec{d} = \dfrac{(\vec{v}_1 + \vec{v}_2)}{2} \Delta t = \dfrac{(+24.2 \text{ m/s}) + (0 \text{ m/s})}{2} (11.5 \text{ s})$

$= +139 \text{ m}$

The car travels 139 m [right].

Outcome S3P-3-06

c) how far the car travels from the time it starts decelerating until the speed is 12.00 m/s. *(2 marks)*

Answer:

Let to the right be positive.

Given: Initial velocity $\vec{v}_1 = +24.2 \text{ m/s}$

Acceleration $\vec{a} = -2.10 \text{ m/s/s}$

Final velocity $\vec{v}_2 = 12.0 \text{ m/s}$

Unknown: Displacement $\vec{d} = ?$

Equation: $2ad = v_2^{\,2} - v_1^{\,2}$ rearranged to $d = \dfrac{v_2^{\,2} - v_1^{\,2}}{2a}$

Substitute and solve:

$$d = \frac{v_2^{\,2} - v_1^{\,2}}{2a} = \frac{(+12.0 \text{ m/s})^2 - (+24.2 \text{ m/s})^2}{2(-2.10 \text{ m/s/s})}$$

$$= +105 \text{ m}$$

The car travels +105 m.

3. A crate has a mass of 35.0 kg. The crate is pulled along a level concrete floor by a force of 95.0 Newtons [east] acting in the horizontal direction. The crate accelerates at 1.20 m/s^2 [east].

Outcome S3P-4-03

a) Calculate the force of gravity acting on the crate. *(1.5 marks)*

Answer:

Given: Mass $m = 35.0\text{ kg}$

Applied force $\vec{F}_A = 95.0\text{ N [E]}$

Acceleration $\vec{a} = 1.20\text{ m/s/s [E]}$

Unknown: Force of gravity $\vec{F}_g = ?$

Equation: $\vec{F}_g = m\vec{g}$

Substitute and solve: $\vec{F}_g = m\vec{g} = (35.0\text{ kg})(9.80\text{ N/kg [down]})$

$= 343\text{ N [down]}$

The force of gravity is 343 N [down].

Outcome S3P-3-13

b) Calculate the net force acting on the cart. *(1.5 marks)*

Answer:

Unknown: Net force $\vec{F}_{\text{NET}} = ?$

Equation: $\vec{F}_{\text{NET}} = m\vec{a}$

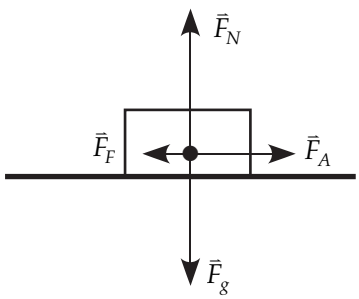
Substitute and solve: $\vec{F}_{\text{NET}} = m\vec{a} = (35.0\text{ kg})(1.20\text{ m/s/s [E]}) = 42.0\text{ N [E]}$

The net force is 42.0 N [E].

Outcome S3P-3-12

c) Draw a free-body diagram of this situation. Label each force and give its size. *(2 marks)*

Answer:



Force of gravity	$\vec{F}_g = 343\text{ N [down]}$
Normal force	$\vec{F}_N = 343\text{ N [up]}$
Applied force	$\vec{F}_A = 95.0\text{ N [east]}$
Force of friction	$\vec{F}_F = ?$

Outcome S3P-4-13

d) Calculate the force of friction acting on the cart. *(1 mark)*

Answer:

The net force is $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_g + \vec{F}_N + \vec{F}_A + \vec{F}_F$.

Since the force of gravity and the normal force cancel out, the net force is given by the sum of the applied force and the force of friction.

$\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_A + \vec{F}_F$

The force of friction is

$\vec{F}_F = \vec{F}_{\text{NET}} - \vec{F}_A$

$\vec{F}_F = 42.0\text{ N [E]} - 95.0\text{ N [E]}$

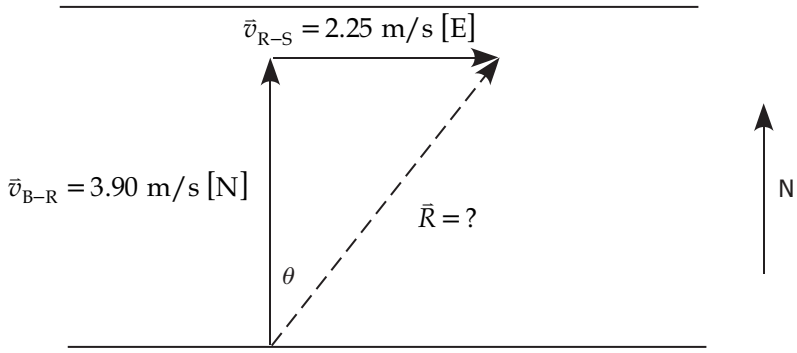
$\vec{F}_F = 42.0\text{ N [E]} + 95.0\text{ N [W]}$

$\vec{F}_F = 53.0\text{ N [W]}$

4. A boat can be paddled at 3.90 m/s in still water. If the boat is aimed straight across a river flowing at 2.25 m/s and the river is 72.0 m wide,

Outcome S3P-0-2h

a) what is the velocity of the boat as observed from the shore? *(4 marks)*



Answer:

Unknown: Velocity of boat next to the shore $\vec{R} = \vec{v}_{B-S} = ?$

Equation: $\vec{R} = \vec{v}_{B-S} = \vec{v}_{B-R} + \vec{v}_{R-S}$

Substitute and solve: You must add the vectors by placing them "tip to tail" as in the diagram.

$$\vec{R} = \vec{v}_{B-S} = \vec{v}_{B-R} + \vec{v}_{R-S}$$

$$\vec{R} = \vec{v}_{B-S} = 3.90 \text{ m/s [E]} + 2.25 \text{ m/s [N]}$$

Using Pythagoras:

$$v_{B-S}{}^2 = (3.90 \text{ m/s})^2 + (2.25 \text{ m/s})^2 = 20.27$$

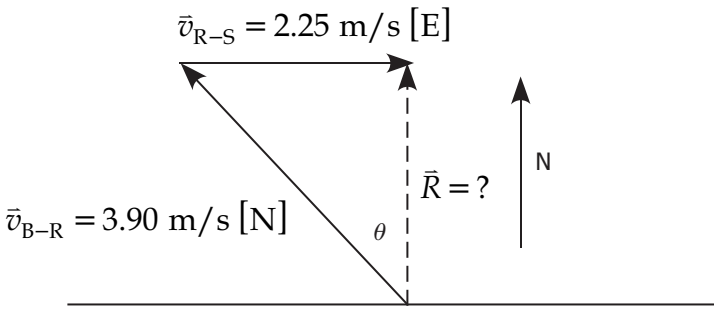
$$v_{B-S} = \sqrt{20.27} = 4.50 \text{ m/s}$$

$$\theta = \tan^{-1}\frac{2.25}{3.90} = 30.0°$$

The velocity of the boat next to the shore is 4.50 m/s [30.0° E of N].

Outcome S3P-0-2h

b) what heading must the boat take to land on the opposite shore directly opposite the starting point? *(2 marks)*



Answer:

The boat must head upstream (to the west) in order to go straight across the river.

$$\theta = \sin^{-1}\frac{2.25}{3.90} = 35.2°$$

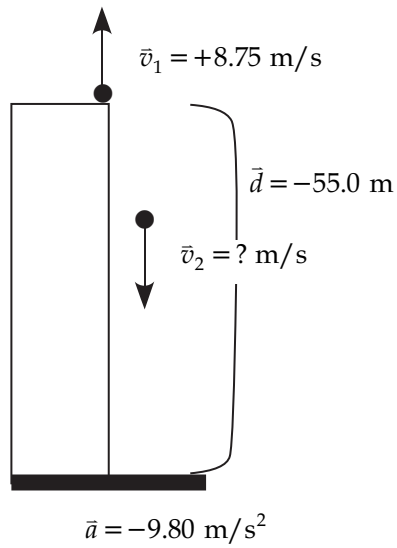
The boat must head at 35.2° West of North.

5. A stone is thrown upwards at 8.75 m/s from the top of a building that is 55.0 m high.
Outcome S3P-4-08

a) Calculate the stone's velocity 2.15 s after being thrown. *(3 marks)*

Answer:

Let up be the positive direction.



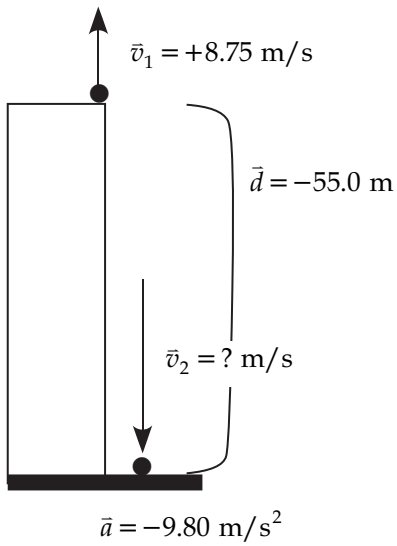
Given: Time interval	$\Delta t = 2.15$ s
Unknown: Final velocity	$\vec{v}_2 = ?$
Equation:	$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t}$ rearranged to $\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$
Substitute and solve:	$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$
	$\vec{v}_2 = (+8.75 \text{ m/s}) + (-9.80 \text{ m/s/s})(2.15 \text{ s})$
	$\vec{v}_2 = -12.3$ m/s

The final velocity is 12.3 m/s [down].

Outcome S3P-4-08

b) Calculate the final velocity of the stone as it strikes the sidewalk at the base of the building. *(3 marks)*

Answer:



Unknown: Final velocity	$\vec{v}_2 = ?$
Equation:	$v_2^{\,2} = v_1^{\,2} + 2ad$
Substitute and solve:	$v_2^{\,2} = v_1^{\,2} + 2ad$
	$v_2^{\,2} = (8.75)^2 + 2(-9.80)(-55.0) = 1154.56$
	$\vec{v}_2 = 34.0$ m/s [down]

The final velocity is 34.0 m/s [down].

Outcome S3P-0-2h

6. Given the vectors $\vec{A}$ = 350 km [W], $\vec{B}$ = 475 km [N], and $\vec{C}$ = 425 km [E],

   a) find the sum of $\vec{A}$, $\vec{B}$, and $\vec{C}$. *(5 marks)*

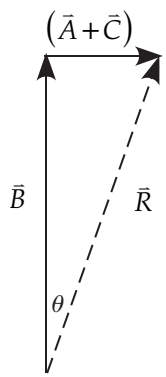
   Answer:

   Use the component method.

   Add the antiparallel vectors $\vec{A}$ and $\vec{C}$.

   $\vec{A}+\vec{C}$ = 350 km [W] + 425 km [E] = 75 km [E].

   Add this sum tip to tail with vector $\vec{B}$ so that you have $\vec{B}+\left(\vec{A}+\vec{C}\right)=\vec{R}$.



$$\vec{R}^2 = \vec{B}^2 + \left(\vec{A}+\vec{C}\right)^2$$
$$\vec{R}^2 = \left(475^2\right) + (75)^2$$
$$\vec{R}^2 = 231250$$
$$\vec{R} = 480 \text{ km}$$
$$\theta = \tan^{-1}\frac{75}{475}$$
$$\theta = 8.97°$$
$$\theta = 9.0°$$

   The sum of the three vectors is 480 km [9.0° east of north].

   b) find $\vec{A}-\vec{C}$. *(1 mark)*

   Answer:

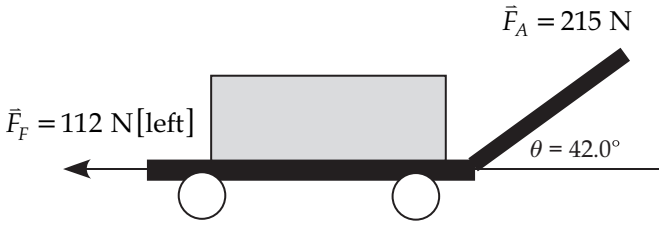
   $\vec{R} = \vec{A}-\vec{C} = \vec{A}+\left(-\vec{C}\right)$ = 350 km [W] + (425 km [W]) = 775 km [W].

7. A crate is pulled along a level floor. The crate rests on a dolly, which has a handle attached to it. The total mass of the crate and dolly is 255 kg. The handle is pulled by a person exerting a force of 215 Newtons at an angle of 42.0° from the horizontal, and the force of friction is 112 newtons.

Outcome S3P-3-13

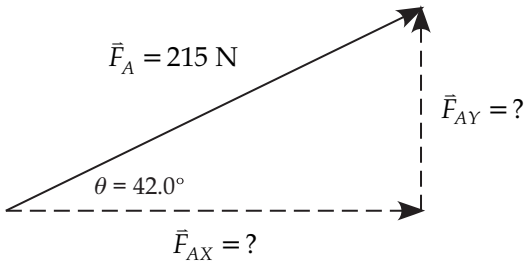
a) Determine the net force acting on the crate. *(3 marks)*

Dynamics

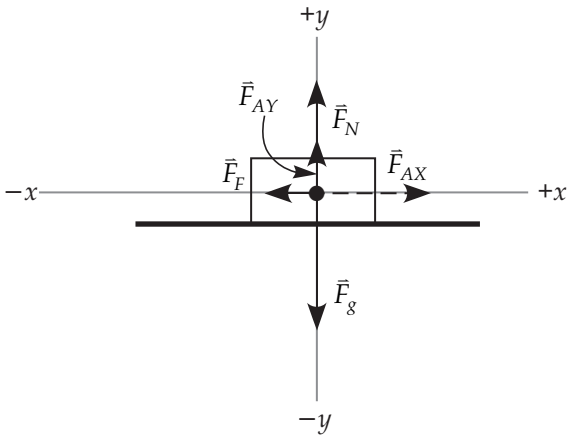


Answer:

You must resolve the applied force into a horizontal component and a vertical component.



$$\vec{F}_{AY} = \vec{F}_A(\sin 42.0°) = (215\text{ N})(\sin 42.0°) = 144\text{ N [up]}$$
$$\vec{F}_{AX} = \vec{F}_A(\cos 42.0°) = (215\text{ N})(\cos 42.0°) = 160\text{ N [right]}$$



The net force is given by $\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_g + \vec{F}_N + \vec{F}_{AY} + \vec{F}_F + \vec{F}_{AX}$.

In this case, the force of gravity, the normal force, and the *y*-component of the applied force all add to 0 N.

Therefore,

$$\vec{F}_{\text{NET}} = \Sigma\vec{F} = \vec{F}_{AX} + \vec{F}_F$$
$$\vec{F}_{\text{NET}} = 160\text{ N}\left[\text{right}\right] + 112\text{ N [left]}$$
$$\vec{F}_{\text{NET}} = 48\text{ N}\left[\text{right}\right]$$

The net force is 48 N [right].

Outcome S3P-3-13

b) How far would the crate travel during 3.75 seconds if it started from rest? *(3 marks)*

Answer:

You must link the dynamics up with the kinematics using Newton's Second Law.

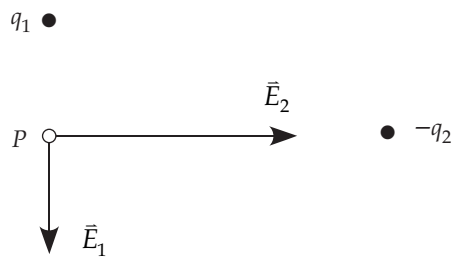
Given:	Net force	$\vec{F}_{\text{NET}} = 48\text{ N}\left[\text{right}\right]$
	Mass	$m = 255\text{ kg}$
	Acceleration	$\vec{a} = \dfrac{\vec{F}_{\text{NET}}}{m} = \dfrac{48\text{ N}\left[\text{right}\right]}{255\text{ kg}} = 0.19\text{ m/s}^2\left[\text{right}\right]$
	Initial velocity	$\vec{v}_1 = 0\text{ m/s}$
	Time interval	$\Delta t = 3.75\text{ s}$
Unknown:	Displacement	$\vec{d} = ?$
Equation:		$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$

Substitute and solve: $\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2 = (0\text{ m/s})(3.75\text{ s}) + \frac{1}{2}(0.19\text{ m/s}^2)(3.75\text{ s})^2$

$$\vec{d} = 1.3\text{ m}\left[\text{right}\right]$$

The crate moves 1.3 m [right].

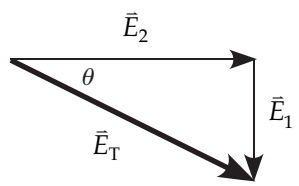
8. A positive point charge, q_1, produces a field, $\vec{E}_1$, of size 5.00 N/C at a location P. A negative point charge, $-q_2$, produces an electric field, $\vec{E}_2$, of size 10.0 N/C at the same location P.



Outcome S3P-4-16

a) Determine the magnitude and direction of the total electric field at P. *(4 marks)*

Answer:



In adding together the two electric field vectors, we attach them tip to tail.

The magnitude of the total electric field vector is

$$\vec{E}_T = \sqrt{(5.00\text{ N/C})^2 + (10.0\text{ N/C})^2} = 11.18\text{ N/C or } 11.2\text{ N/C.}$$

The direction of this vector is

$$\theta = \tan^{-1}\left(\frac{5.00\text{ N/C}}{10.0\text{ N/C}}\right) = 26.57°\text{ S of E or } 26.6°\text{ S of E.}$$

The electric field at P is 11.2 N/C [26.6° S of E].

Outcome S3P-4-16

b) If a 4.00 C charge is placed at P, what is the magnitude and the direction of the force on this charge? *(2 marks)*

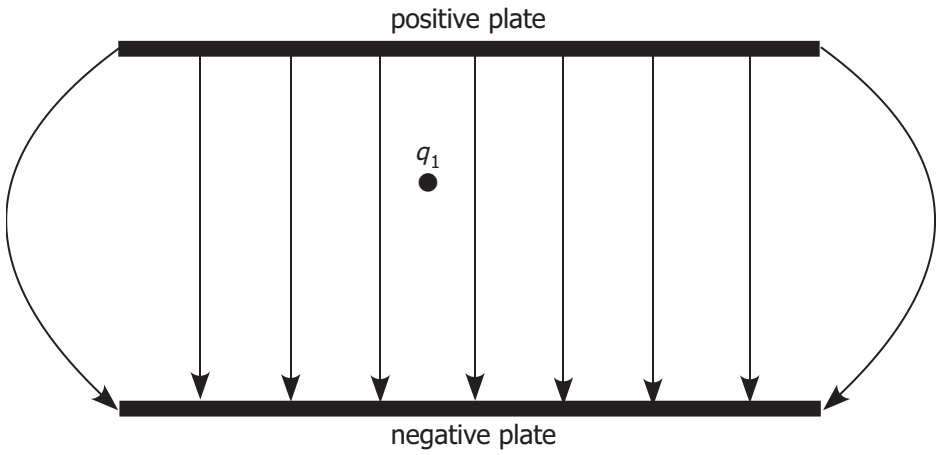
Answer:

The magnitude of the force is $\vec{F} = q\vec{E}_T$ = (4.00 C)(11.2 N/C) = 44.8 N.

The direction of this force is in the same direction as the electric field vector—that is, 26.6° S of E.

The electric force is 44.8 N [26.6° S of E].

9. A charge, q_1 = –2.00 C is placed in an electric field between two charged plates. The electric field strength is $\vec{E}$ = 6.00 N/C. The mass of the charged particle is $m = 5.00 \times 10^{-4}$ kg.



Outcome S3P-4-16

a) Determine the magnitude and direction of the electric force on the charged particle between the plates. *(2 marks)*

Answer:

This time the particle carries a negative charge so it will be attracted to the positive plate. The electric force will point up!

Given:	Charge	q_1 = –2.00 C
	Electric field	$\vec{E} = 6.00$ N/C
	Initial velocity	$\vec{v}_1 = 0$ m/s
	Mass	$m = 5.00 \times 10^{-4}$ kg.
Unknown: Electric force		$\vec{F}_E = ?$
Equation:		To find the magnitude of the electric force use $\vec{F}_E = q\vec{E}$
Substitute and solve:		$\vec{F}_E = q\vec{E} = (2.00\text{ C})(6.00\text{ N/C}) = 12.0\text{ N}$

Since the sign of the charge is negative, the directions of the electric force and the electric field are the opposite.

The electric force is 12.0 N [up].

Outcome S3P-3-13

b) Determine the magnitude and direction of the acceleration of the charged particle between the plates. *(2 marks)*

Answer:

Unknown: Acceleration $\vec{a} = ?$

Equation: Use Newton's Second Law. The net force is the electric force.

$$\vec{F}_{NET} = m\vec{a} \text{ rearranged to } \vec{a} = \frac{\vec{F}_{NET}}{m}$$

Substitute and solve: $$\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{+12.0\ \text{N}}{5.00 \times 10^{-4}\ \text{kg}} = +2.40 \times 10^{4}\ \text{m/s}^2$$

The acceleration of the particle is $+2.40 \times 10^4$ m/s^2.

Outcome S3P-3-13

c) If the particle is released from rest, what will be the final velocity of the particle after a time of 4.00 ms (4.00×10^{-3} s)? *(2 marks)*

Answer:

Given:

$\vec{v}_1 = 0$ m/s

$\vec{a} = 2.40 \times 10^4$ m/s^2

$\Delta t = 4.00 \times 10^{-3}$ s

Equation: Use equation #2.

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ rearranged to } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

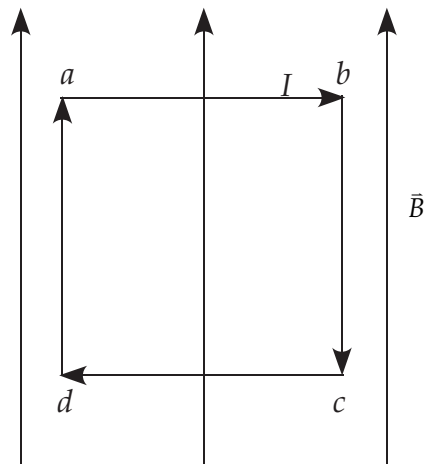
Substitute and solve:

$$\begin{aligned}\vec{v}_2 &= \vec{v}_1 + \vec{a}\Delta t \\ &= (0\ \text{m/s}) + (+2.40 \times 10^4\ \text{m/s})(4.00 \times 10^{-3}\ \text{s}) \\ &= +96.0\ \text{m/s}\end{aligned}$$

The final velocity of the particle is 96.0 m/s [up].

Outcome S3P-4-30, S3P 4-32

10. A square coil of wire containing a single turn is placed in a uniform 0.25 T magnetic field, as the drawing shows. Each side has a length of 0.32 m, and the current in the coil is 12 A. The direction of the current is clockwise.



Determine the magnitude and direction of the magnetic force on

a) *ab (2 marks)*

Answer:

The line segment *ab* is perpendicular to the magnetic field. Therefore the magnitude of the force is $\vec{F} = BIL\sin\theta = (0.25\text{ T})(12\text{ A})(0.32\text{ m})(\sin 90°) = 0.96\text{ N}$. *(1 mark)*

Using the right-hand rule (flat hand), fingertips point in the direction of the field, thumb points in the direction of the current, and the palm points upwards. The direction of the force is vertically upward out of the page. *(1 mark)*

b) *bc (2 marks)*

Answer:

In the line segment *bc*, the current is parallel to the magnetic field. There is no force on the wire (sin 0° = 0).

c) *cd (2 marks)*

Answer:

The magnitude of the force is the same as in (a): 0.96 N.

The direction of the force is in the opposite direction to the force in part (a) because the current is in the opposite direction.

NOTES

Grade 11 Physics
Formula Sheet

Mathematics

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\text{hypotenuse}^2 = (\text{Leg 1})^2 + (\text{Leg 2})^2$$

Kinematics

$$v = \frac{d}{\Delta t}$$

$$\Delta = \text{second value} - \text{first value}$$

$$\vec{d} = \text{pos}_2 - \text{pos}_1$$

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{\text{pos}_2 - \text{pos}_1}{\Delta t}$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ or } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

Waves

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{1-2}$$

$$PLD = |PS_1 - PS_2| = \left(n - \frac{1}{2}\right)\lambda$$

$$f = \frac{1}{T}$$

$$T = \frac{1}{f}$$

$$v = f\lambda$$

Light

$$\text{PLD} = |\text{PS}_1 - \text{PS}_2|$$

$$\frac{\Delta x}{L} = \frac{\lambda}{d}$$

Sound

$$v = 332 + 0.6\ \text{T}$$

Closed-pipe resonant length

$$L_n = \left(\frac{(2n-1)}{4}\right)\lambda$$

Open-pipe resonant length

$$L_n = \left(\frac{n}{2}\right)\lambda$$

$$f_B = |f_2 - f_1|$$

Dynamics

$$\vec{F}_{\text{NET}} = m\vec{a}$$

$$\vec{F}_{\text{NET}} = \sum \text{Forces}$$

$$F_F = \mu F_N$$

Gravity

$$\vec{F}_g = m\vec{g}$$

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$

Electricity

$$\vec{E} = \frac{\vec{F}_E}{q}$$

$$q = \text{N}e$$

$$E = \frac{V}{d}$$

Magnetism

$$\vec{F}_B = BIL\sin\theta$$

Grade 11 Physics (30S)

Topic 3: Waves

Topic 3: Waves

Introduction to Topic 3

So far in this course, you have learned about two different topics. The first topic, found in Modules 1 to 3, was mechanics. The second topic, found in Modules 4 to 6, was fields. The third topic, which will be found in this module and the next, is waves.

There are many examples of waves in nature as well as many examples of people using waves to improve our quality of life. These examples include ocean waves, sound waves, vibrations produced by musical instruments, and the many applications of electromagnetic waves in the communications industry.

The study of waves will be divided into two modules. Module 7 deals with the basic concepts of waves defined in terms of waves moving along in a line—in other words, in one dimension. You will study the characteristics of waves as they travel through a medium, how they change when they pass from one medium to another or reflect from an end, how waves change as they pass through each other, and so on.

Module 8 expands the study of waves to their behaviour as they travel across a surface or move in two dimensions. You have seen waves travel across the surface of water. We will use a small body of water in a tank, called a ripple tank, to study how waves travel, bounce off barriers, pass through openings in barriers or around barriers, and pass from one depth of water to another.

NOTES

Grade 11 Physics (30S)

Module 7: Waves in One Dimension

This module contains the following

- Introduction to Module 7
- Lesson 1: Transverse Waves and Longitudinal Waves
- Lesson 2: Reflection and Transmission of Waves in One Dimension
- Lesson 3: Wave Interference and Standing Waves in One Dimension
- Lesson 4: Resonant Frequency and Harmonies
- Module 7 Summary

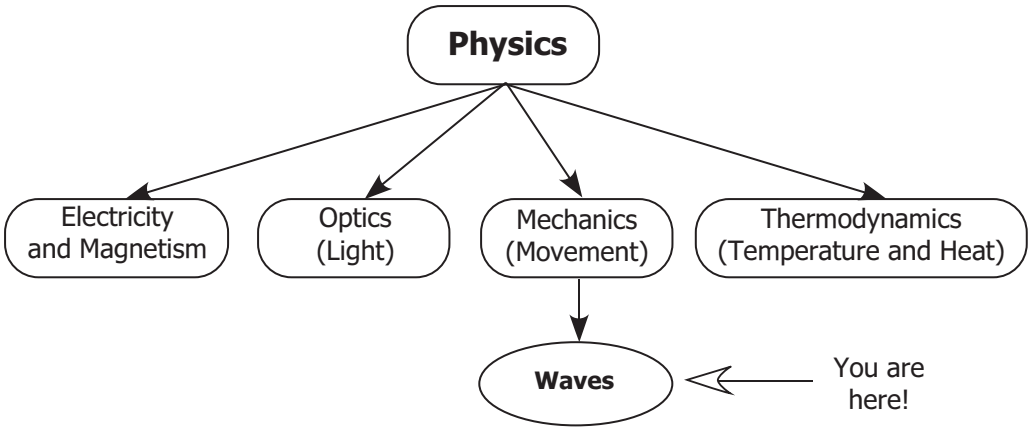
Module 7: Waves in One Dimension

Introduction to Module 7

In this module, we begin our study of waves with a study of waves in one dimension. We will investigate the basic properties of waves. An understanding of these properties will enable us to analyze the behaviour of all phenomena we call waves whether they are mechanical waves that require a medium to travel through (sound, water waves), or waves that can travel through a vacuum (radio waves, microwaves, light).

- **Lesson 1: Transverse Waves and Longitudinal Waves** examines the basic properties of transverse and longitudinal waves.
- **Lesson 2: Reflection and Transmission of Waves in One Dimension** focuses on the reflection and transmission of waves.
- **Lesson 3: Wave Interference and Standing Waves in One Dimension** shows what happens when waves meet and interfere with each other.
- **Lesson 4: Resonant Frequency and Harmonies** extends our study of wave interference to resonant frequencies and harmonics, and the application of waves to communications.

All of this work will lead into the study of waves in two dimensions in the next module.



Assignments in Module 7

When you complete Module 8, you will submit your Module 7 assignments, along with your Module 8 assignments, to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 7.1, Part A	Transverse Waves and Longitudinal Waves
2	Assignment 7.1, Part B	Reflection and Transmission of Waves in One Dimension
3	Assignment 7.1, Part C	Wave Interference and Standing Waves in One Dimension
4	Assignment 7.1, Part D	Resonant Frequency and Harmonies

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Lesson 1: Transverse Waves and Longitudinal Waves (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe a wave as a transfer of energy
- describe the main characteristics of waves
- draw a transverse wave and label the following: crest, trough, amplitude, wavelength
- draw a longitudinal wave and label the following: compression, rarefaction, wavelength
- compare and contrast the "frequency" and the "period" for a wave
- calculate the frequency of a wave if given the period; calculate the period of a wave if given the frequency
- solve problems using the wave equation: $v = f\lambda$
- recognize that the speed of a wave depends only on the medium

Key Words

medium
two-dimensional (2D) wave
pulse
periodic wave
trough
longitudinal wave
period
mechanical wave
equilibrium (or rest) position
wave
transverse wave
amplitude
compression
frequency
one-dimensional (1D) wave
cycle
crest
wavelength
rarefaction

Introduction

In this lesson, you will learn the "basics" about waves—a lot of vocabulary is introduced, as well as two basic equations. This will set the stage for a more advanced look at waves throughout the rest of this (and the next) module. We will introduce the two basic types of waves: **transverse** and **longitudinal**. These waves (and combinations of them) are found in nature as sound waves, light waves, water waves, and so on. We examine the basic characteristics of these waves and how to calculate some of their basic properties, such as frequency, wavelength, and speed.

Basic Ideas

Everybody is familiar with waves. To most people, waves and water are very closely linked together, and some people in fact think that waves are something that is unique to water. Water waves can be found at the beach, in swimming pools, and even in a bathtub or glass of water. As with much of physics, however, some of the terms related to waves as they are commonly used are not quite the same as the way they are used in physics. Remember this as we introduce new terms. In addition, while the idea of waves is familiar, a detailed study of waves is certainly not familiar to most people. Let's begin with some basic terminology. Remember that these terms will be used throughout the remainder of this (and in some cases the next) module, so take the time to learn the meanings of these terms well.

Waves generally have "something that is waving." In the examples used above, this something was water. We use the word **medium** for the material that is shaking around as a wave passes through it (note that if there is more than one medium, the word is **media**, not "mediums"). This means that water is the medium when considering waves at the beach or in your bathtub. Water is by no means the only thing than can serve as a medium however. Certainly other liquids can serve as media, but, more interestingly, just about anything can serve as a medium for waves, including strings, springs, and even air.

> A **medium** (plural **media**) is the material that is in motion while a wave passes through it.

Surprisingly, some waves do not require a physical medium at all. At first, this might seem to be impossible. After all, if there is no medium then what is "waving"? We will deal with this idea at the end of this module, but for now, we will say that any wave that does require a medium can be called a mechanical wave. We will work only with mechanical waves until the very end of this module.

> A **mechanical wave** is a wave that requires there to be a physical medium, such as water, string, spring, air, etc., to travel through.

One-Dimensional Waves

Although water waves are a familiar example of waves, they are a bit too complicated to begin our study of waves with. The surface of water is flat, or two-dimensional. These "two dimensions" can be thought of as being north-south and west-east, or "X" and "Y." The waves on the surface of water have the freedom to move in both of these dimensions, which is why water waves can be described as being two-dimensional waves. When a raindrop or a stone strikes the surface of water, a circular wave forms and moves outward in these two dimensions from where the stone hit the water. We will study two-dimensional waves shortly, but we will begin with a simpler kind of wave: one-dimensional waves.

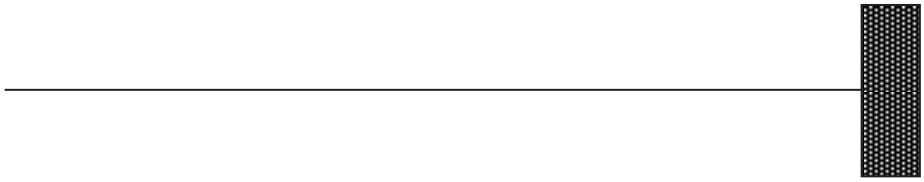
> By definition, a **one-dimensional wave** only has a single dimension: a single line of travel available to it.

This means that the waves can only travel along this line—there is no "spreading out" or options as to which way to go, other than "forwards" and "backwards." One very convenient medium for one-dimensional waves is a spring.

Imagine a very long spring (such as a "slinky") stretched out on the floor, with one end held by a person and the other end attached to a wall quite a distance away. The spring is the medium for waves that are about to be produced. With the spring stretched out, the entire length of the spring is straight, and the whole spring is at rest. Each and every coil of the spring is now at the **rest position** (also known as **equilibrium position**). The rest position is where each point in the medium naturally is when the medium is undisturbed.

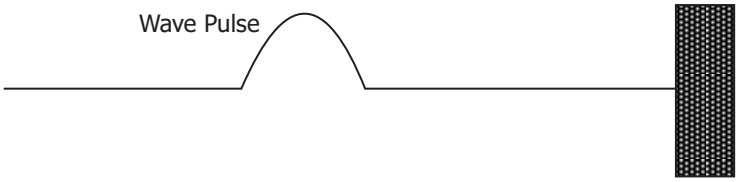
> The **rest position** (also known as **equilibrium position**) is the position where each point in the medium naturally is when the medium is undisturbed.

A Stretched Spring at Its Rest Position



If the end of the spring is now quickly shaken to one side (perpendicular to the length of the spring) and then back, a "bump" will travel down the entire length of the spring as coils are, one by one, pulled away from the rest position and then returned back. This single bump that travels down the length of the spring can be called a wave, but there is perhaps a better word for it. This single disturbance of the medium can be called a **pulse**.

A **pulse** is a single disturbance that travels through the medium.



It is important that you not confuse the movement *of the wave* with the motion *of the medium*—they are not the same! Consider "the wave" as it is sometimes performed at sporting and other events when the audience wants to show its enthusiasm. For simplicity, let's discuss a simplified example of this kind of "wave." Suppose there are ten students sitting in chairs in one straight row, watching a physics teacher showing physics demonstration. Now let's also suppose that the students get so excited by the impressive physics demonstrations that the person on the left end starts "the wave" by standing up and raising both hands up and then down in a sweeping motion, and then sits back down. Catching on to this, the second person then immediately repeats this motion, followed by the third person, the fourth, and so on, until the tenth person completes "the wave" on the right side of the row.

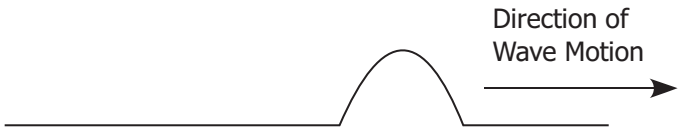
In this "wave," the people themselves were the medium and being seated in a chair was the rest position. A single pulse moved through them from left to right: this was the "bump" that appeared at the left end and worked its way to the right end. Notice, however, that at its completion, everybody had returned to precisely the same place they were when started. This is, in fact,

one of the most fascinating things about waves: "something" (a wave) can move *through* the medium without giving the medium itself any *net movement*. Notice that I used the term "net movement," because it is necessarily true that the medium moved as the wave passed through, but it was a brief movement, and the medium moved back to its original position.

Returning to our discussion of spring waves, when a pulse moves through the spring, it is much the same as our "people wave," but with individual coils momentarily sweeping away from their rest positions and then back. When the pulse has moved through the spring, each coil is back at the rest position where it started. The wave does not relocate matter. Note that spring waves are examples of mechanical waves: a spring wave requires there to be a spring serving as the medium.

In the diagrams of springs, we will not draw in the wall to which the spring is attached. We will focus on the spring itself. Here is the pulse **at this instant in time**.

If you look at the wave an instant later, it will have a new position to the right of the position in the diagram above.



The movement of a wave is not merely the movement of the medium. Waves move *through* the medium, but the medium is returned to its rest position. The wave does not relocate matter.

Although waves do not carry matter from one place to another, they do carry energy. For example, when a rock is thrown into water, some of the energy of the moving rock is transferred to the water, which changes the shape of the water at the surface. This disturbance then causes the water around it to become disturbed, giving it energy. In fact, we can define a wave as a disturbance that transfers energy from one place to another.

A wave can be defined as a travelling disturbance that carries energy.

Continuous or Periodic Waves

So far, we have only been considering waves made up of single pulses. If a source disturbs the medium repeatedly, over and over, in the exact same way, with a regular timing, a **continuous wave** (also known as a **periodic wave**) will result.

Let's use a spring again as an example. As before, consider a spring that is stretched out horizontally, lying on the floor in the rest position. One end is held by a person, and the other end is so far away that we will ignore it. Now, if the person begins to shake the end from side to side, over and over, with regular timing, a periodic wave will result. The medium will have a series of pulses moving through the length of the spring. Some of these pulses will be on one side of the rest position and some will be on the other side of the rest position. In this example, we can describe the person as being the source of the wave. It was due to his or her actions that the wave got started.

A continuous wave, also known as a periodic wave, has a series of pulses that are all the same.

The source of a wave is the object (or person) that starts the wave. For mechanical waves, this means that the source disturbs the medium, providing it with energy.

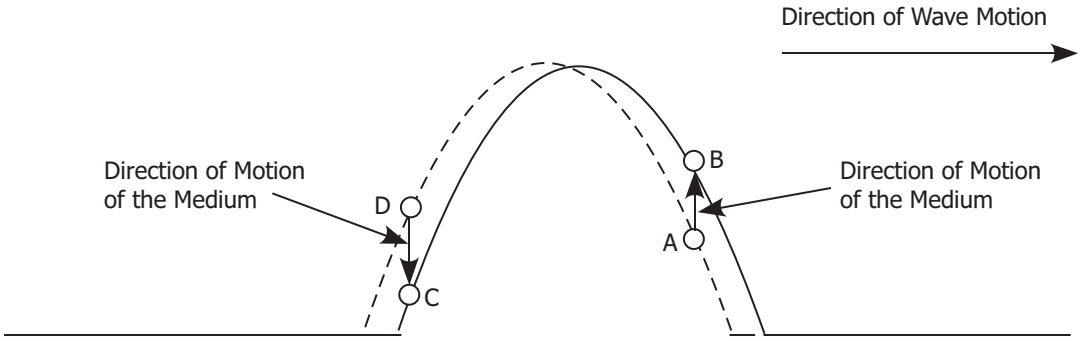
The wave just described is of a type known as a **transverse wave**.

Transverse waves are those waves in which the medium itself moves in a direction perpendicular to the direction of the wave motion.

In the example just discussed, notice that the wave moves away from the person along the length of the spring. The spring itself, however, is shaking from side to side, which is perpendicular to the wave motion.

A transverse wave is one in which the medium shakes perpendicular to the wave motion.

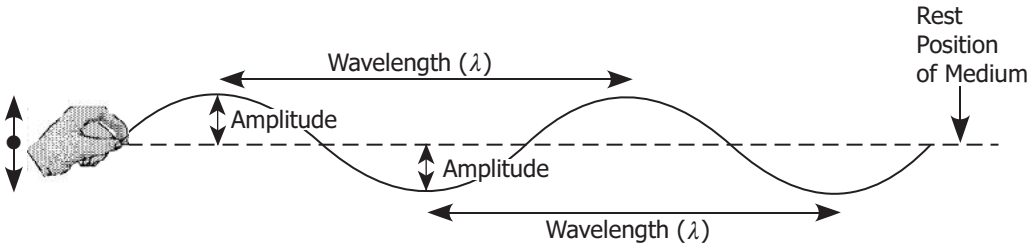
To illustrate how the medium is moving **at this instant**, we will draw a wave pulse at one position and then draw the pulse again an instant later. If the wave is moving to the right, the first pulse is on the left and the second pulse an instant later is drawn on the right.



You can see that point A is moving up to position B, and point D is moving down to position C.

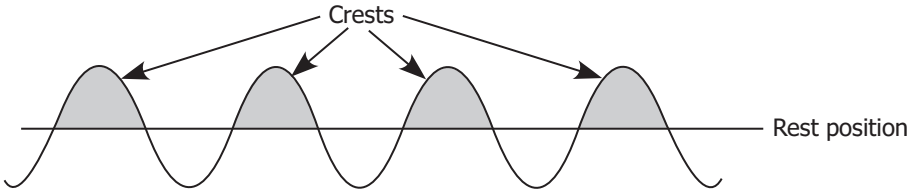
Characteristics of Transverse Waves

There are a number of important characteristics of periodic waves. The diagram below shows a portion of a transverse periodic wave.



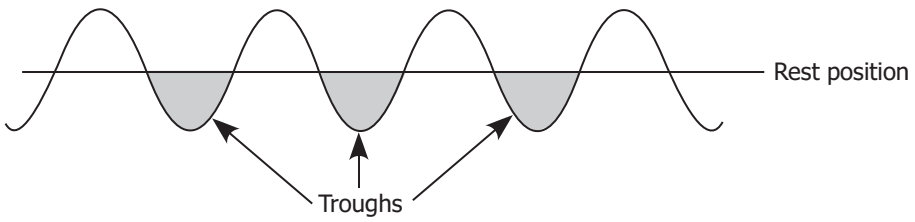
The pulses on one side of the rest position of the medium are called crests. Otherwise, one side is simply chosen to be the "crest side."

> If the medium is shaking up and down, the **crests** are the parts of the wave that are **above** the rest position.



The pulses on the side opposite from the crests are called **troughs**.

If the medium is shaking up and down, the **troughs** are the parts of the wave that are **below** the rest position.



The **amplitude, A,** is the maximum "height" of a crest measured from the rest position to the highest point on a crest.

The amplitude can also be defined as the maximum "depth" of a trough, measured from the rest position to the lowest point of the trough.

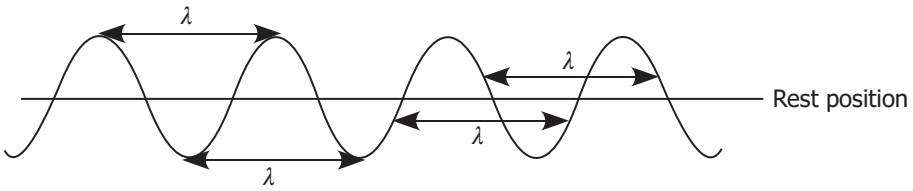
Note that the total distance from the top of a crest to the bottom of a trough is twice the amplitude.

One **cycle** of a wave is one complete grouping of a single crest and a single trough.

The **wavelength** is the length of one cycle of the wave. Note that this means that a wavelength can conveniently be described as the distance between two neighbouring crests or two neighbouring troughs, but it really can be measured between any successive equivalent points on the wave.

The **wavelength** is the distance from a point on a wave to the same point on a successive wave.

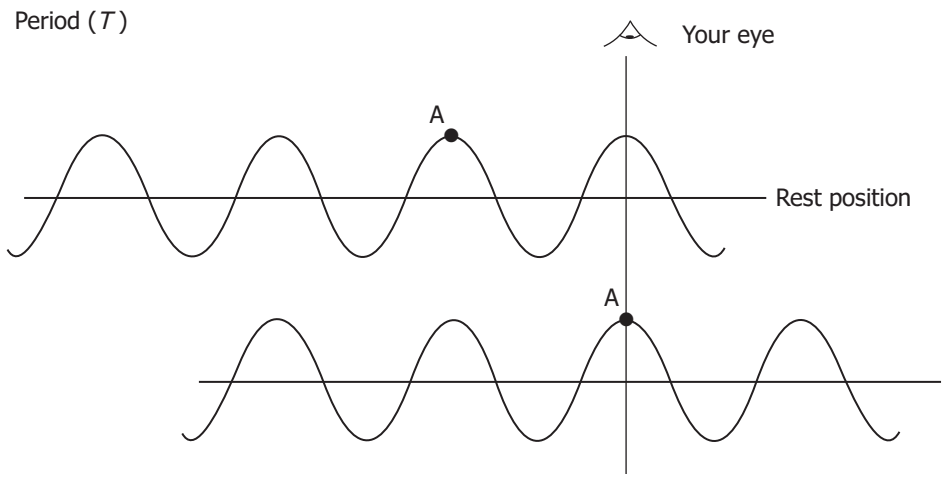
The Greek letter "lambda" (pronounced "lam-dah") λ is used as the symbol for wavelength. Notice that the symbol for lambda looks like an upside-down mirror-image of a lowercase "y."



While all of the above items can be shown on the picture of a wave, there are two more terms that describe the wave in a way that cannot be "seen" in a picture of a wave. This is because these next two terms involve the timing of the wave.

The **period** is the amount of time that the source takes to produce one full cycle (crest and trough).

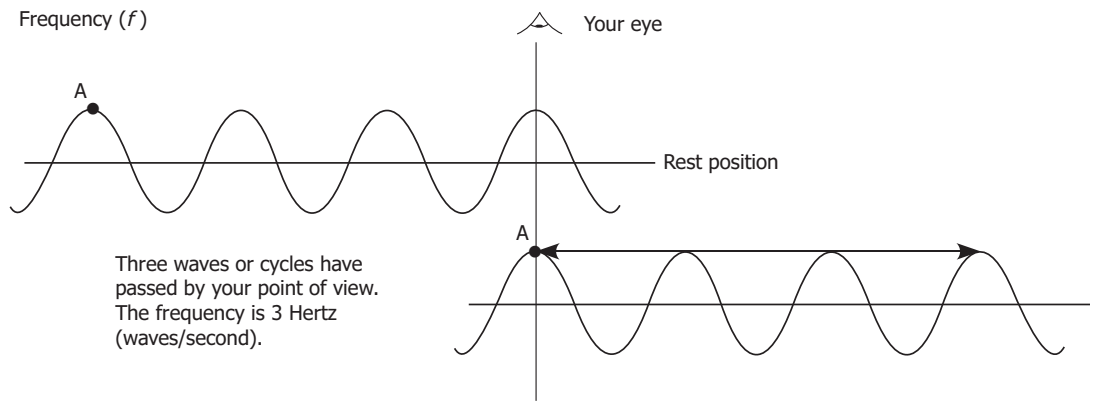
The symbol for period is "*T*," which may at first surprise you (maybe you would have expected it to be a "P"), but remember that the period is really just a measurement of *time*, and so the letter T is appropriate. It is uppercase to remind us that it is a rather special measurement of time—the time to produce exactly one full cycle. Remember that, as before, we must have time measurements (including periods) in seconds.



In the diagram above, the point A moves one wavelength to the right. The time it takes the wave to travel one wavelength past your point of view is one period.

Frequency is an indication of how many cycles are produced per unit of time.

The **frequency** (symbol "*f*") is closely related to the period. While period is essentially "how many seconds to complete a cycle," frequency is "how many cycles are completed in each second." Frequency is commonly measured in "cycles per second," which is given the special name "hertz" (abbreviated "Hz"). To help understand this idea, imagine watching one point of the medium while cycles of the wave go by. If you counted how many full cycles went by in one second, this would be the frequency in hertz.



There is a simple mathematical relationship between period (T) and frequency (f): they are reciprocals, or inverses of each other:

$$T = 1/f \quad \text{and} \quad f = 1/T$$

The **period** (T) is a measure of how much time it takes to produce one cycle of a wave. Being a time, it is measured in seconds. The **frequency** (f) is a measure of how many cycles are produced each second. It is measured in hertz (abbreviated Hz).
$T = 1/f$ and $f = 1/T$.

Example 1: Period and Frequency

You are sitting on a dock watching a piece of wood bob up and down on the waves in the water. Being an astute student of physics, you notice that as the waves pass by the wood bobs up and down eight times in 12 seconds. What is the frequency and the period of this motion?

Given: Number of cycles	$n = 8$ cycles
Time	$t = 12$ s
Unknown: Frequency	$f = ?$
Equation:	frequency = number of cycles/time interval
Substitute and solve:	$f = \dfrac{\text{number of cycles}}{\text{time interval}} = \dfrac{8 \text{ cycles}}{12 \text{ s}} = 0.67 \text{ Hz}$

The frequency is 0.67 Hz.

The period is the time per cycle.

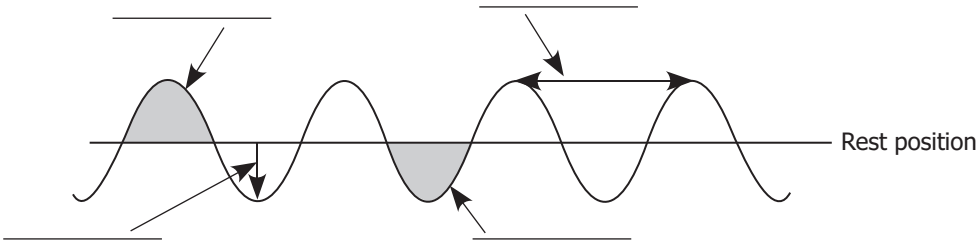
$$T = \frac{\text{time interval}}{\text{number of cycles}} = \frac{12 \text{ s}}{8 \text{ cycles}} = 1.5 \text{ s}$$

Notice that the frequency and the period are reciprocals.

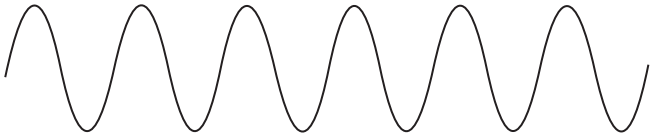
Learning Activity 7.1

Transverse Waves and Longitudinal Waves: Part 1

1. Label each part of a transverse wave as indicated.



2. The periodic transverse wave below travels past a point P in 2.75 s.



   a) What is the wavelength of this wave? Use a ruler to measure it.
   b) What is the amplitude of this wave?
   c) What is the frequency of this wave?
   d) What is the period?

Longitudinal Waves

So far, we have considered one kind of mechanical wave: transverse waves. Transverse waves are those waves that have the medium shaking perpendicular to the motion of the wave. We now turn our attention to a different kind of wave known as a longitudinal wave.

We can set up a longitudinal wave in a very similar way to how we set up transverse waves. We will again imagine a spring stretched out on the floor with one end held by a person, and the other end some distance away fastened to a wall. The difference is that this time the person (in order to produce a longitudinal wave) must alternately push and pull the end of the spring, being careful not to disturb it from side to side.

A **longitudinal wave** is one in which the medium shakes parallel to the direction of motion of the wave.

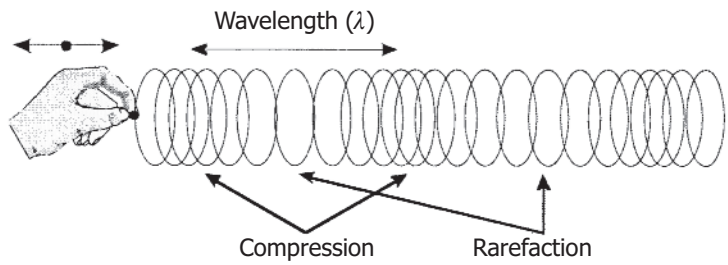
While it makes sense to talk about the "rest position" for a transverse wave, it is perhaps more appropriate that we switch to the term "equilibrium position" for longitudinal waves. Initially, each coil of the spring is in an equilibrium position. In particular, each coil will be pulled by the two neighbouring coils (there is one on each side). When the spring is just lying there, these two neighbouring coils pull equally hard, resulting in there being no net force on any of the coils. A longitudinal wave changes all this, at least briefly.

Let's again imagine 10 students in a row. This time, however, let's have them standing with their arms extended out at their sides, holding hands. Initially, everybody is just standing motionless, but then the person at the left end very quickly takes a small step to the left and then right (returning back to where he or she started). Since they were all holding hands, this means that this person must have pulled and then pushed the second person, who would have to take a small step to the left and then right in order to maintain his or her balance. This repeats itself down the length of the students until the last person has repeated the same motion. It is important in this to realize that all 10 people will not have taken their small steps at the same time; there will be a small delay as this motion works its way down the length of students. This was very much a wave—a single longitudinal pulse. Each person (part of the medium) was briefly pulled and then pushed along the length of the medium; they briefly moved parallel to the motion of the wave.

Longitudinal waves do not have crests and troughs. Instead, they have **compressions** (places in which the medium is relatively bunched up, or compressed) and **rarefactions** (also known as **expansions**, which are places in which the medium is relatively pulled apart, or expanded).

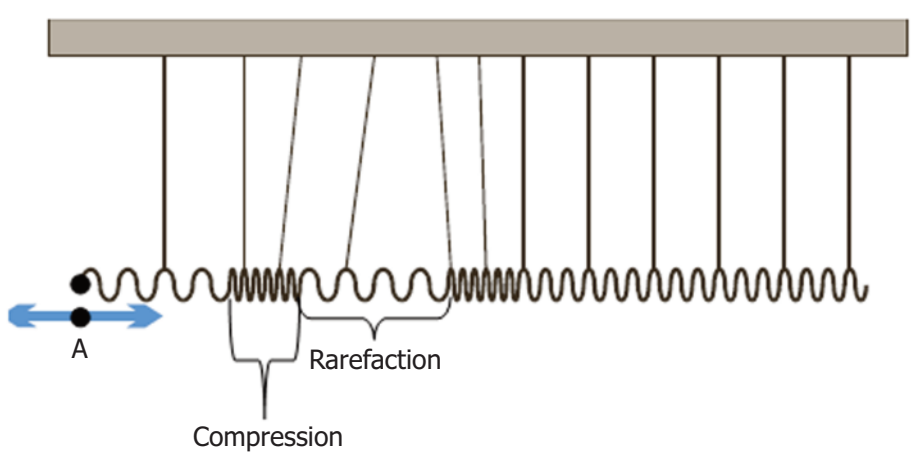
> **Compressions** are places where the medium is compressed (closer together than usual). **Rarefactions** (also called expansions) are sections where the medium is expanded (further apart than usual). Compressions and rarefactions correspond respectively to the crests and troughs of a transverse wave.

The diagram below shows how a longitudinal wave can be formed on a spring by alternately pushing and pulling on one end. A series of compressions and rarefactions can then move along the spring.



Longitudinal waves also have a wavelength. The diagram above shows one possible way to show a wavelength. It is drawn from the centre of a rarefaction to the centre of the next rarefaction. But it can also be described as the distance between any neighbouring equivalent points on the wave.

You can actually produce longitudinal waves yourself using a slinky. If you suspend the slinky from a rod using several strings (as shown in the diagram below), and if you move the coil (point A) at one end back and forth horizontally, a longitudinal wave will result.



Frequency and period have the same meanings for the longitudinal wave as they do for the transverse wave.

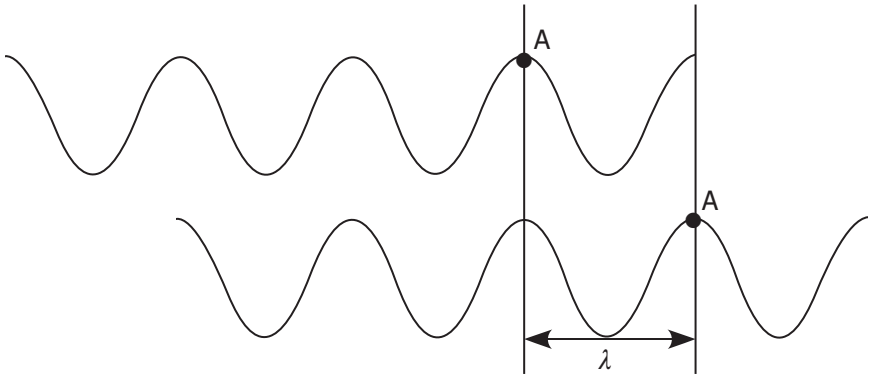
Amplitude is a little more difficult for longitudinal waves, and so we will choose to only use it for transverse waves. (This is for our convenience only. Longitudinal waves certainly do have amplitudes, but it would not be a distance measurement at all.)

Wave Speed

The **wave speed** is simply the speed at which the wave moves through the medium. Again, do not confuse the motion of the wave with the motion of the medium. Generally, the medium moves in a fairly complicated way, back and forth, while the wave simply moves along the medium. To make it convenient to visualize, let us focus on the movement of a single wave crest that has just been produced by the source. This crest will move along the medium at a speed "v" that we would like to be able to easily calculate. We certainly have the option of simply measuring off any distance "d" and timing how long it takes for the wave to travel that distance: $v = d/t$. This is exactly what we did early in our kinematics module when we were considering the movement of objects.

Calculating the speed of a wave can also be done in this way, but periodic waves (ones that involve cycle after cycle with a regular timing that we call the period "T") have another way by which we can calculate the speed. Notice that the crest we are focusing our attention on is just one of many crests. In producing the periodic wave, the source has already produced several crests before our crest, and will continue to produce more after our crest has been produced. Also, note that the spacing of these crests is all the same; the distance from one crest to the next is what we call wavelength (λ).

In following our crest of interest from the moment it is made, we will find that it moves along the medium a distance equal to one wavelength, in a time equal to one period.



The wave travelled a distance of 1 wavelength in a time of 1 period.

This must be the case, as when it has moved the distance of one wavelength, the source must at that same moment be making the next crest, which will follow it. This allows us to rewrite the equation for speed in a "special for periodic waves" version: simply replace the distance (d) with wavelength (λ) and the time (t) with the period (T):

$$v = \frac{d}{t} \rightarrow v = \frac{\lambda}{T}$$

Since period and frequency are reciprocals of each other, this equation can be written another way. Rather than "dividing by the period," we may choose to "multiply by the frequency" instead. This allows us to write the equation as $v = f\lambda$.

Since this equation works for all waves, it is called the **universal wave equation**.

Universal Wave Equation: For any wave, the speed of the wave equals the product of the frequency of the wave and its wavelength.

$$v = f\lambda$$

Quantity	Symbol	Unit
Speed	v	metres/seconds (m/s)
Frequency	f	hertz (Hz)
Wavelength	λ	metres (m)

Example 2: The Speed of a Wave

For example, suppose a wave has a wavelength of 5.00 m, and that it takes 0.200 s for one wavelength to pass a given point.

a) Determine the frequency of the wave.

Notice that this would mean that it also takes 0.200 s to produce one cycle, and so 0.200 seconds would also be the period.

Period and frequency are reciprocals: $T = \frac{1}{f}$ and $f = \frac{1}{T}$.

Since we know the period, we find the frequency using $f = \frac{1}{T}$.

$$f = \frac{1}{0.200\ s} = 5.00\ \text{Hz}$$

b) Determine the speed of the wave.

Given:	Wavelength	$\lambda = 5.00$ m
	Period	$T = 0.200$ s
	Frequency	$f = 5.00$ Hz
Unknown: speed		$v = ?$
Equation:		$v = f\lambda$
Substitute and solve:		$v = f\lambda = (5.00\ \text{Hz})(5.00\ \text{m}) = 25.0\ \text{m/s}$

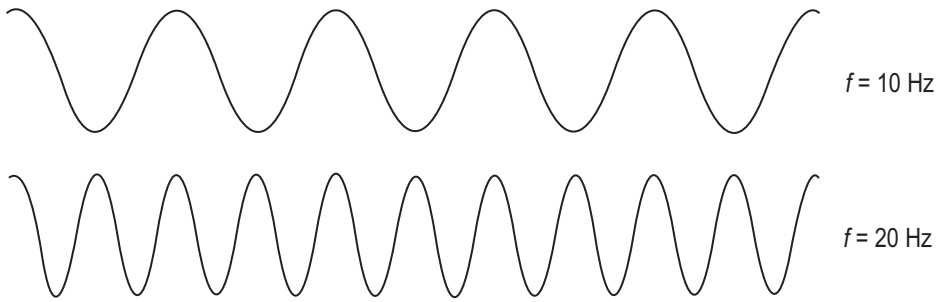
The speed is 25.0 m/s.

Notice you could also use the kinematics equation for speed:

speed = distance/time interval.

$$v = \frac{\lambda}{T} = \frac{5.00\ \text{m}}{0.200\ \text{s}} = 25.0\ \text{m/s}$$

One of the most remarkable things about the speed of a wave is that it only depends on the medium. There is nothing that the source can do to change the speed of the waves that it produces, short of changing the medium itself. This means that if the frequency of the wave produced by a source changes, then the wavelength will change too but the speed will not change at all. This would not be expected from the equation $v = \lambda f$, from which you might incorrectly suppose that doubling the frequency of a wave would double its speed. In fact, if the frequency of a wave doubled, the result would be a wave with only half of the wavelength—the speed would be the same as before. This is illustrated in the following diagram.



The speed of a wave depends only on the medium. To change the speed of a wave, the medium itself must change. Any change in the frequency of the source results in a change in the wavelength also.

For example, the waves on a spring will only change speed if the spring itself is changed. This could be done in a number of ways. The spring could be stretched out more or less tightly, or a "heavier duty" (stiffer) spring could be used in place of the original.

Learning Activity 7.2

Transverse Waves and Longitudinal Waves: Part 2

1. Describe the motion of a point on the medium that occurs in a transverse wave.
2. Describe the motion of a point on the medium that occurs in a longitudinal wave.
3. Define the following terms: crest, trough, compression, rarefaction.
4. What is the frequency of a wave?
5. What is the metric unit of frequency?
6. How is the period of a wave related to its frequency?
7. What is the wavelength of a wave?

(continued)

Learning Activity 7.2: Transverse Waves and Longitudinal Waves: Part 2 (continued)

8. "Domino toppling" involves lining up a large number of dominoes and then letting them topple, one after the other. It is one entry in the *Guinness Book of World Records*. If we think about the disturbance that propagates along the line of dominoes, is it transverse, longitudinal, or both?

9. A person standing in the ocean notices that after a wave crest passes by that ten more crests pass by in a time of 100 s. What must be the frequency of the wave?

10. A popular FM radio station is 97.5 on the FM dial. This number refers to the frequency of the signal in units of megahertz. This station broadcasts at 97.5 MHz. All radio signals travel at the speed of light, 3.00×10^8 m/s. What is the wavelength of this signal?

11. Porpoises emit sound waves in water in order to navigate. A typical wavelength for such a sound wave might be 2.5 cm. The speed of the wave in seawater is typically 1470 m/s. What is the period of the wave?

Lesson Summary

In this lesson, we studied the basic properties of transverse and longitudinal waves. The following are the key ideas:

A **wave** is a disturbance that transfers energy from one place to another. **Mechanical waves** must travel through some material or medium. Waves do not transport matter from one place to another but they do transport energy. Waves do not permanently change the medium through which they travel.

A **pulse** is a single wave bump. In a pulse, the medium of a **transverse wave** moves perpendicular to the wave motion, while for a **longitudinal** wave the medium of the wave moves parallel to the direction of the wave.

A **continuous** or **periodic wave** is one with **cycles** (one crest and one trough each) produced with regular timing.

There are several important characteristics of transverse periodic waves. **Crests** are on the one side of the rest position of the medium (typically above the normal rest position of the medium); **troughs** are on the other side of the rest position of the medium (typically below the normal rest position of the medium).

The **amplitude**, A, is the maximum height of a crest or the depth of a trough as measured from the rest position.

The **wavelength**, λ, is the length of one cycle of the wave, and may be measured between any two successive equivalent points on the wave, such as from crest to neighbouring crest.

The **frequency**, f, is the number of complete cycles that are produced per unit of time.

The **period**, T, is the time taken by the source to produce one full cycle. Period and frequency are reciprocals of each other, $T = 1/f$ and $f = 1/T$.

In a **longitudinal wave**, the motion of the medium is along the same direction as the motion of the wave.

For a longitudinal wave, the **compressions** are those areas in the medium that are momentarily closer together than normal. **Rarefactions** (also called **expansions**) are regions where the medium is farther apart than normal.

As in transverse waves, longitudinal waves have the characteristics of wavelength, frequency, period, and speed.

The **wave speed**, v, is the speed at which the wave moves through the medium. It can be calculated using $v = f\lambda$ or $v = \frac{\lambda}{T}$.

The speed of a wave depends upon only the type and condition of the medium used.

NOTES

Assignment 7.1, Part A

Transverse Waves and Longitudinal Waves (5 MARKS)

The speed of a transverse wave on a string is 450 m/s, while the wavelength is 0.18 m. The amplitude of the wave is 2.0 mm.

a) What is the total up-and-down distance moved by a particle of the medium for each cycle of the wave?

b) What is the frequency of the wave?

c) What is the period of motion of the wave?

d) How many cycles of the wave would have to pass by a given point so that a particle on the string moves a total distance of 1.0 km?

(continued)

Assignment 7.1, Part A: Transverse Waves and Longitudinal Waves (continued)

e) How much time is required for a particle on a string to move through a total distance of 1.0 km?

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Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining the total up and down distance in part (a)
- 1 mark for determining the frequency in part (b)
- 1 mark for determining the period of motion in (c)
- 1 mark for determining the number of cycles in part (d)
- 1 mark for determining the time in part (e)

Lesson 2: Reflection and Transmission of Waves in One Dimension (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe how pulses or waves in one dimension are reflected from a fixed end and a free end
- compare the speed, wavelength, frequency, and amplitude of a transmitted pulse to the incident pulse
- compare the speed, wavelength, frequency, and amplitude of a partially reflected pulse or wave to an incident one, and indicate whether or not the transmitted pulse is inverted or not
- draw diagrams showing the transmission and partial reflection of pulses

Key Words

reflection	transmission	upright
inverted	partial reflection	partial transmission
light medium	heavy medium	amplitude
length		

Introduction

Waves of all types exhibit several common behaviours. The first of these behaviours that we will turn our attention to are those of reflection (the "bouncing back" of a wave) and transmission (the entering of a wave into a new medium). In this lesson, we will limit our study of reflection and transmission to that of waves travelling in only one dimension; we will later expand on this to reflection and transmission of waves in two dimensions.

Reflection

So far we have been ignoring what happens when a wave reaches the end of the medium that it is moving through. In general, there are three ways that a medium can end:

1. The medium can end, and be of a type that we call a **fixed end**, which means that the end of the medium is held firmly in place and cannot move at all. The examples in the previous lesson included ends of this type—one end of the springs discussed was assumed to be firmly connected to a wall (which would be treated as being immoveable).
2 The medium can end, and be of a type that we call a **free end**, which means that the end of the medium is not held at all—it is completely free to move. As an example of a free end, consider a spring that is held at the top, with the length of the spring extending vertically down, with the lower end of the spring hanging freely in the air. The lower end of this spring would be considered to be a free end.
3. The medium ends, but is connected to a second medium that can itself accept the wave. The point at which the two media are connected is sometimes called a **boundary**.

A **fixed end** is when the medium ends and cannot move.

A **free end** is when the medium ends and is free to move.

A **boundary** is the point that connects two different media.

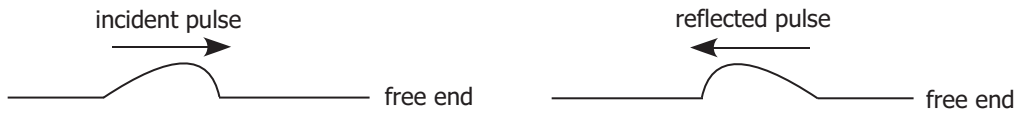
When a wave reaches the end of its medium, two things can occur: reflection and transmission.

We can define **reflection** as the "bouncing" of a wave back into the medium that it was in to begin with. We use the word **incident** for the wave (or individual pulses) before the reflection occurred, and the word **reflected** for the wave or pulses after the reflection has occurred.

Reflection is the bouncing of a wave back into the original medium. **Incident pulses** reach the end of the medium and bounce back, at which point they are called **reflected pulses**.

Reflection from a Free End

By definition, the free end is loose and can move around with ease. Let's consider a crest pulse approaching a free end. The left diagram below shows the incident crest pulse moving to the right towards the free end. The right diagram shows the reflected pulse moving to the left.



When the pulse reaches the end of the medium, the end quickly snaps up and then down. This up-and-down motion is what generates the reflected pulse. Since we started with a crest, the reflection is also a crest. We can describe the reflected pulse as being **upright**. Of course, had the incident pulse been a trough, the same process would occur with the opposite directions. The reflected pulse would be a trough, but we would still use the term "upright" to describe that it is of the same type.

Notice that the pulse in these drawings was not symmetrical. In the left diagram, the front or leading edge of the pulse is more nearly vertical. The leading edge reflects first, and so the more nearly vertical end is still at the front of the pulse as the leading edge is now on the left side.

You will also notice that the length of the wave along the rest position remains constant. This indicates that the speed of the pulse has not changed. This is entirely logical since the medium (the spring) has not changed.

For the work we will be doing, assume that the speed in a given medium will be constant.

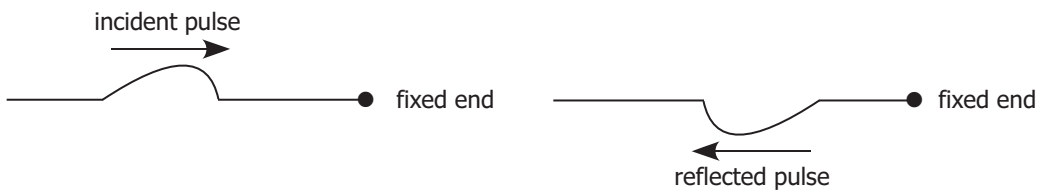
Finally, you will notice that the amplitude of the incident pulse and the reflected pulse are the same.

Pulses **reflected** from a **free end** are

1. **upright**—they remain on the same side of the medium, meaning that crest reflects as crest and trough reflects as trough.
2. **equal in amplitude** to the incident pulse
3. travelling at the **same speed** as the incident pulse
4. **equal in length** to the incident pulse

Reflection from a Fixed End

Now let's look at a pulse in a one-dimensional medium (such as a spring) reflecting from a fixed end. The left diagram below shows a pulse moving to the right approaching the fixed end—the medium has been firmly attached to a solid wall. The right diagram shows the same pulse after it has been reflected from the fixed end; it is now moving to the left.



The remarkable thing about reflection from a fixed end is that the pulses become **inverted**. They change to the other side of the rest position of the medium. This means that if the incident pulse is a crest, then it will reflect back as a trough; and if the incident pulse is a trough, then it will reflect back as a **crest**. Again, the reflected pulse has the same amplitude as the incident pulse. The reflected pulse is in the same medium (spring) so it is travelling at the same speed and has the same length.

Pulses **reflected** from a **fixed end** are

1. **inverted**—they reflect on the opposite side of the medium, meaning that crest reflects as trough and trough reflects as crest.
2. **equal in amplitude** to the incident pulse
3. travelling at the **same speed** as the incident pulse
4. **equal in length** to the incident pulse

A very good question to ask at this point would be "why do the pulses invert when they reflect from a fixed end?" The answer has everything to do with Newton's Third Law. When a pulse reaches the fixed end, the medium exerts a force onto the fixed end itself. The direction of this force will be in the same direction as the side of the incident pulse (in the example above, this means that the crest will exert an upward force on the fixed end when it reaches it). The fixed end then must exert an equal but opposite force—downward in this example, back onto the medium. Notice that this is exactly Newton's Third Law—the medium pushes the fixed end up; the fixed end pushes the medium down. This downward force on the medium is what creates the reflected trough pulse back on the opposite side. Of course, if an incident trough had approached the fixed end, all of these directions would be reversed. A reflected crest would result.

Boundary Reflection and Transmission

When a pulse reaches the boundary separating two media, the pulse does reflect, but that's not all that it does. It also undergoes **transmission**, as it transmits (enters) into the new medium and continues to move in the same direction as before. Note that since the incident wave both transmits and reflects, the energy carried by the incident pulse has to split up—some of it showing up in the reflected pulse, and the rest showing up in the transmitted pulse. For this reason, we refer to these events as **partial reflection** and **partial transmission**.

> Pulses that reach a boundary separating two different media partially reflect (generating a reflected pulse in the original medium) and partially transmit (generating a transmitted pulse in the new medium).

There are several details that we must make note of. First, **transmitted pulses** are always **upright**: incident crests will partially transmit as crests, and incident troughs will partially transmit as troughs. The amplitude of the transmitted pulses will be discussed shortly.

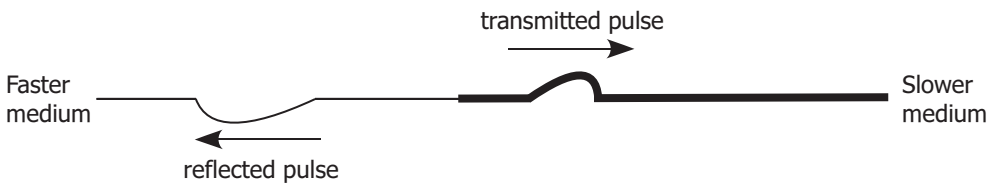
> **Partially transmitted** pulses are **always upright**.

The nature of the partial reflection depends on how the two media compare to each other. In particular, each medium will have a characteristic speed at which the pulses move through it. As was noted in the previous lesson, the speed of a wave is entirely dependent on the medium. Different media will carry waves at different speeds.

Waves Passing through the Junction from a Light Medium to a Heavy Medium (Like a Fixed End)

When a wave passes from a faster medium into a slower medium (for example, from a lighter spring to heavier spring), the partial reflection will resemble that from a **fixed end**. This is because the second medium, being a heavier medium, is harder to get going—it is "relatively fixed" compared to the original medium. The reflected pulses will be inverted. The diagram below shows an incident pulse moving to the right towards a boundary separating two media. The incident pulse is in the faster, lighter medium.

The diagram below is how the media would appear a short while after the incident pulse has hit the boundary. The reflected pulse and the transmitted pulse are both shown.



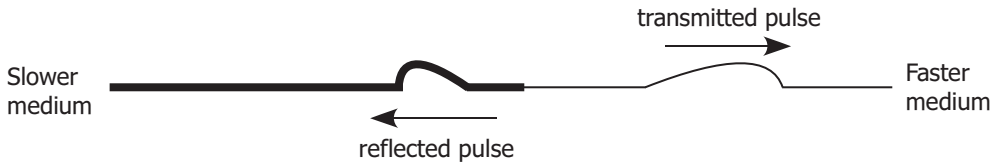
There are several details to make note of:

- The transmitted pulse, as expected, is upright.
- The reflected pulse, as expected, is inverted (reflected from a **fixed end**).
- The transmitted pulse is closer to the boundary than the reflected pulse is. This is because they were both produced at the same time at the boundary, and immediately started moving away from it. The reflected pulse, being in the faster medium, gets away from the boundary faster, and so gets farther in the same time.
- The amplitudes of the reflected pulse and the transmitted pulse are smaller than the incident pulse. This is because the energy of the incident pulse has split, forming the two smaller pulses.
- The reflected pulse is the same length along the rest position as the incident pulse, as expected since the wave is still moving at the same speed.
- The transmitted pulse is shorter than the incident pulse. This is because, when entering the slower medium, the back edge of the incident pulse was going faster than the front edge, which was already in the slower medium. This allowed the back edge of the pulse to "catch up" somewhat to the front edge.

Waves Passing through the Junction from a Heavy Medium to a Light Medium (Like a Free End)

When a wave passes from a slower medium into a faster medium (for example, from a heavier spring to lighter spring), the partial reflection will resemble that from a **free end**. This is because the second medium, being a lighter medium, is easier to get going—it is "relatively free" compared to the original medium. The reflected pulses will be upright. The diagram below shows an incident pulse moving towards the right towards a boundary separating two media. The incident pulse is in the slower medium.

The diagram below is how the medium would appear a short while after the incident pulse has hit the boundary. The reflected pulse and the transmitted pulses are both shown.



Again, there are several details to make note of:

- The transmitted pulse, as expected, is upright.
- The reflected pulse, as expected, is also upright (reflected from a **free end**).
- The transmitted pulse is farther from the boundary than the reflected pulse is. This is because they were both produced at the same time at the boundary, and immediately started moving away from it. The reflected pulse, being in the slower medium, gets away from the boundary less quickly, and so does not get as far in the same time.
- The amplitudes of the reflected pulse and the transmitted pulse are smaller than the incident pulse. This is because the energy of the incident pulse has split, forming the two smaller pulses.
- The reflected pulse is the same width as the incident pulse, as expected since the wave is still moving at the same speed.
- The transmitted pulse is wider than the incident pulse. This is because, when entering the faster medium, the front edge of the incident pulse was going faster than the back edge, which was still in the slower medium. This allowed the front edge of the pulse to "dash away" from the back edge.

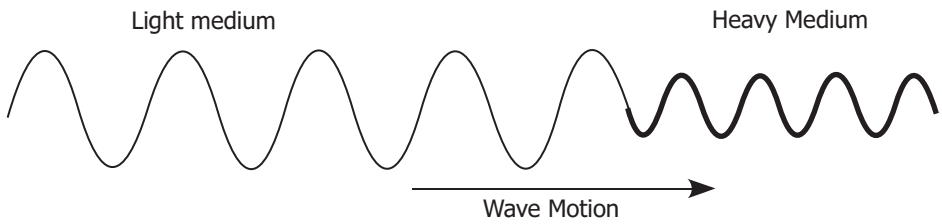
Periodic Wave Transmission

With the reflection of a single pulse now covered, we can turn our attention to the reflection of a wave consisting of many pulses (crests and troughs) regularly spaced. This is a "periodic wave."

Let's again use two different springs that are connected together. Since the **speed** of a wave **depends** on the **medium**, the **wave will change speed** when it **transmits** into the new medium. In general, the **frequency (or period)** of a wave will **be the same** as the frequency (or period) of the source of that

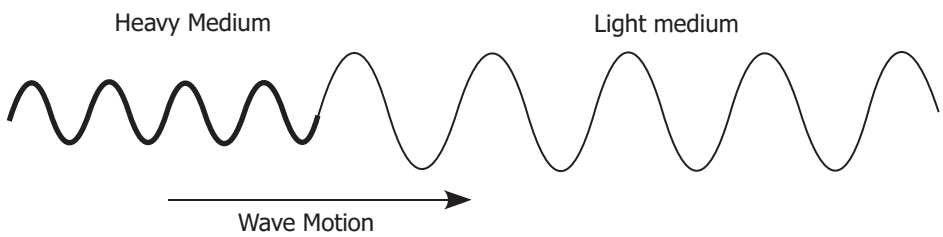
wave. But in this case, the incident waves act as the source for the newly transmitted wave. This means that the frequency of the transmitted wave will necessarily be the same as the frequency of the incident wave. If the frequency of the wave is constant, and the speed of the wave changes in the new material, then the wavelength will need to change. The wave equation $v = \lambda f$ shows how to calculate this change.

Let us examine the case of a wave moving from a less dense (and therefore faster) medium to a more dense (and therefore slower) medium. An example of this would be a wave travelling from a light rope to a heavy rope. In this case, the wave slows down when it transmits into the heavy rope, and so the wavelength will decrease.



Note we are ignoring the reflection of the incident waves in order to simplify the idea of waves changing speed and wavelength, but not frequency when they are transmitted across the boundary between two different media.

If the wave travels from the heavier (slower) rope to the lighter (faster) rope, both the speed and the wavelength increase. When a wave enters a new medium, the speed and the wavelength both change; the frequency (and period) does not change.



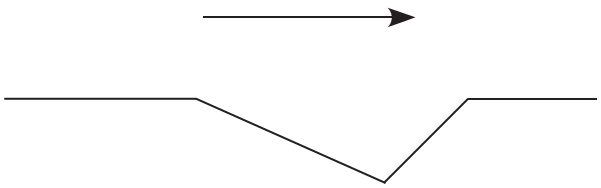
When a wave enters a new medium, the frequency will remain the same as before while the speed and wavelength will both change. The equation $v = \lambda f$ can be used in each of the two media.

Learning Activity 7.3

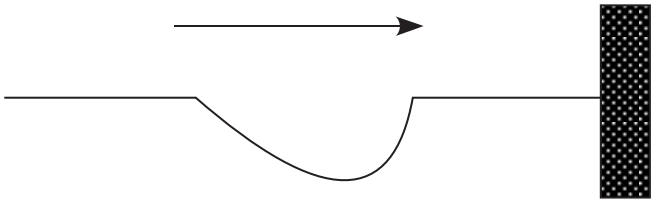
Reflection and Transmission of Waves in One Dimension

1. A pulse is sent down a spring that is attached to another spring with unknown properties. The pulse returns inverted and with a smaller amplitude. Compared to the first spring, is the speed of the waves slower or faster in the second spring?

2. The following pulse is sent along a light spring towards a junction with a free end. Draw and describe the reflected pulse. (Note: Waves with square or sharp corners are called ideal waves. They are used in order to facilitate the drawing of diagrams.)



3. The following pulse is sent along a light spring towards a junction with a fixed end. Draw and describe the reflected pulse.



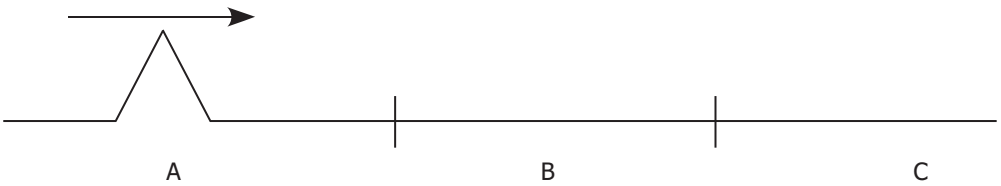
4. A pulse travelling in a heavy medium is incident unto the junction with a light medium, as indicated in the diagram below.

Draw and describe the reflected pulse and the transmitted pulse.

(continued)

Learning Activity 7.3: Reflection and Transmission of Waves in One Dimension (continued)

5. A triangular pulse is created in medium A and passes through media B and C. The speeds of the pulses in media A, B, and C are 1.0 m/s, 2.0 m/s, and 1.5 m/s respectively. The arrow shows the direction of motion of the pulse. For each of the following situations as the wave moves along the medium, draw diagrams to show the wavelength, the approximate amplitude, and whether or not the pulse is inverted.



a) The partially reflected pulse in medium A.
b) The pulse transmitted to B.
c) The partially reflected pulse in medium B.
d) The partially transmitted pulse in medium C.

Lesson Summary

In this lesson, you studied the reflection and transmission of waves and pulses.

We can define **reflection** as the return of a pulse or wave from the boundary of a medium.

Pulses and waves are reflected from a solid barrier in an inverted way. Pulses and waves are reflected from a free end on the same side (upright).

When a wave moves from a less dense material to a material of greater density, the partially transmitted wave does not change its frequency, but the wavelength and speed are less.

When a wave moves from a more dense material to a material of lesser density, the partially transmitted wave does not change its frequency, but the wavelength and speed are greater.

The new wavelength or speed for a partially transmitted wave can be calculated using $v = f\lambda$. The amplitude will also be less because of some energy being carried in the partially reflected wave.

Partial reflection occurs when a wave moves from one medium to another. Some of the energy of the incident wave is reflected back into the original medium.

When a wave travels from a light medium into a heavy medium, the partially reflected wave has the same wavelength, frequency, and speed, but it has a smaller amplitude and is inverted.

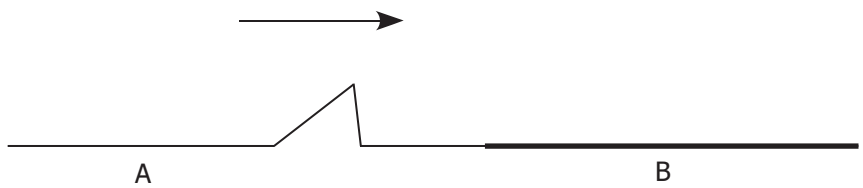
When a wave travels from a heavy medium into a light medium, the partially reflected wave has the same wavelength, frequency, and speed, but it has a smaller amplitude and is not inverted.

NOTES

Assignment 7.1, Part B

Reflection and Transmission of Waves in One Dimension (10 MARKS)

A pulse of the shape below originates in spring A. The speed of the pulse in this spring is 4.0 m/s. Another spring, B, is connected to spring A. The speed of the pulse in spring B is 2.0 m/s. The "short" end of the original pulse is the right side with the steep decline.



a) Draw a diagram showing the reflected pulse. In your diagram, pay particular attention to the wavelength of the reflected pulse, the amplitude of the pulse, whether or not it is inverted, and in what direction the "short" end of the pulse is facing.

(continued)

Assignment 7.1, Part B: Reflection and Transmission of Waves in One Dimension (continued)

b) Draw a diagram showing the partially transmitted pulse. In your diagram, pay particular attention to the wavelength of the transmitted pulse, the amplitude of the pulse, and in what direction the "short" end of the pulse is facing.

c) Of the quantities, speed, wavelength, frequency, and amplitude, which of these does not change as a wave is partially reflected or partially transmitted?

_____

_____

d) Of the quantities, speed, wavelength, frequency, and amplitude, which of these is always decreased in size as a wave is partially reflected or partially transmitted?

_____

_____

Method of Assessment

The total of 10 marks for this assignment will be determined as follows:

For each of parts (a) and(b),

- 1 mark for determining the correct wavelength of the new pulse
- 1 mark for determining the correct relative amplitude of the pulse
- 1 mark for determining the correct side of the new pulse
- 1 mark for determining the correct direction in which the "short" end faces

For each of parts (c) and (d),

- 1 mark for the correct answer

Lesson 3: Wave Interference and Standing Waves in One Dimension (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain what is meant by the terms "wave interference" and the "principle of superposition"
- ❑ define the terms " constructive interference" and "destructive interference"
- ❑ draw a diagram showing the result of two pulses encountering each other in constructive or destructive interference
- ❑ define the term "standing wave"
- ❑ explain what a "node" or "nodal point" is and how it is produced
- ❑ draw the resulting wave in a standing wave pattern when two given waves are over each other
- ❑ define the terms "loops" or "antinodes"
- ❑ describe the spacing between nodes relative to the wavelength of waves producing an interference pattern
- ❑ explain how a change in frequency alters the spacing between the nodal points

Key Words

wave interference
destructive interference
loops
out of phase
principle of superposition
standing wave
antinodes
constructive interference
node
in phase

Introduction

Up until now, we have studied the motion of one wave at a time. In this lesson, we will learn what happens when two waves meet. We will find that the waves pass through each other and keep on moving, but while passing through each other their amplitudes are affected. When particles meet, they do not pass through each other but they may deform each other or bounce off each other. We will also learn what happens when continuous waves travelling out from a source encounter other waves that originate from another source or are reflected from the same source.

Wave Interference and the Principle of Superposition

Interference is the second behaviour of waves that we are exploring (reflection was the first). Interference is closely associated with an ability that waves possess called **superposition**. Superposition is the ability for two waves (or individual pulses) to be in the same place at the same time. Suppose that two pulses are travelling in the same medium in opposite directions towards each other. You might think that when they come together, they will "hit" each other. You may even suppose that they will bounce or reflect off of each other. Surprisingly, they would do neither of these things.

Unlike matter, waves do not object to being "stacked" into the same place at the same time. Of course, stacked isn't quite the right word for it. You can certainly stack books on top of each other, but when you do you do not end up with books in the exact same place. You end up with one book above another. Imagine having two solid books in the exact same place at the exact same time. This isn't possible, of course; they will bump off of each other, and any attempt to squash them together might wreck the books but won't succeed in getting them together in the same place.

Waves, on the other hand, have no problem with being put into the same place at the same time, and when they do we call it "superposition" and say that the waves are superimposed. When two waves or individual pulses are superimposed, the result is called **interference**. When two pulses are in the same place at the same time, the medium carrying those pulses will take on an appearance that is different than either pulse by itself. The medium will, in fact, take on a sort of "combined shape"—the **principle of superposition** guides us in how to find this shape.

> **Superposition** occurs when two waves (or individual pulses) are in the same place at the same time. **Interference** is what happens when two waves (or pulses) are superimposed.

According to the principle of superposition, the amplitudes of the overlapping pulses add. Note that crests are considered to have positive amplitudes, and troughs are considered to have negative amplitudes. This means that if a crest is superimposed with another crest, the result will be an even bigger crest (two positive amplitudes add to a larger positive amplitude), and that two troughs superimposed will result in an even larger trough (two negative amplitudes add to an even larger negative amplitude). Both of these cases (crest with crest and trough with trough) are referred to as **constructive interference** because the amplitudes are built up larger. When waves are aligned so that crests are superimposed with crests and troughs are superimposed with troughs, we say that the waves are **in phase**.

> **Constructive interference** occurs when two similar pulses (two crests or two troughs) are superimposed. The result is a larger crest or trough, and we say that the waves are "**in phase**."

If a crest is superimposed with a trough, however, the crest's positive amplitude and the trough's negative amplitude will somewhat "cancel" out, resulting in a smaller amplitude (the result can even be zero total amplitude in the case of a crest and trough that are equally large). This is referred to as **destructive interference**. When waves are aligned so that crests are superimposed with troughs, we say that the waves are **out of phase**.

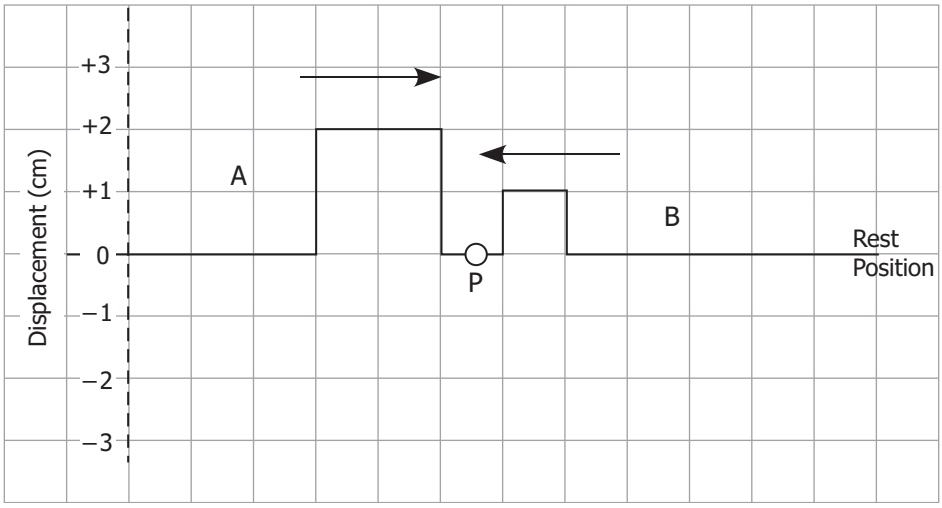
> **Destructive interference** occurs when two opposite pulses (one crest and one trough) are superimposed. The result is a smaller pulse, or possibly even no resultant pulse in the case of a crest and a trough of the same size, and we say that the waves are "**out of phase**."

Regardless of the type of interference that occurs, perhaps the most amazing thing of all here is that, when superimposed, both of the original pulses still exist and are still moving as if nothing unusual is happening. It really is only the shape of the medium itself that is affected by the interference. Shortly after two pulses superimpose, the original pulses will separate from each other and continue in the same direction that they were originally travelling in, completely unchanged by the event!

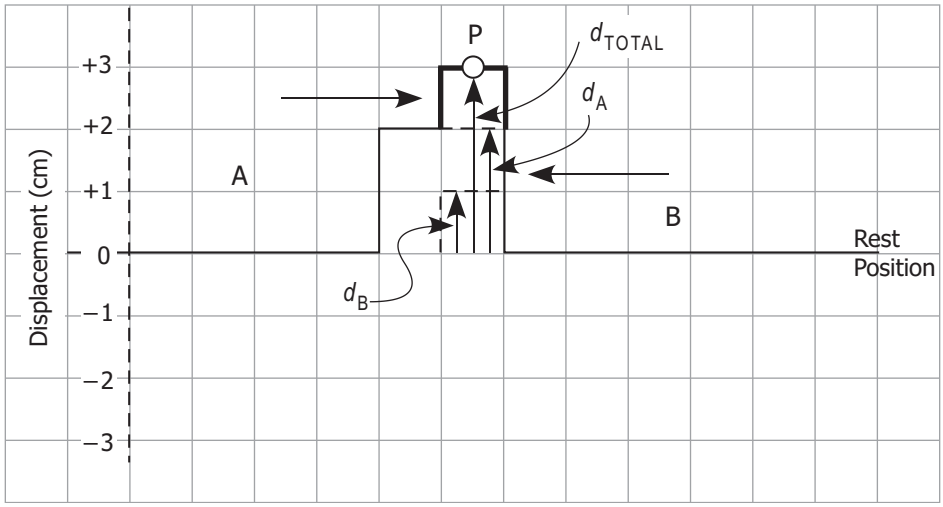
The Principle of Superposition and Constructive Interference

Wave interference occurs when two or more waves act simultaneously on the same particles of a medium, resulting in a new displacement. To determine the new displacement of the particles, we use the **principle of superposition**, which states that the resultant displacement of a given particle is equal to the sum of the displacements that would have been produced by each wave independently. The individual displacements may be positive (+) or negative (–).

The diagram below shows two ideal (square) pulses on a string approaching each other. We are using ideal pulses in order to simplify our analysis. We will follow the motion of point P as the pulses pass through each other.



The amplitude of pulse A is +2 cm and the amplitude of pulse B is +1 cm. At a later moment in time, the pulses begin to interact with each other, as shown below. At the moment shown, point P has been moved up upward +2 cm by pulse A and +1 cm by pulse B.

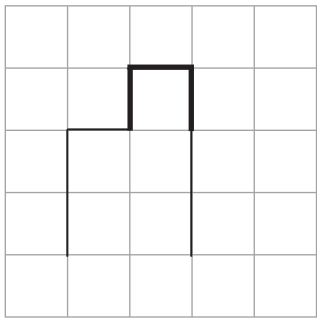


Using the **Principle of Superposition**, we add the displacements for wave A and wave B to give the total displacement for the point P.

$d_A + d_B = d_{TOTAL}$
(+2 cm) + (+1 cm) = +3 cm

Other points in the medium around point P where the waves overlap can also be considered. The displacements for those points follow the principle of superposition, and all of the displacements in the region of overlap will be +3 cm.

The resultant wave that represents the sum of the two waves that are overlapping then has the following shape.



The **resultant wave** represents the total wave that results when two waves overlap and interfere with each other.

You should see that the resultant wave is just wave B (the small wave) added on top of wave A (the large wave).

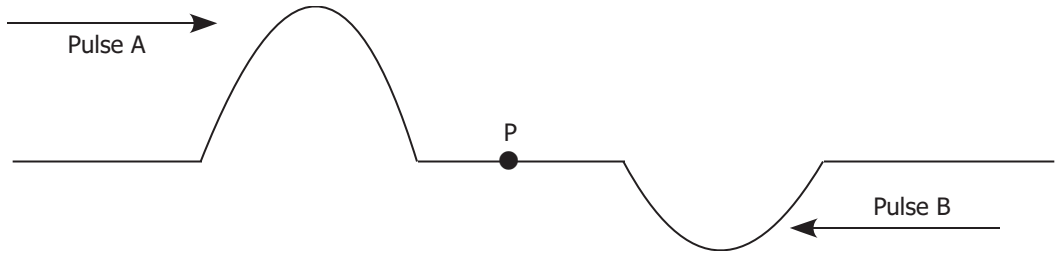
> Two waves interfering to produce a resultant displacement greater than the displacement that would be caused by either wave is called **constructive interference**.

Remember that crest A plus crest B makes a larger crest. Also, trough A plus trough B will produce a large trough. Both of these are constructive interference.

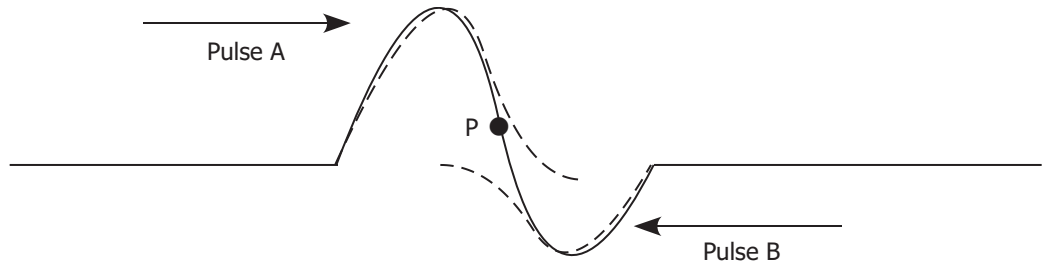
The Principle of Superposition and Destructive Interference

In this section, we will look at an example of **destructive interference**. This occurs when the resultant displacement is smaller than the displacement caused by one wave. Now that you have seen how the displacements of waves add to produce the displacement of the resultant wave using ideal (square) waves, let us consider more realistic waves to illustrate destructive interference.

The diagram below shows pulses A and B approaching each other, as shown.



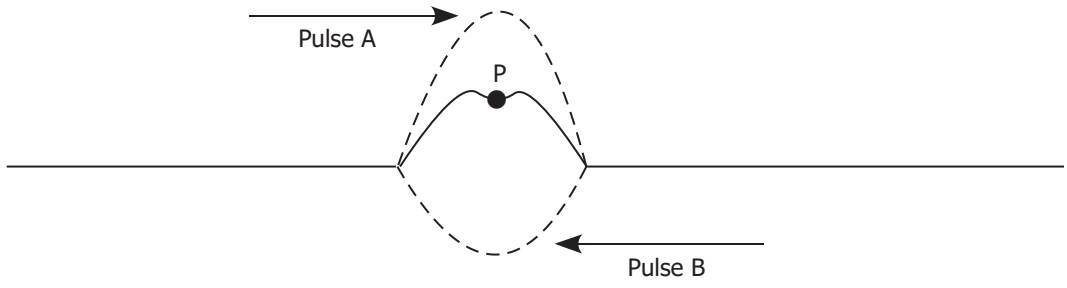
The series of diagrams shows what happens to the point P as pulses A and B interfere with each other.



At the moment shown, pulse A displaces point P upward 8 mm and pulse B displaces the point downward by 3 mm. The resultant displacement of the pulse is 5 mm upward.

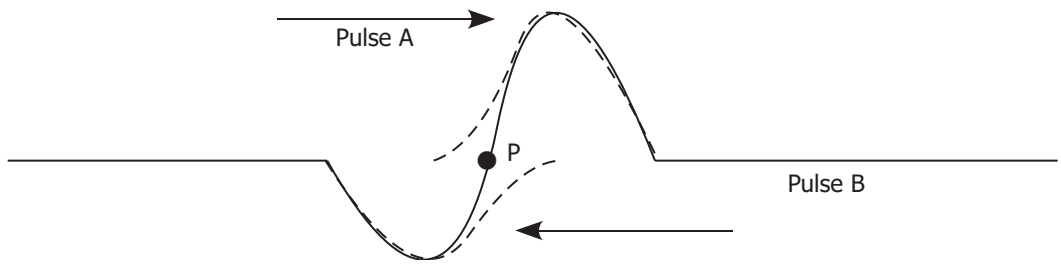
Note that in the areas of the medium where interference does not occur, the position of the particles in the medium (represented by the solid line) is that created by each individual wave.

In the diagram below, the pulses are directly on top of each other.



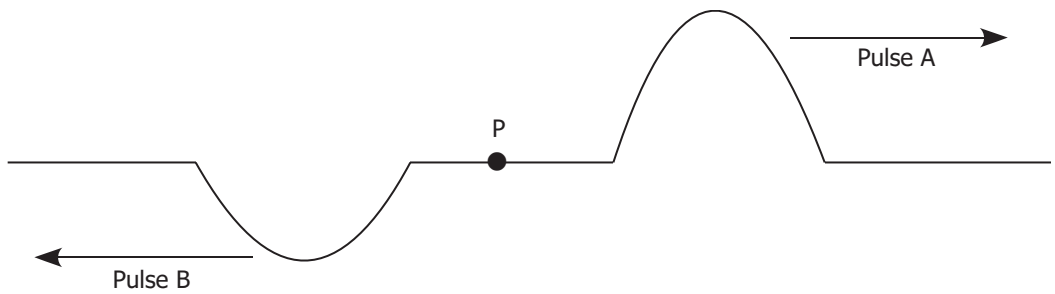
In this diagram, point P is displaced upward 20 mm upward by pulse A and 12 mm downward by pulse B for a net displacement of 8 mm upward.

The final diagram shows the pulses after they have nearly completely passed through each other.



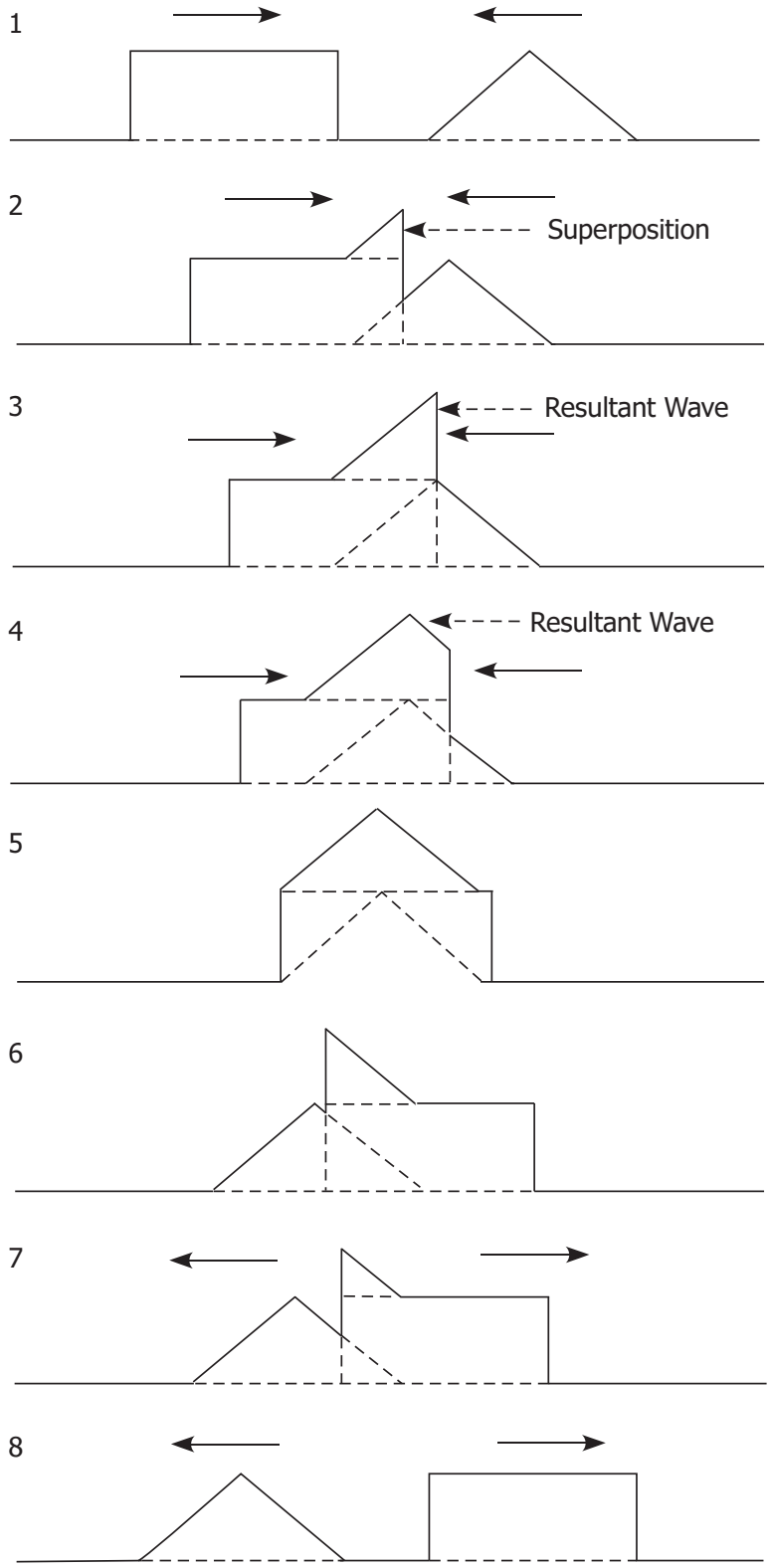
In this diagram, the upward displacement by pulse A (+9 mm) is cancelled by the downward displacement of B (–9 mm).

Again, after the waves have passed through each other, they continue on exactly as they had been before interference occurred.



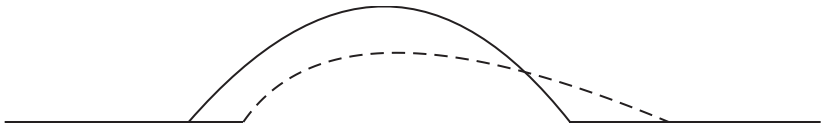
Use the principle of superposition in this series of snapshots of an ideal square wave and an ideal triangular wave interfering as they pass through each other to relate the individual waves to the resultant wave.

Interference of Two Wave Pulses on the Same Medium



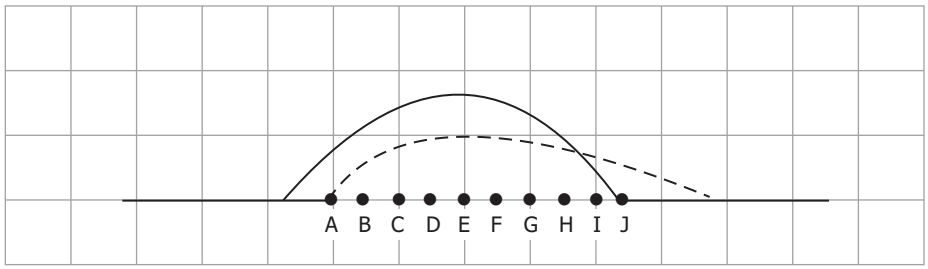
Example 1: Superposition of Waves

Let's use the principle of superposition to draw the resultant wave for two non-ideal pulses.



Draw in the rest position in the region where the two waves overlap.

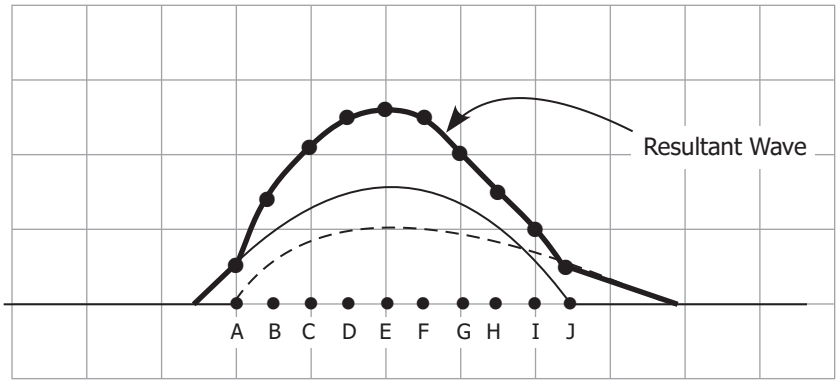
On the rest position, put a dot at the left edge of the broken wave and label it A. Starting at A, make a series of dots 0.5 cm apart along the rest position until you reach the right edge of the solid wave.



Now measure the displacement for each wave at each point A through J, and record these in a chart as indicated below. Add the displacements of the solid wave and the broken wave to determine the displacement of the resultant wave.

Point on Medium	Displacement of Solid Wave (mm)	Displacement of Broken Wave (mm)	Displacement of Resultant Wave (mm)
A	+6	0	+6
B	+10	+4	+14
C	+13	+8	+21
D	+15	+9	+24
E	+16	+10	+26
F	+15	+9	+24
G	+13	+9	+20
H	+8	+7	+15
I	+4	+6	+10
J	0	+4	+4

Now plot in the displacement of the resultant wave and draw in the resultant wave. Where there is no overlapping, the resultant wave is simply due to the one wave that is present at those points on the medium.

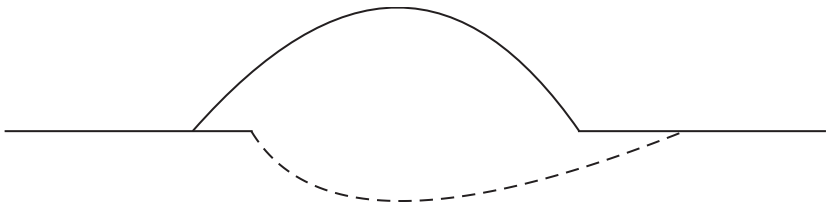


Learning Activity 7.4

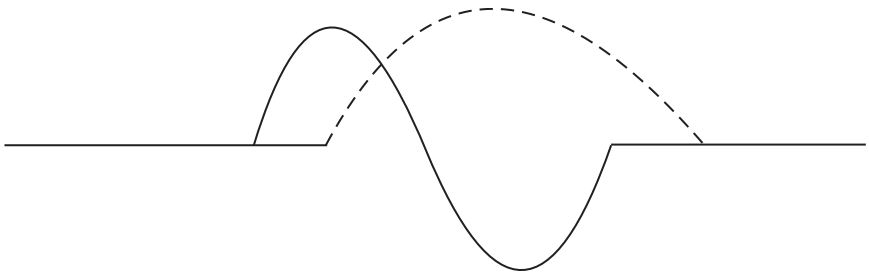
Wave Interference and Standing Waves in One Dimension: Part 1

1. Use the principle of superposition to draw in the resultant wave.

   a)



   b)



Standing Waves

If two periodic waves (consisting of many crests and troughs each) with the same amplitude and wavelength travel in opposite directions, the resulting interference pattern is particularly interesting.

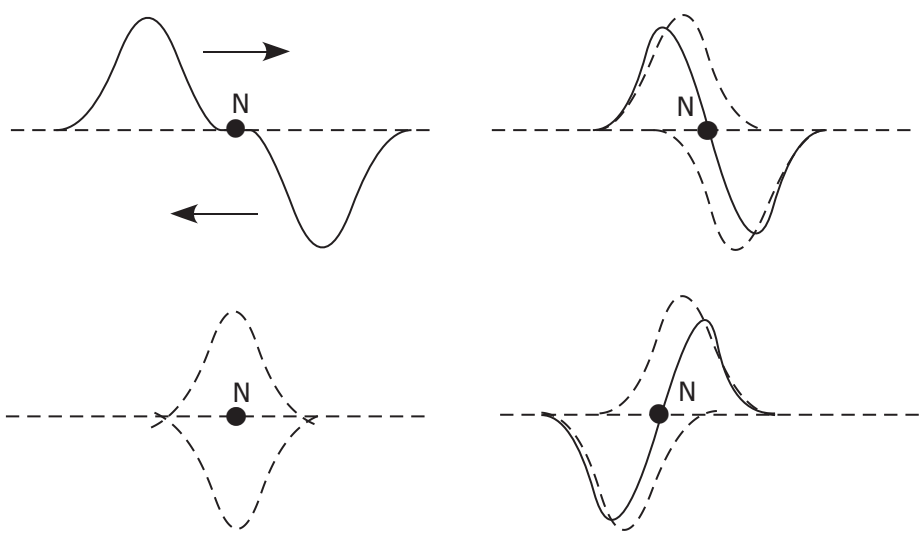
> A **standing wave** can be defined as the result of two waves of the same wavelength and amplitude travelling in opposite directions through the same medium.

Just as for individual pulses, these two waves will ultimately travel right through each other. They will certainly not stop! The reason that we use the term "standing wave" at all is due to the amazing pattern of movement that the medium will undergo as a result of these two moving waves. The medium will continue to shake back and forth, but in a regular repeating way that completely hides the motion of the waves that are causing it to do so.

> A standing wave results when two identical waves pass through each other. Although the waves will continue to move, the medium will take on a motion that conceals this fact.

In working towards explaining standing waves, let's consider what happens when **positive and negative pulses** of **equal amplitude** and **length** travel in opposite directions and interfere.

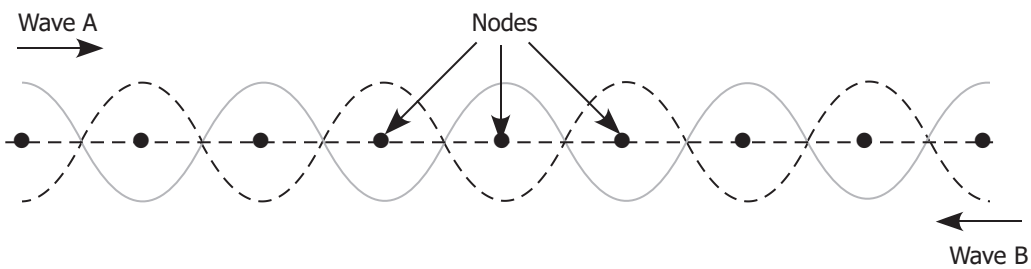
Surprisingly, there will be a point on the medium **that remains perfectly at rest** throughout the entire interference event. This point is called a **node**. The diagram below shows two pulses of equal but opposite amplitudes approaching and passing through each other. The location of the node is shown. At each of the moments, the upward height of the crest pulse is exactly cancelled by the downward height of the trough pulse, which is what produces the node.



A **node** is a point on the medium that does not move at all due to the interference of two equal and opposite pulses.

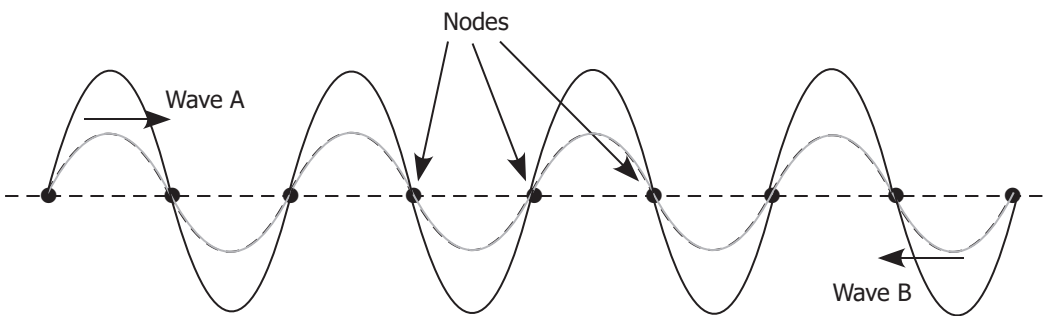
Standing Wave Pattern: Constructive and Destructive Interference

In the situation shown below, a wave A (dotted line) is moving to the right while an identical wave B (broken line) is moving to the left. At the moment shown, the two waves are directly on top of each other. In this case, **destructive interference** occurs at every point in the medium. The resultant shape of the whole medium is that of a flat horizontal line. Although the entire medium is flat at the moment, this will not last for long. As the waves move (A going right and B going left), they will quickly lose this "mirror image" appearance, except at the points indicated with small circles—these are all **nodes**.

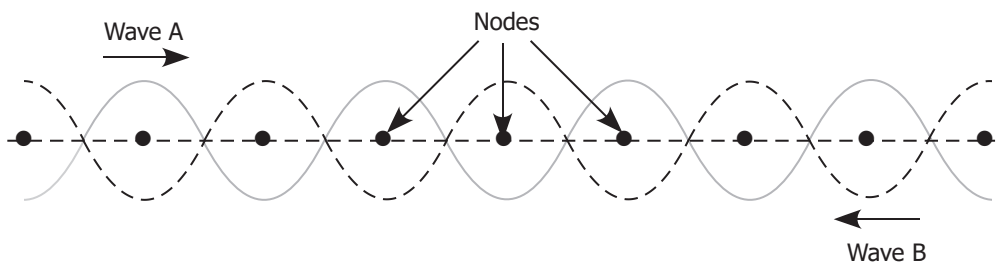


The two waves will continue to move in such a way that troughs are soon over other troughs and crests are over crests. **Constructive interference** occurs and the magnitude of the resultant displacement is twice that of the individual waves.

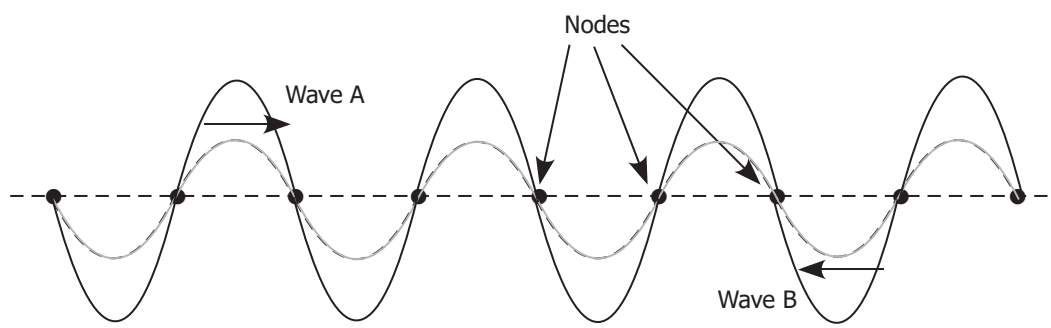
Note however that at the points we have already claimed are **nodes**, the **heights of both waves are zero**. Even though constructive interference is occurring, the points will continue to have zero height!



A short time later, the waves will have moved again to produce a **net horizontal displacement of zero**. While this is the same as our first picture, note that waves A and B have traded places. Where we originally had a crest from A, we now have a crest from wave B; and where we had a trough from B, we now have a trough from A. Nonetheless, the medium has "collapsed" from what we had a moment ago.



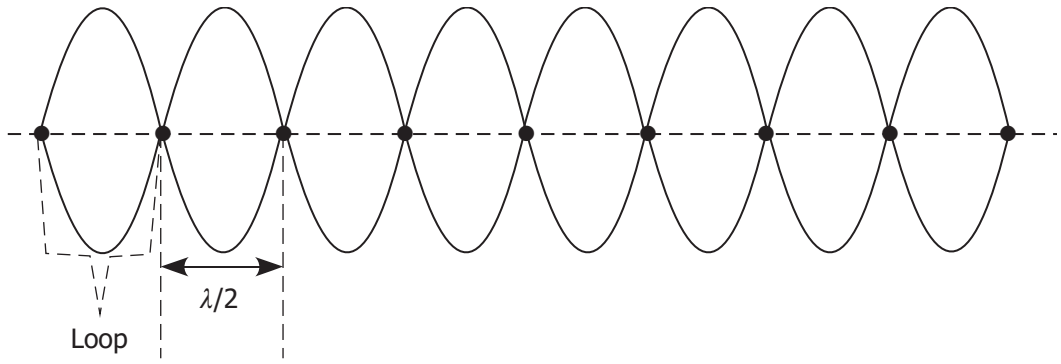
Finally, after another brief bit of time, constructive interference will occur once again. We again have the opposite of what we had not long ago. Where we used to have a large crest, we now have a large trough; and where we had a large trough, we now have a large crest. Seemingly undisturbed by all of this are the nodes.



Standing Wave Pattern: The Overall Form

When the waves that produce a standing wave pattern continually pass through each other, they produce regions in which the medium continually shakes back and forth, as if secured at either end by nodes. Each of these regions may be called a **loop**. The standing wave interference pattern shown below shows these loops. Of course, the medium will never look like this, but if you were watching an actual standing wave, the loops would seem to be there as the medium continually dances back and forth. Midway between the nodes are areas where the medium reaches farthest out from the rest position. These areas are called **antinodes**. Each loop has an antinode at its centre.

Standing waves have the medium moving in such a way as to give the appearance of loops. Each loop has an antinode in its centre (the point that moves most), and a node at each end.



Notice that the nodes are an equal distance apart and that their spacing is equal to one-half the wavelength of the interfering waves.

The **distance between nodes** in a standing wave pattern is **one-half of the wavelength**.

$$d = \frac{1}{2}\lambda$$

Surprisingly, standing waves can even occur between a wave and its own reflection from the end of the medium (from a free or fixed end). The reflected wave acts exactly like our "wave B" in the above discussion, and interferes with the incident wave (wave A) producing the standing wave. The incident wave and the reflected wave have the same amplitude and wavelength, and move in opposite directions through the same medium. These are exactly the ingredients needed for standing waves. The distance between nodal points (and therefore the number of loops present) may be altered by changing the frequency of the source. The larger the frequency, the smaller the wavelength will be, and so the closer together the nodal points will be.

For a given length of rope or any other medium, only certain wavelengths are capable of maintaining a standing wave pattern. This is because the ends of the medium must be nodal points (in the case of a fixed end) or antinodes (in the case of a free end). We will discuss this further in the next section.

Note: The phenomenon of standing waves is difficult to comprehend unless it is observed. At this point, it is suggested that you, the student, find an animation of a standing wave on the Internet. A simple search of "standing wave applet" or "standing wave animation" should provide many sites where you can observe standing waves in action.

Example 2: Standing Waves and the Speed of the Wave

A wave is produced on a spring by shaking one end back and forth 15 times in 3.0 seconds. The waves travel down the spring and reflect from the fixed end. The incident and reflected waves interfere to produce a standing wave with nodes that are 0.40 m apart.

a) What is the frequency of these waves?

Given:	Number of waves	15
	Time interval	$\Delta t = 3.0$ s
Unknown:	Frequency	$f = ?$
Equation:		f = number of events/time interval
Substitute and solve:		$f = \frac{15}{3.0\ \text{s}} = 5.0\ \text{Hz}$

The frequency is 5.0 Hz.

b) What is the wavelength of these waves?

Since the distance between nodes is one-half of the wavelength, the wavelength is double the distance between nodes.

The wavelength is (2)(0.40 m) = 0.80 m.

c) What is the speed of these waves?

Using the universal wave equation ($v = f\lambda$), substitute and solve:

v = (5.0 Hz)(0.80 m) = 4.0 m/s.

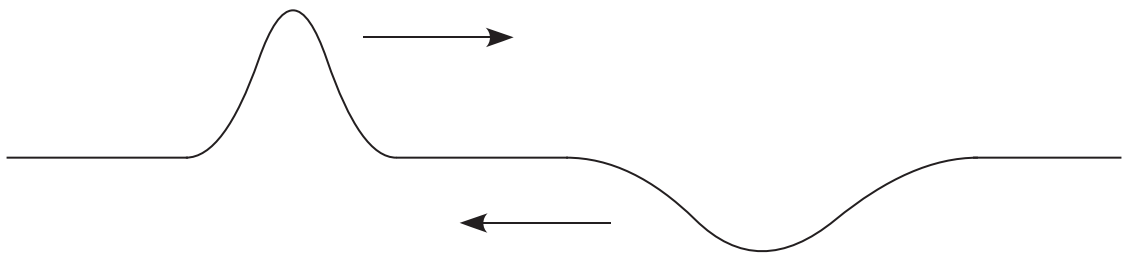
The speed of the wave is 4.0 m/s.

Learning Activity 7.5

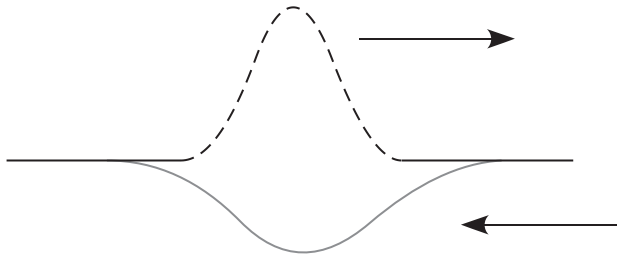
Wave Interference and Standing Waves in One Dimension: Part 2

1. Why are standing waves not produced in a swimming pool where many people may be present?

2. Two pulses move towards each other as shown below.



For the case when the pulses overlap so they are directly above each other, draw the resultant shape.



3. A string in an instrument may vibrate at a frequency of 4.0 Hz, and the distance between the nodes is 0.30 m. What must be the speed of the waves on the string?

4. The speed of a wave on a string instrument such as a guitar may be 350 m/s. If the frequency of the standing waves is 420 Hz, how far apart are the nodes?

(continued)

Learning Activity 7.5: Wave Interference and Standing Waves in One Dimension: Part 2 (continued)

5. A standing wave is produced in a spring fixed at one end. Nodes are counted with the first node located at the fixed end. The distance between the third node and the eighth node is 1.50 m. The frequency of the waves is 12.0 Hz.
   a) Draw a diagram of this standing wave. Number each of the nodes.
   b) What is the distance between adjacent nodes?
   c) What is the wavelength of these waves?
   d) What is the speed of these waves?
6. Waves travel at 15.6 m/s in a particular medium. The waves have a period of 0.500 seconds. If a standing wave is produced, how far apart would the nodes be located?

Lesson Summary

In this lesson, you studied wave interference and learned how to draw the resulting wave interference patterns based on the principle of superposition.

Wave interference occurs when two or more waves act simultaneously on the same particles of a medium, resulting in a new displacement.

The **principle of superposition** states that the resultant displacement of a given particle is equal to the sum of the displacements that would have been produced by each wave independently.

Constructive interference occurs when the resultant displacement is greater than the displacement that would be caused by either wave by itself.

Destructive interference occurs when the resultant displacement is smaller than the displacement caused by one wave.

A **standing wave** can be defined as the resultant of two wave trains of the same wavelength, frequency, and amplitude travelling in opposite directions through the same medium.

A **node** or **nodal point** is the point that remains at rest when positive and negative pulses of equal amplitude and length travel in opposite directions and interfere.

Loops or **antinodes** occur midway between the nodes, and are areas where double crests and double troughs occur.

The nodes in a standing wave pattern are equidistant and their spacing is equal to one-half the wavelength of the interfering waves.

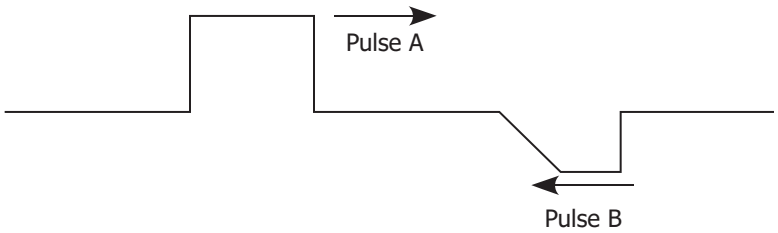
In a standing wave pattern, the incident waves and the reflected waves have the same frequency, wavelength, and amplitude.

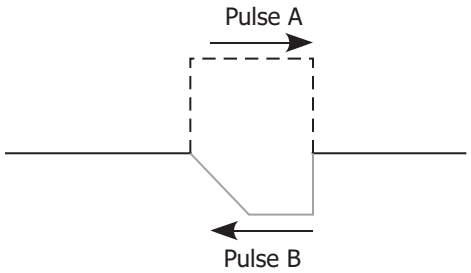
The larger the frequency of standing waves, the closer together the nodal points will be.

Assignment 7.1, Part C

Wave Interference and Standing Waves in One Dimension (5 MARKS)

1. Two pulses as shown below are approaching each other. When they are directly on top of each other, draw the resulting pulse.





2. Standing waves are set up in a string by a source vibrating at 100.0 Hz. Seven nodes are counted in a distance of 63.0 cm (including one node at each of the ends). Draw a diagram to help visualize the situation.

   a) How many wavelengths must there be in the string?

(continued)

Assignment 7.1, Part C: Wave Interference and Standing Waves in One Dimension (continued)

b) What is the wavelength of the waves in the string?

c) What is the distance between each node?

d) What is the speed of these waves?

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for drawing the resulting pulse in question 1
- 1 mark for determining the number of wavelengths in question 2(a)
- 1 mark for determining the wavelength in question 2(b)
- 1 mark for determining the distance between each node in question 2(c)
- 1 mark for determining the speed of the waves in question 2(c)

Lesson 4: Resonant Frequency and Harmonics (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the following terms: "resonant frequency," "natural frequency," "fundamental frequency," "harmonics," "first harmonic," "overtone"
- ❑ describe the relationship between the length of the string, the number of loops, the wavelength, the number of nodal points, and the number of the harmonic

Key Words

resonant frequency
harmonics
natural frequency
first harmonic
fundamental frequency
overtone

Introduction

In this lesson, we extend our study of standing waves to resonant frequencies. We can see the phenomenon of resonant frequency in the vibration of a good quality wine glass, the vibration of a string in a musical instrument, or in the clatter of an ashtray that vibrates to the beat of a car radio. We will see the relationship between frequencies, harmonics, and overtones, and in turn we will see how these relate to the length of a string, the number of loops in the standing wave, the wavelength, the number of nodal points, and the number of the harmonic.

Resonance

The idea of standing waves—that a wave can interfere with its own reflection—leads directly to a very interesting phenomenon called **resonance**. Resonance is perhaps best introduced with a simple example that you are no doubt familiar with. Let's look carefully at how a person can push someone sitting on a swing in order to get them swinging really high.

Consider a person sitting on a swing, which is initially not moving at all. They ask for and receive some pushes from a friend. To keep it simple, let's assume that the person sitting in the swing just sits on the swing and enjoys the ride, doing nothing to help. Without studying any physics at all, most people know that it is best to give several relatively small pushes that are timed just right.

The person on the swing will swing forwards and backwards with a surprisingly regular timing. We could call the amount of time to swing out and back the **period.** We could also call the "regularity" of the swinging cycles the "frequency" (i.e., how many cycles get completed each second, or minute, etc.). The person on the swing will swing back and forth with a frequency that entirely depends on the swing, and not the person pushing it. Perhaps you have noticed that swings with short chains swing more quickly (a higher frequency) while swings with longer chains swing more slowly (lower frequency). Each swing has what we like to call a **natural frequency**, or **harmonic frequency**—the frequency that it swings at automatically, of its own accord due to its design (primarily length for a swing).

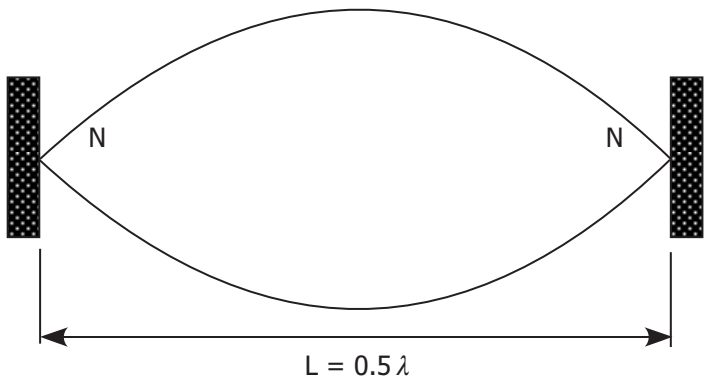
> A **natural** (or **harmonic**) frequency is the lowest frequency at which an object, like a simple pendulum or mass on a spring, will vibrate when it is allowed to vibrate freely.

Now, if the person pushing pushes with a timing (and therefore frequency) that matches the natural frequency, we get the condition that we call **resonance**. The size of the swings (which we could call amplitude) will get larger and larger with each push.

Of course, resonance is not unique to swings. Let's go back to the idea of a spring stretched out on the floor. You are holding one end, and the other end is firmly attached to the wall (and is therefore a fixed end). As the source, you can shake the end of the spring back and forth with any frequency you like, and therefore create waves of any wavelength that you like. You, of course, do not have any say in the speed of the waves, as that depends only on the medium. You would have to change the medium in order to change the speed.

Earlier, we mentioned that each loop of a standing wave is half of a wavelength, which means that if you shake your hand with the exact frequency that results in a wavelength equal to twice the length of the spring, you will create a standing wave with exactly one loop. This should not be much of a surprise as we have already discussed standing waves. The part that might be surprising is that if you continue to act as the source, shaking the spring with that same frequency, the amplitude of the standing wave will grow larger and larger. In essence, this standing wave has a frequency that is the natural frequency for this spring, and you (the source) are matching this frequency!

first harmonic = fundamental frequency (not an overtone)



Actually, to be a bit more exact, this is not "the" natural frequency, but rather "a" natural frequency—there are others.

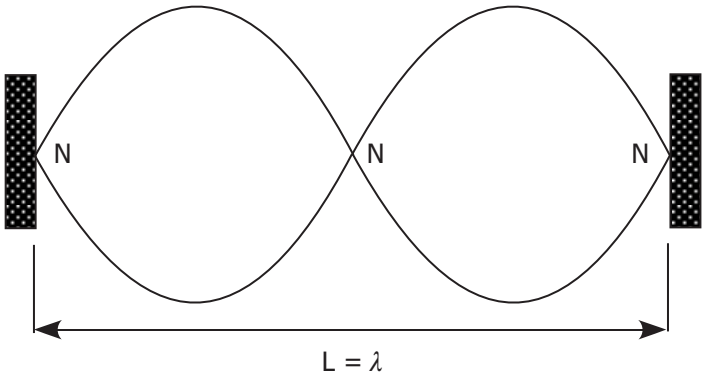
> The frequency that produces a single loop in the standing wave is called the **fundamental frequency**. The fundamental frequency is the lowest natural frequency with which an object will vibrate.

Overtones

If you were to double this frequency you would produce waves with half of the wavelength. This means that the wavelength would now match the length of the spring, and we would have a standing wave with exactly two loops. This would be another natural frequency. It is not the fundamental frequency—there is only one frequency that can be called that.

We would call this frequency an **overtone**. It is a natural frequency higher than the fundamental frequency. In this case, we have the second harmonic (or natural) frequency, which is the first overtone.

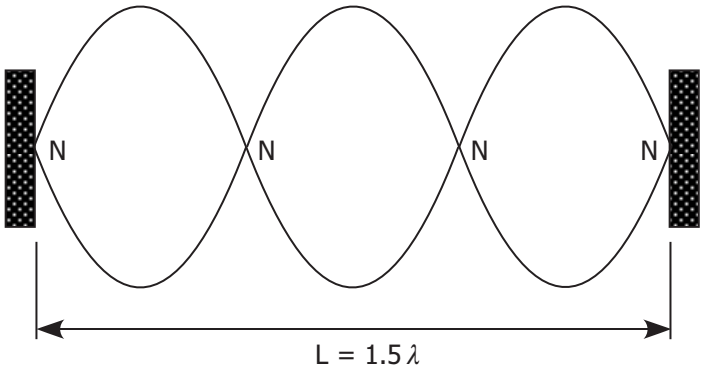
second harmonic = first overtone



The **fundamental frequency** is the lowest possible natural frequency. It results in a standing wave with one loop. Other (higher) frequencies that are also natural (they produce standing waves) are called **overtones**.

While there is only one fundamental frequency, there are lots of overtones—infinitely many in principle. This is because if you were to triple the fundamental frequency, you would get a standing wave with exactly three loops, while quadrupling the natural frequency would produce one with four loops, and so on. In general, an overtone is an integer multiple of the fundamental frequency, beginning with the integer 2.

third harmonic = second overtone



Overtones are integer (starting with 2) multiples of the fundamental frequency.

So let's summarize fundamental frequency, harmonics, and overtones.

The fundamental frequency (f_0) is the lowest frequency with which things naturally vibrate (there is only one loop or antinode). The fundamental frequency is also the **first harmonic** (natural frequency).

> The **number** of the **harmonic equals** the **number** of **loops** or **antinodes** in the standing wave pattern.

If we double the fundamental frequency (**2**f_0), this produces a standing wave in which there are two loops or antinodes. This frequency is also called the **second harmonic** (2x the fundamental frequency).

Now we get into overtones.

> **Overtones** are all natural frequencies higher than (multiples of) the fundamental frequency in a standing wave pattern.

So this frequency of 2x the fundamental frequency is also called the first overtone.

Example 1: Fundamental Frequency, Harmonics, and Overtones

For example, consider a fundamental frequency of 200 Hz, which could also be called the first harmonic frequency (this would be the lowest possible natural frequency and would result in a standing wave of one loop).

The first overtone would be the second harmonic frequency, which would be twice the fundamental frequency: 400 Hz (and would result in a standing wave with two loops).

The second overtone would be the third harmonic frequency, which would be three times the fundamental frequency: 600 Hz (and would result in a standing wave with three loops). And so on.

Frequency	Number of Loops	Harmonic	Overtone
f_0 = 200 Hz	1	first	
$2f_0$ = 400 Hz	2	second	first
$3f_0$ = 600 Hz	3	third	second

Now that you know the pattern, what is the frequency of this string for the sixth harmonic and which overtone is this?

The sixth harmonic means there are six loops or antinodes on the string and that the frequency is 6x the fundamental frequency.

Sixth harmonic frequency = $6f_0$ = 6(200 Hz) = 1200 Hz.

The overtone number is one less than the harmonic number, so in this case it would be the fifth overtone.

Example 2: Length of a String and its Fundamental Frequency

A guitar string has a length of 0.900 m and a fundamental frequency of 250.0 Hz. The string is vibrating with its frequency equal to the second harmonic.

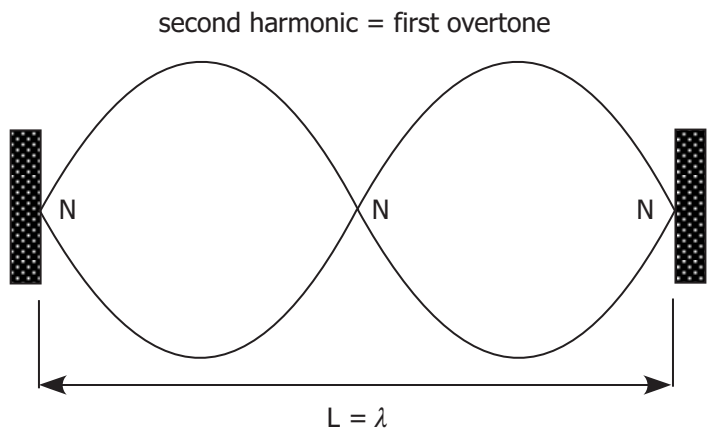
a) What is the frequency of this vibration?

Since this is the second harmonic, this frequency is 2x the fundamental frequency.

So the frequency is 2 x 250.0 Hz or 5.00×10^2 Hz.

b) What is the wavelength of this vibration?

Since this is the second harmonic, the standing wave pattern has two loops or antinodes.



The guitar string is 0.900 m long and this represents two loops or one complete wavelength.

So the wavelength is 0.900 m.

c) What is the speed of this wave on the string?

Use the universal wave equation to calculate the speed of the wave in the string.

$v = \lambda f = (5.00 \times 10^2 \text{ Hz})(0.900 \text{ m}) = 4.50 \times 10^2 \text{ m/s}$

The speed of the wave is 4.50×10^2 m/s.

Learning Activity 7.6

Resonant Frequency and Harmonics

1. If the length of a string is doubled, by what relative amount has the fundamental frequency changed?
2. A piano string is 1.10 m long. The fundamental frequency of the string is 131 Hz.
   a) What is the wavelength of the fundamental frequency?
   b) What are the frequencies of the first two overtones?
3. A string of length 2.50 m is fixed at both ends. The speed of the wave is 85.0 m/s. What is the fundamental frequency of the wave?
4. On one type of flute, when all the holes are closed, the lowest note it can sound is a middle C whose fundamental frequency is 261.6 Hz. At a temperature of 20° C, the speed of sound is 343 m/s. Assume that the flute is a cylindrical tube open at both ends. Determine the distance, *L*; that is, the distance between the mouthpiece to the end of the tube.

Lesson Summary

In this lesson, you extended your knowledge of standing waves to the frequencies associated with these waves.

A **resonant frequency**, or **natural frequency**, is the frequency at which a standing wave can exist.

The lowest resonant frequency is called the **fundamental frequency**. Resonant frequencies are a whole number multiple of the fundamental frequency.

Harmonics is another term for the resonant frequencies of standing waves.

The **first harmonic** is another term for the fundamental frequency.

In the case of the fundamental frequency, the distance between the two end points is equal to one half a wavelength. In this case, there is only one loop or antinode.

Overtones are the natural frequencies above the fundamental frequency.

NOTES

Assignment 7.1, Part D

Resonant Frequency and Harmonics (5 MARKS)

A string has a length of 2.50 m and is fixed at the ends. At a frequency of 85.0 Hz, a standing wave with five loops is formed.

a) What is the wavelength of the waves that travel on the string? Draw a diagram to help visualize the situation.

b) What is the speed of the waves?

c) What is the wavelength of the wave when this string of length 2.50 m is vibrating at the fundamental frequency of the wave?

d) What is the fundamental frequency of the wave?

(continued)

e) At what frequency would the third overtone occur?

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining the wavelength in part (a)
- 1 mark for determining the speed in part (b)
- 1 mark for determining the wavelength in part (c)
- 1 mark for determining the fundamental frequency in part (d)
- 1 mark for determining the frequency in part (e)

Module 7 Summary

Congratulations on completing Module 7.

Submitting Your Assignments

You will not submit your Module 7 assignments to the Distance Learning Unit at this time. Instead, you will submit them, along with the Module 8 assignments, **when you have completed Module 8**.

You are now ready to start Module 8.

NOTES

Grade 11 Physics (30S)

Module 7: Waves in One Dimension

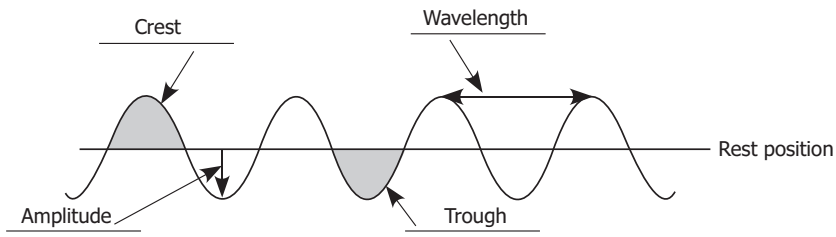
Learning Activity Answer Keys

Module 7: Waves in One Dimension

Learning Activity 7.1: Transverse Waves and Longitudinal Waves: Part 1

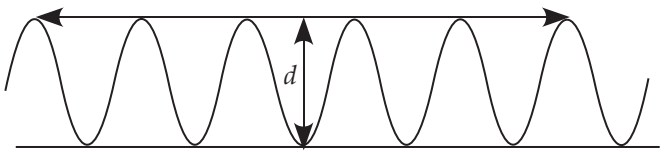
1. Label each part of a transverse wave, as indicated.

   Answer:



2. The periodic transverse wave below travels past a point P in 2.75 s.

   $5\lambda = 7.1$ cm



$d = 1.6$ cm

   a) What is the wavelength of this wave? Assume the picture is actual size and use a ruler to measure the wavelength.

      Answer:

      Measure as many wavelengths as possible to improve your accuracy.

      Here we have 5 wavelengths measured to be 7.1 cm.

      $$\lambda = \frac{7.1 \text{ cm}}{5} = 1.4 \text{ cm}$$

      One wavelength is 1.4 cm.

   b) What is the amplitude of this wave?

      Answer:

      Draw a line at the top of the crests and at the bottom of the troughs. Measure the distance between the lines. One-half of this distance is the wavelength.

      $d = 1.6$ cm = 2 x amplitude

      Amplitude = 1.6 cm/2 = 0.80 cm.

c) What is the frequency of this wave?

Answer:

In the diagram are 6 complete waves. The time for 6 waves is 2.75 s.

Frequency = number of waves/time interval = 6 waves/2.75 s = 2.18 Hz.

d) What is the period?

Answer:

The period is the time interval/waves.

Period = 2.75 s/6 waves = 0.458 s.

Learning Activity 7.2: Transverse Waves and Longitudinal Waves: Part 2

1. Describe the motion of a point on the medium that occurs in a transverse wave.

   Answer:

   In a transverse wave, a point on the medium moves in a direction that is perpendicular to the direction of motion of the wave.

2. Describe the motion of a point on the medium that occurs in a longitudinal wave.

   Answer:

   In a longitudinal wave, a point on the medium moves in a direction that is parallel to the direction of motion of the wave.

3. Define the following terms: crest, trough, compression, rarefaction.

   Answer:

   The crest is that part of a transverse wave that lies above the normal rest position of the medium.

   A trough is that part of a transverse wave that lies below the normal rest position of the medium.

   A compression is that part of a longitudinal wave where parts of the medium are found closer together than they normally occur.

   A rarefaction is that part of a longitudinal wave where parts of the medium are found farther apart than they normally occur.

4. What is the frequency of a wave?

   Answer:

   The frequency of the wave is given by the number of complete waves that pass any given point in a unit time. The frequency is calculated by the number of cycles over the time interval. The frequency has units of hertz.

5. What is the metric unit of frequency?

   Answer:

   The metric unit of frequency is hertz (cycles/second).

6. How is the period of a wave related to its frequency?

   Answer:

   The period of a wave and its frequency are reciprocals: $T = \frac{1}{f}$.

7. What is the wavelength of a wave?

   Answer:

   Wavelength is the distance from a point on a wave to the identical point on a successive wave.

8. Domino toppling is an event that consists of lining up a large number of dominoes and then letting them topple, one after the other. It is one entry in the *Guinness Book of World Records*. If we think about the disturbance that propagates along the line of dominoes, is it transverse, longitudinal, or both?

   Answer:

   As the dominoes topple, their displacements contain both a vertical and horizontal component. The vertical component comes from the downward movement and the horizontal comes from the forward movement. Therefore, the disturbance that moves along the line of dominoes has both a longitudinal (horizontal) and transverse (vertical) component.

9. A person standing in the ocean notices after a wave crest passes by that ten more crests pass by in a time of 100 s. What must be the frequency of the wave?

   Answer:

   The period T is the time required for one complete cycle of a wave to pass a fixed point. From the data given in the problem, T = (time for all cycles)/(the number of cycles)

   = (100 s)/10 = 10 s.

   The frequency f (in hertz) is the number of wave cycles that pass an observer every second and is the reciprocal of the period T in seconds. Therefore,

   $$f = \frac{1}{T} = \frac{1}{10\text{ s}} = 0.10\text{ Hz}$$

10. A popular FM radio station is 97.5 on the FM dial. This number refers to the frequency of the signal in units of megahertz. This station broadcasts at 97.5 MHz. All radio signals travel at the speed of light, 3.00×10^8 m/s. What is the wavelength of this signal?

Answer:

Given: Frequency $f = 97.5 \text{ MHz} = 97.5 \times 10^6 \text{ Hz} = 9.75 \times 10^7 \text{ Hz}$

Speed $v = 3.00 \times 10^8 \text{ m/s}$

Unknown: Wavelength $\lambda = ?$

Equation: $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$

Substitute and solve: $\lambda = \frac{v}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{9.75 \times 10^7 \text{ Hz}} = 3.08 \text{ m}$

The wavelength is 3.08 m

11. Porpoises emit sound waves in water in order to navigate. A typical wavelength for such a sound wave might be 2.50 cm. The speed of the wave in seawater is typically 1470 m/s. What is the period of the wave?

Answer:

We will find the frequency using the universal wave equation, then calculate the period.

Given: Wavelength $\lambda = 2.50 \text{ cm} = 0.0250 \text{ m}$

Speed $v = 1470 \text{ m/s}$

Unknown: Frequency $f = ?$

Equation: $v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$

Substitute and solve: $f = \frac{v}{\lambda} = \frac{1470 \text{ m/s}}{0.0250 \text{ m}} = 58800 \text{ Hz}$

$T = \frac{1}{f} = \frac{1}{58800 \text{ Hz}} = 1.70x10^{-5} \text{ s}$

The period of the wave is 1.70×10^{-5} s.

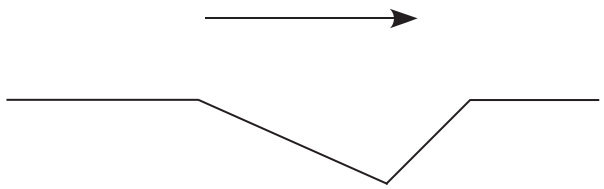
Learning Activity 7.3: Reflection and Transmission of Waves in One Dimension

1. A pulse is sent down a spring that is attached to another spring with unknown properties. The pulse returns inverted and with a smaller amplitude. Compared to the first spring, is the speed of the waves slower or faster in the second spring?

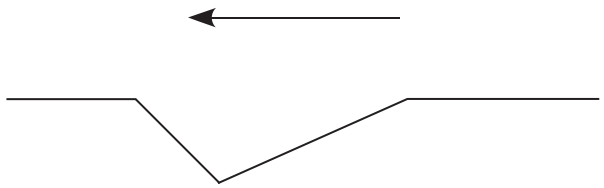
   Answer:

   The second wave returned inverted. This must mean that the second spring is composed of a denser medium and that the speed of the wave is therefore slower.

2. The following pulse is sent along a light spring towards a junction with a free end. Draw and describe the reflected pulse. (Note: Waves with square or sharp corners are called ideal waves. They are used to facilitate the drawing of diagrams.)



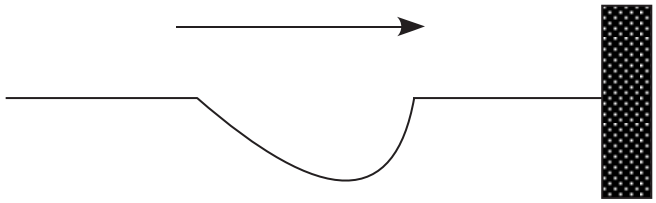
   Answer:



   Pulses reflected from a free end are

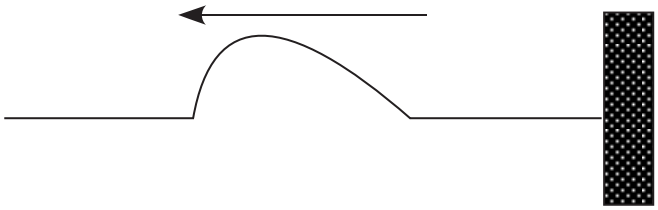
   1. upright—they remain on the same side of the medium, meaning that crest reflects as crest and trough reflects as trough.
   2. equal in amplitude to the incident pulse
   3. travelling at the same speed as the incident pulse
   4. equal in length to the incident pulse

3. The following pulse is sent along a light spring towards a junction with a fixed end. Draw and describe the reflected pulse.



Answer:

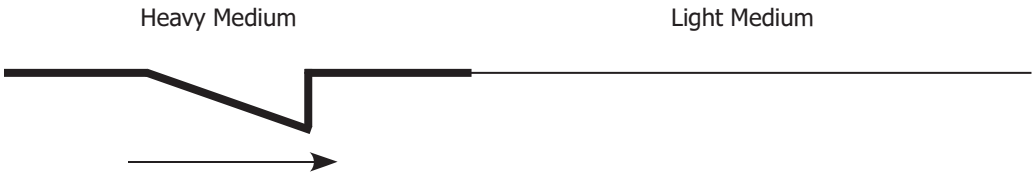
At a fixed end, the pulse reflects inverted. The leading edge (right side) of the incident pulse reflects first and leads the reflected pulse to the left.



Pulses reflected from a fixed end are

1. inverted—they reflect on the opposite side of the medium, meaning that crest reflects as trough and trough reflects as crest
2. equal in amplitude to the incident pulse
3. travelling at the same speed as the incident pulse
4. equal in length to the incident pulse

4. A pulse travelling in a heavy medium is incident unto the junction with a light medium, as indicated in the diagram below.



Draw and describe the reflected pulse and the transmitted pulse.

Answer:

The pulse will partially reflect (free end) and be partially transmitted (upright or same side).

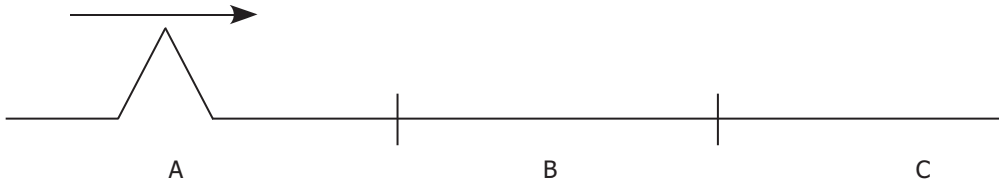
The reflected pulse is

1. upright—reflected on the same side as the incident pulse
2. smaller in amplitude since some energy was transmitted to the light medium
3. travelling at the same speed as the incident pulse
4. the same length along the rest position as the incident pulse.

The transmitted pulse is

1. upright—on the same side as the incident pulse
2. smaller in amplitude than the incident pulse since only some energy is transmitted
3. travelling with a higher speed than the incident pulse
4. longer in length along the rest position since the pulse is travelling faster now.

5. A triangular pulse is created in medium A and passes through media B and C. The speeds of the pulses in media A, B, and C are 1.0 m/s, 2.0 m/s, and 1.5 m/s, respectively. The arrow shows the direction of motion of the pulse. Draw diagrams to show the wavelength, the approximate amplitude, and whether the pulse is inverted or not in each of the following situations as the wave moves along the medium.

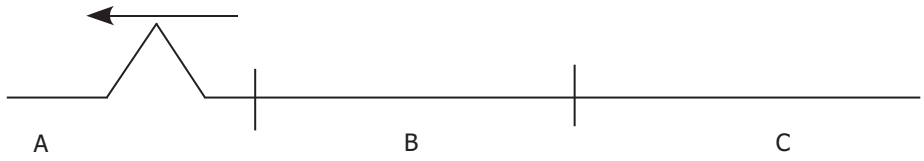


a) The partially reflected pulse in medium A.

Answer:

The speed in A is 1.0 m/s and in B is 2.0 m/s. This is like going from a heavy (slow medium) to a lighter (fast) medium. This approximates a FREE END.

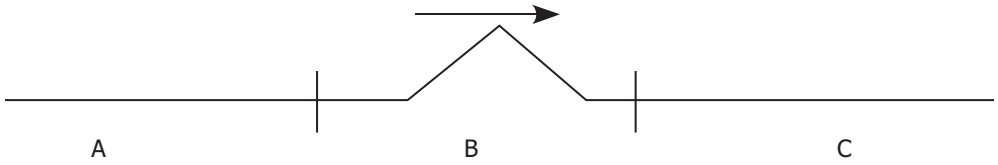
The speed of the partially reflected pulse in medium A is the same as the original pulse. The wavelength is also unchanged. The pulse is upright and of a smaller amplitude.



b) The pulse transmitted to B.

Answer:

The speed of the pulse in medium B is twice the speed in medium A. Therefore, the wavelength will be twice as long. It will also be upright. Since some energy is lost due to the partial reflection, the amplitude will be less than the original pulse.

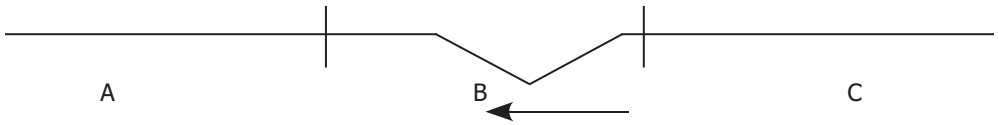


c) The partially reflected pulse in medium B.

Answer:

You have to start with the transmitted pulse in B. The speed in B is 2.0 m/s and in C is 1.5 m/s—the wave slows down. This junction is like a light to heavy junction and approximates a FIXED END. The reflected pulse will be inverted.

The speed of the partially reflected pulse in medium B will be the same as the transmitted pulse (which is twice the speed in medium A). The wavelength will be the same as the transmitted pulse in B. It will be inverted. The amplitude will be less than the transmitted pulse since some energy was transmitted.

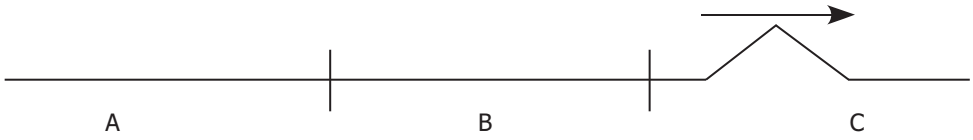


d) The partially transmitted pulse in medium C.

Answer:

The partially transmitted pulse in B that was originally in A is incident unto the junction between B and C (FIXED END).

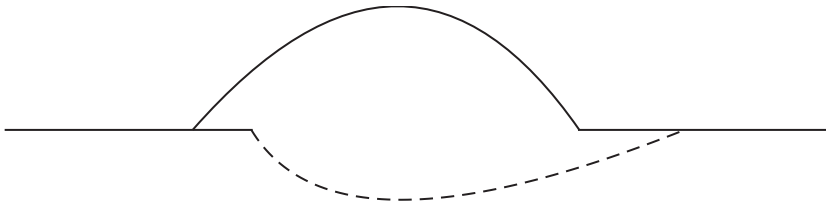
The speed of the transmitted pulse in medium C will be 1.5 times the speed of the pulse in medium A. The wavelength will be 1.5 times as much. It will be upright. The amplitude will be less than the transmitted pulse in medium B.



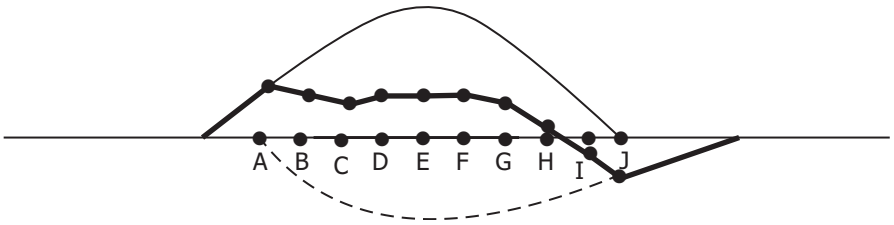
Learning Activity 7.4: Wave Interference and Standing Waves in One Dimension: Part 1

1. Use the Principle of Superposition to draw in the resultant wave.

   a)

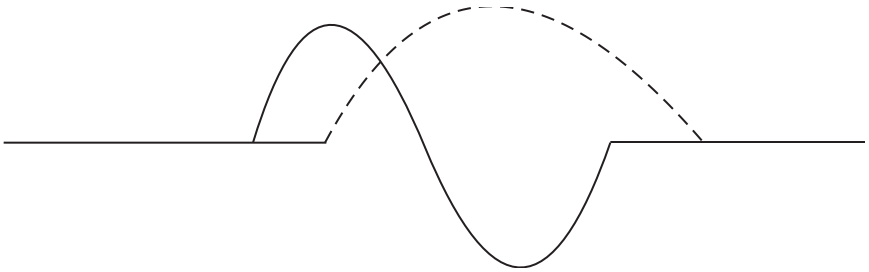


Answer:

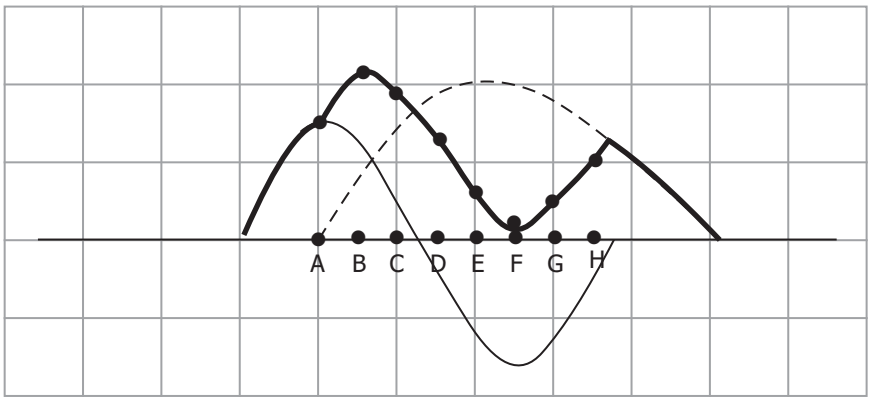


Point on Medium	Displacement of Solid Wave (mm)	Displacement of Broken Wave (mm)	Displacement of Resultant Wave (mm)
A	+7	0	+7
B	+10	–4	+6
C	+13	–8	+5
D	+15	–9	+6
E	+16	–10	+6
F	+15	–9	+6
G	+13	–8	+5
H	+8	–7	+1
I	+4	–6	–2
J	0	–4	–4

b)



Answer:



Point on Medium	Displacement of Solid Wave (mm)	Displacement of Broken Wave (mm)	Displacement of Resultant Wave (mm)
A	+14	0	+14
B	+8	+13	+21
C	+4	+14	+18
D	–4	+17	+13
E	–13	+20	+7
F	–16	+18	+2
G	–13	+17	+4
H	–4	+14	+10

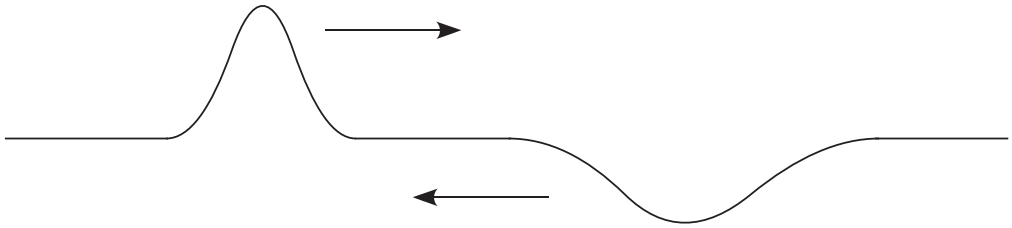
Learning Activity 7.5: Wave Interference and Standing Waves in One Dimension Part 2

1. Why are standing waves not produced in a swimming pool where many people may be present?

   Answer:

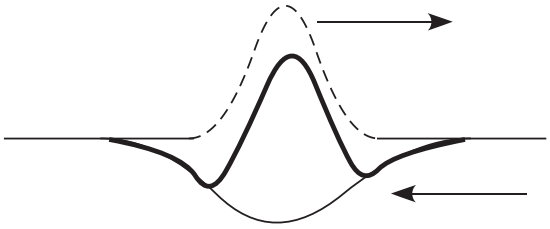
   In a swimming pool, there are multiple reflections from all sides. Complete destructive interference would be random if it appeared at all. Also, waves produced by people in the pool would be produced in a random fashion with different frequencies and amplitudes, making any interference random.

2. Two pulses move towards each other, as shown below. When the pulses overlap so they are directly above each other, draw the resultant shape.



   Answer:

   When the two pulses overlap, the resultant pulse is shown below.



3. A string in an instrument may vibrate at a frequency of 4.0 Hz, and the distance between the nodes is 0.30 m. What must be the speed of the waves on the string?

   Answer:

   The wavelength of the waves producing the interference pattern is twice the distance between the nodes.

   $\lambda = 2(0.30\text{ m}) = 0.60\text{ m}$

   The speed of the waves is $v = f\lambda = (4.0\text{ Hz})\ (0.60\text{ m}) = 2.4\text{ m/s}$

4. The speed of a wave on a string instrument such as a guitar may be 350 m/s. If the frequency of the standing waves is 420 Hz, how far apart are the nodes?

   Answer:

   The speed of the waves is given by $v = f\lambda$. The wavelength must therefore be

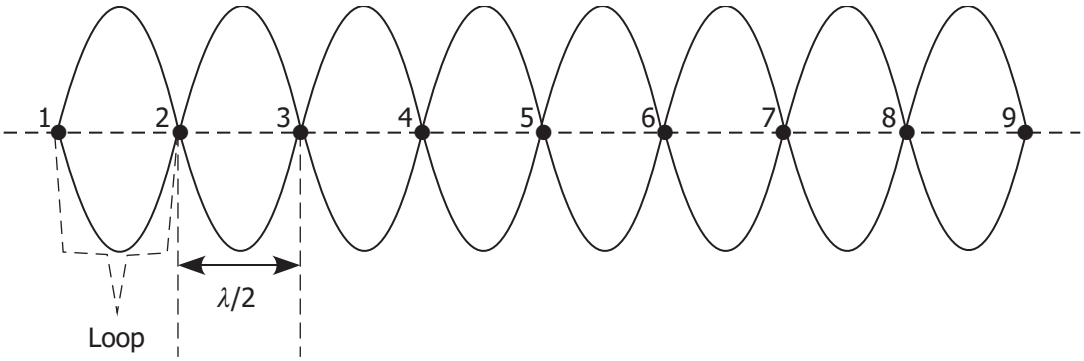
   $$\lambda = \frac{v}{f} = \frac{350\text{ m/s}}{420\text{ Hz}} = 0.83\text{ m.}$$

   The nodes are one-half of this distance apart: 0.83 m/2 = 0.42 m

5. A standing wave is produced in a spring fixed at one end. Nodes are counted with the first node located at the fixed end. The distance between the third node and the eighth node is 1.50 m. The frequency of the waves is 12.0 Hz.

   a) Draw a diagram of this standing wave. Number each of the nodes.

   Answer:



b) What is the distance between adjacent nodes.

Answer:

The distance from the third to the eighth node represents 5 nodal distances.

So, $5d = 1.50$ m

$$d = \frac{1.50 \text{ m}}{5} = 0.300 \text{ m}$$

c) What is the wavelength of these waves?

Answer:

The distance between nodes is $\frac{1}{2}\lambda$.

So, $\lambda = 2d = 2(0.300 \text{ m}) = 0.600$ m.

d) What is the speed of these waves?

Answer:

With $\lambda = 0.600$ m and $f = 12.0$ Hz, use the universal wave equation ($v = f\lambda$) to calculate speed.

$v = f\lambda$

$v = (12.0 \text{ Hz})(0.600 \text{ m}) = 7.20$ m/s

6. Waves travel at 15.6 m/s in a particular medium. The waves have a period of 0.500 seconds. If a standing wave is produced, how far apart would the nodes be located?

Answer:

Given: Speed $v = 15.6$ m/s

Period $T = 0.500$ s

Unknown: node to node distance $d = ?$

Equation: d is found using the relationship $d = \frac{1}{2}\lambda$

So, we have to find the wavelength first.

Use $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$.

We are given T so we find f using $f = \frac{1}{T} = \frac{1}{0.500 \text{ s}} = 2.00$ Hz.

Substitute: $\lambda = \frac{15.6 \text{ m/s}}{2.00 \text{ Hz}}$

Solve $\lambda = 7.80$ m

And finally, $d = \frac{1}{2}\lambda = \frac{1}{2}(7.80 \text{ m}) = 3.90$ m.

The node to note distance is 3.90 m in this case.

Learning Activity 7.6: Resonant Frequency and Harmonics

1. If the length of a string is doubled, by what relative amount has the fundamental frequency changed?

   Answer:

   We can assume that the speed of the waves is not affected if the material of the string and its tension are unchanged. The fundamental frequency is determined using $f = \frac{v}{\lambda}$.

   The wavelength at which the fundamental frequency occurs is doubled if the length of the string is doubled. Therefore, the fundamental frequency is halved.

2. A piano string is 1.10 m long. The fundamental frequency of the string is 131 Hz.

   a) What is the wavelength of the fundamental frequency?

      Answer:

      The wavelength of the fundamental frequency is $\lambda = 2L = 2(1.10\text{ m}) = 2.20\text{ m}$.

   b) What are the frequencies of the first two overtones?

      Answer:

      The frequency of the first overtone (second harmonic) is 2(131 Hz) = 262 Hz.

      The frequency of the second overtone (third harmonic) is 3(131 Hz) = 393 Hz.

3. A string of length 2.50 m is fixed at both ends. The speed of the wave is 85.0 m/s. What is the fundamental frequency of the wave?

   Answer:

   The fundamental frequency occurs when there is only one loop in the standing wave. The wavelength in this case is therefore 2(2.50 m) = 5.00 m.

   The fundamental frequency is therefore $f = \frac{v}{\lambda} = \frac{85.0\text{ m/s}}{5.00\text{ m}} = 17.0\text{ Hz}$.

4. On one type of flute, when all the holes are closed, the lowest note it can sound is a middle C whose fundamental frequency is 261.6 Hz. At a temperature of 20° C, the speed of sound is 343 m/s. Assume that the flute is a cylindrical tube open at both ends. Determine the distance, L—that is, the distance between the mouthpiece to the end of the tube.

Answer:

In this case, the fundamental frequency means that the length of the flute is one-half of a wavelength.

Given:	Fundamental frequency	$f = 261.6$ Hz
	Speed	$v = 343$ m/s
Unknown:	Wavelength	$\lambda = ?$
Equation:		Use $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$
Substitute and solve:		$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{261.6 \text{ Hz}} = 1.31 \text{ m}$

The flute is $\frac{1}{2}\lambda = (0.5)(1.31 \text{ m}) = 0.656 \text{ m}$.

NOTES

Grade 11 Physics (30S)

Module 7: Waves in One Dimension

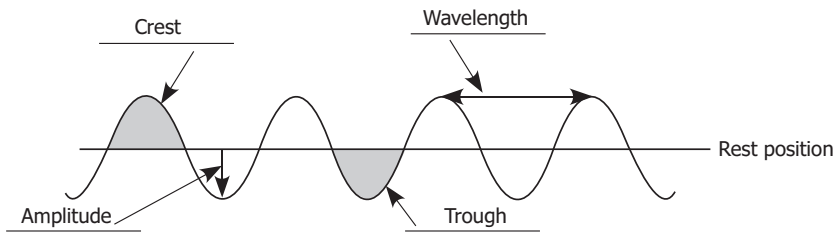
Learning Activity Answer Keys

Module 7: Waves in One Dimension

Learning Activity 7.1: Transverse Waves and Longitudinal Waves: Part 1

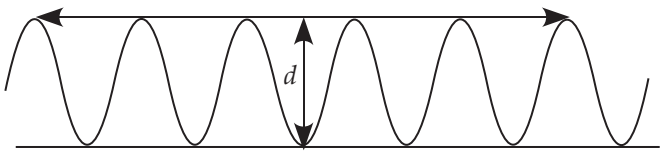
1. Label each part of a transverse wave, as indicated.

   Answer:



2. The periodic transverse wave below travels past a point P in 2.75 s.

   $5\lambda = 7.1$ cm



$d = 1.6$ cm

   a) What is the wavelength of this wave? Assume the picture is actual size and use a ruler to measure the wavelength.

      Answer:

      Measure as many wavelengths as possible to improve your accuracy.

      Here we have 5 wavelengths measured to be 7.1 cm.

      $$\lambda = \frac{7.1 \text{ cm}}{5} = 1.4 \text{ cm}$$

      One wavelength is 1.4 cm.

   b) What is the amplitude of this wave?

      Answer:

      Draw a line at the top of the crests and at the bottom of the troughs. Measure the distance between the lines. One-half of this distance is the wavelength.

      $d = 1.6$ cm = 2 x amplitude

      Amplitude = 1.6 cm/2 = 0.80 cm.

c) What is the frequency of this wave?

Answer:

In the diagram are 6 complete waves. The time for 6 waves is 2.75 s.

Frequency = number of waves/time interval = 6 waves/2.75 s = 2.18 Hz.

d) What is the period?

Answer:

The period is the time interval/waves.

Period = 2.75 s/6 waves = 0.458 s.

Learning Activity 7.2: Transverse Waves and Longitudinal Waves: Part 2

1. Describe the motion of a point on the medium that occurs in a transverse wave.

   Answer:

   In a transverse wave, a point on the medium moves in a direction that is perpendicular to the direction of motion of the wave.

2. Describe the motion of a point on the medium that occurs in a longitudinal wave.

   Answer:

   In a longitudinal wave, a point on the medium moves in a direction that is parallel to the direction of motion of the wave.

3. Define the following terms: crest, trough, compression, rarefaction.

   Answer:

   The crest is that part of a transverse wave that lies above the normal rest position of the medium.

   A trough is that part of a transverse wave that lies below the normal rest position of the medium.

   A compression is that part of a longitudinal wave where parts of the medium are found closer together than they normally occur.

   A rarefaction is that part of a longitudinal wave where parts of the medium are found farther apart than they normally occur.

4. What is the frequency of a wave?

   Answer:

   The frequency of the wave is given by the number of complete waves that pass any given point in a unit time. The frequency is calculated by the number of cycles over the time interval. The frequency has units of hertz.

5. What is the metric unit of frequency?

   Answer:

   The metric unit of frequency is hertz (cycles/second).

6. How is the period of a wave related to its frequency?

   Answer:

   The period of a wave and its frequency are reciprocals: $T = \frac{1}{f}$.

7. What is the wavelength of a wave?

   Answer:

   Wavelength is the distance from a point on a wave to the identical point on a successive wave.

8. Domino toppling is an event that consists of lining up a large number of dominoes and then letting them topple, one after the other. It is one entry in the *Guinness Book of World Records*. If we think about the disturbance that propagates along the line of dominoes, is it transverse, longitudinal, or both?

   Answer:

   As the dominoes topple, their displacements contain both a vertical and horizontal component. The vertical component comes from the downward movement and the horizontal comes from the forward movement. Therefore, the disturbance that moves along the line of dominoes has both a longitudinal (horizontal) and transverse (vertical) component.

9. A person standing in the ocean notices after a wave crest passes by that ten more crests pass by in a time of 100 s. What must be the frequency of the wave?

   Answer:

   The period T is the time required for one complete cycle of a wave to pass a fixed point. From the data given in the problem, T = (time for all cycles)/(the number of cycles)

   = (100 s)/10 = 10 s.

   The frequency f (in hertz) is the number of wave cycles that pass an observer every second and is the reciprocal of the period T in seconds. Therefore,

   $$f = \frac{1}{T} = \frac{1}{10\text{ s}} = 0.10\text{ Hz}$$

10. A popular FM radio station is 97.5 on the FM dial. This number refers to the frequency of the signal in units of megahertz. This station broadcasts at 97.5 MHz. All radio signals travel at the speed of light, 3.00×10^8 m/s. What is the wavelength of this signal?

Answer:

Given: Frequency $f = 97.5 \text{ MHz} = 97.5 \times 10^6 \text{ Hz} = 9.75 \times 10^7 \text{ Hz}$

Speed $v = 3.00 \times 10^8 \text{ m/s}$

Unknown: Wavelength $\lambda = ?$

Equation: $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$

Substitute and solve: $\lambda = \frac{v}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{9.75 \times 10^7 \text{ Hz}} = 3.08 \text{ m}$

The wavelength is 3.08 m

11. Porpoises emit sound waves in water in order to navigate. A typical wavelength for such a sound wave might be 2.50 cm. The speed of the wave in seawater is typically 1470 m/s. What is the period of the wave?

Answer:

We will find the frequency using the universal wave equation, then calculate the period.

Given: Wavelength $\lambda = 2.50 \text{ cm} = 0.0250 \text{ m}$

Speed $v = 1470 \text{ m/s}$

Unknown: Frequency $f = ?$

Equation: $v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$

Substitute and solve: $f = \frac{v}{\lambda} = \frac{1470 \text{ m/s}}{0.0250 \text{ m}} = 58800 \text{ Hz}$

$T = \frac{1}{f} = \frac{1}{58800 \text{ Hz}} = 1.70x10^{-5} \text{ s}$

The period of the wave is 1.70×10^{-5} s.

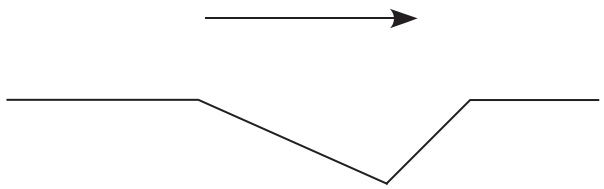
Learning Activity 7.3: Reflection and Transmission of Waves in One Dimension

1. A pulse is sent down a spring that is attached to another spring with unknown properties. The pulse returns inverted and with a smaller amplitude. Compared to the first spring, is the speed of the waves slower or faster in the second spring?

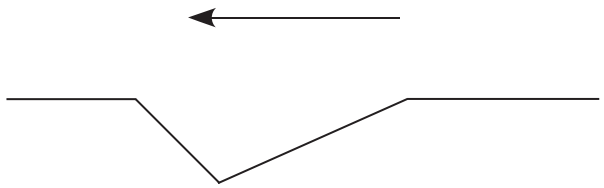
   Answer:

   The second wave returned inverted. This must mean that the second spring is composed of a denser medium and that the speed of the wave is therefore slower.

2. The following pulse is sent along a light spring towards a junction with a free end. Draw and describe the reflected pulse. (Note: Waves with square or sharp corners are called ideal waves. They are used to facilitate the drawing of diagrams.)



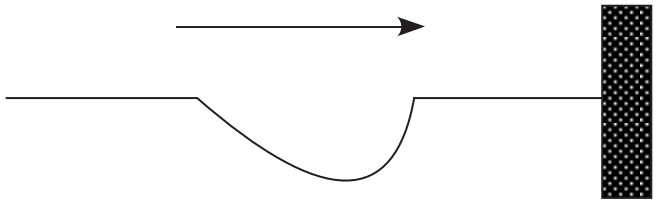
   Answer:



   Pulses reflected from a free end are

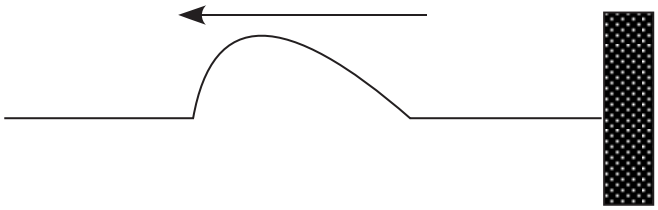
   1. upright—they remain on the same side of the medium, meaning that crest reflects as crest and trough reflects as trough.
   2. equal in amplitude to the incident pulse
   3. travelling at the same speed as the incident pulse
   4. equal in length to the incident pulse

3. The following pulse is sent along a light spring towards a junction with a fixed end. Draw and describe the reflected pulse.



Answer:

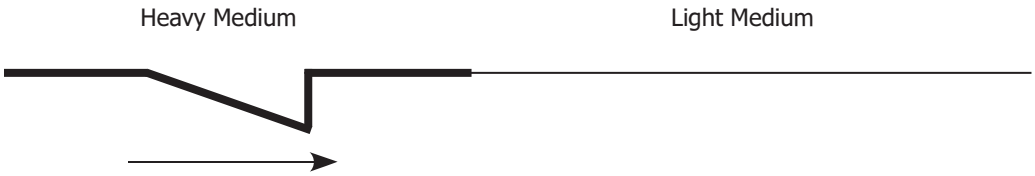
At a fixed end, the pulse reflects inverted. The leading edge (right side) of the incident pulse reflects first and leads the reflected pulse to the left.



Pulses reflected from a fixed end are

1. inverted—they reflect on the opposite side of the medium, meaning that crest reflects as trough and trough reflects as crest
2. equal in amplitude to the incident pulse
3. travelling at the same speed as the incident pulse
4. equal in length to the incident pulse

4. A pulse travelling in a heavy medium is incident unto the junction with a light medium, as indicated in the diagram below.



Draw and describe the reflected pulse and the transmitted pulse.

Answer:

The pulse will partially reflect (free end) and be partially transmitted (upright or same side).

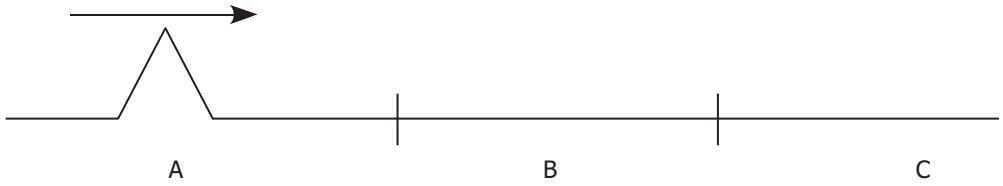
The reflected pulse is

1. upright—reflected on the same side as the incident pulse
2. smaller in amplitude since some energy was transmitted to the light medium
3. travelling at the same speed as the incident pulse
4. the same length along the rest position as the incident pulse.

The transmitted pulse is

1. upright—on the same side as the incident pulse
2. smaller in amplitude than the incident pulse since only some energy is transmitted
3. travelling with a higher speed than the incident pulse
4. longer in length along the rest position since the pulse is travelling faster now.

5. A triangular pulse is created in medium A and passes through media B and C. The speeds of the pulses in media A, B, and C are 1.0 m/s, 2.0 m/s, and 1.5 m/s, respectively. The arrow shows the direction of motion of the pulse. Draw diagrams to show the wavelength, the approximate amplitude, and whether the pulse is inverted or not in each of the following situations as the wave moves along the medium.

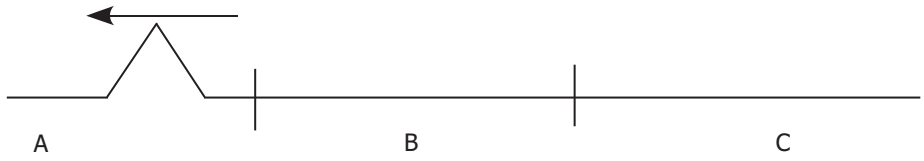


a) The partially reflected pulse in medium A.

Answer:

The speed in A is 1.0 m/s and in B is 2.0 m/s. This is like going from a heavy (slow medium) to a lighter (fast) medium. This approximates a FREE END.

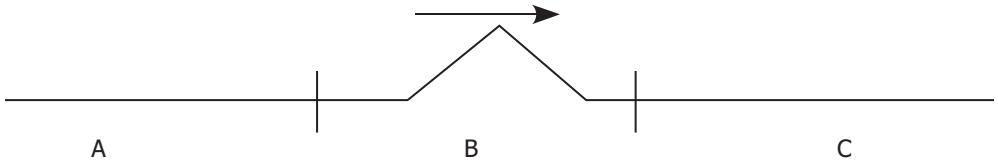
The speed of the partially reflected pulse in medium A is the same as the original pulse. The wavelength is also unchanged. The pulse is upright and of a smaller amplitude.



b) The pulse transmitted to B.

Answer:

The speed of the pulse in medium B is twice the speed in medium A. Therefore, the wavelength will be twice as long. It will also be upright. Since some energy is lost due to the partial reflection, the amplitude will be less than the original pulse.

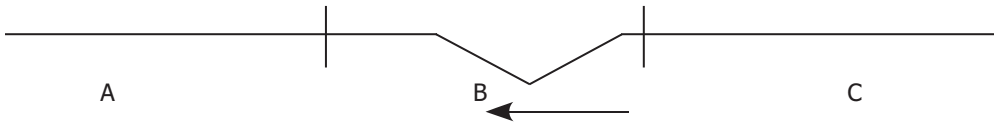


c) The partially reflected pulse in medium B.

Answer:

You have to start with the transmitted pulse in B. The speed in B is 2.0 m/s and in C is 1.5 m/s—the wave slows down. This junction is like a light to heavy junction and approximates a FIXED END. The reflected pulse will be inverted.

The speed of the partially reflected pulse in medium B will be the same as the transmitted pulse (which is twice the speed in medium A). The wavelength will be the same as the transmitted pulse in B. It will be inverted. The amplitude will be less than the transmitted pulse since some energy was transmitted.

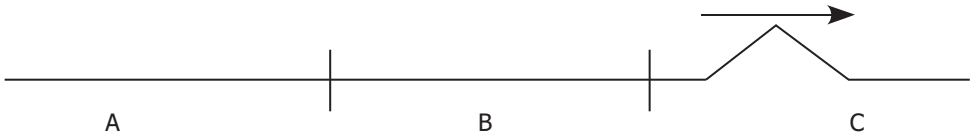


d) The partially transmitted pulse in medium C.

Answer:

The partially transmitted pulse in B that was originally in A is incident unto the junction between B and C (FIXED END).

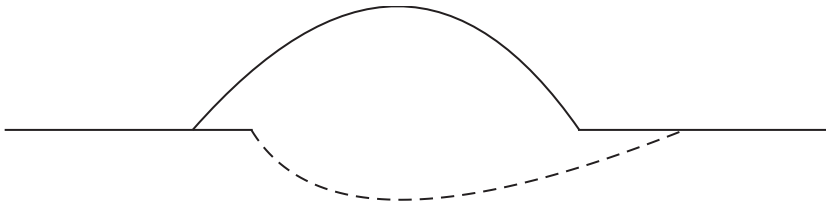
The speed of the transmitted pulse in medium C will be 1.5 times the speed of the pulse in medium A. The wavelength will be 1.5 times as much. It will be upright. The amplitude will be less than the transmitted pulse in medium B.



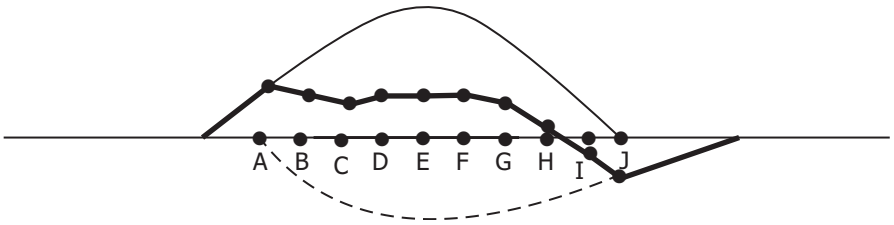
Learning Activity 7.4: Wave Interference and Standing Waves in One Dimension: Part 1

1. Use the Principle of Superposition to draw in the resultant wave.

   a)

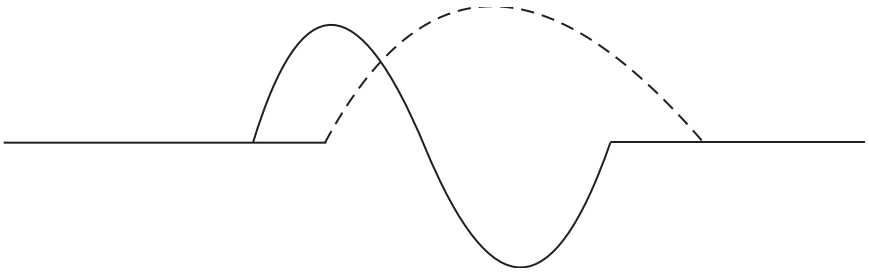


Answer:

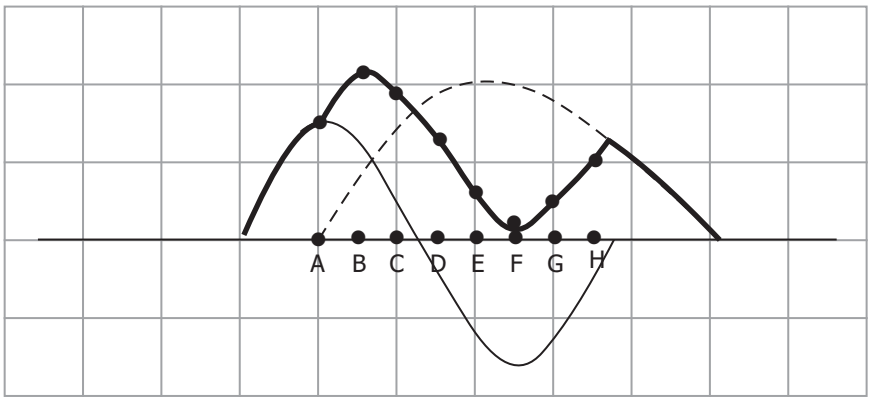


Point on Medium	Displacement of Solid Wave (mm)	Displacement of Broken Wave (mm)	Displacement of Resultant Wave (mm)
A	+7	0	+7
B	+10	–4	+6
C	+13	–8	+5
D	+15	–9	+6
E	+16	–10	+6
F	+15	–9	+6
G	+13	–8	+5
H	+8	–7	+1
I	+4	–6	–2
J	0	–4	–4

b)



Answer:



Point on Medium	Displacement of Solid Wave (mm)	Displacement of Broken Wave (mm)	Displacement of Resultant Wave (mm)
A	+14	0	+14
B	+8	+13	+21
C	+4	+14	+18
D	–4	+17	+13
E	–13	+20	+7
F	–16	+18	+2
G	–13	+17	+4
H	–4	+14	+10

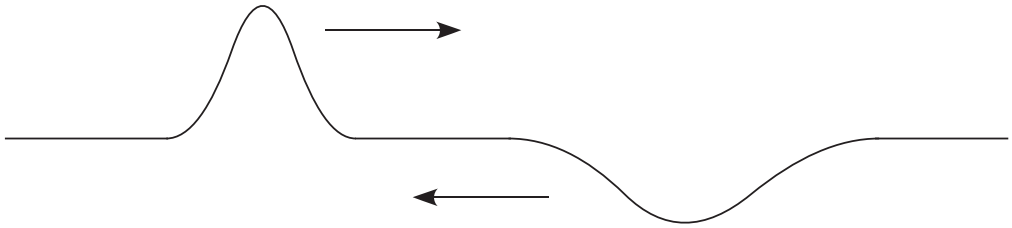
Learning Activity 7.5: Wave Interference and Standing Waves in One Dimension Part 2

1. Why are standing waves not produced in a swimming pool where many people may be present?

   Answer:

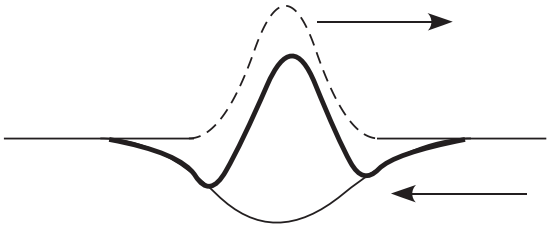
   In a swimming pool, there are multiple reflections from all sides. Complete destructive interference would be random if it appeared at all. Also, waves produced by people in the pool would be produced in a random fashion with different frequencies and amplitudes, making any interference random.

2. Two pulses move towards each other, as shown below. When the pulses overlap so they are directly above each other, draw the resultant shape.



   Answer:

   When the two pulses overlap, the resultant pulse is shown below.



3. A string in an instrument may vibrate at a frequency of 4.0 Hz, and the distance between the nodes is 0.30 m. What must be the speed of the waves on the string?

   Answer:

   The wavelength of the waves producing the interference pattern is twice the distance between the nodes.

   $\lambda = 2(0.30\text{ m}) = 0.60\text{ m}$

   The speed of the waves is $v = f\lambda = (4.0\text{ Hz})\ (0.60\text{ m}) = 2.4\text{ m/s}$

4. The speed of a wave on a string instrument such as a guitar may be 350 m/s. If the frequency of the standing waves is 420 Hz, how far apart are the nodes?

   Answer:

   The speed of the waves is given by $v = f\lambda$. The wavelength must therefore be

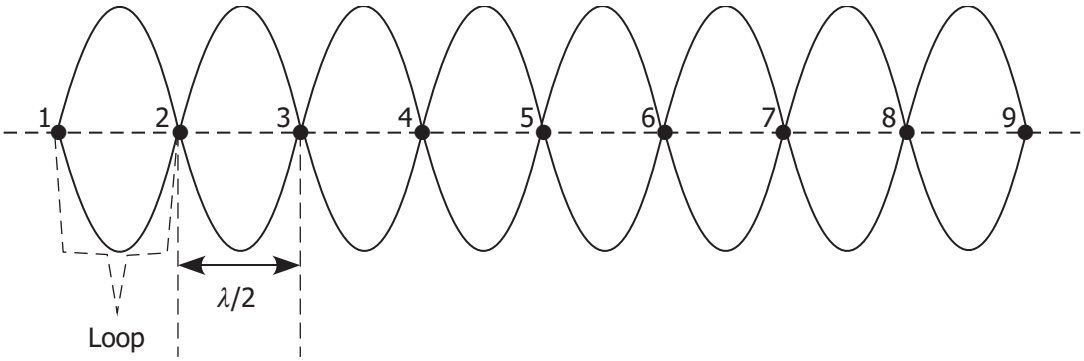
   $$\lambda = \frac{v}{f} = \frac{350\text{ m/s}}{420\text{ Hz}} = 0.83\text{ m.}$$

   The nodes are one-half of this distance apart: 0.83 m/2 = 0.42 m

5. A standing wave is produced in a spring fixed at one end. Nodes are counted with the first node located at the fixed end. The distance between the third node and the eighth node is 1.50 m. The frequency of the waves is 12.0 Hz.

   a) Draw a diagram of this standing wave. Number each of the nodes.

   Answer:



b) What is the distance between adjacent nodes.

Answer:

The distance from the third to the eighth node represents 5 nodal distances.

So, $5d = 1.50$ m

$$d = \frac{1.50 \text{ m}}{5} = 0.300 \text{ m}$$

c) What is the wavelength of these waves?

Answer:

The distance between nodes is $\frac{1}{2}\lambda$.

So, $\lambda = 2d = 2(0.300 \text{ m}) = 0.600$ m.

d) What is the speed of these waves?

Answer:

With $\lambda = 0.600$ m and $f = 12.0$ Hz, use the universal wave equation ($v = f\lambda$) to calculate speed.

$v = f\lambda$

$v = (12.0 \text{ Hz})(0.600 \text{ m}) = 7.20$ m/s

6. Waves travel at 15.6 m/s in a particular medium. The waves have a period of 0.500 seconds. If a standing wave is produced, how far apart would the nodes be located?

Answer:

Given: Speed $v = 15.6$ m/s

Period $T = 0.500$ s

Unknown: node to node distance $d = ?$

Equation: d is found using the relationship $d = \frac{1}{2}\lambda$

So, we have to find the wavelength first.

Use $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$.

We are given T so we find f using $f = \frac{1}{T} = \frac{1}{0.500 \text{ s}} = 2.00$ Hz.

Substitute: $\lambda = \frac{15.6 \text{ m/s}}{2.00 \text{ Hz}}$

Solve $\lambda = 7.80$ m

And finally, $d = \frac{1}{2}\lambda = \frac{1}{2}(7.80 \text{ m}) = 3.90$ m.

The node to note distance is 3.90 m in this case.

Learning Activity 7.6: Resonant Frequency and Harmonics

1. If the length of a string is doubled, by what relative amount has the fundamental frequency changed?

   Answer:

   We can assume that the speed of the waves is not affected if the material of the string and its tension are unchanged. The fundamental frequency is determined using $f = \frac{v}{\lambda}$.

   The wavelength at which the fundamental frequency occurs is doubled if the length of the string is doubled. Therefore, the fundamental frequency is halved.

2. A piano string is 1.10 m long. The fundamental frequency of the string is 131 Hz.

   a) What is the wavelength of the fundamental frequency?

      Answer:

      The wavelength of the fundamental frequency is $\lambda = 2L = 2(1.10\text{ m}) = 2.20\text{ m}$.

   b) What are the frequencies of the first two overtones?

      Answer:

      The frequency of the first overtone (second harmonic) is 2(131 Hz) = 262 Hz.

      The frequency of the second overtone (third harmonic) is 3(131 Hz) = 393 Hz.

3. A string of length 2.50 m is fixed at both ends. The speed of the wave is 85.0 m/s. What is the fundamental frequency of the wave?

   Answer:

   The fundamental frequency occurs when there is only one loop in the standing wave. The wavelength in this case is therefore 2(2.50 m) = 5.00 m.

   The fundamental frequency is therefore $f = \frac{v}{\lambda} = \frac{85.0\text{ m/s}}{5.00\text{ m}} = 17.0\text{ Hz}$.

4. On one type of flute, when all the holes are closed, the lowest note it can sound is a middle C whose fundamental frequency is 261.6 Hz. At a temperature of 20° C, the speed of sound is 343 m/s. Assume that the flute is a cylindrical tube open at both ends. Determine the distance, L—that is, the distance between the mouthpiece to the end of the tube.

Answer:

In this case, the fundamental frequency means that the length of the flute is one-half of a wavelength.

Given:	Fundamental frequency	$f = 261.6$ Hz
	Speed	$v = 343$ m/s
Unknown:	Wavelength	$\lambda = ?$
Equation:		Use $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$
Substitute and solve:		$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{261.6 \text{ Hz}} = 1.31 \text{ m}$

The flute is $\frac{1}{2}\lambda = (0.5)(1.31 \text{ m}) = 0.656 \text{ m}$.

NOTES

Topic 3 - Audio/Videos

Module 7

1. Transverse and Longitudinal Waves
2. GCSE Science Physics (9-1) Transverse and Longitudinal Waves
    a. This video introduces waves. It describes what waves are. It also compares waves on water (transverse waves) to waves of sound (longitudinal) waves. For each type of wave the video illustrates the direction of motion of a point on the medium compared to the direction of motion of the wave disturbance. The video notes that transverse waves require a medium to transmit the disturbance
3. Transverse Waves
    a. A simulation of transverse waves. This illustrates a transverse wave on the surface of water with a duck floating on the surface of the water as waves move across the surface of the water.
    b. A diagram of transverse waves illustrates some of the characteristics of transverse waves.
4. Longitudinal Wave
    a. This applet animates the motion of longitudinal waves and allows you to change some parameters to make it interactive. Have some fun.
    b. The applet demonstrates how a longitudinal wave travels in a medium of points marked by dots. As the wave moves to the right the dots side to side
    c. Click on the animation area to switch the animation to dots.
    d. Select “Progressive Wave”. Set amplitude to “Low” and frequency to “Low”.
    e. Observe the motion of the particles and note how far the particles travel horizontally from the normal rest position. This is the amplitude. You can control the animation step by step by resting the cursor on the line after start and using the switches that appear.
    f. Select “Progressive Wave”. Set amplitude to “High” and frequency to “Low”.
    g. Repeat the steps above and compare the maximum distance a point moves from the normal undisturbed position.
    h. Select “Progressive Wave”. Set amplitude to “Low” and frequency to “Low”.
    i. Observe and note the number of waves made each second by timing for 10 seconds and counting the back and forth motions of the piston. Calculate the frequency using
    j. f = (number of cycles) / time.
    k. Reset amplitude to “Low” and frequency to “High”.
    l. Again count the number of cycles the piston makes in 10 seconds.
    m. Calculate the frequency.
    n. Change the wave type to “Pulsed Rarefaction” and observe how the spacing of the points on the medium changes.
    o. Finally change the wave type to “Pulsed Compression” and observe how the spacing of the points on the medium changes.
5. Wave Speed

6. Longitudinal versus Traverse Waves
7. Transverse Wave - Reflection & Transmission
    a. This animation does an excellent job of illustrating the reflection and transmission of waves at an end or at a junction between two different media.
    b. For reflection there is only the incident wave and the reflected wave.
    c. For transmission there will be an incident wave, a partially reflected wave in the first medium and a partially transmitted wave in the second medium. Both of these must be described.
    d. The waves that are reflected and transmitted are described using 4 characteristics:
    e. 1. Orientation – upright or inverted compared to the incident wave
    f. 2. Speed –faster or slower that the incident wave
    g. 3. Wavelength – longer or shorter than the incident wave
    h. 4. Amplitude – larger or smaller that the incident wave
    i. Start with the Free End Reflection. Describe the reflected wave using the 4 characteristics.
    j. Change the animation to Fixed End Reflection and repeat the analysis of the reflected wave.
    k. Change the animation to a Thinner to Thicker and describe both transmitted and reflected waves.
    l. Finally change the animation to Thicker to Thinner and do the analysis one more time.
    m. If you hover your cursor in the lowest part of the animation a control bar appears by which you can control the speed of the animation including step by step.
8. Wave Superposition
9. Wave interference | Mechanical waves and sound | Physics | Khan Academy
    a. The narrator uses ideal waves (squares, rectangles and triangles) to illustrate the principle of superposition.
    b. There is a link on the left side of the screen “Practice: Predicting Wave Interference Patterns”. When you click on that link you will be presented with 4 problems to practice the Principle of Superposition.
10. Standing Waves
    a. This video illustrates the production of standing waves as the result of superposition of two waves traveling in the same medium.
    b. An animation shows the superposition of a wave in blue with its reflected wave in white to produce a standing wave in black. The standing wave has places called nodes where the medium does not move. The two waves are constantly canceling each other out. In between the nodes are antinodes, that is locations which are constantly in motion.
    c. Examples of standing waves are provided in baseball bats, guitar strings (two fixed ends), and wind instruments such as a trumpet (one fixed and 1 open end column) and a pan flute (a two open end column). This is a precursor to musical instruments and how they work.
11. Transverse Wave Addition

a. This animation shows superposition and standing waves.
b. Part 1. Select Animation 11. Set the animation to Gaussian Pulse with Equal Amplitude and In Phase.
c. Start the animation. Observe the waves before they interact, while they interact and after they interact.
d. Before the interaction, the red pulse moves to the right and the white pulse moves to the left. During the interaction the interaction the two pulses interfere constructively to produce the yellow pulse.
e. Stop the animation when the largest yellow pulse is formed. At each dot, the displacement for the yellow wave is the sum of the displacement of the red wave plus the displacement of the white wave.
f. Continue the animation. After the passing through each other the red and with pulses continue to move as before with the same shape and size.
g. Part 2. Repeat part 1 with the two pulses having Unequal Amplitudes.
h. Part 3. Back up 1 page in your browser so that you see choices of Animation 11 and Animation 111. Switch the animation to Animation 111. Set Wavelength to Small.
i. A continuous pair of waves, blue moving left and white moving right, pass through each other and interfere with each other. Together a yellow wave is produced by the principle of superposition.
j. Stop the animation when the blue wave and white wave are at the same position. Again observe that the displacement of the yellow wave is the sum of the displacements of the blue wave and white wave.
k. Start the animation.
l. Notice that there are nodes (points that do not move) and antinodes (the points that move from the bottom of the screen to the top of the screen) formed.
m. The distance from a node to the adjacent node is one half of a wavelength (½λ).

12. [The Physics of Music: Crash Course Physics #19]
    a. This video introduces music. Music is produced by standing waves in strings in string instruments or standing waves in columns of air in wind instruments.
    b. The video covers the fundamental frequency, harmonics and overtones and the relationships between these. The narrator speaks very rapidly so you may have to pause the video or repeat sections to catch all the information being conveyed.
    c. For a string vibrating at its fundamental frequency f0 the string has a node at each end and an antinode in the middle of the string. The length of the string is ½λλ. The fundamental frequency is also the frequency of the first harmonic, n=1.
    d. If the frequency in this same string is doubled a standing wave with a node at each end plus a node in the middle of the string is formed. This pattern then has 2 antinodes. This is the pattern for the second harmonic. The frequency of the second harmonic f2 is 2x f0.
    e. So a pattern of harmonic numbers and fundamental frequency emerges.
    f. For a given harmonic, n, the frequency of the harmonic, fn, is given by fn = n x f0 .

g. We tie this in with the universal wave equation, $v = f\lambda$. We can, knowing the length of the string and the fundamental frequency, determine the wavelength using $L = \frac{1}{2}\lambda$. Then knowing the fundamental frequency, f_0, and λ we use $v = f\lambda$ to determine the speed.
h. There is a nice comparison using animation for the fundamental frequency or first harmonic in a string with 2 fixed ends and in a pipe or column of air with two open ends. In a string fixed at both ends there is a node at each end with an antinode in the middle of the string. In a pipe with to open ends there is an antinode at each end and a node in the middle of the air column.
i. For a column of air in a pipe closed at one end, the fundamental frequency is not $\frac{1}{2}\lambda$ but $\frac{1}{4}\lambda$. This fact results in there being no harmonic at even numbered harmonics.

13. AP Physics 1: Mechanical Waves Review

Grade 11 Physics (30S)

Module 8: Waves in Two Dimensions

This module contains the following

- Introduction to Module 8
- Lesson 1: Waves in Two Dimensions—Reflection
- Lesson 2: Waves in Two Dimensions—Refraction
- Lesson 3: Waves in Two Dimensions—Diffraction
- Lesson 4: Waves in Two Dimensions—Interference
- Lesson 5: An Introduction to Electromagnetic Waves
- Module 8 Summary

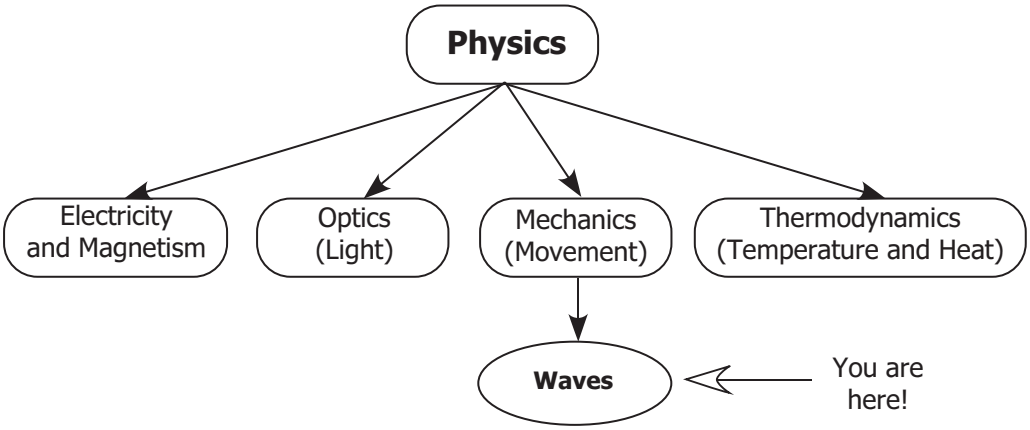
Module 8: Waves in Two Dimensions

Introduction to Module 8

We began our study of waves in the previous module by considering waves in one dimension. In this module, we study waves in two dimensions. We commonly see this in water waves. There are five lessons in this module.

- **Lesson 1: Waves in Two Dimensions—Reflection** discusses the reflection of waves in two dimensions. The ripple tank is a convenient way to study reflection of water waves in a classroom. We will be able to study the reflection of both straight waves and curved waves.
- **Lesson 2: Waves in Two Dimensions—Refraction** discusses the bending or refraction of two-dimensional waves as they pass from one depth to another. You will complete a video lab on refraction.
- **Lesson 3: Waves in Two Dimensions—Diffraction** discusses diffraction of two-dimensional waves as they pass through openings or bend around sharp corners.
- **Lesson 4: Waves in Two Dimensions—Interference** discusses wave interference in two dimensions.
- **Lesson 5: An Introduction to Electromagnetic Waves** introduces a special type of wave—the electromagnetic wave—that is an integral part of our lives. We will discuss the electromagnetic spectrum, how electromagnetic waves exhibit the properties of waves, and we will focus on radio waves and their wave behaviour

All of this work has applications to other kinds of two-dimensional waves such as light waves, radio waves, sound waves, and earthquake waves.



Assignments in Module 8

When you have completed the assignments for Module 8, submit your completed assignments for Module 7 and Module 8 to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 8.1	Waves in Two Dimensions—Reflection
2	Assignment 8.2	Video Laboratory Activity: Snell's Law
2	Assignment 8.3, Part A	Waves in Two Dimensions—Refraction
3	Assignment 8.3, Part B	Waves in Two Dimensions—Diffraction
4	Assignment 8.3, Part C	Waves in Two Dimensions—Interference
5	There are no assignments in Lesson 5.	

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Lesson 1: Waves in Two Dimensions—Reflection (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ state that a water wave is an example of a two-dimensional wave
- ❑ describe how a bright and dark spot are produced on a screen below the tank of a ripple tank
- ❑ define the terms "wavefront" and "wave ray"
- ❑ draw diagrams showing the wavefront of a wave and the direction of the wave ray relative to the wavefront
- ❑ define the terms "angle of incidence" and "angle of reflection" for both wavefronts and wave rays
- ❑ define the term "normal" when used with wave rays
- ❑ draw diagrams showing the reflection of a straight wavefront from a straight reflective surface
- ❑ draw diagrams of circular wavefronts reflecting from straight reflective surfaces
- ❑ draw diagrams showing how straight wavefronts or circular wavefronts reflect from parabolic reflective surfaces

Key Words

ripple tank	wavefront	wave ray
angle of incidence	angle of reflection	normal
straight wave	circular wave	reflection

Introduction

In the previous module, you studied one-dimensional waves—waves that are able to only move along a line, such as the length of a spring. We now turn our attention to waves that have more freedom in their motion: waves that can move in two dimensions. We begin with a short description of a useful piece of equipment called a ripple tank and how it can be used to study two-dimensional water waves. You will then learn how straight waves reflect from straight and parabolic barriers. You will also learn how circular waves reflect from these same barriers. The knowledge of how two-dimensional water waves reflect from barriers can be helpful in understanding how other kinds of waves, such as light waves, radio waves, and sound waves, reflect from surfaces.

Two-Dimensional Waves

In the previous module, you examined waves moving in one dimension. Waves such as these are found on a spring, and can only move in the one dimension available to them: the length of the spring. By definition, a two-dimensional wave is allowed to move along two dimensions—a "flat surface." Examples of such two-dimensional waves would include the waves that travel on the surface of a liquid such as water or flat solid, such as the skin of a drum. Two-dimensional waves are also useful in that we can often simplify three-dimensional waves down to two-dimensional waves by either ignoring their motion in the third dimension, or by limiting their motion to nearly two dimensions only.

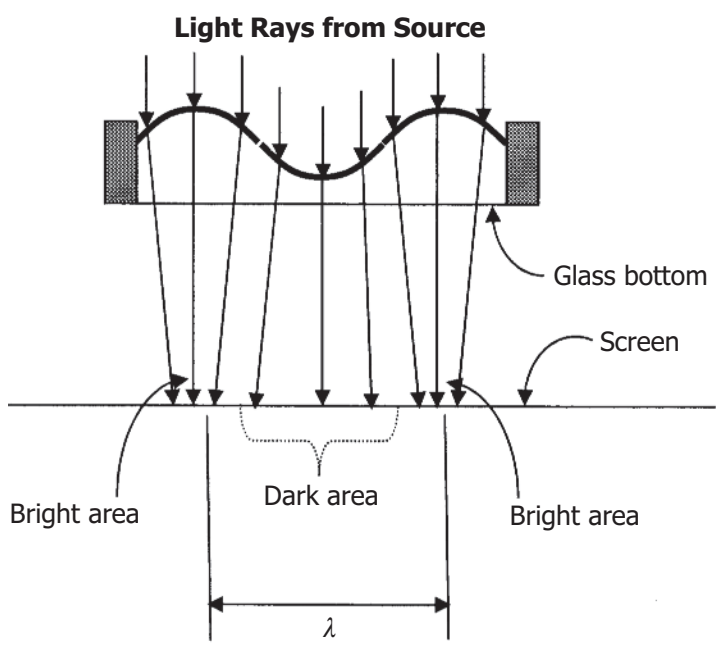
> Two-dimensional waves can move freely in two dimensions, such as along the surface of a liquid.

An excellent example of waves moving in two dimensions is waves moving along the surface of water. Note that the surface of water may be considered to be a two-dimensional space, as these waves may move through this space in any horizontal direction (such as north, south, east, and west) but they simply cannot move vertically up or down. Again, you must not confuse the motion of the medium (water) with the motion of the waves. Certainly when there are waves in the water, the water itself will rock up and down—much like the springs in previous lessons did. The waves themselves, however, only skim along the surface. In fact, we may identify these waves as being transverse waves, as the wave motion (horizontal along the surface) is perpendicular to the motion of the medium (vertical). This is actually not entirely accurate, as water waves are more complicated than this (they actually would have a longitudinal component in addition to the transverse one just described), but we will ignore this complexity.

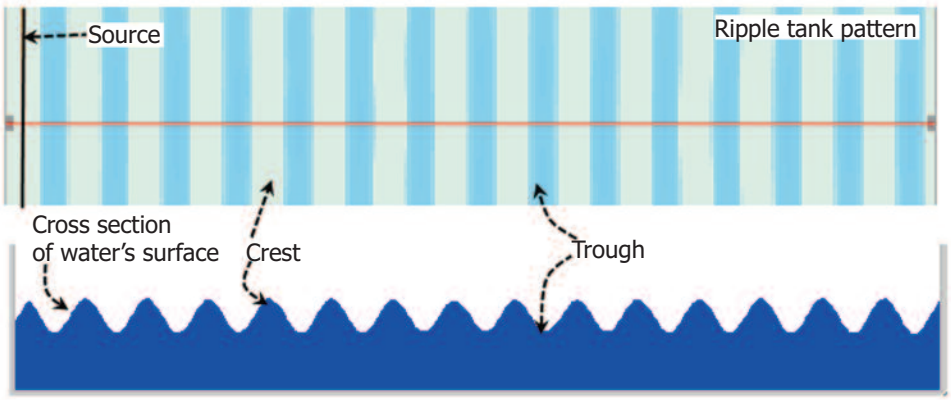
The Ripple Tank

Water waves can be studied in any surface of water. A **ripple tank** is a fairly common piece of equipment designed to allow us to study water waves in classrooms, physics labs, et cetera. A ripple tank usually consists of a shallow tank with a glass bottom. Water is placed in the tank to a depth of about 2 cm. So far, this might sound merely like a container for water (which it is)—but here is the clever part: since small water waves can be difficult to see directly, there is a light bulb above the tank that shines light through the water to a screen on the table underneath the tank. If the surface of water does not have any waves on it, it will be flat and the light will go essentially straight through it, resulting in the screen being equally lit up everywhere. However, if there are waves on the water, then the crests and troughs on the water bend the light in a way that makes the screen especially bright directly underneath the crests and somewhat darker beneath the troughs. You may have noticed exactly this happening on the floor of a swimming pool or bathtub (and if you haven't noticed it, look for it next time you have the chance!).

A **ripple tank** is a container with a flat glass bottom. A ripple tank is a device that makes it easier to study water waves. Instead of looking directly at the water waves, we may look at the screen underneath the tank. Crests will appear bright while troughs will appear dark.



The graphic below illustrates a simulation of the wave pattern seen in a ripple tank. According to the diagram above, the dark lines represent troughs on the surface of the water and the lighter lines represent crests.



A crest on the surface of the water appears as a bright line.
A trough on the surface of the water appears as a dark line.

A typical ripple tank pattern is illustrated below.

Again, the brighter lines represent crests on the water's surface while the darker lines represent troughs on the water's surface.

Wavefronts and Wave Rays

With spring waves, the source usually consisted of a person holding one end of the spring. With water waves, this isn't an option. Instead, we need an object to disturb the surface of the water. This may be done by having an object dip or drop into the water (of course, the reverse would also work—having an object emerge from the water).

Circular waves may be generated on the surface of water by a small object, such as a drop of water from an eyedropper or a finger touching the surface of the water. If the object disturbing the water is quite small, we refer to it as a point source. Dropping a long straight stick into the water so that it lands flat would not be considered to be a **point source**. We would call this long source a **line source**. In general, point sources produce circular waves while line sources produce straight or **plane waves**.

> A **point source** is a small object disturbing the water at only one point (**circular waves** result). A **long straight object** that disturbs the water along its whole length is called a **line source** (**plane waves** [straight waves] result).

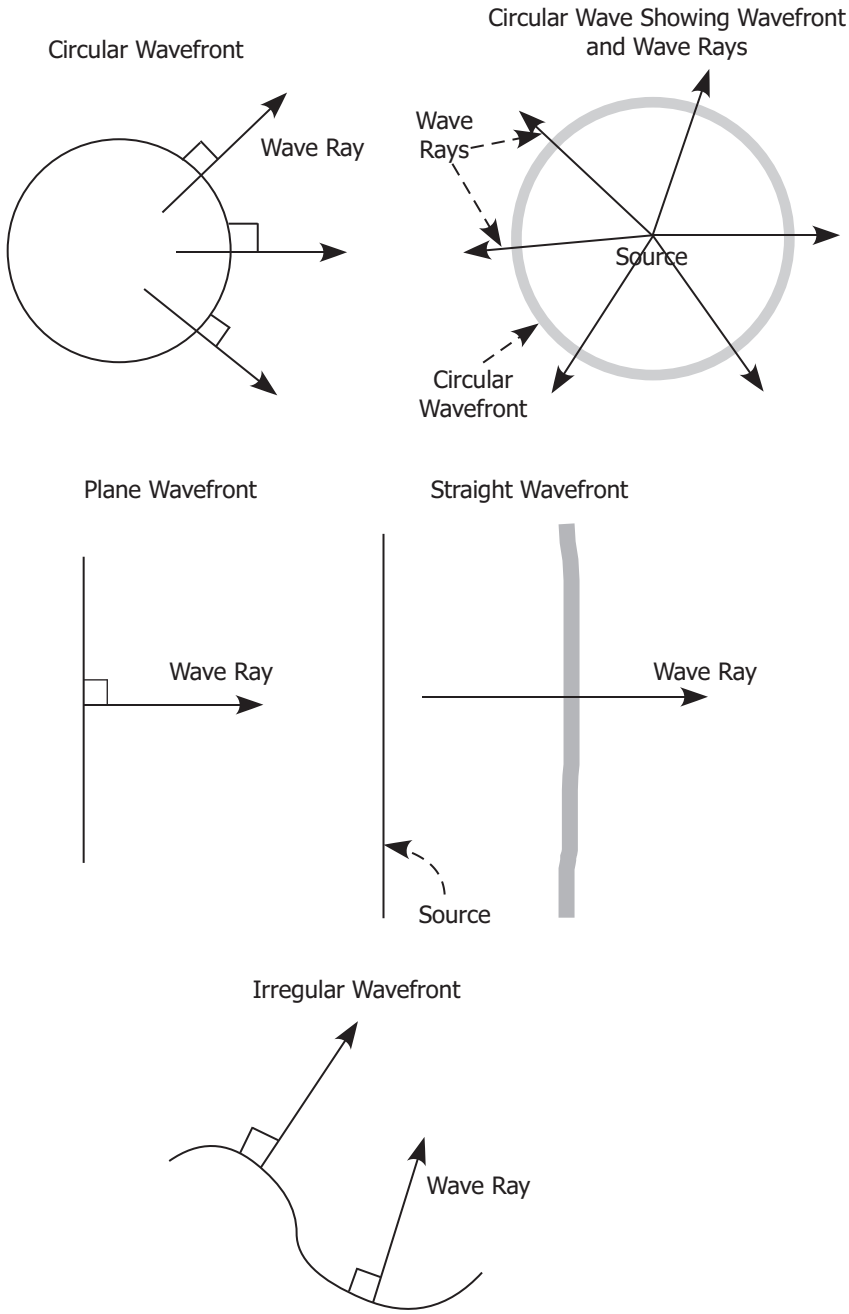
The fact that the waves can move in two dimensions at the same time makes them a little harder to keep track of than one-dimensional waves. One way to help us with this is the idea of **wavefronts**. Essentially, a wavefront is an extended crest or trough. With one-dimensional waves, crests and troughs were single bumps and dips in the medium. With two-dimensional waves, these crests and troughs are indeed bumps and dips, but now they extend out to the sides (possibly for very large distances). Consider a large surfing-style water wave in the ocean. The water goes up above the rest position of the water, which is what makes it a crest, but this crest also goes out to the side, making it appear almost like a wall of water. We can call this "wall of water" a crest front. Some distance behind it will be a trough front.

> A **wavefront** is a feature of a wave that reveals its shape. A **crest front** is an extended crest while a **trough front** is an extended trough. A continuous crest or trough extending across the surface of the water is called a **wavefront**.

While wavefronts are our way of working with the shape of the wave, we use **wave rays** to help us work with the motion of the wave. Wave rays simply show which way a point on a wavefront is moving. Wave rays are arrows that cross a wavefront at one point, showing the direction of motion for that point of the wavefront. It is always true that waves move in a direction perpendicular to the wavefronts, and so wave rays are also always perpendicular to the wavefronts. Of course, realize that you cannot "see" wave rays on an actual wave. If you were looking at an actual wave, you would see that the wave is moving. When we draw diagrams of waves, the diagrams are necessarily not moving. Wave rays drawn into the diagram help us to "see" the motion that we cannot otherwise draw.

> **Wave rays** are arrows that cross a wavefront at one point, showing the direction of motion for that point on the wavefront. Wave rays are drawn perpendicular to the wavefront.

The diagrams below show a wavefront and a few wave rays for a circular wave, a straight wave, and an irregular wave. The illustrations on the left demonstrate how we draw these on a diagram while the graphic on the right shows the wavefront in a ripple tank pattern.



Wave rays reveal the direction in which the wavefronts are moving, which is always perpendicular to the wavefront itself. Unlike wavefronts, wave rays are not visible features of a wave; rather, they are an aid for us to show motion on a diagram.

A Barrier in a Ripple Tank

A **barrier** is the equivalent of an "end" in a spring. Barriers may either be literally ends to the two-dimensional medium, such as the walls of a swimming pool (each wall is a barrier and the end of the water medium) or an obstacle placed within the medium (the body of a person standing waist-deep in the pool would also be a barrier to water waves). When water waves strike a barrier, they reflect from it, much like spring waves reflecting from an end.

Recall that we saw two very different kinds of reflection for spring waves: reflection from **fixed ends** (which invert the pulses upon reflection) and reflection from **free ends** (which do not invert the pulses upon reflection).

Which of these two types of reflection occur for water waves striking a barrier? The answer comes from another question: with regard to our barrier in the water, is it free or fixed? You have to be careful when answering this question. It is tempting to think of the barrier itself being fixed, which we are assuming to be the case—but this is not really what we are after. The medium is water, so the real question is "is the end of the water (at the location of the barrier) free or fixed?" Thinking this through should reveal that it is certainly free! The water at the location of the barrier (at the wall of a pool, for example) is entirely free to rise and fall against it. The pulses, therefore, do not invert. Of course, this argument is just that—an argument. What matters most is what actually happens. If you are able to go right now and fill up a sink or bathtub with water (or better yet, if you have a pool handy, use it!), you should "play" with waves and see what happens when they strike the edge of the tub, sink, or pool (the barrier). If you look carefully, you will, in fact, find that the pulses do not invert.

Reflection of Straight Waves from a Straight Barrier—Head On

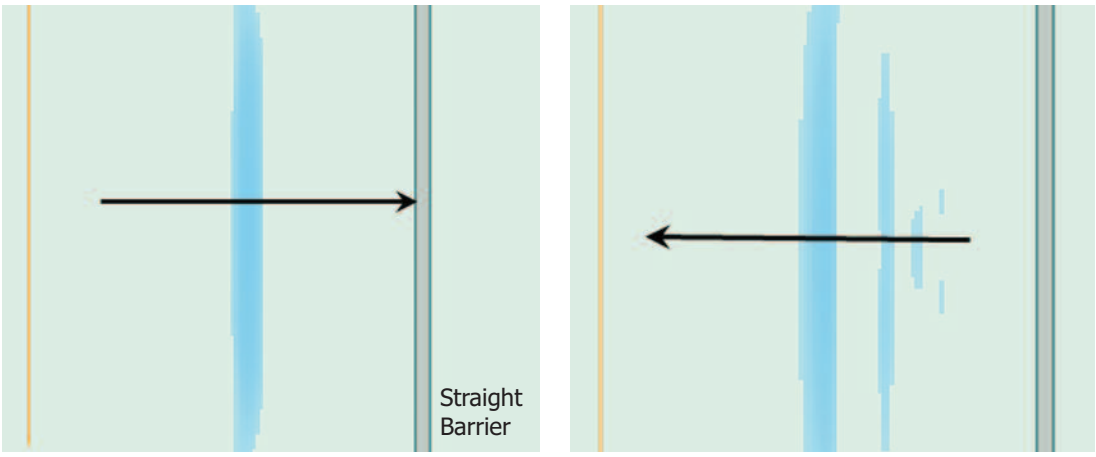
The diagram below shows what happens when a straight wave approaches a straight barrier **head on**, and then is reflected. The wave is reflected back along its original path, as shown.

This is an important kind of diagram. We will be working with similar diagrams often from this point, so let's discuss it in detail. There is more to the diagram than you may initially suppose. First off, we are looking from above, straight down onto the surface of the water. We are assuming that the surface of water is very large, but this is just a small part of it. On the right of each of these diagrams is a shaded rectangle; this represents a portion of the barrier. Again, we are assuming that it is very large, extending farther than

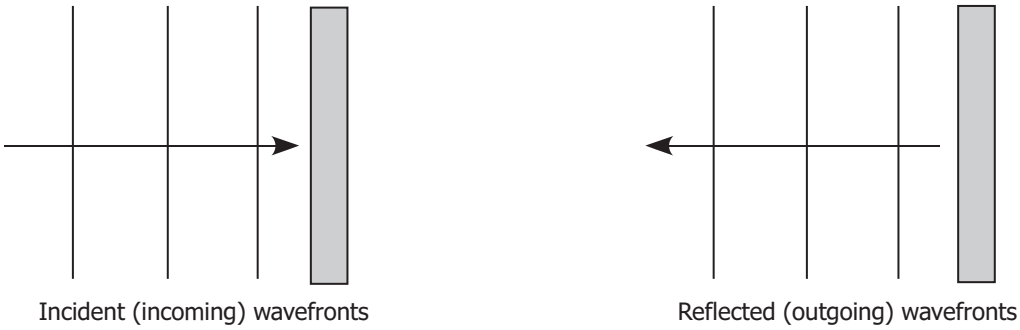
the diagram reveals. The vertical lines represent wavefronts. They are **crest fronts** since they are solidly drawn. We will use dashed lines to represent trough fronts, but we will often choose not to bother showing them, since they would automatically be between the crest fronts. As with the previous items, these wavefronts are assumed to be large, but we are only seeing the parts that "fit" in this view.

The arrows are the **wave rays** representing the motion of the wavefronts. Remember that they would not be visible in the actual view of the water surface. They are only there to help us appreciate the motion of the wave. They are drawn perpendicular to the wavefronts, as that is the direction of motion of the wavefronts.

The graphic below illustrates the reflection of a straight wavefront from a straight barrier. The wavefront strikes the barrier head on. The arrows represent the wave rays.



This diagram shows how we would draw a similar situation.

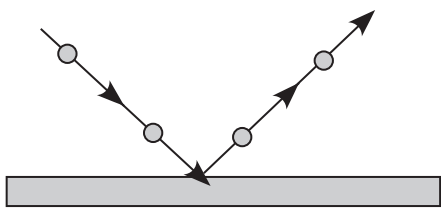


Notice that these two diagrams just are, in fact, identical except for the wave rays. This shows how important they can be! Essentially, this is what the picture reveals: three crest fronts initially (first diagram) were moving to the right, towards a barrier. They struck the barrier (not shown) and reflected. They then moved to the left, still as crest fronts (not inverted) and moved to the left (second diagram).

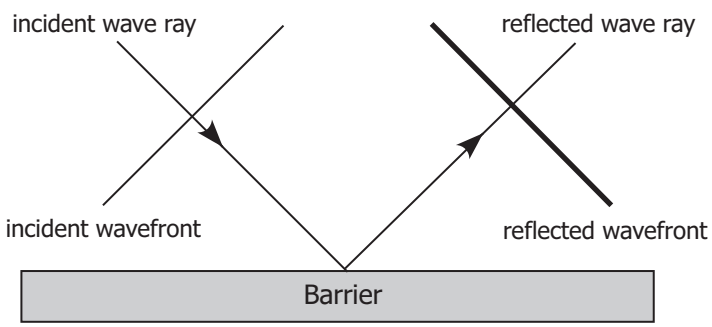
Wave rays turn out to be so useful, that we sometimes prefer to use them in our diagrams instead of the wavefronts. Remember that the wavefronts will always be perpendicular to the wave rays, so we should be able to add them in later if we need to. In the above diagram, the wave rays were both perpendicular to the barrier. This means that if a wave strikes a barrier head on, it will reflect straight back. This is similar to a ball rolling directly into a wall, and bouncing back.

Reflection of Straight Waves from a Straight Barrier at an Angle

What if a ball rolls into a wall along the floor, not head on but, rather, at an angle? You can probably predict what would happen: the ball would again bounce off, but this time it wouldn't go back in the direction it came from. Instead, it would go in a direction so that the overall path (before and after the bounce) would make a "V" shape, as seen in this diagram (where we are looking straight down at the ball rolling on the floor).



A wave would reflect in from a straight barrier in very much the same way, as shown in this diagram.

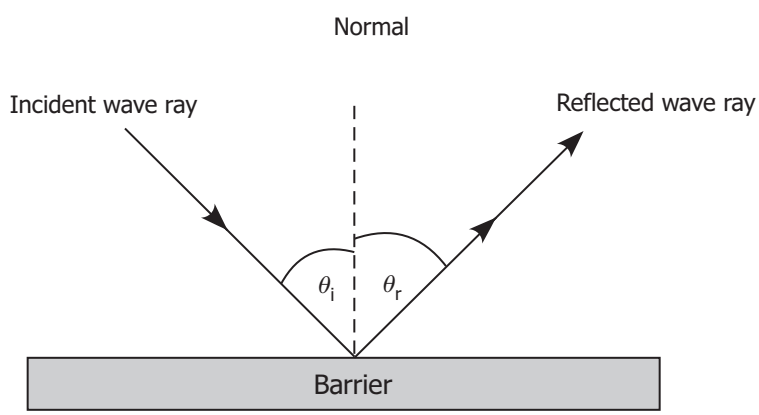


In general, there will be symmetry between the incident and reflected wave rays. This is the "V" shape, which is very similar to the path taken by the bouncing ball above. This means that the angle between the **incident ray** and the **barrier** will be the same as the angle between the **reflected ray** and the **barrier**.

However, in physics we have a very strong preference for measuring angles in cases such as this. We generally insist that we NOT measure angles directly to the barrier. Instead, we choose to draw in a **normal**, and measure angles to it. Here "normal" means "perpendicular."

> The "**normal**" is a drawn line perpendicular to the barrier, at the point that the ray strikes it.

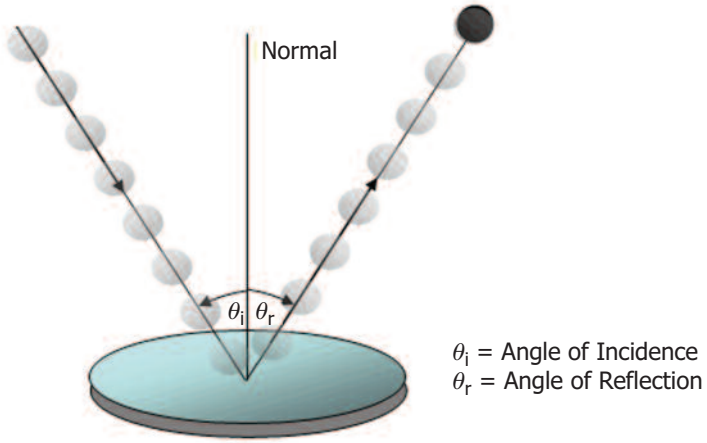
We can then measure the **angle of incidence** (symbol θ_i) between the incident ray and the normal, and the **angle of reflection** (symbol θ_r) between the reflected ray and the normal. The **law of reflection** states that the angle of incidence is always the same size as the angle of reflection, but these angles are always on opposite sides of the normal. This can be seen clearly in this diagram.



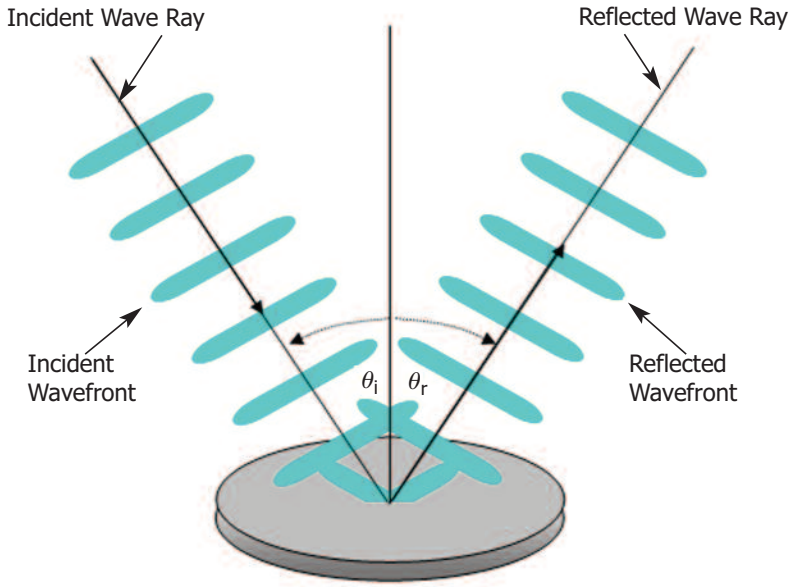
A normal is a line drawn in perpendicular to the barrier at the point that the incident ray strikes the barrier. The angle of incidence is the angle formed between the incident ray and the normal; the angle of reflection is the angle formed between the reflected ray and the normal. According to the law of reflection, these two angles are the same size, but are on opposite sides of the normal.

Here is a diagram illustrating these terms using a ball reflecting from the floor.

Reflection of a Ball off the Floor

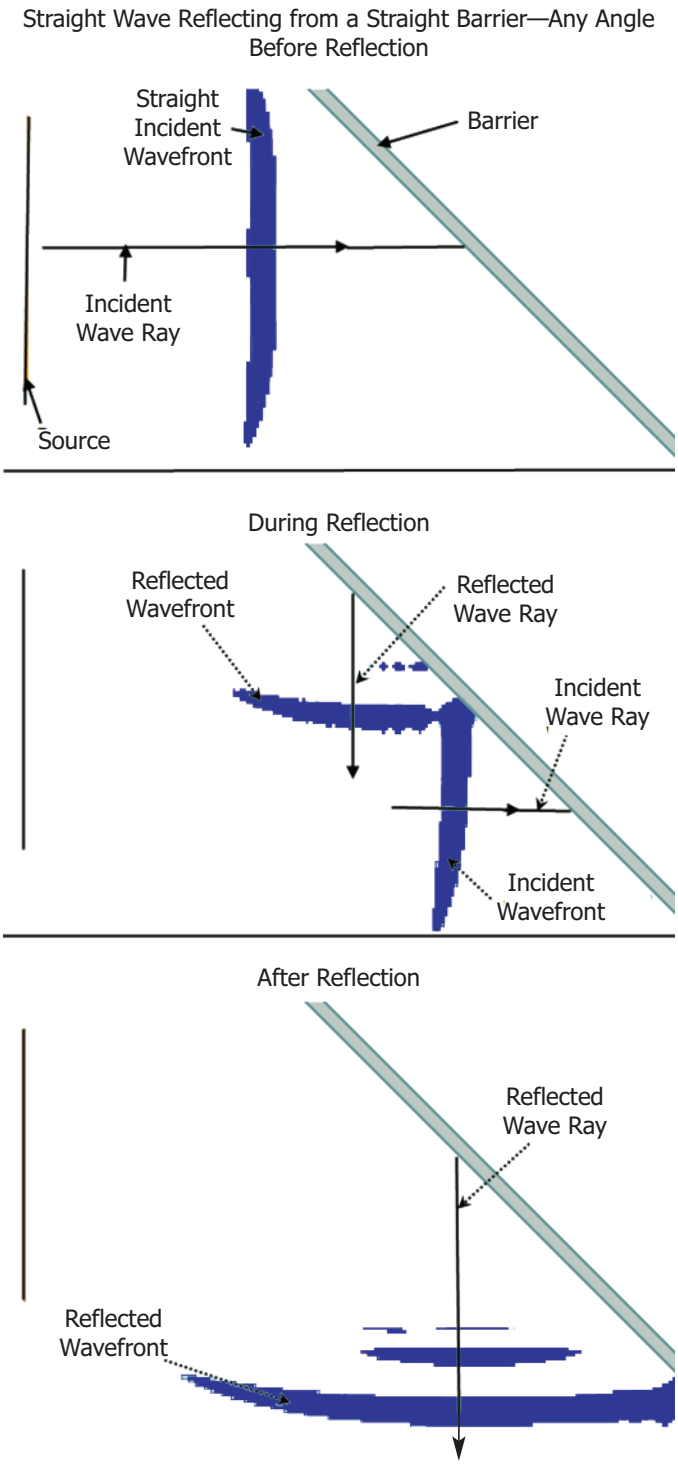


Now let's consider a series of wavefronts reflecting from a straight barrier.



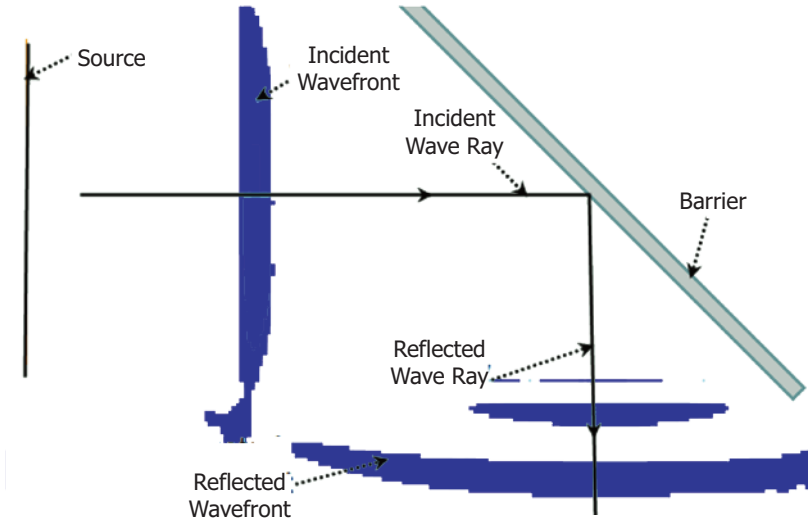
Reflection of a Straight Wave from a Straight Barrier in a Ripple Tank

The diagram below illustrates the reflection of a straight wavefront from a straight barrier in a ripple tank. There are three stages: before reflection, during reflection, and after reflection.

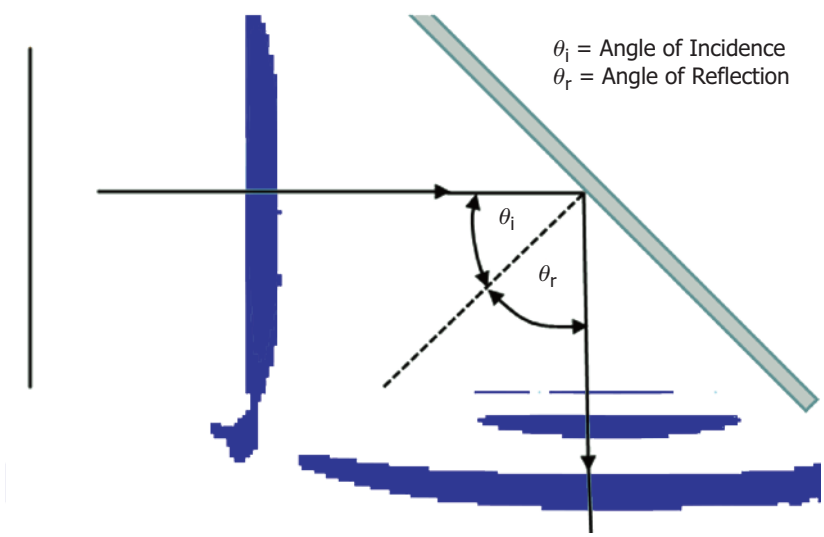


If we combine the before and after reflection frames, we can add in the information about angles of incidence and reflection.

Reflection of a Straight Wave Front from a Straight Barrier
Showing the Fronts and Rays



Reflection of a Straight Wave Front from a Straight Barrier
Showing the Angles of Incidence and Reflection

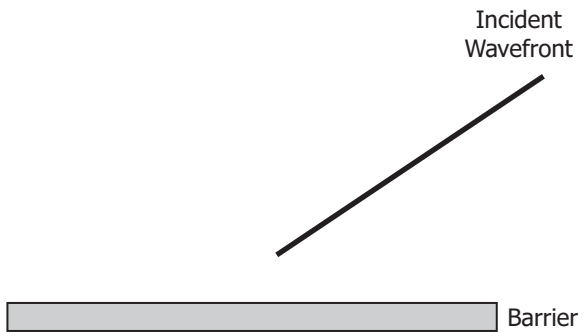


Again, you can see that the wavefront, during its motion, demonstrates the law of reflection.

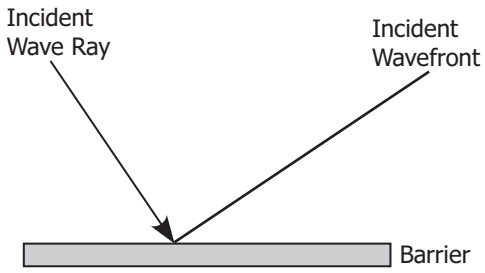
Drawing the Reflection of a Straight Wave from a Straight Barrier

If you are given a straight wave incident unto (travelling towards) a straight barrier, we can use the following procedure to draw in the reflected wavefront.

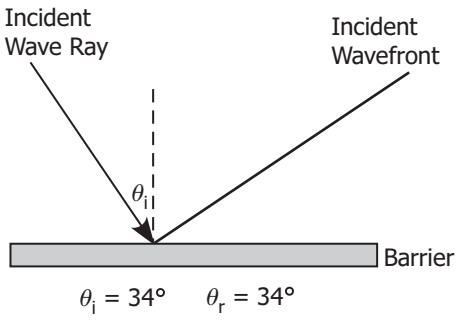
Given:



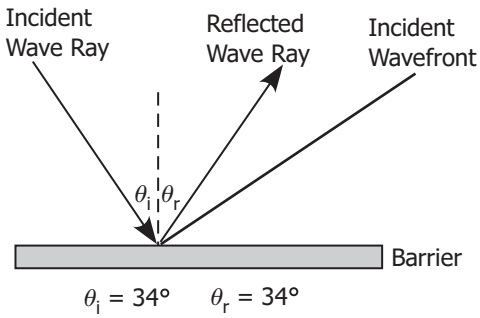
Step 1: Draw in the incident wave ray. Extend the incident wavefront until it touches the barrier. At the point where the incident wavefront intersects the barrier, draw a wave ray for the incident wavefront. Label the incident wave ray.



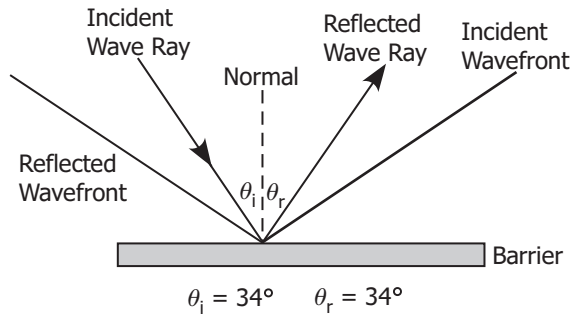
Step 2: Draw in the angle of incidence. Draw in the normal at the point of reflection. Measure the angle of incidence and label the angle of incidence.



Step 3: Draw in the reflected ray. From the normal, measure the angle of reflection at 34°. Draw in the reflected wave ray starting from the point of reflection. Label the reflected wave ray.



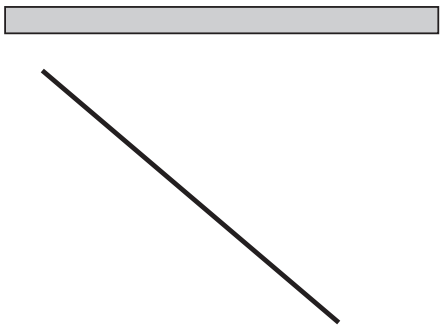
Step 4: Draw in the reflected wavefront. At the point of reflection, draw in the reflected wavefront. This is drawn perpendicular to the reflected wave ray. Label the reflected wavefront.



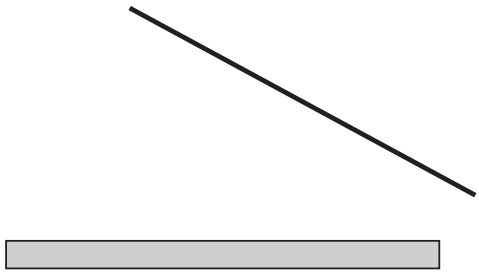
Learning Activity 8.1

Waves in Two Dimensions—Reflection: Part 1

1. The diagram below shows a wavefront moving upwards to the right approaching a barrier. For this wavefront, draw in the wave ray. Extend the wave ray to the barrier and draw in a normal. What is the angle of incidence?



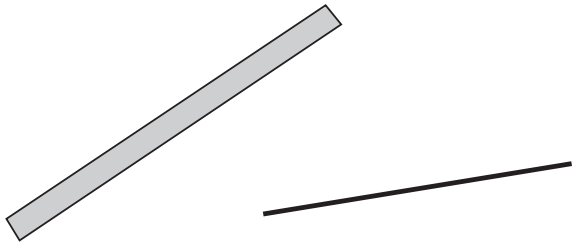
2. The diagram below shows a wavefront travelling away from a barrier (upwards to the right). For this wavefront, draw in the wave ray. Extend the wave ray to the barrier and draw in a normal. What is the angle of reflection?



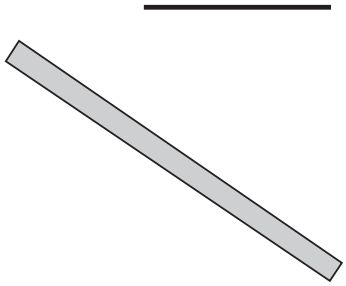
(continued)

Learning Activity 8.1: Waves in Two Dimensions—Reflections: Part 1 (continued)

3. The diagram below shows one wavefront approaching (moving upwards to the left) a straight barrier. Using the procedure outlined above, draw in the reflected wave pulse.



4. The diagram below shows one wavefront moving downward approaching a straight barrier. Add to this diagram the following.
   a) Draw the incident wave rays from the left edge and the right edge of the wavefront.
   b) Using a dashed line, draw a normal from the point where the incident wave ray makes contact with the barrier.
   c) Draw the reflected wave rays.
   d) Draw the reflected wavefront at some point on the wave rays.
   e) What is the angle of incidence?
   f) Draw in the angle of incidence and the angle of reflection.

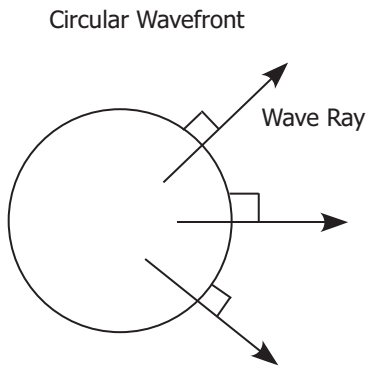


Special Cases for Reflection of Waves

In principle, the law of reflection will handle any situation (any shape of wave, and any shape of barrier). There are, however, three special cases that we will now turn our attention to. We will find that in each of these special cases, the law of reflection can be "bypassed" since the result of the reflection is quite simple. You can see how much work it is to actually draw the wave rays and wavefronts, the normals, and the angles. The point of the work from now on is to use the law of reflection (which you should now understand) to predict the path of a given wave ray. Once you know which way the wave ray will travel, you can draw it in along with the reflected wavefront.

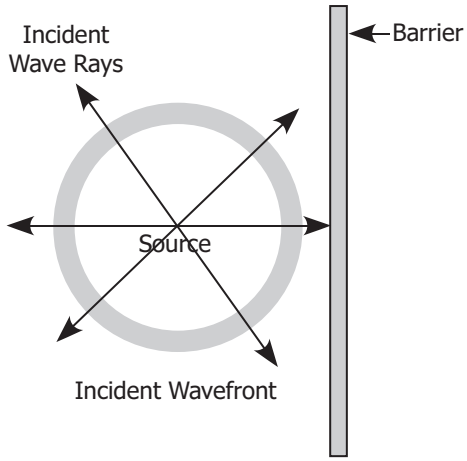
Reflection of Circular Waves from a Straight Barrier

The diagram below shows a circular wavefront. The wave rays indicate that the circular wavefront moves outward as though it is originating from the centre of the circle (which it may in fact have been the case). This is the diagram we saw earlier in this section.



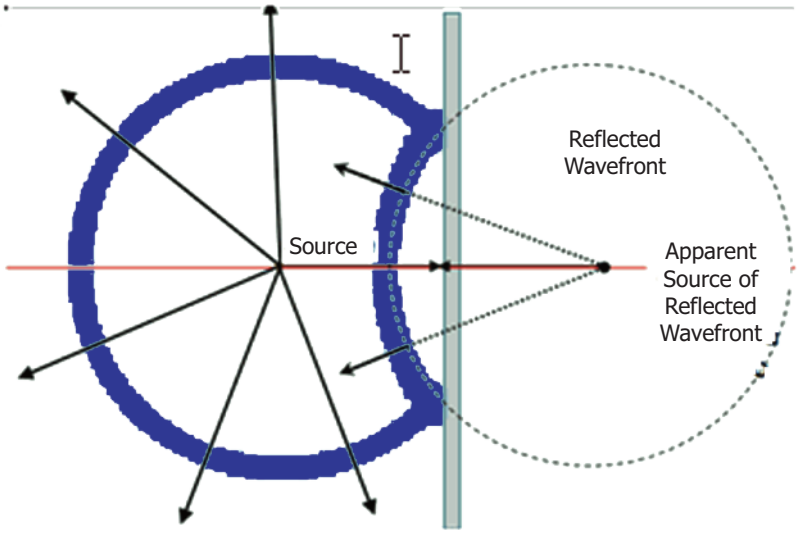
When the various parts of the circular wave reflect from a straight barrier, the angle of incidence equals the angle of reflection for each and every ray. This is somewhat difficult to imagine, because the wave rays will all be pointing in different directions.

Circular Wave Reflecting from a Straight Barrier
Before Reflection



There is an incredible thing, however, that makes reflection of a circular wavefront very easy to draw. The reflected wavefront from a circular incident wave will still be circular, and will appear to originate from a point behind the reflector. This point is the centre of the reflected wavefront. It is located the same distance behind the barrier as the distance of the centre of the incident wavefront in front of the barrier. The arrows originating at the apparent source show the direction of motion of the reflected wavefront.

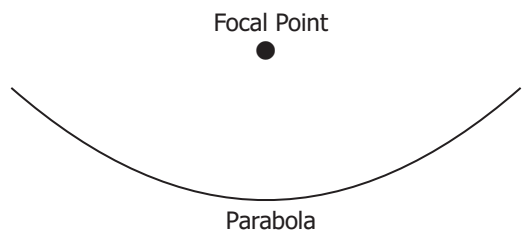
During Reflection



When a circular wavefront strikes a straight barrier, the reflected wavefront will still be circular, and will be centred on a point on the other side of the barrier. The centres of these two circles will be the same distance from the barrier.

Reflection of Plane Waves from a Parabolic Reflector

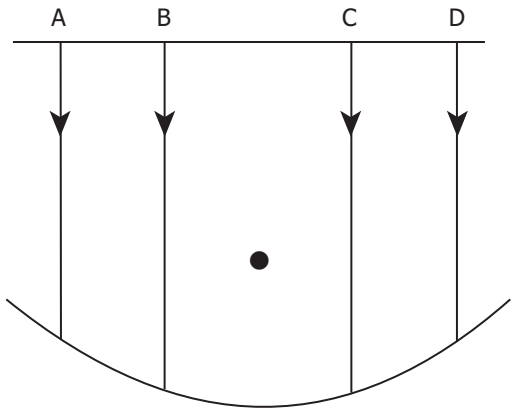
A **parabola** is a very specific kind of curve, defined by special mathematical equations. While the details of these shapes are very important, we will not focus on them here, other than stating that in addition to the shape itself, each parabola has a special point called a **focal point.** This focal point is not on the curve itself, but is rather located somewhat "within" the curve, as shown in the diagram here.



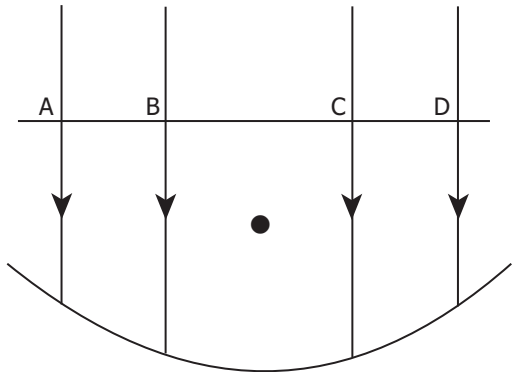
A parabola is a type of curve that has a spot called a focal point located within itself.

When plane (straight) waves directly approach, and then reflect from a parabolic reflector (striking the inside of the curve as shown), they (like all waves) obey the law of reflection. Remarkably, these wave rays reflect directly to (and then through) the focal point of the parabola, resulting in circular wavefronts, exactly as if a point source had been placed there, as shown below.

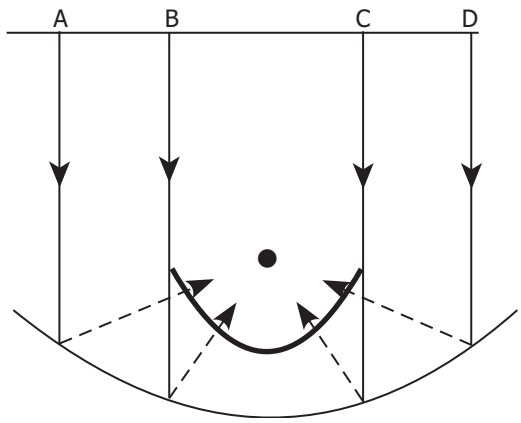
Here is a series of illustrations showing how the straight wavefront travelling directly into a parabola approaches, reflects, meets at the focal point, and finally how it looks after the wavefront has passed through the focal point.



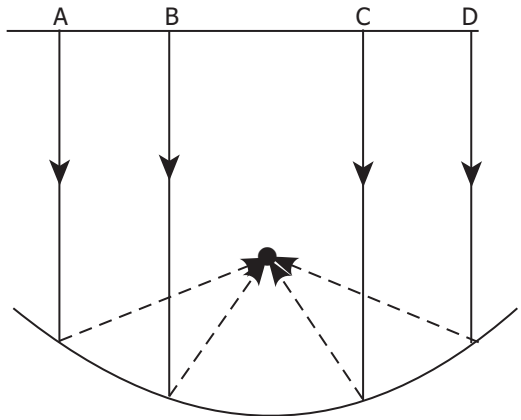
The straight wave moves towards the parabolic reflector.



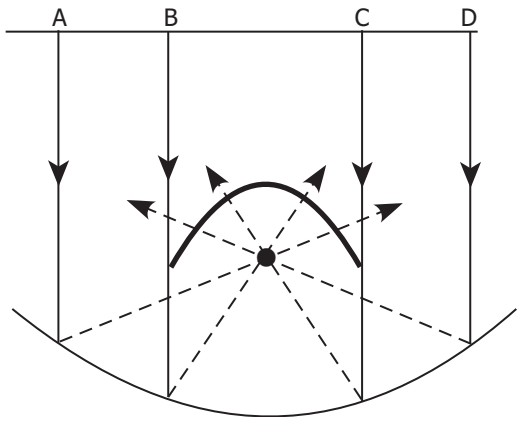
The wavefronts have reflected from the parabolic reflector and are approaching the focal point.



The reflected wavefronts converge at the focal point.



Finally, after passing through the focal point, the reflected wavefront spreads out from the focal point.



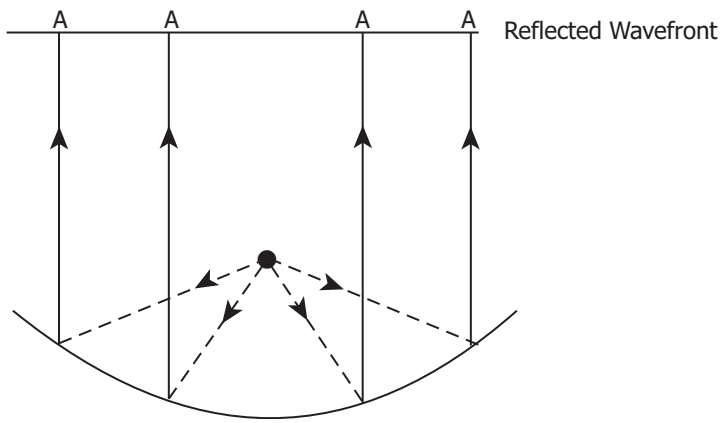
This behaviour turns out to be very useful, as it provides a way for us to redirect the entire portion of a wave approaching the reflector towards a particular spot—the focal point.

This is, in fact, the principle governing **satellite dishes**. If you look at a satellite dish, you will see that it has a curved shape like a shallow bowl or dish (which explains the second part of its name). This curve is, in fact, a parabola—or at least a three-dimensional version of one. If you were to cut a satellite dish in half, the cut sections would be parabolic in shape. In front of the dish is an arm that has the actual receiver in it—this is essentially an antenna. When the TV signal waves strike the dish, they reflect from it to the focal point, where the receiver is located. Having the receiver at the focal point allows the entire TV signal (which is a wave) that strikes the dish reflect towards the antenna. This enables a strong enough signal at the antenna to provide adequate reception. Not that long ago, satellite dishes were quite a lot larger than they commonly are today. This is, in part, because the signals were weaker then, which meant that the dish had to be larger in order to "collect" more of the wave to send to the receiver.

When plane waves directly approach and then reflect from the inside curve of a parabolic barrier, they move directly towards the focal point of the parabola.

Reflection of Circular Waves from a Parabolic Reflector

If circular waves are generated at the focal point, a portion of the wave will approach the reflector and reflect from it. Again, they will follow the rules of the law of reflection, with an interesting result: they will be reflected away from the parabolic surface as straight waves. If you think about this, you will find that this is exactly the opposite of the case above. This is the principle behind spotlights, flashlights, and headlights for cars (among other things). These lights are designed so that the light bulb is at the focal point of a parabolic mirror, which is inside the light itself (have a close look at a headlight or flashlight—you will see the light bulb surrounded by this curved mirror). The light hits the mirror and reflects outward as a beam of nearly parallel light rays. This allows the light to be more easily directed to where it is needed, in effect guiding the light to move in one direction. The diagram below shows the wave rays of such a circular wave originating at the focal point.



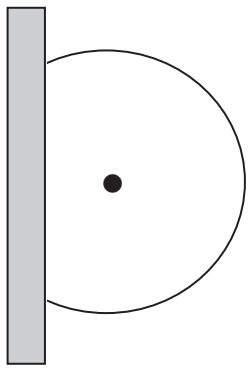
Circular waves originating at the focal point of a parabolic reflector reflect from it as plane waves—moving away from the reflecting parabola.

Learning Activity 8.2

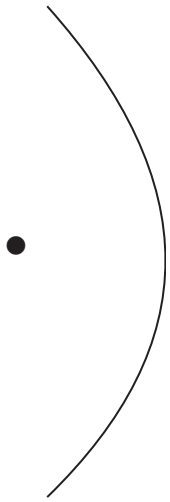
Waves in Two Dimensions—Reflection: Part 2

1. Under what conditions would straight reflected wavefronts have exactly the same size and orientation as the incident wavefronts (assuming no loss in energy)?

2. The diagram below shows a circular wave approaching a barrier. The centre of the wave is shown. Draw that part of the wave that has been reflected. Also draw a wave ray for the reflected ray from the place where the reflected wavefront seems to originate.



3. The diagram below shows a parabolic reflector. The focal point of the reflector is indicated by a dot. Circular pulses are generated from the dot. Draw two incident wavefronts and two reflected wavefronts. Add to the diagram an incident wave ray and a reflected wave ray.



Lesson Summary

In this lesson, we learned about the reflection of two-dimensional waves from straight and parabolic surfaces.

In a **ripple tank**, the crests on the water waves make light converge so that a **bright area** appears on the screen below. The troughs make the light spread out, creating **dark areas** on the screen. The distance between the bright areas is the length of one wavelength.

Circular waves can be created by touching the water surface with a point. **Straight waves** can be produced by rolling a dowel in the water.

A **wavefront** is a continuous crest or trough. A **wave ray** is a line at right angles to the wavefront, indicating the direction of travel of the wavefront.

A straight wave approaching a straight barrier parallel to the barrier is reflected back parallel to the barrier.

Wave rays are arrows that are drawn perpendicular to the wavefronts and show the direction of motion of the fronts.

The **normal** is the straight line perpendicular to the barrier. It is constructed at the point where the incident wave ray strikes the reflecting material.

The **angle of incidence** (θ_i) for the wave ray is defined as the angle between the normal and the incident wave ray. The **angle of reflection** (θ_r) for the wave ray is defined as the angle between the normal and the reflected wave ray. The angle of incidence is equal to the angle of reflection.

A circular wavefront moves outward as though it is originating from the centre of the circle. If the circular wave reflects from a straight barrier, then the reflected wavefront appears to originate from an imaginary point behind the reflector. This point is located the same perpendicular distance behind the barrier as the distance of the centre of the incident wavefront in front of the barrier.

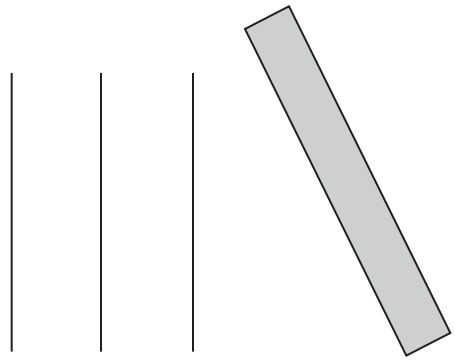
The **focal point** is the point in front of the parabolic reflector where the wave rays heading straight into the parabolic reflector converge after reflecting. When **straight waves** approach a parabolic reflector, they are **reflected** as **circular waves** to the **focal point**. **Circular waves** that **originate** at the **focal point** are reflected as **straight waves** that travel away from the parabolic reflector.

Assignment 8.1

Waves in Two Dimensions—Reflection (5 MARKS)

Be sure to show all your work and explain the method of arriving at your answer.

The diagram below shows three wavefronts moving to the right, approaching a solid barrier.



a) We will focus on the wavefront closest to the barrier. Draw the incident wave ray indicating the direction of motion of the incident wavefront. Draw this ray from the top end of the wavefront and show the ray in contact with the barrier.

b) Draw a normal using a dashed line, and label the angle of incidence (θ_i) for this wave ray.

c) Draw the reflected wave ray and label the angle of reflection (θ_r).

d) Draw one possible location of the reflected wave crest anywhere on the reflected wave ray. In your answer, pay particular attention to the orientation of the reflected wavefront relative to the reflected wave ray. Also, be careful to indicate what part of the reflected wavefront is connected to the reflected wave ray.

(continued)

Assignment 8.1: Waves in Two Dimensions—Reflection

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for drawing the incident wave ray in part (a)
- 0.5 marks for drawing a normal in part (b)
- 0.5 marks for labelling the angle of incidence in part (b)
- 0.5 marks for drawing the reflected wave ray in part (c)
- 0.5 marks for labelling the angle of reflection in part (c)
- 1 mark for the proper orientation of the reflected wavefront relative to the wave ray in part (d)
- 1 mark for connecting the correct part of the wavefront to the wave ray

Lesson 2: Waves in Two Dimensions—Refraction (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain how frequency, wavelength, and speed are related for water waves in different depths of water
- ❑ define the term "refraction"
- ❑ draw a diagram showing the refraction of water waves as they move from one depth of water to another
- ❑ describe how the wavelength of refracted waves and the speed of the refracted waves change as the waves move from one depth of water to another
- ❑ use Snell's Law for water waves to determine angles of incidence or refraction, and the speeds and wavelengths of incident or refracted waves

Key Words

refraction	wavelength
frequency	universal wave equation
speed	medium

Introduction

In the previous lesson, we investigated the reflection of water waves. In this lesson, we study the refraction or bending of water waves as they move from one depth to another. We will use diagrams to help us in this study. We will conclude the lesson with a derivation of Snell's Law. This law will allow us to calculate angles, wavelengths, and speeds for waves that are moving from one medium to another or from one depth of water to another. This work also has applications to other waves, such as sound waves and earthquake waves.

Waves Moving from One Depth to Another Straight On

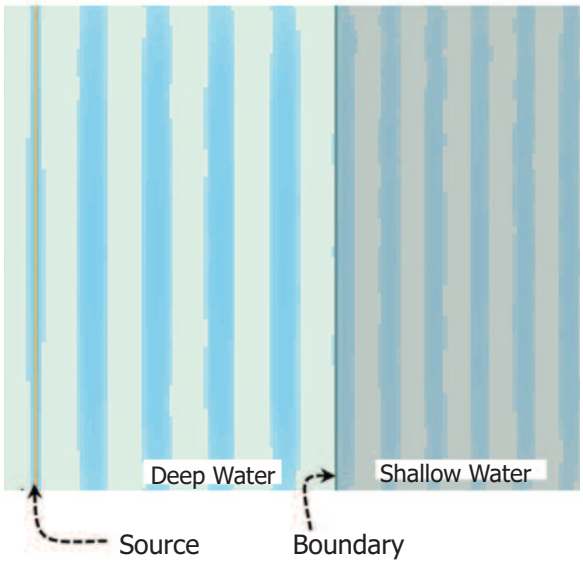
As was discussed earlier in this module, the speed of a wave depends only on the medium. In general, different media support waves at different speeds. We saw this by looking at one-dimensional waves transitioning from one kind of spring to another. You may wish to review Module 7, Lesson 2 at this time, as we will now expand on this idea for water waves in two dimensions.

The speed of a water wave depends on the depth of the water. Deep water supports waves at a higher speed than shallow water. Much as a swimming pool can have a "deep end" and a "shallow end," we can create shallower parts in a ripple tank by placing plates of glass or plastic at the bottom of a ripple tank. The water will then have a greater depth in those parts that do not contain additional plates.

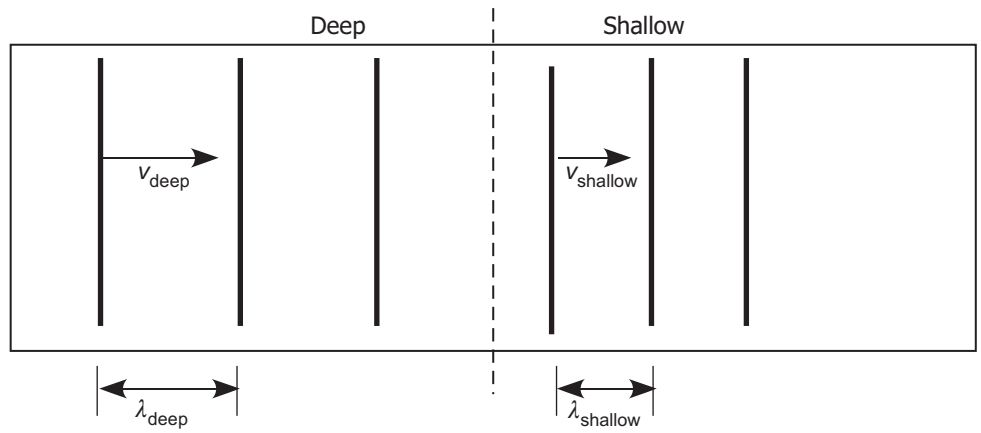
> Water waves move faster in deeper water and slower in shallower water.

The diagram below shows waves initially moving in deep water entering directly into shallow water. As the waves move into the shallow water, the frequency of the waves does not change. This is because, in general, the frequency of a wave is the same as the frequency of its source. In this case, the wave in the deep water is the source of the wave that results in the shallow water.

> The frequency of a wave does not change when it transmits (enters) into a new medium.



The diagram below represents the ripple tank situation above.



In the deep water, we can call the speed of the waves v_{deep} and notice that in accord with the equation $v = \lambda f$, $v_{deep} = \lambda_{deep} f$.

In the shallow water, the speed of the waves can be called $v_{shallow}$ and we note that $v_{shallow} = \lambda_{shallow} f$.

The two frequencies are identical.

We can solve both of these equations for frequency, f.

From the first equation, we have $f = \dfrac{v_{deep}}{\lambda_{deep}}$ and from the second equation we have $f = \dfrac{v_{shallow}}{\lambda_{shallow}}$.

This means that $\dfrac{v_{shallow}}{\lambda_{shallow}} = \dfrac{v_{deep}}{\lambda_{deep}}$ or, rearranging this equation, $\dfrac{v_{deep}}{v_{shallow}} = \dfrac{\lambda_{deep}}{\lambda_{shallow}}$. Of course, more generally, we can simply refer to the two speeds as v_1 and v_2 and the two wavelengths as λ_1 and λ_2. This allows us to write this most recent equation as $\dfrac{v_1}{v_2} = \dfrac{\lambda_1}{\lambda_2}$, which tells us that the ratio of the speeds is equal to the ratio of the wavelengths. If a wave enters a new medium that supports the wave at twice the speed, the new medium will also have twice the wavelength; if the new medium supports the wave at half the speed, then it will also have half the wavelength (and so on).

Speed and Wavelength of Waves in Different Media: When a wave enters a new medium, its wavelength will increase or decrease by the same proportion that its speed changes.

$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Quantity	Symbol	Unit
Speed in medium 1	v_1	metres/second (m/s)
Speed in medium 1	v_2	metres/second (m/s)
Wavelength in medium 1	λ_1	metres (m)
Wavelength in medium 1	λ_2	metres (m)

This is shown in the diagrams above, which show water waves initially moving in deep water entering directly into shallow water. Notice that since shallow water supports the waves more slowly, the wavelength must decrease.

Example 1: Water Waves Passing from Deep Water to Shallow Water in a Pool

Now consider this example: a water wave has a wavelength of 2.00 m in the deep end of a pool, and 1.50 m in the shallow end. If the speed of the water wave in the shallow end is 1.20 m/s, calculate the speed in the deep section.

The two media are deep water (medium 1) and shallow water (medium 2).

Given: Wavelength in deep water $\lambda_{deep} = 2.00$ m

Wavelength in shallow water $\lambda_{shallow} = 1.50$ m

Speed of wave in shallow water $v_{shallow} = 1.20$ m/s

Unknown: Speed of waves in deep water $v_{deep} = ?$

Equation:

$$\frac{v_{deep}}{v_{shallow}} = \frac{\lambda_{deep}}{\lambda_{shallow}}$$

Rearrange to $v_{deep} = \dfrac{v_{shallow}\lambda_{deep}}{\lambda_{shallow}}$

The equation has been solved for the unknown.

Substitute and solve:

$$v_{deep} = \frac{(1.20\text{ m/s})(2.00\text{ m})}{1.50\text{ m}} = 1.60\text{ m/s}$$

The speed in the deep water was 1.60 m/s. This makes sense as the waves move more quickly in deeper water.

Refraction of Water Waves

When a wave travels from one depth of water to another in such a way that it meets the boundary between the two depths straight on, it simply transmits into the new medium. While the speed and wavelength will change, there is no change in the direction of motion. When the wave meets the boundary at an angle, however, the direction of travel does change. This change in direction of motion of a wave as it passes from one medium to another is called **refraction**.

> **Refraction** occurs when a wave enters a new medium at an angle, and the direction of motion changes as a result.

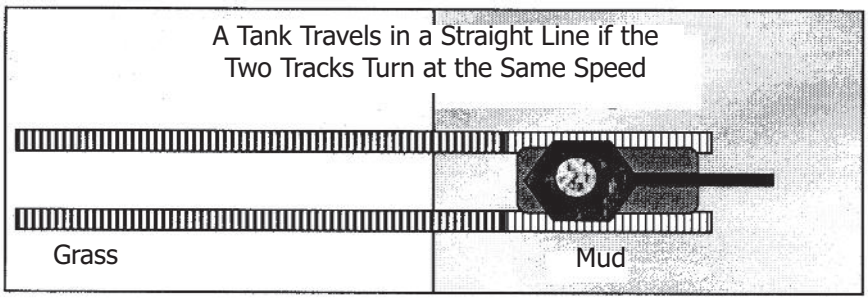
Refraction occurs because the different parts of the wavefront enter the new medium (and therefore change speed) at different times. This can be compared to the motion of a tank (the army-style vehicle). A tank does not have any tires in the usual sense. Instead, it has two treads, one on each side. If these two treads turn at the same speed the tank will go straight ahead.

A Tank Travels in a Straight Line if the
Two Tracks Turn at the Same Speed

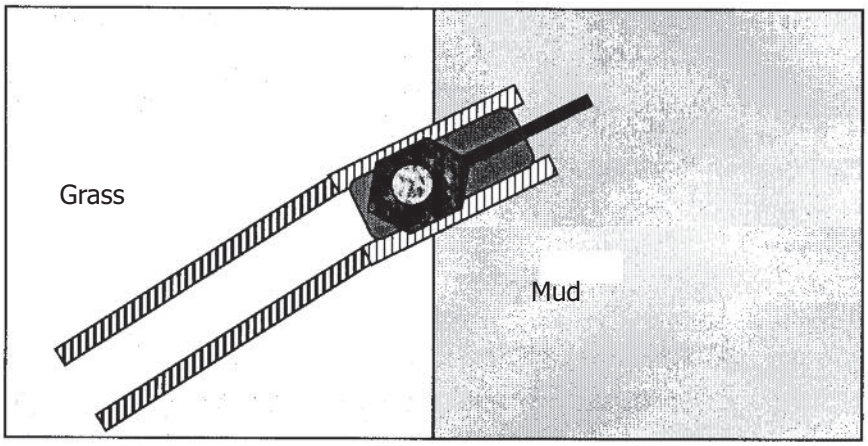
If they do not turn at the same speed, then the tank will turn. (This is, in fact, how they "steer" tanks. Unlike a car, there are no front tires to rotate in order to control the motion.)

Let's now consider a tank moving across a smooth grassy field. It can easily move across the grass quickly. Let us suppose there is thick, wet mud on the other side of the field. Being a tank, it will be able to get through this mud, but since the mud is thick and wet, the tank will not be able to move through it as quickly. In effect, we are considering the field to be a "fast medium" and the mud to be a "slow medium." If the tank is entirely in either of these media, it will go straight. (For this analogy to work, we assume that treads are turning as quickly as they can, which depends on whether the tread is on grass or mud.)

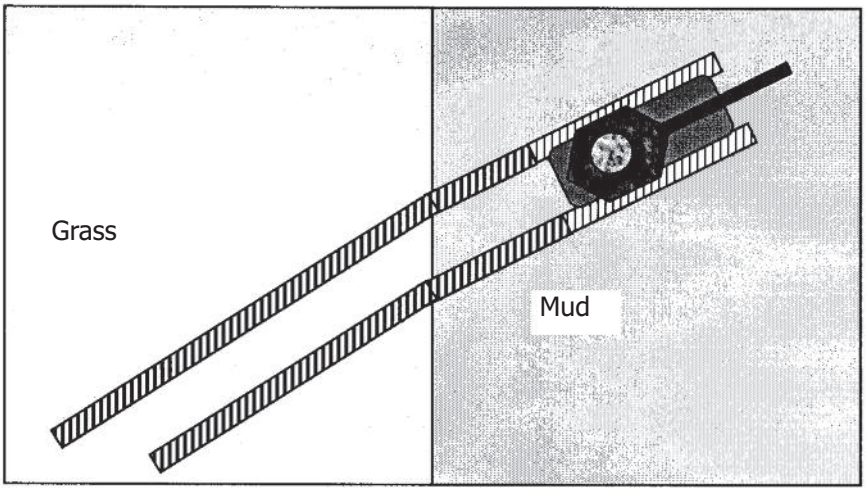
Now, if the tank is driving quickly across the field and enters into the mud "head on," both treads will enter the mud at the same time and the tank will slow down. It will not, however, change the direction it is moving. We can say that the tank has "transmitted" into the mud, but it has not "refracted." (Properly speaking, neither of these words should be used for objects, but we will anyway!)



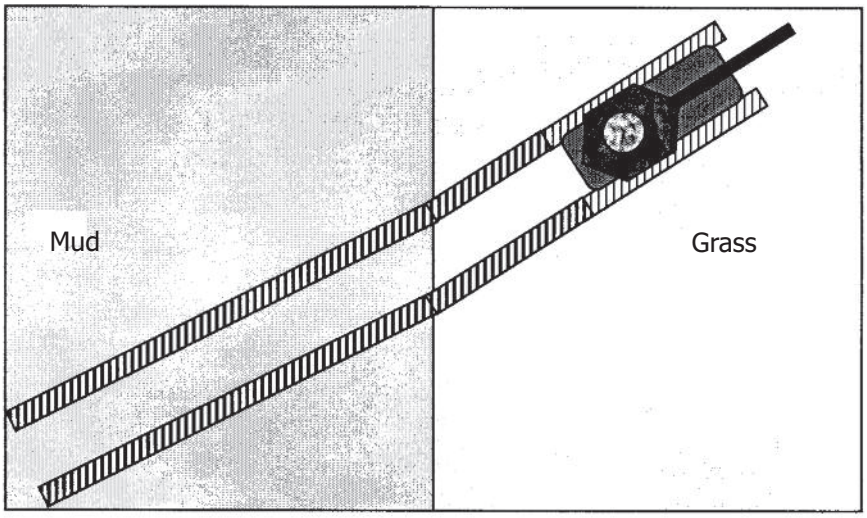
If the tank was moving across the field in such a way that its right-side treads enter the mud first (this could happen if it entered at an angle), then the right tread would be in the mud (slow) while the left tread would still be, for a little longer, on the grass (fast). This would cause the tank to momentarily veer to its right upon entering the mud.



Of course, once it is entirely in the mud, it will continue going straight—just not quite the same way as before it entered the mud. We can say that the tank did "refract" upon "transmitting" into the mud.



Now consider a tank that is already entirely in the mud approaching the grassy field. If it enters the grassy field directly, it will again transmit without refracting. But if it enters at an angle, it will refract. Consider the tank getting out of the mud (slow) in such a way that its right tread hits the grass first. This time, with the right tread going faster, the tank will momentarily veer to its left.



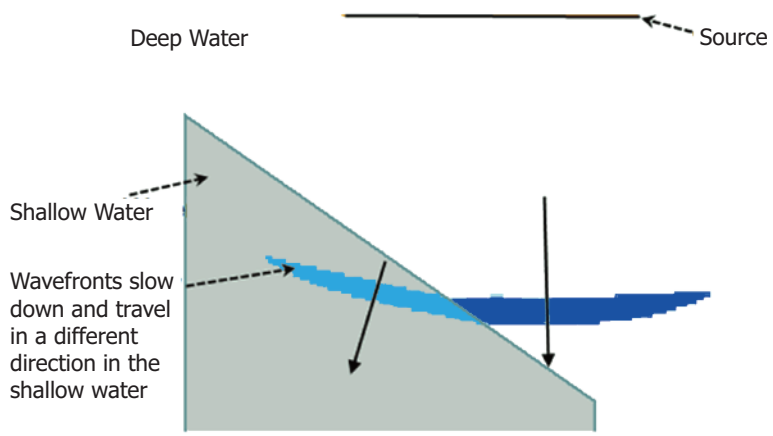
In the above, we used a tank to represent a wavefront (the front would span from one side of the tank to the other). The direction of motion of the tank corresponds to the direction of motion of the front, and this could be visualized with rays.

Refraction of Waves in a Ripple Tank

Waves in a ripple tank exhibit the same behaviour (a change in the direction of motion) as the army tank in terms of their motion as they pass (transmit) from one medium to another.

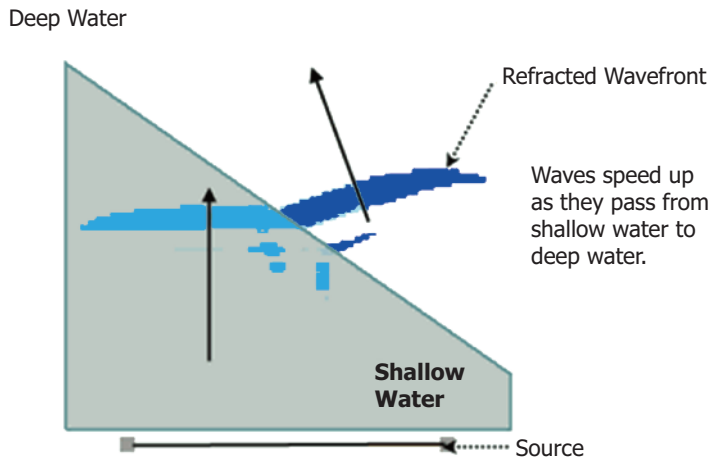
Below is the refraction of wavefronts as they pass from deep water to shallow water.

Refraction of Waves



Here is the refraction of wavefronts as they pass from shallow water to deep water.

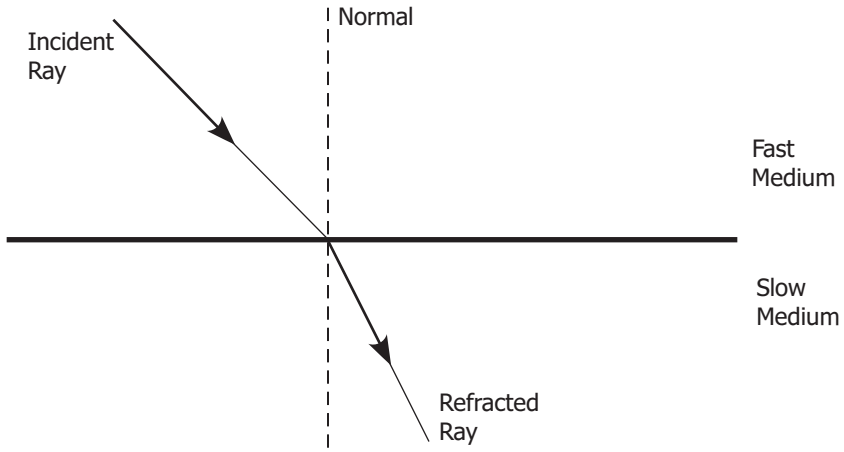
Refraction of Waves—Shallow Water to Deep Water



Note: Now would be a good time to observe animations of refraction on the Internet. Check the appendix or do a search for appropriate Internet sites.

Wavefronts, Wave Rays, Angle of Incidence, and Angle of Refraction

In general, when a wave travels at an angle into a medium in which its speed is less, the refracted wave is said to "bend towards the normal." If you view the refracted wave ray, it is not in the same direction as the incident ray is; it is turned so that it is closer to the normal than the incident wave ray is. The diagram below shows exactly this.

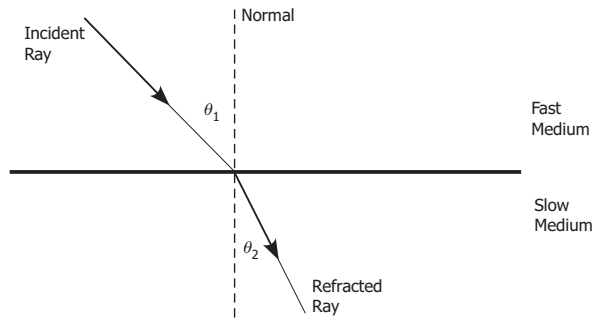


Note that the **incident ray** travels in the first medium **towards** the boundary. The **refracted ray** travels in the second medium away from the boundary.

In keeping track of refraction numerically, we measure the angle that each of these two rays makes to the normal. Again, note that the angles are measured from the normal and not from the boundary separating the two media. These angles may be called the **angle of incidence** (as it was for reflection) and the **angle of refraction**. It is common to label the angle of incidence θ_1 and the angle of refraction θ_2.

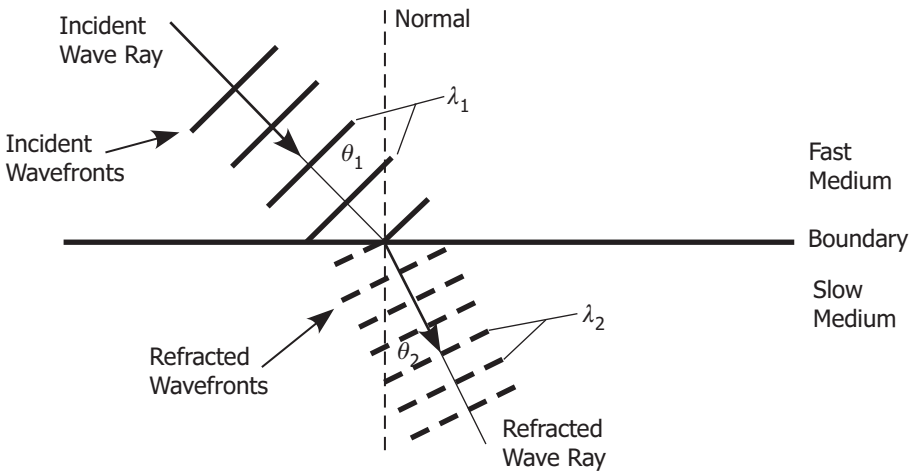
The **angle of incidence** (θ_1) is measured in the incident medium from the normal to the surface, drawn at the point of refraction to the **incident wave ray**.

The **angle of refraction** (θ_2) is measured in the refracted medium from the normal to the medium from the normal to the surface, drawn at the point of refraction to the **refracted wave ray**.



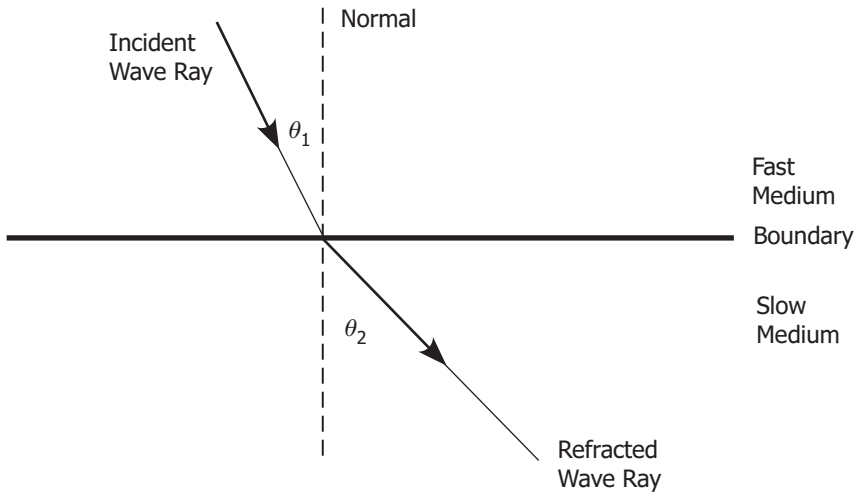
Of course, you must remember that the rays and normal would not be visible on the actual medium. The only thing visible on the medium itself would be the wavefronts, which do not appear in the above diagrams.

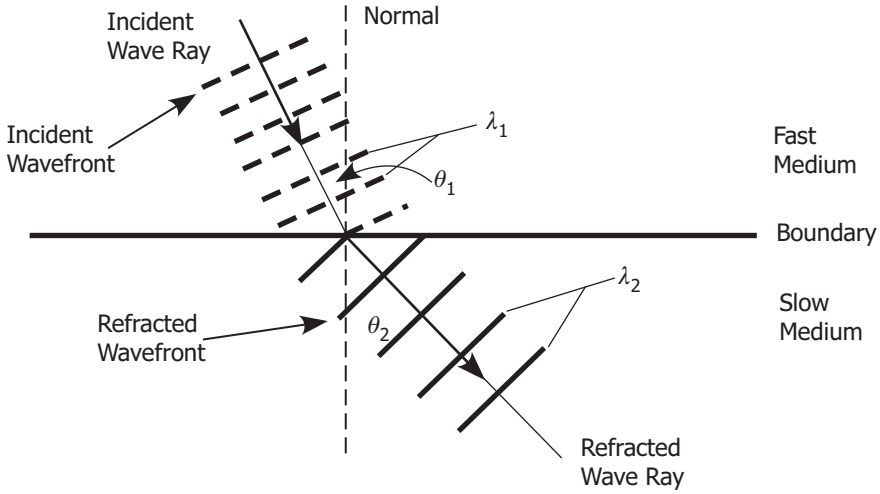
We can add the wavefronts to the diagram to arrive at the following diagram (though it is generally not needed to show the actual fronts). Notice that the wavelength in the slower medium is smaller than the wavelength in the faster medium, as was previously discussed.



When a wave enters a **slower** medium (goes from fast medium to slow medium) at an angle, the ray bends **towards the normal**. This means that the **angle of refraction** (as measured between the refracted ray and the normal) will **be smalle**r than the **angle of incidence** (as measured between the incident ray and the normal). At all times, the fronts are perpendicular to the rays.

Now, if the waves are initially in the slower medium and enter the faster medium, everything that we have just said will be exactly the opposite. This can be seen in the next series of diagrams, which correspond to those above.





The Law of Refraction

The **Law of Refraction** is most easily thought of as being a mathematical relationship which relates the speeds of two media to the angles of incidence and refraction. The law of refraction is sometimes called "Snell's Law" in honour of one of its discoverers, Willebrord van Roijen Snell who was a Dutch mathematician.

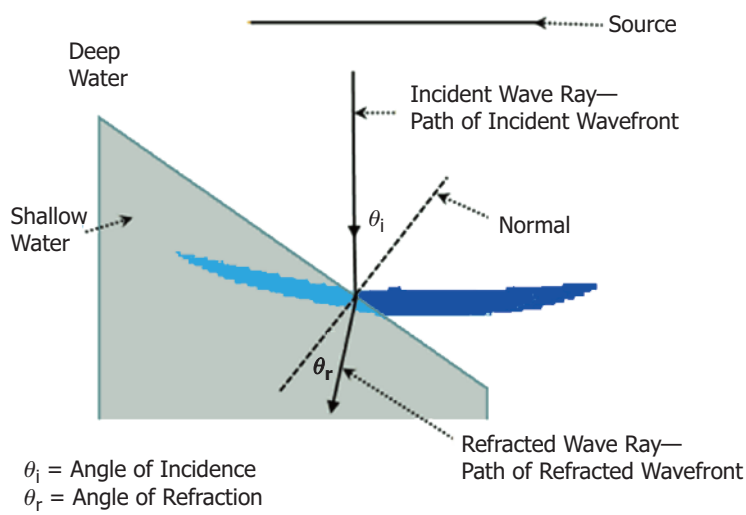
The equation form of the Law of Refraction contains four variables: the speed of the wave in the incident medium (v_1), the speed of the wave in the refracted medium (v_2), and the wavelengths in each of these two media (λ_1 and λ_2).

Instead of merely stating this equation with the hopes that you believe it to be true, we will go through the steps of where the equation comes from—the "derivation" of this equation. You should try your best to follow carefully each step of this derivation—you should be able to do so, but you can relax a bit while going over it, as you do not have to memorize it, or be able to repeat these steps on your own. You will of course have to work with the end result which is the Law of Refraction.

We will begin with previously established ideas and then use some mathematical tools to generate a new equation.

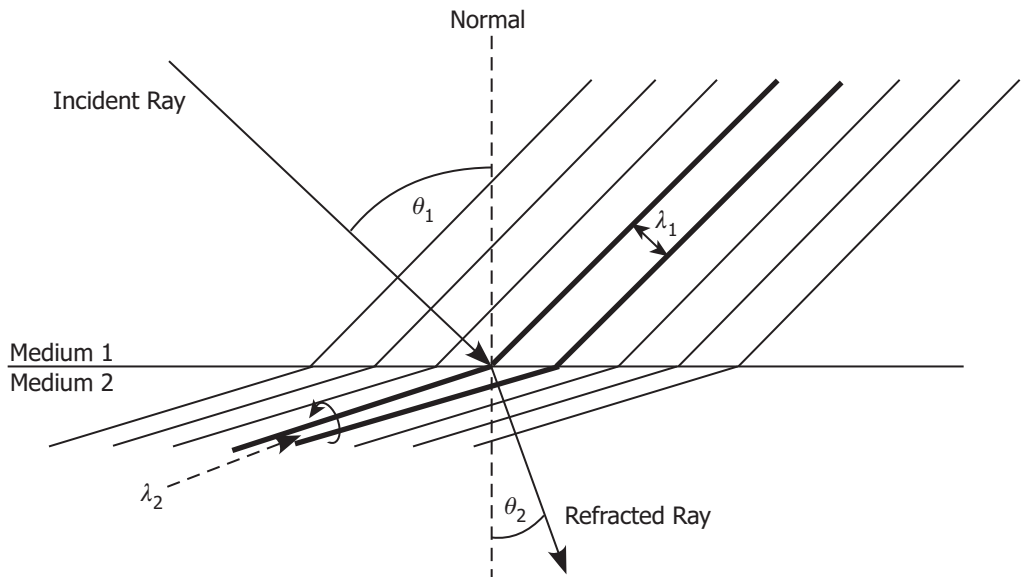
The graphic below shows a wavefront refracting as it passes from deep to shallow water. The wave rays have been drawn in at the point where refraction occurs. The normal to the surface (boundary) between the two media is also drawn in with the angle of incidence and the angle of refraction.

Angles of Incidence and Refraction



Now imagine that there was a series of wavefronts undergoing refraction. The diagram below shows how we would draw this.

The diagram below will also help us to understand how the law is derived.

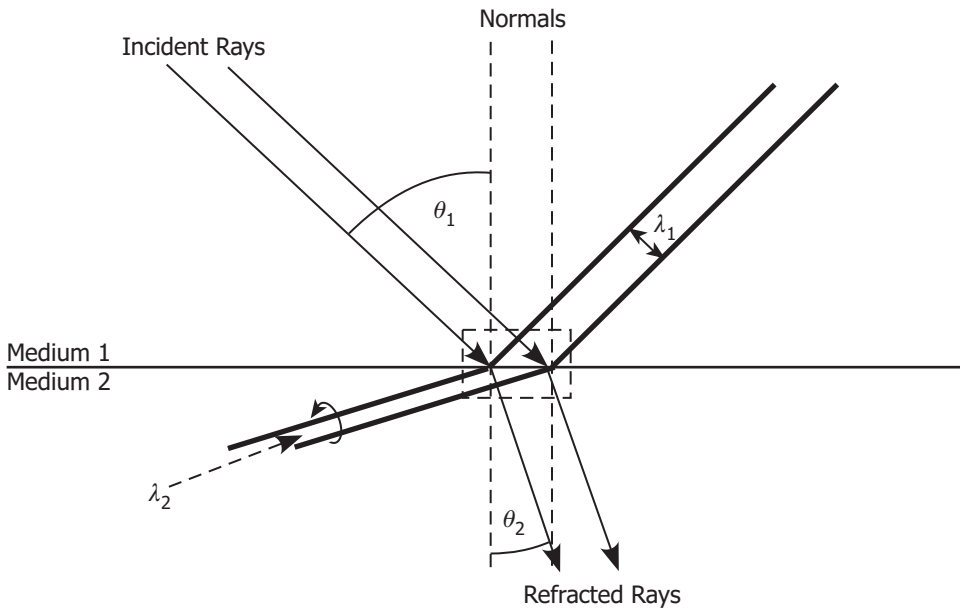


This diagram contains a lot of information and is somewhat confusing to look at, but it should be fairly familiar by now.

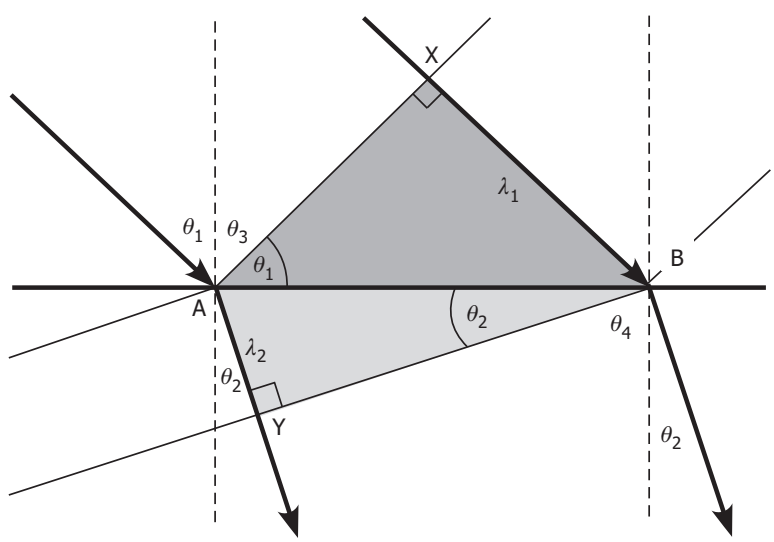
The horizontal line near the middle of the diagram is the boundary separating two media, which are labelled "Medium 1" and "Medium 2." An incident ray is drawn and labelled, as is the refracted ray. In the example we are using, it should be clear that medium 1 is the "fast" medium while medium 2 is the "slow" medium. (Think of the rays as the path of the tank that we introduced earlier. Medium 1 would be like the grassy field and medium 2 would be like the mud.)

The normal is drawn in at the point that the incident ray strikes the boundary and the angles θ_1 and θ_2 representing the incident and refracted angles are shown (between each ray and the normal as required).

In addition, several wavefronts are shown. These are the diagonal lines, and since they are all crest fronts, as is the norm for our diagrams (trough fronts are understood to be present but not drawn), the wavelength can be found between any two of these fronts. (Two examples of this are shown in the diagram.) Notice that the fronts are perpendicular to the rays, and that the fronts are "bent" at the boundary due to refraction. Two of the fronts appear darker in the diagram. Let's have a closer look at these particular fronts.



This diagram is the same as the previous with a few changes. The "extra" fronts have been removed, leaving only those that we are focusing our attention on. In addition, each front shown is "complete" with its very own normal and set of rays at the point where it intersects the boundary between the two media. Finally, a dashed rectangular box has been added. This box shows a region that we can now zoom in on to have a closer look. This is seen in the next diagram.



In this diagram, two triangles have been shaded to draw your attention to them.

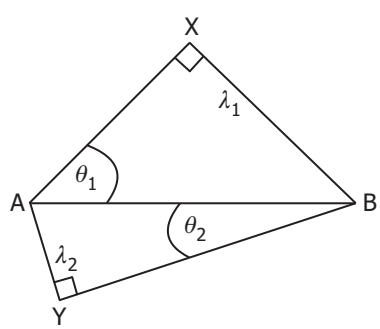
- The upper triangle is formed from the upper wavefront, the right ray, and the boundary.
- The lower triangle is formed from the lower wavefront, the left ray, and the boundary.

There is some interesting geometry worth pointing out. First of all, notice that the angle θ_1 is and always has been formed between the ray in medium 1 and the normal. This, however, is not the only place where θ_1 can be found in this diagram. Notice that it also appears in the upper triangle. This is because these two angles are guaranteed to be the same size. Have a look at θ_3, which is also newly labelled in this diagram. We won't need θ_3 for long. It is only there to convince you that both of the angles labelled θ_1 are, in fact, equal.

Remember that the normal is by definition perpendicular to the boundary, and also that the rays are by definition perpendicular to the wavefronts. Each of the angles labelled θ_1 must be complementary with θ_3 (complementary means add up to 90°). This is a geometric proof that θ_1 can indeed be labelled inside the upper triangle as shown.

θ_2 belongs in the lower triangle for exactly the same reason. Each angle labelled θ_2 must be simultaneously complementary with the angle labelled θ_4.

There is one more thing that we must point out: both the upper triangle and the lower triangle share one side, which is labelled "AB." In fact, the segment labelled AB is the hypotenuse of both of these triangles, as can be seen in the next diagram, which focuses entirely on the triangles themselves.



We can apply basic trigonometry to each of these two triangles. Notice that for the upper triangle:

$$\sin\theta_1 = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\lambda_1}{\text{AB}}$$

$$\sin\theta_1 = \frac{\lambda_1}{\text{AB}} \rightarrow \frac{\lambda_1}{\sin\theta_1} = \text{AB}$$

And for the lower triangle:

$$\sin\theta_2 = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{\lambda_2}{\text{AB}}$$

$$\sin\theta_2 = \frac{\lambda_2}{AB} \rightarrow \text{AB} = \frac{\lambda_2}{\sin\theta_2}$$

Since AB is equal to both $\frac{\lambda_1}{\sin\theta_1}$ and $\frac{\lambda_2}{\sin\theta_2}$, then these two expressions must be equal to each other:

$$\frac{\lambda_1}{\sin\theta_1} = \frac{\lambda_2}{\sin\theta_2}$$

Finally, we can rearrange this equation into $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2}$.

We are nearly finished with this derivation.

Recall that for any wave, the wave equation $v = f\lambda$ can be applied to relate the speed, wavelength, and frequency of the wave.

This equation can be solved for wavelength: $\lambda = \frac{v}{f}$.

We may substitute $\frac{v}{f}$ in place of each λ in the above equation:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\frac{v_1}{f_1}}{\frac{v_2}{f_2}} \left(\begin{array}{l}\text{division requires you to multiply by the reciprocal} \\ \text{of the divisor}\end{array}\right)$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{f_1} \times \frac{f_2}{v_2}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$$

Putting this all together gives $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$.

But, as we have discussed earlier, these two waves must have the same frequencies, as the first wave acts as the source for the second wave. This means that $f_1 = f_2$ (so we can refer to both of them as "f"), which allows us to "cancel" the frequency out of this equation, as shown here .

This final equation completes the derivation. It is known as the **Law of Refraction**. Remember that if you didn't quite follow every step of this derivation, it's okay. For this course, it is important for you to see where it comes from, but you will not be expected to derive the equation on your own.

Of course, you will need to be able to work with the end result, which relates the speeds of the wave in the two media with the angles of incidence and refraction.

This is the **Law of Refraction** (sometimes called "**Snell's Law**"). It relates the speeds and wavelengths of the waves in two media with the angles of incidence and refraction.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Quantity	**Symbol**	**Unit**
Angle of incidence	θ_1	degrees (°)
Angle of refraction	θ_2	degrees (°)
Speed in medium 1	v_1	metres/second (m/s)
Speed in medium 2	v_2	metres/second (m/s)
Wavelength in medium 1	λ_1	metres (m)
Wavelength in medium 2	λ_1	metres (m)

Example 2: Law of Refraction

The wavelength of a straight wave in the deep end of a ripple tank is 2.00 cm, and the frequency is 11.0 Hz. Wavefronts strike the boundary of the shallow section of the tank at an angle of 60.0° and are refracted at an angle of 30.0°. Calculate the speed of the wave in deep water and in shallow water.

Let the deep water be medium 1 and the shallow water be medium 2.

Given: Angle of incidence (deep water) $\theta_1 = 60.0°$

Wavelength in medium 1 $\lambda_1 = 2.00$ cm

Frequency $f = 11.0$ Hz

Angle of refraction $\theta_2 = 30.0°$

Unknown: Speed in deep water $v_1 = ?$

Equation: Since you know the wavelength and frequency, you can use the universal wave equation to find the speed.

$$v = \lambda f$$

Substitute and solve:

$$v_1 = \lambda_1 f_1 = (11.0 \text{ Hz})(2.00 \text{ cm})$$
$$= 22.0 \text{ cm/s}$$

To find the speed in shallow water, you must use Snell's Law:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}.$$

Rearrange to $v_2 = \dfrac{v_1 \sin\theta_2}{\sin\theta_1}$.

You have the angles and one velocity so you can find the other velocity using this part of Snell's law:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}.$$

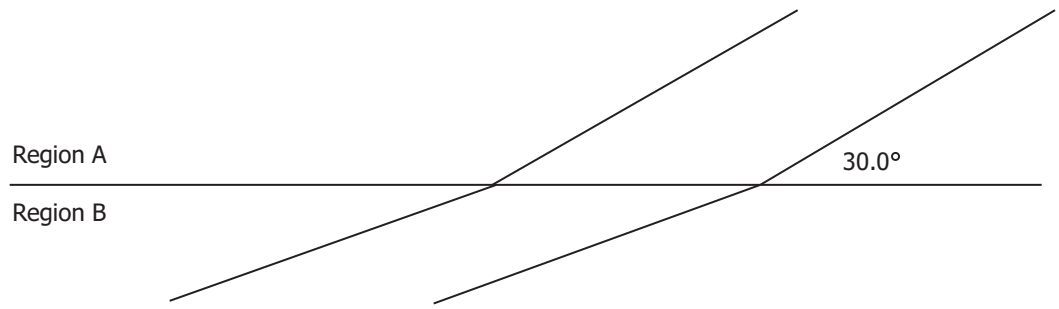
Substitute and solve:

$$v_2 = \frac{(22.0 \text{ cm/s})(\sin 30.0°)}{\sin 60.0°}$$
$$= \frac{(22.0 \text{ cm/s})(0.500)}{0.866} = 12.7 \text{ cm/s}$$

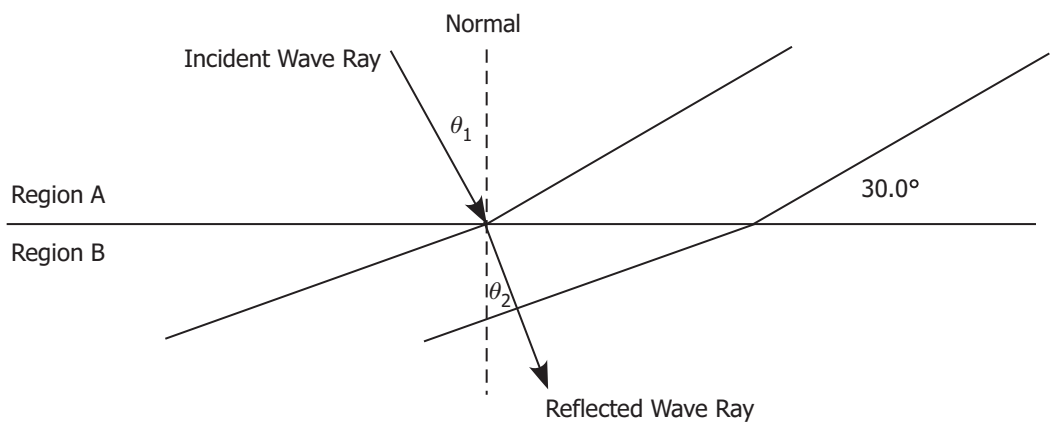
The speed of the wavefronts in the shallow medium is 12.7 cm/s.

Example 3: The Law of Refraction and Waves in a Ripple Tank

A plane wave generator with a frequency of 6.00 Hz creates a water wave with a wavelength of 1.75 cm in region A of a ripple tank. The angle between the wave crests and the straight boundary between regions A and B of the tank is 30.0°.



a) At the point where the incident wave crest hits the boundary for the wave crest on the left, draw in and label the following: the incident wave ray, the normal, the angle of incidence, the refracted wave ray, the angle of refraction.



b) Find the velocity of the wavefronts in medium A.

Let medium A be medium 1.

Given: Angle of incidence $\theta_1 = 30.0°$ (measure θ_1)

Wavelength in medium 1 $\lambda_1 = 1.75$ cm

Frequency $f = 6.00$ Hz

Unknown: Speed in medium 1 $v_1 = ?$

Equation: Since you know the wavelength and frequency, you can use the universal wave equation to find the speed.

$$v = f\lambda$$

Substitute and solve: $v_1 = \lambda_1 f_1 = (6.00 \text{ Hz})(1.75 \text{ cm}) = 10.5 \text{ cm/s}$

c) On the diagram, measure the wavelength of the wavefronts in medium B.

The wavelength is 1.2 cm in medium B.

d) Calculate the speed of the wavefronts in medium B.

Given: Wavelength in medium 2 $\lambda_2 = 1.2$ cm

Frequency $f = 6.00$ Hz

Unknown: Speed in medium 2 $v_2 = ?$

Equation: Since you know the wavelength and frequency, you can use the universal wave equation to find the speed.

$$v = f\lambda$$

Substitute and solve: $v_2 = \lambda_2 f_2 = (6.00 \text{ Hz})(1.2 \text{ cm}) = 7.2 \text{ cm/s}$

e) Calculate the angle of refraction in medium B. Measure the angle of refraction with a protractor.

Since you know the angle in medium A and the two wavelengths, you can use Snell's Law to find the angle of refraction in medium 2.

Given: Angle of incidence $\theta_1 = 30.0°$

Wavelength in medium 1 $\lambda_1 = 1.75$ cm

Frequency $f = 6.00$ Hz

Wavelength in medium 2 $\lambda_2 = 1.2$ cm

Unknown: Angle of refraction $\theta_2 = ?$

Equation:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} \text{ rearranged to}$$

$$\sin\theta_2 = \frac{\sin\theta_1(\lambda_2)}{\lambda_1}$$

Substitute and solve:

$$\sin\theta_2 = \frac{\sin 30.0°(1.2 \text{ cm})}{1.75 \text{ cm}}$$

$$\theta_2 = 20.0°$$

Remember, you take inverse sine of 0.343 to find the angle.

The angle is 2.0×10^1 ° (2 significant digits).

By measurement the angle in medium B is 2.0×10^1 °.

e) Which medium is the deep water? Explain your reasoning.

The wavefronts will travel more quickly in deep water. Since medium A has the larger speed, medium A is the deep water.

Learning Activity 8.3

Waves in Two Dimensions—Refraction

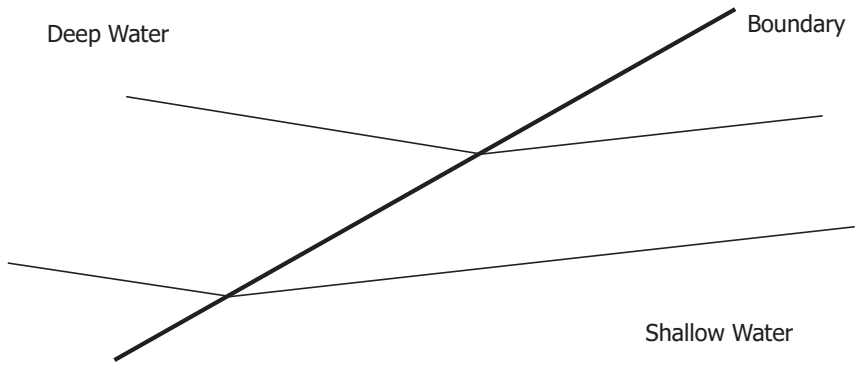
1. A water wave in deep water has a speed of 18.0 cm/s and a wavelength of 2.00 cm. In the shallow water, the speed of the wave is 10.0 cm/s. What is the wavelength of this wave?

2. A water wave of frequency 10.0 Hz and speed 40.0 cm/s is travelling in deep water. It then moves into shallow water where its speed is 30.0 cm/s. The angle of incidence is 30.0°. Find
   a) the index of refraction
   b) the wavelengths in the two media
   c) the angle of refraction in the shallow water

3. The velocity of a sound wave in cold air is 320 m/s, and in warm air 384 m/s. Assume that the wavefront in cold air is nearly linear. What will be the angle of refraction in the warm air if the angle of incidence is 30.0°?

4. An earthquake P wave travelling at 9.0 km/s strikes a boundary within the earth between two kinds of material. If it approaches the boundary at an incident angle of 47° and the angle of refraction is 27°, what is the speed in the second medium?

5. In the diagram below, draw in the following: the incident wave ray, the normal, the angle of incidence, the refracted wave ray, the angle of refraction. Measure and state the measurements of the wavelengths and the angles of incidence and refraction.



6. What is refraction? What is the cause of refraction?

Lesson Summary

When water waves move from one depth to another, the **frequency** of the waves **does not change**.

In shallow water, the speed and the wavelength of the wave decrease.

Refraction occurs when waves approach a boundary between two water depths at an angle, causing the direction of travel of the refracted waves to change. The reason that refraction occurs is that the wavefronts travel at different speeds in the two media.

When a wave travels at an angle into shallow water where its speed is **less**, the refracted wave ray is bent (refracted) **towards the normal**. The **wavelength** and the **speed** of the refracted wavefronts are **less** than in the deep water.

When a wave moves from **shallow water** into **deep water**, the **speed** of the wave **increases**, the **wavelength increases**, and the refracted wave **rays bend away from** the normal.

This is the **Law of Refraction** (sometimes called "**Snell's Law**"). It relates the speeds and wavelengths of the waves in two media with the angles of incidence and refraction.

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Quantity	**Symbol**	**Unit**
Angle of incidence	θ_1	degrees (°)
Angle of refraction	θ_2	degrees (°)
Speed in medium 1	v_1	metres/second (m/s)
Speed in medium 2	v_2	metres/second (m/s)
Wavelength in medium 1	λ_1	metres (m)
Wavelength in medium 2	λ_1	metres (m)

Video Laboratory Activity: Snell's Law

In this lab activity, you will view *Snell's Law*, a short video laboratory activity found in the learning management system (LMS). You will collect some data from the video, so you should begin by reading the introduction and answering the pre-lab questions.

When you have finished the lab, you will complete a Laboratory Report, which is found at the end of this and every other Laboratory Assignment. The Laboratory Report is the only part of this assignment that you will hand in. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

Introduction

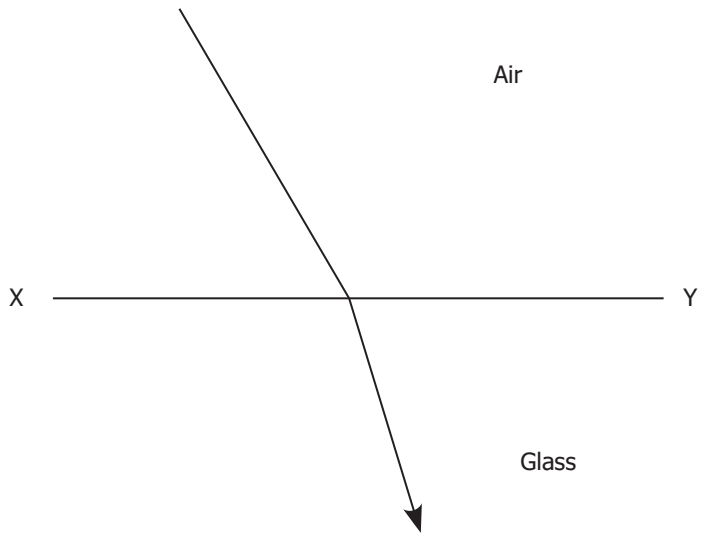
Place a pencil in a clear glass of water and look at it from the side. The pencil appears to be broken. The reason is that the light reflecting off of the part of the pencil in the water refracts or bends when it passes into the air. When light passes from one medium (such as air) to another medium (such as water), it bends.

Snell's Law relates the speeds and wavelengths of the waves in two media with the corresponding angles of incidence and refraction. The ratio is a constant for any two media and is called the index of refraction. The index of refraction of a vacuum (and very nearly air) is one. Therefore, the absolute index of refraction of a material is given by ${}_2n_1 = \frac{\sin\theta_1}{\sin\theta_1}$, where ${}_2n_1$ is a constant and is called the index of refraction.

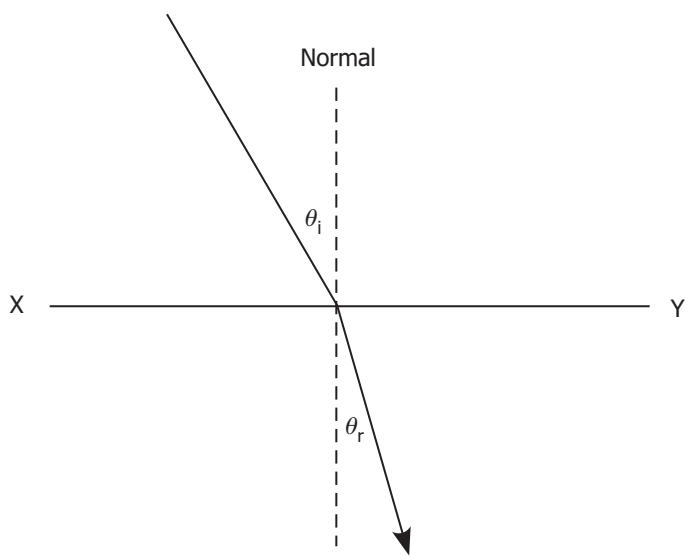
The absolute index of refraction is characteristic of the material and can be used to identify the material.

Sample Problem 1

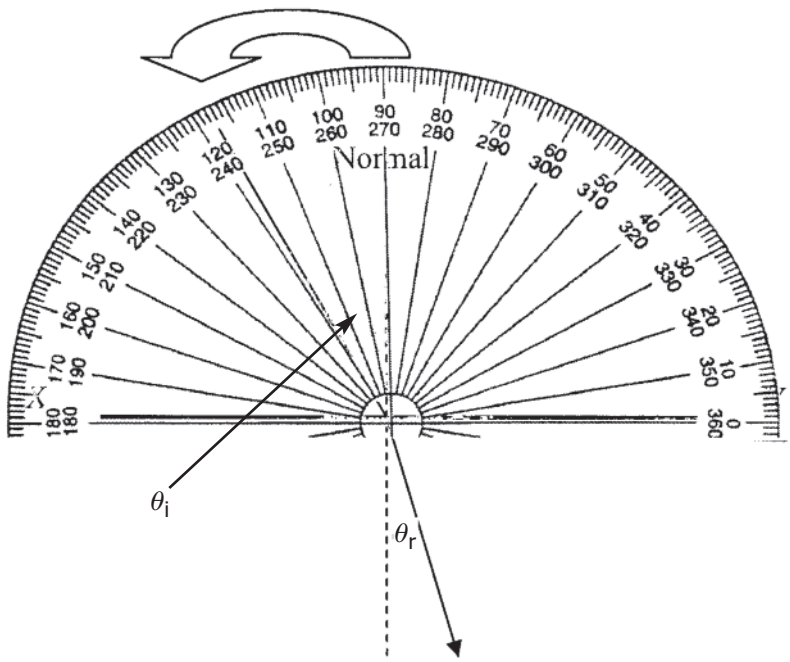
Light bends at surface XY, as shown in the diagram (for example, between air and glass). Measure the angle of incidence and the angle of refraction, and calculate the index of refraction.



First, draw a normal to the surface. A normal is a perpendicular line at the surface from which we measure our angles from the normal.



Next, measure the angle with a protractor. Remember that we want the angle measured from the normal. In our example, $\theta_i = 27°$ (117° — 90°).



Using your protractor, measure θ_r.

Calculate the index of refraction.

$$_{i}n_{r} = \frac{\sin \theta_i}{\sin \theta_r}$$

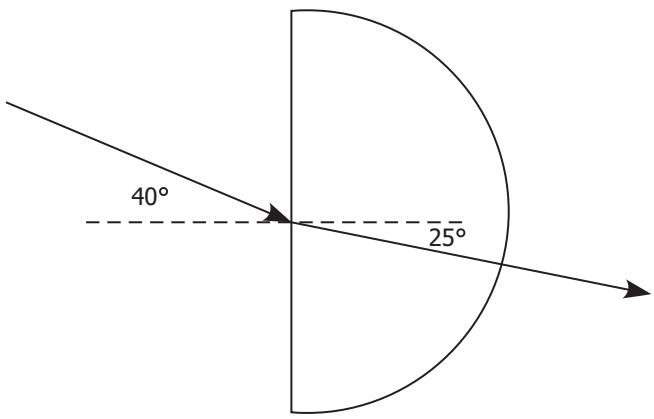
$$_{i}n_{r} = \frac{\sin 27°}{\sin 18°}$$

$$_{i}n_{r} = 1.47$$

An index of refraction of 1.47 is common for light going from air to glass.

Sample Problem 2

Consider a ray of light passing from air into a medium such as the semi-circular translucent block shown in the diagram. The angle of incidence is 40° and the angle of refraction is 25°.



Calculate the index of refraction:

$$_{i}n_{r} = \frac{\sin \theta_{i}}{\sin \theta_{r}}$$

$$_{i}n_{r} = \frac{\sin 40°}{\sin 25°}$$

$$_{i}n_{r} = 1.52$$

Notice that the light ray does not bend at the curved surface because it is perpendicular to the surface.

Purpose

a) To find the index of refraction of a block of clear plastic.

b) To identify an unknown liquid by its index of refraction.

Apparatus

- light box
- clear plastic block
- cheese box
- unknown liquid
- ruler
- protractor

Procedure (Part A)

1. Set up the apparatus such that a ray of light is incident on a clear plastic block and the ray is refracted by the block.
2. Mark the flat surface of the block. Remember that the ray does not refract at the curved surface so we only need to mark the flat surface.
3. Mark the path of the incident and refracted light rays.
4. From the diagram of the incident and refracted light rays on the following page (taken from the video), draw in the normal and measure the angles of incidence and refraction.
5. Calculate the index of refraction.

Video Viewing

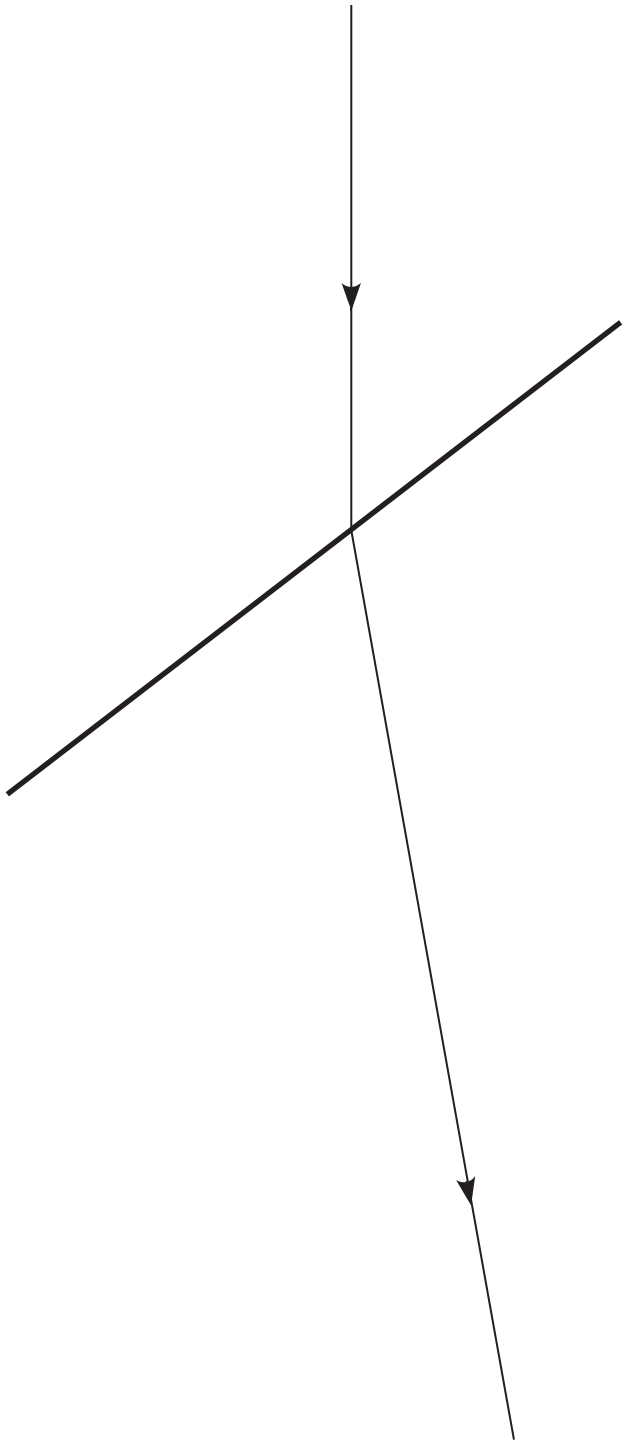
View the video *Snell's Law, Part 1*, which can be found in the learning management system (LMS).

Data and Calculations

Angle of Incidence (°)	**Angle of Refraction (°)**

$${}_{\mathrm{i}}n_{\mathrm{r}} = \frac{\sin \theta_{\mathrm{i}}}{\sin \theta_{\mathrm{r}}}$$

Snell's Law Diagram Part A



Procedure (Part B)

1. Set up the apparatus such that a ray of light is incident on the cheese box and the ray is refracted by the liquid in the box.
2. Mark the flat surface of the block. Remember that the ray does not refract at the curved surface so we only need to mark the flat surface.
3. Mark the path of the incident and refracted light rays.
4. From the diagram of the incident and refracted light rays on the following page (taken from the video), draw in the normal and measure the angles of incidence and refraction.
5. Calculate the index of refraction. From the table, identify your liquid.

Video Viewing

View the video *Snell's Law, Part 2*, which can be found in the learning management system (LMS).

Data and Calculations

Angle of Incidence (°)	Angle of Refraction (°)

$$_{\mathrm{i}}n_{\mathrm{r}} = \frac{\sin \theta_{\mathrm{i}}}{\sin \theta_{\mathrm{r}}}$$

Material	Index of Refraction
Glycerin	1.47
Water	1.33
Alcohol	1.37

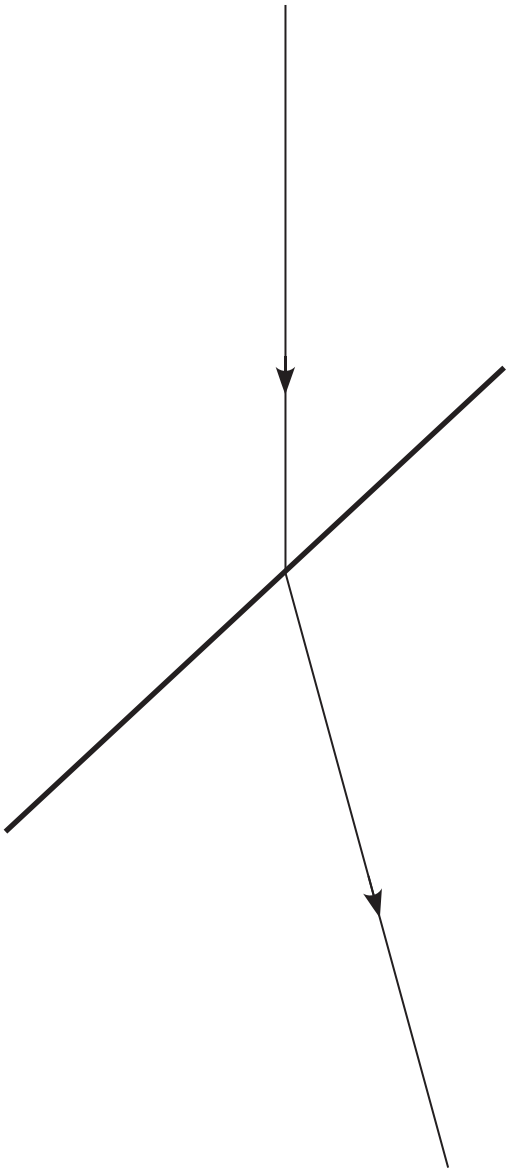
Discussion and Observations

Discuss possible sources of error in this experiment and how you could reduce the error.

Conclusion

Answer the purpose.

Snell's Law Diagram Part B



Assignment 8.2

Video Laboratory Activity: Snell's Law (20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow those directions.

The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words, in a brief paragraph (do not use point form), how the experiment was performed.

_____

_____

_____

_____

_____

(continued)

Assignment 8.2: Video Laboratory Activity: Snell's Law (continued)

Data and Calculations:

- Include photocopies of your data measurements (e.g., tapes or tracks) if they were provided in the notes.
- Record the raw data for each part of the experiment in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data. For example, if you use a formula, write out the formula and show your substitutions and calculations. This should be done for each different calculation (that is, whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be done.

(continued)

Assignment 8.2: Video Laboratory Activity: Snell's Law (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce the error.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. In making measurements, errors are always made. In the error analysis, your job is to look critically at the procedure, identify possible sources of error (there may be several), and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 8.2: Video Laboratory Activity: Snell's Law (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

_____

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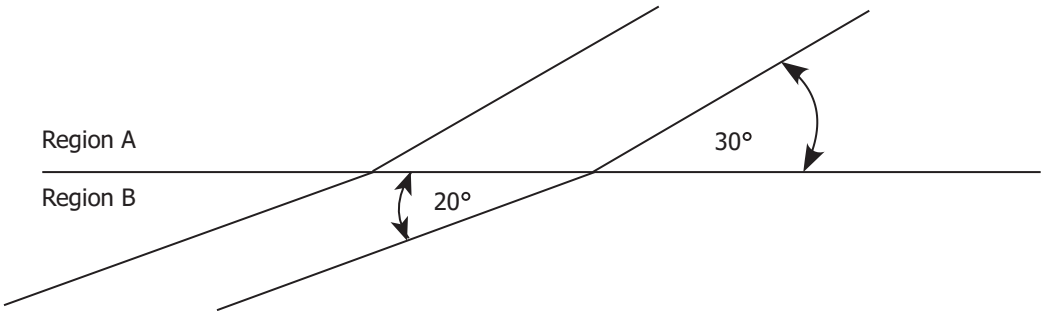
Marking Rubric for Assignment 8.2

Section of Report	Possible	Actual
Part A		
Purpose	1	
Apparatus and Procedure	2	
Measurement of the Angles on Diagram A	2	
Complete the Data Table	2	
Calculate using Snell's Law	2	
Part B		
Purpose	1	
Apparatus and Procedure	2	
Measurement of the Angles on Diagram B	2	
Complete the Data Table	1	
Calculate using Snell's Law	1	
Identify Unknown Along with the Reason	1	
Discussion—Sources of Error	2	
Conclusion	1	
Total	**20**	

Assignment 8.3, Part A

Waves in Two Dimensions—Refraction (7 MARKS)

A generator produces straight waves with a frequency of 6.0 Hz. The wavelength of the water wave in region A is 2.0 cm. The angle between the wavefronts and the straight boundary is 30.0°. In region B, the angle between the wavefront and boundary is 20.0°. The waves are moving from region A to region B.

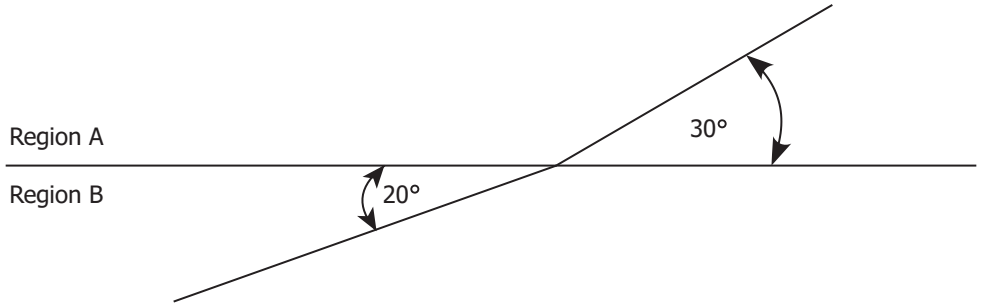


a) What is the velocity of the wave in the first medium?

(continued)

Assignment 8.3, Part A: Waves in Two Dimensions—Refraction (continued)

b) The diagram above has been redrawn to show one of the incident wavefronts and its corresponding refracted wavefront. On the diagram below, draw and label the incident wave ray, the refracted wave ray, and the normal, and label the angle of incidence (θ_1) using the normal and the incident wave ray as a reference, and label the angle of refraction (θ_2) using the normal and the refracted wave ray as a reference.



c) What is the angle of incidence?

d) What is the velocity of the wave in the second medium?

(continued)

Assignment 8.3, Part A: Waves in Two Dimensions—Refraction (continued)

e) What is the wavelength of the wave in the second medium?

_____

_____

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Method of Assessment

The total of seven marks for this assignment will be determined as follows:

- 1 mark for determining the velocity of the wave in the first medium in part (a)
- 0.5 marks for drawing in the normal in part (b)
- 1 mark for drawing the incident wave ray and labelling θ_i in part (b)
- 1 mark for drawing the refracted wave ray and labelling θ_r in part (b)
- 0.5 marks for correctly determining the angle of incidence in part (c)
- 2 marks for correctly determining the velocity of the wave in part (d)
- 1 marks for determining the velocity of the wave in the second medium in part (e)

NOTES

Lesson 3: Waves in Two Dimensions—Diffraction (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "diffraction"
- ❑ explain how diffraction around the sharp edge of a barrier changes as the wavelength of the waves increases or decreases
- ❑ explain how the degree of diffraction depends on the size of the opening relative to the wavelength
- ❑ apply the principle of diffraction to sound waves or light waves

Key Words

diffraction

Introduction

If you stood in a room with the door open and another person stood in the hallway outside of the door but out of your sight and the person in the hallway spoke, you were able to hear what was spoken. Now, since you could not see the person, the sound could not travel in a straight line from the person's mouth to your ear; it had to travel around the wall. The path of the sound was bent. This behaviour of sound, whereby its path is bent in air as it travels around corners, is diffraction.

In this lesson, we will study this property characteristic of waves called diffraction. Essentially, when waves pass around a barrier or through an opening, they bend. This bending is called diffraction (and the wave itself is said to have diffracted). The amount of diffraction depends on the wavelength of the wave and on the size of the opening.

Basic Diffraction

Having just completed a lesson on refraction, it is important to note that **refraction** is when a wave changes its direction of travel by entering a new medium that carries the wave at a different speed. Diffraction has one thing in common with refraction: they both involve waves changing their direction of travel. Unlike refraction however, **diffraction occurs** in a **single, uniform medium**.

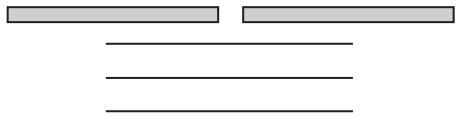
In working with refraction, we are able to develop an equation, the Law of Refraction, which enables us to relate the angles to the speeds of the waves in two media. While there are equations that allow us to work with diffraction mathematically, these equations are more sophisticated, and so we will only explore diffraction "qualitatively"—that is, with no equations. We will begin by focusing on the diffraction of water waves.

Diffraction—Small Openings

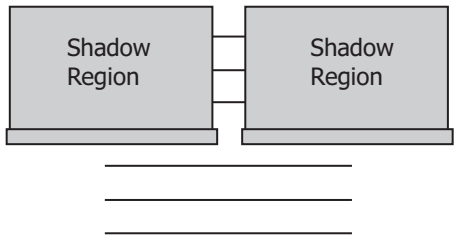
Water waves generally move in a straight line, provided that the water is uniform (to prevent refraction) and also provided that the waves do not strike a barrier in the water (to prevent reflection). So what would happen if a water wave encountered a small barrier placed inside of the water?

We already know that the wave that strikes the barrier will reflect, but what about the parts of the wave that do not strike the barrier?

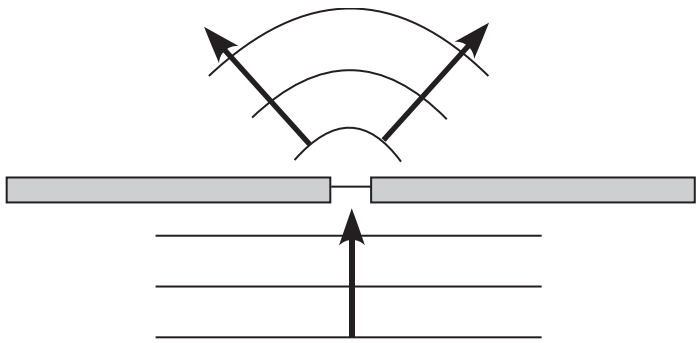
Most people would expect that since they miss the barrier, they would not be affected at all. Consider the following diagram showing plane wavefronts moving upwards, approaching a barrier that has a small part "missing." There is a small opening in the barrier.



Notice that part of the wavefront will strike the barrier. These parts will reflect, as we have already discussed. For the remainder of this lesson, we will ignore any reflections in order to focus our attention on the new behaviour at hand. We are particularly interested at this time on the part of the wave that goes through the opening. It would perhaps be reasonable to assume that the part of the wavefront that gets through the opening simply keeps going, and the surrounding area would become a "shadow region" that shows no wave activity, as shown in this diagram:

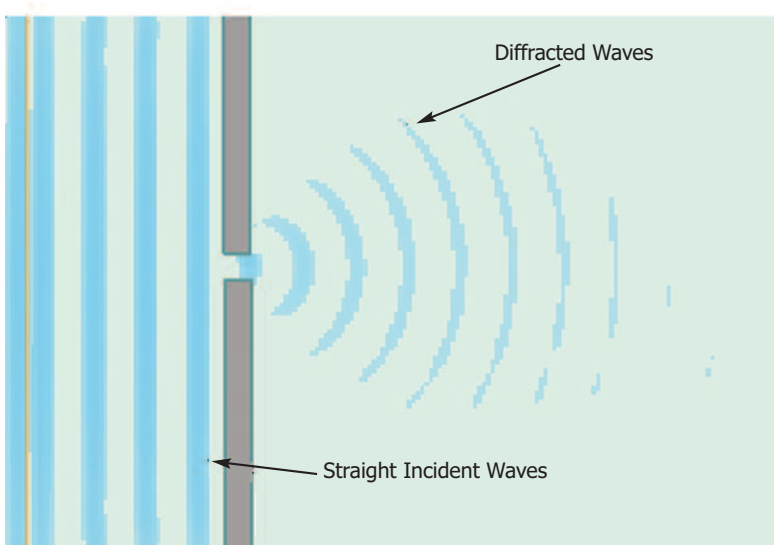


If this actually happened, there would be no need for this lesson at all! What actually happens is much more interesting: the wave "fans out" somewhat on going through the opening. This spreading of a wave as it goes through a narrow opening is called **diffraction**. The next diagram shows this effect. Notice that the wave ray for the incident wavefronts point straight up the page, but in the region above the barrier the wave rays point in different directions. The path of the wavefronts has changed.



The graphic below illustrates diffraction of waves in a ripple tank.

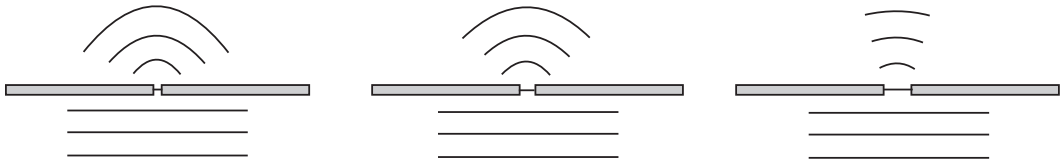
Diffraction of Straight Waves through an Opening in a Barrier



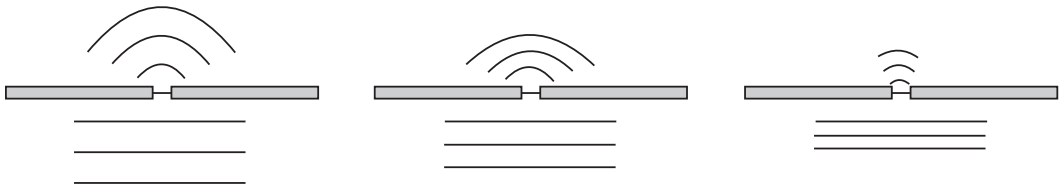
One type of **diffraction** is the spreading of a wave into the shadow region when the wave goes through a small opening in a barrier.

The reason for this diffraction can be understood by thinking of the medium itself. The medium (water, in this case) would be shaking up and down as the crest and trough fronts passed through. With plane waves, these fronts are straight, but when the wave encounters a small hole, the water in the hole shakes up and down too but doesn't as strongly resemble a plane wave. The smaller the hole, the more closely it will resemble a point source, which, as we have seen, produces circular waves. In fact, the smaller the opening, the more "complete" these circular waves will be. In other words, smaller openings generally result in a larger diffraction spread.

Of course, "small" is a relative term. Ants are small compared to people, but are staggeringly large compared to atoms. When describing the size of an opening for a wave, we must compare it to the wavelength of the wave. This means that, in general, larger wavelengths generally show a larger diffraction spread. In fact, if the wavelength is very small, a very narrow opening is required to produce any significant diffraction. For any obvious diffraction to occur, the opening should be smaller than the wavelength. In the diagrams below, there are three openings, with the same wavelength wave striking each opening. The narrowest opening produces the largest amount of diffraction. The largest opening is nearly equal to the wavelength, and shows little diffraction as a result.



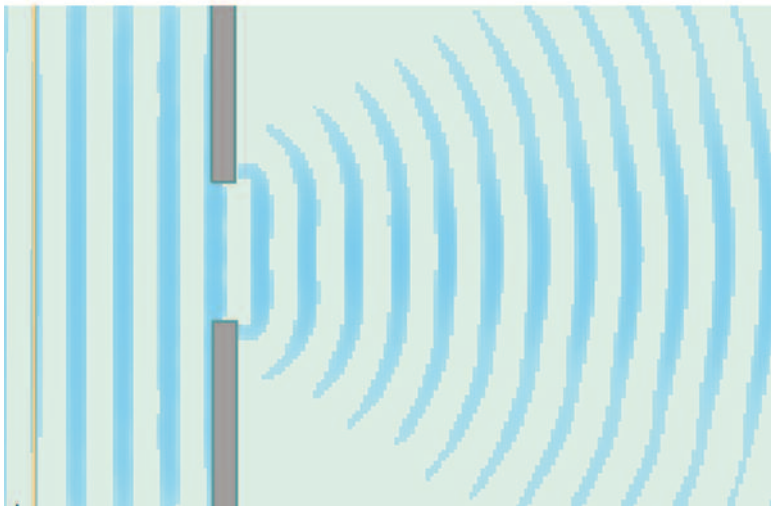
In the diagrams below there are, again, three openings, but this time all of them are the same size. The wave with the largest wavelength shows the largest amount of diffraction while the wave with the smallest wavelength shows the least.



We can ignore any diffraction spreading for openings that are as large as or larger than the wavelength. In general, smaller openings and larger wavelengths produce a larger diffraction spread.

Here is a graphic showing waves in a ripple tank passing through an opening that is much larger than the wavelength. Notice that the bending in the path takes place near the edges of the wavefronts.

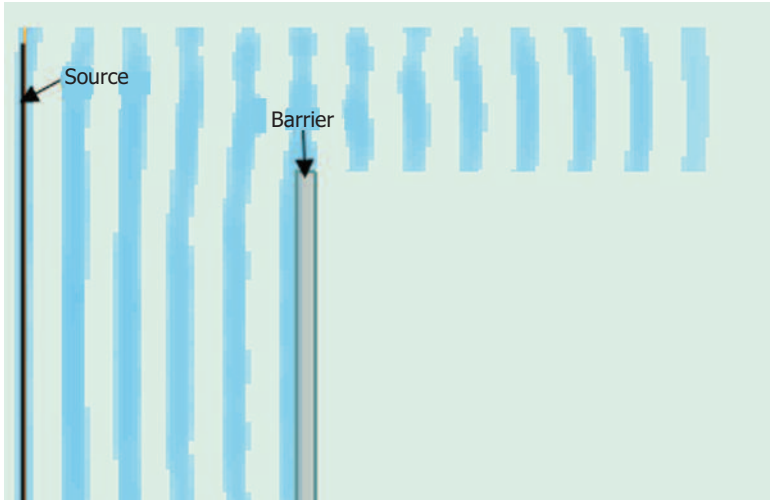
Waves Diffracting through a Large Opening in a Barrier



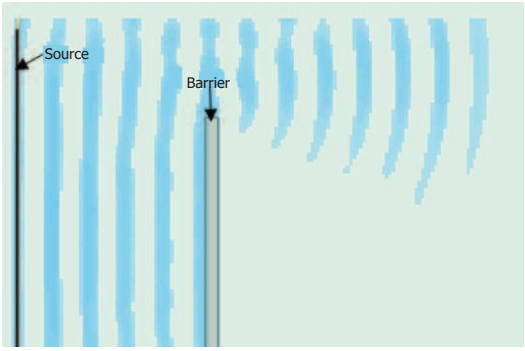
Diffraction around the Edge of a Barrier

What if the wave encounters a barrier? Certainly there will be a partial reflection off of the barrier, which we will again ignore, focussing our attention on what the wavefront that misses the barrier does. Once more, intuition may lead to the following prediction: the wave that misses the barrier will simply keep going, as suggested by the following diagram (in which the wavefronts are again moving to the right):

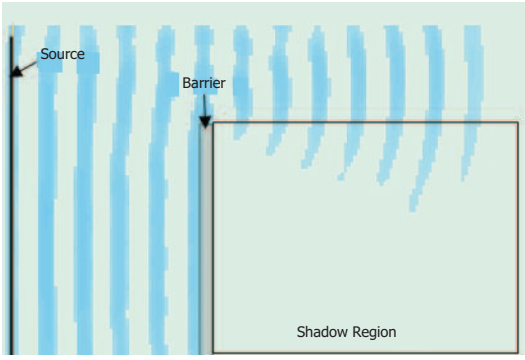
Expected Path of Waves Passing the Edge of a Barrier



Straight Waves Diffracting around the Edge of a Barrier



Straight Waves Diffracting around the Edge of a Barrier

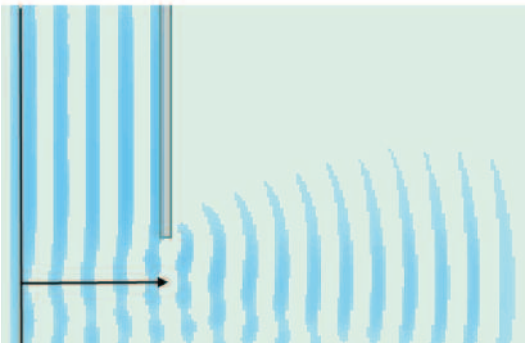


Once more, we find that this is not what happens. What actually happens is that the wavefronts, again, diffract.

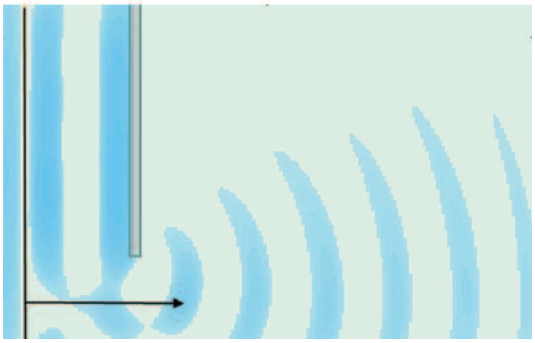
You can see in the graphics above that the straight waves travelling to the right bend into the region of shadow behind the barrier. Again, the diffraction occurs at the edge of the barrier.

It also turns out that the wavelength has an effect on the amount of diffraction. In the graphics below, you can see that the longer wavelength waves show a greater amount of diffraction under the same conditions. The wavelength in the graphic on the right is twice the wavelength of that on the left.

Diffraction of Short Wavelength Waves around the Edge of a Barrier



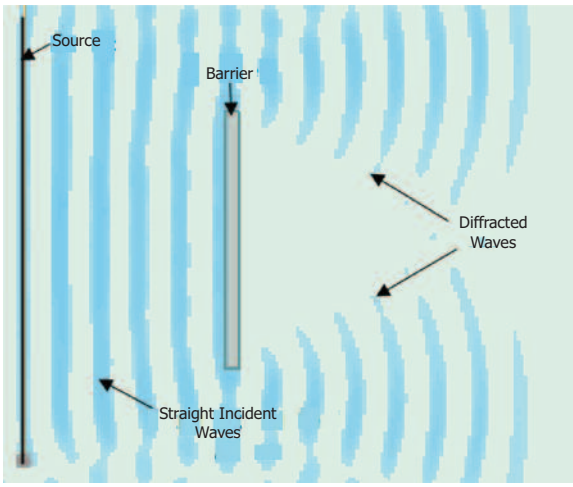
Large Wavelength Waves Diffracting around the Edge of a Barrier



Diffraction—Around Large Barriers

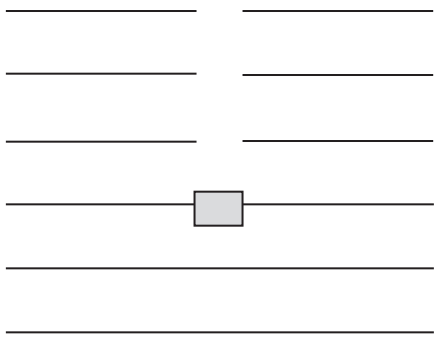
Around large straight barriers, you should expect diffraction to occur at both edges. This is in fact what occurs.

Straight Waves Diffracting around the Edge of a Barrier

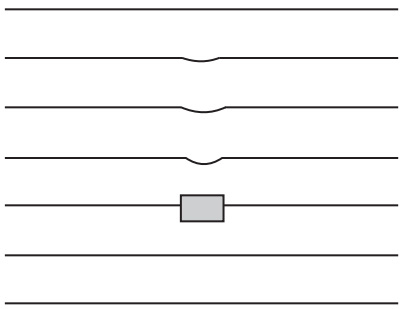


Diffraction—Around Small Barriers

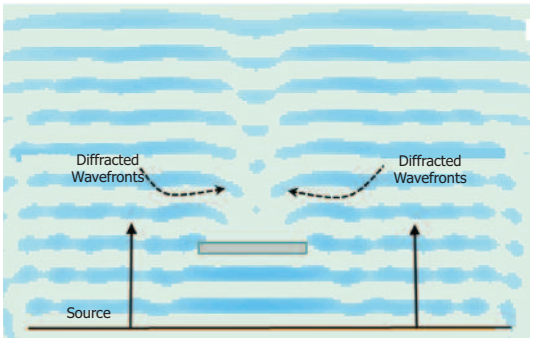
What if the wave encounters a small barrier? Certainly there will be a partial reflection off of the small barrier, which we will again ignore, focussing our attention on what the wavefront that misses the barrier does. Once more, intuition may lead to the following prediction: the wave that misses the barrier will simply keep going, as suggested by the following diagram (in which the wavefronts are again moving upwards):



Once more, we find that this is not what happens. What actually happens is that the wavefronts once again diffract: this time bending inwards to "seal off" the missing piece. This is shown in the following diagram and in the graphic of waves in a ripple tank:



Diffraction of Waves around a Small Barrier



Once again, we find that the amount of this diffraction depends on the size of the wavelength and the size of the barrier. This diffraction effect is most apparent with large wavelengths and small barriers.

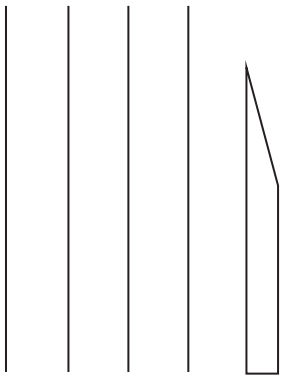
Another type of diffraction is the spreading of a wave into the shadow region behind a small barrier. This effect is strongest with large wavelengths and small barriers.

Learning Activity 8.4

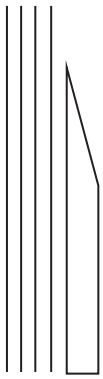
Waves in Two Dimensions—Diffraction

1. The diagram below shows two different types of water waves approaching a sharp edge. Which type of wave will show the greatest diffraction: the waves in situation A or the waves in situation B?

Situation A



Situation B



(continued)

Learning Activity 8.4: Waves in Two Dimensions—Diffraction (continued)

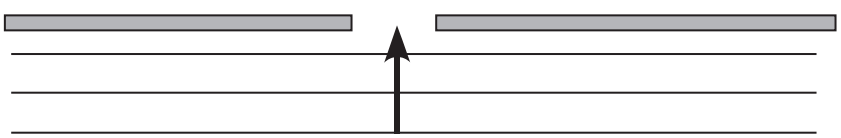
2. Ocean waves are approaching an opening into a harbour. The opening is 100 m wide. For which wavelength of ocean waves would there be the greater diffraction: those with a wavelength of 50 m or those with a wavelength of 200 m?

3. A D note in music has a frequency of 294 Hz. A G note has a frequency of 392 Hz. If music was playing in a hallway around the corner, what frequency of sound could you most clearly hear?

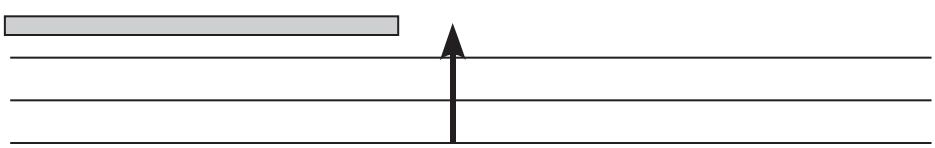
4. Light of wavelength 470 nm is blue in colour, and 610 nm light is orange. If these colours of light pass through a 500 nm hole, which colour of light will show the greatest diffraction?

5. Draw the diffraction pattern for the following situations involving waves in a ripple tank:

a)

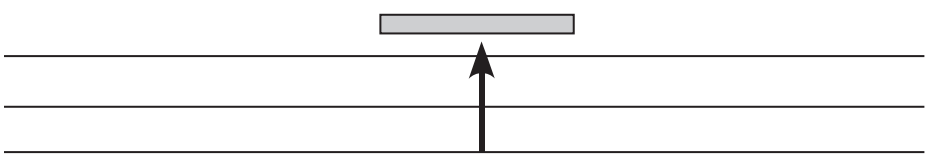


b)



(continued)

c)



Lesson Summary

Diffraction is the bending of waves around an object in their path.

The **larger** the wavelength, the **greater** is the diffraction of waves around the sharp edge of a barrier.

The **smaller** the **opening** compared to the wavelength of the waves, the **greater** is the diffraction.

The **larger** the **wavelength** compared to the size of an **opening**, the **greater** is the **diffraction** of waves as they pass through the opening.

Assignment 8.3, Part B

Waves in Two Dimensions—Diffraction (5 MARKS)

1. The wavelengths of various colours of light can vary. Violet light can have a wavelength of 400 nm and red light can have a wavelength of 700 nm.
   a) If these two colours of light pass by a very sharp edge such as a razor blade, which light will bring about the greater diffraction? Why?

   _____

   b) If these two colours pass through an opening that is 500 nm wide, which colour will show the greater diffraction? Why?

   _____

2. A small island 200 m wide is in the middle of an ocean. On one day, wave crests 50 m apart approach the island. On another day, wave crests 400 m apart approach the same island. In which case will there be a greater diffraction of the waves around the island? Why?

   _____

3. Bats can hear sounds of frequencies as high as 100 000 Hz while a human can hear a sound of frequency 10 000 Hz.
   a) Which frequency of sound would best diffract around a barrier through an opening such as a small hole in a wall?

   _____

   _____

   b) If a small insect was flying behind a tree, which sound would more likely bend around the tree and reach the insect?

   _____

   _____

(continued)

Assignment 8.3, Part B: Waves in Two Dimensions—Diffraction (continued)

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for stating which light will bring the greater diffraction in 1(a)
- 1 mark for stating which light will bring the greater diffraction in 1(b)
- 1 mark for stating which wave will show the greater diffraction in 2
- 1 mark for stating which frequency of sound would diffract the best in 3(a)
- 1 mark for stating which sound would more likely bend in 3(b)

Lesson 4: Waves in Two Dimensions—Interference (2 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ label areas of constructive and destructive interference when crests and troughs meet in a two-dimensional situation
- ❑ describe the appearance of nodal lines and areas of constructive interference produced when waves from two point sources interfere
- ❑ explain what happens to the number of nodal lines if the frequency of the vibrating sources or the distance between the sources is changed
- ❑ explain what happens to the symmetry of the pattern if the phase of the sources is changed
- ❑ define and calculate the "path length difference" (PLD) for a point in a medium with two point-source-generated waves
- ❑ determine and use the relationships between the wavelength of waves producing a standing wave pattern using

$$\left|\overline{P_nS_1} - \overline{P_nS_2}\right| = \left(n - \frac{1}{2}\right)\lambda$$

Key Words

interference
nodal lines
lines of antinodes
two-dimensional standing wave pattern
nodes
path length difference
antinodes
in phase

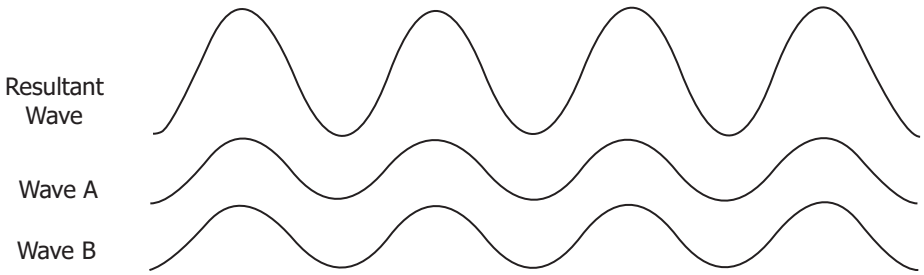
Introduction

In this lesson, we turn to the last wave behaviour that we will study in this module: two-dimensional wave interference. Waves in two dimensions show constructive and destructive interference, just like waves in one dimension. We will limit our study of this kind of interference to that resulting from two sources creating waves of the same frequency (and therefore the same wavelength) in a uniform medium with no barriers, resulting in a **two-dimensional standing wave**. We will see that it is possible to predict what the interference pattern will look like. A mathematical equation can be used to determine the location of nodes in the interference pattern. An understanding of wave interference in two dimensions can be used to understand wave interference for electromagnetic waves such as light waves and for sound waves.

Two-Dimensional Standing Waves

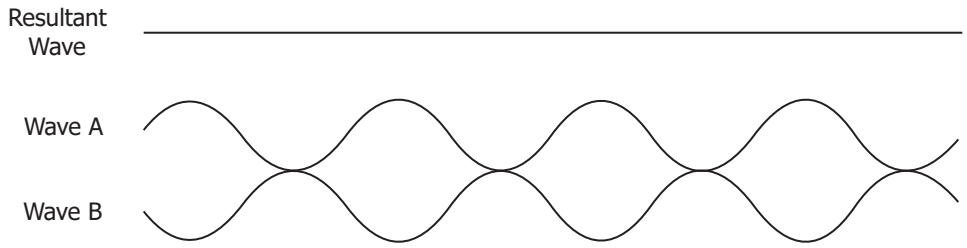
We have previously discussed constructive and destructive interference for waves in one dimension. Recall that when **two crests** (or **two troughs**) are superimposed, we say that they are "**in phase**" and the result is **constructive interference**: an even bigger crest (or trough).

Two In-Phase Periodic Waves Produce Constructive Interference



Superimposing a crest with an identically sized **trough** (i.e., "**out of phase**" pulses) results in destructive interference: a cancellation of the pulses.

Two Out-of-Phase Periodic Waves Produce Destructive Interference



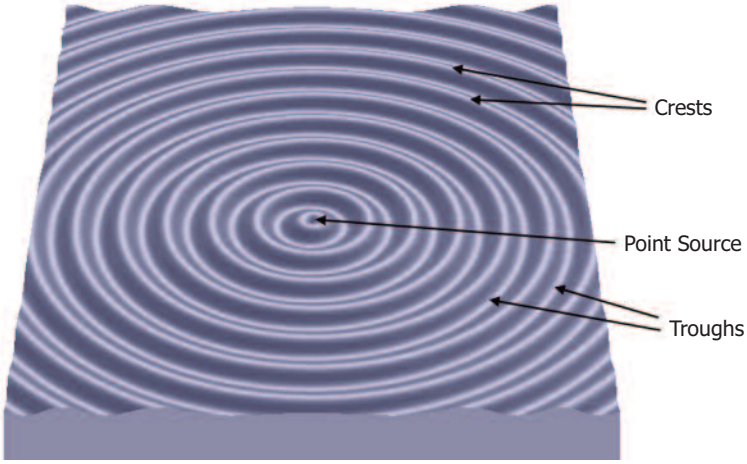
Also remember that a **node** is a special place in which this **destructive interference** always happens, while an **antinode** is a place where **constructive interference** always happens.

Much as two one-dimensional waves travelling along a spring can produce a one-dimensional standing wave, two-dimensional waves can produce a two-dimensional standing wave. There are important differences however. Notice that in the one-dimensional case, the waves needed to be travelling in opposite directions, such as an incident wave and its reflection off of the end of the medium. Two-dimensional waves need not be moving in opposite directions in order to produce standing waves.

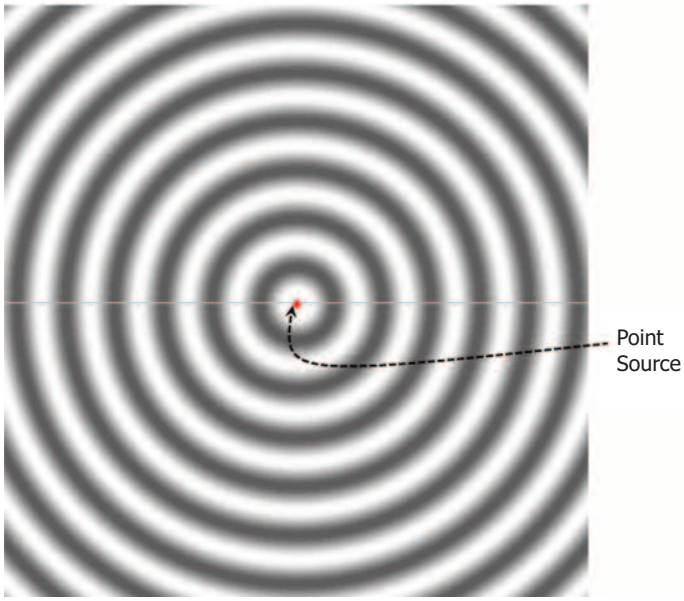
We will explore one type of two-dimensional standing wave: that produced from two point sources that are near each other. We will further assume that we have the ideal situation of both sources vibrating (and therefore disturbing the medium) equally—that is to say that they produce identical circular waves (equal frequency, wavelength, and amplitude). Being point sources, these waves will have circular wavefronts. In a ripple tank, this may be achieved by the use of a "wave generator," which is essentially nothing more than an electric motor that repeatedly (and regularly) dips and retracts one or more sources on the surface of the water in the ripple tank.

The graphics below show the actual three-dimensional pattern on the surface of the water on the left, while to the right is the ripple tank pattern that results in this case.

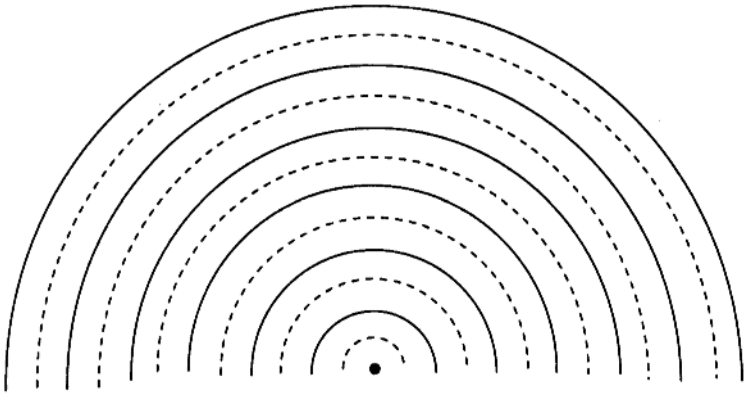
Three-Dimensional Waves on the Surface of Water



Ripple Tank Wave Patterns for a Periodic Point Source



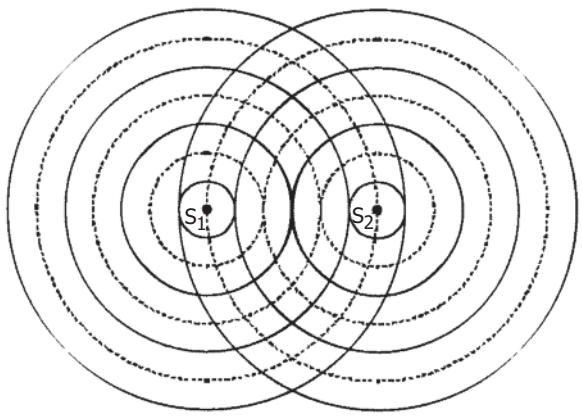
When illustrating this pattern in a diagram, the crest fronts are shown as **solid** lines, as we have seen in numerous diagrams earlier in this module. Additionally, **trough** fronts are shown as **dashed** lines. Only the top half of the pattern is shown.



Two-dimensional standing waves may result from two point sources producing identical circular waves. This may be accomplished by two point sources attached to an electric wave generator in a ripple tank.

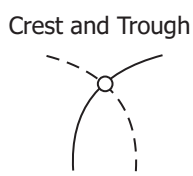
The circular wave patterns—one from each point source—will overlap, producing a two-dimensional standing wave pattern.

The diagram below shows wavefronts produced by two vibrating point sources. As was the case in the one-dimensional case, the pulses pass through one another unchanged. But as the crests and troughs from one source superimpose with those from the other source, they interfere with each other—sometimes crest on crest, sometimes trough on trough, and sometimes crest on trough.

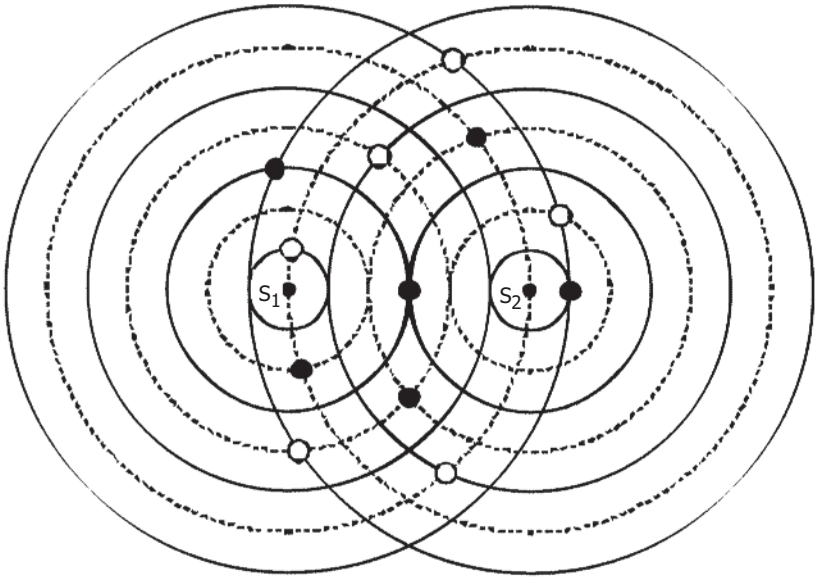


Constructive interference occurs at points where either two crests or two troughs are superimposed. We will indicate these areas of constructive interference by a small solid circle.

Destructive interference occurs when a crest and a trough meet. Areas of destructive interference will be indicated by a small open circle.



Certainly, you can see that there are several places of constructive interference as well as several places of destructive interference in the superimposed two-dimensional waves shown earlier. The following diagram shows several examples of these points of interference:



Of course, a standing wave requires more than just places of constructive and destructive interference. Standing waves have the locations in which these two types of interference don't move around, even though the waves themselves do move. In other words, a **standing wave** has places where **only destructive interference happens (nodes)** and places where **only constructive interference happens (antinodes)**. Amazingly enough, this condition will automatically be the case here. This is a standing wave!

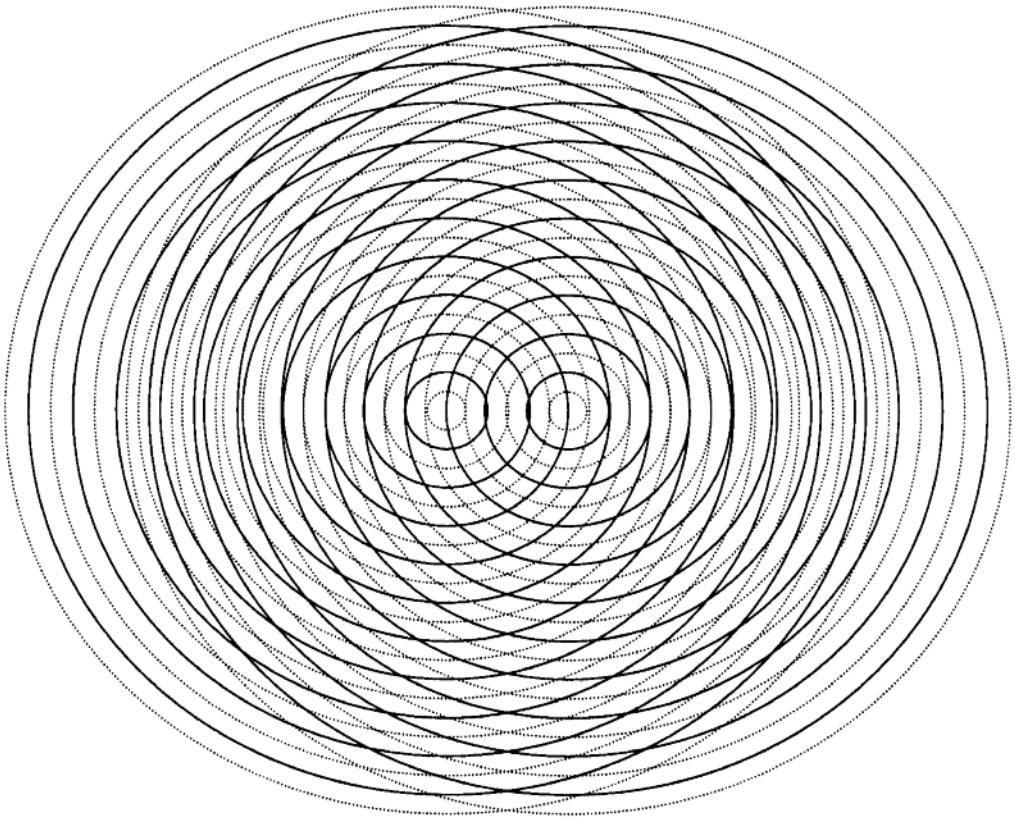
It is difficult to visualize this from a mere picture such as the above diagram, but even as both waves move outwards away from the sources, the places marked with closed circles will always be places of constructive interference. In fact, the water at those places will be vibrating up (when two crests are there) and down (when two troughs are there). Similarly, the water at the places marked with open circles will be calm the entire time, showing no wave activity, despite the fact that the water around them is sloshing up and down. Of course, we have just described exactly the essence of nodes and antinodes.

Learning Activity 8.5

Waves in Two Dimensions—Interference: Part 1

1. Where the waves from two point sources meet on the surface of the water, what must there be to produce
   a) constructive interference?
   b) destructive interference?
   c) antinode?
   d) node?

2. On the pattern for two point sources given below, label source 1 as S_1 on the left side of the pattern and label source 2 as S_2 on the right side of the pattern. Draw in a horizontal line through the two sources. Find the midpoint of the line segment S_1S_2 and draw in the perpendicular bisector of this line segment. This is called the centre line. Mark in all of the nodes with an open circle and all of the antinodes with a circle that is filled in or shaded in.

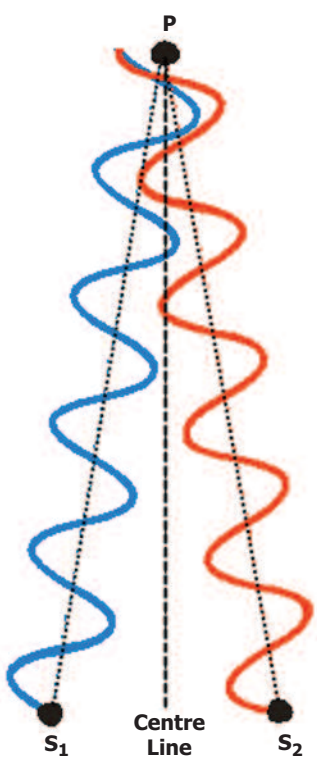


Formation of Nodes

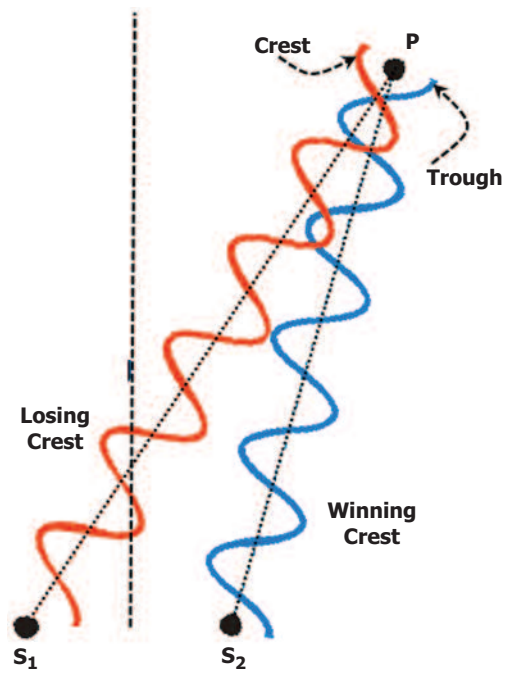
The reason that these nodes and antinodes form is best explained with a bit of geometry.

Recall that the two sources are **in phase**—they both produce crests at the same time, and they also both produce troughs at the same time. These crests and troughs then move outwards away from the sources as circular wavefronts, moving with identical speeds.

Suppose we consider a point that is exactly **halfway** between the two sources. Being halfway between the sources, each wave must travel identical distances to reach that point from each source. Suppose that, at one particular moment, both sources produce a crest. These crests then spread out in two dimensions with a part of each front moving towards our point of interest. Which crest will arrive there first? The answer, of course, is that it will be an exact tie—both crest fronts will arrive at the same time. After all, they move equally fast, starting at the same time and moving at the same distance. This will likewise be true of the two troughs that follow them, and the next two crests that follow those, and so on. The point midway between the sources is guaranteed to be a place of continual constructive interference—the waves will always arrive there in phase.



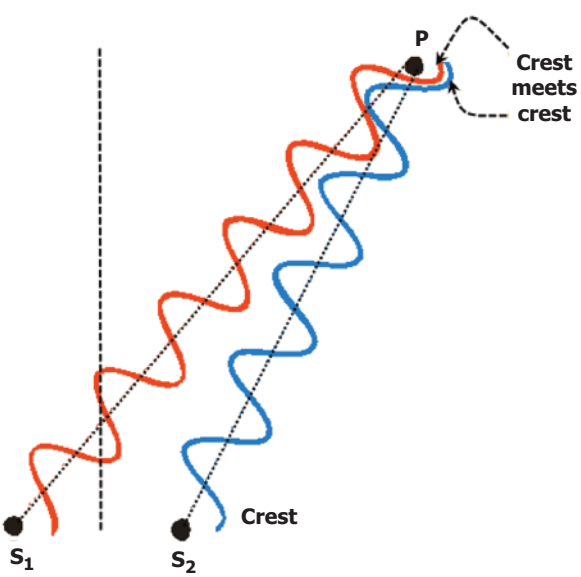
As for other places in the medium, we can do a similar analysis. We can imagine two crests (or troughs—it doesn't really matter) "racing" towards any point of interest in order to determine what will happen at that point. It should not be difficult to appreciate that any point that involves the two waves moving identical distances will similarly result in continual constructive interference. This is true of **all points along the centre line**—the line that is perpendicular to the line joining the two points, and perpendicular to it. We expect there to be **antinodes** everywhere along that line. The diagram on the left shows this in a way that should make sense. Although the waves are two dimensional (as seen in the above diagrams), we can temporarily imagine them to be one dimensional and heading towards our point of interest (which has been labelled "P").



As soon as we shift our attention away from that line, however, we are necessarily closer to one source and farther from the other source. There will be a definite "winner" between two crests produced at the same time from the two sources in the race to get to these points. Imagine a point that is a little closer to the source S_2, and two crests produced by the two sources at the same time "racing" to that point. Clearly, the crest produced from S_2 will win the race, but by how much depends on how much closer it is (and, therefore, how much "extra distance" the other crest has to travel to get there).

If the one crest beats out the other by half a wavelength, then our "winning crest" arrives at the point of interest at the exact same time as the trough, which was always ahead of the "losing crest." **Destructive interference** will happen at the point of interest. This is seen in the above diagram.

Furthermore, note that when the losing crest does arrive at our point of interest, the winning crest will have moved on, but the trough that was following it (a half wavelength behind) will then have arrived at the point of interest, again resulting in destructive interference! The crest from one source will always reach this point at the same time as a trough from the other source. This is a **node**.

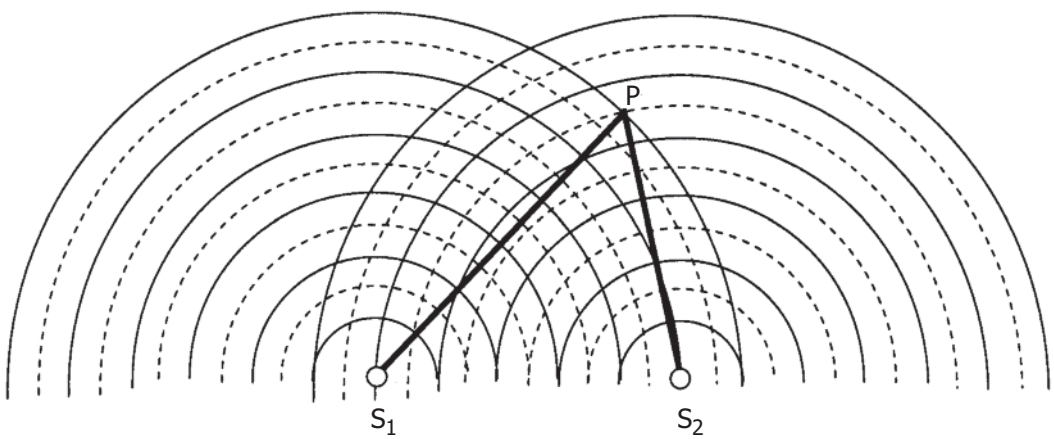


Finally, let us consider another point of interest in which the one racing crest beats out the other by a whole period. Although it has clearly won, as the other crest it was racing is a whole cycle behind, in a way it will be a perfect tie again, as our racing crest reaches the point of interest at the exact same time as the crest that was ahead of the crest it was originally racing with.

It doesn't matter *which* crests arrive at the point of interest—**two crests arriving at the same time will produce constructive interference**. Stated another way, the one crest ties at the point of interest with another crest; this other crest had a head start from its source, since its source is farther from the point of interest. Clearly, the other source is one wavelength farther from the point of interest.

The Difference in Path Length

We can generalize what was discussed above by measuring distances from any point of interest to the two sources. If we label the two sources "S_1" and "S_2", then any point of interest P will be a distance we can call "PS_1" to source 1, and a distance we can call "PS_2" to source 2. These distances are not of direct interest to us … what is more interesting is how they compare to each other—how much farther one source is than the other. This is the essence of the **path length difference**, abbreviated down to **PLD**. It is a measure of how much further one source is than another from a point of interest. Mathematically, the PLD is the difference in the length of the two distances (PS_1 and PS_2). To avoid calculating a negative answer, we use absolute value bars in the calculation of the PLD.



The **path length difference (PLD)** between two point sources, S_1 and S_2, and a point of interest, P, is given by the absolute value of the difference in length between the path length from S_1 to P and S_2 to P.

$$PLD = |PS_1 - PS_2|$$

Quantity	Symbol	Unit
Path length difference	PLD	metres (m)
Path length for source 1 to P	PS_1	metres (m)
Path length for source 2 to P	PS_2	metres (m)

Example: Determining Path Length Difference

In the diagram above, determine the path length difference to the point P.

In this diagram, you can count how many wavelengths the path length is from each source. Remember that each solid line in the concentric circles around a given source represents a crest. The wavelength is the distance from one crest to the adjacent crest.

Express each path length in terms of wavelengths.

The two sources are both producing crests at this instant, so start with a crest at S_1 and at S_2.

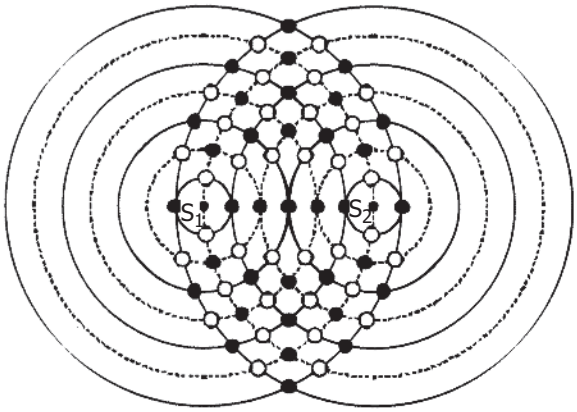
Given: Path length of S_1 to P	$PS_1 = 6.0\,\lambda$
Path length of S_2 to P	$PS_2 = 4.5\,\lambda$
Unknown: Path length difference	PLD = ?
Equation:	$PLD = \lvert PS_1 - PS_2 \rvert$
Substitute and solve:	$PLD = \lvert PS_1 - PS_2 \rvert = \lvert 6.0\,\lambda - 4.5\,\lambda \rvert$ $= 1.5\,\lambda$

The path length difference to the given point P is 1.5 wavelengths.

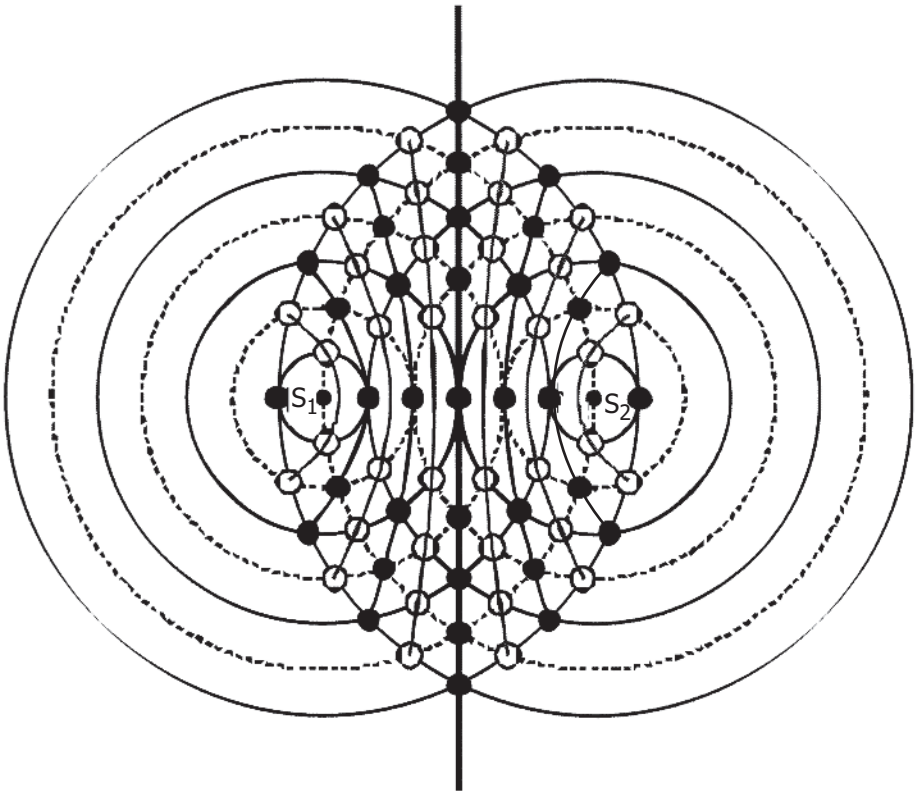
Two-Dimensional Standing Wave Patterns—Interference Patterns

With one-dimensional standing waves, nodes were points along the medium where destructive interference occurred, and anti-nodes were points along the medium where constructive interference occurred. This remains true for two-dimensional standing waves with one important difference: nodes and antinodes are no longer merely points, but become extended into what we call **nodal lines** and **antinodal lines**. Note that while we refer to them as being "lines," they are generally curves.

The diagram below is similar to the one seen earlier, but this one shows all of the nodes and antinodes produced so far (there would be more if more wavefronts were shown). Notice that the nodes and antinodes form a pattern.



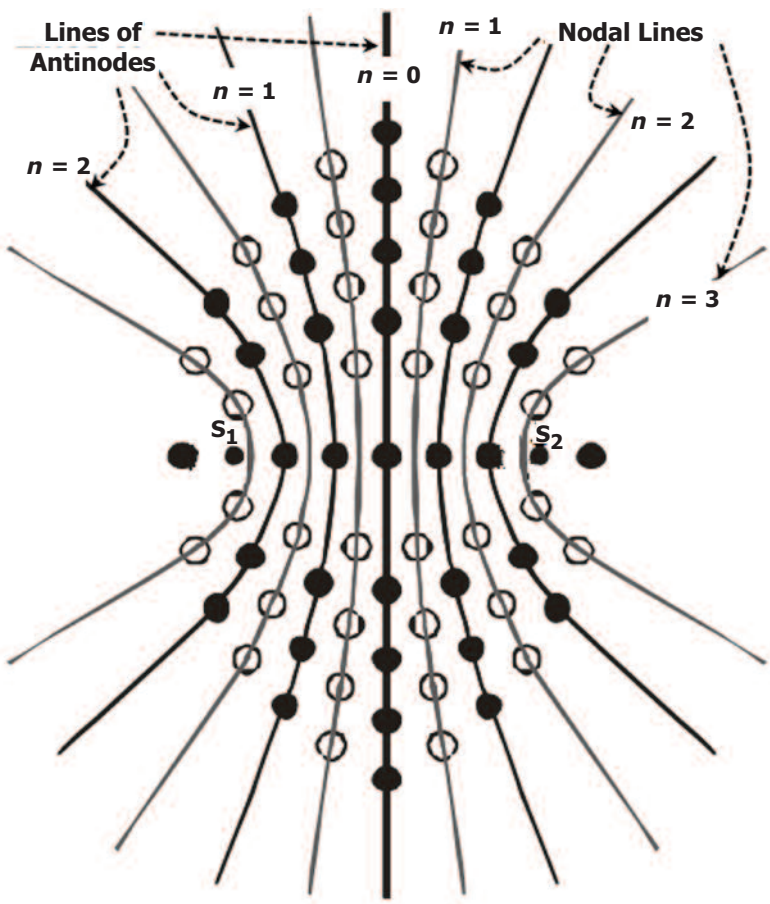
This pattern can be made clearer by connecting the nodes that lie along a single nodal line (this is done with grey lines) and the antinodes which lie along an antinodal line (this is done with black lines).



This pattern of nodal and antinodal lines is called an **interference pattern**. The next picture makes this pattern even more clear by removing the wavefronts from the picture, and extending the nodal and antinodal lines.

The nodal lines are numbered in each quadrant starting from the centre line. In quadrant 1 (north and east) there are three nodal lines. The first one to the right of the centre line is $n = 1$, the next nodal line to the right is $n = 2$, and the final nodal line to the right of the other two is $n = 3$.

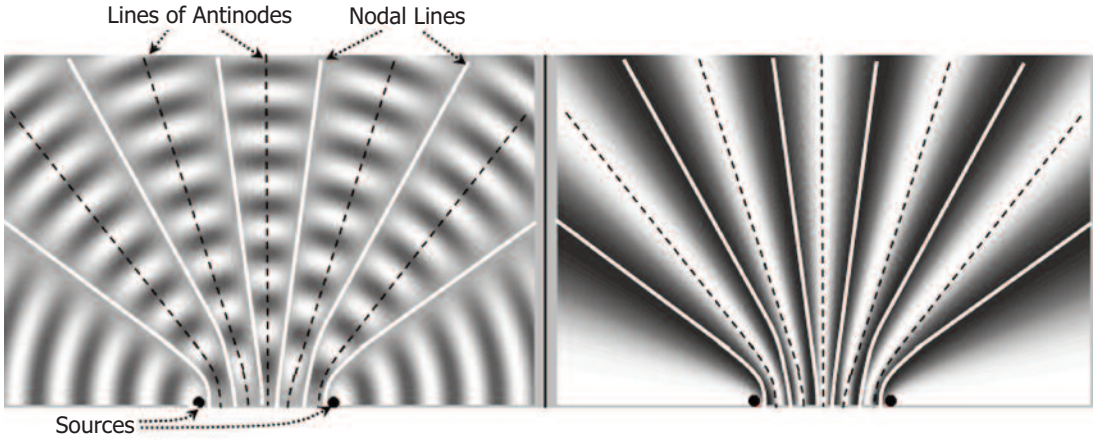
The pattern is symmetrical so we will number the lines of antinodes in quadrant 2 (north and west). There is a line of antinodes on the centre line so this is numbered $n = 0$. The first line of antinodes to the left is $n = 1$ and the next one to the left is $n = 2$.



This kind of a pattern can be seen in a ripple tank. When illuminated from above in a ripple tank, the nodal lines appear as areas that are not particularly bright and that are unchanging. This is because the water along the nodal lines does not have any wave activity, and so it is calm and flat. The water along the antinodal lines, however, does reveal the wave activity. Essentially, it appears that the wave moves along the antinodal lines, but is "forbidden" from crossing the nodal lines.

Here is an example of the interference pattern of two point sources generating in phase of how it appears in a ripple tank.

Interference Pattern for Two Point Sources of Waves



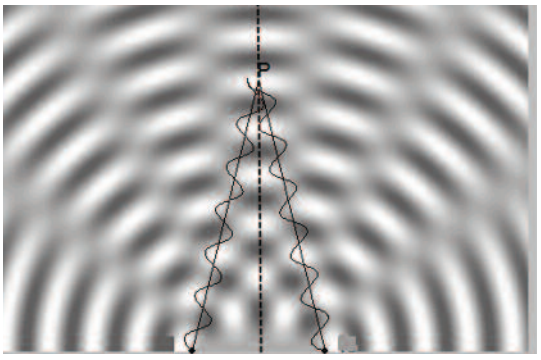
Ripple Tank Pattern of Displacement on Water's Surface Showing Lines of Nodes and Antinodes

This is the ripple tank pattern of light intensity showing the dark lines of nodes and the bright lines of antinodes.

Path Length Difference to a Point P on a Line of Antinodes

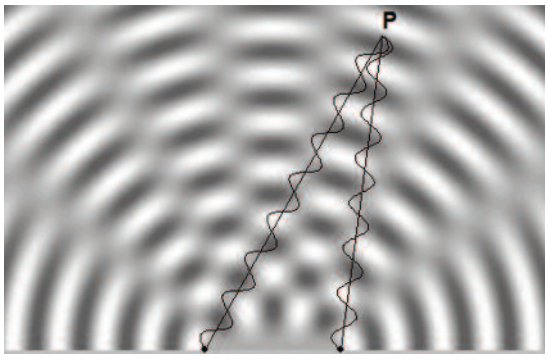
Let us consider a point P on the centre line (n = 0). The following illustration indicates how the PLD would be found.

Path Length Difference to a Point on the Centre Line (n = 0)



PS_1 = Pathlength from S_1 to Point P = 6 λ
PS_2 = Pathlength from S_2 to Point P = 6 λ
$PS_1 - PS_2$ = Pathlength Difference 6 λ – 6 λ = 0 λ

The PLD to a Point on the First Line of Antinodes (n = 1)



Source Separation = 3 Wavelengths
PLD = $PS_1 - PS_2$
PLD = 8 λ – 7 λ = 1 λ
The PLD to all points on the first line of antinodes is 1 λ.

By calculating the PLD for any point of interest, we can determine whether that point will be a point of continual constructive or destructive (or neither) interference. If the PLD = 0, we have the "true" tie that was discussed above. The result is that the waves always arrive in phase and so the point of interest would be an **antinode**.

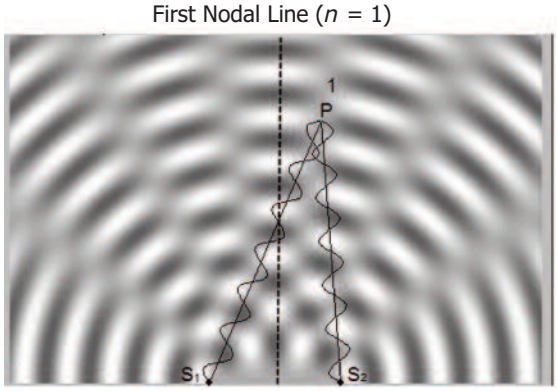
If the PLD = λ, we would again have the waves arriving in phase, and so again have an antinode. In fact, if the PLD was 2λ, 3λ, 4λ, et cetera (any whole number of wavelengths), then the waves will certainly arrive in phase, producing an antinode. We can use the symbol "n" to stand for any whole number (n = 0, 1, 2, 3 …).

> If the PLD = $n\lambda$, then the point of interest is an antinode. The symbol "n" stands for the number of the antinodal line and "n" can be any whole number (0, 1, 2, 3 …).

Path Length Difference to a Point on a Nodal Line

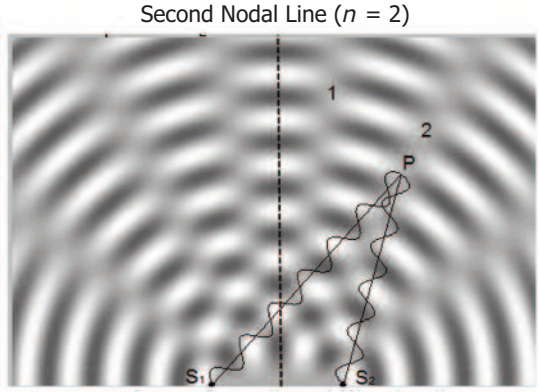
We can perform a similar analysis for the nodal lines.

Path Length Difference to a Point on the First Nodal Line (n = 1)



Source Separation = 3 Wavelengths
$PS_1 = 6.5\lambda$; $PS_2 = 6.0\lambda$
$PLD = PS_1 - PS_2 = 6.5\lambda - 6.0\lambda = 0.5\lambda$
The path length difference to all points on the first nodal line is 0.5λ.

Path Length Difference to a Point on the Second Nodal Line (n = 2)



Source Separation = 3 Wavelengths
$PS_1 = 6.5\lambda$; $PS_2 = 5.0\lambda$
$PLD = PS_1 - PS_2 = 6.5\lambda - 5.0\lambda = 1.5\lambda$
The path length difference to any point on the second nodal line is 1.5λ.

Similarly, if the PLD is $\frac{1}{2}\lambda$, then the waves will continually arrive out of phase, and the result is that the point of interest is a node. This will also be true if the PLD is $1\frac{1}{2}\lambda$, $2\frac{1}{2}\lambda$, $3\frac{1}{2}\lambda$, et cetera. We can generalize this pattern by using the expression $(n - \frac{1}{2})\lambda$.

> If the PLD = $(n - \frac{1}{2})\lambda$, then the point of interest is a node in which "n" can be any whole number (1, 2, 3 …) representing the number of the nodal line.

This symmetrical interference pattern will remain stationary, provided three factors do not change:

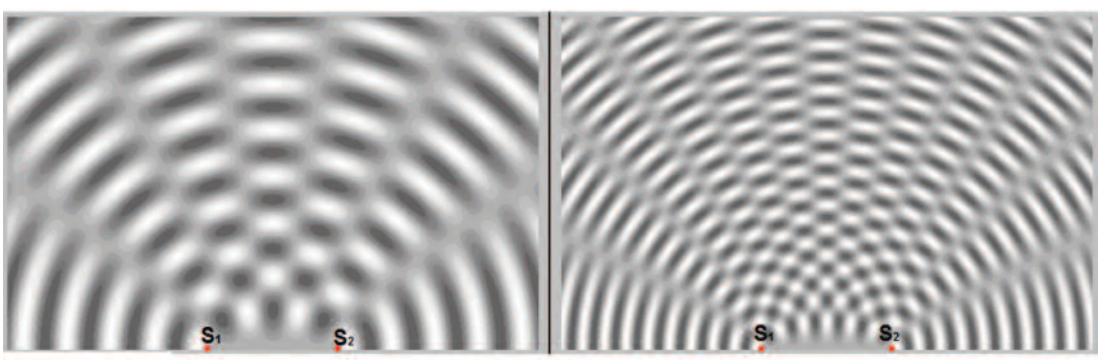
1. the frequency of the two sources
2. the distance between the sources
3. the relative phase of the sources (whether they produce crests and troughs at the same time or not)

We will not deal with the third factor. All of the situations we will consider will have the two sources in phase.

However, for the other two, the frequency of the sources and the distance between the sources, any change that results in more crests and troughs between the two sources will **increase** the points at which interference can occur. If there are **more crests** and troughs between the sources, the **number of lines** of nodes and antinodes **increases**. Since there are more lines in one quadrant, the lines must be squeezed closer together.

If the frequency of the two sources is increased, the wavelength decreases, as expected. This places more crests and troughs between the two sources, resulting in more nodal lines in the pattern. The nodal lines will also be spaced closed together.

The Effect on Decreasing Wavelength on a Two Point Source Interference Pattern

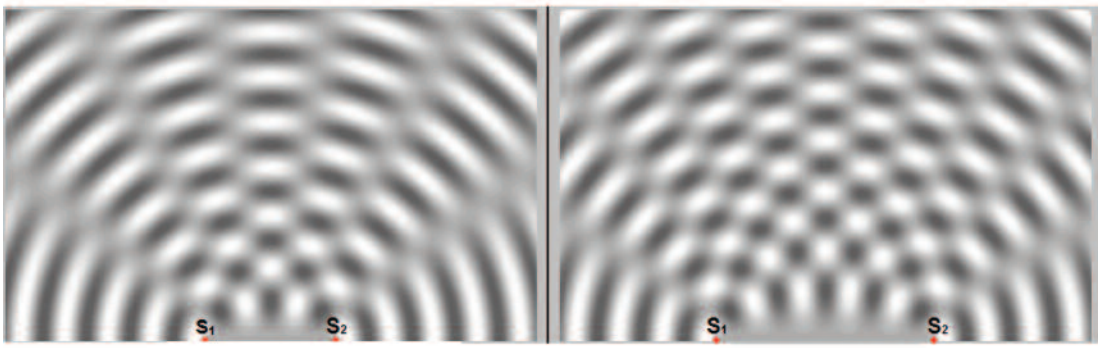


Source separation = 3.00 λ Source separation = 6.00 λ

This has the additional effect of resulting in the nodal lines being closer together and, therefore, increasing their number.

If the wavelength is decreased but the separation of the sources remains constant, this again will place more crests and troughs between the sources and increase the number of nodal lines in the pattern.

The Effect of Increasing the Separation of the Sources on the Inference Pattern for Two Point Sources



Source separation = 3.00 λ Source separation = 5.00 λ

The number of nodal lines will also increase if the distance between the two sources increases. Neither of these two factors will change the symmetry of the pattern.

A New PLD Formula

Now that you know about nodal lines and how they are numbered, we can combine this information with our relationship for PLD.

We know that PLD = $|PS_1 - PS_2|$.

We also saw that the PLD to a point on a given nodal line, n, was PLD = $(n - \frac{1}{2})\lambda$.

The **path length difference** to a point $\mathbf{P_n}$ on a given nodal line, $\boldsymbol{n}$, can be written as

$$\text{PLD} = |P_nS_1 - P_nS_2| = \left(n - \frac{1}{2}\right)\lambda.$$

Quantity	Symbol	Unit
Path length difference	PLD	metres (m)
Number of the nodal line	n	no units
Path length for source 1 to P_n	P_nS_1	metres (m)
Path length for source 2 to P_n	P_nS_2	metres (m)

Example: Determining the Wavelength from an Interference Pattern

In an interference pattern for two point sources, the path length from source 1 to a point P_n is 12.27 cm, and the path length from source 2 to the same point is 14.74 cm. The point is found on the fourth nodal line.

a) What is the path length difference to P_n?

Given: Path length from S_1 to P_n — $P_nS_1 = 12.27$ cm

Path length from S_2 to P_n — $P_nS_2 = 14.74$ cm

Number of the nodal line — $n = 4$

Unknown: Path length difference — PLD = ?

Equation: $\text{PLD} = |P_nS_1 - P_nS_2|$

Substitute and solve:

$$\begin{aligned}\text{PLD} &= |P_nS_1 - P_nS_2| \\ &= |12.27\text{ cm} - 14.74\text{ cm}| \\ &= 2.47\text{ cm}\end{aligned}$$

The path length difference is 2.47 cm.

b) What is the wavelength of these waves in the ripple tank?

Unknown: Wavelength — $\lambda = ?$

Equation:

$$|\text{PLD}| = |P_nS_1 - P_nS_2| = \left(n - \frac{1}{2}\right)\lambda$$

Substitute and solve:

$$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

$$2.47\text{ cm} = \left(4 - \frac{1}{2}\right)\lambda$$

$$2.47\text{ cm} = (3.5)\lambda$$

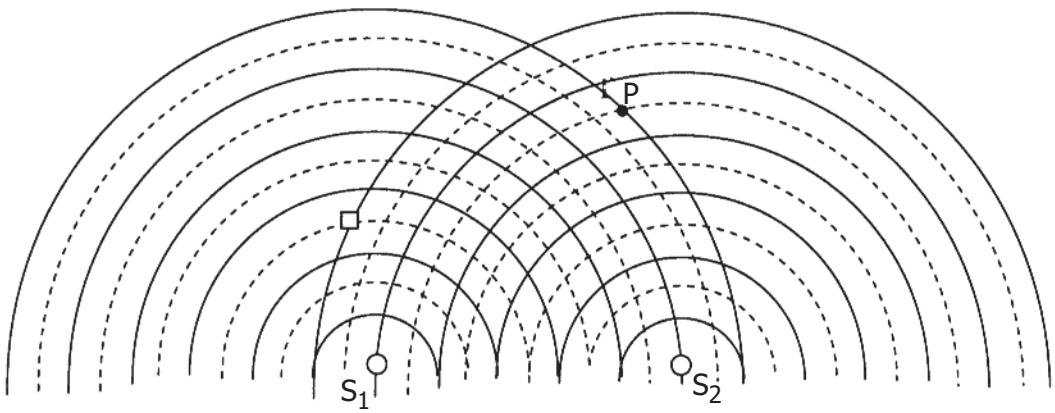
$$\lambda = 0.706\text{ cm}$$

The wavelength is 0.706 cm.

Learning Activity 8.6

Waves in Two Dimensions—Interference: Part 2

1. Two point sources are generating waves at the same frequency and phase. The pattern is shown below. The solid lines represent the crests and the dashed lines represent the troughs.



Draw in the perpendicular bisector of S_1S_2.

a) Draw the **second nodal line to the left** and the **third nodal line to the right** of the perpendicular bisector.

b) What kind of interference, constructive or destructive, is occurring at the location of the square?

c) On which nodal line would the square be located?

d) What would be the distance between the square and the source S_2 if the wavelength of the waves is 4.0 cm?

e) On which nodal line is point P? What is the path length difference to point P?

f) What is the path length difference to the square?

2. Two point sources are generating waves in a ripple tank, causing the waves to interfere. The two point sources are 10.0 cm apart, and the frequency of the waves is 4.00 Hz. A point on the first nodal line is located 16.0 cm away from one source and 15.0 cm away from the other.

a) What is the wavelength of the waves?

b) What is the speed of the waves?

(continued)

Learning Activity 8.6: Waves in Two Dimensions—Interference: Part 2 (continued)

3. State the effect on the interference pattern for two point sources if the following changes were made:
   a) the wavelength of the waves was increased
   b) the two sources were moved closer together
   c) the frequency of the waves was increased

Lesson Summary

In this lesson, the **interference of two-dimensional waves** was discussed. The waves had the same frequency and amplitude and were in phase.

When **two crests** or **two troughs** meet, **constructive interference** occurs. When a **crest** and a **trough** meet, **destructive interference** occurs.

In a ripple tank, areas of **destructive interference**, **the nodal lines**, appear as relatively **stationary grey areas**. The areas of **constructive interference** appear as **alternating bright (double-crest)** and **dark (double-trough)** areas.

The number of nodal lines will increase if the frequency of the vibrating sources is increased or if the distance between the sources is increased.

If the two vibrating sources are not in phase, the number of nodal lines will not change, but the pattern will shift so that the areas of constructive interference will not run along the perpendicular bisector.

The **path length difference (PLD)** between two point sources, S_1 and S_2, and a point of interest, P, is given by the absolute value of the difference in length between the path length from S_1 to P and S_2 to P.

$$\text{PLD} = |PS_1 - PS_2|$$

For points of interest, P_n, on a given nodal line, n, the PLD can be found using

$$\text{PLD} = |P_nS_1 - P_nS_2| = \left(n - \frac{1}{2}\right)\lambda.$$

The wavelength of waves producing an interference pattern in two dimensions can be determined using the equation

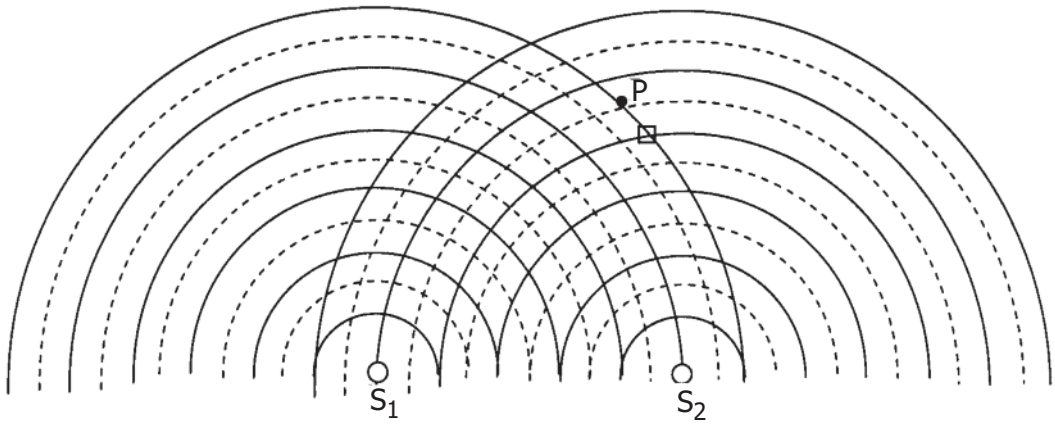
$$|P_nS_1 - P_nS_2| = \left(n - \frac{1}{2}\right)\lambda.$$

Assignment 8.3, Part C

Waves in Two Dimensions—Interference (5 MARKS)

The physics of wave interference in a ripple tank

The following diagram shows the pattern produced when two sources, S_1 and S_2, are vibrating in phase at the same frequency in a ripple tank. The solid lines represent crests and the dashed lines represent troughs.



a) Draw the line showing the third nodal line to the left of the perpendicular bisector.

b) What kind of interference is occurring at the location of the square shown to the right of the perpendicular bisector? How can you tell?

_____

c) How many nodal lines will there be in total in this pattern, including all lines to the left and the right of the perpendicular bisector?

_____

(continued)

Assignment 8.3, Part C: Waves in Two Dimensions—Interference (continued)

d) In the diagram above, the distance between P and S_1 is 12.0 cm. The distance between P and S_2 is 9.0 cm. Using the equation $\left|P_nS_1 - P_nS_2\right| = \left(n - \frac{1}{2}\right)\lambda$, determine the wavelength.

_____

_____

_____

_____

e) If the speed of the waves is 5.0 cm/s, what must be the frequency?

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for drawing the third nodal line in part (a)
- 1 mark for indicating the kind of interference in part (b)
- 1 mark for indicating the number of nodal lines in part (c)
- 1 mark for determining the wavelength in part (d)
- 1 mark for determining the frequency in part (e)

Lesson 5: An Introduction to Electromagnetic Waves (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe electromagnetic waves
- describe the electromagnetic spectrum
- identify how electromagnetic waves differ from each other in different parts of the electromagnetic spectrum
- describe how electromagnetic waves exhibit wave behaviour: wavelength, frequency, speed, reflection, refraction, diffraction, interference
- state what kind of electromagnetic wave, radio wave, microwave, or infrared wave is used in the following methods of communication: radio and television communication, satellites, phone and cell phone, motion detectors, and remote controls

Key Words

electromagnetic wave	electromagnetic spectrum	radio waves
microwave	infrared wave	frequency
wavelength	amplitude modulation	frequency modulation

Introduction

Please note that there is no assignment in this lesson.

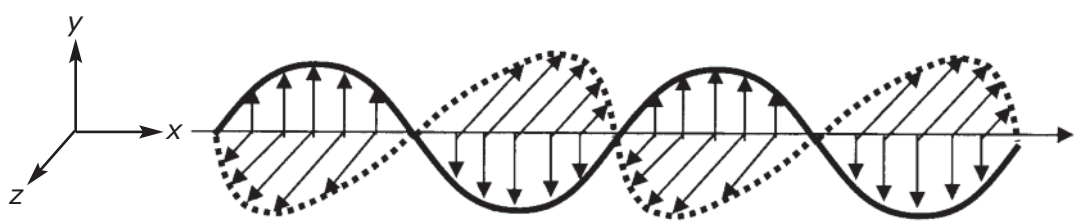
We now complete this module by introducing a very important kind of wave: electromagnetic waves. In studying these waves, we will find that they are in many ways similar to the waves seen we've seen so far, but that they also have some important differences. This lesson will use electromagnetic waves to focus on some particularly interesting applications and examples of much of the physics introduced in earlier lessons. This also sets the stage nicely for a closer look in the final module at a special kind of electromagnetic wave—light.

Electromagnetic Waves

In a previous module, we investigated electric and magnetic fields. We saw that electric charges produce electric fields, and that electric charges in motion (i.e. "currents") produce magnetic fields. If an electric charge is made to vibrate back and forth, it will continue to produce an electric field, but with the charge continually changing its position the electric field will become "wavy." In addition, because the charge moves while vibrating back and forth, it will produce a magnetic field which will similarly be "wavy." The details of how this happens are both amazing and complicated, but we can call the result an **electromagnetic wave**. Notice that the name itself is quite descriptive: there is a wave that is in part electric in nature, and another part which is magnetic in nature. It would simply not be possible to produce such a wave without this dual nature being present. Note that electromagnetic waves are transverse—both the electric and magnetic fields will be waving perpendicular to the motion of the waves.

The diagram below shows two transverse waves. The wave with the **solid line** could represent the **electric field lines** and the wave with the **dashed lines** could represent the **magnetic field lines**. The electric and magnetic field lines are perpendicular to each other and to the direction of motion of the waves.

In the diagram below, the electric field vibrates in an up and down way. This is equivalent to the wave vibrating along the y-axis. The magnetic field vibrates into and out of the paper, along the z-axis. The wave itself moves to the right along the x-axis.



Electromagnetic waves are transverse waves of electric and magnetic fields. They are produced from vibrating electric charge.

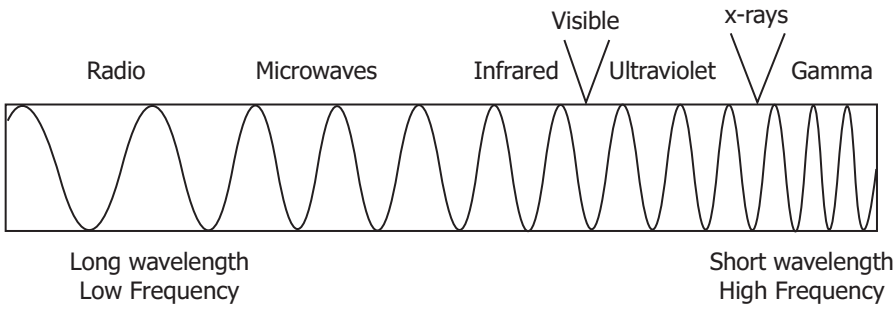
As with all waves, the frequency of the wave depends on the frequency of the source. In this case, that means that the frequency of the vibrating charge will be the frequency of the resulting electromagnetic wave. Unlike all of the other waves we have seen so far, however, these waves do not need a medium at all. While "spring waves" needed springs and "water waves" needed water, electromagnetic waves can exist in otherwise empty space because electric and magnetic fields can exist in otherwise empty space. For this reason, electromagnetic waves are not mechanical waves; electromagnetic waves are a whole new kind of wave for us. Of course, they are not limited to being in empty space. They can also exist within just about any kind of material, including air, water, and glass.

The Electromagnetic Spectrum

Electromagnetic waves can have many different frequencies.

> When we include all of the frequencies of electromagnetic waves, it is called the **electromagnetic spectrum**.

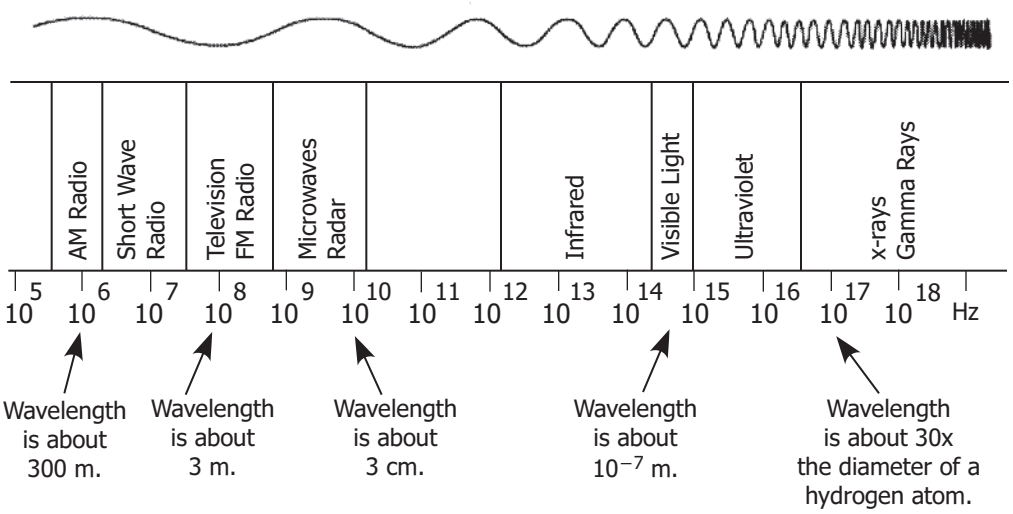
The graphic below shows how the electromagnetic spectrum is arranged from low-frequency waves to high-frequency waves. Again, notice how the wavelength changes (decreases) as the frequency changes (increases).



Another important feature of electromagnetic waves is that electromagnetic waves of different frequencies (and therefore different wavelengths) actually have different names. This is because electromagnetic waves tend to have special uses or properties, depending on the frequency and wavelength.

The graphic below gives a more detailed look at the electromagnetic spectrum. The different parts of the electromagnetic spectrum correspond to their uses.

Electromagnetic Spectrum



Here is a list of the different kinds of electromagnetic waves, listed from the lowest to highest frequency (and therefore from the largest wavelength to the smallest wavelength):

- **Radio Waves**—commonly used for communication. Not only for "radios" but also for broadcast television, remote control toys, and cordless telephones.
- **Microwaves**—most famously used for microwave cooking, but also used for communication, most notably in cell phones. Electromagnetic radiation that is in the region of less than 1 cm to about 30 cm can penetrate earth's atmosphere. This makes microwaves especially useful for space-vehicle communications and radio astronomy. Microwaves are used to communicate through the use of satellites, and therefore are useful in telephone or cell phone technology. Airplanes communicate with each other and with ground stations using microwaves. Television stations that communicate with each other do so through microwaves.
- **Infrared**—often associated with warmth, these waves can be used for (among other things) night vision, burglar alarms, and even remote controls for television, et cetera. Infrared radiation is really heat radiation. One application of infrared radiation in the communications field is its use as a remote control unit for your television. Infrared devices can also be used as motion detectors and therefore as security devices.
- **Light**—light itself can be described as being an electromagnetic wave, as we will see in more detail in a future module.
- **Ultraviolet**—this is naturally present in sunlight, and is responsible for causing suntans as well as sunburns. In addition, these waves are sometimes called "black lights" (since you cannot see them), and can be found in places ranging from bowling alleys to novelty shops, where they cause certain objects to fluoresce, or glow in the dark.

- **X-Rays**—most famously used in dental and other medical imaging. These waves are able to transmit fairly well through skin and other soft body parts, but do not transmit as well through bones and teeth. This mean that x-rays will cast a "shadow" of your bones and teeth after going through your body, which will be made visible if they then strike a photographic film.
- **Gamma Rays**—the highest frequency of all electromagnetic waves, these waves are even more penetrating than x-rays. Gamma rays are even better at transmitting through objects than x-rays, and they can also be quite harmful to living things. They have numerous uses including sterilizing equipment in hospitals, detecting internal defects inside of important parts (such as weld joints of an aircraft), and are also used to kill tumours.

Radio

As revealed in the above list, electromagnetic waves can be tremendously useful. One of the more familiar examples of this is radio. By explaining the essence (but certainly not the details!) of how radios work, you will gain a better understanding of electromagnetic waves, and also see how much of what we learned earlier in this module applies to electromagnetic waves.

Today, we often take communication for granted. We think nothing of the fact that we can pick up a telephone and call virtually anyone on the earth, from just about anywhere on the earth (although perhaps doing so in certain situations, such as driving, may not be a good idea). Similarly, we think nothing of tuning in a radio to listen to music that is actually being played at a radio station, which may be hundreds of kilometres away.

Not all that long ago, communicating over great distances was very difficult. If you wanted to get a message to a faraway place in the 1700s, you had very few options. Of course, you could go to the destination and personally deliver the message, but the message could also be written down, and the piece of paper physically carried by others to the destination.

As our knowledge of electricity grew, people discovered that electrical currents could travel great distances through wires. One of the earliest uses of this science was communication by means of a device called a **telegraph**. If two towns were connected by a long wire, then a person in one town could send spurts of electricity into their end of the wire, which would then travel through the wire to the other town where they would be "**received**." If the spurts themselves were generated in a patterned way, then a message could be carried by the "pulses" of electricity, rather than by a physical object such as paper. The first signals were a series of long and short pulses that could be translated into letters and words by **Morse code**.

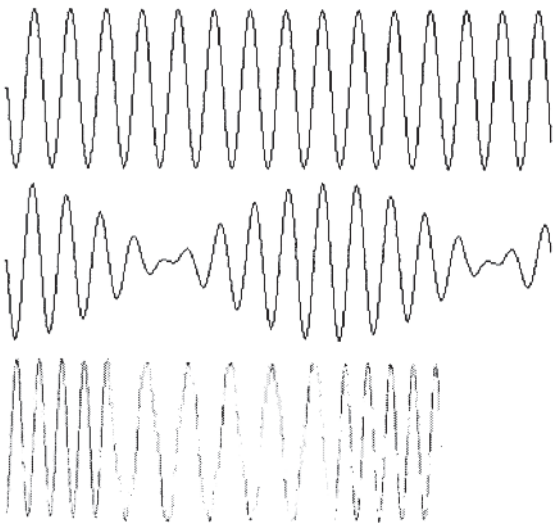
The telegraph revolutionized communication. For the first time, it became possible to send messages to distant places practically instantaneously. There was, of course, one drawback: there had to be wires connecting the sending and receiving end of the message.

Since electromagnetic waves such as radio waves can go very large distances through air, the possibility of transmitting information over long distances with them was realized shortly after their discovery. One of the first scientists to realize this and put this into practice was Guglielmo Marconi (1874–1937). In the 1800s, he invented and developed the "**wireless telegraph**." With it, messages could be sent hundreds of kilometres without the use of wires. Whereas the regular telegraph used spurts of electricity travelling through wires, the wireless telegraph used spurts of radio waves travelling through the air.

In the years following the invention of the wireless telegraph, our ability to produce and receive radio waves improved dramatically. No longer were people limited to merely sending "spurts" of these waves; they could produce radio waves with great precision. In particular, a critical piece of technology, vacuum tubes, were developed. This led to the birth of radio as we know it today, and later to television (although the transistor would eventually replace the vacuum tube, which has become relatively rare).

AM Radio and FM Radio

The radios we listen to are most often either AM (amplitude modulation) or FM (frequency modulation). The AM and FM radio waves are transverse waves that consist of electric and magnetic disturbances. They are a type of electromagnetic radiation. These waves travel at 3.00×10^8 m/s.



Unmodulated Radio Waves—These waves carry no signal that can be detected by a radio.

Amplitude Modulated Radio Waves—These waves carry signals that can be detected by AM radios.

Frequency Modulated Waves—These carry signals that can be detected by an FM radio.

AM radio stations broadcast waves that are in the kilohertz (10^3) range. For example, 990 on the AM dial refers to radio waves that have a frequency of 990 kHz. The frequency range for AM waves is 545 kHz to 1605 kHz.

FM radio stations broadcast waves in the megahertz (10^6 Hz) range. 103.1 on the FM dial refers to radio waves that have a frequency of 103.1 MHz. The frequencies of FM radio waves lie between 88 MHz and 108 MHz. Conventional television (not cable or satellite) channels 2 to 6 utilize electromagnetic waves with frequencies between 54 and 88 MHz, while channels 7 to 13 use frequencies between 174 and 216 MHz.

How Radios Work

Let's now turn to explaining how radios work. In particular, let's suppose that you have your car stereo tuned into a station, and are hearing a song that they are playing. Although extremely simplified, here is the basic physics involved in getting the song from the radio station to your car:

Earlier in this module, we stated that sound itself is a wave. We will learn more details about this in the next module, but for now let us say that the song (or any other sound) may be considered to be a wave of a very particular pattern of crests and troughs. If the radio station is playing this song from a CD, then the CD itself has this pattern recorded onto it in a form that computers (and CD players which have computers inside them) can understand. Note that the CD does not have the wave itself on it, or anything that even remotely resembles the wave. It only contains information about the wave. It is only by means of a sophisticated computer and support equipment that the sound wave itself can be reproduced when the CD is played.

The radio station plays this CD on its stereo, which is not all that different than a CD player you might find in your home or car. But the radio station has extra equipment too. In particular, one thing they have is a transmission tower. The transmission tower sends out radio waves, which are then received by antennas. You are likely familiar with antennas as they are found on cars and radios (among other things). In its simplest form, an antenna is simply a metal rod. Essentially, the transmitting tower is a metal rod too, but much larger than a typical antenna.

Being metal rods, the transmitting tower and antennas are both conductors, so electric charge can move around within them fairly easily. The transmission tower has electronics attached to it that force electrons up and down within the tower. You can think of the electrons (charge) as "sloshing" up and down within the wire. Of course, they very precisely control the frequency of this charge vibration. With electric charge vibrating up and

down within the tower, electromagnetic waves are produced, as was described earlier. Since the electrons within the tower have a controlled frequency, the resulting electromagnetic waves also have a controlled frequency.

By varying the amplitude (in the case of AM radio) or the frequency (in the case of FM radio), a signal can be sent out that carries information about the sound it is supposed to be transmitting inside of it. The music is not literally in the radio waves. In the same way that a CD has information about the music encoded on it, the radio waves have the music encoded within them. You could be standing right beside the transmission tower, and you would not hear anything coming from it—radio waves are not sound waves. The radio waves would slip invisibly (and inaudibly) past and through you.

If these radio waves encounter an antenna, the charges within the antenna will experience electric forces as a result of the electric field component of the radio waves. These forces will be wavy, since the electric field itself is wavy. In fact, the electrons within the antenna will begin to vibrate up and down within the antenna in the exact same patterned way as those in the transmission tower are vibrating. Since this vibration was based in part on the sound wave, further electronics inside the radio can extract this information and reproduce the original sound—you will hear your song.

Music is encoded in radio waves, which are generated by the vibrating charges within a transmitting tower. This information travels through the air via electromagnetic waves. These waves strike antennas and force the charge within them to vibrate in the same way. Information about the sound can be extracted and played.

The Wave Behaviour of Radio Waves

Radio waves can **reflect**, **refract**, **superimpose**, **interfere**, and **diffract**, just like water waves can. The effects of all of these, except for refraction, are observable (radio waves certainly can refract, but since the direction that the waves are moving in does not affect the sound heard on the radio, you won't normally notice radio wave refraction).

In the above, we only discussed a single radio transmission tower. Of course, in most places, you can "tune" your radio in to one of several stations. This means that the radio waves from many towers are moving through space together, and yet they don't "hit" each other. Instead, they pass directly through each other and continue moving. This is **superposition**.

Of course, this also means that the radio waves from several stations are simultaneously striking the antenna of your radio. How can your radio "tune" into just one? The answer, in a word, is **resonance**. By changing the

characteristics of the electric circuits inside of the radio, the circuitry connected to the radio can be given a natural frequency that matches the frequency of the desired radio waves. Only the "right" frequency will significantly affect the circuitry. In changing to another station, the circuit's natural frequency is changed so that only the new station's frequency significantly affects the circuitry.

The **interference** of radio waves is also easily noticeable, and one way in which this commonly occurs is related to the fact that these waves can also **reflect**. In the above discussion, we discussed the radio waves coming from the transmission tower to the antenna directly, which they certainly can do. If these waves strike a large relatively flat surface (such as a wall), these waves can also reflect, and if the geometry is right these reflected waves can also head towards the antenna. This means that the exact same wave is striking the antenna twice (once from the direct path from the source, and once more from the indirect path involving a reflection). Note that these two waves do not travel the same distance in getting to the antenna. There will therefore be a "difference in path length."

If, by chance, this difference is $0.5\,\lambda$ (or $1.5\,\lambda$, et cetera), then they will cancel, resulting in the antenna being located at a **node**. There will be no reception at that location (although it is more likely that the reception will be merely reduced, as the amplitudes of these two waves will not be identical). You have likely noticed that there are certain places where radios tuned into a station go quiet or "staticky," and yet moving the radio a small amount brings the reception back. This is due to interference.

Interference of radio waves doesn't always involve reflections. Any **radio wave** of the same or even **close frequency** will result in **interference**. Transmission towers aren't the only things that send out radio waves. Many electric devices, though not designed to, unavoidably produce radio waves. Appliances (such as blenders), power tools, and even flicking a light switch on and off are all capable of producing radio waves that can interfere with the radio waves from the transmission tower. There are many natural sources of radio waves as well, including lightning and the sun. If this happens at the antenna of a radio, the reception will again be affected.

The **diffraction** of radio waves cannot be directly observed (at least not casually), but in certain situations we can notice its effects. If a large object is located directly between a radio and the radio transmission tower, the radio waves can diffract back into the "shadow region" to enable reception of that station. This is best noticed when comparing AM radio to FM radio. As was mentioned above, AM radio uses radio waves with frequencies in the hundreds of kilohertz range, while FM radio uses radio waves with frequencies around a hundred megahertz. This means that FM radio waves

are quite a bit higher in frequency (and therefore have significantly smaller wavelengths) than AM radio waves. As was discussed, diffraction is most easily observed with larger wavelengths, so we should predict that AM radio waves diffract better.

It's not easy to notice this, but FM radio waves cast more distinct "shadows" than AM radio waves. This means that "behind" obstacles (such as large buildings or hills), there will be places of poor FM reception, and yet quite good AM radio reception. This is most noticeable when driving across the country, far enough from the broadcast towers that the signals are weak (from AM and from FM), but the reception is reasonably good. In these locations, you will notice while driving that the FM stations will more frequently "come and go." You may be getting good reception on an FM radio station for a stretch of highway, lose it for a while, and then have it come a back a short while later, whereas the AM stations were more dependable. In essence, the longer AM radio waves can diffract more readily, greatly reducing dead spots.

The graphics below illustrate how the longer wavelength AM waves (in the top diagram) diffract more than the shorter wavelength FM waves (in the bottom diagram). The antenna on the house is able to detect the AM signal but cannot detect the FM signal.

Learning Activity 8.7

Electromagnetic Waves

1. Compare electromagnetic waves to mechanical waves. How are they alike and how are they different?
2. How does an AM radio signal differ from an FM radio signal?
3. Briefly describe how the electromagnetic waves represented by radio waves demonstrate the properties of waves.
4. Within the electromagnetic spectrum, what characteristics of the waves changes from one region to another of the spectrum?
5. How are electromagnetic waves produced?

Lesson Summary

Electromagnetic waves are transverse waves of electric and magnetic fields. They are produced from vibrating electric charge.

When we include all of the frequencies of electromagnetic waves, it is called the electromagnetic spectrum.

Here is a list of the different kinds of electromagnetic waves, listed from the lowest to highest frequency (and therefore from the largest wavelength to the smallest wavelength):

- **Radio Waves**—commonly used for communication. Not only for "radios" but also for broadcast television, remote control toys, and cordless telephones.
- **Microwaves**—most famously used for microwave cooking, but also used for communication, most notably in cell phones.
- **Infrared**—often associated with warmth, these waves can be used for (among other things) night vision, burglar alarms, and even remote controls for television, et cetera. Infrared radiation is really heat radiation.
- **Light**—light itself can be described as being an electromagnetic wave, as we will see with more detail in a future module.

- **Ultraviolet**—this is naturally present in sunlight, and is responsible for causing suntans as well as sunburns. In addition, these waves are sometimes called "black lights" (since you cannot see them), and can be found in places ranging from bowling alleys to novelty shops, where they cause certain objects to fluoresce, or glow in the dark.
- **X-Rays**—most famously used in dental and other medical imaging. These waves are able to transmit fairly well through skin and other soft body parts, but do not transmit as well through bones and teeth. This mean that x-rays will cast a "shadow" of your bones and teeth after going through your body, which will be made visible if they then strike a photographic film.
- **Gamma Rays**—the highest frequency of all electromagnetic waves, these waves are even more penetrating than x-rays. Gamma rays are even better at transmitting through things than x-rays, and they can also be quite harmful to living things. They have numerous uses including sterilizing equipment in hospitals, detecting internal defects inside of important parts (such as weld joints of an aircraft), and are also used to kill tumours.

Radio is a technology that employs electromagnetic waves from the radio wave part of the spectrum to transmit signals from a transmitter to a receiver. The radio waves could have the music or other information encoded in the waves by varying the amplitude at constant frequency (**AM radio**) or varying the frequency and constant amplitude (**FM radio**).

Radio waves show all of the characteristics of waves, indicating that they truly consist of waves. These radio waves, indeed all electromagnetic waves, exhibit characteristics like the same speed in a uniform medium, a wavelength, and a frequency. They follow the universal wave equation. They also reflect, refract, interfere, and diffract.

Module 8 Summary

Congratulations on completing Module 8.

Submitting Your Assignments

It is now time for you to submit Assignment 7.1 from Module 7 and Assignments 8.1 to 8.3 from Module 8 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 7 and Module 8 assignments and organize your material in the following order:

- Modules 7 and 8 Cover Sheet (found at the end of the course Introduction)
- Assignment 7.1, Part A: Transverse Waves and Longitudinal Waves
- Assignment 7.1, Part B: Reflection and Transmission of Waves in One Dimension
- Assignment 7.1, Part C: Wave Interference and Standing Waves in One Dimension
- Assignment 7.1, Part D: Resonant Frequency and Harmonics
- Assignment 8.1: Waves in Two Dimensions—Reflection
- Assignment 8.2: Video Laboratory Activity: Snell's Law
- Assignment 8.3, Part A: Waves in Two Dimensions—Refraction
- Assignment 8.3, Part B: Waves in Two Dimensions—Diffraction
- Assignment 8.3, Part C: Waves in Two Dimensions—Interference

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

You are now ready to start Module 9.

NOTES

Grade 11 Physics (30S)

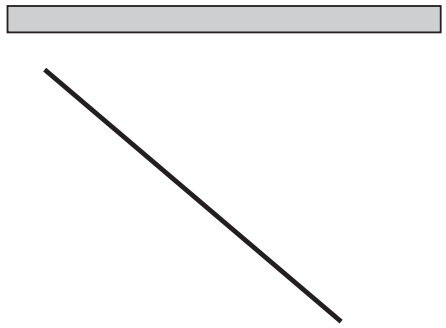
Module 8: Waves in Two Dimensions

Learning Activity Answer Keys

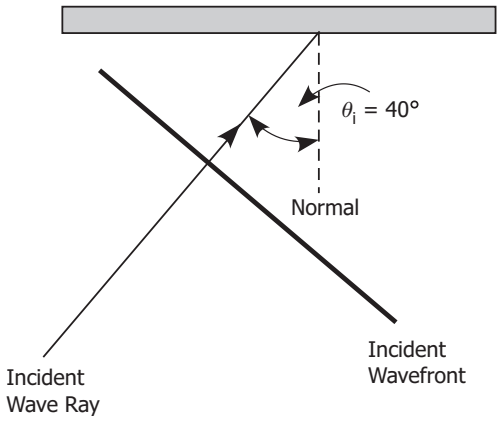
Module 8: Waves in Two Dimensions

Learning Activity 8.1: Waves in Two Dimensions—Reflection: Part 1

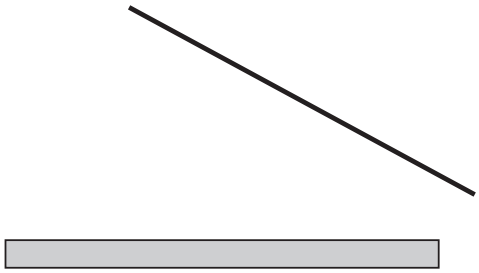
1. The diagram below shows a wavefront moving upwards to the right approaching a barrier. For this wavefront, draw in the wave ray. Extend the wave ray to the barrier and draw in a normal. What is the angle of incidence?



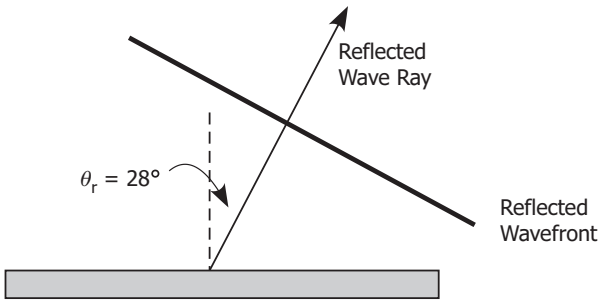
Answer:



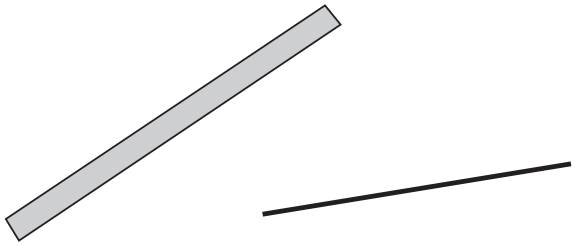
2. The diagram below shows a wavefront travelling away from a barrier (upwards to the right). For this wavefront, draw in the wave ray. Extend the wave ray to the barrier and draw in a normal. What is the angle of reflection?



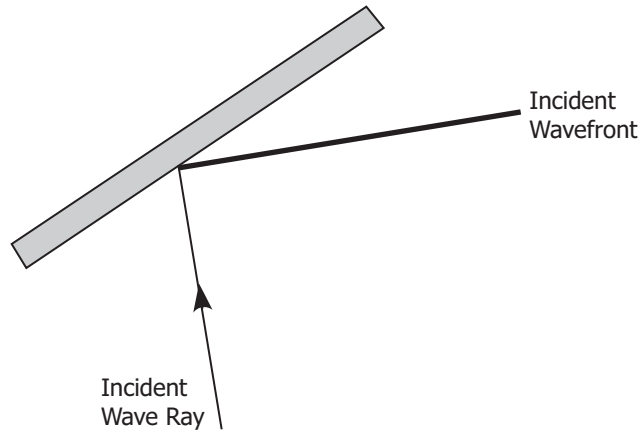
Answer:



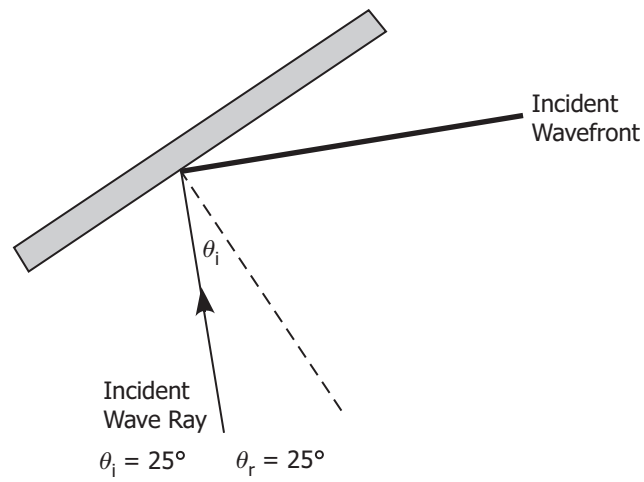
3. The diagram below shows one wavefront approaching (moving upwards to the left) a straight barrier. Using the procedure outlined above, draw in the reflected wave pulse.



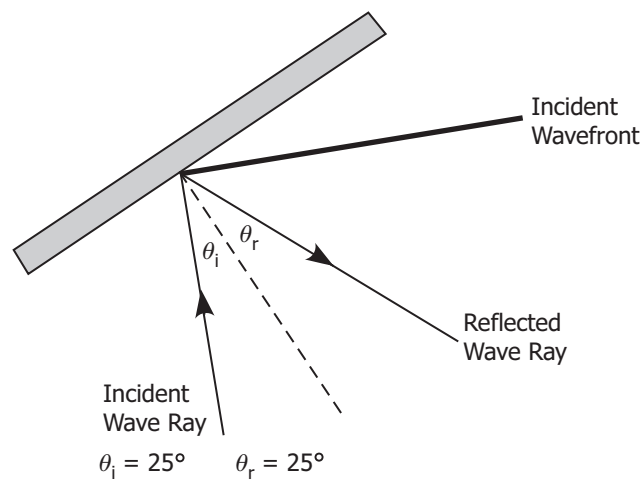
Step 1:
Draw in the incident wave ray. Extend the incident wavefront until it touches the barrier. At the point where the incident wavefront intersects the barrier, draw a wave ray for the incident wavefront. Label the incident wave ray.



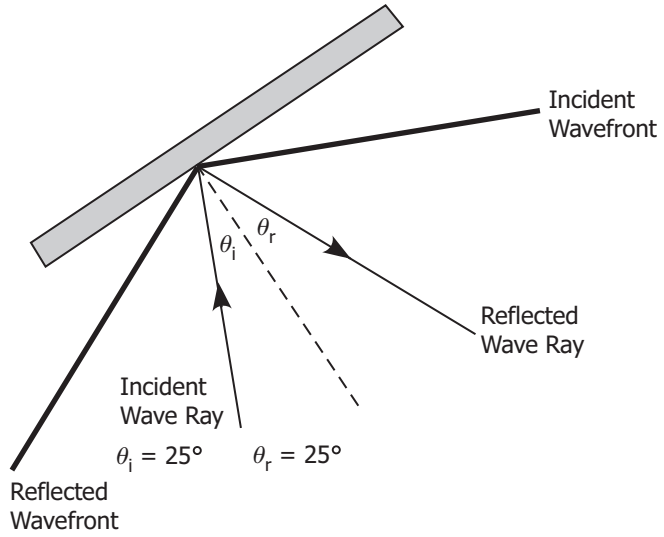
Step 2.
Draw in the angle of incidence. Draw in the normal at the point of reflection. Measure the angle of incidence and label the angle of incidence.



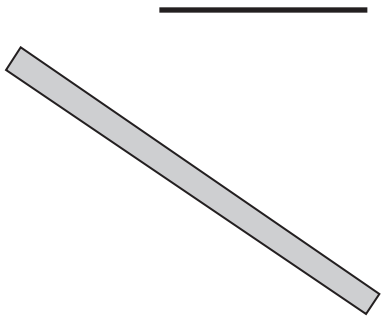
Step 3:
Draw in the reflected ray. From the normal, measure the angle of reflection at 34°. Draw in the reflected wave ray starting from the point of reflection. Label the reflected wave ray.



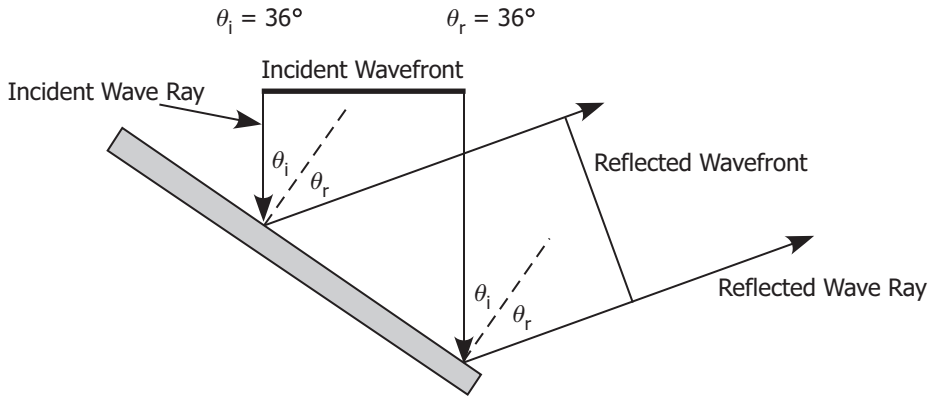
Step 4.
Draw in the reflected wavefront. At the point of reflection, draw in the reflected wavefront. This is drawn perpendicular to the reflected wave ray. Label the reflected wavefront.



4. The diagram below shows one wavefront moving downward approaching a straight barrier. Add to this diagram the following:
   a) Draw the incident wave rays from the left edge and the right edge of the wavefront.
   b) Using a dashed line, draw a normal from the point where the incident wave ray makes contact with the barrier.
   c) Draw the reflected wave rays.
   d) Draw the reflected wavefront at some point on the wave rays.
   e) What is the angle of incidence?
   f) Draw in the angle of incidence and the angle of reflection.



Answer:


θ_i = 36°
θ_r = 36°
Incident Wavefront
Incident Wave Ray
θ_i
θ_r
Reflected Wavefront
θ_i
θ_r
Reflected Wave Ray

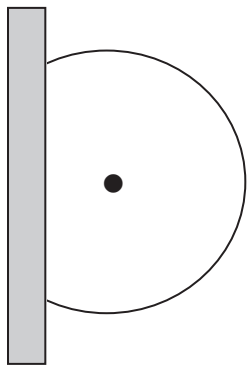
Learning Activity 8.2: Waves in Two Dimensions—Reflection: Part 2

1. Under what conditions would straight, reflected wavefronts have exactly the same size and orientation as the incident wavefronts (assuming no loss in energy)?

   Answer:

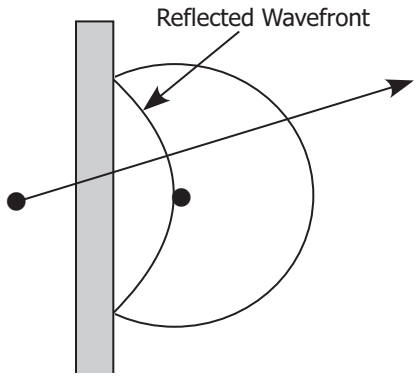
   This would occur when the incident wavefronts are approaching a straight, reflecting surface parallel to the surface.

2. The diagram below shows a circular wave approaching a barrier. The centre of the wave is shown. Draw that part of the wave that has been reflected. Also, draw a wave ray for the reflected ray from the place where the reflected wavefront seems to originate.

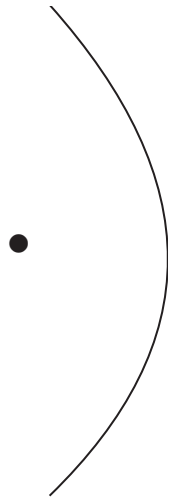


   Answer:

   The reflected pulse seems to originate from a centre point to the left of the barrier. This point is located the same distance behind the barrier as the centre of the originate wavefront in front of the barrier. The reflected wave ray is drawn from the imaginary centre away from the barrier.

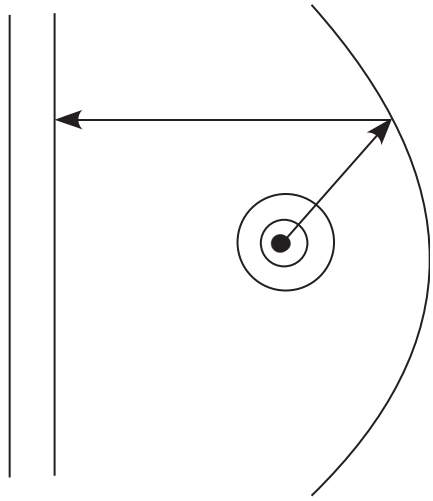


3. The diagram below shows a parabolic reflector. The focal point of the reflector is indicated by a dot. Circular pulses are generated from the dot. Draw two incident wavefronts and two reflected wavefronts. Add to the diagram an incident wave ray and a reflected wave ray.



Answer:

The diagram below shows two circular pulses approaching the parabolic reflector. One of the possible incident wave rays has its origin at the focal point. The reflected wave ray moves away from the reflector horizontally. Two wavefronts are straight and perpendicular to the wave rays.



Learning Activity 8.3: Waves in Two Dimensions—Refraction

1. A water wave in deep water has a speed of 18.0 cm/s and a wavelength of 2.00 cm. In the shallow water, the speed of the wave is 10.0 cm/s. What is the wavelength of this wave in shallow water?

   Answer:

   Let medium 1 be the deep water.

   Given: Speed in medium 1 $v_1 = 18.0$ cm/s

   Wavelength in medium 1 $\lambda_1 = 2.00$ cm

   Speed in medium 2 $v_2 = 10.0$ cm/s

   Unknown: Wavelength in medium 1 $\lambda_2 = ?$

   Equation: From Snell's law, use the part that relates speeds and wavelengths.

   $$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} \text{ rearranged to solve for } \lambda_2$$

   Substitute and solve:

   $$\lambda_2 = \frac{\lambda_1}{v_1} v_2 = \frac{(10.0 \text{ cm/s})(2.00 \text{ cm})}{18.0 \text{ cm}}$$
   $$= 1.11 \text{ cm}$$

   The wavelength in the shallow section is 1.11 cm.

2. A water wave of frequency 10.0 Hz and speed 40.0 cm/s is travelling in deep water. It then moves into shallow water where its speed is 30.0 cm/s. The angle of incidence is 30.0°. Find

   a) the wavelengths in the two media

   Answer:

   Let the deep water be medium 1.

   Given: Speed in medium 1 $v_1 = 40.0$ cm/s

   Speed in medium 2 $v_2 = 30.0$ cm/s

   Frequency $f = 10.0$ Hz

   Unknown: Wavelength in medium 1 $\lambda_1 = ?$

   Equation: Use the universal wave equation.

   $$v = f\lambda \text{ rearranged to } \lambda_1 = \frac{v_1}{f_1}$$

   Substitute and solve:

   $$\lambda_1 = \frac{v_1}{f_1} = \frac{40.0 \text{ cm/s}}{10.0 \text{ Hz}} = 4.00 \text{ cm}$$

   Unknown: Wavelength in medium 2 $\lambda_2 = ?$

Equation: Use the universal wave equation.

$$v = f\lambda \text{ rearranged to } \lambda_2 = \frac{v_2}{f_2}$$

Substitute and solve: $\lambda_2 = \frac{v_2}{f_2} = \frac{30.0 \text{ cm/s}}{10.0 \text{ Hz}} = 3.00 \text{ cm}$

The wavelength in the deep water (the incident medium) is 4.00 cm.

The wavelength in the shallow water (the refractive medium) is 3.00 cm

b) the angle of refraction in the shallow water.

Answer:

The angle of refraction is determined from Snell's Law. We can use the speeds of the waves, or the wavelengths of the waves. In this solution, we will use the speed of the waves.

Given: Speed in medium 1 $v_1 = 40.0$ cm/s

Speed in medium 2 $v_2 = 30.0$ cm/s

Angle of incidence $\theta_1 = 30.0°$

Unknown: Angle of refraction $\theta_2 = ?$

Equation: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$ rearranged to $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1}$

Substitute and solve: $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1} = \frac{(\sin 30.0°)(30.0 \text{ cm/s})}{40.0 \text{ cm/s}} = 0.375$

$$\theta_2 = \sin^{-1}(0.375) = 22.0°$$

The angle of refraction is 22.0°.

3. The velocity of a sound wave in cold air is 320 m/s and in warm air 384 m/s. Assume that the wavefront in cold air is nearly linear. What will be the angle of refraction in the warm air if the angle of incidence is 30.0° in the cold air?

Answer:

Let medium 1 be the cold air.

Given: Speed in medium 1 $v_1 = 320$ m/s

Speed in medium 2 $v_2 = 384$ m/s

Angle of incidence $\theta_1 = 30.0°$

Unknown: Angle of refraction $\theta_2 = ?$

Equation: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$ rearranged to $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1}$

Substitute and solve: $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1} = \frac{(\sin 30.0°)(384 \text{ m/s})}{320 \text{ m/s}} = 0.60$

$\theta_2 = \sin^{-1}(0.60) = 37°$

The angle of refraction in cold air is 37°.

4. An earthquake P wave travelling at 9.0 km/s strikes a boundary within the Earth between two kinds of material. If it approaches the boundary at an incident angle of 47° and the angle of refraction is 27°, what is the speed in the second medium?

Answer:

Given: Speed in medium 1 $v_1 = 9.0$ km/s

Angle of incidence $\theta_1 = 47°$

Angle of refraction $\theta_2 = 27°$

Unknown: Speed in medium 2 $v_2 = ?$

Equation: The speed in the second medium is found using Snell's Law.

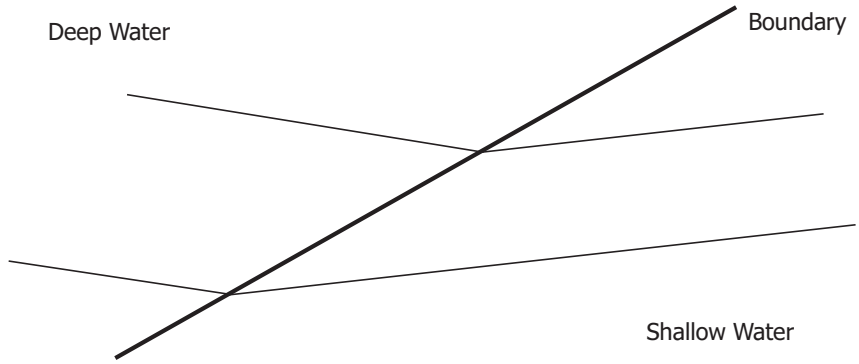
$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$ rearranged to $v_2 = \frac{v_1 \sin\theta_2}{\sin\theta_1}$

Substitute and solve: $v_2 = \frac{v_1 \sin\theta_2}{\sin\theta_1} = \frac{(9.0 \text{ km/s})\sin 27°}{\sin 47°}$

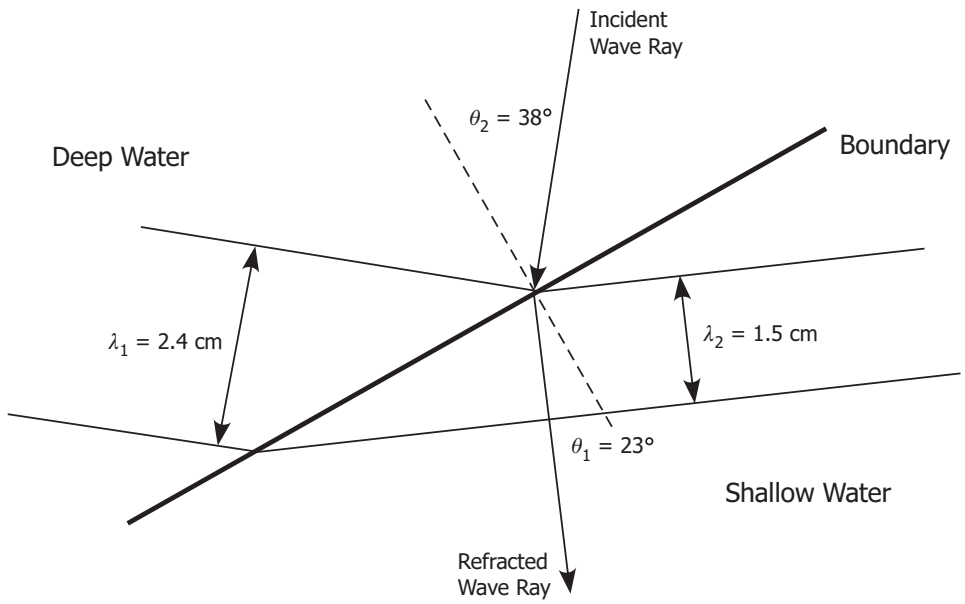
$= 5.6$ km/s

The speed of the waves in the second medium is 5.6 km/s.

5. In the diagram below, draw in the following: the incident wave ray, the normal, the angle of incidence, the refracted wave ray, and the angle of refraction. Measure and state the measurements of the wavelengths and the angles of incidence and refraction.



Answer:



6. What is refraction? What is the cause of refraction?

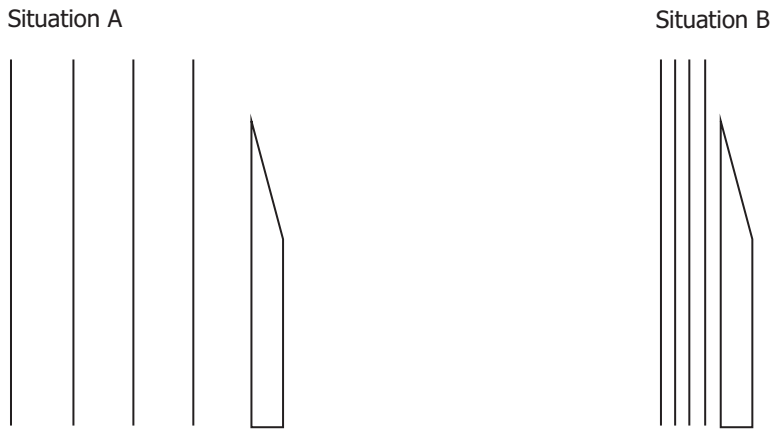
Answer:

Refraction is the bending in the path of a wave as it passes from one medium into another. The direction of the wave ray for the incident wavefront changes as the wavefront passes into the second medium.

The cause of refraction is a change in the speed of the wavefront as it passes into the second medium. If the wavefront slows down, the wave ray is bent towards the normal. If the wavefront speeds up, the wave ray is bent away from the normal.

Learning Activity 8.4: Waves in Two Dimensions—Diffraction

1. The diagram below shows two different types of water waves approaching a sharp edge. Which type of wave will show the greatest diffraction: the waves in situation A or the waves in situation B?



Answer:

The waves in situation A have a larger wavelength and will therefore show the greatest diffraction.

2. Ocean waves are approaching an opening into a harbour. The opening is 100 m wide. For which wavelength of ocean waves would there be the greater diffraction: those with a wavelength of 50 m or those with a wavelength of 200 m?

Answer:

The larger the wavelength, the greater will be the diffraction. Therefore, there will be a greater diffraction for the waves of 200 m wavelength.

3. A D note in music has a frequency of 294 Hz. A G note has a frequency of 392 Hz. If music was playing in a hallway around the corner, what frequency of sound would you most clearly hear?

Answer:

The lower frequency of sound would diffract more as it bent around a corner. Therefore, you would hear the 294 Hz sound better.

4. Light of wavelength 470 nm is blue in colour, and 610 nm light is orange. If these colours of light were to pass through a 500-nm hole, which colour of light would show the greatest diffraction?

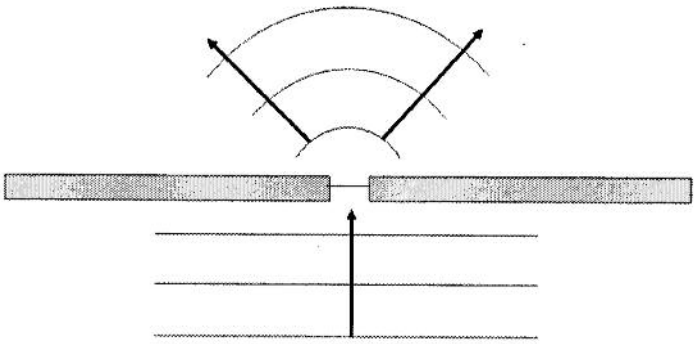
Answer:

The 610 nm light would show the greater diffraction.

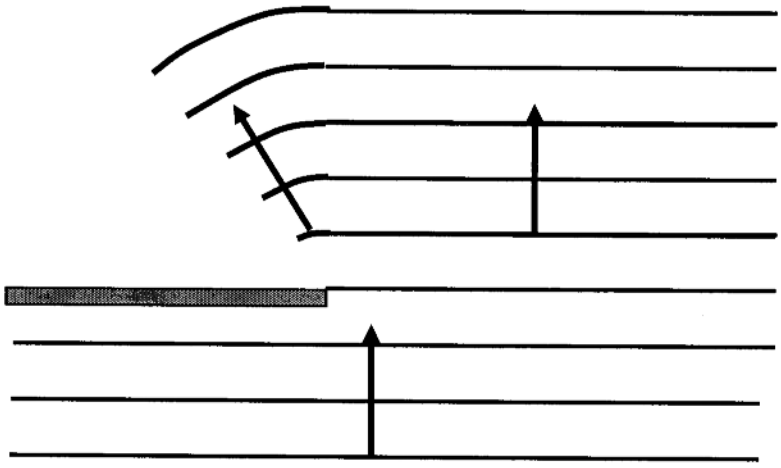
5. Draw the diffraction pattern for the following situations involving waves in a ripple tank.

Answers:

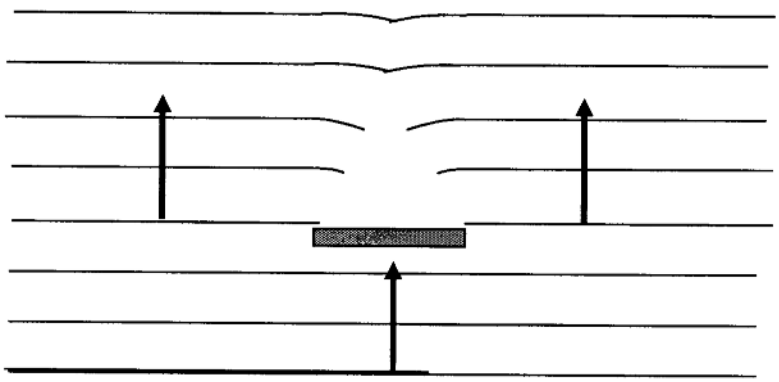
a)



b)



c)



Learning Activity 8.5: Waves in Two Dimensions—Interference: Part 1

There are two practice questions in this assignment. An answer key is available at the end of the module for you to check your answers after you have completed the practice questions.

1. What must there be where the waves from two point sources meet on the surface of the water to produce
   a) constructive interference?

      Answer: Two crests (solid lines) meet or two troughs (dotted lines) meet

   b) destructive interference?

      Answer: A crest (solid line) meets a trough (dotted line)

   c) antinode?

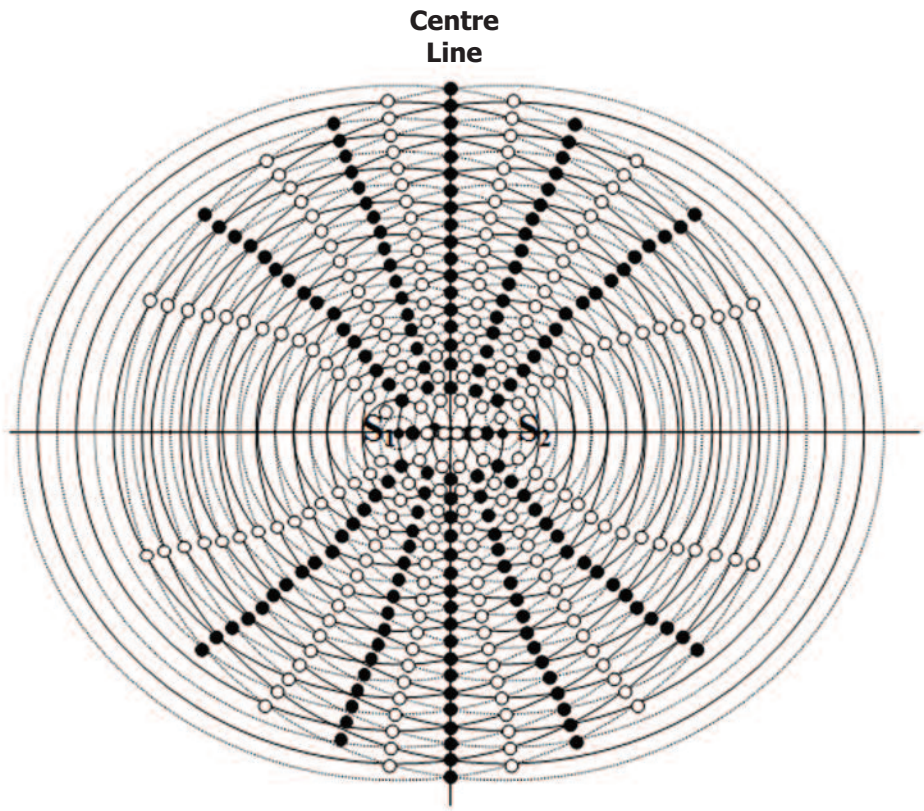
      Answer: Two crests (solid lines) meet or two troughs (dotted lines) meet

   d) node?

      Answer: A crest (solid line) meets a trough (dotted line)

2. On the pattern for two point sources given below, label source 1 as S_1 on the left side of the pattern and label source 2 as S_2 on the right side of the pattern. Draw in a horizontal line through the two sources. Find the midpoint of the line segment S_1S_2 and draw in the perpendicular bisector of this line segment. This is called the centre line. Mark in all of the nodes with an open circle and all of the antinodes with a circle that is filled in or shaded in.

   Answer:

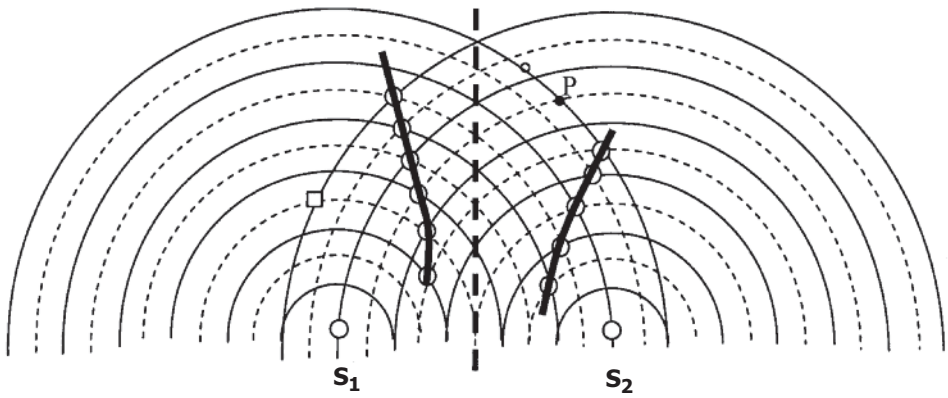


Learning Activity 8.6: Waves in Two Dimensions—Interference: Part 2

1. Two point sources are generating waves at the same frequency and phase. The pattern is shown below. The solid lines represent the crests and the dashed lines represent the troughs.

   a) Draw the second nodal line to the left and the third nodal line to the right of the perpendicular bisector.

   Answer:



   b) What kind of interference, constructive or destructive, is occurring at the location of the square?

   Answer:

   A crest and a trough meet at the square. This is destructive interference.

   c) On which nodal line would the square be located?

   Answer:

   The square is located at the fourth nodal line.

   d) What would be the distance between the square and the source S_2 if the wavelength of the waves is 4.0 cm?

   Answer:

   The square is located 6 wavelengths away from S_2. Therefore, the distance is 6(4.0 cm) = 24 cm.

e) On which nodal line is point P? What is the path length difference to the point P?

Answer:

P is on the second nodal line.

Given: Number of nodal line $n = 2$

Wavelength $\lambda = 4.0$ cm

Unknown: Path length difference PLD = ?

Equation: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

Substitute and solve: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

$$\text{PLD} = \left(2 - \frac{1}{2}\right)(4.0\text{ cm})$$

$$\text{PLD} = (1.5)(4.0\text{ cm}) = 6.0\text{ cm}$$

f) What is the path length difference to the square?

Answer:

The square is on the fourth nodal line.

Given: Number of nodal line $n = 4$

Wavelength $\lambda = 4.0$ cm

Unknown: Path length difference PLD = ?

Equation: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

Substitute and solve: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

$$\text{PLD} = \left(4 - \frac{1}{2}\right)\lambda$$

$$\text{PLD} = (3.5)(4.0\text{ cm}) = 14\text{ cm}$$

2. Two point sources are generating waves in a ripple tank, causing the waves to interfere. The two point sources are 10.0 cm apart, and the frequency of the waves is 4.00 Hz. A point on the first nodal line is located 16.0 cm away from one source and 15.0 cm away from the other.

   a) What is the wavelength of the waves?

      Answer:

      Given: Path length from S_1 to P_n $\quad P_nS_1 = 16.0$ cm

      Path length from S_2 to P_n $\quad P_nS_2 = 15.0$ cm

      Number of the nodal line $\quad n = 1$

      Unknown: Wavelength $\quad \lambda = ?$

      Equation: $$\text{PLD} = \left| P_nS_1 - P_nS_2 \right| = (n - \frac{1}{2})\lambda$$

      Substitute and solve: $$\left| P_nS_1 - P_nS_2 \right| = (n - \frac{1}{2})\lambda$$

      $$\left| 16.0 \text{ cm} - 15.0 \text{ cm} \right| = (1 - \frac{1}{2})\lambda$$

      $$\lambda = \frac{1.0 \text{ cm}}{0.5} = 2.0 \text{ cm}$$

      The wavelength is 2.0 cm.

   b) What is the speed of the waves?

      Answer:

      $v = f\lambda = (4.0 \text{ Hz})(2.0 \text{ cm}) = 8.0 \text{ cm/s}$

3. State the effect on the interference pattern for two point sources if the following changes were made:

   a) the wavelength of the waves was increased

      Answer:

      If the wavelength is increased, fewer waves fit between the two sources and there will be fewer waves in the pattern.

      Therefore, there will be fewer nodal lines and the nodal lines will be spaced farther apart.

b) the two sources were moved closer together

Answer:

If the two sources are moved closer together, fewer waves fit between the two sources and there will be fewer waves in the pattern.

Therefore, there will be fewer nodal lines and the nodal lines will be spaced farther apart.

c) the frequency of the waves was increased.

Answer:

If the frequency of the waves is increased, the wavelength will decrease. There will now be more waves between the two sources and there will be more waves in the pattern.

Therefore, the number of nodal lines will increase and the lines will be spaced more closely together.

Learning Activity 8.7: Electromagnetic Waves

1. Compare electromagnetic waves to mechanical waves. How are they alike and how are they different?

   Answer:

   Electromagnetic waves and mechanical waves are alike in that they both exhibit the usual characteristics of waves: speed, wavelength, frequency, reflection, resonance, refraction, diffraction, and interference.

   Electromagnetic waves and mechanical waves differ in that the mechanical wave requires a physical medium through which to travel while electromagnetic waves are able to travel through a vacuum.

2. How does an AM radio signal differ from an FM radio signal?

   Answer:

   Amplitude modulation radio signals operate by encoding the information in a radio signal that has a changing amplitude but a constant frequency. Frequency modulation radio signals operate by encoding the information in a radio signal that has a changing frequency but a constant amplitude.

   AM radio signals tend to have a lower frequency and larger wavelength than FM radio signals.

3. Briefly describe how the electromagnetic waves represented by radio waves demonstrate the properties of waves.

   Answer:

   Radio waves travel with a fixed speed in a given medium. Radio waves and indeed all electromagnetic waves travel at 3.00×10^8 m/s in a vacuum. Radio waves have a frequency and a wavelength that are related to the speed by the universal wave equation.

   Radio waves can bounce off large obstacles like buildings or hills. Radio waves can also bounce off part of the atmosphere called the ionosphere. This allows for the reception of radio waves far from the source.

   Radio waves are able to pass through each other, interfere, or undergo superposition, then continue on their way.

   Resonance is used in tuning your radio to receive the signal from a certain radio station. The frequency of the radio signal matches a natural frequency of the tuner, causing it to resonate.

   Radio waves are able to spread into a region in the shadow or diffract as they pass by obstacles like hills. The longer radio waves are able to diffract to a greater extent than the shorter radio waves.

Radio waves from different sources with the same frequencies will interfere. Using an electric appliance, turning on a light switch, or incidences of lightning can cause interference when the waves emitted by these events interfere with the radio waves coming from the transmission tower.

4. Within the electromagnetic spectrum, what characteristics of the waves changes from one region to another of the spectrum?

   Answer:

   The electromagnetic spectrum begins on the left with waves that have a low frequency and large wavelength. As you proceed through the electromagnetic spectrum to the right, the frequency increases and the wavelength decreases.

   Another change that occurs as the frequency increases is that the energy carried by the electromagnetic waves also increases. Radio waves carry very little energy compared to x-rays or gamma rays, which are harmful to the body.

5. How are electromagnetic waves produced?

   Answer:

   Electromagnetic waves are produced by electrons, which are pushed and pulled along a conducting rod. If the electrons are stationary, the electric field surrounding the rod will be stationary as well. If the electrons move, this causes the electric field to change. If the electrons are pulled and pushed back and forth along the conducting rod in a regular fashion, then there is a regular change in the electric field. This is how the electric component of electromagnetic waves is formed.

   However, if the electrons move back and forth, then we have a current that is moving back and forth. A current in a wire produces a magnetic field. A changing current will produce a changing magnetic field. This is how the magnetic component of electromagnetic waves is formed.

   The two components travel together as transverse waves with the electric component vibrating in one plane and the magnetic component vibrating in a perpendicular plane to the electric component.

NOTES

Grade 11 Physics (30S)

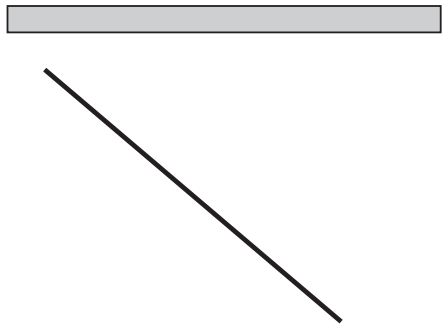
Module 8: Waves in Two Dimensions

Learning Activity Answer Keys

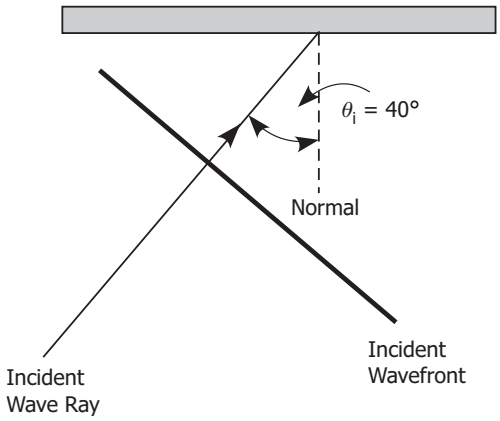
Module 8: Waves in Two Dimensions

Learning Activity 8.1: Waves in Two Dimensions—Reflection: Part 1

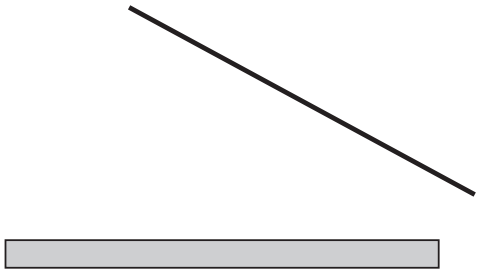
1. The diagram below shows a wavefront moving upwards to the right approaching a barrier. For this wavefront, draw in the wave ray. Extend the wave ray to the barrier and draw in a normal. What is the angle of incidence?



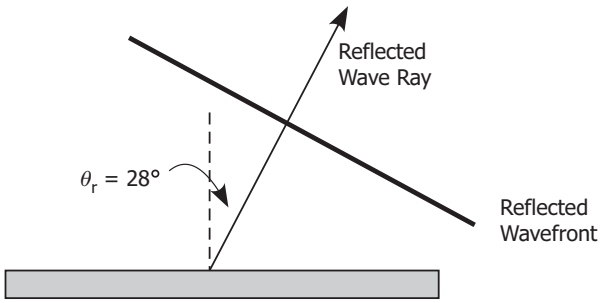
Answer:



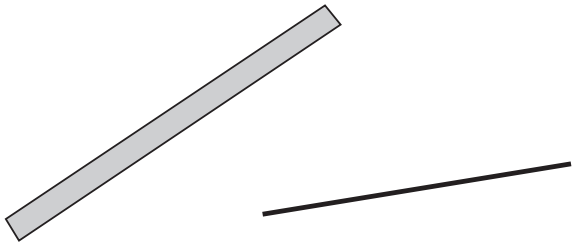
2. The diagram below shows a wavefront travelling away from a barrier (upwards to the right). For this wavefront, draw in the wave ray. Extend the wave ray to the barrier and draw in a normal. What is the angle of reflection?



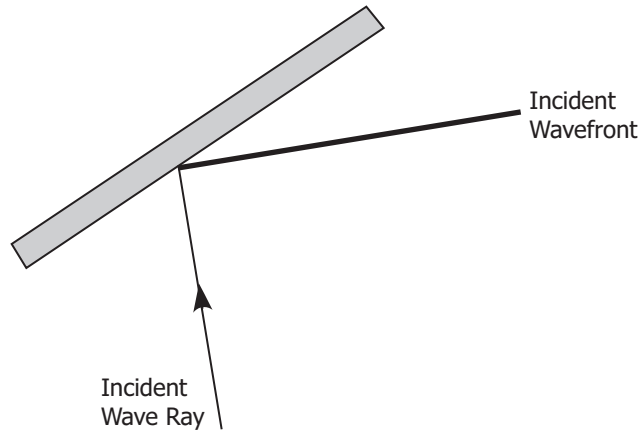
Answer:



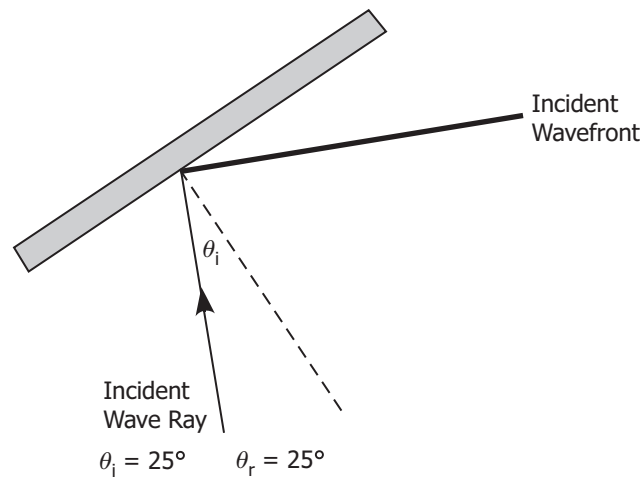
3. The diagram below shows one wavefront approaching (moving upwards to the left) a straight barrier. Using the procedure outlined above, draw in the reflected wave pulse.



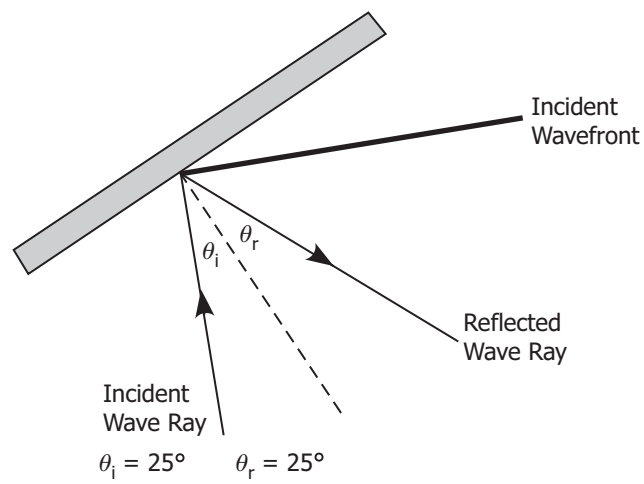
Step 1:
Draw in the incident wave ray. Extend the incident wavefront until it touches the barrier. At the point where the incident wavefront intersects the barrier, draw a wave ray for the incident wavefront. Label the incident wave ray.



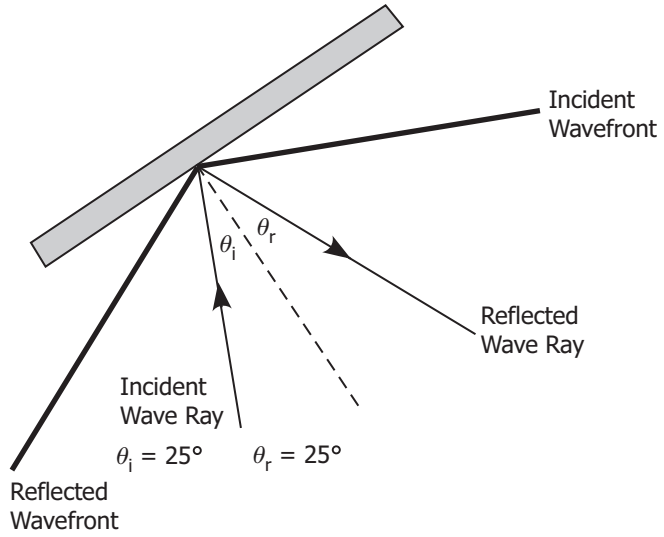
Step 2.
Draw in the angle of incidence. Draw in the normal at the point of reflection. Measure the angle of incidence and label the angle of incidence.



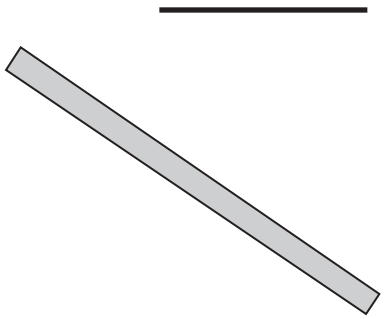
Step 3:
Draw in the reflected ray. From the normal, measure the angle of reflection at 34°. Draw in the reflected wave ray starting from the point of reflection. Label the reflected wave ray.



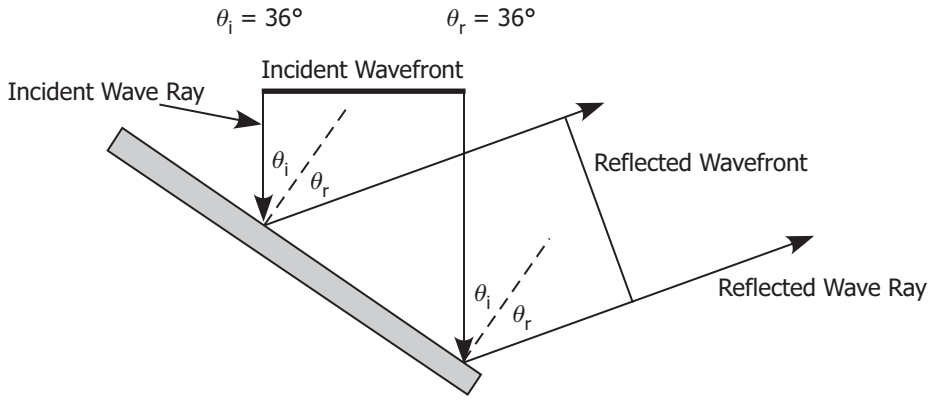
Step 4.
Draw in the reflected wavefront. At the point of reflection, draw in the reflected wavefront. This is drawn perpendicular to the reflected wave ray. Label the reflected wavefront.



4. The diagram below shows one wavefront moving downward approaching a straight barrier. Add to this diagram the following:
   a) Draw the incident wave rays from the left edge and the right edge of the wavefront.
   b) Using a dashed line, draw a normal from the point where the incident wave ray makes contact with the barrier.
   c) Draw the reflected wave rays.
   d) Draw the reflected wavefront at some point on the wave rays.
   e) What is the angle of incidence?
   f) Draw in the angle of incidence and the angle of reflection.



Answer:


θ_i = 36°
θ_r = 36°
Incident Wavefront
Incident Wave Ray
θ_i
θ_r
Reflected Wavefront
θ_i
θ_r
Reflected Wave Ray

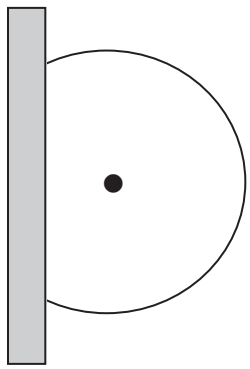
Learning Activity 8.2: Waves in Two Dimensions—Reflection: Part 2

1. Under what conditions would straight, reflected wavefronts have exactly the same size and orientation as the incident wavefronts (assuming no loss in energy)?

   Answer:

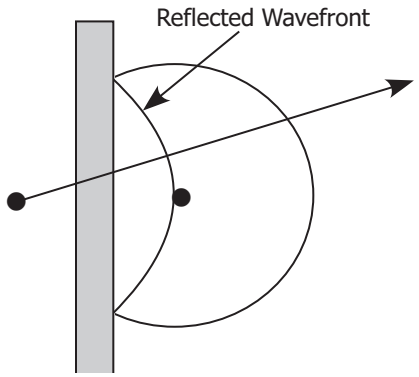
   This would occur when the incident wavefronts are approaching a straight, reflecting surface parallel to the surface.

2. The diagram below shows a circular wave approaching a barrier. The centre of the wave is shown. Draw that part of the wave that has been reflected. Also, draw a wave ray for the reflected ray from the place where the reflected wavefront seems to originate.

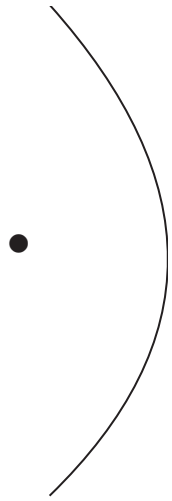


   Answer:

   The reflected pulse seems to originate from a centre point to the left of the barrier. This point is located the same distance behind the barrier as the centre of the originate wavefront in front of the barrier. The reflected wave ray is drawn from the imaginary centre away from the barrier.

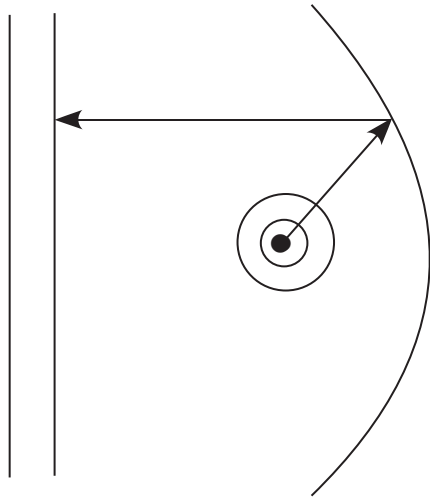


3. The diagram below shows a parabolic reflector. The focal point of the reflector is indicated by a dot. Circular pulses are generated from the dot. Draw two incident wavefronts and two reflected wavefronts. Add to the diagram an incident wave ray and a reflected wave ray.



Answer:

The diagram below shows two circular pulses approaching the parabolic reflector. One of the possible incident wave rays has its origin at the focal point. The reflected wave ray moves away from the reflector horizontally. Two wavefronts are straight and perpendicular to the wave rays.



Learning Activity 8.3: Waves in Two Dimensions—Refraction

1. A water wave in deep water has a speed of 18.0 cm/s and a wavelength of 2.00 cm. In the shallow water, the speed of the wave is 10.0 cm/s. What is the wavelength of this wave in shallow water?

   Answer:

   Let medium 1 be the deep water.

   Given: Speed in medium 1 $v_1 = 18.0$ cm/s

   Wavelength in medium 1 $\lambda_1 = 2.00$ cm

   Speed in medium 2 $v_2 = 10.0$ cm/s

   Unknown: Wavelength in medium 1 $\lambda_2 = ?$

   Equation: From Snell's law, use the part that relates speeds and wavelengths.

   $$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} \text{ rearranged to solve for } \lambda_2$$

   Substitute and solve:

   $$\lambda_2 = \frac{\lambda_1}{v_1} v_2 = \frac{(10.0 \text{ cm/s})(2.00 \text{ cm})}{18.0 \text{ cm}}$$
   $$= 1.11 \text{ cm}$$

   The wavelength in the shallow section is 1.11 cm.

2. A water wave of frequency 10.0 Hz and speed 40.0 cm/s is travelling in deep water. It then moves into shallow water where its speed is 30.0 cm/s. The angle of incidence is 30.0°. Find

   a) the wavelengths in the two media

   Answer:

   Let the deep water be medium 1.

   Given: Speed in medium 1 $v_1 = 40.0$ cm/s

   Speed in medium 2 $v_2 = 30.0$ cm/s

   Frequency $f = 10.0$ Hz

   Unknown: Wavelength in medium 1 $\lambda_1 = ?$

   Equation: Use the universal wave equation.

   $$v = f\lambda \text{ rearranged to } \lambda_1 = \frac{v_1}{f_1}$$

   Substitute and solve:

   $$\lambda_1 = \frac{v_1}{f_1} = \frac{40.0 \text{ cm/s}}{10.0 \text{ Hz}} = 4.00 \text{ cm}$$

   Unknown: Wavelength in medium 2 $\lambda_2 = ?$

Equation: Use the universal wave equation.

$$v = f\lambda \text{ rearranged to } \lambda_2 = \frac{v_2}{f_2}$$

Substitute and solve: $\lambda_2 = \frac{v_2}{f_2} = \frac{30.0 \text{ cm/s}}{10.0 \text{ Hz}} = 3.00 \text{ cm}$

The wavelength in the deep water (the incident medium) is 4.00 cm.

The wavelength in the shallow water (the refractive medium) is 3.00 cm

b) the angle of refraction in the shallow water.

Answer:

The angle of refraction is determined from Snell's Law. We can use the speeds of the waves, or the wavelengths of the waves. In this solution, we will use the speed of the waves.

Given: Speed in medium 1 $v_1 = 40.0$ cm/s

Speed in medium 2 $v_2 = 30.0$ cm/s

Angle of incidence $\theta_1 = 30.0°$

Unknown: Angle of refraction $\theta_2 = ?$

Equation: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$ rearranged to $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1}$

Substitute and solve: $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1} = \frac{(\sin 30.0°)(30.0 \text{ cm/s})}{40.0 \text{ cm/s}} = 0.375$

$$\theta_2 = \sin^{-1}(0.375) = 22.0°$$

The angle of refraction is 22.0°.

3. The velocity of a sound wave in cold air is 320 m/s and in warm air 384 m/s. Assume that the wavefront in cold air is nearly linear. What will be the angle of refraction in the warm air if the angle of incidence is 30.0° in the cold air?

Answer:

Let medium 1 be the cold air.

Given: Speed in medium 1 $v_1 = 320$ m/s

Speed in medium 2 $v_2 = 384$ m/s

Angle of incidence $\theta_1 = 30.0°$

Unknown: Angle of refraction $\theta_2 = ?$

Equation: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$ rearranged to $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1}$

Substitute and solve: $\sin\theta_2 = \frac{(\sin\theta_1)(v_2)}{v_1} = \frac{(\sin 30.0°)(384 \text{ m/s})}{320 \text{ m/s}} = 0.60$

$\theta_2 = \sin^{-1}(0.60) = 37°$

The angle of refraction in cold air is 37°.

4. An earthquake P wave travelling at 9.0 km/s strikes a boundary within the Earth between two kinds of material. If it approaches the boundary at an incident angle of 47° and the angle of refraction is 27°, what is the speed in the second medium?

Answer:

Given: Speed in medium 1 $v_1 = 9.0$ km/s

Angle of incidence $\theta_1 = 47°$

Angle of refraction $\theta_2 = 27°$

Unknown: Speed in medium 2 $v_2 = ?$

Equation: The speed in the second medium is found using Snell's Law.

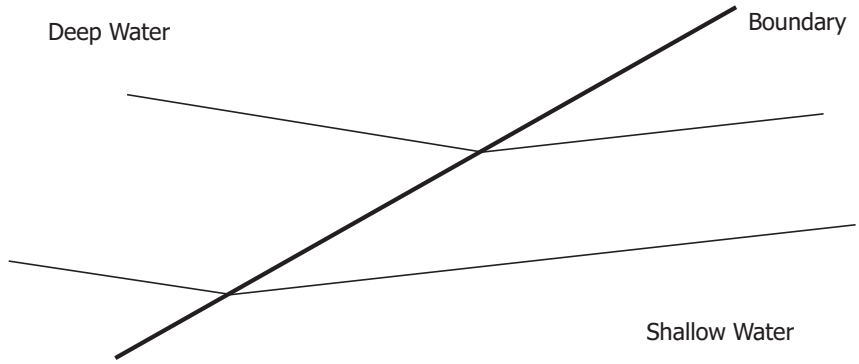
$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$ rearranged to $v_2 = \frac{v_1 \sin\theta_2}{\sin\theta_1}$

Substitute and solve: $v_2 = \frac{v_1 \sin\theta_2}{\sin\theta_1} = \frac{(9.0 \text{ km/s})\sin 27°}{\sin 47°}$

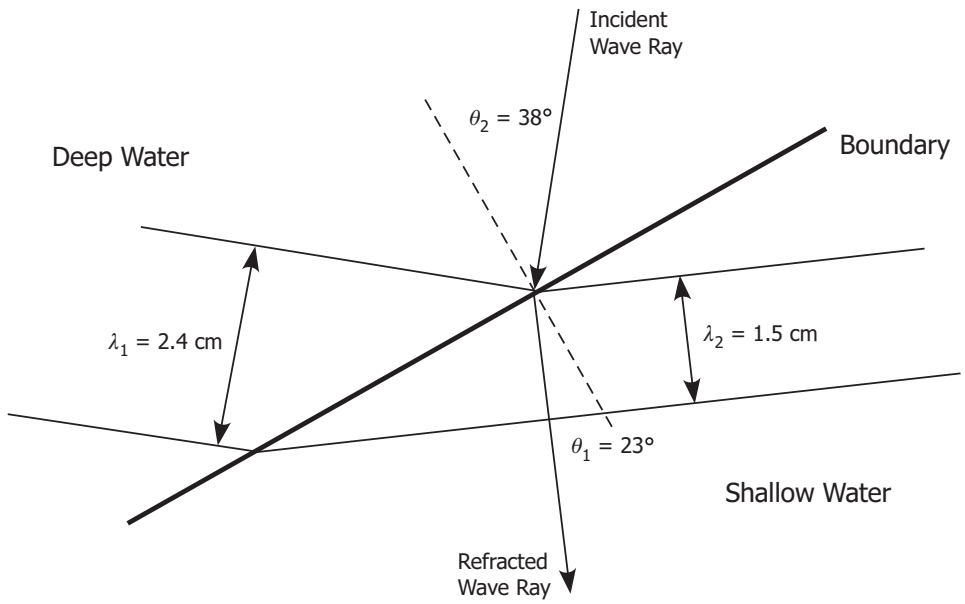
$= 5.6$ km/s

The speed of the waves in the second medium is 5.6 km/s.

5. In the diagram below, draw in the following: the incident wave ray, the normal, the angle of incidence, the refracted wave ray, and the angle of refraction. Measure and state the measurements of the wavelengths and the angles of incidence and refraction.



Answer:



6. What is refraction? What is the cause of refraction?

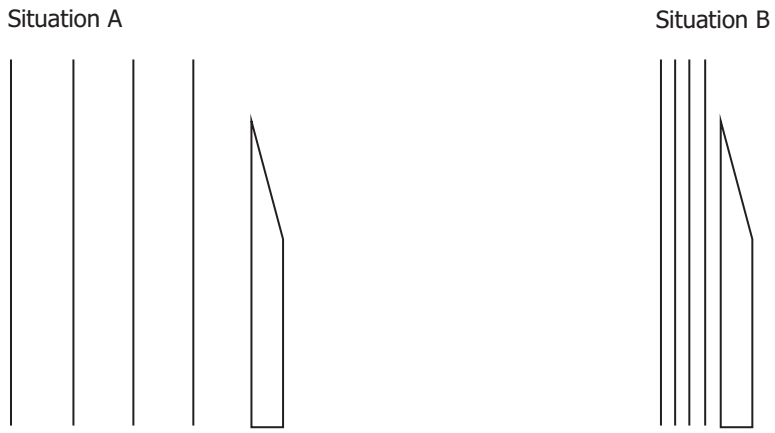
Answer:

Refraction is the bending in the path of a wave as it passes from one medium into another. The direction of the wave ray for the incident wavefront changes as the wavefront passes into the second medium.

The cause of refraction is a change in the speed of the wavefront as it passes into the second medium. If the wavefront slows down, the wave ray is bent towards the normal. If the wavefront speeds up, the wave ray is bent away from the normal.

Learning Activity 8.4: Waves in Two Dimensions—Diffraction

1. The diagram below shows two different types of water waves approaching a sharp edge. Which type of wave will show the greatest diffraction: the waves in situation A or the waves in situation B?



Answer:

The waves in situation A have a larger wavelength and will therefore show the greatest diffraction.

2. Ocean waves are approaching an opening into a harbour. The opening is 100 m wide. For which wavelength of ocean waves would there be the greater diffraction: those with a wavelength of 50 m or those with a wavelength of 200 m?

Answer:

The larger the wavelength, the greater will be the diffraction. Therefore, there will be a greater diffraction for the waves of 200 m wavelength.

3. A D note in music has a frequency of 294 Hz. A G note has a frequency of 392 Hz. If music was playing in a hallway around the corner, what frequency of sound would you most clearly hear?

Answer:

The lower frequency of sound would diffract more as it bent around a corner. Therefore, you would hear the 294 Hz sound better.

4. Light of wavelength 470 nm is blue in colour, and 610 nm light is orange. If these colours of light were to pass through a 500-nm hole, which colour of light would show the greatest diffraction?

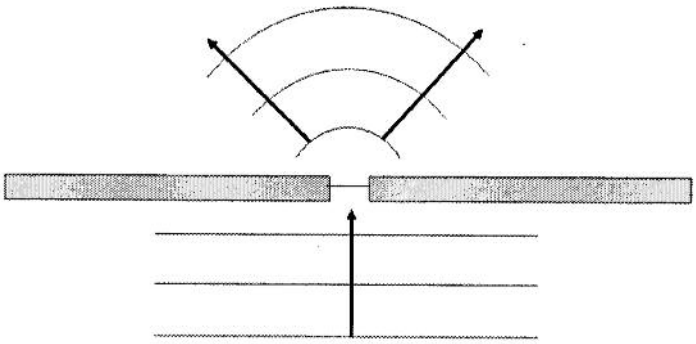
Answer:

The 610 nm light would show the greater diffraction.

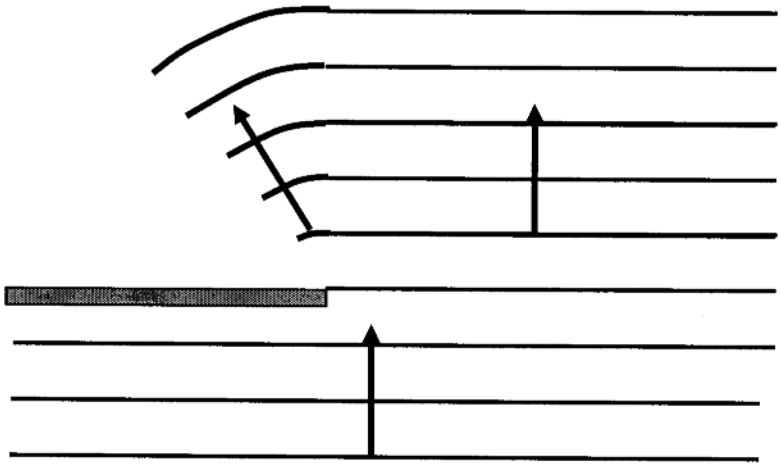
5. Draw the diffraction pattern for the following situations involving waves in a ripple tank.

Answers:

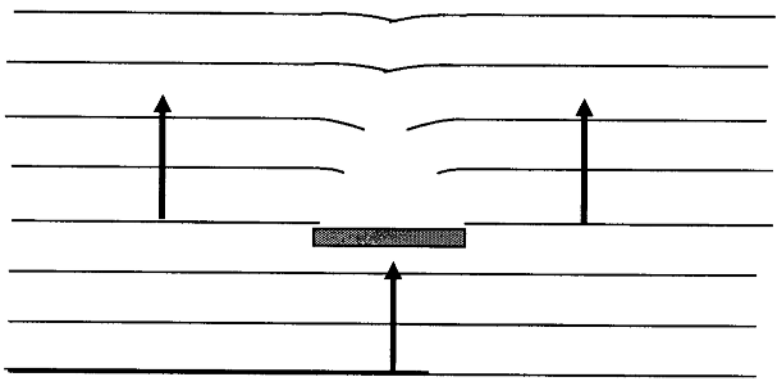
a)



b)



c)



Learning Activity 8.5: Waves in Two Dimensions—Interference: Part 1

There are two practice questions in this assignment. An answer key is available at the end of the module for you to check your answers after you have completed the practice questions.

1. What must there be where the waves from two point sources meet on the surface of the water to produce
   a) constructive interference?

      Answer: Two crests (solid lines) meet or two troughs (dotted lines) meet

   b) destructive interference?

      Answer: A crest (solid line) meets a trough (dotted line)

   c) antinode?

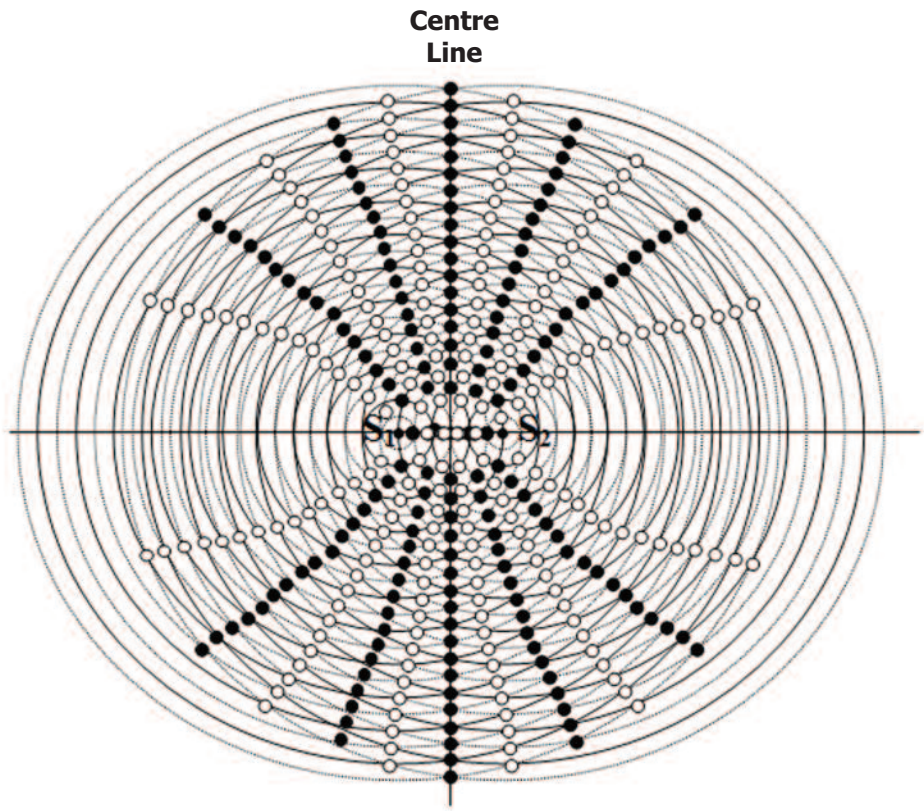
      Answer: Two crests (solid lines) meet or two troughs (dotted lines) meet

   d) node?

      Answer: A crest (solid line) meets a trough (dotted line)

2. On the pattern for two point sources given below, label source 1 as S_1 on the left side of the pattern and label source 2 as S_2 on the right side of the pattern. Draw in a horizontal line through the two sources. Find the midpoint of the line segment S_1S_2 and draw in the perpendicular bisector of this line segment. This is called the centre line. Mark in all of the nodes with an open circle and all of the antinodes with a circle that is filled in or shaded in.

   Answer:

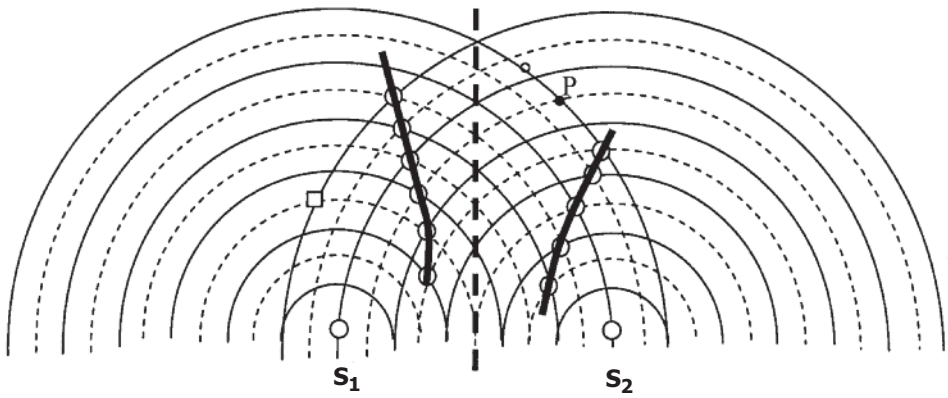


Learning Activity 8.6: Waves in Two Dimensions—Interference: Part 2

1. Two point sources are generating waves at the same frequency and phase. The pattern is shown below. The solid lines represent the crests and the dashed lines represent the troughs.

   a) Draw the second nodal line to the left and the third nodal line to the right of the perpendicular bisector.

   Answer:



   b) What kind of interference, constructive or destructive, is occurring at the location of the square?

   Answer:

   A crest and a trough meet at the square. This is destructive interference.

   c) On which nodal line would the square be located?

   Answer:

   The square is located at the fourth nodal line.

   d) What would be the distance between the square and the source S_2 if the wavelength of the waves is 4.0 cm?

   Answer:

   The square is located 6 wavelengths away from S_2. Therefore, the distance is 6(4.0 cm) = 24 cm.

e) On which nodal line is point P? What is the path length difference to the point P?

Answer:

P is on the second nodal line.

Given: Number of nodal line $n = 2$

Wavelength $\lambda = 4.0$ cm

Unknown: Path length difference PLD = ?

Equation: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

Substitute and solve: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

$$\text{PLD} = \left(2 - \frac{1}{2}\right)(4.0\text{ cm})$$

$$\text{PLD} = (1.5)(4.0\text{ cm}) = 6.0\text{ cm}$$

f) What is the path length difference to the square?

Answer:

The square is on the fourth nodal line.

Given: Number of nodal line $n = 4$

Wavelength $\lambda = 4.0$ cm

Unknown: Path length difference PLD = ?

Equation: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

Substitute and solve: $$\text{PLD} = \left(n - \frac{1}{2}\right)\lambda$$

$$\text{PLD} = \left(4 - \frac{1}{2}\right)\lambda$$

$$\text{PLD} = (3.5)(4.0\text{ cm}) = 14\text{ cm}$$

2. Two point sources are generating waves in a ripple tank, causing the waves to interfere. The two point sources are 10.0 cm apart, and the frequency of the waves is 4.00 Hz. A point on the first nodal line is located 16.0 cm away from one source and 15.0 cm away from the other.

   a) What is the wavelength of the waves?

      Answer:

      Given: Path length from S_1 to P_n $\quad P_nS_1 = 16.0$ cm

      Path length from S_2 to P_n $\quad P_nS_2 = 15.0$ cm

      Number of the nodal line $\quad n = 1$

      Unknown: Wavelength $\quad \lambda = ?$

      Equation: $$\text{PLD} = \left| P_nS_1 - P_nS_2 \right| = (n - \frac{1}{2})\lambda$$

      Substitute and solve: $$\left| P_nS_1 - P_nS_2 \right| = (n - \frac{1}{2})\lambda$$

      $$\left| 16.0 \text{ cm} - 15.0 \text{ cm} \right| = (1 - \frac{1}{2})\lambda$$

      $$\lambda = \frac{1.0 \text{ cm}}{0.5} = 2.0 \text{ cm}$$

      The wavelength is 2.0 cm.

   b) What is the speed of the waves?

      Answer:

      $v = f\lambda = (4.0 \text{ Hz})(2.0 \text{ cm}) = 8.0 \text{ cm/s}$

3. State the effect on the interference pattern for two point sources if the following changes were made:

   a) the wavelength of the waves was increased

      Answer:

      If the wavelength is increased, fewer waves fit between the two sources and there will be fewer waves in the pattern.

      Therefore, there will be fewer nodal lines and the nodal lines will be spaced farther apart.

b) the two sources were moved closer together

Answer:

If the two sources are moved closer together, fewer waves fit between the two sources and there will be fewer waves in the pattern.

Therefore, there will be fewer nodal lines and the nodal lines will be spaced farther apart.

c) the frequency of the waves was increased.

Answer:

If the frequency of the waves is increased, the wavelength will decrease. There will now be more waves between the two sources and there will be more waves in the pattern.

Therefore, the number of nodal lines will increase and the lines will be spaced more closely together.

Learning Activity 8.7: Electromagnetic Waves

1. Compare electromagnetic waves to mechanical waves. How are they alike and how are they different?

   Answer:

   Electromagnetic waves and mechanical waves are alike in that they both exhibit the usual characteristics of waves: speed, wavelength, frequency, reflection, resonance, refraction, diffraction, and interference.

   Electromagnetic waves and mechanical waves differ in that the mechanical wave requires a physical medium through which to travel while electromagnetic waves are able to travel through a vacuum.

2. How does an AM radio signal differ from an FM radio signal?

   Answer:

   Amplitude modulation radio signals operate by encoding the information in a radio signal that has a changing amplitude but a constant frequency. Frequency modulation radio signals operate by encoding the information in a radio signal that has a changing frequency but a constant amplitude.

   AM radio signals tend to have a lower frequency and larger wavelength than FM radio signals.

3. Briefly describe how the electromagnetic waves represented by radio waves demonstrate the properties of waves.

   Answer:

   Radio waves travel with a fixed speed in a given medium. Radio waves and indeed all electromagnetic waves travel at 3.00×10^8 m/s in a vacuum. Radio waves have a frequency and a wavelength that are related to the speed by the universal wave equation.

   Radio waves can bounce off large obstacles like buildings or hills. Radio waves can also bounce off part of the atmosphere called the ionosphere. This allows for the reception of radio waves far from the source.

   Radio waves are able to pass through each other, interfere, or undergo superposition, then continue on their way.

   Resonance is used in tuning your radio to receive the signal from a certain radio station. The frequency of the radio signal matches a natural frequency of the tuner, causing it to resonate.

   Radio waves are able to spread into a region in the shadow or diffract as they pass by obstacles like hills. The longer radio waves are able to diffract to a greater extent than the shorter radio waves.

Radio waves from different sources with the same frequencies will interfere. Using an electric appliance, turning on a light switch, or incidences of lightning can cause interference when the waves emitted by these events interfere with the radio waves coming from the transmission tower.

4. Within the electromagnetic spectrum, what characteristics of the waves changes from one region to another of the spectrum?

   Answer:

   The electromagnetic spectrum begins on the left with waves that have a low frequency and large wavelength. As you proceed through the electromagnetic spectrum to the right, the frequency increases and the wavelength decreases.

   Another change that occurs as the frequency increases is that the energy carried by the electromagnetic waves also increases. Radio waves carry very little energy compared to x-rays or gamma rays, which are harmful to the body.

5. How are electromagnetic waves produced?

   Answer:

   Electromagnetic waves are produced by electrons, which are pushed and pulled along a conducting rod. If the electrons are stationary, the electric field surrounding the rod will be stationary as well. If the electrons move, this causes the electric field to change. If the electrons are pulled and pushed back and forth along the conducting rod in a regular fashion, then there is a regular change in the electric field. This is how the electric component of electromagnetic waves is formed.

   However, if the electrons move back and forth, then we have a current that is moving back and forth. A current in a wire produces a magnetic field. A changing current will produce a changing magnetic field. This is how the magnetic component of electromagnetic waves is formed.

   The two components travel together as transverse waves with the electric component vibrating in one plane and the magnetic component vibrating in a perpendicular plane to the electric component.

NOTES

Topic 3 - Audio/Videos

Module 8

1. Waves in 2d Includes basic reflection
    a. This video presents an introduction to waves in two dimensions on the surface of water.
    b. A point source is shown to generate circular waves. The waves on the diagram are represented by lines. The lines would represent the crests on the surface of the water. In a ripple tank pattern the wave crests appear as bright lines.
    c. The space between two lines or crests would be a trough. A trough appears as a dark line in a ripple tank pattern.
    d. A point source generates circular waves. The circular lines that represent the waves are called wave fronts. The wave front is the crest moving along the surface of the water.
    e. To show the direction of motion of a point on the wave front we use arrows called wave rays. Wave rays are drawn perpendicularly to the wave front at the point in question. A wave ray and wave fronts form a 90° angle.
    f. A circular wave has each point of the wave front starting at the source and moving away from the source. The motion of a particular wave front is an ever expanding circle.
    g. The narrator then shifts to describing how straight or planar waves travel across the surface of the water. These wave fronts are produced by a straight source, like a ruler, dipping into the water. Again the wave front has a direction of motion given by the wave ray drawn perpendicularly to the wave front at each point on the wave front. In a uniform medium all of the points on the wave front travel at the same speed and in the same direction so the straight wave front remains straight as it travels.
    h. If these straight wave fronts are incident unto a barrier the wave fronts reflect (bounce off) the barrier. A diagram of wave rays is used to plot the path of the wave rays using the law of reflection. The direction of the incident wave ray is measured from the normal to the surface of the barrier to form the angle of incidence. The angle of reflection is equal to the angle of incidence. The angle of reflection is measured from the normal to the surface to the reflected wave ray. Once the reflected wave ray is drawn on the diagram, then reflected wave fronts are drawn perpendicularly to the reflected wave ray.
    i. Finally a photograph of straight wave fronts reflected from a straight barrier is analyzed to illustrate the law of reflection for actual waves on the water's surface in a ripple tank.
2. Ripple Tank Simulation - Circular Waves
    a. This website contains a virtual ripple tank.
    b. On the left side is a green area which represents the surface of a ripple tank.
    c. On the right side are found several popups. The top popup selects the type of source. If you click on the arrow a list of possible sources will appear.
    d. The second popup sets the Waves = Sound. Leave this one as is.

e. The third popup sets the color scheme. Use Color Scheme 1.
f. The next button Clear Waves will clear all the waves and structures in the ripple tank. Always start with a blank ripple tank.
g. The next selection is Stopped. At the start have this set to Stopped. Once you have selected the Source and other structures like barriers, you begin the simulation by unchecking Stopped.
h. For the sliders the only one you might change will be the Frequency of the waves.
i. Circular Waves I
j. Generating a single circular wave front.
k. Select "Single Source", clear any waves and select "STOPPED".
l. Right click on the single source at the top of the ripple tank. Delete this point source.
m. Then move the cursor to the centre of the ripple tank and left click. This will generate a single circular wave which starts and travels away from the point that you clicked on with the cursor.
n. Circular Waves II
o. Generating a periodic circular wave.
p. For this simulation select "Single Source".
q. If the simulation does not react, uncheck Stopped. You may also have to select a different example and then "Single Source".
r. Observe the motion of circular wave fronts. Identify the wave fronts and remember that the wave rays begin at the point source and radiated outwards.
s. Circular Waves III
t. Clear the waves and check Stopped.
u. Right click on the point source at the top of the ripple tank and select DELETE from the menu. This will delete the point source.
v. On the menu bar at the top of the ripple tank, click on ADD.
w. From the menu that appears select "Add point source". A dot should appear in the ripple tank.
x. Uncheck Stopped to run the simulation which now shows the completed circular pattern of waves that are formed.

3. Ripple Tank Simulation - Straight Waves
   a. This simulation will produce a straight wave front on the surface of the water in the ripple tank.
   b. Clear Waves and check STOPPED.
   c. From the first popup select Example:Plane Wave.
   d. Uncheck STOPPED. A train of straight waves will travel form the top to the bottom of the ripple tank.
   e. Imagine the wave rays drawn perpendicularly to the wave fronts. All of these will be parallel to each other and pointing towards the bottom of the page.
   f. Check STOPPED. Slide the FREQUENCY bar to the right to increase the frequency. Uncheck STOPPED and compare the wavelength of the high frequency waves to the wavelength of the low frequency waves.

4. Ripple Tank Simulation - Reflection of Circular Waves from a Straight Barrier
    a. Start with an empty ripple tank.
    b. Set the first popup to "Single Source". Clear Waves and check STOPPED.
    c. If the single point source is creating waves, right click on the point source and from the menu click on "DELETE". This will delete the point source.
    d. Go to ADD and select "ADD WALL". Drag the ends of the wall to position the wall about 2/3 of the way down the page and parallel to the bottom of the page. The wall should extend completely across the ripple tank.
    e. Place your cursor about 4 cm above the wall and left click. Uncheck "STOPPED".
    f. A single circular pulse will be generated. Observe how it reflects from the straight barrier. Where does the reflected circular pulse originate?
    g. To check this run the simulation again. Stop the simulation after the incident pulse has reflected
5. Ripple Tank Simulation – Reflection of Circular Waves from a Circular Barrier
    a. CLEAR all waves and check STOPPED.
    b. In the first popup select "Example: Circle:.
    c. Uncheck STOPPED. The simulation will show a circular wave starting at the centre of a circular barrier.
    d. Observe the reflection of the wave front from the barrier and watch it travel back to the source. The wave front passes through the centre of the circle and continues to repeat the motion.
6. Ripple Tank Simulation – Reflection of Straight Waves from a Parabolic Barrier
    a. CLEAR all waves and check STOPPED.
    b. In the first popup select "Example: Parabolic Mirror 2".
    c. Uncheck STOPPED. A circular wave is generated at the focus of the parabolic barrier. The circular wave travels outwards from the source, reflects from the parabolic barrier and then becomes a straight wave traveling away from the parabolic reflector with the wave ray pointing along the axis of the parabolic reflector.
    d. The last two simulations are just the opposite of each other.
    e. In **Reflection of Straight Waves from a Parabolic Barrier** a straight wave is traveling towards the parabolic barrier with the wave ray pointing towards the parabolic barrier along the axis of the parabolic barrier. All of the points on the straight wave reflect and meet at the focus.
    f. In **A Circular Wave Generated at the Focal Point of a Parabolic Barrier Reflects from the Barrier** a circular wave front starts at the focus of the parabolic barrier. Each point on the part of the circular wave front that travels towards the parabolic barrier reflects from the barrier and travels away from the barrier moving with wave rays that point along the principal axis of the parabolic barrier. All of the points join up to form a straight wave front traveling parallel to the principal axis of the parabolic barrier.
7. Huygen's Principle - Reflection & Refraction

a. This applet shows the reflection and refraction of wave fronts using Huygen's Principle.
b. In the text box found in the upper right hand corner of the applet select "Refraction".
c. The angle of incidence is set to 45 degrees.
d. Click/tap at the left edge to change the mode (single wavefront/multiple wavefronts). Set the mode to multiple wave fronts.
e. Start the applet.
f. Wave fronts will descend towards the barrier along the blue section on the left. The moving white lines are the incident wave fronts. The line along the middle of the blue section represents the wave ray for the incident wave fronts.
g. At the boundary between two different media each point represents a point source.
h. When a part of the incident wave front strikes a point that point generates a circular wave in the second medium. A circular wave is generated by each point source in succession as the incident wave front strikes it.
i. These circular waves again combine to form the refracted wave front which is now traveling in the second medium.
j. The wave ray in the second medium for these refracted wave fronts no longer points in the same direction as the incident wave ray. The path of the wave fronts has been changed, bent towards the normal to the boundary in the second medium.
k. The angle of incidence is smaller than the angle of refraction in the second medium.
l. Things to notice.
m. The wave fronts travel faster in medium 1.
n. You can see that the wave fronts are separated by a distance equal to their wavelength. Since the speed of the wave fronts is larger in medium 1 and the frequency of the wave fronts is the same in both media it follows that the wavelength in medium 1 must be larger than the wavelengths in medium 2.
o. Change the angle of incidence and repeat the refraction of the waves. The angle of refraction in medium 2 is always smaller than the angle of incidence and the refracted wave ray is bent towards the normal.

8. Geophysics: Lecture 2. Wave Theory, refraction and reflection
    a. (Start the video at 22:20. The section on Wave Propagation ends at 26:04.)
    b. This part of the video deals with the propagation of waves according to Huygen's Principle.
    c. Understanding how waves propagate or reproduce themselves will also help you understand how the reflection of waves occurs as a waves strikes a barrier and how waves refract as they pass through the boundary or interface between two different media.
9. All the circular wave fronts generated by the point sources combine to form .Huygen's Principle - Reflection & Refraction

a. This applet shows the reflection and refraction of wave fronts using Huygen's Principle.
b. In the text box found in the upper right hand corner of the applet select "Reflection".
c. The angle is set to 45 degrees.
d. Click/tap at the left edge to change the mode (single wavefront/multiple wavefronts). Set the mode to single wave front.
e. Start the applet.
f. Wave fronts will descend towards the barrier along the blue section on the left. The moving white line is the incident wave front. The line along the middle of the blue section represents the wave ray for the incident wave front.
g. At the boundary each yellow point represents a point source.
h. When a part of the incident wave front strikes a yellow point that yellow point generates a circular wave. A circular wave is generated by each yellow point source in succession as the incident wave front strikes it.
i. The circular waves generated have different sizes. The first yellow point struck has the largest circular wave front. The last yellow point source struck has the smallest circular wave front.
j. All the circular wave fronts generated by the point sources combine to form the reflected wave front.
k. This reflected wave front travels up to the right.
l. The line along the centre of the right blue section represents the wave ray for the reflected wave fronts.
m. The angle of incidence will equal the angle of reflection.
n. Change the angle of incidence to 30 degrees and observe. What is the angle of reflection?
o. Change the angle of incidence to 60 degrees and observe. What is the angle of reflection?

10. PHet Simulation - Refraction - Bending Light
    a. This simulation illustrates refraction, the bending of the path of light as the ray passes from one medium into a second medium.
    b. Be sure the simulation selected is INTRO. You will see two different media represented by 2 layers of different colours. The line between the two media is the boundary or interface.
    c. Each media has a control box which is used to set the substance that is that media. If you click on the button next to MATERIAL you can select the material for the upper medium. There is a similar control to select the material for the lower level.
    d. There is a light source in the upper medium (medium 1). You can set the angle of incidence by moving this light source.
    e. In medium 1 has another control which selects whether the light is given as a wave ray or as waves.

f. In the lower left hand side in found a tool box. You will be using the protractor which can be moved by clicking in the protractor and dragging it to a new location.

g. Trial I: Measuring the Angle of Incidence, the angle of reflection and the angle of refraction.

h. Choose air for medium 1. Use RAY for the light. Choose water for medium 2. Move the light source about midway between the normal and the boundary.

i. Click and drag the protractor and position it so that the crosshairs are at the intersection of the normal and the boundary.

j. Measure each of the angle of incidence, angle of reflection and the angle of refraction.

k. Check the index of refraction for medium 1 and compare the size of the index of refraction to the size of the angle of incidence. Compare the index of refraction for medium 2 to the size of the angle of refraction.

l. Trial II: Measuring the Angle of Incidence, the angle of reflection and the angle of refraction.

m. Repeat the simulation in trial 1. Change only the upper medium to water and the lower medium to air.

n. Trail III: Comparing the Speed of the Waves and Wavelength for Each Medium to the Index of Refraction

o. Set the simulation to the same parameters as Trial I except select WAVE instead of RAY.

p. This time focus on the speed of the wave in each medium. Compare the speed of the wave in medium I to the index of refraction for medium I. Repeat this for medium 2.

q. Next focus on the wavelength in each medium. Compare the wavelength in medium I to the index of refraction for medium I. Repeat this for medium 2.

r. Complete this chart. Enter Large or Small in the empty cells.

Index of Refraction	Angle Size	Speed	Wavelength
Large			
Small			

s. A useful way of remembering the speed and direction changes of light during refraction is **'FAST': Faster - Away / Slower - Towards**.

11. AP Physics 1: Waves 7: Refraction 2: 2-Dimensional Waves and the Law of Refraction
12. Lesson 54: Snell's Law

a. This webpage makes use of Snell's Law in the form

$$\frac{\sin\theta_1}{\sin\theta_2}=\frac{n_2}{n_1}=\frac{\lambda_1}{\lambda_2}=\frac{v_1}{v_2}$$

b. where θ = angle measured from normal
c. n = index of refraction for medium
d. λ = wavelength of light
e. v = velocity of light.
f. These terms are defined. The index of refraction is a new term found in the video lab in this lesson.
g. Three problems are presented. Each problem is solved. The solution is accompanied with an explanation of the strategy to use.

13. Grade 11 Physics Track 5 Snell's Law Part A Mod 8 A8.2
14. Ripple Tank Simulation – Diffraction I
    a. Diffraction I : Low Frequency (Large Wavelength) Waves Passing by the Edge of a Barrier
    b. CLEAR all waves and check STOPPED.
    c. In the first popup select "Example: Half Plane".
    d. Set the frequency to a low value by sliding the control to a spot near the left end of the slider.
    e. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) near the top of the ripple tank.
    f. The part of the wave that hits the barrier will reflect and travel back towards the top of the ripple tank, interfere with the incoming waves and form a standing wave.
    g. The part of the wave that misses the barrier continues to travel towards the bottom of the ripple tank.
    h. However the waves that passed by the edge of the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
    i. The bending of the wave fronts as they pass by the edge of a straight barrier is called **diffraction**.
15. Ripple Tank Simulation – Diffraction II
    a. Diffraction II: High Frequency (Small Wavelength) Waves Passing by the Edge of a Barrier
16. CLEAR all waves and check STOPPED.
    a. In the first popup select "Example: Half Plane".
    b. Set the frequency to a high value by sliding the frequency control to a spot near the right end of the slider.
    c. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) near the top of the ripple tank.
    d. The waves that passed by the edge of the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.

e. The bending of the wave fronts as they pass by the edge of a straight barrier is called **diffraction**.
   f. Compare the amount of diffraction for low frequency (large wavelength) waves to that of high frequency (small wavelength) waves.

17. Ripple Tank Simulation: Diffraction III
   a. Diffraction III: High Frequency (Small Wavelength) Waves Passing Around the Edges of a Barrier

18. CLEAR all waves and check STOPPED.
   a. In the first popup select "Example: Half Plane".
   b. Set the frequency to a high value by sliding the control to a spot near the right end of the slider.
   c. Click on the barrier and drag the barrier to the centre of the ripple tank. CLEAR all waves if necessary.
   d. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) in the middle of the ripple tank.
   e. The waves that missed the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
   f. The bending of the wave fronts as they pass by the edge of a straight barrier is called diffraction.
   g. Note the extent of the **diffraction**.

19. Ripple Tank Simulation - Diffraction IV
   a. Diffraction IV: Low Frequency (Large Wavelength) Waves Passing Around the Edges of a Barrier
   b. CLEAR all waves and check STOPPED.
   c. In the first popup select "Example: Half Plane".
   d. Set the frequency to a low value by sliding the control to a spot near the left end of the slider.
   e. Click on the barrier and drag the barrier to the centre of the ripple tank. CLEAR all waves if necessary.
   f. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) in the middle of the ripple tank.
   g. The waves that missed the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
   h. The bending of the wave fronts as they pass by the edge of a straight barrier is called **diffraction**.
   i. Note the extent of the diffraction.
   j. Compare the amount of diffraction for low frequency (large wavelength) waves to that of high frequency (small wavelength) waves.

20. Ripple Tank Simulation - Diffraction V
   a. Diffraction V: Low Frequency (Large Wavelength) Waves Passing Through an Opening in a Barrier
   b. CLEAR all waves and check STOPPED.

c. In the first popup select "Example: Half Plane".
d. Set the frequency to a low value by sliding the control to a spot near the left end of the slider.
e. Click on the barrier and drag the barrier down to the centre of the ripple tank. CLEAR all waves if necessary.
f. Right click on the surface of the ripple tank. In the menu that pops up select ADD WALL. A short wall with controls on each end will pop up in the ripple tank. Click on one of the end controls and stretch the wall so that it is about the same size as the original barrier.
g. Click on this wall and move it next and parallel to the first wall so that the two walls form one horizontal line. Separate the walls by about 0.5 cm.
h. CLEAR all waves if necessary.
i. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank.
j. Some parts of the wave will travel through the opening in the barrier, begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
k. The bending of the wave fronts as they pass through an opening in a straight barrier is called **diffraction**.
l. Note the extent of the diffraction.
m. CLEAR all waves and select STOPPED.
n. Move one of the barriers to create an opening of about 1 cm then run the simulation.
o. Repeat the steps above using openings of 1.5 cm, 2.0 cm, and 4 cm.
p. Compare the amount of diffraction as the width of the opening in the barrier increases.
q. Extension: Repeat the simulation using high frequency waves with short wavelengths.

21. Interference of Waves | Superposition and Interference in light and water waves | Physics
22. Ripple Tank
    a. Interference 1: Setting Up the Ripple Tank for the Interference of Waves from 2 Point Sources
    b. CLEAR all waves and check STOPPED.
    c. In the first popup select "Example: Two Sources". Two point sources will appear in the middle of the ripple tank. Drag each source up to the top of the ripple tank and place the point sources about 2 cm apart.
    d. Using the “SOURCE FREQUENCY’ slider set the frequency to a low value by sliding the control to a spot under the letter “F” near the left end of the slider.
    e. Using the BRIGHTNESS slider set the brightness slider to a position about ¾ of the way to the right.
    f. If necessary CLEAR all waves.
    g. Uncheck STOPPED.

h. Circular waves begin to travel form each source. These circular waves interfere. There are points where crests from source 1 meet troughs from source 2. This results in destructive interference. The crest and the trough cancel out and a node results. A node appears as the same color as the undisturbed medium.
i. In the pattern the nodes appear to form a line (nodal line) that becomes straight at a great distance from the sources.
j. In other places a crest from source 1 meets a crest from source 2 to form a larger, double crest. This appears as a bright area in the pattern. Also a trough from source 1 meets a trough from source 2 to form a larger, double trough. This appears as dark area in the pattern. This results in constructive interference. Where constructive interference occurs a line of antinodes appears in the pattern.
k. If you image the perpendicular bisector of the line joining the 2 sources, S1S2, you will notice that a line of antinodes lies on the perpendicular bisector of S1S2. This line of antinodes lies between 2 nodal lines.
l. We number the nodal lines in a quadrant starting from the perpendicular bisector of S1S2 . The first nodal line to the right of the perpendicular bisector of S1S2 is n=1.
m. Count the number of nodal lines in the right hand quadrant.

23. Interference II
    a. Use the same setup as in Interference I.
    b. Use the cursor to drag the right hand source horizontally by 2 cm to double the separation of the source.
    c. If necessary CLEAR all waves.
    d. Uncheck STOPPED.
    e. Again count the number of nodal lines in the right hand quadrant.
    f. Check STOPPED and CLEAR all waves.
    g. Move the right hand source horizontally a further 2cm.
    h. Uncheck STOPPED.
    i. Again count the number of nodal lines in the right hand quadrant.
    j. What is the effect of increasing the separation of the point sources on the number of nodal lines in a given quadrant?
24. Interference III
    a. Use the same setup as in Interference I.
    b. Using the “SOURCE FREQUENCY’ slider set the frequency to a low value by sliding the control to a spot under the letter “F” near the left end of the slider.
    c. If necessary CLEAR all waves.
    d. Uncheck STOPPED.
    e. Again count the number of nodal lines in the right hand quadrant.
    f. Check STOPPED and CLEAR all waves.
    g. Using the “SOURCE FREQUENCY’ slider set the frequency to a higher value by sliding the control to a spot under the letter “q”.
    h. Uncheck STOPPED.
    i. Again count the number of nodal lines in the right hand quadrant.
    j. Check STOPPED and CLEAR all waves.

k. Using the “SOURCE FREQUENCY’ slider set the frequency to a higher value by sliding the control to a spot under the letter “c”.
l. Uncheck STOPPED.
m. Again count the number of nodal lines in the right hand quadrant.
n. What is the effect of increasing the frequency and this decreasing the wavelengths of the waves produced by the point sources on the number of nodal lines in a given quadrant?

25. Interference IV
    a. The 2 sources in the first 3 simulations had the 2 sources generating waves fronts in phase. This means that the two point sources generate crests at the same time. They also generated troughs at the same time.
    b. You will adjust the phase of one of the sources in this new simulation to have the two sources generate waves out of phase. Source 1 and source 2 will make their crests at different times.
    c. So the question is how does changing the phase delay between 2 sources affect the pattern of nodal lines?
    d. Once the applet opens you must then open a different version of the applet.
    e. Below the ripple tank window scroll down 6 lines to this line: This is the WebGL version. You can also still access the old javascript version, and the even older Java Version.
    f. Click on javascript version. This will open a slightly different applet where you will be able to change the phase of the sources.
    g. Adjust the parameters as follow.
    h. Move the 2 sources to the top of the ripple tank and place them about 3 cm apart.
    i. Set the top line to SETUP: Two Sources
    j. Set the second line to 2Scr, 1Freq
    k. CLEAR waves if necessary.
    l. Move the PHASE DIFFERENCE slider completely to the left. This gives a phase delay of 0 which means the two sources make crests at the same time.
    m. Run the simulation and note the position of the first nodal line relative to the perpendicular bisector of S1S2.
    n. Stop the simulation by checking STOPPED.
    o. CLEAR the waves.
    p. Change only the phase delay by sliding the slider halfway across to the right. This setting has source 1 generating a crest. Then one quarter of a period later source 2 generates a crest. The crest from source 1 has traveled ¼ of a wavelength before the crest is generated by source 2.
    q. Note the position of the first nodal line relative to the position of the perpendicular bisector.
    r. Stop the simulation by checking STOPPED.
    s. CLEAR the waves.
    t. Change only the phase delay by sliding the slider all the way across to the right. This setting has source 1 generating a crest. Then one half of a period later

source 2 generates a crest. The crest from source 1 has traveled ½ of a wavelength before the crest is generated by source 2.

u. Note the position of the first nodal line relative to the position of the perpendicular bisector.
v. What is the effect of changing the phase delay on the positions of the nodal lines and the lines of antinodes in the interference patterns?

26. Wave interference | Mechanical waves and sound | Physics | Khan Academy
27. Introduction to Electromagnetic Waves
    a. This video has a nice review of wave basics: wavelength, frequency, and speed. These of course are related by the Universal Wave Equation: $v = f\lambda$. In the video c is used as the symbol for speed instead of v.
    b. The video introduces a new equation: energy of a wave = constant x frequency. Symbolically the equation is $E = hf$.
    c. The video then switches to electromagnetic radiation. A graphic of the electromagnetic spectrum is introduced. Trends in frequency, energy and wavelength are described for the electromagnetic spectrum.
28. Electromagnetic Wave
    a. This animation illustrates the propagation of an electromagnetic wave.
    b. The vectors of the fluctuating electric field in red vibrate parallel to the x-axis. The vectors of the fluctuating magnetic field in blue vibrated parallel to the y-axis. The EM wave travels along the z-axis.
29. Electromagnetic Waves(HD)
    a. This video provides a qualitative look at how electromagnetic (EM) radiation is generated. It briefly reviews the history of the scientific discoveries that lead to a theory that explains EM radiation.
    b. The video also reviews some of the properties of EM radiation such as the electric disturbance occurs in the vertical plane and the magnetic disturbance occurs in the horizontal plane. The two disturbances are coupled, that is they travel in lock step with the changing electric field producing the magnetic disturbance and the changing magnetic field producing the electric disturbance. All the while the EM radiation moves in a direction perpendicular to both the electric disturbance and the magnetic disturbance.
    c. Because EM occurs in the electric and magnetic fields EM radiation can travel through a vacuum. Thus EM radiation is not a mechanical wave.
30. Accelerating Charges Emit Electromagnetic Waves - "Light" - Radio Antennas! | Doc Physics
31. The Electromagnetic Spectrum

Grade 11 Physics (30S)

Topic 4: Sound and Light

Topic 4: Sound and Light

Introduction to Topic 4

This last topic of Grade 11 Physics deals with two phenomena with which you are very familiar: sound and light.

Module 9 deals with sound. You will discover that sound exhibits the properties of a longitudinal wave. You will apply the knowledge you have gained in the last two modules on waves in the study of sound.

Our last module essentially deals with how science works. We can think of science as a body of knowledge. You are familiar with the different divisions of science, such as physics, such as chemistry, biology, and geology. Each of these already has a body of knowledge representing what has been learned in these fields over the years. Countless hours have been devoted by countless scientists to studying how things work, how and why things happen, what exists in the world around us and how to organize these living or non-living materials and so on.

The second part of science is the "doing" part. How do we do science? This is an ongoing process asking questions and of gaining new knowledge about the world around us and then fitting it into what we already know. In order to contribute our "new knowledge" it must be consistent with the "old knowledge" or it must be able to show that the "old knowledge" was somehow incorrect making it necessary for it to be revised. You can see that this becomes a bit complicated. Questions arise like: "Is this new knowledge valid?" "Can it be supported by evidence?" "Is there a good theory to explain this knowledge?"

The first part of this final module will address some of these questions. It will investigate what is the process of doing science and then the criteria for integrating any knowledge gained into existing theories, models and laws.

Then we will turn our attention to the nature of light. The accepted theories of light have changed over the centuries. The history of the discoveries of these theories illustrates the dynamic or changing nature of science. You may have the impression that science is written in stone, unchanging over the years. While this is true in some cases, you will realize that research is an ongoing process that is constantly contributing new ideas. Many times our science must change to include this new knowledge. You will discover that light is a special phenomenon since it does not "fit" a single theory.

NOTES

Grade 11 Physics (30S)

Module 9: Sound

This module contains the following

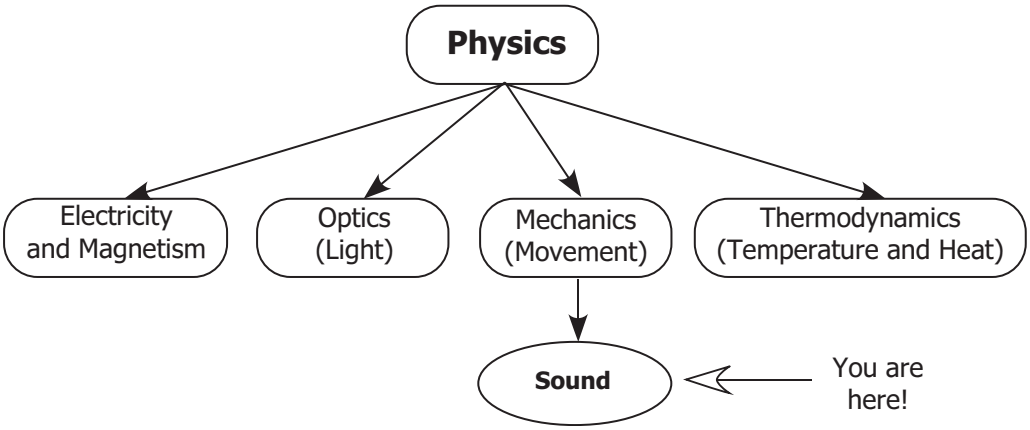
- Introduction to Module 9
- Lesson 1: The Nature of Sound
- Lesson 2: Beats and Resonance
- Lesson 3: The Speed of Sound in Air and the Doppler Effect
- Lesson 4: Video Laboratory Activity: Resonance and the Speed of Sound
- Lesson 5: Music and Noise
- Module 9 Summary

MODULE 9: SOUND

Introduction to Module 9

In this module, we will study sound. You have already learned about the characteristics of one-dimensional and two-dimensional waves in the previous two modules. We will extend this study to sound. There are five lessons in this module.

- **Lesson 1: The Nature of Sound** will review the nature of sound through a study of what causes sound waves, the different frequencies of sound, what it means for a sound to be loud, and some of the medical applications of ultrasound.
- **Lesson 2: Beats and Resonance** is a study of beats and resonance and how this applies to tubes that are open at both ends or at one end. This has interesting applications to how wind instruments work.
- **Lesson 3: The Speed of Sound in Air and the Doppler Effect** looks at how the speed of sound can be determined. The lesson also reviews the Doppler effect that we commonly experience as a siren approaches us and passes by. A medical application of the Doppler effect concludes the third lesson.
- **Lesson 4: Video Laboratory: Resonance and the Speed of Sound** is an experiment where the speed of sound will be determined by means of a resonating air column.
- **Lesson 5: Music and Noise** is a study of various aspects of the science of music. The lesson concludes with a discussion of what noise is and how to control noise.



Assignments in Module 9

When you complete Module 10, you will submit your Module 9 assignments, along with your Module 10 assignments, to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 9.1, Part A	The Nature of Sound
2	Assignment 9.1, Part B	Beats and Resonance
3	Assignment 9.1, Part C	The Doppler Effect
4	Assignment 9.2	Video Laboratory Activity: Resonance and the Speed of Sound
5	Assignment 9.3	Music and Noise

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Lesson 1: The Nature of Sound (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe a sound wave as a longitudinal wave
- name and label the compression and the rarefaction parts of a longitudinal wave
- describe the direction of motion of the particles of the medium in relation to the direction of motion of the wave
- explain how a vibrating object creates the longitudinal waves
- explain why a medium is necessary in the creating and transmission of a sound wave
- explain how the eardrum and the brain work together to help us perceive the sound
- explain what is meant by "frequency" for a sound wave
- define the term "pure tone"
- discuss how a push-button telephone uses pure tones
- define the terms "infrasonic" and "ultrasonic"
- give examples of animals that use infrasonic and ultrasonic sounds
- define the term "pitch"
- give examples of instruments that use a high pitch or a low pitch
- draw an air pressure versus distance graph for a sound wave
- explain how loudness and the amplitude of a wave are related
- explain some of the medical uses of ultrasound

Key Words

longitudinal wave	compression	rarefaction
frequency	pure tone	infrasonic
ultrasonic	pitch	pressure graph
intensity	decibel	ultrasound

Introduction

In this first lesson, we will review some of the basic characteristics of sound. We will learn what causes sound waves and why a medium is important. In studying the frequencies of sound, we will learn about pure tones, infrasonic and ultrasonic sounds, and pitch. By studying a pressure versus distance wave, we will learn about what it means for a sound wave to be loud. We will see how loudness, the intensity of sound, and the decibel level of sound are related.

Producing Sound

In considering what sound fundamentally is, let us take a moment to investigate some examples of things that produce sound:

- You can talk, which produces a sound.
- Speakers are devices that are designed to make sound. They are commonly found in devices such as stereos, televisions, telephones, etc.
- Musical instruments produce sounds. Examples include pianos, guitars, drums, saxophones, etc.
- When two things hit into each other, there is generally a sound produced on impact. This may be the "crack" of a baseball off of a bat, two hands clapping together, or just about anything else.
- Numerous machines make loud sounds when operating. Examples include cars, trains, leaf blowers, and blenders.

The list could certainly go on as there is no shortage of examples of things that produce sound. Even though our list is fairly brief, it shows a pretty amazing variety of things that can make sound. The question is, what do all of these things (as well as other sources of sound) have in common? What is it about these things that causes them to make sound?

The answer is that all of these things have vibrating parts!

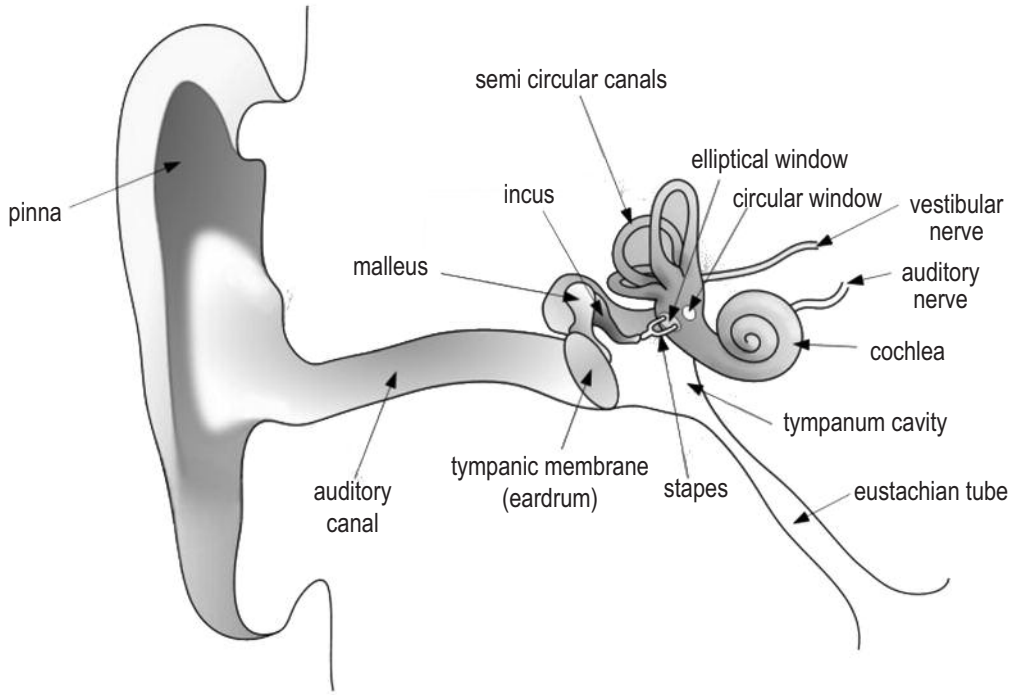
- When you talk, you force air out of your lungs. This air passes through flaps of tissue called "vocal cords" and causes them to vibrate. You can actually feel this vibration if you press your fingers against the front of your neck while speaking. The vibrating vocal cords then cause the air itself to vibrate.
- When you use the speakers that are attached to your stereo system, you might notice that they literally vibrate. This is usually not visible with small speakers, as they tend to vibrate quite quickly, and don't move very far while vibrating, but if you touch them while they are working, you would feel their vibration. Of course, if you have ever seen an especially large speaker (such a subwoofer) that is "thumping," you can quite easily see the speaker popping forwards and backwards.
- Every musical instrument involves vibration. In the pianos and guitars, it is strings that vibrate. Similarly, when the skin of a drum is struck by a stick, the surface of the drum is set to vibrate (somewhat like a speaker vibrates). Saxophones have a wooden reed that has air blown across it by the musician. Much like the vocal cords mentioned above, this reed will set air into vibration.
- On impact, the colliding objects will quite literally vibrate. If you have ever played baseball, you probably know that the bat certainly does vibrate when it hits the ball (sometimes this vibration can be quite large, which can leave a "stinging" sensation). The same is certainly true for clapping hands.
- Any machine with moving parts is likely to have these parts vibrating—some more than others.

Here is an activity you can try on your own. Obtain a 30 cm ruler made of wood or plastic. Hold the ruler with one end 10 cm over the edge of a desk or table. Secure the end of the ruler that is on the table by pressing down hard on it. With your free hand, strike the end of the ruler that is free to move. Observe its movement and listen for its sound. What kind of movement did the free end of the ruler make? What did you hear? Move the ruler so that 15 cm of it is projecting over the edge of the table. Generate the sound again. How does it differ from the first sound?

Detecting Sound

Now that we recognize that an object must be vibrating in order to produce sounds, let us turn our attention to how we hear or otherwise detect sounds. It is obvious that the ear is our main organ for detecting sounds. A simplified version of how you hear would go something like this: When a sound enters your ear, the eardrum (which is a delicate flap of skin at the end of your ear canal) starts to vibrate. This vibration is picked up by nerves, which then

deliver this vibrating message to your brain. Of course, ears aren't the only part of your body that can detect sounds. Your whole body can "feel" certain sounds. You will know this to be true if you have ever attended a rock concert or experienced a very loud sound.



Source: Dan Pickard. Human Ear.jpg

To summarize, sound is produced by vibrating objects; it can be detected by the vibration it causes in your body

Sound as a Wave

Having just completed a module on waves, we should certainly see that the production and detection of sound is consistent with waves. In the case of water waves, a vibrating source in one location creates waves on the surface of the water. These waves then move outward from the source. If these waves come across something in the water, such as a floating piece of wood, they will cause the wood to vibrate, literally making it rise and fall with the waves.

With sounds that we experience, there is typically no water, but let's not forget that there certainly is something else: air. If an object is in the air (which is usually the case for most ordinary situations that we tend to come across), then it will cause the air around it to vibrate if the object itself is vibrating. The air itself is the medium for sound waves, which can then transmit through the air and be felt or heard by you or anyone else nearby.

Of course, the medium for sound waves does not need to be air. Just about anything can serve as a medium for sound. Dolphins and whales, for example, have excellent hearing. For them, water is the medium for sound waves. In the case of sound waves moving through water, you must realize that we are not talking about the same kind of water waves that we discussed in the previous module: the sound waves move through the entire volume of water, and not just along the surface.

Sound waves can even move through solid materials. You will know this to be true if you have ever heard something happening in the next room (or next floor) while your door is closed. The sound produced in one room can transmit right through the wall to get to you, enabling you to hear it.

> Sound is a mechanical wave—it requires a medium. This medium is most commonly (for us) air, but it can be anything including solids and liquids.

The Speed of Sound

Based on what we learned about waves in previous modules, we should not be surprised to find that the speed of sound depends on the medium and not on anything else. The speed of sound can be very different from one medium to another, since the media themselves can be very different (air, water, and steel, for example, can all be sound wave media). In fact, even the details of the medium can play an important role (such as temperature and pressure). Here are some examples of the speed of sound in different media:

Medium	Speed of Sound
Air (at 0° C)	331 m/s
Air (at 20° C)	343 m/s
Water	1482 m/s
Steel	5960 m/s

Notice that the speed of sound is slowest in air, faster in water, and even faster in steel. This pattern of sound being slowest in a gas, faster in a liquid, and faster yet in a solid is generally true regardless of which types of solid, liquid, or gas are being compared. This is because the particles making up a gas are relatively far apart but are closer together in a liquid, and even closer in a solid. Considering that the sound wave involves the collision of these particles, the waves can move faster when they are closer together.

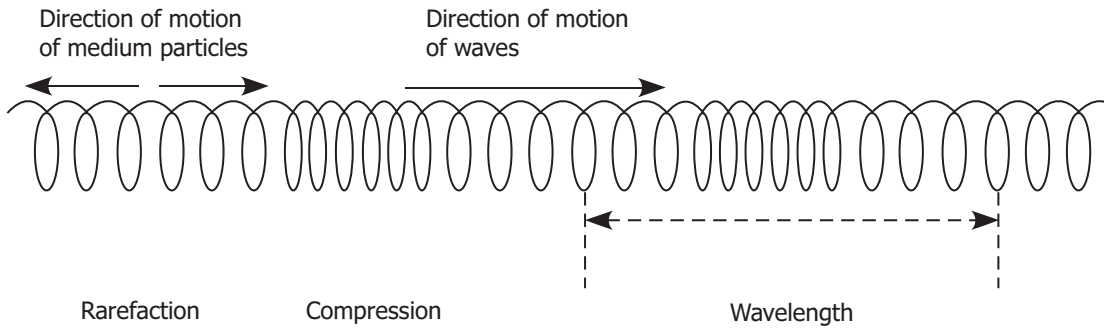
Also notice that sound waves move faster in warmer air than in colder air. Initially, you may have expected the opposite to be true, since colder air tends to be more dense. Cold air's greater density is overshadowed by the fact that the particles making up the air move faster at higher temperatures. The faster the particles move, the more quickly they can carry the sound wave.

Sound as a Longitudinal Wave

In previous modules, we saw two types of mechanical waves: **transverse waves** are those in which the **medium vibrates perpendicular** to the **motion** of the **wave**; and **longitudinal waves** have the **medium vibrating parallel** to the **motion** of the **wave**.

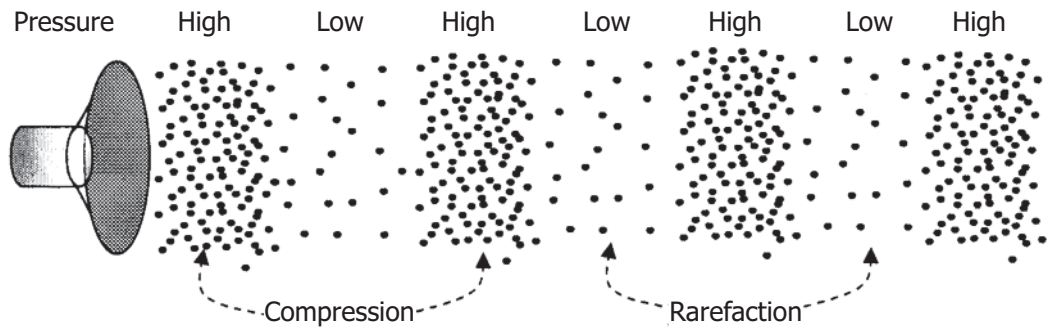
> Sound waves are longitudinal: the vibrating source alternately pushes and pulls the particles of the medium, which then push and pull the particles of the medium ahead of them, advancing the wave.

This is very much like the longitudinal waves we discussed in springs. A series of **compressions** and **rarefactions** (or expansions) can then propagate along the medium. The compressions are those regions where the particles of the medium are closer together than usual, while rarefactions are regions where the particles of the medium are further apart than usual. Compressions and rarefactions correspond to the crests and troughs of a transverse wave.



To better understand how a vibrating object creates a longitudinal sound wave and why the medium is important, let's think again about a vibrating speaker. The hard, cone-shaped part of a speaker that vibrates is called a **diaphragm**. When the **diaphragm** moves **outward**, it compresses the air directly in front of it. This compression causes the air pressure to rise slightly. The region of **increased air pressure** is the **compression** part of the wave. The compression travels away from the speaker at the speed of sound, which, as was discussed, depends on the medium. This compression is analogous to the compressed region of coils in a spring carrying a longitudinal wave.

After producing the compression, the **diaphragm** reverses its motion and **moves inward**, creating a space for the air to fill (although it does not literally "pull" the air, the effect is the same). The **air pressure** is now slightly **less than normal**—this is the **rarefaction** part of the wave. This is similar to the stretched-out region of coils in a spring carrying a longitudinal wave. This rarefaction follows immediately behind the compression and also travels away from the speaker at the speed of sound.



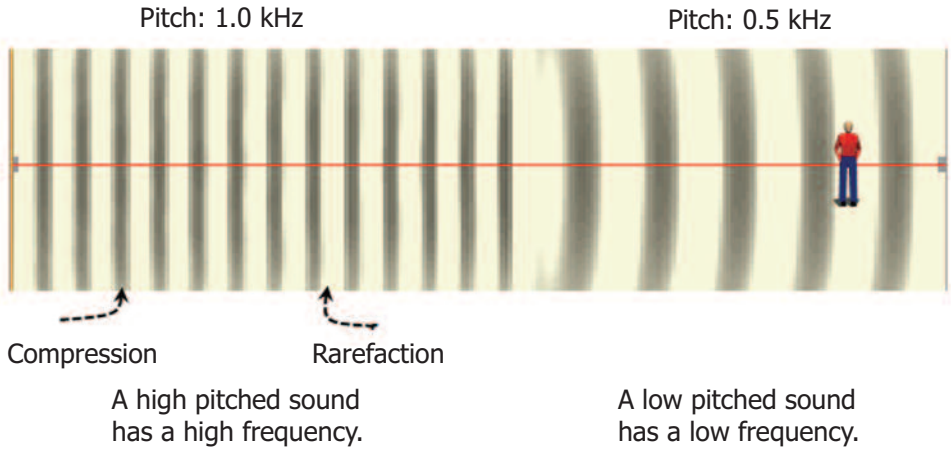
When the compressions and rarefactions arrive at the ear, they force the eardrum to vibrate at the same frequency as the vibrating source that produced the sound. The vibrating motion of the eardrum is interpreted by the brain as sound.

Sound Frequency and Pitch

> The **frequency** for any wave can be defined as the number of cycles that is produced per second. This frequency affects the sound that we hear and we use the word **pitch** to describe this aspect of the sound.

A low-pitch sound is sometimes called bass, and is commonly produced by such things as tubas and distant thunder, while high-pitch sounds are sometimes referred to as treble and are commonly produced by such things as whistles and mosquitoes.

Different Pitches at the Same Loudness



Each cycle of the sound wave includes one compression and one rarefaction. If, for example, a speaker vibrates back and forth at a frequency of 500 Hz, then 500 compressions, each followed by a rarefaction, are generated every second.

> A sound with a single frequency is called a **pure tone**.

A healthy young person with normal hearing can hear all sounds that have frequencies ranging from about 20 Hz to 20 000 Hz (which can be written as 20 kHz). This range of frequencies is called the **audible range**. Sound can exist at higher frequencies than 20 kHz, but they are mostly inaudible—people cannot hear them.

> Sounds with a frequency higher than 20 kHz are described as being **ultrasonic**, while sounds with a frequency lower than 20 Hz are said to be **infrasonic**.

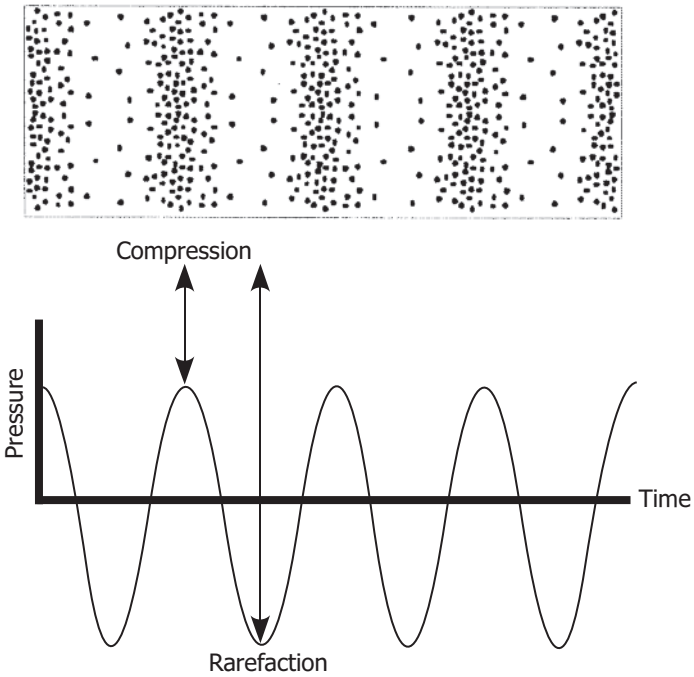
As people age, their ability to hear high frequencies tends to decrease. A normal middle-aged adult can hear frequencies only up to about 12-14 kHz. Similarly, sounds below about 20 Hz cannot be heard by people.

However, many animals have a range of hearing beyond the range of humans. You may have used a dog whistle to call your dog. When you blow on the whistle, there is silence as far as you can perceive. The whistle is producing sound waves in the ultrasonic range. The ears of a dog are still sensitive to these frequencies, and therefore your dog hears the sound and comes running (hopefully).

An example of where pure tones are used is in push-button telephones. When a button is pressed, the phone simultaneously produces two pure tones—each row of buttons has one frequency associated with it, and each column of buttons has another frequency associated with it. A different pair of tones is produced for each different button (one for which row it is in, and one for which column it is in). While you can hear these tones, they are also transmitted electronically to the phone company in order to complete a call.

Sound Pressure, Amplitude, and Loudness

The diagram below shows the particles of a medium (such as molecules of air) that are carrying a pure-tone sound wave through it. Note that the pressure at any given point would depend on how closely spaced these particles are. In the areas of rarefaction, there are fewer molecules, resulting in the air pressure there being low. In the areas of compression, the air pressure is high, as there are many more molecules there. If we create a graph of pressure throughout the medium, the graph would take on the appearance of a transverse wave even though sound itself is a longitudinal wave. Note that the zero point for pressure on the graph would actually correspond to "normal" pressure—the pressure the medium was under prior to the wave disturbing it. The pressure thus rises and falls, and can be thought of in much the same way as a transverse wave.



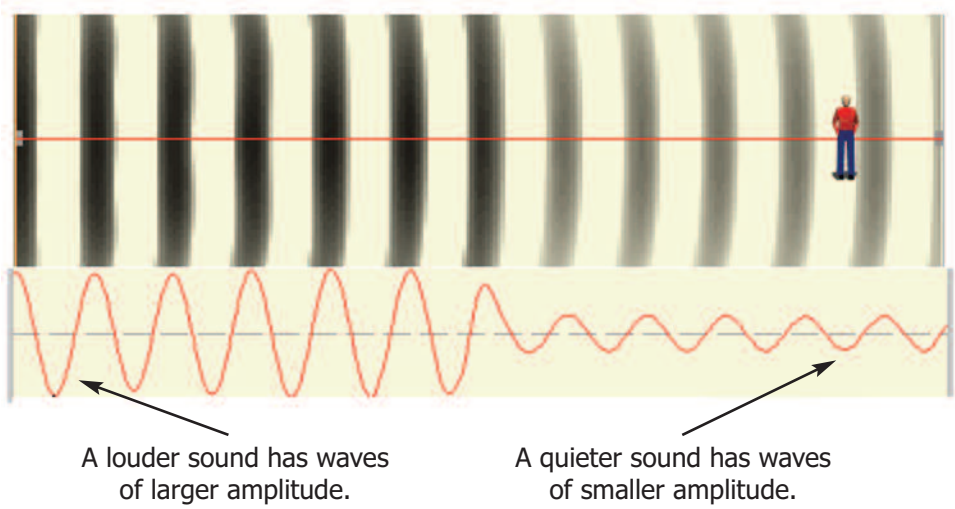
The **pressure amplitude** shown in the graph above is the size (magnitude) of the maximum change in pressure measured compared to undisturbed (typically atmospheric) pressure.

Loudness is a tricky idea. Fortunately, the meaning of this word in physics is exactly the same as its meaning in everyday use, but this concept is a little difficult to describe in words. Essentially, loudness is a measure of how "strongly" a sound is heard. While the amplitude of the sound pressure wave does affect the loudness (in general, larger amplitudes are perceived as being louder), there is no simple way to predict the loudness of a sound by studying the wave alone. There is an element of subjectivity to it, which means that it is in part based on who is doing the listening.

Nevertheless, there is a connection between **amplitude** and **loudness**: the larger the amplitude of the pressure wave, the louder the sound that will be heard.

In the following graphic, the sound waves have the same pitch (frequency). The sound waves on the left have a higher pressure (the compressions are darker) than the sound waves on the right (the compressions are lighter). On the pressure-time graph, you can see that the sound waves on the left have larger pressure amplitudes, which we perceive as a louder sound.

Different Loudnesses of Sound at the Same Pitch



Medical Applications of Ultrasound

Ultrasonic waves can be used for diagnostic purposes in medicine. High-frequency sound pulses are produced by a source and directed into the body. This sound wave will enter the body and transmit through it. Each time this wave encounters a new medium (such as from a soft tissue to a harder tissue), the sound wave will partially reflect, much as a spring wave partially reflects from the point separating two different springs. By sending ultrasonic waves into the body and detecting the echoes generated from various internal locations, it is possible to obtain information which can then be turned over to a computer, which can then produce an image or **sonogram** of these inner parts.

Ultrasonic waves are used extensively in examining the developing foetus inside the womb of its mother. The foetus, surrounded by the amniotic sac, can be distinguished from other anatomical features. This makes it possible to determine the size and position of the foetus, as well as identifying possible abnormalities that it may have.

Ultrasound is also used in other medically related areas. For example, tumours in the liver, kidney, brain, and pancreas can be detected with ultrasound. It is also possible to use ultrasound to monitor the real-time movement of pulsating structures such as heart valves and large blood vessels.

When ultrasound is used to locate internal anatomical features or foreign objects in the body, the wavelength of the sound must be about the same size or smaller than the object to be located. To locate objects smaller than a millimetre, the frequency of the ultrasound ranges from 1 to 15 MHz (1 megahertz = 1×10^6 Hz). This is why ultrasound (with its higher frequency and therefore smaller wavelength) is used, and not audible sound.

Ultrasound also has other applications in medicine. Neurosurgeons use a device called a Cavitron Ultrasonic Surgical Aspirator (CUSA) to remove brain tumours that were once thought to be inoperable. Ultrasonic sound waves cause the slender tip of the CUSA probe to vibrate at approximately 23 kHz. The probe shatters any section of the tumour that it touches, and the fragments are flushed out of the brain with a saline solution. Because the tip of the probe is small, the surgeon can selectively remove small bits of tumours without damaging the surrounding healthy tissue.

Learning Activity 9.1

The Nature of Sound

1. Some animals rely on an acute sense of hearing for survival, and the visible part of the ear on such animals is often relatively large. Explain how this anatomical feature helps to increase the sensitivity of the animal's hearing for low-intensity sounds.
2. Distinguish between
   a) loudness and pitch
   b) ultrasonic and infrasonic
3. A dog can hear a sound produced by a dog whistle, while its owner cannot. Explain how this is possible.
4. What physical characteristic of a wave would you change to
   a) increase the loudness of a sound?
   b) change the pitch?
5. In December 1916, a major disaster befell a contingent of the Austrian army in the Alps fighting in World War I. Almost as soon as they began a cannon barrage, an avalanche of snow came roaring down, burying thousands of soldiers. What does this suggest about sound?

Lesson Summary

Sound waves are longitudinal waves. The vibration of the particles of the medium is along the same direction as the motion of the wave. The **compressions** are those areas in a longitudinal wave that are momentarily close together. **Rarefactions** (also called **expansions**) are regions of the wave that are momentarily far apart. One way to illustrate the wavelength of a longitudinal wave is the distance between the centre of one rarefaction to the centre of the next rarefaction.

Vibrating objects create the longitudinal waves that make up sound. A medium is necessary to transmit the sounds. A vibrating object creates a compression when the object moves outward, creating a slight rise in pressure of the medium. When the object reverses direction, it creates a region of low pressure called a rarefaction. The compressions and rarefactions cause the eardrum to vibrate at the same frequency as the source of the sound. The brain interprets the motion of the eardrum as sound.

Frequency for any wave can be defined as the number of cycles of the wave that pass by a given point every second. A healthy young person hears all sound frequencies from 20 Hz to 20 000 Hz (20 kHz). The **audio spectrum** is the range of audible frequencies for a healthy person: 20 Hz to 20 kHz.

A **pure tone** is a sound with a single frequency. Push-button telephones use pure tones.

Infrasonic sound waves are those below the range of normal human hearing. These frequencies occur below 20 Hz. **Ultrasonic** frequencies occur above the range of normal human hearing and therefore are above 20 kHz.

A **pitch** is a perceived quality of sound that pertains to the frequency of the sound.

An air pressure versus distance graph has the appearance of a transverse wave, even though sound itself is a longitudinal wave. The **pressure amplitude** is the magnitude of the maximum change in pressure measured relative to undisturbed or atmospheric pressure.

Loudness is a subjective characteristic of sound that depends primarily on the amplitude of the wave. Sound waves carry energy with them as they move from one place to another. The larger the amplitude of the sound wave, the more energy it carries.

Ultrasonic sound waves can be used in medical diagnostic techniques (1 to 15 MHz) or in the use of the CUSA device (23 kHz) to remove brain tumours.

NOTES

Assignment 9.1, Part A

The Nature of Sound (4 MARKS)

The following assignment must be submitted to the Distance Learning Unit for evaluation. Be sure to show all your work and explain the method of arriving at your answers. Submit this assignment, along with all the other assignments from Module 9, after you have completed Module 10.

1. In order to produce a sound, a vibrating object is necessary. What else is necessary for the sound to be heard some distance away? What type of wave is sound?

   _____

   _____

2. Distinguish between
   a) amplitude and loudness

   _____

   _____

   _____

   _____

   _____

   _____

   b) frequency and pitch

   _____

   _____

   _____

   _____

(continued)

Assignment 9.1, Part A: The Nature of Sound (continued)

3. What is the range of frequencies to which the human ear is sensitive and what is this range called?

_____

_____

Method of Assessment

The total of four marks for this assignment will be determined as follows:

- 0.5 mark for stating what else is necessary for sound to be heard in question 1
- 0.5 mark for stating what type of wave sound is in question 1
- 1 mark for stating the difference between intensity and loudness in questions 2(a)
- 1 mark for stating the difference between frequency and pitch in question 2(b)
- 0.5 mark for stating the range of frequencies is in question 3
- 0.5 marks for stating what the range is called in question 3

Lesson 2: Beats and Resonance (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "beats"
- ❑ explain, using the principles of constructive and destructive interference, why beats occur
- ❑ calculate the best frequency given the frequency of the waves producing the sounds
- ❑ analyze a pressure time graph showing the interference of sound waves to determine when a sound is loud and faint and what the beat frequency is
- ❑ describe how nodes and antinodes behave in a standing wave pattern formed by a longitudinal wave
- ❑ compare the pressure patterns inside a resonating tube open at both ends, or one end, with the positions of the node and antinode in a standing wave
- ❑ calculate the wavelength of sound and the natural frequencies at which resonance occurs in a tube open at both ends, or one end

Key Words

beats	beat frequency	resonance
resonating tube	closed end	open end
node	antinode	

Introduction

In our previous study of waves, we learned that waves can interfere with each other constructively or destructively. In this lesson, you will see that sound waves can interfere this way and produce a "beat frequency." Musicians make use of this phenomenon to tune instruments. You will see how standing wave patterns occur in longitudinal waves, and how these kinds of patterns occur in tubes that are open at both ends or at one end. This also has applications in understanding how wind instruments function.

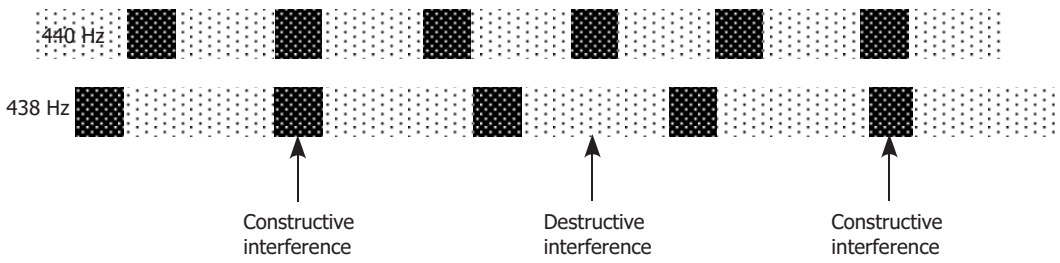
Beats and Beat Frequency

We learned in our work with waves that constructive and destructive interference occur when waves pass through each other. Both transverse waves and longitudinal waves show this characteristic. Furthermore, we saw that standing waves occur when the waves are of the same frequency. In this lesson, we will see that sound waves having slightly different frequencies produce a phenomenon called "**beats**."

The diagram below shows sound waves produced from two different tuning forks. A tuning fork produces a single frequency sound wave when it is struck. One of the tuning forks produces a 440 Hz tone, while the other one produces sound with a frequency of 438 Hz. Since the frequencies are different, they must have different wavelengths: the higher frequency wave will have a smaller wavelength. If you were to hear the sound produced from either one of these tuning forks, it would sound like a constant sound, gradually getting quieter until after several seconds later it would be difficult to hear at all—but it was pretty constant for the first 5 to 10 seconds (or so). So what would you predict two tuning forks producing sound at the same time to sound like?

Most people who have never tried this would likely expect that two tuning forks together will simply produce a louder sound—approximately twice as loud as one alone, if they each produce sounds of similar loudness. If this were the case, this lesson would not exist! When the two forks are struck simultaneously, the loudness of the sound rises and falls periodically so that it is faint, then loud, then faint, then loud, and so on. Rather than producing a constant louder sound, these two nearly constant sound waves together sound "wobbly"—anything but constant!

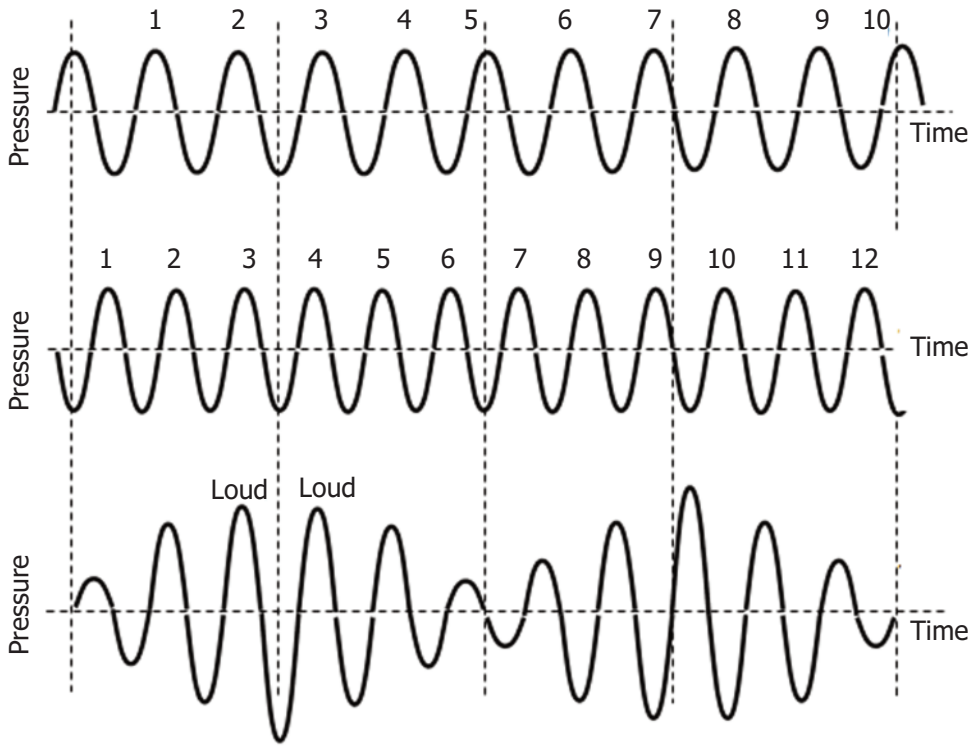
> The interference of sound waves with slightly different frequencies results in periodic variations in loudness called **beats**.



For clarity, the diagram shows the compressions and rarefactions of the sound waves separately. In reality the waves spread out and superimpose, and you would hear the combined total of the two. Note that there are regions where the waves **interfere constructively** and places where they **interfere destructively**.

Two compressions add to form a larger compression according to the principle of linear superposition discussed earlier for waves. This constructive interference results in a louder sound.

When a **compression** and a **rarefaction** come together, destructive interference occurs and the sound intensity drops. If the waves have the same amplitude, it will **drop to zero**. Due to the differences in frequency (and therefore wavelength) these waves will "slip in and out of phase"—sometimes interfering constructively and sometimes interfering destructively. This is shown in the diagrams below. The first two diagrams show two waves with a slightly different frequency while the third diagram shows these same two waves drawn in with the resulting wave. Notice that the resulting wave has a larger amplitude when the two original waves are in phase, and is smaller when they are out of phase. This resulting wave gets larger and smaller in a patterned way, which is what we would hear as a beat.



Interference of the sound waves explains the "wobbly" sound, which is what we call a beat. If the frequencies of the two sound sources are constant, then the beat will have a very regular timing—using the word "beat" to describe this is appropriate.

The frequency of this wobbly sound is called the **beat frequency**.

The beat frequency produced by two sounds is found by determining the absolute value of the difference of the two frequencies of the two component waves.

$$f_{BEAT} = |f_2 - f_1|$$

Quantity	Symbol	Unit
Beat frequency	f_{BEAT}	hertz (Hz)
Frequency of sound wave 1	f_1	hertz (Hz)
Frequency of sound wave 2	f_2	hertz (Hz)

The beat frequency is the difference between the two sound frequencies. For the 440 Hz and 438 Hz waves discussed above, the beat frequency will be 2 Hz—you would hear the sound "come and go" two times per second.

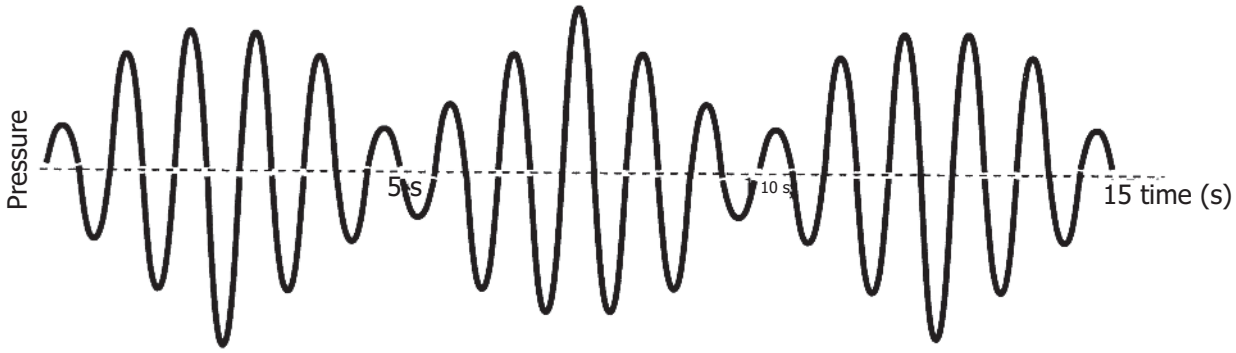
Musicians sometimes tune their instruments by listening for a beat. For instance, a guitar player sounds an out-of-tune string along with a tone from a source known to have the correct frequency (this could be a tuning fork or another guitar). The guitarist adjusts the tension in the string until the beats vanish, ensuring that the string is vibrating at the correct frequency.

Learning Activity 9.2

Beats and Resonance: Part 1

1. A tuning fork vibrates at a frequency of 524 Hz. An out-of-tune piano string vibrates at 529 Hz.
   a) What is the beat frequency?
   b) How much time separates successive beats?

2. When two sound waves whose frequencies are near each other interfere, they produce a pressure-time graph as shown below.



For the graph above, what is the
   a) period of the beat?
   b) beat frequency?

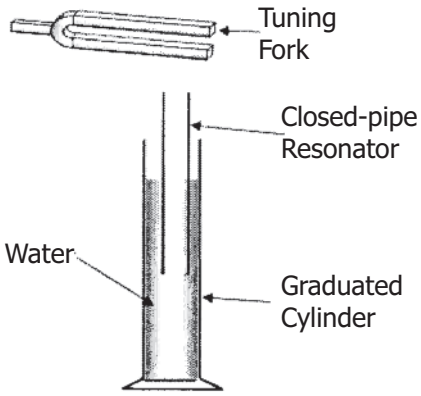
Resonance in Air Columns

In our study of waves in one dimension, we observed that a **standing wave pattern** can form on a spring when reflected waves interfere with incident waves. We learned that any frequency at which the standing wave can exist is called a **harmonic frequency**. Each harmonic frequency is a whole-number multiple of the lowest harmonic frequency, which is called the **fundamental frequency**.

Of course, spring waves are one-dimensional—they can only travel back and forth along the length of the spring. Sound waves are three-dimensional—they can travel freely in any direction within a medium. But what if we have a medium for sound waves that is itself one-dimensional (or nearly so)? If we had a long narrow "tube" of air, then the sound waves inside this tube could move freely along the length of the tube, but being narrow would not have much room to move in any other direction. This means that tubes of air can carry sound waves that are very nearly one dimensional—they should behave very nearly the same as spring waves!

Sound waves that originate at one end of a tube travel down the length of the tube and then reflect from the end of the tube—regardless of whether the end of the tube is "**closed**" (sealed off) or "**open**," the wave will encounter a "different" medium in either case.

Closed Air Column



This is easiest to explain for the closed end—the sound was travelling in air, and then it strikes the solid end of the tube; reflection should be expected.

A tuning fork above a hollow tube can produce resonance in an air column, as shown in the figure to the left. The tube is placed with one end below the surface of the water in a graduated cylinder. This forms a resonating tube with one end closed, and is called a closed-pipe resonator. The tuning fork is struck with a hammer and vibrates, producing sound.

To produce resonance (heard as a loud sound), the tuning fork is held near the mouth of the tube and the tube is raised or lowered until the closed-pipe column resonates. A resonating air column intensifies the sound of the tuning fork.

Standing Pressure Wave

How is resonance produced?

Let us consider what occurs with the pressure waves. The vibrating tuning fork produces sound by alternately making compressions (areas of high pressure) and rarefactions (areas of low pressure) in the air. This wave of alternating high pressure and low pressure travels down the air column. If we follow a high-pressure section, it will travel down the air column, hit the water (like a fixed end), and reflect as a high-pressure section (unlike a pulse on a spring, reflection from a fixed end is upright for longitudinal waves).

If the reflected high-pressure area meets another high-pressure area at the mouth of the tube coming from the tuning fork, the two will reinforce and intensify the sound. The superposition of these areas of high pressure and low pressure within the column of air produces a definite pattern called a **standing wave**. When the standing wave is formed, the closed column of air will **resonate**.

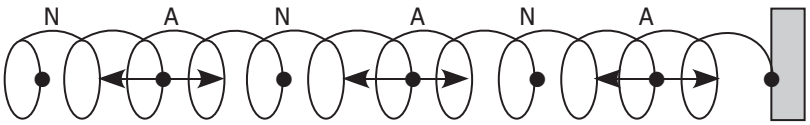
> The shortest closed tube in which resonance can occur is called the **first resonant length**. The frequency of the sound that resonates at the first resonant length is called the **fundamental frequency**.

Closed-Pipe Column

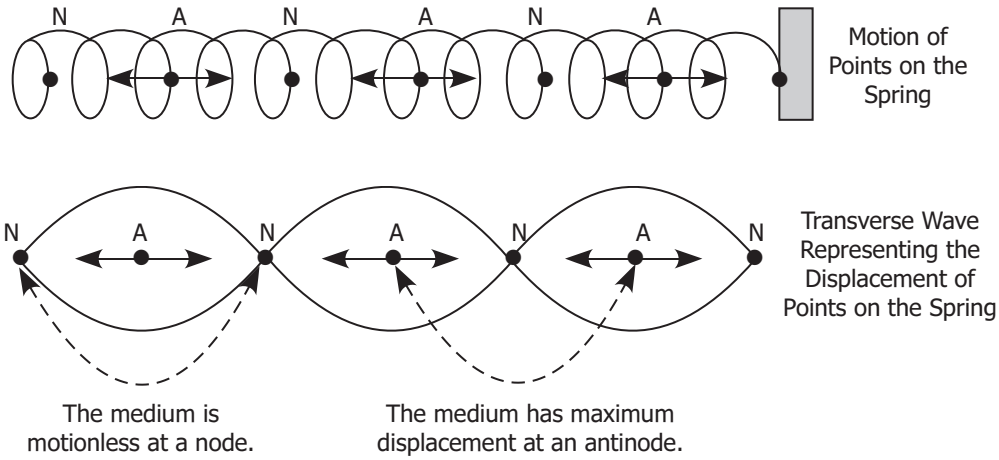
In the case of the closed-pipe resonator, the first resonant length occurs at a length of one-quarter of the wavelength of the sound. This is the length of tube that the sound can travel down, reflect from the water's surface, and interfere with incoming sound waves to produce a standing wave.

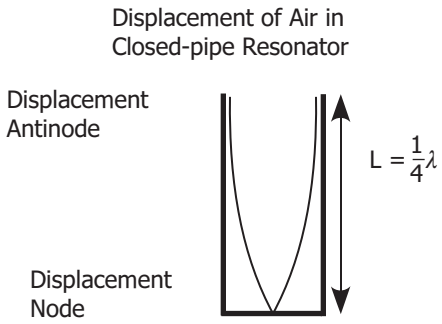
Let us turn our attention to the **displacement** of points on the medium.

Sound waves are longitudinal waves, so to understand standing waves in sound let us look again at the Slinky. When the longitudinal waves reflect from a wall, the forward and backward waves can produce a standing wave. As in a transverse wave, there are nodes and antinodes. At the nodes the coils of the Slinky do not vibrate at all—that is, they do not have any displacement. At the antinodes, the coils vibrate with maximum amplitude. This is indicated by the dots with the arrows indicating back and forth movement. At an antinode, the coils have a maximum displacement. The vibration occurs along the line of travel of the individual waves. In a standing wave, the molecules and atoms of the medium behave as the dots in the diagram do.



It is difficult to represent the longitudinal motion of the medium, so we will use a transverse wave for this purpose. In the graphic below, the displacement nodes are just the points of the medium that do not move. In the transverse wave, the amplitude will be zero. At the displacement antinodes, points on the medium are whipping back and forth along the medium. In the transverse wave, this corresponds to an alternating crest and trough—much like a standing wave on a spring.





If we apply these ideas about displacement to the standing waves in the column of air for the **first resonant length**, there should be a **displacement node** at the **surface** of the water and a **displacement antinode** at the **mouth** of the tube. We represent the displacement of points on the medium using a transverse wave. A node would have no displacement and an antinode should have alternating maximum displacements (crest then trough then crest, and so on).

If we extend the pattern of standing waves, the next displacement antinode would occur if a half of a wavelength was added to the length of the closed pipe. Remember that node-to-node and antinode-to-antinode distances are one-half of the wavelength.

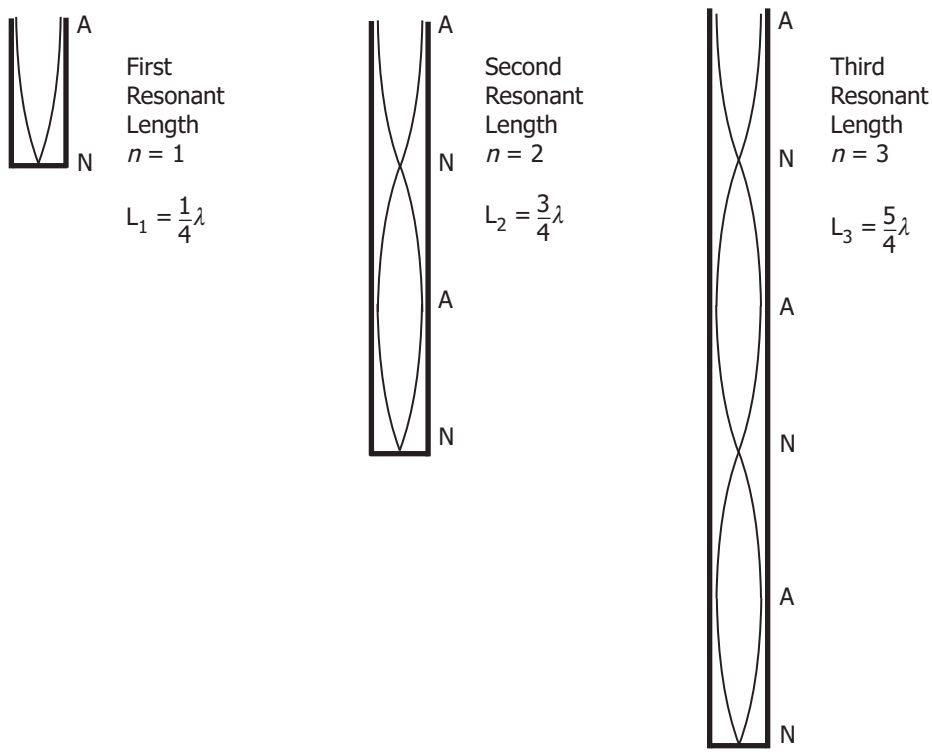
So the second resonant length of a closed-pipe column will be

$$\frac{1}{4}\lambda + \frac{1}{2}\lambda = \frac{3}{4}\lambda.$$

The third resonant length will be longer by another half wavelength or

$$\frac{3}{4}\lambda + \frac{1}{2}\lambda = \frac{5}{4}\lambda.$$

Resonant Lengths of Closed-Pipe Columns of Air Showing the Displacement of Nodes and Antinodes



You can notice in the pattern for standing waves above that the closed end of the column is always a **displacement node**. The **open end** is always a **displacement antinode**. So to draw the pattern inside a closed-pipe column, start with a displacement node at the closed end. There will be as many nodes as the number of the resonant length (second length has two nodes). Draw in the nodes and end the pattern with a displacement antinode, and there it is! The tube can then be drawn around the standing wave pattern.

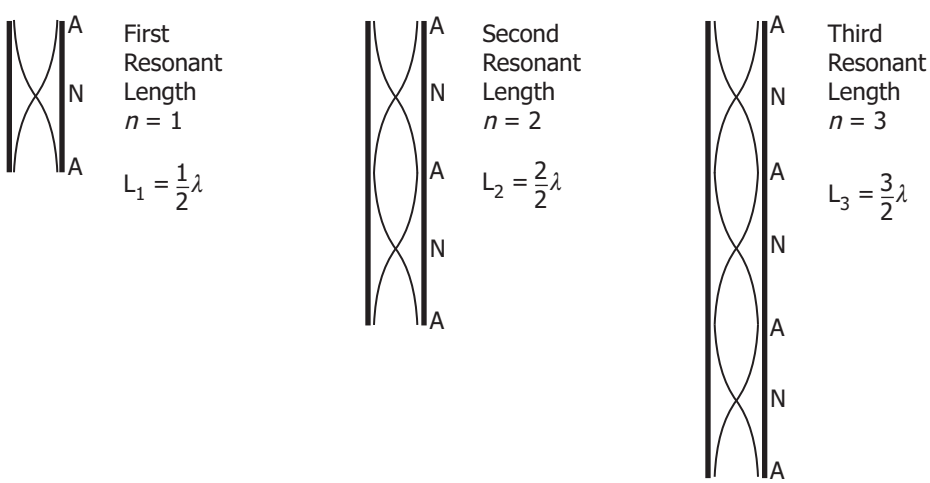
Open-Pipe Column

It's a little more difficult to see why the wave would reflect from an open end. After all, it was travelling in air, and seems to be reflecting off of more air! While this is true, the air inside the tube is, as discussed, one-dimensional, while outside the tube it is fully three-dimensional. This is very much a change in the medium. An incoming high-pressure area will reflect from the open end as a low-pressure area (inverted). This low-pressure, reflected area will have to meet up with an incoming low-pressure area in order for resonance to occur. The shortest length for which a standing wave occurs for this open-end resonator (its fundamental frequency) is at one-half of a wavelength.

Again, if we examine the **displacement** of the medium, we arrive at displacement nodes and displacement antinodes. An open-end column will have **two antinodes** at its **ends** for any resonant length. The **first resonant length** will have **one displacement node**; the **second length** will have **two displacement nodes**; the third three, and so on.

Again, if you know which resonant length you have, you can use the information above to easily draw the standing wave pattern for displacement.

Resonant Lengths of Open-Pipe Columns of Air Showing the Displacement Nodes and Antinodes



If the frequency of the source matches one of the natural frequencies of the air column, the incident and reflected waves combine to form a standing wave, and the sound heard from this particular frequency will be distinctly heard. Musical instruments in the "wind family" depend on exactly this. Wind instruments like the trumpet, flute, clarinet, pipe organ, and so on, are essentially columns (or tubes) of air.

As was the case for spring waves, the harmonic frequencies must have wavelengths that "fit" within the length of the medium. Notice that this means that longer columns of air will support waves with larger wavelengths. Since longer wavelengths mean lower frequencies (which we perceive as pitch), then longer tubes will support sound waves with a lower pitch, and shorter tubes support waves with a higher pitch. This explains why a tuba (which is an especially long tube that has been coiled up for practical reasons) plays such "low" pitch sounds while a flute (a much shorter tube) plays such high pitch sounds (better still would be a piccolo, which is even shorter and higher pitched).

This also explains how these types of instruments can produce different sounds. This is readily observable in many musical instruments, but the trombone is a particularly good example that is familiar to most people. A trombone is an instrument that has a section of tube that slides back and forth. When this tube slides out, it effectively makes the entire tube longer (which then plays a lower pitched sound), and when it slides back in, the tube becomes shorter (and so it plays a higher pitched sound).

Example: Drawing a Closed-Pipe Column for the Fourth Resonant Length

Your task is to draw the standing wave pattern that fits into the fourth resonant length for a closed-pipe column. Here is how you can go about this task.

Since this is a closed-pipe column, you will have a displacement node at the closed end. Since this is the fourth resonant length there must be four displacement nodes (including the one at the end) in the standing wave pattern.

The pattern must end with a displacement antinode.

The resonant length is $\frac{7}{4}\lambda$.

If the length of the closed-pipe column is 85.0 cm, what is the wavelength for this sound?

$$L_4 = \frac{7}{4}\lambda = 84.0 \text{ cm}$$

$$\lambda = \frac{4}{7}(84.0 \text{ cm}) = 48.0 \text{ cm}$$

The wavelength is 48.0 cm.

Learning Activity 9.3

Beats and Resonance: Part 2

1. When a stream of water is used to fill a graduated cylinder, a sound of steadily increasing pitch is heard. Explain why this happens.
2. Sketch the displacement standing wave patterns for the first three resonant lengths of an open-pipe column.
3. The first resonant length for an open-pipe column occurs when the column is 17.8 cm in length.
   a) What is the wavelength of this sound?
   b) If the speed of sound in air is 342 m/s, what is the frequency of this sound?
4. a) Draw the displacement standing wave pattern for a closed-pipe column for the third resonant length.
   b) If the wavelength of the sound is 23.8 cm, what is the length of this closed-pipe column?
   c) If the frequency of the sound increased, would the third resonant length increase or decrease? Justify your answer.
5. The auditory canal is essentially a narrow chamber closed at one end by the eardrum that forms a standing wave cavity. In an adult, this canal is about 2.70 cm long. Determine the fundamental frequency of the sound that will be amplified if the speed of sound is 343 m/s.

Lesson Summary

Beats are the periodic variations in loudness resulting from the interference of sound waves with slightly different frequencies.

Beats occur when sound waves interfere constructively, forming a loud sound and destructively forming a soft sound or no sound.

Beat frequency is the number of times that the loudness rises and falls every second. The beat frequency is the difference between the two sound frequencies.

In a pressure-time graph that results from the interference from sound sources, the loud sound occurs when the pressure is the greatest and the faint sound occurs when the amplitude of the graph is the lowest. The time period from one faint sound to the next is the period of the beats.

Sound waves consist of alternating high-pressure areas and low-pressure areas.

Sound waves can travel down narrow columns, reflect from the end of the column, and interfere with incoming sound waves to produce standing waves (a series of nodes and antinodes). If a displacement antinode is located at the end of the column near the source of the sound, resonance occurs (the sound is louder).

The lowest frequency with which a column of air resonates is the fundamental frequency or the first harmonic.

For a **closed-pipe column**, a **displacement node** is found at the closed end and a **displacement antinode** is found at the open end near the source of the sound.

The first resonant length is $\frac{1}{4}\lambda$. Each succeeding resonant length is $\frac{1}{2}\lambda$ larger (nodes are $\frac{1}{2}\lambda$ apart).

For an **open-pipe column**, a **displacement antinode** is found at the open end where reflection occurs, and a **displacement antinode** is also found at the open end near the source of the sound.

The first resonant length is $\frac{1}{2}\lambda$. Each succeeding resonant length is $\frac{1}{2}\lambda$ larger (nodes are $\frac{1}{2}\lambda$ apart).

NOTES

Assignment 9.1, Part B

Beats and Resonance (6 MARKS)

1. When a guitar string is sounded with a 440 Hz tuning fork, a beat frequency of 5 Hz is heard. When the same string is sounded with a 436 Hz tuning fork, the beat frequency is 9 Hz. What is the frequency of the string?

2. The range of human hearing is about 20.0 Hz to 20 000 Hz. Assume that the speed of sound is 343 m/s in a place where a pipe organ may be found. We assume that the pipes are open at both ends and are producing sound at their fundamental frequencies. What must be the lengths of the shortest and longest pipes?

(continued)

Assignment 9.1, Part B: Beats and Resonance (continued)

Method of Assessment

The total of six marks for this assignment will be determined as follows:

- 1 mark for determining the correct possible frequencies for each guitar string in question 1
- 1 mark for determining what the frequency of the tuning fork must be in question 1
- 0.5 marks for using the correct equation for the resonant length of the short pipe in question 2
- 1 mark for determining the wavelength correctly for the short pipe in question 2
- 0.5 marks for determining the length of the short pipe correctly in question 2
- 0.5 marks for using the correct equation for the resonant length of the long pipe in question 2
- 1 mark for determining the wavelength correctly for the long pipe in question 2
- 0.5 marks for determining the length of the long pipe correctly in question 2

Lesson 3: The Speed of Sound in Air and the Doppler Effect (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- describe a method to determine the speed of sound given distance and time, or given the frequency and wavelength from a resonance experiment
- explain how the speed of sound is dependent on the temperature of a material or the type of the material
- explain what is meant by the term "Doppler effect"
- explain what happens to the observed wavelength and frequency of the sound by a stationary observer for a moving source
- explain what happens to the observed wavelength and frequency by a moving observer when the source is stationary
- explain how the Doppler flow meter can be used to diagnose a problem with blood flow in a person

Key Words

speed of sound	frequency	resonance
Doppler effect	Doppler flow meter	

Introduction

In this lesson, you will learn how to determine the speed of sound. We will be able to make use of two different but related ideas, $v = d/t$ and $v = \lambda f$. You will learn how the speed of sound depends on the temperature of the medium carrying the sound and on the type of material. You will then learn about the Doppler effect, and how the wavelength and frequency of the sound change or appear to change when the sound source or the observer are moving. An interesting medical application of the Doppler effect is the Doppler flow meter. You will learn how this device can be used to measure blood flow in a blood vessel. Finally, we will discuss how the intensity of sound is measured and how this intensity is related to everyday sounds.

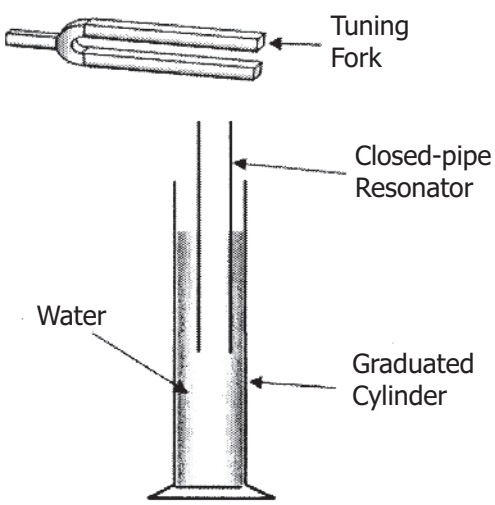
Measuring the Speed of Sound

During a thunderstorm, a distant lightning flash can be seen several seconds before the accompanying thunder is heard. You may have been at a track meet and noticed that the timer at the finish line sees the smoke from a starter's pistol before the sound is heard.

Over short distances, light travels almost instantaneously. Therefore, the time that elapses between seeing a lightning flash and hearing the thunder or the time between firing a gun and hearing the bang must be the time required for the sound to travel from its source to the listener. This could be one way to attempt to measure the speed of sound. Another way would be to make a loud sound, such as clapping your hands, and to time how long it takes an echo to return. If you also know the distance to the reflecting surface, then by using $v = d/t$, you could calculate the speed of the sound wave. In this case, d would represent the total distance travelled and t would be the total time. In 1636 in the city of Paris, Father Mersenne used a similar technique to measure the speed of sound. He found it to be 1000 ft./s, which is not far off the present value of 331.45 m/s (i.e., 1087.4 ft./s) in air at 0° C.

In the previous lesson, we learned that the air in a tube that is closed at one end will produce the best resonance when the tube is one-fourth as long as the wavelength of the sound that it reinforces. So, for example, a tube that is one metre long produces resonance with a sound wave that is four metres long.

One way to carry out this experiment is to place water into a large cylinder. A smaller diameter glass tube that is open at both ends could be moved up and down to adjust the length of the column of air inside the tube. A tuning fork is set to vibrate above the column of air. As the vibrating tuning fork is held over the open end of the tube, the glass tube can be moved slowly up and down in the water of the cylinder until the loudest sound produced by the resonance is found. The length of the air column can then be measured. The wavelength of the sound that produced this resonance will be four times the length of the air column. The frequency of the tuning fork is known. By using $v = \lambda f$, the speed of sound can be calculated.



This technique will be used in the next lesson, where your task will be to use a closed-pipe resonator to measure the speed of sound in air.

Temperature and Material and the Speed of Sound

We have already seen that the speed of sound depends on the type of material it is travelling through. Sound travels through gases, liquids, and solids at considerably different speeds. At 20° C, the speed of sound in air is 343 m/s. In fresh water at 20° C, the speed of sound is 1482 m/s. In steel, the speed of sound is 5960 m/s.

In general, sound travels slowest in gases, faster in liquids, and fastest in solids.

The **speed** of sound in a material also depends on the temperature of the material.

In the previous section of this lesson, we learned that the speed of sound in air at 0° C is 331.35 m/s. In a confined sample the speed of sound increases with the temperature. In air, the speed of sound increases by 0.60 m/s for each 1.0° C increase. If we use 331 m/s for the speed of sound at 0° C, then the speed of sound at 20° C is v = 331 m/s + (20)(0.60 m/s) = 343 m/s. The speed of sound in the air does not depend on the air pressure. So the speed of sound in the thin air on a mountaintop is the same as it is at sea level, provided the temperature is the same. Also, the speed of the sound does not depend on the frequency of the sound. This is easily confirmed every time you listen to sound in a large space such as a concert hall or a stadium. The high frequencies and the low frequencies reach your ears at the same time.

To calculate the speed of sound in air, take 331 m/s and add the product of (0.60 m/s)/° C and the temperature of the air.

$$v = 331 \text{ m/s} + (0.60 \text{ m/s/° C})T$$

Quantity	**Symbol**	**Unit**
Speed of sound in air	v	metres/second (m/s)
Temperature of the air	T	degrees Celsius (° C)

Example 1: The Speed of Sound in Air

What is the speed of sound in air at 0° C? … at room temperature of 20.5° C?

Using the equation above, simply substitute the temperature into the equation and solve for the speed of sound in air.

At 0° C:

$$v = 331 \text{ m/s} + (0.60 \text{ m/s/° C})T$$
$$v = 331 \text{ m/s} + (0.60 \text{ m/s/° C})(0° \text{ C}) = 331 \text{ m/s}.$$

At 20.5° C:
At 0° C:

$$v = 331 \text{ m/s} + (0.60 \text{ m/s/° C})T$$
$$v = 331 \text{ m/s} + (0.60 \text{ m/s/° C})(20.5° \text{ C}) = 331 \text{ m/s} + 12 \text{ m/s} = 343 \text{ m/s}$$

You can see that at higher temperatures, sound travels at a greater speed.

The Doppler Effect and a Moving Source

The strange thing about the Doppler effect is that while most people have heard of the term "Doppler effect" they don't know what it is, even though (it turns out) practically everybody has actually observed this neat phenomenon. So what we must first do is connect what you have likely already experienced to the term.

To best understand the Doppler effect, let's start with a silly request. Right now, make the sound of a fast motorcycle that "blows by you" (imagine that you are standing on the side of the road when the motorcycle comes past you). Go ahead—actually make the sound as best you can. It would go something like this: "WHZZZZZZ-YOOOOOO." This noise is an example of the Doppler effect—really! The essence of the Doppler effect is that the sound of an object will change, depending on how it is moving compared to you.

When the motorcycle was moving **towards you**, it sounded one way; and when it was moving **away from you** it sounded different. This is why the sound changed at the moment that it passed by you. This is not something special about motorcycles—anything that makes noise while moving has the way it sounds affected. There are two important things needed though: sound and movement. It turns out that at least one of either the source of the sound (the motorcycle in this case) or the observer of the sound (you in this case) must be moving.

> The Doppler effect is produced from the combination of sound and motion—either the source of the sound, the listener of the sound, or both must be moving.

The person riding on the motorcycle did not hear what you heard at all—he or she only heard one kind of sound coming from the motorcycle, and it wasn't either of the distinct sounds that you heard. In fact, we could say that the rider heard the "true sound" of the motorcycle, and you heard two different kinds of sounds: when the motorcycle was coming towards you, you heard a higher pitched sound than the motorcycle was really producing (due to the Doppler effect) and when the motorcycle was moving away from you, you heard a lower pitch sound (again, due to the Doppler effect). In general, when a source and a listener **move** to get **closer** to each other, the listener will hear **higher pitch sound**, and when they **move** in a way as to get **farther** from each other, the listener hears a **lower pitch sound**.

> The Doppler effect is the perceived change in pitch (or frequency) of a sound detected by a listener, compared to the pitch (or frequency) actually produced by the source due to the motion involved.

Phenomena such as this were first identified in 1842 by the Austrian physicist Christian Doppler (1803–1853) and are now referred to as the Doppler effect; the sound heard is sometimes said to have been "Doppler Shifted" (either higher or lower pitched).

An Analogy for the Doppler Effect

Imagine that you and I are standing on opposite sides of a field, and that I have a stack of Frisbees. Let's also imagine that I can throw the Frisbees with perfect accuracy—and that you can catch them perfectly every time. In this, I am acting as the "source" of Frisbees. I am throwing them to you, and you are the "observer" of these Frisbees—you are receiving them.

If I start throwing them towards you at the rate of one Frisbee per second (1 Hz), you will catch them at that same rate (1 Hz) if we are both standing still in the field. Notice that since we are standing some fair distance apart, at any given moment there will be several Frisbees in the air moving from me to you. Of course, this would be extremely difficult to actually do, but we are assuming that we are quite talented!

If I double the rate at which I throw the Frisbees, you will have to double the rate at which you catch them. If I start throwing them at the rate of two Frisbees per second (2 Hz), you will have to catch them at that same rate, and of course now the Frisbees would be more closely spaced in the air, and there would be twice as many in the air at any given moment, compared to before (the "length between Frisbees" is only half now, in response to my frequency doubling).

Now for the interesting part: what if I go back to my original 1 Hz throwing rate, but this time I start running towards you, still throwing the Frisbees at 1 Hz (I'll take my motion into account when throwing so that the Frisbees don't move any faster through the air). Would you still be catching them at 1 Hz? The answer is no—you will catch them at a higher frequency than 1 Hz. This is because when I throw one Frisbee and it moves towards you, the next Frisbee I throw won't have to go as far in getting to you…because I would be closer to you when I throw it. In fact, the spacing of the Frisbees in the air would again get closer, even though I am still only throwing them at 1 Hz. In fact, if I run fast enough, I could achieve the same spacing as we had when I was throwing them at 2 Hz. This would mean that you would necessarily be catching them at 2 Hz.

Of course, this can't last forever. Eventually, I'll get to you. But if I simply "run by" and keep running so that I am now moving away from you (being so talented with Frisbees, I should be able to keep throwing my Frisbees in the exact same way as before), we would find that unlike a moment ago when the Frisbee spacing was "extra close," resulting in your catching them at a higher frequency, the Frisbee spacing would instead be extra far and you would be catching them at a lower frequency than I would be throwing them. In effect, we have produced a "Doppler effect" with Frisbees.

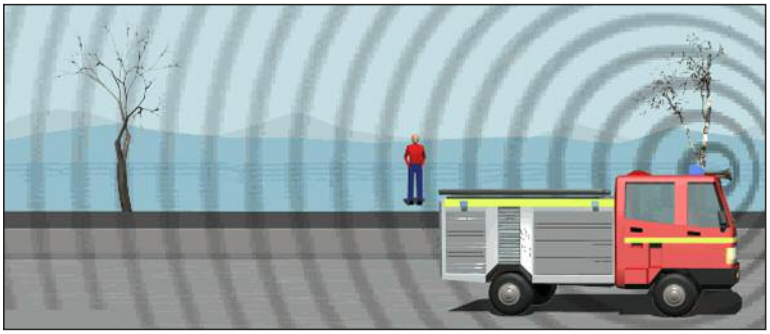
The Doppler Effect and Sound Waves

To see how the Doppler effect arises with sound waves, realize that the source of sound waves emits wave pulses (which is similar to the way I was throwing Frisbees). In the diagram below, each circular arc represents a sound wave pulse emitted by the siren on the stationary truck. The sound pattern is symmetrical. Listeners standing in front of or behind the truck detect the same number of pulses per second and consequently hear the same frequency.

Once the truck begins to move as in the diagram below, the compressions ahead of the truck are now closer together resulting in a decrease of the wavelength of the sound. This "bunching-up" occurs because the truck "gains ground" on a previously emitted compression before emitting the next one. Since the compressions are closer together, the observer standing in front of the truck senses more of them arriving per second than when the truck is stationary. The increased rate of arrival corresponds to a greater sound frequency, which the observer hears as a high pitch.

At the moment when the truck passes the observer, the frequency of the sound waves reaching the observer decreases. This is when the observer hears the change in pitch, from a high pitch to a lower pitch.

Behind the truck the compressions are farther apart than they are when the truck is stationary. This increase in wavelength occurs because the truck pulls away from compressions emitted toward the rear. As a result, fewer compressions per second arrive at the ear of the observer behind the truck, corresponding to a smaller sound frequency or lower pitch.



The Doppler Effect and a Moving Observer

Going back to our Frisbee game, let's now imagine that I am throwing Frisbees at a rate of 1 Hz, and that you are running towards me. You will now find that you are again receiving them at a higher frequency than 1 Hz. This is because every time you catch one, instead of merely waiting for the next one to arrive, you are running out to meet it. As a result, you catch it sooner than you otherwise would have. Similarly, once you have run past me (and so are now running away from me), you will be receiving them less frequently. This is similar to what we saw for a moving source, and allows us to more generally state the Doppler effect.

> The observed frequency will be higher than that of the source when the source and/or observer move to decrease the space between them. The observed frequency will be lower than that of the source when the source and/or observer move to increase the space between them.

It is important to note that the physical reason for the Doppler effect is different, depending on which is moving—the source or the observer. When the source moves and the observer is stationary, the wavelength of the sound changes, which gives rise to the higher frequency and a higher pitch heard by the observer. On the other hand, when the observer moves and the source is stationary, the wavelength of the sound does not change. Instead, the moving observer intercepts a different number of wave pulses per second than a stationary observer would, and therefore detects a different frequency.

Medical Applications of the Doppler Effect

A particularly interesting medical application of the Doppler effect is the **Doppler flow** meter. This device is used to measure the speed of blood flow.

The transmitting and receiving elements are placed directly on the skin. The transmitter emits a continuous sound whose frequency is typically about 5 Hz. When the sound is reflected from the red blood cells, the frequency is changed because the red blood cells are moving. The receiving element detects the reflected sound and an electronic counter measures its frequency. The reflected frequency is Doppler-shifted relative to the transmitter frequency. From the change in frequency, the speed of the blood flow can be determined. Typically, the change in frequency is around 600 Hz for flow speeds of about 0.1 m/s. The Doppler flow meter can be used to locate regions where blood vessels have narrowed, since greater flow speeds occur in narrowed regions.

Learning Activity 9.4

The Doppler Effect

1. A tuning fork of frequency 261.6 Hz (C note) is vibrating over an air column that is a tube that is closed at one end. If the speed of sound is 331 m/s, what should be the shortest length of the air column to produce resonance?
2. A loudspeaker produces a sound wave. When the wave travels from air into water, does the wavelength of the sound increase, decrease, or remain the same? Justify your answer. Note that the frequency of the sound wave does not change as it moves from the air into the water.
3. An aircraft carrier has a speed of 13.0 m/s relative to the water. A jet is catapulted from the deck and has a speed of 67.0 m/s relative to the water. The engines produce a whine at a frequency of 1550 Hz and the speed of the sound is 343 m/s. Would the crew hear a higher pitched sound or a lower pitched sound?
4. An ultrasonic wave at 80 000 Hz is emitted by a transmitter into a vein where the speed of sound is about 1.5 km/s. The wave reflects off the red blood cells moving toward the stationary receiver. Will the reflected frequency be higher or lower than the frequency of the emitted sound?

(continued)

Learning Activity 9.4: The Doppler Effect (continued)

5. a) What is the speed of sound in air at a temperature of 25.0° C?
   b) If a sound from a vibrating tuning fork resonates in an open-pipe air column that is 44.8 cm long for the second resonant length, what is the wavelength of these waves?
   c) What is the frequency of these waves?
6. a) Give two factors upon which the speed of sound depends, and describe how the speed depends on each factor.
   b) Account for each of the factors listed in part (a)

Lesson Summary

It is possible to measure the speed of sound by $v = d/t$ if the distance the sound travels and the time are known. It is also possible to measure the speed of sound using $v = \lambda f$ by an experiment involving resonance in an air column.

The higher the temperature of the medium through which sound travels, the greater is the speed of sound. In air, the speed of sound, at some temperature above 0° C, is given by $v = 331$ m/s + (T ° C)(0.60 m/s/° C).

The higher the temperature of the medium through which sound travels, the greater is the speed of sound.

In general, sound travels slowest in gases, faster in liquids, and fastest in solids.

The **Doppler effect** is the change in pitch or frequency of the sound detected by an observer because the sound source and the observer have different velocities with respect to the medium in which the sound travels.

When a moving source approaches an observer, the wavelength of the sound at the observer is shorter and the frequency is higher. When the source moves away from a stationary observer, the wavelength of the sound at the observer is longer and the frequency of the sound is lower.

When a moving observer approaches a stationary source of sound, the actual wavelength of the sound is not changed, but only appears to be shorter to the observer. The perceived frequency is higher and a higher pitch is heard.

The Doppler flow meter can be used to measure the speed of blood flow. The change in frequency between transmitted sound and reflected sound can be used to determine the speed of blood flow. This in turn can be used to locate regions where blood vessels have narrowed, since greater flow speeds occur in narrowed regions.

Assignment 9.1, Part C

The Doppler Effect (5 MARKS)

1. An ultrasonic ruler can be used to measure the distance between itself and a target, such as a wall. To initiate the measurement, the ruler generates a pulse of ultrasonic sound that travels to the wall and, like an echo, reflects from it. The reflected pulse returns to the ruler, which measures the time it takes for the round-trip. Suppose the round-trip travel is 20.0×10^{-3} s on a day when the temperature of the air is 23.0° C.

   a) Determine the speed of sound in the air at this temperature.

   _____

   b) Determine the distance to the wall.

   _____

   _____

   _____

   _____

2. A music fan at a swimming pool is listening to a radio on a diving platform. The radio is playing at a constant frequency tone when this person, clutching the portable radio, jumps. Describe the observed frequency or pitch for the following three observers. Explain your reasoning.

   a) The person holding the radio.

   _____

   _____

   _____

(continued)

Assignment 9.1, Part C: The Doppler Effect (continued)

b) A person left behind on a platform.

_____

_____

_____

c) A person below the platform floating on a rubber raft.

_____

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for determining the speed of sound in question 1(a)
- 1 mark for determining the distance to the wall in question 1(b)
- 1 mark for each of parts (a), (b), and (c) in question 2

Lesson 4: Video Laboratory Activity: Resonance and the Speed of Sound (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ determine the wavelength of sound waves at three different frequencies using the principle of sound resonance
- ❑ determine the speed of sound at three different frequencies

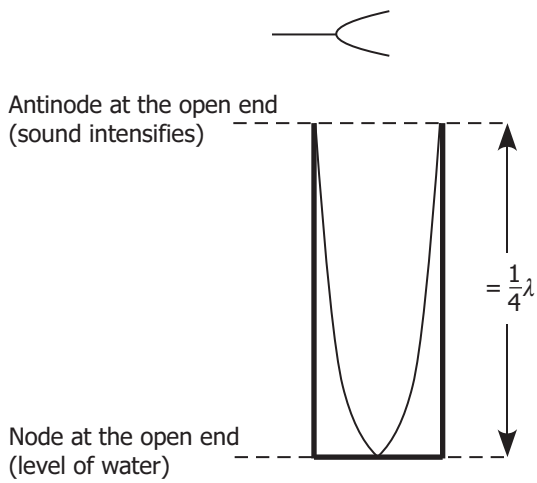
Introduction

In this lesson, you will view *Resonance and the Speed of Sound*, a short video laboratory activity found in the learning management system (LMS). In this lab, you will determine the wavelength and the speed of sound by using the ideas of resonance and standing waves in a tube that is closed at one end.

When a tuning fork is struck with a rubber hammer, it vibrates at its fundamental frequency. The vibrating tuning fork can be used to make the air inside of a closed tube vibrate. By adjusting the length of the air column inside of the tube, we can find a point where the sound we hear is the loudest. At this point, the longitudinal sound waves that are travelling towards the closed end, and the waves that are reflecting from the closed end reinforce each other to produce a **standing wave**. In a standing wave, the points where the medium does not vibrate are called **nodes**. For a closed tube, one of the nodes is found at the closed end. In between the nodes are the places where sections of the medium reinforce each other. The points of maximum reinforcement are called **antinodes**.

In the case of a closed tube, the minimum length of a standing wave that can be formed occurs when there is a node at the closed end of the tube and an antinode occurs at the open end. In the ideal case, the length of the tube is one-quarter of a wavelength $\left(L = \frac{1}{4}\lambda\right)$. Therefore, the wavelength of the sound for a resonating air column with a closed end can be found using $\lambda = 4L$. However, in this lab, we use the equation $\lambda = 4(L + 0.4d)$ where λ is the wavelength of the sound, L is the length of the closed tube, and d is the

diameter of the tube. The $0.4d$ is placed in the equation as a small correction that takes into account the fact that the air molecules at the open end of the tube do not move in only one dimension but form an antinode slightly above the open end of the tube. This is a more accurate way to calculate the wavelength for this kind of experiment.



When a standing wave is formed, it vibrates to produce a sound for that wavelength. The lowest frequency of sound is called the **fundamental frequency** or **first harmonic** and the symbol f_0 is used to represent this frequency. Once the wavelength of the sound is known, we can determine the speed of the sound using $v = \lambda f$. This value of v is considered the experimental value. We will compare this value to the theoretical value found using $v = 331.5\ \text{m/s} + 0.6T$ where T is the temperature of the air in ° C.

Video Laboratory: Resonance and the Speed of Sound

Introduction

In this lab activity, you will view *Resonance and the Speed of Sound*, a short video laboratory activity found in the learning management system (LMS). You will collect some data from the video so you should begin by reading the introduction and answering the pre-lab questions.

When you have finished the lab, you will complete a Laboratory Report, which is found at the end of this and every other Laboratory Assignment. The Laboratory Report is the only part of this assignment that you will hand in. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

Sample Problem

The first node in a tube of 4.0 cm in diameter is found at 22.0 cm from the top of the tube. The tube is resonating at the fundamental frequency from a source of 356 Hz and the temperature of the room is 21.0° C.

1. Find the wavelength:

   $\lambda = 4(L + 0.4d)$

   $\lambda = 4(22.0 + 0.4(4))$

   $\lambda = 0.944$ m

2. Find the experimental value of the speed of sound:

   $v = \lambda f$

   $v = 356(0.944)$

   $v = 336$ m/s

3. What is the theoretical speed of sound at this temperature?

   $v = 331.5 \text{ m/s} + 0.6T$

   $v = 331.5 + 0.6(21.0)$

   $v = 344$ m/s

4. Calculate the percentage error between the experimental and theoretical values for the speed of sound.

$$\% \text{ error} = \frac{\left| v_{\text{actual}} - v_{\text{experimental}} \right|}{v_{\text{actual}}} \times 100$$

$$\% \text{ error} = \frac{344 - 336}{344} \times 100$$

$$\% \text{ error} = 2.33\%$$

Purpose

Part 1: To determine the wavelength of sound using the principle of sound resonance.

Part 2: To determine the frequency of an unknown tuning fork.

Apparatus

- large cylinder
- graduated glass tube
- thermometer
- tuning fork of frequency 512 Hz
- unknown tuning fork

Procedure

Part 1

1. Fill a large cylinder nearly to the top with water and insert into the water a graduated glass tube that is open at both ends.
2. Record the frequency of the tuning fork. The tuning fork is made to vibrate and is held over the open end of the tube.
3. Move the glass tube up and down until the resonance produces the loudest sound at the first node.
4. Record the length of the resonating air column using the markings on the tape.
5. Record the diameter of the tube and the temperature of the room.

Video Viewing

View the video *Resonance and the Speed of Sound*, which can be found in the learning management system (LMS).

Data and Calculations

Frequency of the Tuning Fork (Hz)	Diameter of the Tube (m)	Temperature of the Room (°C)	Distance to the First Antinode (m)

The wavelength of the sound wave is calculated using $\lambda = 4(L + 0.4d)$, where λ is the wavelength of the sound, L is the distance to the first antinode, and d is the diameter of the tube. The calculated speed is $v = f\lambda$ or $v = f[4(L + 0.4d)]$.

Wavelength (cm)	Speed of Sound (m/s)

Part 2

An unknown tuning fork was found in the lab. Using the theoretical speed as $v = 331.5$ m/s + $0.6T$, find the frequency of the tuning fork.

1. Record the point where the first antinode appears. Remember this occurs when the level of the sound is reinforced.
2. The inside diameter of the tube is 3.5 cm = 0.035 m. The air temperature was 23.0° C.

Theoretical Speed of Sound (m/s)	Diameter of the Tube (m)	Temperature of the Room (°C)	Distance to the First Antinode (m)

Unknown Frequency (experimental)	
Unknown Frequency (actual)	

Discussion

As the frequency of the tuning fork increased, what happened to the distance to the first antinode?

Discuss possible sources of error and how you would reduce the error.

Calculate the percent error for the speed of sound in Part 1 using:

$$\% \text{ error} = \frac{|\text{actual speed} - \text{experimental speed}|}{\text{actual speed}} \times 100$$

Calculate the percent error for the frequency in Part 2 using:

$$\% \text{ error} = \frac{|\text{actual frequency} - \text{experimental frequency}|}{\text{actual frequency}} \times 100$$

The expression in the numerator is an absolute value sign. The positive value of the difference is used.

Conclusion

Answer the Purpose.

Assignment 9.2

Video Laboratory Activity: Resonance and the Speed of Sound

(20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow those directions.

The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words, in a brief paragraph (do not use point form), how the experiment was performed.

_____

_____

_____

_____

_____

(continued)

Assignment 9.2: Video Laboratory Activity: Resonance and the Speed of Sound (continued)

Data and Calculations:

- Include photocopies of your data measurements (e.g., tapes or tracks) if they were provided in the notes.
- Record the raw data for each part of the experiment in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data. For example, if you use a formula, write out the formula, and show your substitutions and calculations. This should be done for each different calculation (i.e., whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be done.

(continued)

Assignment 9.2: Video Laboratory Activity: Resonance and the Speed of Sound (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce the error.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. Errors are always made when making measurements. In the error analysis, your job is to look critically at the procedure, identify possible sources of error (there may be several), and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 9.2: Video Laboratory Activity: Resonance and the Speed of Sound (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

_____

_____

_____

_____

_____

Marking Rubric for Assignment 9.2

Section of Report	Possible	Actual
Purpose	1	
Apparatus and Procedure	2	
Completed Data Tables—Part 1	4	
Calculations of Wavelength and the Speed of Sound	4	
Completed Data Tables—Part 2	2	
Calculations of Unknown Frequency	2	
Discussion—Sources of Error	2	
Calculation of Percentage Error (Parts 1 and 2)	2	
Conclusion	1	
Total	**20**	

Lesson 5: Music and Noise (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the terms "diatonic scale," "major triad," and "octave"
- ❑ calculate the frequency of notes in a major triad given the frequency of one of the notes in a triad
- ❑ calculate the frequency of a note an octave above or below a given note
- ❑ explain why the sounds heard from different instruments are perceived differently even when the same note at the same loudness is played
- ❑ explain what is meant by the terms "timbre" and "complex sound wave"
- ❑ explain what characteristics of a sound make it a pleasing sound, and what characteristics of sound make it noise
- ❑ explain how loudness and the amplitude of a wave are related
- ❑ differentiate between the intensity of sound and the decibel level of the sound

Key Words

diatonic scale	major triad	octave
timbre	complex sound wave	noise
intensity	decibel	

Introduction

In this lesson, we will see how loudness can be indicated by use of the decibel scale and also explain what gives different sources of sound (both pleasing sounds as well as unpleasing noises) their distinct sound. In this lesson, we study some of the science behind music. You will see the strong relationship between the frequencies of sound and how the diatonic scale, the major triad, and the octave are related. You will see how the tone quality or timbre of sound is related to fundamental frequency, harmonics, and complex sound waves. You will learn what constitutes noise and how noise can be controlled.

Sound Energy, Intensity, and Decibels

Sound waves carry energy with them as they move from one place to another. This energy is what makes an eardrum vibrate when the sound is heard. In extreme cases, such as a sonic boom, the energy can be sufficient to cause damage to windows and buildings. The amount of energy that is carried depends on the amplitude of the wave. So for example, if a guitar string is plucked with a greater force, then more energy is given to the string, which makes it vibrate with a larger amplitude. This results in the sound being louder and it too carries more energy.

> The intensity of a sound wave is a measure of how "concentrated" the energy carried by a sound wave is (both in time and in space).

Thus, a high-intensity sound is one that carries a lot of energy into a small space in a short amount of time. Intensity is closely related to amplitude. In general, larger amplitude waves have a greater intensity. As the sound wave travels away from its source, it spreads out, and so the energy is less focused—the intensity of the wave is less.

> The **decibel** (dB) is a measurement that is used to compare two sound intensities.
>
> A sound of zero decibels (0 dB) is the quietest sound that can be heard by a person with average hearing. This is called the **threshold of hearing**.

A sound that is 10 (10^1) times more intense than the threshold of hearing is assigned a sound level of 10 dB. Rustling leaves would have a level of 10 dB. A sound that is 100 (10^2) times more intense than the threshold of hearing is assigned a sound level of 20 dB. This is the sound of a whisper. An increase in 10 decibels represents an increase of 10 times in the intensity of the sound—the sound carries 10 times as much energy.

A sound that is 100,000 (10^5) times more intense than the threshold has a sound level of 50 dB. This is the sound of an average classroom with students actively working with each other. Other examples of sound levels are a car without a muffler at 100 dB and a live rock concert at 120 dB. The threshold of pain is the level of sound at which it actually becomes painful to hear the sound, which is about 130 dB.

> Sounds with decibel levels higher than about 130 dB are painful to hear—this is called the **threshold of pain**.

Earlier in this module we learned that **loudness** is a subjective measure of sound as interpreted by the person hearing the sound. It is important to note that doubling the intensity of the sound does not make the sound twice as loud. Hearing tests have shown that a one-decibel (1 dB) change in the intensity level is approximately the smallest change that the average listener can detect—two sounds that are less than 1 dB different are heard as being the same loudness. Experiments have also shown that if the intensity level **increases by 10 dB**, then the new sound **seems approximately twice as loud** as the original sound. For instance a 70 dB intensity level sounds about twice as loud as a 60 dB level, and an 80 dB intensity level sounds about twice as loud as a 70 dB level.

Musical Notes and Frequencies of Sound

The notes that make up the music we listen to correspond to specific frequencies of sound. For example, the note known as "Middle C" on a piano corresponds to a frequency of about 256 Hz (although this can vary as there is more than one standard for musical notes).

The most basic of the musical scales is called the **diatonic scale**. It is the fundamental building block of Western music tradition. If the nonsensical phrase "Do-Re-Mi-Fa-Sol-La-Ti-Do" means anything to you, then you are familiar with the diatonic scale. A diatonic scale is one that consists of three sets of major triads.

As suggested by the name, a **major triad** is a collection of **three** notes. These three notes have an interesting mathematical relationship in that they have frequencies in the ratio 4:5:6 (perhaps even more interestingly, they may be described as being "pleasing" to hear together). This means that if we wanted to construct a major triad with the lowest note having a frequency of 20 Hz, we would simply need to find the other two frequencies that fit this ratio. We could begin by dividing this lowest frequency by 4 to get 5 Hz. Although 5 Hz will not be in this major triad, we can describe it as the "base" frequency upon which the triad is based—it is the 4th, 5th, and 6th multiples of this

base that will make up the major triad. This means that the major triad would be 20 Hz (4 times the base frequency), 25 Hz (5 times the base frequency) and 30 Hz (6 times the base frequency). Since 20 Hz, 25 Hz, and 30 Hz are 4, 5, and 6 times the same base frequency, they are in the ratio of 4:5:6—which is what makes them a major triad.

An **octave** consists of the range of frequencies between a given musical tone (frequency) and the tone with double or half of this frequency. So, for example, the C note one octave above Middle C (which may be symbolized as C′) is 2(256 Hz) = 512 Hz. The C note one octave below Middle C is (256 Hz)/2 = 128 Hz. As for the other notes, which are lettered A though G, we may find their frequencies by recognizing the mathematical connections they have with each other. In particular, the notes C, E, and G form a major triad, as do F, A , and C′, as do G, B, and D′.

Consider this example: if the frequency of the C note is 256 Hz, then how can we find the frequency of the D note? Even though D is the "next" note, C and D are not in a major triad at all. But C, E, and G are, so by knowing C we can calculate either of these other two notes. G is also in the major triad G, B, D′, so if we know G we could then calculate D′, which is one octave higher than the D that we are trying to find. This means that D is half of D′. Although this sounds a bit complicated, it's not that bad at all, provided you know two things: the three major triad groupings and the fact that the notes making the major triad are in the ratio 4:5:6. Let's actually do this now.

Step 1: Knowing that C is 256 Hz, use the major triad C, E, G to calculate the base frequency for this major triad:

Since C is the first member of this major triad, we can find the base frequency for this triad by dividing its frequency by 4. Thus, the base frequency is 256/4 = 64 Hz.

Step 2: Knowing the base frequency is 64 Hz, calculate the frequency of G.

Since G is the third member of this major triad, it must be 6 times the frequency of the base frequency. Thus, G has a frequency of 6(64) = 384 Hz.

Step 3: Knowing that G has a frequency of 384 Hz, use the major triad G, B, D′ to find the frequency of D′.

Since G is the first member of this major triad, we can find the base frequency for this triad by dividing its frequency by 4. Thus, the base frequency is 384/4 = 96 Hz.

Step 4: Knowing the base frequency is 96 Hz, calculate the frequency of D′.

Since D′ is the third member of this major triad, it must be 6 times the frequency of the base frequency. Thus, D′ has a frequency of 6(96) = 576 Hz.

Step 5: Since D is one octave lower than D′, we can find the frequency of D.

D has a frequency that is one half of the frequency of D′. Thus, the frequency of D is 576/2 = 288 Hz—this is the frequency of the D note.

Tonal Quality and Timbre

Of course, up until now our investigation of musical notes has necessarily been quite simplified (and, to be honest, will continue to be somewhat simplified), but we must now address a very good question: if the physics explaining musical notes is simply that each note is a particular frequency of sound, then why doesn't any note played on two different types of instruments sound exactly the same? For example, why doesn't a C played on a piano sound the same as a C played on a guitar?

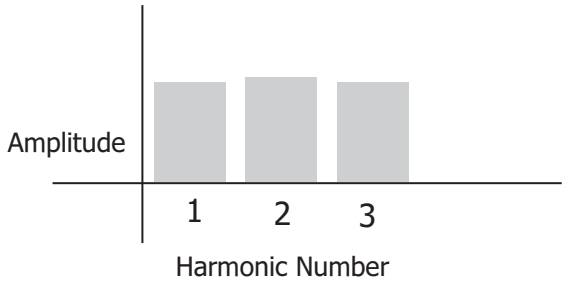
It is true that a C played on a piano as well as a C played on a guitar are both associated with the same frequency (assuming that they are in the same octave). But there is little chance of mistaking the sound produced by a piano for that of a guitar. In fact, if a pure tone of 256 Hz (a note of C) is played, it would not sound like a piano or a guitar! It would sound very much like a tuning fork, which produces pure tones (or nearly so).

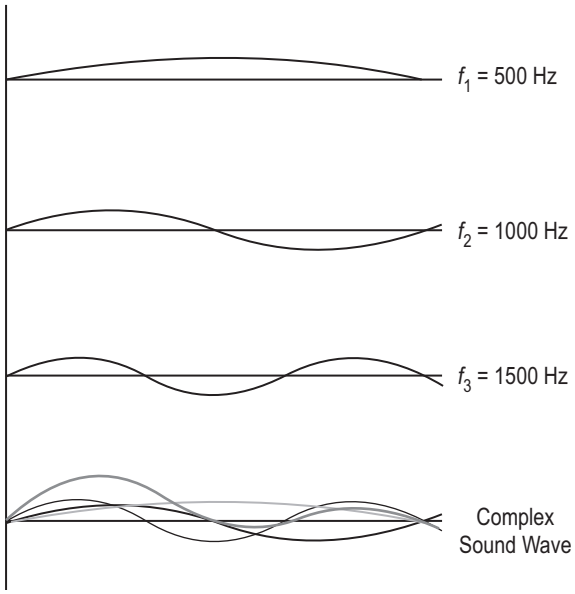
It turns out that musical instruments produce blends of frequencies at the same time. There is typically one dominant frequency for any particular note, and it is this dominant frequency that we have been speaking of. The actual sound waves from these instruments are quite complicated, and it is the specifics of these blends that give guitars and pianos (and indeed any instrument) their characteristic sounds. We refer to these frequency blends as the **timbre** of the sound.

> **Timbre** refers to the blend of frequencies present in a sound. While the same note played on two different types of instruments may be the same, they will differ in timbre.

We have already seen how standing waves are produced in transverse waves. Such standing waves are produced in string instruments such as the guitar or violin. We have also studied the production of longitudinal standing waves in air columns in instruments such as the flute or trumpet. The sounds from these instruments are produced at the fundamental frequencies of the instrument. However, when a musical instrument plays a note, it does not produce just the fundamental frequency. It also generates a number of harmonics. Different instruments generate harmonics to different extents, and the harmonics give instruments their characteristic sound qualities or timbres.

The sound wave produced by a musical instrument is called a **complex sound wave** because it consists of a mixture of the fundamental and harmonic frequencies. The pattern of pressure fluctuations in a complex wave can be obtained by the principle of linear superposition. The drawing below shows a bar graph in which the heights of the bars give the relative amplitudes of the harmonics contained in a note that a singer might produce. When the individual pressure patterns for each of the three harmonics are added together, they yield a complex pressure pattern. In practice, a bar graph such as that shown below can be determined using an electronic instrument called a **spectrum analyzer**.





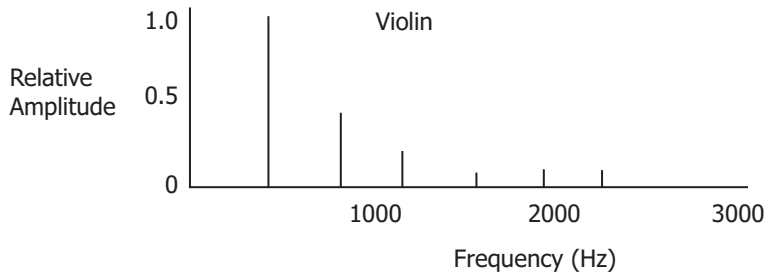
From the spectrum analyzer bar graph above, we see that three frequencies of sound (500 Hz, 1000 Hz, and 1500 Hz) are the first harmonic, second harmonic, and third harmonic frequencies. All three are at about the same amplitude.

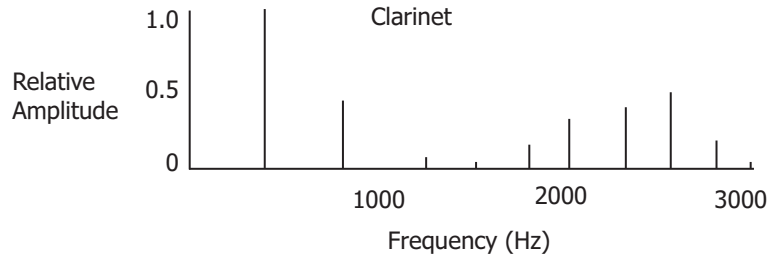
These three harmonics add together to give the complex sound wave. While each separate frequency is a pure tone and has a rather monotone sound, the complex wave has a more "pleasing" sound.

Pleasing Sounds

We have seen that a musical tone or timbre can be a pleasing sound. The **tone quality** is enhanced by the **complexity** of the sound wave. This complexity in enhanced by the number and distribution of the harmonics of the fundamental frequency superimposed on the sound wave. What is important is that the harmonics are based on the fundamental frequency. **Pitch** is associated principally with the **fundamental frequency** of a complex sound wave. So even though there may be several harmonics in a complex wave, they are related to the fundamental frequency and we hear this as a pitch we can identify.

The diagrams below show the same note played on a violin and on a clarinet. These diagrams are called **sound spectra**. The relative amplitudes of the harmonics are displayed. Note that the frequency with the **largest amplitude** is the **fundamental frequency** and it is this frequency that we hear as the **pitch**. The number of the harmonics for each instrument are not necessarily the same, and the amplitudes of these harmonics are different.



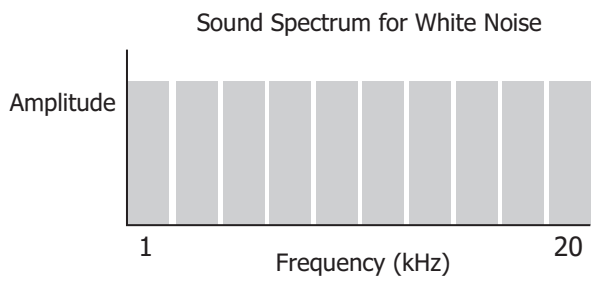


Noise

If there is a random mixture of frequencies, then the sound is not easily identified based on any pitch. This is not a pleasing sound and we call this **noise**.

> **Noise** is defined as a sound produced by irregular vibrations in a manner that is unpleasant to the listener.
>
> If all frequencies of sound are present in equal amplitudes, the result is called **white noise**.

This is the sound spectrum for white noise.



White noise has been found to have a relaxing effect and some dentists have used this to help patients relax.

Environmental Noise and Noise Control

There are many sources of noise in our environment. Some of them include traffic noise, airport noise, noise from the sonic boom of aircraft, and noise from music that may be played too loud. Exposure to noise or loud sounds has been shown to cause the ear to lose its sensitivity, especially to high frequencies. **The longer the person is exposed to loud sounds, the greater is the effect.**

A person can recover from short-term exposure in a period of hours, but the effects of long-term exposure can last for days or weeks. Long exposure to 100 dB or greater sound levels can produce permanent damage. Some rock performers have suffered serious hearing loss, some as much as 40%. Another source of hearing loss is the result of loud music from headphones used with CD and mp3 players. Headphones are placed next to the ear, in some cases right in the ear canal. The sound waves are funnelled directly into the eardrum, which experiences the maximum sound intensity. When these devices are played at a "normal volume," they may be producing sound at

the ear drum with an intensity of 120 dB. This efficient delivery system of the sound at maximum intensity over prolonged periods of time will result in physical damage to the ear and a loss of hearing.

There are various techniques to control the loudness of undesirable sounds. One of the more interesting ways of doing so is the use of **"noise-cancelling" headphones**. These look and function just like regular headphones, but they additionally have built in microphones and circuitry that detect external noise (such as the droning noise of an airplane). The electronic signals from the microphones are processed by the circuitry inside the headphones and reproduce a noise that is exactly **out of phase** compared to the original signal. This out-of-phase version is superimposed with the desired signal from the music being played, and played through the headphone speakers. The external noise then literally cancels due to destructive interference when it combines with the out of phase noise. The result is a dramatic reduction in the external noise heard by the person wearing these headphones (the music being played is unaffected).

Another very effective (and much less expensive) way to reduce sound is simply to wear ear plugs. They can reduce the sound level by about 10 dB. Construction workers and aircraft personnel are two examples of people in occupations that regularly wear ear protection.

Learning Activity 9.5

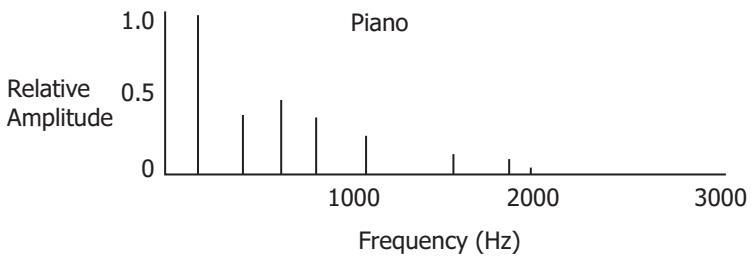
Music and Noise

1. If the frequency of a G note is 384 Hz, what must be the frequency of the B note? Use the major triad to determine the frequency.
2. The tones produced by a typical orchestra are complex sound waves, and most have fundamental frequencies less than 5000 Hz. However, a high-quality stereo system must be able to reproduce 20 000 Hz frequencies accurately. Explain why.
3. The soprano voice has a frequency range of approximately 250 Hz to 1000 Hz. The bass voice has a frequency range of approximately 80 Hz to 400 Hz. How would the sound spectrum be similar and different if both voices sang the same note at a fundamental frequency of 360 Hz?

(continued)

Learning Activity 9.5: Music and Noise (continued)

4. The diagram below shows the sound spectrum of a piano playing the A_3 note.



   a) Which line would represent the fundamental frequency?
   b) How would the sound spectrum of a flute playing the same note be different than the one for the piano?
   c) How would the sound spectrum for white noise be different than the one shown above for the piano?

5. Three distinguishing features of sound are tone quality, pitch, and loudness. Briefly describe what these are and upon what physical properties of waves they depend.

Lesson Summary

The **intensity** of a sound wave is the energy that is transported past a given area per unit of time. The intensity of the sound is greater as the amplitude increases and less when the distance from the source increases. The **decibel** (dB) is a measurement that is used to compare two sound intensities. An increase of 10 dB indicates a sound that is twice as loud.

The **diatonic scale** consists of three sets of major triads.

A **major triad** is a collection of three notes with frequencies in the ratio 4:5:6. In the diagram below, a major triad is the C-E-G triad shown below. If the frequency of the C note is 256 Hz, then the frequency of the E note is (5/4)(256) = 320 Hz and the frequency of the G note is (6/4)(256) = 384 Hz (or (6/5)(320 Hz) = 384 Hz).

An **octave** consists of the interval between a given musical tone and one with double or half the frequency. Within an octave, three major triads can be constructed, as shown below.

C	D	E	F	G	A	B	C′	D′
4	...	5	...	6				
			4	...	5	...	6	
				4	...	5	...	6

Timbre refers to the sound quality or tone colour and this depends on the spectrum of sound frequencies that produce a complex wave.

A **complex sound wave** consists of a mixture of the fundamental and harmonic frequencies.

The reason instruments sound different is because the relative amplitudes of the harmonics that the instruments create are different.

The **sound spectrum** of a pleasing tone has a **dominant resonant frequency** or pitch and a number of harmonics.

We can define **noise** as a sound produced by irregular vibrations or frequencies in a manner that is unpleasant to the listener. If all frequencies of sound are present in equal amplitudes, the result is white noise.

Hearing loss can occur if ears are exposed to loud sounds. Noise-cancelling headphones can control noise. Microphones and circuitry inside the headphone can detect and produce a sound that is exactly out of phase with the noise, producing a quieter background.

NOTES

Assignment 9.3

Music and Noise (5 MARKS)

1. What is the frequency of the C note two octaves above Middle C (f = 256 Hz)?

_____

_____

2. Two different instruments may play the same C note. What is it about the note and its harmonics that makes it possible for a person to distinguish between the instruments?

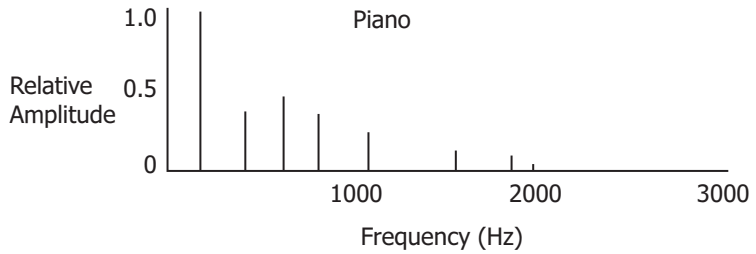
_____

_____

_____

_____

3. The diagram below shows the sound spectrum of a piano playing the A_3 note.



a) Which line would represent the fundamental frequency?

_____

_____

(continued)

Assignment 9.3: Music and Noise (continued)

b) How would the sound spectrum of a flute playing the same note be different than the one for the piano?

_____

_____

c) How would the sound spectrum for white noise be different than the one shown above for the piano?

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for the frequency of the C note in question 1
- 1 mark for the frequency of the C note in question 2
- 1 mark for the fundamental frequency in question 3(a)
- 1 mark for the explanation in question 3(b)
- 1 mark for the explanation in question 3(c)

Module 9 Summary

Congratulations on completing Module 9.

Submitting Your Assignments

You will not submit your Module 9 assignments to the Distance Learning Unit at this time. Instead, you will submit them, along with the Module 10 assignments, **when you have completed Module 10**.

You are now ready to start Module 10.

NOTES

Grade 11 Physics (30S)

Module 9: Sound

Learning Activity Answer Keys

MODULE 9: SOUND

Learning Activity 9.1: The Nature of Sound

1. Some animals rely on an acute sense of hearing for survival, and the visible part of the ear on such animals is often relatively large. Explain how this anatomical feature helps to increase the sensitivity of the animal's hearing for low-intensity sounds.

   Answer:

   Animals that rely on an acute sense of hearing for survival often have relatively large external ear parts. Low-intensity sounds do not have very much energy. The large ears intercept and direct more of the sound energy into the auditory system than small outer ears do.

2. Distinguish between

   a) loudness and pitch

      Answer:

      Pitch refers to the frequency of sound. We perceive sound with a higher frequency as having a higher pitch.

      Loudness is a subjective perception of sound. Generally, the larger the amplitude of the pressure-time transverse wave for sound, the louder the sound is.

   b) ultrasonic and infrasonic

      Answer:

      Humans have a range of frequencies of sound that they can hear. Sounds with a frequency that is too low for humans to hear is called infrasonic sound. Those frequencies of sound that are too high for humans to hear are called ultrasonic.

3. A dog can hear a sound produced by a dog whistle while its owner cannot. Explain how this is possible.

   Answer:

   The dog whistle is ultrasonic, which is above the range of human hearing.

4. What physical characteristic of a wave would you change to
   a) increase the loudness of a sound?
   b) to change the pitch?

   Answer:

   a) To change the loudness of the sound, you would change the amplitude.
   b) To change the pitch of the sound, change the frequency.

5. In December 1916, a major disaster befell a contingent of the Austrian army in the Alps fighting in World War I. Almost as soon as they began a cannon barrage, an avalanche of snow came roaring down, burying thousands of soldiers. What does this suggest about sound?

   Answer:

   This suggests that the vibrations of the sound waves carried enough energy to trigger the avalanche.

Learning Activity 9.2: Beats and Resonance: Part 1

1. A tuning fork vibrates at a frequency of 524 Hz. An out-of-tune piano string vibrates at 529 Hz.

   a) What is the beat frequency?

   b) How much time separates successive beats?

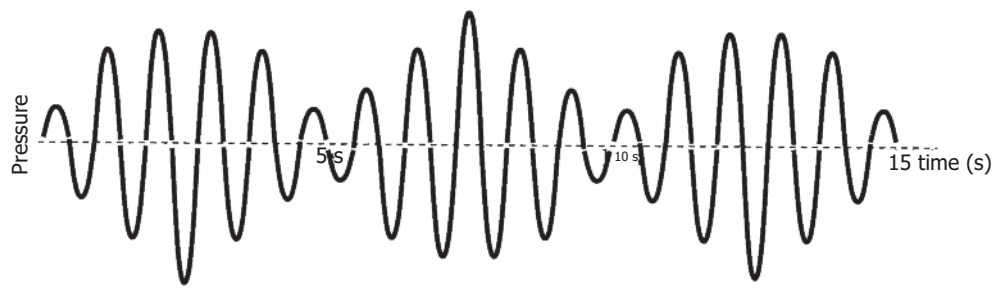
   Answer:

   a) The beat frequency is f = 529 Hz – 524 Hz = 5 Hz.

   b) When the "time between successive beats" is asked for, this means the period.

   The period of the beats is $T = \frac{1}{f} = \frac{1}{5\text{ Hz}} = 0.2\text{ s}$.

2. When two sound waves whose frequencies are near to each other interfere, they produce a pressure-time graph as shown below.



   For the graph above, what is the

   a) period of the beat?

   b) beat frequency?

   Answer:

   a) The diagram above shows three full cycles of the beats. One full cycle of the beat occurs over a time of 5 s. This is the period of the beat.

   b) The beat frequency is $f = \frac{1}{T} = \frac{1}{5\text{ s}} = 0.2\text{ Hz}$.

Learning Activity 9.3: Beats and Resonance: Part 2

1. When a stream of water is used to fill a graduated cylinder, a sound of steadily increasing pitch is heard. Explain why this happens.

   Answer:

   The water splashing into the cylinder produces all sorts of different wavelengths of sound. As the water fills the cylinder, a closed-pipe column of air is formed. At a given length of this column, a certain wavelength will form a standing wave inside the column. We hear the resonance of this column at that frequency.

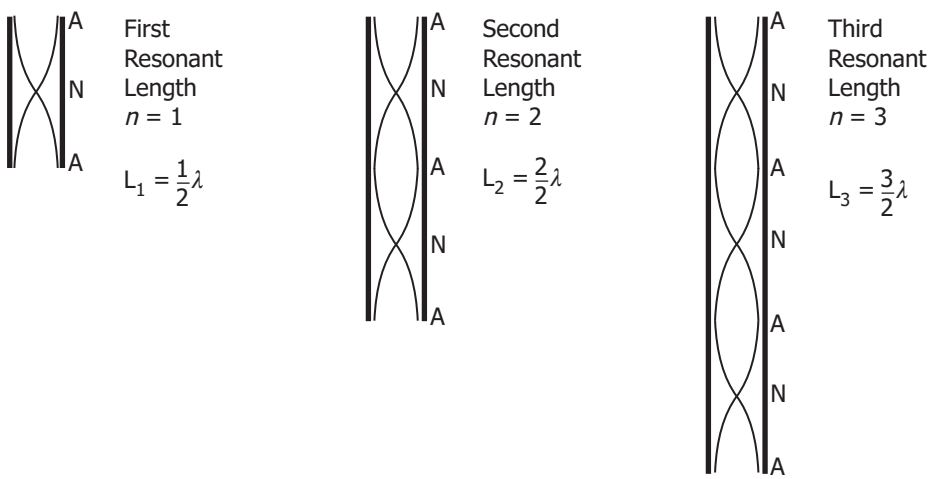
   As more water is added to the cylinder, the closed-pipe column of air decreases in length. The standing wave pattern that will fit into this shorter column of air will have a shorter wavelength and a higher pitch.

   So as the column continues to decrease in size, shorter and shorter wavelengths of sound produce the standing wave, resulting in a higher and higher pitch.

2. Sketch the displacement standing wave patterns for the first three resonant lengths of an open-pipe column.

   Answer:

Resonant Lengths of Open-Pipe Columns of Air Showing the Displacement Nodes and Antinodes



3. The first resonant length for an open-pipe column occurs when the column is 17.8 cm in length.

   a) What is the wavelength of this sound?

   Answer:

   Given: First resonant length $L_1 = 17.8$ cm

   Unknown: Wavelength $\lambda = ?$

   Equation: $L_1 = \frac{1}{2}\lambda$ rearranged to $\lambda = 2L_1$

   Substitute and solve: $\lambda = 2L_1 = 2(17.8 \text{ cm}) = 35.6 \text{ cm}$

   The wavelength of this sound is 35.6 cm.

   b) If the speed of sound in air is 342 m/s, what is the frequency of this sound?

   Answer:

   Given: Wavelength $\lambda = 35.6 \text{ cm} = 0.356 \text{ m}$

   Speed of sound $v = 342 \text{ m/s}$

   Equation: $v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$

   Substitute and solve: $f = \frac{v}{\lambda} = \frac{342 \text{ m/s}}{0.356 \text{ m}} = 961 \text{ Hz}$

   The frequency of the sound is 961 Hz.

4 a) Draw the displacement standing wave pattern for a closed-pipe column for the third resonant length.

   Answer:

   This standing wave will have a node at the closed end, 3 nodes in total, and an antinode at the open end of the air column.

b) If the wavelength of the sound is 23.8 cm, what is the length of this closed-pipe column?

Answer:

The third resonant length is $1\frac{1}{4}\lambda$.

$$L_3 = 1\frac{1}{4}\lambda = 1\frac{1}{4}(23.8\text{ cm}) = 29.8\text{ cm}$$

The third resonant length is 29.8 cm.

c) If the frequency of the sound increased, would the third resonant length increase or decrease? Justify your answer.

Answer:

If the frequency of the sound increased but the speed of the sound remained constant, then the wavelength would decrease (more waves have to fit into the same distance that the wave travels in 1 second). If the wavelengths are shorter, then the resonant lengths have to decrease.

5. The human auditory canal is essentially a narrow chamber closed at one end by the eardrum, forming a standing wave cavity. In an adult, this canal is about 2.70 cm long. Determine the fundamental frequency of the sound that will be amplified if the speed of sound is 343 m/s.

Answer:

For a closed-pipe air column, the first resonant length is $\frac{1}{4}\lambda$.

Given:	First resonant length	L_1 = 2.70 cm = 0.0270 m
	Wavelength	$\lambda = 4L_1 = 4(0.0270\text{ m}) = 0.108\text{ m}$
	Speed of sound	v = 343 m/s
Unknown: Frequency		f = ?
Equation:		$v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$
Substitute and solve:		$f = \frac{v}{\lambda} = \frac{343\text{ m/s}}{0.108\text{ m}} = 3180\text{ Hz}$

The fundamental frequency is 3180 Hz.

Learning Activity 9.4: The Doppler Effect

1. A tuning fork of frequency 261.6 Hz (C note) is vibrating over an air column in a tube that is closed at one end. If the speed of sound is 331 m/s, what should be the shortest length of the air column to produce resonance?

   Answer:

   The loudest resonance will occur when the length of the resonating air column is one-quarter the wavelength of the sound.

   $$L_1 = \frac{1}{4}\lambda$$

   Since we know the frequency and speed of the sound, we can determine the wavelength using the universal wave equation.

Given:	Frequency	$f = 261.6$ Hz
	Speed of sound	$v = 331$ m/s
Unknown:	Wavelength	$\lambda = ?$
Equation:		$v = f\lambda$ arranged to $\lambda = \frac{v}{f}$
Substitute and solve:		$\lambda = \frac{v}{f} = \frac{331 \text{ m/s}}{261.6 \text{ Hz}} = 1.26 \text{ m}$
		So, $L_1 = \frac{1}{4}(1.26 \text{ m}) = 0.315 \text{ m}$

   Therefore, the length should be 0.315 m.

2. A loudspeaker produces a sound wave. Does the wavelength of the sound increase, decrease, or remain the same, when the wave travels from air into water? Justify your answer. Note that the frequency of the sound wave does not change as it moves from the air into the water.

   Answer:

   The speed of sound is about 4 times greater in water as compared to air. The speed of sound can be determined by $v = f\lambda$. Since the speed of sound in water increases but the frequency remains the same, the wavelength of the sound must increase.

3. An aircraft carrier has a speed of 13.0 m/s relative to the water. A jet is catapulted from the deck and has a speed of 67.0 m/s relative to the water. The engines produce a whine at a frequency of 1550 Hz and the speed of the sound is 343 m/s. Would the crew hear a higher-pitched sound or a lower-pitched sound?

   Answer:

   Both the source and the observers are moving with respect to the air, but the source (the jet) is moving away from the observers (the crew). The observers would therefore hear a lower-pitched sound.

4. An ultrasonic wave at 80 000 Hz is emitted by a transmitter into a vein where the speed of sound is about 1.5 km/s. The wave reflects off the red blood cells moving toward the stationary receiver. Will the reflected frequency be higher or lower than the frequency of the emitted sound?

   Answer:

   As the red blood cells approach the transmitter, the sound waves are reflected at a higher frequency. The receiver detects the sound waves at a higher frequency.

5. a) What is the speed of sound in air at a temperature of 25.0° C?

   Answer:

   Temperature = 25.0 °C

   v = 331 m/s + (T °C)(0.60 m/s/ °C)

   v = 331 m/s + (25.0 °C)(0.60 m/s/°C) = 331 m/s + 15 m/s = 346 m/s

   b) If a sound from a vibrating tuning fork resonates in an open-pipe air column that is 44.8 cm long for the second resonant length, what is the wavelength of this wave?

   Answer:

Given: Second resonant length	L_2 = 44.8 cm
Unknown; Wavelength	λ = ?
Equation:	Second resonant length for an open pipe is $L_2 = 1\,\lambda$

   So the wavelength is 44.8 cm or 0.448 m.

c) What is the frequency of these waves?

Answer:

Given: Wavelength $\lambda = 0.448$ m

Speed of sound $v = 331$ m/s

Unknown: Frequency $f = ?$

Equation: $v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$

Substitute and solve: $f = \frac{v}{\lambda} = \frac{331 \text{ m/s}}{0.448 \text{ m}} = 739 \text{ Hz}$

The frequency is 739 Hz.

6. a) Give two factors upon which the speed of sound depends and describe how the speed depends on each factor.

Answer:

At the same temperature, the speed of sound is slowest in gases, faster in liquids, and fastest in solids.

In a given material in the same state, the speed of sound increases with temperature.

b) Account for each of the factors listed in part (a).

Answer:

For the states, it is the distance between the particles of the medium that determines the speed of sound. In gases, the particles are relatively far apart. It takes a long time for the disturbance to be transferred from one particle to another. In liquids, the particles are closer together so the disturbances are transferred more quickly. The transfer of the disturbance is still faster in solids where the particles are rigidly held in place.

For the effect of temperature in a given state, the higher the temperature, the faster the particles are moving and the more quickly a disturbance can be transferred from one particle to another. Therefore, the speed of sound increases.

Learning Activity 9.5: Music and Noise

1. If the frequency of a G note is 384 Hz, what must be the frequency of the B note. Use the major triad to determine the frequency.

   Answer:

   On the triad G-B-D′, G is 4. The base frequency is 384 Hz/4 = 96 Hz.

   In the triad, B is 5 so the frequency is 96 Hz x 5 = 480 Hz.

2. The tones produced by a typical orchestra are complex sound waves, and most have fundamental frequencies less than 5000 Hz. However, a high-quality stereo system must be able to reproduce 20 000 Hz frequencies accurately. Explain why.

   Answer:

   Tones produced by a typical orchestra are complex sound waves, and most have fundamental frequencies less than 5000 Hz. Since these tones are complex sound waves, each one consists of a mixture of the fundamental and the higher harmonic frequencies. The higher harmonics are integer multiples of the fundamental frequency. For example, in a tone with a fundamental frequency of 5000 Hz, the fourth harmonic will have a frequency of 20 000 Hz. Since most orchestra tones have fundamental frequencies less than 5000 Hz, a high-quality stereo system must be able to reproduce accurately all frequencies up to 20 000 Hz in order to include at least the fourth harmonic of all tones.

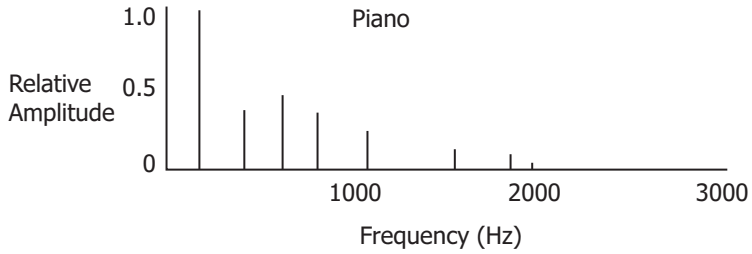
3. The soprano voice has a frequency range of approximately 250 Hz to 1000 Hz. The bass voice has a frequency range of approximately 80 Hz to 400 Hz. How would the sound spectrum be similar and different if both voices sang the same note at a fundamental frequency of 360 Hz?

   Answer:

   The sound spectrums would be similar in that the amplitude of the fundamental frequency would be the greatest.

   The sound spectrum would be different in that the number of harmonics would not necessarily be the same and their relative amplitudes would also be different.

4. The diagram below shows the sound spectrum of a piano playing the A3 note.



a) Which line would represent the fundamental frequency?

Answer:

The fundamental frequency would be the longest line, or the one at the far left.

b) How would the sound spectrum of a flute playing the same note be different than the one for the piano?

Answer:

The number of harmonics would not be the same. Also, the relative amplitude of the harmonics would be different.

c) How would the sound spectrum for white noise be different than the one shown above for the piano?

Answer:

The white noise spectrum would contain bars at all the frequencies and the amplitudes would all be the same.

5. Three distinguishing features of sound are tone quality, pitch, and loudness. Briefly describe what these are and upon what physical properties of waves they depend.

Answer:

The tone quality is enhanced by the complexity of the sound wave. This complexity in enhanced by the number and distribution of the harmonics of the fundamental frequency superimposed on the sound wave. What is important is that the harmonics are based on the fundamental frequency.

Pitch is associated principally with the fundamental frequency of a complex sound wave. So even though there may be several harmonics in a complex wave, they are related to the fundamental frequency and we hear this as a pitch we can identify.

Loudness is a subjective measure of sound as interpreted by the person hearing the sound. It is most closely related to the amplitude of the sound waves.

NOTES

Grade 11 Physics (30S)

Module 9: Sound

Learning Activity Answer Keys

MODULE 9: SOUND

Learning Activity 9.1: The Nature of Sound

1. Some animals rely on an acute sense of hearing for survival, and the visible part of the ear on such animals is often relatively large. Explain how this anatomical feature helps to increase the sensitivity of the animal's hearing for low-intensity sounds.

   Answer:

   Animals that rely on an acute sense of hearing for survival often have relatively large external ear parts. Low-intensity sounds do not have very much energy. The large ears intercept and direct more of the sound energy into the auditory system than small outer ears do.

2. Distinguish between

   a) loudness and pitch

      Answer:

      Pitch refers to the frequency of sound. We perceive sound with a higher frequency as having a higher pitch.

      Loudness is a subjective perception of sound. Generally, the larger the amplitude of the pressure-time transverse wave for sound, the louder the sound is.

   b) ultrasonic and infrasonic

      Answer:

      Humans have a range of frequencies of sound that they can hear. Sounds with a frequency that is too low for humans to hear is called infrasonic sound. Those frequencies of sound that are too high for humans to hear are called ultrasonic.

3. A dog can hear a sound produced by a dog whistle while its owner cannot. Explain how this is possible.

   Answer:

   The dog whistle is ultrasonic, which is above the range of human hearing.

4. What physical characteristic of a wave would you change to
   a) increase the loudness of a sound?
   b) to change the pitch?

   Answer:

   a) To change the loudness of the sound, you would change the amplitude.
   b) To change the pitch of the sound, change the frequency.

5. In December 1916, a major disaster befell a contingent of the Austrian army in the Alps fighting in World War I. Almost as soon as they began a cannon barrage, an avalanche of snow came roaring down, burying thousands of soldiers. What does this suggest about sound?

   Answer:

   This suggests that the vibrations of the sound waves carried enough energy to trigger the avalanche.

Learning Activity 9.2: Beats and Resonance: Part 1

1. A tuning fork vibrates at a frequency of 524 Hz. An out-of-tune piano string vibrates at 529 Hz.

   a) What is the beat frequency?

   b) How much time separates successive beats?

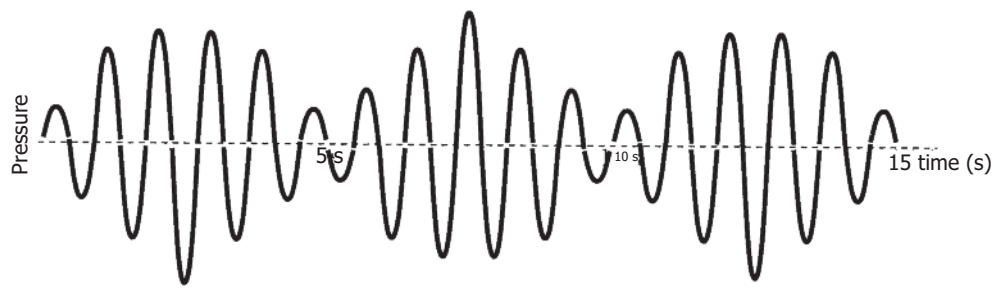
   Answer:

   a) The beat frequency is f = 529 Hz – 524 Hz = 5 Hz.

   b) When the "time between successive beats" is asked for, this means the period.

   The period of the beats is $T = \frac{1}{f} = \frac{1}{5\text{ Hz}} = 0.2\text{ s}$.

2. When two sound waves whose frequencies are near to each other interfere, they produce a pressure-time graph as shown below.



   For the graph above, what is the

   a) period of the beat?

   b) beat frequency?

   Answer:

   a) The diagram above shows three full cycles of the beats. One full cycle of the beat occurs over a time of 5 s. This is the period of the beat.

   b) The beat frequency is $f = \frac{1}{T} = \frac{1}{5\text{ s}} = 0.2\text{ Hz}$.

Learning Activity 9.3: Beats and Resonance: Part 2

1. When a stream of water is used to fill a graduated cylinder, a sound of steadily increasing pitch is heard. Explain why this happens.

   Answer:

   The water splashing into the cylinder produces all sorts of different wavelengths of sound. As the water fills the cylinder, a closed-pipe column of air is formed. At a given length of this column, a certain wavelength will form a standing wave inside the column. We hear the resonance of this column at that frequency.

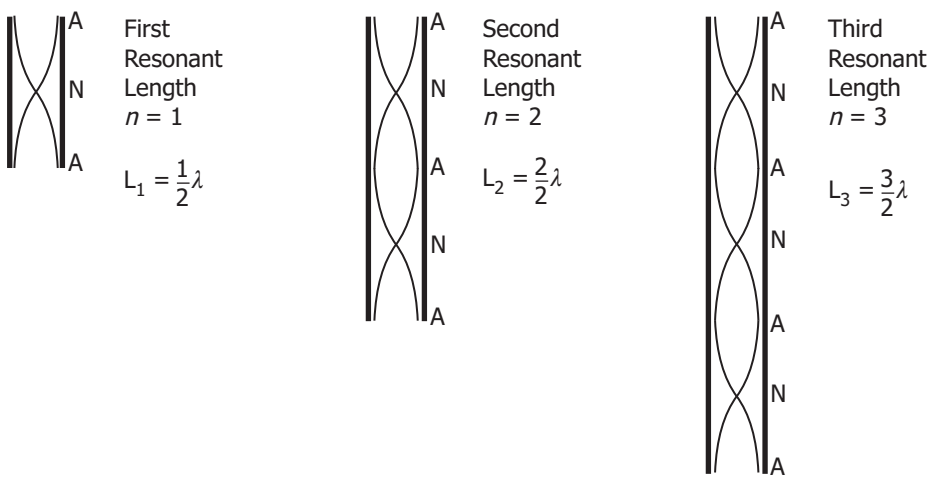
   As more water is added to the cylinder, the closed-pipe column of air decreases in length. The standing wave pattern that will fit into this shorter column of air will have a shorter wavelength and a higher pitch.

   So as the column continues to decrease in size, shorter and shorter wavelengths of sound produce the standing wave, resulting in a higher and higher pitch.

2. Sketch the displacement standing wave patterns for the first three resonant lengths of an open-pipe column.

   Answer:

Resonant Lengths of Open-Pipe Columns of Air Showing the Displacement Nodes and Antinodes



3. The first resonant length for an open-pipe column occurs when the column is 17.8 cm in length.

   a) What is the wavelength of this sound?

   Answer:

   Given: First resonant length $L_1 = 17.8$ cm

   Unknown: Wavelength $\lambda = ?$

   Equation: $L_1 = \frac{1}{2}\lambda$ rearranged to $\lambda = 2L_1$

   Substitute and solve: $\lambda = 2L_1 = 2(17.8 \text{ cm}) = 35.6 \text{ cm}$

   The wavelength of this sound is 35.6 cm.

   b) If the speed of sound in air is 342 m/s, what is the frequency of this sound?

   Answer:

   Given: Wavelength $\lambda = 35.6 \text{ cm} = 0.356 \text{ m}$

   Speed of sound $v = 342 \text{ m/s}$

   Equation: $v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$

   Substitute and solve: $f = \frac{v}{\lambda} = \frac{342 \text{ m/s}}{0.356 \text{ m}} = 961 \text{ Hz}$

   The frequency of the sound is 961 Hz.

4 a) Draw the displacement standing wave pattern for a closed-pipe column for the third resonant length.

   Answer:

   This standing wave will have a node at the closed end, 3 nodes in total, and an antinode at the open end of the air column.

b) If the wavelength of the sound is 23.8 cm, what is the length of this closed-pipe column?

Answer:

The third resonant length is $1\frac{1}{4}\lambda$.

$$L_3 = 1\frac{1}{4}\lambda = 1\frac{1}{4}(23.8\text{ cm}) = 29.8\text{ cm}$$

The third resonant length is 29.8 cm.

c) If the frequency of the sound increased, would the third resonant length increase or decrease? Justify your answer.

Answer:

If the frequency of the sound increased but the speed of the sound remained constant, then the wavelength would decrease (more waves have to fit into the same distance that the wave travels in 1 second). If the wavelengths are shorter, then the resonant lengths have to decrease.

5. The human auditory canal is essentially a narrow chamber closed at one end by the eardrum, forming a standing wave cavity. In an adult, this canal is about 2.70 cm long. Determine the fundamental frequency of the sound that will be amplified if the speed of sound is 343 m/s.

Answer:

For a closed-pipe air column, the first resonant length is $\frac{1}{4}\lambda$.

Given:	First resonant length	L_1 = 2.70 cm = 0.0270 m
	Wavelength	$\lambda = 4L_1 = 4(0.0270\text{ m}) = 0.108\text{ m}$
	Speed of sound	v = 343 m/s
Unknown: Frequency		f = ?
Equation:		$v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$
Substitute and solve:		$f = \frac{v}{\lambda} = \frac{343\text{ m/s}}{0.108\text{ m}} = 3180\text{ Hz}$

The fundamental frequency is 3180 Hz.

Learning Activity 9.4: The Doppler Effect

1. A tuning fork of frequency 261.6 Hz (C note) is vibrating over an air column in a tube that is closed at one end. If the speed of sound is 331 m/s, what should be the shortest length of the air column to produce resonance?

   Answer:

   The loudest resonance will occur when the length of the resonating air column is one-quarter the wavelength of the sound.

   $$L_1 = \frac{1}{4}\lambda$$

   Since we know the frequency and speed of the sound, we can determine the wavelength using the universal wave equation.

Given:	Frequency	$f = 261.6$ Hz
	Speed of sound	$v = 331$ m/s
Unknown:	Wavelength	$\lambda = ?$
Equation:		$v = f\lambda$ arranged to $\lambda = \frac{v}{f}$
Substitute and solve:		$\lambda = \frac{v}{f} = \frac{331 \text{ m/s}}{261.6 \text{ Hz}} = 1.26 \text{ m}$
		So, $L_1 = \frac{1}{4}(1.26 \text{ m}) = 0.315 \text{ m}$

   Therefore, the length should be 0.315 m.

2. A loudspeaker produces a sound wave. Does the wavelength of the sound increase, decrease, or remain the same, when the wave travels from air into water? Justify your answer. Note that the frequency of the sound wave does not change as it moves from the air into the water.

   Answer:

   The speed of sound is about 4 times greater in water as compared to air. The speed of sound can be determined by $v = f\lambda$. Since the speed of sound in water increases but the frequency remains the same, the wavelength of the sound must increase.

3. An aircraft carrier has a speed of 13.0 m/s relative to the water. A jet is catapulted from the deck and has a speed of 67.0 m/s relative to the water. The engines produce a whine at a frequency of 1550 Hz and the speed of the sound is 343 m/s. Would the crew hear a higher-pitched sound or a lower-pitched sound?

   Answer:

   Both the source and the observers are moving with respect to the air, but the source (the jet) is moving away from the observers (the crew). The observers would therefore hear a lower-pitched sound.

4. An ultrasonic wave at 80 000 Hz is emitted by a transmitter into a vein where the speed of sound is about 1.5 km/s. The wave reflects off the red blood cells moving toward the stationary receiver. Will the reflected frequency be higher or lower than the frequency of the emitted sound?

   Answer:

   As the red blood cells approach the transmitter, the sound waves are reflected at a higher frequency. The receiver detects the sound waves at a higher frequency.

5. a) What is the speed of sound in air at a temperature of 25.0° C?

   Answer:

   Temperature = 25.0 °C

   v = 331 m/s + (T °C)(0.60 m/s/ °C)

   v = 331 m/s + (25.0 °C)(0.60 m/s/°C) = 331 m/s + 15 m/s = 346 m/s

   b) If a sound from a vibrating tuning fork resonates in an open-pipe air column that is 44.8 cm long for the second resonant length, what is the wavelength of this wave?

   Answer:

Given: Second resonant length	L_2 = 44.8 cm
Unknown; Wavelength	λ = ?
Equation:	Second resonant length for an open pipe is $L_2 = 1\,\lambda$

   So the wavelength is 44.8 cm or 0.448 m.

c) What is the frequency of these waves?

Answer:

Given: Wavelength $\lambda = 0.448$ m

Speed of sound $v = 331$ m/s

Unknown: Frequency $f = ?$

Equation: $v = f\lambda$ rearranged to $f = \frac{v}{\lambda}$

Substitute and solve: $f = \frac{v}{\lambda} = \frac{331 \text{ m/s}}{0.448 \text{ m}} = 739 \text{ Hz}$

The frequency is 739 Hz.

6. a) Give two factors upon which the speed of sound depends and describe how the speed depends on each factor.

Answer:

At the same temperature, the speed of sound is slowest in gases, faster in liquids, and fastest in solids.

In a given material in the same state, the speed of sound increases with temperature.

b) Account for each of the factors listed in part (a).

Answer:

For the states, it is the distance between the particles of the medium that determines the speed of sound. In gases, the particles are relatively far apart. It takes a long time for the disturbance to be transferred from one particle to another. In liquids, the particles are closer together so the disturbances are transferred more quickly. The transfer of the disturbance is still faster in solids where the particles are rigidly held in place.

For the effect of temperature in a given state, the higher the temperature, the faster the particles are moving and the more quickly a disturbance can be transferred from one particle to another. Therefore, the speed of sound increases.

Learning Activity 9.5: Music and Noise

1. If the frequency of a G note is 384 Hz, what must be the frequency of the B note. Use the major triad to determine the frequency.

   Answer:

   On the triad G-B-D′, G is 4. The base frequency is 384 Hz/4 = 96 Hz.

   In the triad, B is 5 so the frequency is 96 Hz x 5 = 480 Hz.

2. The tones produced by a typical orchestra are complex sound waves, and most have fundamental frequencies less than 5000 Hz. However, a high-quality stereo system must be able to reproduce 20 000 Hz frequencies accurately. Explain why.

   Answer:

   Tones produced by a typical orchestra are complex sound waves, and most have fundamental frequencies less than 5000 Hz. Since these tones are complex sound waves, each one consists of a mixture of the fundamental and the higher harmonic frequencies. The higher harmonics are integer multiples of the fundamental frequency. For example, in a tone with a fundamental frequency of 5000 Hz, the fourth harmonic will have a frequency of 20 000 Hz. Since most orchestra tones have fundamental frequencies less than 5000 Hz, a high-quality stereo system must be able to reproduce accurately all frequencies up to 20 000 Hz in order to include at least the fourth harmonic of all tones.

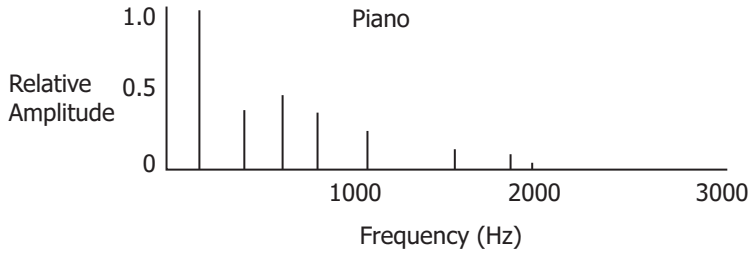
3. The soprano voice has a frequency range of approximately 250 Hz to 1000 Hz. The bass voice has a frequency range of approximately 80 Hz to 400 Hz. How would the sound spectrum be similar and different if both voices sang the same note at a fundamental frequency of 360 Hz?

   Answer:

   The sound spectrums would be similar in that the amplitude of the fundamental frequency would be the greatest.

   The sound spectrum would be different in that the number of harmonics would not necessarily be the same and their relative amplitudes would also be different.

4. The diagram below shows the sound spectrum of a piano playing the A3 note.



a) Which line would represent the fundamental frequency?

Answer:

The fundamental frequency would be the longest line, or the one at the far left.

b) How would the sound spectrum of a flute playing the same note be different than the one for the piano?

Answer:

The number of harmonics would not be the same. Also, the relative amplitude of the harmonics would be different.

c) How would the sound spectrum for white noise be different than the one shown above for the piano?

Answer:

The white noise spectrum would contain bars at all the frequencies and the amplitudes would all be the same.

5. Three distinguishing features of sound are tone quality, pitch, and loudness. Briefly describe what these are and upon what physical properties of waves they depend.

Answer:

The tone quality is enhanced by the complexity of the sound wave. This complexity in enhanced by the number and distribution of the harmonics of the fundamental frequency superimposed on the sound wave. What is important is that the harmonics are based on the fundamental frequency.

Pitch is associated principally with the fundamental frequency of a complex sound wave. So even though there may be several harmonics in a complex wave, they are related to the fundamental frequency and we hear this as a pitch we can identify.

Loudness is a subjective measure of sound as interpreted by the person hearing the sound. It is most closely related to the amplitude of the sound waves.

NOTES

Topic 4 - Audio/Videos

Module 9

1. THE NATURE OF SOUND - SYMPHONY OF SCIENCE
2. Longitudinal Wave
3. The Nature of Sound
4. Explain That Stuff- Sound
    a. Scroll down to the UNDERSTANDING AMPLITUDE AND FREQUENCY text box.
    b. There are 4 waves drawn as transverse wave to represent 4 sound waves.
    c. You can listen to each sound by pressing the start button. The sounds generated are tones – sound of a single frequency.
    d. Listen to each of the 4 tones and describe the effect of changing the frequency on the tone and also of changing the amplitude on the tone.
    e. Scroll down to WHY INSTRUMENTS SOUND DIFFERENT.
    f. Here you will read about why musical instruments sound different even though they are playing the same tone or frequency.
5. Introduction to the Intensity of Sound and Human Hearing
6. Beats Animation
    a. This animation allows you to control the frequencies of 2 waves and then view the interference pattenr that is produced by the two waves. Beats are produced as the waves from the 2 sources overlap. In some spots waves overlap to produce constructive interference which is a loud sound. In other places wave overlap to produce destructive interference or no sound.
    b. You can vary the frequency of both of the waves by sliding the control button.
    c. This animation does not produce any sounds.
    d. Begin the animation with the following settings. Use the IN PHASE setting.
    e. **Trial 1:** Top wave: 14 HZ Bottom Wave: 14 Hz
    f. The two waves are producing the same tone. Describe the resultant wave that appears.
    g. **Trial 2:** Top Wave: 14 Hz Bottom Wave: 15 Hz
    h. **Trail 3:** Top Wave: 14 HZ Bottom Wave: 13 HZ
    i. **Trial 4:** Top Wave: 14 Hz Bottom Wave: 16 HZ
    j. **Trial 5:** Top Wave: 14 HZ Bottom Wave: 17 Hz
    k. In each case identify the difference in the frequencies and the number of beats produced.
7. Demonstration of Beats
8. Beat frequency | Physics | Khan Academy
9. MIT Physics Demo Tuning Forks Resonance & Beat Frequency 720

a. An apparatus consisting of a tuning fork attached to the top of a wooden box which is open at one end is used in this demonstration. When the tuning fork is struck the the tuning fork vibrates which causes the top of the box to which the tuning fork is attached to vibrate also. The large surface of the top of the box causes the air inside the box to vibrate and the amplified sound exits the box through the open end. So this is an apparatus that amplifies sound.
b. Two of these pieces of apparatus are used. Each tuning fork vibrates at the same frequency.
c. When both tuning forks are struck, you hear the same tone.
d. When one tuning fork is struck and then the tines are prevented from vibrating, the other tuning fork is hear to be vibrating and producing sound. This demonstrates resonance. Each object like a tuning fork has a natural frequency at which it vibrates. Since the two tuning forks have the same frequency if one is vibrating the second tuning fork will also begin to vibrate at its resonant or fundamental frequency. Remember the boxes serve to amplify the sound and the effect.
e. The final demonstration shows the production of beats. A weight is attached to the tine of one tuning fork. This causes the tuning fork to vibrate at a different frequency. When both tuning forks are struck beats are heard. These beats are alternating loud and soft sounds rather than a steady tone.

10. Standing wave in pipe open at both ends at the fundamental frequency or first harmonic
    a. This short video shows the standing wave for the displacement of points on the medium in a pipe open at both ends for the fundamental frequency or the first harmonic.
    b. Note for the first harmonic there is one node at the centre of the pipe. There is an antinode at each end of the pipe.
    c. The length of the pipe is ½ λ.
    d. This follows the formula for the length of a pipe open at each end.
    e. $L_n = (n/2)\ \lambda$
    f. where n = the number of the harmonic or resonant length, L = the length of the pipe and λ = wavelength.
11. Standing wave in pipe open at both ends - 2nd Harmonic
    a. This short video shows the standing wave for the displacement of points on the medium in a pipe open at both ends for the second harmonic where the frequency is 2 x the fundamental frequency.
    b. There are 2 nodes in this standing wave pattern. There is an antinode at each end of the pipe plus one antinode between the 2 nodes.
    c. The length of this pipe is 1λ.
    d. This follows the formula for the length of a pipe open at each end.
    e. $L_n = (n/2)\ \lambda$
    f. where n = the number of the harmonic or resonant length, L = the length of the pipe and λ = wavelength.

12. Standing Waves in Air Columns for a Pipe Open at Both Ends - Waves & Sound
    a. This website illustrates the interference of longitudinal waves in a tube open at both ends using a displacement pattern. Vertical lines are used for the purpose of representing points on the medium. When the lines are close together we have a compression. When the lines are far apart we have a rarefaction. If you look carefully there are lines that do not move. That line is at a displacement node. At either end of the tube the lines are continually moving. These lines represent a displacement antinode. The lines represent the displacement pattern for a standing longitudinal sound wave.
    b. We are familiar with transverse waves and the nodes and antinodes found on a standing transverse wave.
    c. A transverse standing wave is superimposed on the air column. You can clearly see the antinodes at each end of the tube and the node in the center of the tube.
    d. In the first tube the website shows the length of the tube (½ λ) at the first resonant frequency or fundamental frequency (**f_0**) or the first harmonic.
    e. In the second tube the website shows the length of the tube at the second resonant frequency (**$2f_0$**) or second harmonic.
    f. A tube with a standing wave with a frequency of the third harmonic (**$3f_0$**) is the final example shown.
    g. Click on the "Next Page" link at the bottom of the page. This will bring you to another page that repeats the animation of standing waves found in a pipe closed at one end.
    h. In the first tube the animation shows the length of the tube (¼ λ) at the first resonant frequency or fundamental frequency (**f_0**) or the first harmonic.
    i. In the second tube we do not have a standing wave for the second harmonic. Instead the next standing wave in the sequence is for the third harmonic **($3f_0$**).
    j. The last tube has the standing wave for the fifth harmonic **($5f_0$).**
13. Doppler Effect
    a. In this video the perceived frequency of a sound as heard by an observer depends both on the motion of the source and the motion of the observer.
    b. Using animation the video shows that if the source of sound is moving the wave fronts pile up in front the source creating a higher frequency (higher pitch). Also behind the moving source the wave fronts are spread apart creating a lower frequency (lower pitch).

    c. As a moving source of sound moves towards you and then passes by you hear first the higher pitched sound as the source approaches you and then a lower pitched sound as the source moves away from you.
    d. This effect also is created when the source is stationary and the observer moves relative to the source.
    e. Examples of the Doppler Effect are given.
14. Sound Waves, Intensity level, Decibels, Beat Frequency, Doppler Effect, Open Organ Pipe - Physics
15. The Doppler Effect: solving for the speed of the source
16. Introduction to Supersonic Speeds and the Sonic Boom
17. Resonance and the Sounds of Music
18. Grade 11 Physics Track 6(1) Resonance the speed of sound part 1 Mod 9 A9.2
19. Grade 11 Physics Track 6(2) Resonance the speed of sound part 2 Mod 9 A9.2
20. Speed of Sound Lab
    a. This video an instructor performing the experiment to determine the speed of sound using resonance in a tube closed at one end.
    b. The instructor explains the Physics behind the experiment and reviews the calculations that must be performed to determine the speed of sound.
    c. The calculations presented are a bit different that our video lab.
    d. First the temperature is not measured or included in the calculation of the speed of sound.
    e. Secondly the diameter of the tube is not measured or included in the calculation of the speed of sound.
    f. Thirdly, the length of the resonating tube is measured for n = 1, 2, 3, 4, 5. Our activity only measures the length of the tube for n =1.
21. Science - Sound - Music or Noise - English
22. Sound Waves, Intensity level, Decibels, Beat Frequency, Doppler Effect, Open Organ Pipe - Physics
    a. (Duration 29:00 to 32:50)
    b. Intensity is defined as power/area, that is how much energy in Joules is reaching 1 m2 of area in 1 second.
    c. This video constructs a table of sound intensity in watts/m2, Level in decibels (dB) and Loudness compared to the threshold level.
    d. As the intensity of the sound increases by 101 , the level in decibels increases by 10 dB. Also the loudness doubles from the previous loudness value.
    e. As the intensity increase observe how the level in decibels increases and the loudness compared to the threshold energy increases.
23. Learn about sound and musical frequencies - Black Book Lesson One
24. Resonance and the Sounds of Music
    a. This video covers resonance as the main concept. In addition to defining resonance the presenter demonstrates many applications of this phenomenon. This is a long video that switches topics along the way. A description of the topics is provided below.

b. In all there is a nice connection between resonance and music. This video serves nicely to tie together this module on sound.
c. 0-10:00 Resonance on a String
    i. This section contains a definition of resonance and applies this to resonance on a string. There is a demonstration of resonance using a rubber tube.
d. 10:00 – 26:00 Resonance and Musical Instruments
    i. This section of the video shows how resonance is used in how a string instrument and a wind instrument plays music.
e. 26:20 – 31:00 Introduction of the Apparatus to Detect and Display Sound Waves on an Oscilloscope
    i. A 440 Hz tuning fork generates a tone that is displayed on an oscilloscope as a regular sine wave.
f. 31:00- 39:30
    i. Five different instruments are used to illustrate the 440 HZ sound wave that is generated by each instrument.
    ii. This part of the video shows the connection between resonance and string instruments (violin and guitar) and wind instruments (clarinet, saxophone and bassoon) . Each instrument plays a 440 Hz note and the sound wave along with its harmonics produce a complex wave. The number of the harmonics and their amplitudes produced as the instrument resonates interfere to form a complex wave. Even though the instruments all play the same note, the instruments sound different. Each instrument has its own timbre (a different complex wave). These complex waves are displayed on an oscilloscope which displays a sine wave picture of the sound disturbance.
g. 39:30—49:00 Everyday Examples of Resonance
    i. Many examples of resonance are mentioned. A demonstration of resonance on a wine glass shows that the wine glass actually moves as it resonates. A copper tube and a square metal plate are also made to resonate.
h. 49:00-53:00 Destructive Resonance
    i. A video shows the Tacoma Narrows Bridge collapsing in 1940 when it is set in motion (made to resonate) by a 40 miles per hour (67 km/hour) wind. The swinging becomes so violent that the bridge breaks apart.
i. 53:00-56:30 Using Sound and Resonance to Break a Wine Glass
    i. The idea here is that sound is made to cause resonance in a wine glass. In the end the wine glass shatters.
j. 56:30 – End Resonance and the Human Voice
    i. The presenter breathes in helium. Helium conducts sound at a different speed that air thus changing the resonant frequency of the presenter's throat and mouth. Listen to how speaking with helium sounds.

25. The Basics of the Physics of a Guitar

Grade 11 Physics (30S)

Module 10: Models, Laws, and Theories, and the Nature of Light

This module contains the following

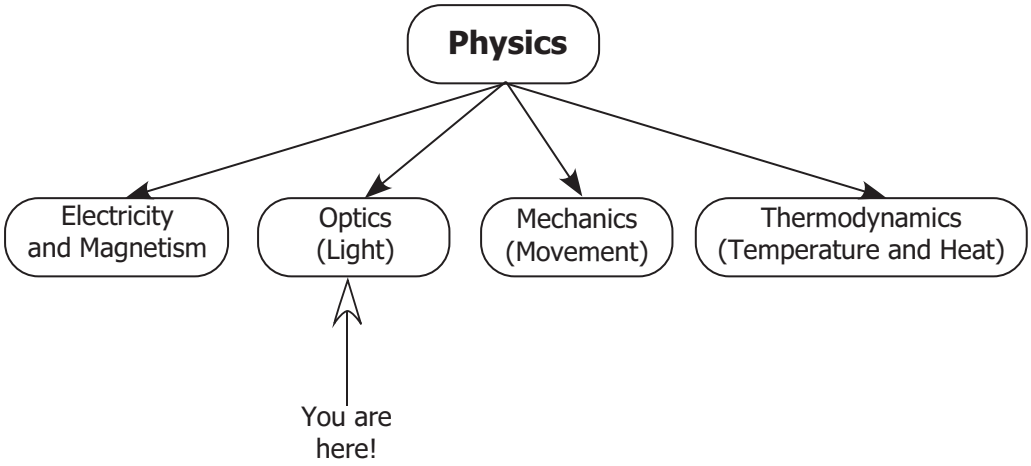
- Introduction to Module 10
- Lesson 1: The Scientific Method, Laws, Theories, and Models
- Lesson 2: The Nature of Light and Newton's Corpuscular Theory
- Lesson 3: Determining the Speed of Light
- Lesson 4: Wave Theory of Light
- Lesson 5: Young's Experiment
- Lesson 6: The Photoelectric Effect and Wave-Particle Duality
- Module 10 Summary

Module 10: Models, Laws, and Theories, and the Nature of Light

Introduction to Module 10

In our previous work dealing with waves in one dimension, waves in two dimensions, and sound, we described wave behaviour by using models such as waves on a rope or spring or water waves. These models help us to visualize the behaviour of these waves. In this module, we will study models, laws, and theories, and then extend these ideas to the historical confrontation between the wave and particle models of light.

- **Lesson 1: The Scientific Method, Laws, Theories, and Models** studies the characteristics of models, laws, and theories, and how they are developed as we expand our knowledge of science. We will study how knowledge claims can be supported by evidential arguments.
- **Lesson 2: The Nature of Light and Newton's Corpuscular Theory** reviews various models through history starting with the debate between Plato and Pythagoras, and with an emphasis on Newton's corpuscular theory explanation of various properties of light.
- **Lesson 3: Determining the Speed of Light** discusses the different ways in which the speed of light was measured from the time of Galileo in the 1600s to Michelson in the 1900s.
- **Lesson 4: Wave Theory of Light** discusses how the wave theory of light explains properties of light.
- **Lesson 5: Young's Experiment** is devoted mainly to an experiment done by Thomas Young that lends support to the wave model of light.
- **Lesson 6: The Photoelectric Effect and Wave-Particle Duality** discusses how the wave theory and particle theories of light make different predictions about the effects of the frequency and the intensity of light on the photoelectric effect. This lesson will conclude with a discussion of the wave-particle duality and the Principle of Complementarity.



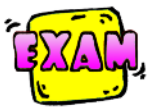
Assignments in Module 10

When you have completed the assignments for Module 10, submit your completed assignments for Module 9 and Module 10 to the Distance Learning Unit either by mail or electronically through the learning management system (LMS). The staff will forward your work to your tutor/marker.

Lesson	Assignment Number	Assignment Title
1	Assignment 10.1	The Scientific Method, Laws, Theories, and Models
2	Assignment 10.2	Video Laboratory Activity: The Particle Model of Light
2	Assignment 10.3, Part A	The Nature of Light and Newton's Corpuscular Theory
3	Assignment 10.3, Part B	Determining the Speed of Light
4	Assignment 10.3, Part C	Wave Theory of Light
5	Assignment 10.3, Part D	Young's Experiment
6	Assignment 10.4	The Photoelectric Effect and Wave-Particle Duality

As you work through this course, remember that your learning partner and your tutor/marker are available to help you if you have questions or need assistance with any aspect of the course.

Writing Your Final Examination



You will write the final examination when you have completed Module 10 of this course. The final examination is based on Modules 1 to 10, and is worth 30 percent of your final mark in the course. To do well on the final examination, you should review all the work you complete in Modules 1 to 10, including all the learning activities and assignments. You will write the final examination under supervision. Please note that 25% of your final mark is based on Modules 7 to 10 and 5% of your final mark is based on Modules 1 to 6.

DPSU 10–2014

NOTES

Lesson 1: The Scientific Method, Laws, Theories, and Models (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain what is meant by the scientific method
- ❑ outline the steps of the scientific method
- ❑ explain what is meant by an observation, and what makes an observation quantitative or qualitative
- ❑ explain what is meant by an inference, a hypothesis, and a conclusion
- ❑ explain what is meant by a scientific law or principle
- ❑ explain what is meant by a scientific theory
- ❑ explain why theories may need to be changed
- ❑ explain what constitutes a good theory
- ❑ explain what a scientific model is
- ❑ compare a theory and a model showing how they are the same and different

Key Words

scientific method	observation	inference
qualitative	quantitative	hypothesis
conclusion	scientific law	scientific principle
theory	model	

Introduction

The aim of physics is to understand the natural events of the universe. We want to understand what it is, how it works, what it is doing, and maybe even why it exists. If this is at all possible it is only because natural phenomena occur in ways that are reproducible. There are rules and rhythms in the seeming chaos. In this lesson, we will begin our study of the universe through the scientific method, and the development of laws, theories, and models.

The Scientific Method

More than 150 years ago, the English physicist Michael Faraday (1791–1867) made crucial discoveries that led to the invention of the electric motor. The electric motor has since become extremely important. We find it in refrigerators, automobile starters, hair dryers, video equipment, and many other devices. Yet when Faraday was making his discoveries, none of these machines had been invented. The new scientific knowledge that Faraday gathered did not have any practical value. The real value of his work lay in its potential for further growth and applications. As it turned out, Faraday's work changed the world completely.

Faraday's work is one example of the tremendous potential in science. This comes from the way in which scientific knowledge is gathered.

> The **scientific method** is an orderly and systematic approach to gathering knowledge.

With this approach, new ideas about the world are constantly checked against reality. We can also think of the scientific method as a way of answering questions about the world we live in.

A brief outline of the scientific method might include the following:

- First the scientist makes **observations**, or records facts of what is seen.
- The observation leads to a question. (Sometimes the question may come before the observations are made.)
- Thinking about the question produces a **hypothesis**, a tentative answer to the question based on present knowledge.
- The scientist tests the hypothesis with a carefully designed procedure, an **experiment**. As part of the experiment, the scientist carefully records and analyzes data, or information, gathered in the experiment.

- The experiment produces a result, or **conclusion**—a statement of what was learned based on the evidence gathered. The scientist interprets the conclusion carefully. From the interpretation, or inference, the result may raise new questions and lead to new hypotheses and new experiments.
- After a number of experiments, the scientist may be able to summarize the results in a **natural law**, which describes how nature behaves but does not explain why nature behaves in that particular way. It often takes a mathematical form.
- Finally, the scientist may be able to formulate a **theory**. The theory explains why nature behaves in the way described by the natural law. It answers the original questions as well as any other questions that were raised during the process. The theory also predicts the results of further experiments, and this is how the theory is checked. A **model** could also be formed at this point along with or instead of the theory. The model is a mental picture that helps us to understand what it is that we are observing.

The Scientific Method: Observations to Conclusion

In order to illustrate the use of the scientific method and to better understand some of the ideas and terms associated with the method, we will use a mystery container that we can call a **black box**.

> The black box is a closed container that has in it one or more objects. The idea is to try to determine what is inside the box without opening it.

Assume that we know at the outset that the box contains only one object. Our question could be "What is the object inside the box?"

To begin with, we can tilt the box to one side and listen for the sound produced by the object inside. We might listen for rolling, sliding, or chunking noises. In so doing, we are making an observation.

> An **observation** is a fact that is noticed either qualitatively or quantitatively.

A **qualitative** observation would be one where we try to answer what is present and provide some **description** of what is present. A **quantitative** observation is one that is concerned with **how much** of each is present or with the dimensions of the object. For example, you may notice that when the box is tilted in one direction, you hear a rolling sound. But when the box is tilted in a different direction, there is a sliding sound. This is a qualitative observation.

After making these observations, we could make an inference.

> An **inference** as a deduction, conclusion, or interpretation based on the facts made during the observation.

In this case, we might infer that the object inside the black box is a cylinder. This inference could also be our hypothesis.

> A **hypothesis** as a plausible solution to a problem, an answer to a question, or an unproven explanation of the facts.

So in this situation, our hypothesis is also that the object is a cylinder.

To confirm your hypothesis, you could do an experiment.

> An **experiment** is a carefully devised procedure for making observations and gathering data.

In this case, it might simply be confirming what you observed initially. You would tilt the box in different directions to determine if the object inside really does behave as though it were a cylinder. You might be more systematic about how you tilt the box and listen very carefully to the sounds to confirm your inference. Your observations might also lead you to form some ideas about the size of the object inside the black box, and so become more quantitative in nature.

You are now ready to make a conclusion.

> A **conclusion** as a judgment or opinion based on the evidence of the observations; it is formed by analyzing the experimental data.

You decide whether or not the object is a cylinder. If your experiment and additional observations indicate that it is not a cylinder, then you may need to form a new hypothesis and do the experiment again.

We will now discuss scientific laws, theories, and models in a general way, and then apply our understanding of these concepts to the black box experiment.

Scientific Laws

Scientists give the title **law** to certain concise but general statements about how nature behaves. The law is a summary of the results of our observations.

> A **law** is a description of nature without an explanation of why nature behaves that way.

An example of this is to state that momentum is conserved. Sometimes the statement takes the form of a relationship or equation between two quantities, such as Einstein's famous equation $E = mc^2$.

To be called a law, a statement must be found experimentally valid over a wide range of observed phenomena. In a sense, the law brings unity to many observations. For less general statements, the term **principle** is often used (such as Archimedes' principle). The line between laws and principles is arbitrary, so there is not always perfect consistency.

Scientific laws are different from political laws in that the latter are prescriptive: they tell us how we *must* behave. Scientific laws are descriptive: they do not say how nature must behave, but rather describe how nature *does* behave. As with theories, laws cannot be tested in the infinite variety of cases that are possible. So we cannot be sure that any law is absolutely true. We use the term law when its validity has been tested over a wide range of cases. We must also understand any limitations of the law and when it is valid. Even then, as new information comes in, certain laws may have to be modified or discarded.

Scientists normally do their work as if the accepted laws and theories were true, but they are obliged to keep an open mind in case new information should alter the validity of any given law or theory.

The Scientific Theory

Scientific observations and laws are like pieces of a jigsaw puzzle. When enough pieces have fallen into place, a meaningful pattern emerges. This pattern is a theory.

> A **theory** provides a general explanation for the observations, and is created to explain these observations.

These observations may be made by many scientists over a long period of time. Theories are inspirations that come from the minds of human beings. For example, the idea that matter was made up of atoms (atomic theory) was not derived because someone observed atoms. The idea sprang from a creative mind. The kinetic theory of gases is an example of one of the great theories of science that has been highly successful in explaining and predicting the behaviour of all kinds of gases under all sorts of conditions. Other great theories are the theory of relativity and the electromagnetic theory of light.

Sometimes it becomes necessary to **modify** a theory. There may be new observations or new laws that a theory cannot explain. When this happens, it may be possible to modify the theory to fit new facts. For example, the molecular theory of gases in its original form did not predict the behaviour of gases under great pressure or at very low temperatures. However, it was possible to modify the theory to make it agree with the new observations.

Earlier theories can be said to be speculative or first attempts to explain phenomena.

> When a theory can explain a greater range of observations, we may refer to it as being robust.

A new theory may be accepted by scientists because its predictions are quantitatively in much better agreement than those of the older theory: in other words, its predictions are more accurate. But in many cases, a new theory is accepted only if it explains a greater range of phenomena than that of the older one—that is, it has a larger scope. For example, Copernicus's sun-centred theory of the universe was no more accurate than Ptolemy's earth-centred theory for predicting the motion of heavenly bodies. But Copernicus's theory had consequences that Ptolemy's did not. For example, it made the determination of the order and distance of the planets, and predicted the moonlike phases of Venus. A simpler (or no more complex) and richer theory—one that unifies and consistently explains a greater variety of phenomena—is more useful and beautiful to a scientist. This aspect, as well as quantitative agreement, plays a major role in the **acceptance** of a theory.

An important aspect of any theory is how well it can **quantitatively predict** phenomena. From this point of view, a new theory may often be only a minor advance over the old one. For example, Einstein's theory of relativity gives predictions that differ very little from the older theories of Galileo and Newton in everyday situations; its predictions are better mainly in the extreme case of very high speeds close to the speed of light. From this point of view, the theory of relativity might be considered a mere "fine-tuning" of the older theory.

But quantitative predictions are not the only outcome of a theory. Our view of the world is affected as well. As a result of Einstein's theory of relativity, for example, our concepts of space and time have been completely changed. Our view of the world underwent a major change when relativity theory came to be accepted.

The Scientific Model

Scientists often make use of models to help them interpret their observations. A scientific model is not like a model airplane or a globe.

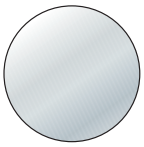
> A **scientific model** is a mental picture that helps us understand something we cannot see or experience directly.

The model may include an analogy with something we are already familiar with. One example used in the last module dealt with throwing Frisbees to aid in your understanding of the Doppler effect. Another example is the wave model of light. We will study this model in more detail in later lessons. We cannot see waves of light as we can water waves, but it is valuable to think of light as if it were made up of waves. Experiments on light show us that light does behave in many respects as water waves do. In atomic science, a good model of the atom helps to explain the characteristics of the atom, but it is not an actual picture of the atom. The purpose of a model is to give us a mental or visual picture, something to hold onto when we cannot see what is actually happening. Models give us a deeper understanding. The analogy to a known system, such as the water waves discussed above, can suggest new experiments to perform and can provide ideas about what other related phenomena can occur.

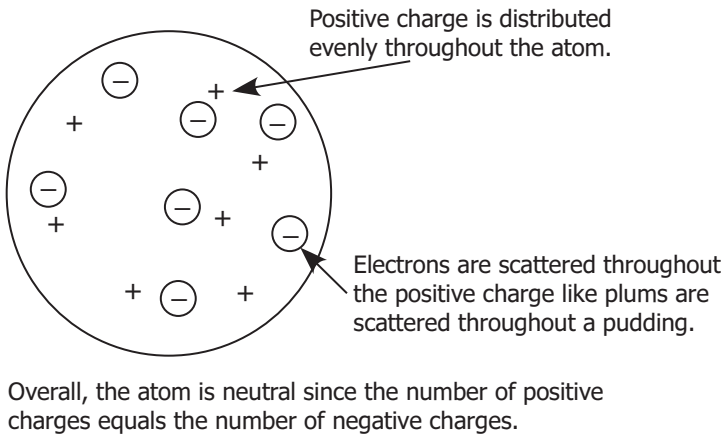
> Scientific models change as new discoveries are made.

One of the first models of the atom was proposed by John Dalton (1766–1844) who proposed his model in the early 1800s. Part of his model stated that elements are composed of atoms that are indivisible and indestructible particles. He viewed the atom as a solid sphere that could not be broken apart or changed in any way.

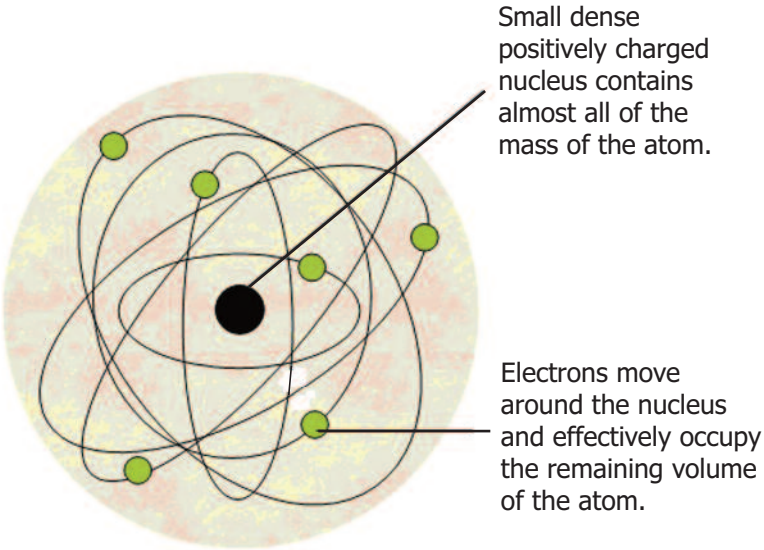
To Dalton, an atom looked like this:



When electrons were discovered, the model had to be changed to include them. Since electrons are negatively charged, the model of the atom had to include positive charges to make the atom as a whole neutral. In the early 1900s, **J. J. Thompson** (1856–1940) proposed a model (**Plum Pudding Model**) in which the atom is a positively charged sphere (a ball of rice) in which the negatively charged electrons (the plums) are embedded.

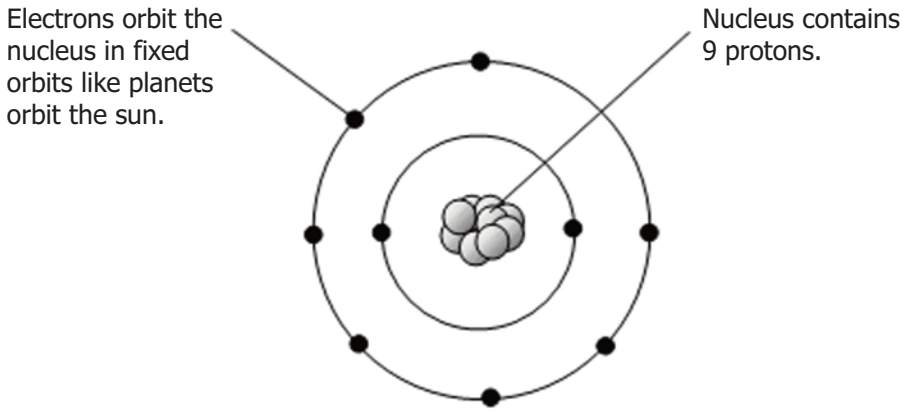


This model was changed again in further experiments by Ernest Rutherford (1871–1937) who proposed the nuclear model of the atom. This model had the protons (positive charge) in the dense nucleus of the atom with the negatively charged electrons occupying the rest of the space of the atom. The atom was essentially made up of empty space.



Rutherford's nuclear model of the atom could not account for why the electrons were not drawn into the nucleus, causing the atom to collapse. **Niels Bohr** proposed the **planetary model** of the atom. His model was that the electrons circled the sun in circular orbits just like the planets orbit the sun (hence the name "planetary" model). Bohr reasoned that the planets are attracted to the sun but do not spiral into the sun because of their motion in their orbits. Electrons are attracted to the nucleus, but if they showed this orbital motion they would not spiral into the nucleus.

Bohr Model of the Fluorine Atom



Further discoveries could not be reconciled with the planetary model of the atom. The planetary model required one to know the location and path of the electron. It was shown later that if you know the location of an electron, you cannot know its path; and if you know the path, you cannot know the location. This idea, among others, led to today's **quantum mechanical model**, which has been able to explain all of our observations and make successful predictions about new observations.

> The theory behind the quantum mechanical model of the atom can be classified as a **robust theory**, since it is successfully able to lead to a great range of observations.

Both models and theories help to explain how nature behaves. Both summarize and account for the facts gained from experiments. Both enable scientists to make predictions, and both can be changed if necessary as new observations are made. Often, the terms are used interchangeably so, for example, we can speak of the atomic model or the atomic theory.

You may wonder what the difference is between a theory and a model.

> A model is usually fairly simple and there is a structural similarity to the phenomenon being studied.

For example, Dalton's model of the atom was similar to a billiard ball.

> A theory is broader and more detailed and attempts to solve a set of problems, often with mathematical precision.

As a model is developed and modified and corresponds more closely to an experiment over a wide range of phenomena, it may come to be referred to as a theory. The atomic theory is an example, as is the wave theory of light. Thus, models can be very helpful and often lead to important theories. It is important not to confuse a model or a theory with the real system or the phenomenon itself.

The Black Box: Natural Law, Model, and Theory

In the case of our black box experiment, the results cannot be described in terms of a mathematical law, but they could be described in a non-mathematical or qualitative form. For example, we might state the law in this case as "whenever I hold the mystery container upright and rotate it to the left, I hear a rolling sound then a chunk as the object hits the side wall."

In our experiment, we came to the conclusion that the object inside behaved like a cylinder. The cylinder is our **model**, or mental picture, of what is inside the black box. We could also say that this model represents our **theory** of what is inside the box. For a situation as simple as this one, it is difficult to make a broader statement or explanation, so the terms model and theory can be used interchangeably to explain what is happening inside the box.

The model (or theory) of a cylinder inside the box can now be used to make a prediction. The prediction might be that if the box is rotated rapidly, the cylinder should tumble or roll instead of slide. This prediction can then be tested, and based on the results the model is confirmed, or it may have to be revised.

Knowledge Claims, Evidence, and Evidential Arguments

As the scientific model is followed and carefully designed experiments lead to laws, models, and theories, scientific knowledge grows. It becomes possible to make valid statements or arguments about how nature behaves based on well-founded knowledge. As we come into contact with statements that we may hear or read, we need to be critical about whether these statements are based on solid evidence.

We can define a **knowledge claim** as a declaration of conviction consisting of a sentence of the type "I know that ..." or "I believe that." Knowledge claims can be supported by evidence that depends on the training and experience of the claimer. **Evidence** can be first hand observations, a deference to authority, or plausible explanations. Deference to authority can range from naive acceptance of the authority to a more careful consideration of the evidence. In our study of physics, we would prefer to generate as much evidence as we can through experiments. However, it is not always feasible to do so because of the need for specialized equipment, some experiments are dangerous, and so on. However, we can still evaluate claims made by authority. We can do this by relating what is said to our own experiences. We may want to do the experiment ourselves if possible. We can question in ourselves what makes us believe and how we know.

For a person to make a statement convincing, the claimer must formulate a relevant argument with the intended audience. Sometimes this evidence is given in the form of a critical experiment that is overwhelmingly convincing. An argument based on good evidence can be referred to as **evidential argument**.

Suppose for example that a friend makes the following knowledge claim: "I believe that Dr. Pop is the best." You are not convinced and ask for evidence to support this opinion. To convince you, your friend may choose evidence that is relevant to you. The evidence may be based on authority such as "Celine Dion recommends this product." Or the evidence could be statistical data such as "three out of four people prefer Dr. Pop." Perhaps your friend could provide a biochemical explanation that this product contains less caffeine and less sugar and is therefore better for one's health.

An example of a knowledge claim in science is the statement that the atom has a small positive nucleus surrounded by negative electrons. There is a great deal of evidence to support this claim. Ernest Rutherford (1871–1937) performed an experiment using alpha radiation and a gold foil where he showed that matter consists of a small positive nucleus and a large empty space occupied by negative charges.

Learning Activity 10.1

The Scientific Method, Laws, Theories, and Models

1. In doing the black box experiment, you are told that there is one object in the box, but you are not given any information about what that object is. At first, you move, tilt, and shake the box and you can see that there is indeed what appears to be one object in the box. You then proceed more slowly and carefully. You tilt the box slowly and you hear a sliding sound. You never hear a rolling sound. It does not matter if you tilt the box slowly or rapidly. You never hear a rolling sound, but if you tilt the box rapidly you may hear a tumbling sound of the kind that a cube might make.
   a) If you were to state that the object inside the black box was a cube, would this be an observation or an inference? Justify your answer.
   b) If you were to state that when you tilt the box in any of the front-to-back or back-to-front ways, the object inside slides and does not roll, would this be a statement of theory or a statement of a scientific law?
   c) If you were to state that the object inside the box must be a cube, could we say that this statement is an example of a scientific model? Explain your reasoning.
   d) What would make it necessary to change the law or theory developed for the object inside the black box in this example?
2. What are the characteristics of a good theory?
3. Distinguish between:
   a) observation and conclusion
   b) theory and model
   c) law and inference
4. Why are theories changed?
5. If a friend said that Levi's jeans are the best, what kind of evidential arguments would support this statement?

Lesson Summary

The **scientific method** is an orderly and systematic approach to gathering knowledge. A brief outline of the scientific method might include the following:

- Observations are made.
- The observation leads to a question. (The question may come before the observation.)
- A hypothesis is made.
- The hypothesis is tested with an experiment.
- A conclusion is made. New questions may lead to new hypotheses and new experiments.
- The results may be summarized in a natural law.
- A theory may be formulated.

An **observation** is a fact that is noticed either qualitatively or quantitatively. A **qualitative** observation would be one where we try to answer what is present and present some description of what is present. A **quantitative** observation is one that is concerned with how much of each is present or with the dimensions of the object. An **inference** is a deduction, conclusion, or interpretation based on the facts noted during the observation. A **hypothesis** is a plausible solution to a problem, an answer to a question, or an unproven explanation of the facts. An **experiment** is a carefully devised procedure for making observations and gathering data. A **conclusion** is a judgment or opinion formed as a result of analyzing the experimental data.

A **law** is a concise but general statement about how nature behaves. It is a summary of the results of our observations. It is a description of nature without an explanation of why nature behaves that way. A less general statement may be called a **principle**.

A **scientific model** is a mental picture that helps us understand something we cannot see or experience directly. Models can suggest new experiments to perform and can provide ideas about what other related phenomena can occur. Scientific models change as new discoveries are made.

A **theory** provides a general explanation for the observations. Theories are inspirations that come from a creative human mind to explain observations. Early attempts at forming theories may be speculative, first attempts to explain phenomena. New observations or laws may not be explained by a theory, so it needs to be modified. A theory that can explain a greater range of phenomena may be referred to as robust.

Good theories have the following characteristics:

- A good theory explains phenomena accurately and its predictions are accurate.
- It consistently explains a wide range of phenomena; it has a wide scope.
- The theory is simple, or less complex.
- It can quantitatively predict phenomena.

A **knowledge claim** is a declaration of conviction consisting of a sentence of the type "I know that ..." or "I believe that." Knowledge claims can be supported by evidence that depends on the training and experience of the claimer. **Evidence** can be first-hand observations, a deference to authority, or plausible explanations. An argument based on good evidence can be referred to as **evidential argument**.

Assignment 10.1

The Scientific Method, Laws, Theories, and Models (5 MARKS)

Jacques Charles (1746–1823) observed under controlled conditions, a relationship between temperature and volume for most gases. He wrote this relationship as $\frac{V}{T} = k$.

a) Would this relationship best be described as a law or a theory? Explain your answer.

b) How does Charles' law differ from the law requiring you to stop your bike at a stop sign?

c) In order to arrive at his mathematical law, would Charles' observations more likely have been qualitative observations, or quantitative observations? Justify your answer.

(continued)

Assignment 10.1: The Scientific Method, Laws, Theories, and Models (continued)

d) Suppose we could explain the effect that Charles observed by imagining very small spheres moving about more rapidly at a higher temperature, therefore needing more space at a constant pressure. Would this be an example of a law or a theory (model)? Explain your answer.

_____

_____

e) Besides explaining the events that Charles observed, what else would be necessary for this theory to be considered robust?

_____

_____

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Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for each of parts (a) to (e)

Lesson 2: The Nature of Light and Newton's Corpuscular Theory (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain the early Greek tactile theory and emission theory of the nature of light
- ❑ explain briefly Newton's particle or corpuscular theory and Huygen's wave theory of light
- ❑ explain the difference between Maxwell's electromagnetic theory and Planck's quantum hypothesis
- ❑ explain what the theory of quantum mechanics says about the nature of light
- ❑ explain what is meant by Newton's corpuscular theory of light
- ❑ discuss the evidence supporting Newton's corpuscular theory
- ❑ explain what is meant by the rectilinear propagation of light
- ❑ explain why Newton thought that the particles that make up light travel very fast but have little if any mass
- ❑ explain how Newton's corpuscular theory was able to explain reflection, refraction, and dispersion
- ❑ discuss how Newton's corpuscular theory could not explain the effects of diffraction, partial reflection and partial refraction, and the speed of light in a denser medium

Key Words

tactile theory
rectilinear propagation
dispersion
partial refraction
Newton's corpuscular theory
Maxwell's electromagnetic theory
emission theory
reflection
diffraction
optically dense medium
Huygens' wave theory
Planck's quantum hypothesis
quantum mechanics
refraction
partial reflection

Introduction

In this first lesson, we outline several historical models to explain the nature of light. For centuries there has been a debate about whether the properties of light could best be explained using a particle model of light or a wave model. We will begin with theories proposed by the early Greeks, then those proposed in the 17th century, and finally the debate of the 19th century. We will focus mainly on Newton's corpuscular theory of light, and at the end of the lesson reflect on the care we must take in accepting the theories of eminent scientists.

The Nature of Light: Early Greece to 20th Century

Early models of light were concerned with the source of light. Did light originate in the eyes or did objects emit light? The earliest views on the nature of light came to us from the Greeks. Plato thought that light consisted of "streamers" or filaments, emitted by the eye, and that when these streamers came in contact with an object, it was possible to see the object. Euclid agreed with Plato with the argument "How else can we explain that we do not see a needle on the floor until our eyes fall on it?" Plato's theory can be referred to as a **tactile theory** based on the ability of the eye to "touch objects."

Not all Greeks agreed with Plato. The Pythagoreans believed that light travelled as a stream of fast-moving particles. According to this **emission theory**, objects sent out light beams or particles that would ricochet off objects and enter the eye. One Greek, Empedocles, believed that light travelled as a wave-like disturbance. So as early as ancient Greece, we see a debate between a particle theory of light and a wave theory.

By the 17th century, these apparently contradictory views of the nature of light placed scientists in two camps. **Newton** was the principal advocate of the particle, or **corpuscular theory**. He was supported by the French mathematician, physicist, and astronomer Laplace.

> Newton's **corpuscular** theory stated that light consisted of particles that travelled in straight lines.

The wave theory, which supports the idea that light has wave-like properties, was supported principally by Christiaan Huygens of Holland, also a mathematician, physicist, and astronomer.

> Huygens' **wave** theory stated that light consists of waves and exhibits wave-like properties in its behaviour.

He, in turn, was supported by Robert Hooke of England, president of the Royal Society and a vigorous personal opponent of Newton. Because of the plausibility of both theories, a scientific debate developed between the followers of Newton and the followers of Huygens that continued for more than a century. By the late 19th century, however, there appeared to be overwhelming evidence that the nature of light could be explained much better by using the wave model.

At the end of the 19th century, James Clerk Maxwell combined electricity, magnetism, and light into one theory. He called his theory the electromagnetic theory of light.

> According to Maxwell's **electromagnetic** theory, light was an electromagnetic wave with the same properties as other electromagnetic waves.

Maxwell's theory, however, was not able to explain all the properties of light including one called the photoelectric effect.

> In 1900, Max Planck, proposed the **quantum hypothesis** suggesting that light was transmitted and absorbed in small bundles of energy called "quanta."

Albert Einstein agreed with Planck's theory and explained the photoelectric effect using the particle model of light.

> The theory of **quantum mechanics**, developed over several years in the early 1900s, combines the two major theories of light by suggesting that light does not always behave as a particle and light does not always behave as a wave.

Recall in the previous module the discussion of scientific models and theories. Their function is to explain the known properties of a phenomenon, and to predict new behaviour or new properties. As we study the theories of light, keep in mind these characteristics of theories and how they are illustrated in this history.

Newton's Corpuscular Theory and Rectilinear Propagation

Newton built on an earlier theory proposed by Descartes that imagined light consisting of streams of tiny particles called "**corpuscles**."

The diagram to the left represents a light bulb in the centre. Newton imagined tiny particles shooting out from the source. The particles spread out evenly in all directions, and all are moving at the same very fast speed.

This theory is referred to as the **corpuscular theory** of light. There were various arguments that could be used to support the particle theory.

One argument was the **rectilinear propagation** of light—that is, light travels in straight lines. We can see this effect when sunlight passes through clouds forming straight "rays." We can also see sharp shadows cast by sunlight when large objects, such as buildings, intercept the sunlight. Newton also commented on the fact that the speed of light must be very large. When a ball is thrown at some angle, we can clearly see that it follows a curved path. If a cannon ball or bullet is fired at the same angle, there is less of a curve over the same distance because it is moving faster. Since the path of light has no noticeable curve, Newton argued that the **speed of light** must be **extremely high**. He also argued that since light **does not exert** any noticeable **pressure**, the **mass** of the particles must be **extremely small**.

Newton also noted that two beams of light pass through each other without reflecting to the side. In fact, after this passage through each other, the beams of light were exactly as before. This also indicated to Newton that the particles were **extremely small** in **size**—so small that they would not collide as a stream of particles in one beam passed through another stream of particles in a second beam.

It is primarily because light appears to move in a straight line that Newton rejected the wave theory of light. Newton argued that a wave should spread out a great deal as it passes through an opening, filling almost the whole region beyond the opening due to diffraction. Therefore, he felt that waves could not possibly produce a narrow beam. He similarly argued that a wave would diffract around objects to fill in the area behind the object, resulting in there being no shadow. Again, this suggested to Newton that light could not

possibly be a wave. Yet we know that these things are possible with waves—the amount of diffraction depends on the wavelength; small wavelengths diffract less. In our earlier studies with waves, we saw that when the opening is large compared to the wavelength, that the diffraction is not great, and the beam is relatively straight. Unfortunately, neither Newton nor anyone else knew very much about waves at that time. Nevertheless, Newton's corpuscular theory did appear to have a fair bit of merit to it—it appeared to explain many of the basic behaviours of light known at the time.

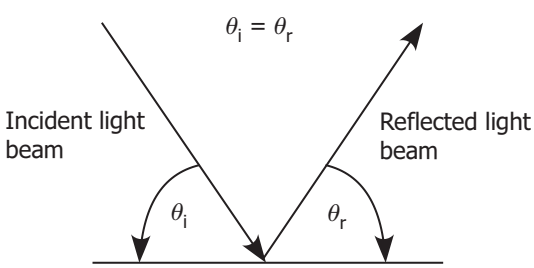
Newton's Corpuscular Theory and Reflection

When light falls on the smooth surface of a mirror, it reflects in such a way that the angle the incoming light beam makes with the surface (the angle of incidence, θ_i) is equal to the angle the reflected beam makes with the surface (the angle of reflection, θ_r). Newton demonstrated that very hard spheres collide with very hard surfaces in a similar manner. (Note that Newton measured the angles from the surface, not the normal to the surface. This was before the convention of measuring angles from the normal was adopted.)

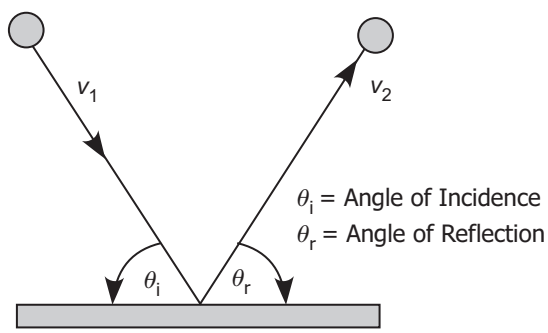
He was also able to show that under ideal conditions the speed of the sphere, when it reflects from the surface (v_2), is equal to the speed it had when it approached the surface (v_1). This kind of a collision is called an **elastic collision**.

By analogy, think about bouncing a basketball between two people. In order for the ball to bounce up to the same height as it was thrown from, it must hit the floor in the middle of the two people. This means that the ball will hit and leave the floor at the same angle and will also come off at the same speed as it hits the floor. Thus, Newton's corpuscular theory was able to explain reflection—light did indeed appear to act like small hard bits of matter.

Reflection of Light Beam from a Surface



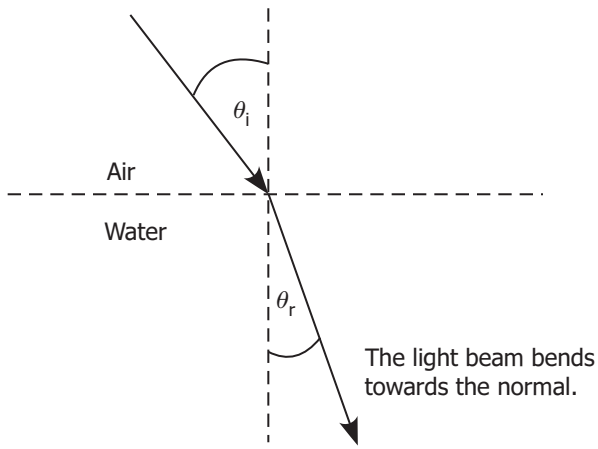
Reflection of a Particle



Newton's Corpuscular Theory and Refraction

When light passes from air into water, it bends, or refracts, towards the normal. Light beams will always refract towards the normal when they pass from a **less dense** to a **more dense** material.

Light Beam Moving from Air to Water

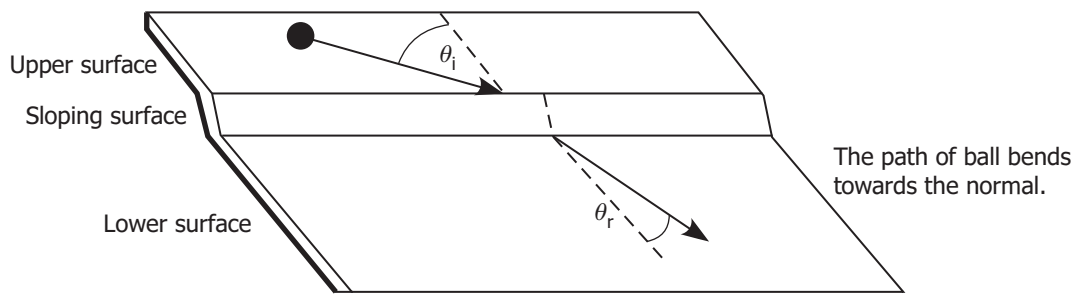


Newton was able to explain this effect using his corpuscular theory. In explaining refraction, he considered a light particle to be a small mass—essentially a small ball. He was then able to use his own laws of motion to prove that the motion of the particle will change upon entering a new material if there was a net force acting on the particle while it transitioned from the one medium to the next. Essentially, here is Newton's reasoning:

While the light particles are moving through the air, there is no net force on them and so they move in a straight line. This is also true while the particles are entirely in the water, but when the light particles are partly in the air and partly in the water, there is a lack of symmetry. If, during that time, there is a net force acting on them towards the water, then that force will pull them towards the normal, and so their motion will change—which is exactly what we see.

While this was absolutely brilliant, it actually leads to a severe problem for Newton's theory. The undeniable consequence of this theory is that the light must travel faster in the water than in the air. This is because, on being pulled into the water (as Newton's theory requires), it will accelerate in that direction, and so must speed up. This can be illustrated by the following analogy. Consider the motion of a ball that is initially moving along a horizontal, flat surface. This ball then goes down a small slope to another flat horizontal surface. When the ball is on either horizontal surface, it will experience no net force and so move in a straight line (this is rectilinear

propagation). However, when the ball moves from one to the other (by the ramp), it will experience a net force towards the lower surface and so will accelerate and change which way it's going. The upper surface represents air and the lower surface represents water.



Newton believed that water attracts approaching particles of light in much the same way that gravity attracts a rolling ball on an incline. The rolling ball model shows that light particles accelerate as they pass from air into water. Newton predicted that the speed of light in water must be greater than the speed of light in air. At the time of Newton, the speed of light in air, water, or anything else was not known. It was not until 123 years after Newton's death, in 1850, that the French physicist, Jean Foucault (1819–1868), demonstrated experimentally that the speed of light in water is actually less than the speed of light in air—the reverse of that predicted by the particle theory, but exactly what is required by the refraction of waves.

Video Laboratory Activity: The Particle Model of Light

In this lab activity, you will view *The Particle Model of Light*, a short video laboratory activity found in the learning management system (LMS). You will collect some data from the video so you should begin by reading the introduction and answering the pre-lab questions.

When you have finished the lab, you will complete a Laboratory Report, which is found at the end of this and every other Laboratory Assignment. The Laboratory Report is the only part of this assignment that you will hand in. It is worth a total of 20 marks, and you will be assessed on how well you complete it.

Introduction

If light is a particle, as Newton described, then light and particles must exhibit the same behaviour. We know that when light passes from one medium to another it bends according to Snell's law (refraction). That is, the ratio of the sine of the incident angle to the sine of the refractive angle is a constant. Thus, ${}_2n_1 = \frac{\sin\theta_1}{\sin\theta_2}$, where ${}_2n_1$ is a constant called the index of refraction.

To determine if particles behave according to Snell's law we will roll a metal sphere (our particle) down an inclined plane. The acceleration of the particle causes it to bend towards the normal. If we measure the angles of incidence and refraction, we can calculate the sines and graph $\sin\theta_i$ versus $\sin\theta_r$. If the ratio is constant then the line on the graph will be straight and the slope will be the index of refraction.

Purpose

To determine if the refraction of light behaves like a particle by demonstrating that a particle moving from one medium to another obeys Snell's law.

Apparatus

- two flat surfaces of different heights
- metal sphere
- ramp
- carbon paper
- pencil
- paper
- protractor

Procedure

1. Set up the apparatus and lay carbon paper over two sheets of blank white paper.
2. Place the launching ramp at the corner of the paper.
3. Place a metal sphere (our particle) on the launch ramp and let it roll down the ramp onto a flat surface. The metal sphere is released from the same point on the ramp in all trials. The metal sphere rolls across the flat surface with a constant velocity and then accelerates down the inclined plane. The sphere is pulled towards the normal.

4. Mark the path of the ball on the upper and lower surfaces from the points left behind by the carbon paper. Label trial #1.
5. Change your angle of launch and repeat steps #2–4 for four different angles.

Video Viewing

View the video *The Particle Model of Light*, which can be found in the learning management system (LMS).

Data and Calculations

Using the photocopies of the tracks of the metal sphere on the following pages draw a normal to the surface and measure the angles of incidence and refraction. Complete the table.

θ_i	θ_r	$\sin \theta_i$	$\sin \theta_r$

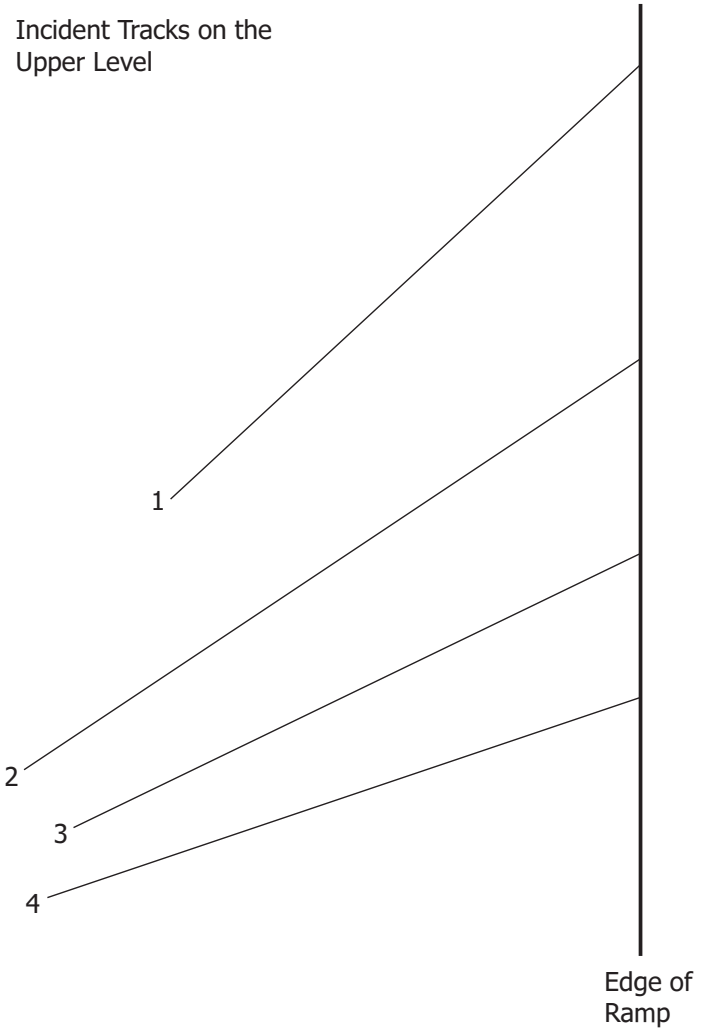
Graph $\sin \theta_i$ versus $\sin \theta_r$. Draw a best fit line and calculate the slope of the line.

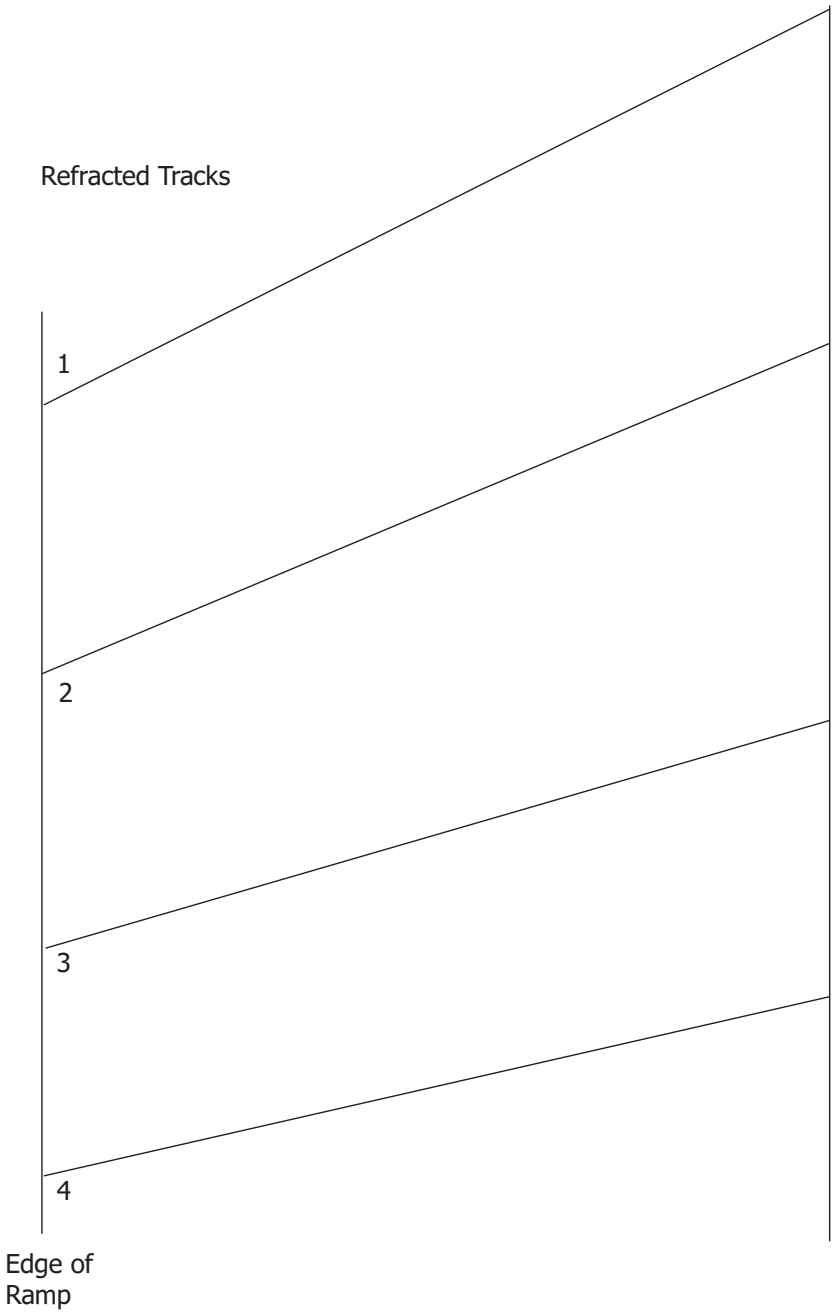
Discussion and Observations

Discuss possible sources of error in this experiment and how you could reduce the error.

Conclusion

What can you infer about the behaviour of light from this experiment?




Refracted Tracks
1
2
3
4
Edge of
Ramp

NOTES

Assignment 10.2

Video Laboratory Activity: The Particle Model of Light (20 MARKS)

You will be completing a Laboratory Report for each lab in the course. Use the information from the assignment itself to complete it. There are directions in each category. Follow them as closely as possible. You will be assessed on how well you follow those directions.

The Laboratory Report is the only part of this assignment that you will submit to the Distance Learning Unit.

Title:

Purpose: This gives the purpose of the experiment.

_____

_____

Apparatus and Procedure: Describe in your own words, in a brief paragraph (do not use point form), how the experiment was performed.

_____

_____

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(continued)

Assignment 10.2: Video Laboratory Activity: The Particle Model of Light (continued)

Data and Calculations:

- Include photocopies of your data measurements (e.g., tapes or tracks) if they were provided in the notes.
- Include the raw data for each part of the experiment in an appropriate data table.
- Provide a sample calculation for any values that are found from the raw data. For example, if you use a formula, write out the formula, show your substitutions and calculations. This should be done for each different calculation (that is, whenever you use a different formula or procedure). If there are many of the same calculation, only one example needs to be done.

(continued)

Assignment 10.2: Video Laboratory Activity: The Particle Model of Light (continued)

Discussion and Observations:

- Describe what was observed during the experiment. Qualitative observations should be included as complete grammatically correct statements.
- Discuss possible sources of error and how you could reduce the error.
- Answer any questions that have been posed in the lab outline.
- Provide an error analysis. In making measurements, errors are always made. In the error analysis, your job is to look critically at the procedure, identify possible sources of error (there may be several), and suggest how the procedure could be revised to eliminate or decrease these errors. In some cases, an error calculation needs to be shown.

(continued)

Assignment 10.2: Video Laboratory Activity: The Particle Model of Light (continued)

Conclusion: The conclusion answers the purpose and is supported by analysis of the data and observations.

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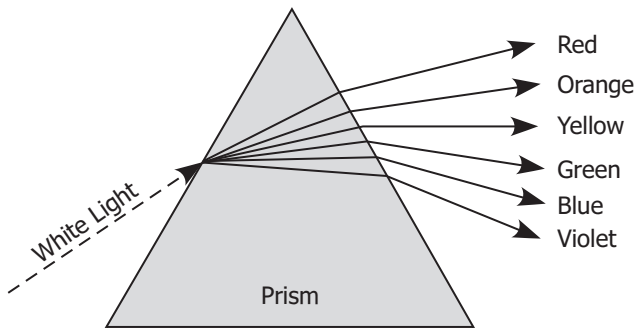
Marking Rubric for Assignment 10.2

Section of Report	Possible	Actual
Purpose	1	
Apparatus and Procedure	2	
Measuring the Angles	4	
Completed Data Tables with Sines	4	
Plot Graph and Find Slope	4	
Discussion—Sources of Error	3	
Conclusion	2	
Total	**20**	

Newton's Corpuscular Theory and Dispersion

> When a beam of white light passes through a prism, the light can change from white to a range of colours that is most often referred to as the "colours of the rainbow." This is called **dispersion**.

A prism is a transparent material (often glass) typically in the shape of a triangle



This phenomenon has been known since the time of the ancient Egyptians. It wasn't until 1666 that Newton investigated this phenomenon systematically.

To explain dispersion using the corpuscular theory, Newton hypothesized that the particles of light are not all the same mass: different colours could be explained as differences in the mass of the light particle. Since violet particles are refracted the most, Newton argued that the violet particles must have the smallest mass. This is because smaller masses would accelerate more greatly from the forces. Similarly, the particles that correspond to red light have the largest mass in the visible spectrum.

Newton's corpuscular theory provided a satisfactory explanation for four properties of light: rectilinear (straight line) propagation, reflection, refraction, and dispersion. It was weak in its explanation of other effects such as diffraction, partial reflection, and partial refraction. Considering the evidence available to Newton, his hypothesis was valid. In its day, it was superior to the competing wave theory of light because it used the laws of mechanics that had been proven to be valid in other areas of physics. When new evidence became available that could not be explained using Newton's corpuscular theory, this was bound to give stronger support to the wave theory. However, Newton's stature and authority was so great that the corpuscular theory of light dominated for over a century. In fact, Newton's successors adhered to the corpuscular theory of light more strongly than Newton ever did himself.

Newton recognized that the experimental evidence was not strong enough for either particles or waves. Although he preferred the particle theory, he was not dogmatic about it. He considered both theories to be hypotheses—that is, they required further testing.

The lesson to be learned from this is that theories and opinions of esteemed, famous people should be evaluated on the basis of the supporting evidence and not the reputation of any individual. As plain and simple as this is, it is a sad reality even today that people continually make this same mistake. Consider this the next time that you see a famous person making claims in support of a product on a television commercial. If, for example, a particular rock star claims that one soft drink is better than another soft drink, you should consider the evidence (the drinks themselves) and not the opinions of that person.

Difficulties with Newton's Corpuscular Theory

1. **Diffraction**

   Newton's corpuscular theory had difficulty explaining some of the properties of light. We learned in our earlier work that waves undergo diffraction—that is, the bending of waves as they pass around a barrier or through an opening.

   Newton believed that light travels in straight lines and does not travel "around a corner." In making this statement, Newton discounted the work of Francesco Grimaldi (1618–1663) who showed that a beam of light passing through two successive narrow slits produced on a screen a band of light slightly larger than the width of the slits. Grimaldi believed that the beam had been bent slightly outward at the edges of the second aperture. It was Newton's position that this effect resulted from the interactions and collisions between the light particles at the edges of the slit.

2. **Partial Reflection and Partial Refraction**

   When light refracts (bends as it passes into a different medium), some of the light is reflected. Newton had difficulty explaining the phenomenon of partial reflection and partial refraction using the corpuscular theory. Newton's explanation was the so-called "theory of fits": particles of light arrived at the surface sometimes in a "fit" of easy reflection and sometimes in a "fit" of easy refraction. This was obviously a weak explanation, as Newton himself recognized.

3. **Speed of Light in a Denser Medium**

   We have already seen Newton's explanation of refraction using the corpuscular theory. As mentioned earlier, Newton predicted that the speed of light would be greater in water than in air. We know today that this in fact is not the case.

   Thus, Newton's corpuscular theory did not accurately explain diffraction, partial reflection and partial refraction, and the speed of light in a denser medium after it refracts.

Learning Activity 10.2

The Nature of Light and Newton's Corpuscular Theory

1. When a "particle" such as a steel ball strikes a hard surface, its speed is usually reduced. If the speed of light were reduced, how would the light appear to be different after the reflection as compared to the incoming light beam? (You will need to use your knowledge of how the speed of light, the wavelength of light, and the frequency are related from your work on waves.)
2. We can think of momentum as the amount of push a moving mass has. A more precise definition of momentum will be given later in the course. People such as Benjamin Franklin rejected the corpuscular theory of light on the basis of momentum considerations. Suggest an argument he may have used.
3. From the brief descriptions given above of Planck's quantum hypothesis, how does it compare with Newton's corpuscular theory?
4. We know now that Newton's corpuscular theory had limitations and that light really does not consist of particles. What can we learn about placing too great a belief in a theory and the kind of evidence needed to support the theory?
5. Briefly describe how Newton's corpuscular theory was able to explain each of the following behaviours of light. Include a diagram where appropriate.
   a) rectilinear propagation
   b) reflection
   c) refraction
   d) dispersion

Lesson Summary

Plato's theory of light was a **tactile theory** based on the ability of the eye to "touch objects." Plato thought that light consisted of "streamers" or filaments, emitted by the eye, and that when these streamers came in contact with an object it was possible to see the object. The **emission theory** was proposed by the Pythagoreans who believed that objects sent out light beams or particles that would ricochet off objects and enter the eye.

Newton was the principal advocate of the **particle, or corpuscular, theory**. Newton's theory stated that light consisted of particles that travelled in straight lines. The wave theory was supported principally by Christiaan Huygens and stated that light behaves as a wave.

Maxwell's **electromagnetic theory** of light stated that light was an electromagnetic wave with the same properties as other electromagnetic waves. Max Planck's **quantum hypothesis** suggested that light was transmitted and absorbed in small bundles of energy called "quanta." The **quantum mechanical theory**, developed by several scientists in the early 1900s, combines the two major theories of light suggesting that light does not always behave as a particle and light does not always behave as a wave.

Newton's **corpuscular theory** of light proposed that light consisting of streams of tiny particles called "corpuscles." There were various arguments that could be used to support the particle theory.

Rectilinear propagation of light is light travelling in straight lines. We can see this effect in sharp shadows cast by sunlight. Newton argued that the speed of light must be very high because the path of light has no noticeable curve. Since light does not exert any pressure, the mass of the particles must be very small.

Newton's corpuscular theory was able to explain **reflection** of light by showing that in the ideal case, very hard spheres reflect from a surface so that the angle of incidence is equal to the angle of reflection, and that the reflected speed of the spheres equals the incident speed.

Newton's corpuscular theory demonstrated that when light **refracts** towards the normal while moving into a denser medium, this is analogous to a ball rolling from a higher horizontal surface to a lower one and also bending towards the normal. However, the particle model predicts that light will travel faster through a denser material—the opposite of what actually happens.

Dispersion occurs when white light passes through a prism and is refracted by different amounts, resulting in the formation of the spectrum of colours. Newton's corpuscular theory was able to explain dispersion by assuming that each particle of the spectrum had a different mass. Violet particles have the smallest mass and so were refracted the most, while red particles had the greatest mass and were refracted the least.

The corpuscular theory could not adequately explain diffraction, partial reflection and partial refraction, and the speed of light in a denser medium.

NOTES

Assignment 10.3, Part A

The Nature of Light and Newton's Corpuscular Theory (5 MARKS)

Newton's corpuscular theory of light explained various properties of light. The following questions refer to this theory.

a) In explaining rectilinear propagation of light, what did Newton's corpuscular theory say about the speed of light and the mass of light, and how did he justify these statements?

b) In explaining reflection, what two angles are equal to each other in both the corpuscular theory and the wave theory?

c) What does the corpuscular theory predict about the speed of light in a denser medium, and how did Newton use the idea of gravity to explain this effect?

(continued)

Assignment 10.3, Part A: The Nature of Light and Newton's Corpuscular Theory (continued)

d) In explaining the dispersion of light, what did Newton say about the masses of the particles that make up the different colours of light?

_____

_____

e) Why was the corpuscular theory so well accepted among some scientists, and why was it eventually replaced?

_____

_____

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Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for each of parts (a) to (e)

Lesson 3: Determining the Speed of Light (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain how the following scientists attempted to measure the speed of light: Galileo Galilei, Christiaan Huygens, Olaus Roemer, Armand Fizeau, Jean Foucault, and Albert Michelson

Key Words

speed of light
rotating mirror

Introduction

Measuring the speed of light has always been a challenge. The reason for the difficulty is that the speed of light is so great that the usual distances over which we might measure the speed results in very short time intervals. Only recently has technology enabled us to measure the short time intervals during which light travels over very short distances (like a laboratory). In this lesson, we will review the methods used starting with that attempted by Galileo, through the 1600s when Roemer and Huygens used similar approaches by looking at the eclipses and orbits of Jupiter and one of its moons, Io. We will then review the 1800s, when Fizeau and Foucault used rotating wheels and mirrors to measure the speed of light, and the 1900s, when Michelson improved on Foucault's technique and obtained a very accurate measurement of the speed of light.

Measuring the Speed of Light: Galileo, Roemer, and Huygens

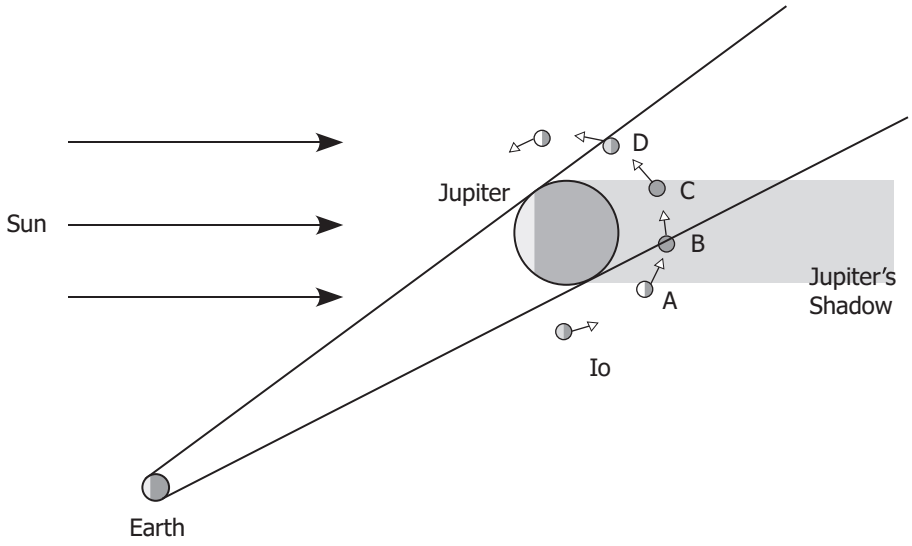
Galileo Galilei (1564–1642) carried out experiments to measure the speed of light by measuring the time it took for light to travel a known distance between two hilltops. He stationed an assistant on one hilltop and himself on another, and ordered the assistant to lift the cover from a lamp the instant he saw a flash from Galileo's lamp. Repeated experiments failed to accurately measure any time interval between when the first and second lanterns were uncovered. They could only say that light travel was at least 10 times faster than sound.

Measuring the Speed of Light: Olaus Rœmer

The invention of the telescope in 1608 by Hans Lippershey (1570–1619), a German-born Dutch lens maker, enabled scientists to turn to the skies to study the motion of planets more closely. Using a version of this new-found telescope, Galileo discovered in 1610 that Jupiter had four moons regularly circling about it.

Towards the end of the 16th century, the determination of a ship's position at sea (especially its longitude) was a problem in need of a solution. Clocks of the time were accurate for only a matter of hours, so it was thought that the regular motions of heavenly objects—like moons whizzing around a large planet like Jupiter—could act as a kind of "clock." By the late 1600s, precise and accurate clocks were available, and Roemer made good use of this technology for the timing of the eclipses of Jupiter's moon Io. Jupiter is so far away from Earth that observing an eclipse of one of Jupiter's moons would be a so-called "mutual event"—all people standing on Earth's surface would see it at the same moment. But, like time zones today, the local time of day would be different for each observer, depending on where they were.

Roemer did not initially set out to make any sort of determination of the speed of light. Most already believed that light travelled *in an instant* from one place to another, or was just so fast that no one would ever be able to measure its speed. Roemer made a detailed study of the frequent eclipses of Io by Jupiter. As observed from Earth, Io would pass into the shadow of Jupiter, pass behind Jupiter, then emerge from behind Jupiter to become visible again on the other side of Jupiter.



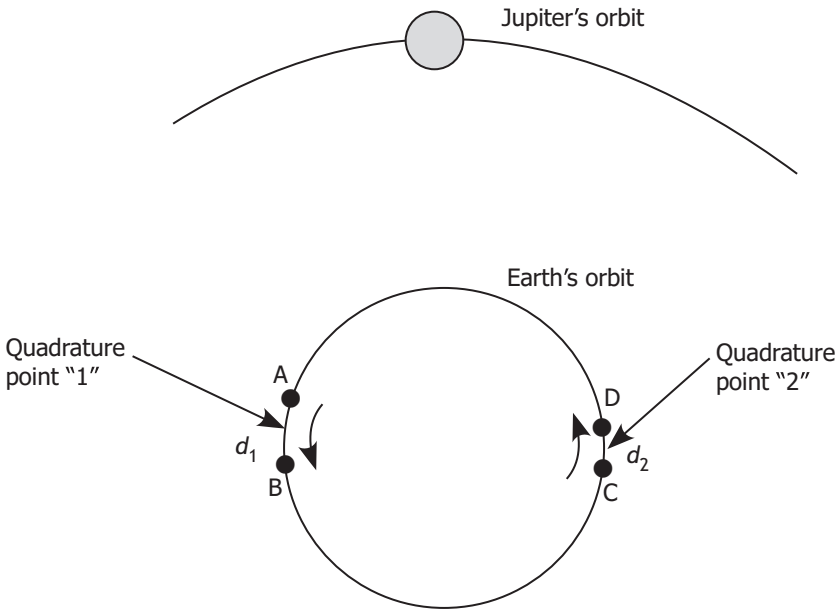
In the graphic above, Io enters the shadow of Jupiter at A. At B, Io is totally in the shadow of Jupiter. At C, Io emerges from the shadow of Jupiter, ending the eclipse. At D, Io appears in the line of sight of an observer on the earth and once more can be seen.

During the period 1668–1678, Ole Roemer timed eclipses of Io over 50 times. Not all the observations were true eclipses, however, with Io passing into Jupiter's shadow behind the planet. Occasionally, Roemer was timing what is called a **transit**, where the moon Io actually passed in **front** of Jupiter as seen from earth.

Some of the early observations from the period 1668–1672 took place at Tycho Brahe's famous Uraniborg ("city of the Heavens") observatory near Copenhagen, Denmark, and were done in partnership with the astronomers Jean Picard and Giovanni Domenico Cassini of France. Over the period 1672–1678, observations were made from the Paris Observatory. For some of Roemer's observations, Earth was moving towards Jupiter. However, for the majority of the eclipses of Io, Earth was moving away from Jupiter. This was likely done to accommodate observing Jupiter during "prime time" in the hours from sunset to midnight when Jupiter was an easy-to-see object in the evening sky. He published his results in 1676 among some of the most distinguished scientific organizations of his day—the French Academy of Sciences and the Royal Society in London, England.

From this work he was able to predict when the next eclipses would occur. Over a period of months, Roemer's observations at the telescope were steadily off predictions by longer and longer intervals of time when Earth was moving away from Jupiter. In an equally unusual find, whenever Earth was moving *toward* Jupiter in its orbit, the eclipse timings were *earlier than expected*. This must have fascinated and troubled Roemer for a period of years. His observations showed that eclipse times were eventually off by as much as eight minutes. Even stranger was the fact that, eventually, the problem disappeared and the observations actually matched what the eclipse tables had predicted. The gap in the timings seemed to "open" and "close" with astonishing predictability. This strange cycle repeated itself over and over again with great regularity, and so it made sense to seek out an explanation for this.

Roemer's Observation



Roemer found that the orbital period of Io was always slightly longer when the Earth was moving away from Jupiter (left side of diagram above) as compared to when the Earth was moving toward Jupiter (right side of diagram above. Roemer concluded that the speed of light was the reason for this discrepancy of time. The drawing of Roemer's observation shown shows the Earth-Jupiter system that he may have used to make an early determination of the speed of light.

Therefore, the speed of light will be accounted for in the *extra distance* that light travels divided by the time that has elapsed over that distance. We calculate this twice: when Earth is moving away from Jupiter, and when Earth is moving towards Jupiter, and then we compare our data. For a first approximation, we assume that Jupiter does not move at all over such a short period of days to weeks, and motions of Earth and Jupiter occur in the same plane.

We know:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

From your data, calculate the speed of light.

$$\text{speed} = (2)(1.821 \times 10^{11}\ \text{m})/597.024\ \text{s}$$
$$= 6.100 \times 10^{8}\ \text{m/s}$$

This value for the speed of light is in the same *order of magnitude* as the modern value.

Roemer realized that this time difference was caused by the difference between the distance between Earth and Jupiter. When Jupiter was closest to earth, the eclipses happened on time. The further Jupiter was away from the earth, the later the eclipses became if Earth was moving away. This was because light had a longer distance to travel to earth and this took longer. The size of Earth's orbit and Jupiter's orbit around the sun were known at that time, but then only roughly. Roemer used these figures to determine the distance between the earth and Jupiter for all his observations. Others quickly realized that enough information was available to be convinced that the speed of light was finite, and was in fact knowable. It is not known whether Roemer actually performed a calculation that would have given a value to the speed of light—all of his notebooks were burned in a fire that destroyed the Royal Copenhagen Observatory. It is certain that one of his observing friends—Cassini—used these somewhat inaccurate distances (as it was known in 1675) to calculate the speed of light to be about 200 000 km/s or 2.0×10^{8} m/s. But who got the recognition first?

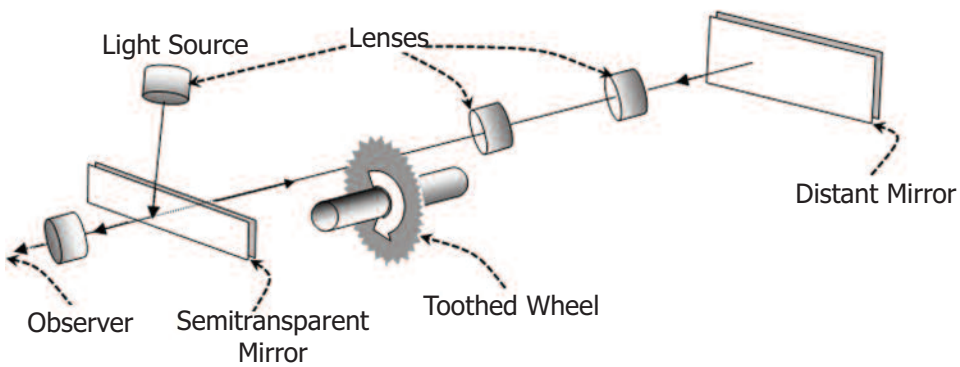
In 1677, Christiaan Huygens (1629–1695) in Holland read about Roemer's work on calculating the speed of light. He immediately sent a letter to Roemer asking for more information. In 1678, Huygens presented his "Traite de lumiere" for the Academie des Sciences. He used the size of Earth's orbit, and the time delay presented by Roemer, to calculate the speed of light. He was the first to give the speed in terrestrial units as 16-2/3 earth diameters per second. This was about 2/3 the present value of the speed of light. Not bad work considering how difficult the whole process was in those times.

Measuring the Speed of Light: Fizeau and Foucault

The French physicist, **Armand Fizeau** (1819–1896), shone a light between the teeth of a rapidly rotating toothed wheel. A mirror reflected the beam back through the same gap between the teeth of the wheel. There were over a hundred teeth in the wheel. The wheel rotated at hundreds of times a second—therefore a thousandth of a second was easy to measure.

Light was reflected from mirrors more than 6 kilometres apart. By varying the speed of the wheel is was possible to determine at what speed the wheel was spinning too fast for the light to pass through the gap between the teeth and back through the same gap. Fizeau had to decrease the rate of rotation of the toothed wheel until the first instance at which the light was able to pass through the gap going toward the distant mirror, reflect and return through the same gap.

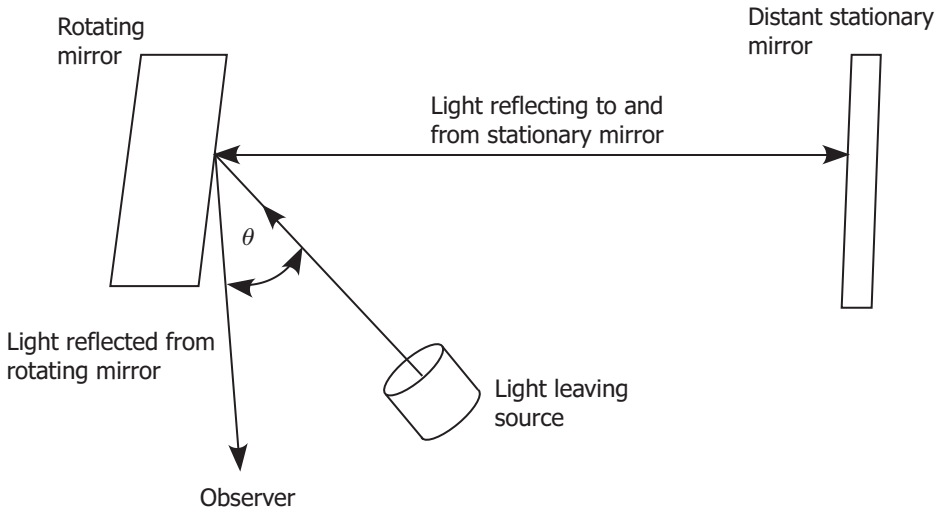
Fizeau's Method for Measuring the Speed of Light



Fizeau calculated the speed of light to be $3.133\,00 \times 10^8$ m/s. He was able to do this because he knew how short a time the light had to get through that gap and back, and he knew how far the light travelled. By dividing the distance by the time he obtained the speed of light.

Jean Foucault (1819–1868) bounced light from a rotating mirror back to a stationary mirror. The light from the rotating mirror bounced back at an angle slightly different from the angle it hit the mirror with—because the mirror was rotating. By measuring this angle it was possible to measure the speed of the light. Foucault continually increased the accuracy of this method. His final measurement determined that light travelled at $2.997\,96 \times 10^8$ m/s.

Foucault's Experiment



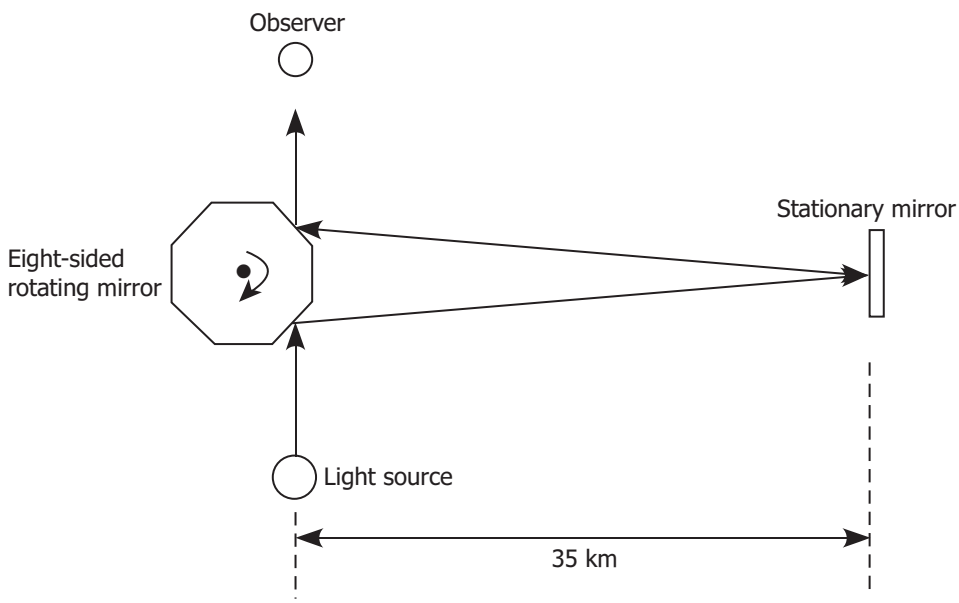
Measuring the Speed of Light: Michelson

The American, **Albert A. Michelson** (1852-1931) was an instructor in physics at the United States Naval Academy. He had to do a lecture demonstration of how Foucault measured the speed of light. It was years since Foucault made his measurements. When Michelson was setting up his demonstration, he saw how it could be improved to give a much more accurate measurement.

Michelson used a rotating mirror apparatus for a series of high precision experiments carried out from 1880 to the 1920s. Light from a source was directed at one face of a rotating eight-sided mirror. The reflected light travelled to a stationary mirror and back again as shown. The U.S. Coast and Geodetic Survey found the distance between the mirrors to be 35 385.5 m accurate to about one part in seven million. This was a larger distance than the 10 m or so that Foucault used. The rate at which the mirror was rotating was measured accurately using a stroboscopic comparison with an electric signal of standard frequency. If the rotating mirror was turning at just the right rate, the returning beam of light would reflect from one face of the mirror into a small telescope through which the observer looked. At a different speed of rotation, the beam would be deflected to one side and would not be seen by the observer. From the required speed of the rotating mirror and the known distance to the stationary mirror the speed of light could be calculated. Michelson set up the rotating mirror on the top of Mt. Wilson in southern California and the stationary mirror on Mt. Baldy (Mt. San Antonio) 35 km away. He determined the speed of light to be $2.997\,29 \times 10^8$ m/s.

Michelson conducted similar experiments using an evacuated tube one mile (1.6 km) long to eliminate the problems of haze and variations in air density. In these investigations, he determined the speed of light to be $2.997\ 96 \times 10^8$ m/s which he believed to be accurate within one km/s.

Today, the accepted value for the speed of light is $2.997\ 924\ 58 \times 10^8$ m/s.



Learning Activity 10.3

Determining the Speed of Light

1. Galileo attempted to measure the speed of light using lanterns on two hilltops. Explain why this technique might have worked if he was attempting to find the speed of sound, but not the speed of light.
2. What technique allowed Fizeau to measure time accurately enough to determine the speed of light much better than Galileo?
3. What was it about Michelson's technique that allowed him to measure the speed of light so accurately?
4. After doing his experiments on two mountains, Michelson did another series of experiments in a long evacuated tube. What improvements did this new method have?

Lesson Summary

Galileo Galilei attempted to measure the speed of light by measuring the time light took to travel between lamps on hilltops. He could only determine that light travels at least ten times faster than sound.

Olaus Roemer measured the speed of light using data of the eclipses of one of Jupiter's moons, Io. He calculated the speed of light to be about 2.0×10^8 m/s.

Armand Fizeau in 1849 used a rapidly rotating toothed wheel to measure the speed of light. He determined the speed of light to be 3.133×10^8 m/s.

Jean Foucault in 1850 bounced light from a rotating mirror back to a stationary mirror. He determined that light travelled at $2.997\,96 \times 10^8$ m/s.

Albert Michelson between 1880 and 1920 used a rotating octagonal mirror and a stationary mirror to determine the speed of light. He determined the speed of light to be $2.997\,96 \times 10^8$ m/s.

NOTES

Assignment 10.3, Part B

Determining the Speed of Light (5 MARKS)

The physics of measuring the speed of light by different scientists.

a) In all of the experiments discussed, from Galileo to Michelson, it was necessary to measure two very important quantities to determine the speed of light. What were these two quantities?

_____

_____

b) Roemer was the first to measure the speed of light with any degree of accuracy. But he was limited in how accurate he could be. What measurement was not well known at that time, and therefore limited Roemer?

_____

_____

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c) How did Fizeau know if the toothed wheel was spinning too fast for a proper measurement for the speed of light?

_____

_____

d) Besides measuring distance and time, what else did Foucault have to measure to determine the speed of light?

_____

_____

(continued)

e) Was Michelson's experimental apparatus more like Fizeau's or Foucault's? Why?

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for each of parts (a) to (e)

Lesson 4: Wave Theory of Light (1 hour)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ state Huygens's Principle, and use it to explain the future position of a wavefront based on an earlier position of the same wave
- ❑ explain, using diagrams, how two dimensional waves are reflected from a barrier so that the angle of incidence is equal to the angle of reflection
- ❑ explain how the wave theory explains refraction
- ❑ explain how the wave theory and the corpuscular theory differ in predicting the speed of light in an optically denser medium
- ❑ explain how the wave theory explains partial reflection and partial refraction
- ❑ explain how the wave theory explains diffraction
- ❑ explain the basis for Newton's criticism of the wave theory in explaining the diffraction effects observed by Grimaldi
- ❑ explain why it was so difficult to use the wave theory to explain interference effects at the time of Newton

Key Words

wavefront	wave ray	reflection
refraction	partial reflection	partial refraction
diffraction	interference	wave theory

Introduction

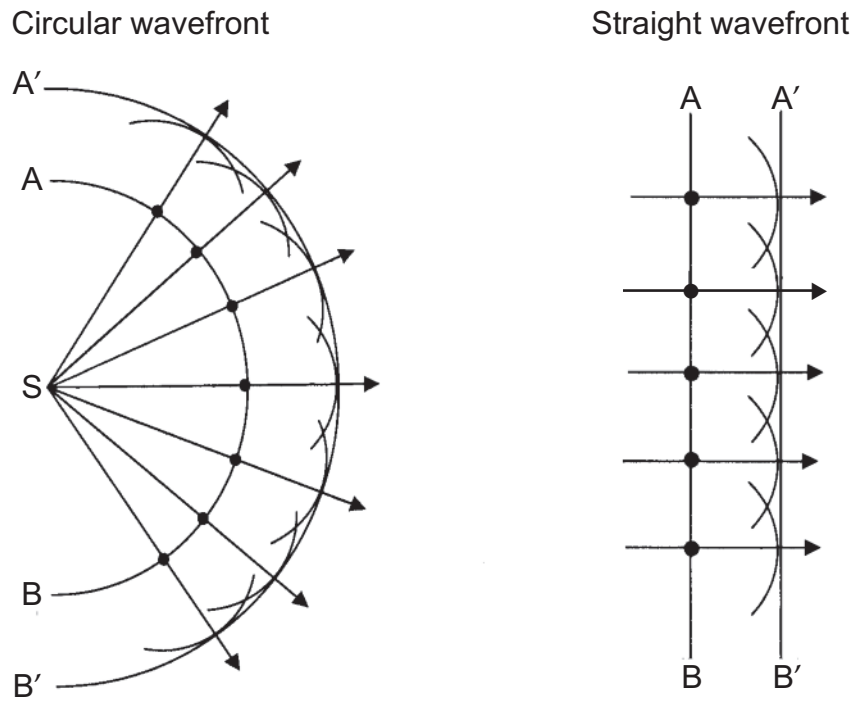
In this lesson, we focus on the wave theory and how it explains the behaviour of light. We will first review Huygens's Principle and how it explains the propagation of waves. We will then use the wave theory to explain reflection, refraction, partial reflection and partial refraction, and diffraction. The wave theory provides a better explanation of partial reflection–partial refraction, and diffraction than the corpuscular theory does. It also makes a more accurate prediction of the speed of light in an optically denser medium than the corpuscular theory does. We will see why it was difficult to explain diffraction using the wave theory at the time of Newton. Throughout this discussion diagrams will be used to illustrate the principles involved.

Huygens's Principle and Rectilinear Propagation

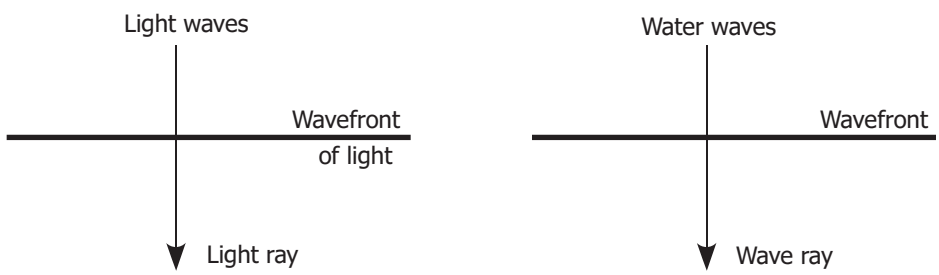
The wave theory of light was proposed by Robert Hooke in 1665. Twenty years later, it was improved by the Dutch scientist Christiaan Huygens. He developed a technique for predicting the future position of a wave front based on an earlier position of the same wave. His explanation became known as **Huygens's Principle**.

> **Huygens's Principle** states that every point on a wave front can be considered as a point source of tiny secondary wavelets that spread out in front of the wave at the same speed as the wave itself. The surface envelope, tangent to all the wavelets, constitutes the new wave front.

As an example of the use of Huygens's Principle, consider the wavefront AB that is travelling away from the source S at some instant in time. The points on the wave front represent the centres of the new wavelets, seen as a series of small circles. The common tangent to all these wavelets, the line A'B', is the new position of the wave front a short time later.



The **wave theory** treats **light** as a series of wavefronts perpendicular to the light rays.

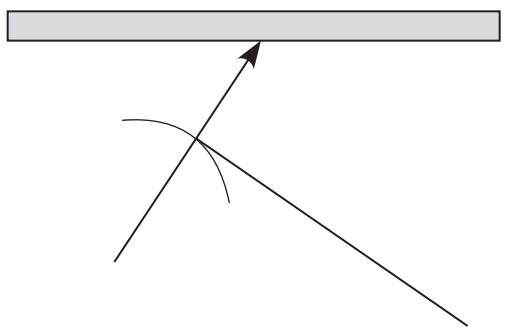


Huygens thought of the **rays** as simply representing the **direction of motion** of a **wavefront**. This was how the wave theory explained **the rectilinear (straight line) propagation of light**.

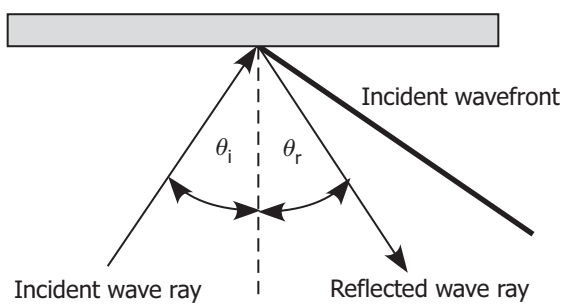
Newton felt that the wave theory did not adequately explain the rectilinear propagation of light since waves emitted from a point source spread out in all directions.

The Wave Theory and Reflection

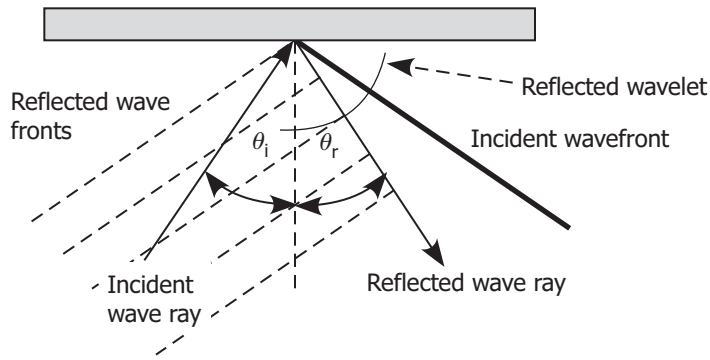
Light reflects from surfaces in such a way that the angle of incidence is equal to the angle of reflection. In our studies of waves in two dimensions, we learned that water waves also reflect from surfaces so that the angle of incidence is equal to the angle of reflection. The diagram below shows one incident wave front approaching a barrier. The arrow is the incident wave ray showing the direction that the wave front is moving. A wavelet is shown at one edge of the wave front. You will recall that you drew this type of diagram for reflection of water waves in a ripple tank. You may want to review the steps for the procedure for drawing the reflection of straight wavefronts from a straight barrier back in Module 8, Lesson 1.



When the wavefronts reflect, they do so in such a way that the angle of incidence (θ_i) is equal to the angle of reflection (θ_r) for the wave rays. The diagram below shows only one of the incident wavefronts at the point when one edge is making contact with the barrier.



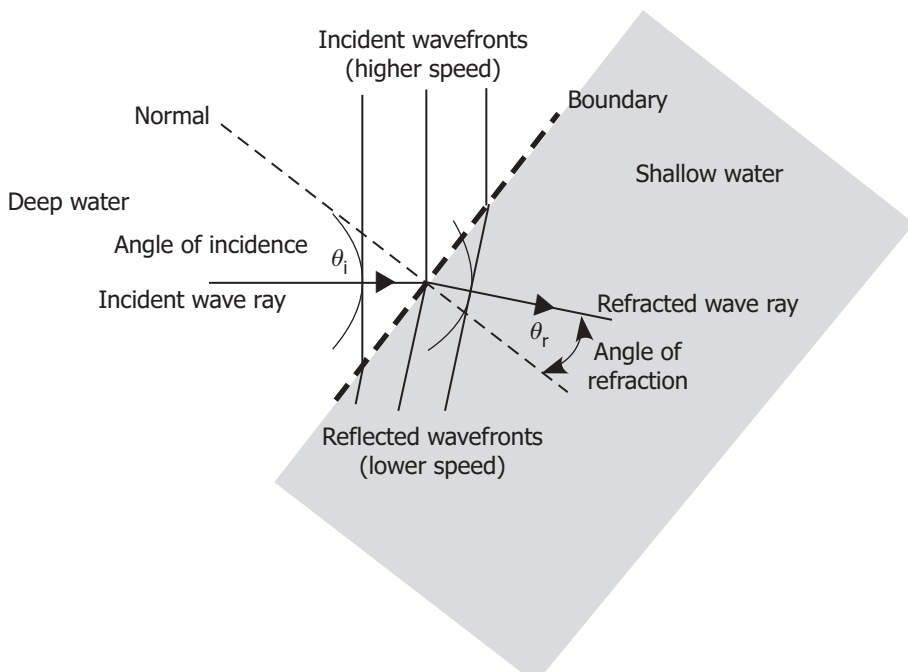
The following diagram shows how several reflected wave fronts (broken lines) would move. Note that the wavefronts are drawn perpendicular to the wave rays. One reflected wavelet is shown.



The Wave Theory and Refraction

Using his wavelet concept, Huygens predicted that light is bent towards the normal as it passes into an optically denser medium such as glass, because its velocity is slower in the second medium.

In our work in the unit waves in two dimensions, we studied a diagram similar to the one shown below.



The diagram shows incident wavefronts in **deep water**. This corresponds to light moving in a **low density material** like **air**. The direction of the wavefronts is indicated by the incident wave ray. One of the wavelets is included on this ray. Note that the wavefront is tangent to the wavelet.

After the wavefronts move into the **shallow water**, they refract in such a way that the **angle of refractio**n is smaller than the **angle of incidence**. The wave ray in the **shallow water** corresponds of light moving in a **higher density material** such as water or glass. A wavelet is drawn on the refracted wave ray.

The distance between the wavefronts (wavelength) in the shallow water (denser material), is less than the wavelength in the deeper water. This corresponds to a **decrease in speed** of the wavefronts in the **shallow water**. Thus the wave theory predicts a decrease in speed of light as it moves into a denser material. Newton's corpuscular theory predicted the reverse—that is, the speed of light in the denser material was greater.

Snell's Law applies to light waves as it does for water waves. The direction of the refracted wave can be determined using the ratio of the two velocities in the two media.

$$\frac{\sin \theta_i}{\sin \theta_r} = \frac{\lambda_i}{\lambda_r} = \frac{v_i}{v_r}$$

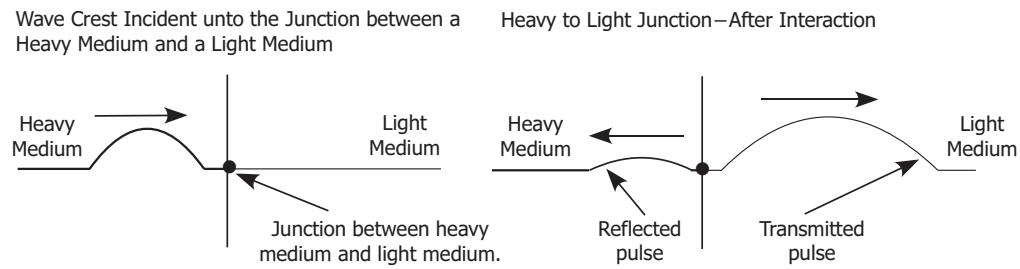
The sine of the angle in a medium is directly related to the speed of the wave in that medium. The wave theory for refraction is consistent with Snell's Law. The medium with waves with a **larger velocity** also has the **larger angle** for the direction of motion of the wavefronts.

The Wave Theory and Partial Reflection and Partial Refraction

Waves **partially reflect** and **partially refract** whenever there is a change in the velocity of the wave. This happens when waves pass from one medium into another at a surface.

The **amount** of **partial reflection** varies with the **angle of incidence**. When the angle of incidence is **small** (wavefronts head straight into another medium) **almost all** of the wavefront is transmitted through the surface. When the angle of incidence is **large** (wavefronts sort of skim the surface like the sun's rays bouncing of the surface of a lake) then the amount of reflection is **larger**. Also partial reflection is much more apparent when there is an increase in velocity than when there is a decrease. This would be a situation where the light waves pass from water to air or glass to air.

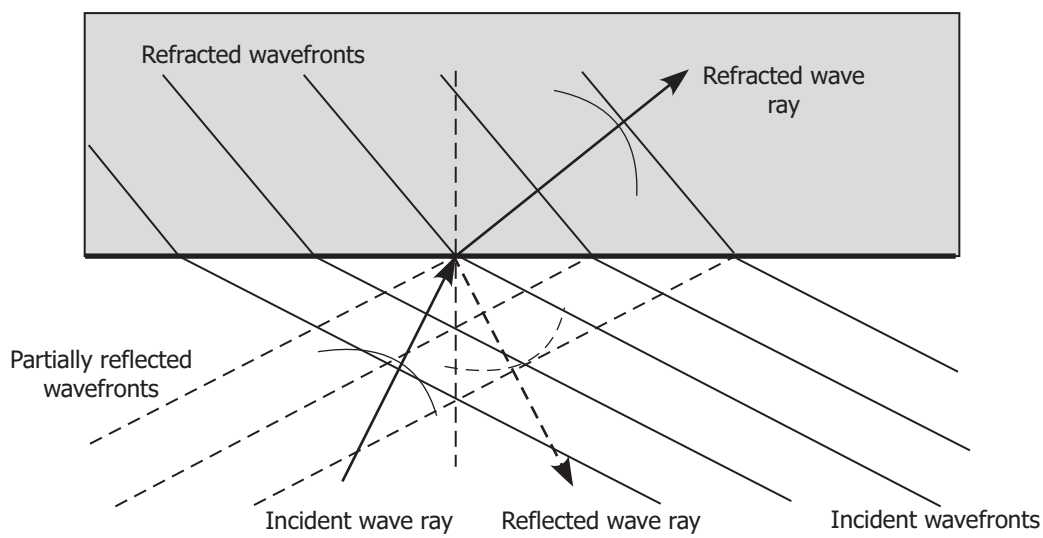
Partial reflection is a well documented behaviour of waves. For waves in one dimension you observed that waves would partially reflect and partially transmit at the junction between two medium (where speed changes).



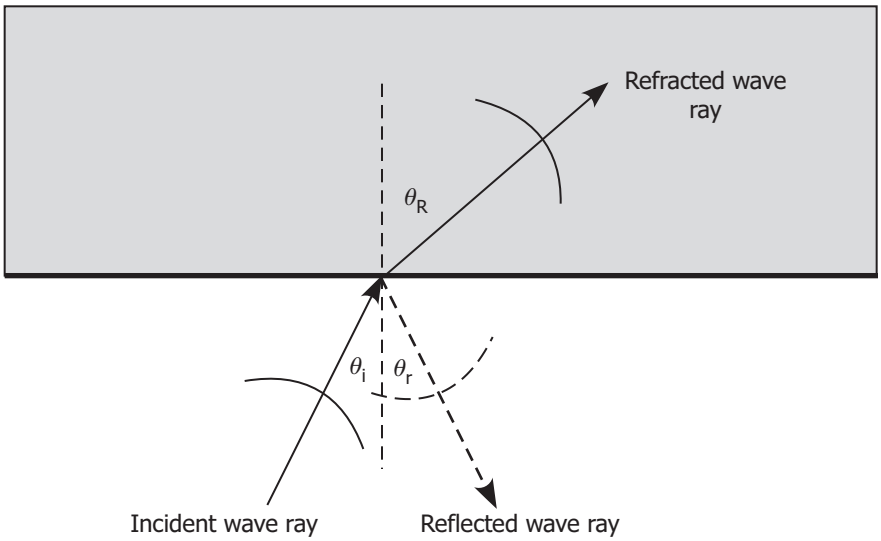
You also studied waves in two dimensions and here too waves exhibit partial reflection and partial transmission.

The diagram below shows incident wavefronts in a slow medium approaching a boundary. This slow medium could represent shallow water, or it could represent an optically dense medium that light waves travel through.

Part of the incident wavefronts is reflected. These are shown by dashed lines. Part of the incident wavefronts is also refracted. The corresponding wave rays are shown. One wavelet is also shown on each of the three types of wavefronts.



The lower diagram shows the angle of incidence (θ_i) equal to the angle of reflection (θ_r), and the angle of incidence is less than the angle of refraction (θ_R) for this kind of a wave moving from a slow medium to a fast medium.

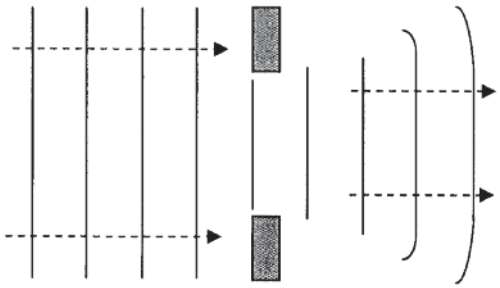


The wave theory is an excellent model for explaining the behaviour of light for partial reflection and partial refraction.

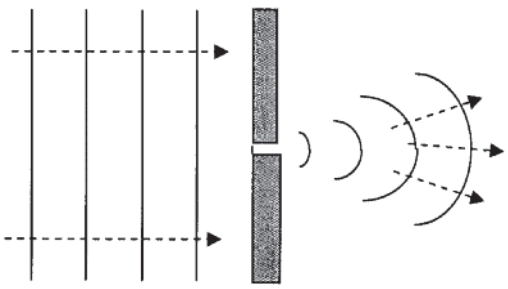
The Wave Theory and Diffraction

At the time of Newton, Grimaldi observed the diffraction of light when a ray was directed through two successive narrow slits. Newton criticized Grimaldi's work by saying that if light was a wave, then light waves should bend much more than was observed by Grimaldi.

In our earlier work in diffraction of water waves, we observed that there is considerable diffraction only when the **size of the aperture** is of approximately the **same size** as the **wavelength** of the waves. For example, in the left diagram below, the size of the opening is large compared to the wavelength and there is little diffraction. In the right diagram, the opening size is small and therefore there is a great deal of diffraction.

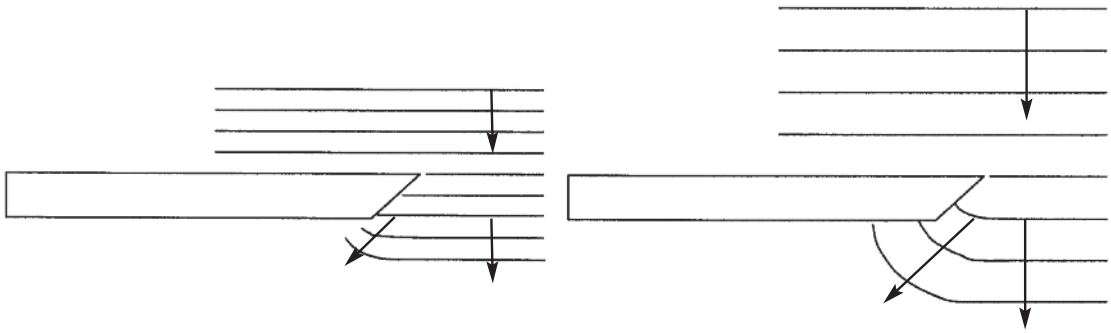


There is little diffraction when waves pass through an opening that is much larger than the wavelength.



There is more diffraction when waves pass through an opening that is about the same size as the wavelength.

The diagrams below also show that diffraction around a sharp barrier is less for shorter wavelengths.



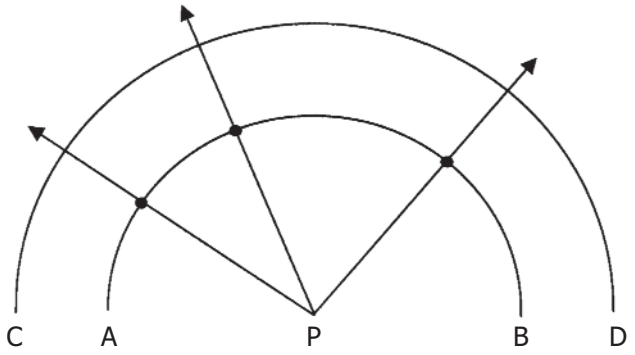
At the time of Huygens and Newton, the wavelength of visible light was not known. We know today that because the wavelength of visible light is so small, that diffraction effects are also very small for the relatively large openings we regularly experience. Upon further investigation however, it was discovered that with a sufficiently tiny (very tiny!) opening (in the form of a narrow slit carved into a barrier), light very much does in fact diffract. This suggested (correctly) that the wavelengths of light are very, very small. So small in fact that in any ordinary situation, the diffraction of light can be ignored. Of course with the right size opening, light diffracts exactly as it should.

The wave theory provided a much better explanation of diffraction than did the corpuscular theory.

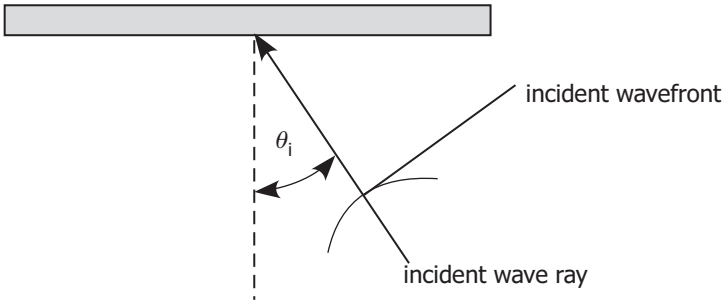
Learning Activity 10.4

Wave Theory of Light

1. A source of light is at the point P. The diagram shows three of the light rays that may be travelling out from this point. The wave theory would predict that the light source is sending out circular waves. One of those waves is labelled AB. At the places where the light rays cross the wave, there are dots representing new sources of wavelets. When the wave AB expands to become wave CD, draw the wavelets at each of the places where the light rays intersect with the wave CD.



2. The diagram below shows a wave front and the associated wavelet approaching a barrier. The wave ray indicates the direction of motion of the wavelet. The angle of incidence is also shown. Show the wavelet at some later time after reflection has occurred. In your diagram include the following.
   a) the wave ray indicating the direction of motion of the reflected wavelet
   b) a possible location of the wave front
   c) the correct location of the wavelet in relation to the wave front
   d) the angle of reflection



(continued)

Learning Activity 10.4: Wave Theory of Light (continued)

3. The wave theory provides a good model for describing refraction.
   a) When waves move from deep water to shallow water, what does the wave theory show about the change to the wavelength of the wave and the speed of the wave in the shallow water?
   b) How does the wave theory prediction about the speed of light in an optically denser medium compare with the corpuscular theory?
4. If we wanted to observe the diffraction of light as it passes through an opening, how large should the opening be in order to observe the effect?

Lesson Summary

Huygens's Principle states that every point on a wave front can be considered as a **point source** of **tiny secondary wavelets** that spread out in front of the wave at the same speed as the wave itself. The **surface envelope**, tangent to all the wavelets, constitutes the new wavefront.

The **wave theory explains** the **reflection** of light. Work in an earlier module showed that two-dimensional **waves** also **reflect** so that the **angle of incidence** is **equal** to the **angle of reflection**.

The **wave theory** explains the **refraction** of light. When a water wave moves into a shallow area, it bends towards the normal, and the speed of the wave decreases. This also happens with light. The wave theory correctly predicted that the **speed** of light would be **less** in a **denser material**.

The **wave theory** correctly explained **partial reflection** and **partial refraction**. During partial reflection, the angle of incidence is equal to the angle of reflection. When the water wave moves into shallow water from deep water, the angle of refraction is smaller than the angle of incidence, its speed decreases and the wavelength decreases. Light also shows this behaviour.

The **wave theory** correctly explained **diffraction**. In an opening, diffraction is greater when the size of the opening approaches the wavelength of the incident waves. If the opening is too large, very little diffraction will occur.

Since light has a very small wavelength, it was difficult for scientists during Newton's time to see diffraction.

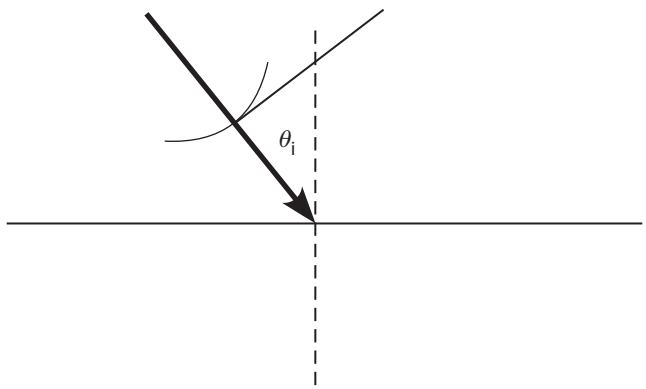
The **wave theory of light** explains the **propagation of light, reflection, refraction, partial reflection** and **partial refraction**, and **diffraction**.

NOTES

Assignment 10.3, Part C

Wave Theory of Light (5 MARKS)

1. The wave theory is able to provide a better model than the corpuscular theory for partial reflection and partial refraction. The diagram below shows a wave front moving from a dense material to a lighter material. The equivalent for a water wave would be moving from shallow water to deep water. The ray indicates the direction of motion of the wavefront and a wavelet is shown. The angle of incidence is labelled. For this diagram, do the following:



a) Draw a ray representing the direction of motion for the reflected wavefront. Show a possible location of the reflected wavefront and be sure to draw it correctly in reference to the ray. Also draw a wavelet on the ray at the location of the reflected wavefront. Label each of the items listed above.

_____

_____

_____

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(continued)

b) Draw a possible ray showing the direction of motion of a refracted wavefront. Show a possible wavefront for the ray and then the wavelet. Label all structures.

2. Why was it so difficult to see the diffraction of light at the time of Newton?

_____

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for correctly drawing the reflected wavefront in question 1(a)
- 1 mark for correctly drawing the reflected wavelet in question 1(a)
- 1 mark for correctly drawing the refracted wavefront in question 1(b)
- 1 mark for correctly drawing the wavelet on the refracted wavefront in question 1(b)
- 1 mark for the correct explanation in question 2

Lesson 5: Young's Experiment (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ explain why early experiments to produce interference with light were not successful
- ❑ explain why Young's experimental set up allowed him to see interference effects in light
- ❑ define the term "interference fringes"
- ❑ explain what path differences from the sources to the screen determine if a bright spot or a dark spot occurs
- ❑ use the equation $\lambda = \Delta x \frac{d}{L}$ in problem solving to determine one of the variables in the equation
- ❑ describe the effect on the spacing between adjacent nodal lines in the two-slit interference pattern if the wavelength of the light used is changed
- ❑ describe the effect on the spacing between adjacent nodal lines in the two-slit interference pattern if the distance at which the pattern is viewed is changed
- ❑ describe the effect on the spacing between adjacent nodal lines in the two-slit interference pattern if the separation of the slits is changed

Key Words

interference	slit spacing	nodal line
two-slit interference pattern	nodal line spacing	path length difference
constructive interference	destructive interference	wavelength

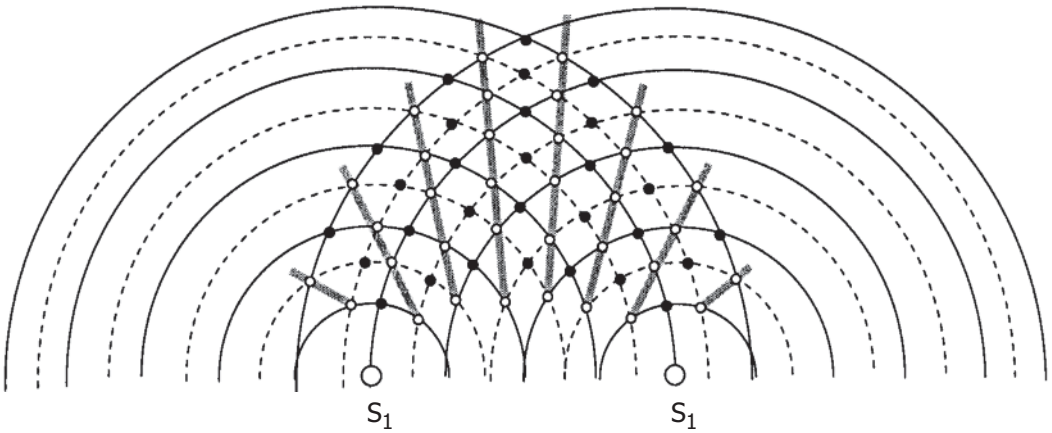
Introduction

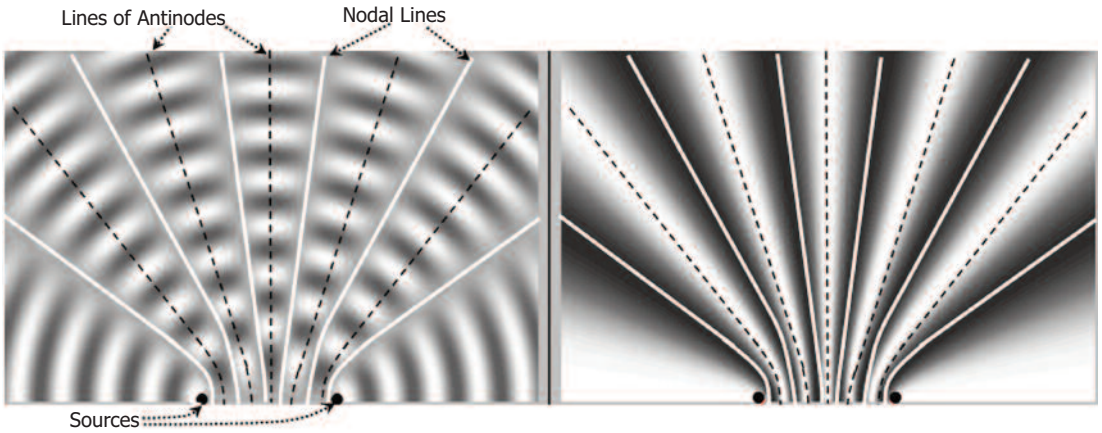
The research by Thomas Young (1773–1829) into the interference of light was critical in demonstrating that light has wave-like properties. His famous experiment has become known as "Young's experiment." In this lesson, we will review what we learned about the interference of two-dimensional waves from our work in an earlier module. We will then extend this knowledge to an understanding of the interference of light waves. This will lead us to a mathematical equation that will allow us to determine the wavelength of light based on measurements taken from the interference of light.

Early Attempts to Produce an Interference Pattern in Light

In our studies of waves in two dimensions, we learned that waves generated by **two point sources** in a ripple tank interfere with each other to produce areas of **constructive** and **destructive interference**, as shown below.

In the diagram below, the nodal lines are grey in colour. They represent areas of **destructive interference** where **troughs** and **crests** meet. The areas with the shaded-in circles represent areas of **constructive interference** where **crest** meets **crest** and **trough** meets **trough**. The line joining the shaded-in dots would appear to have bright and dark areas on a ripple tank screen.

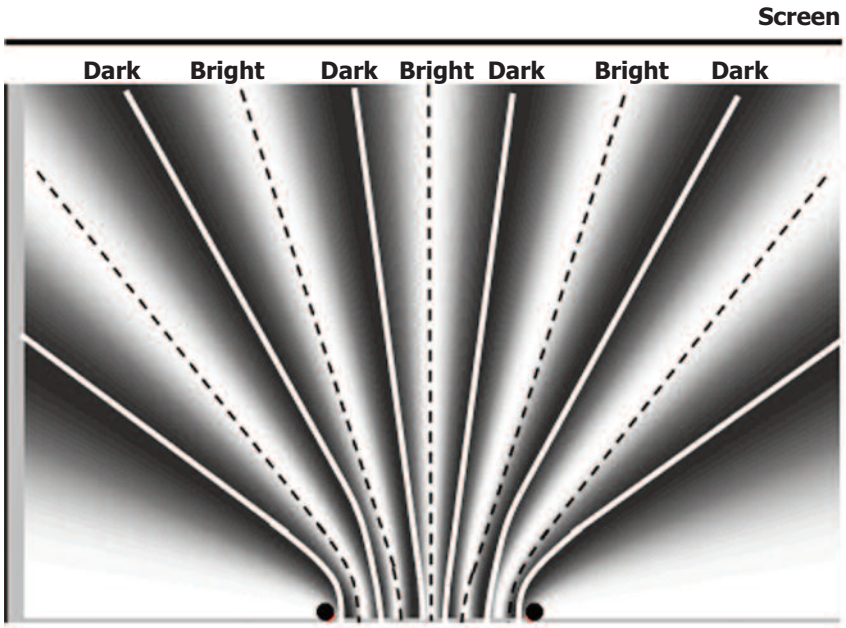




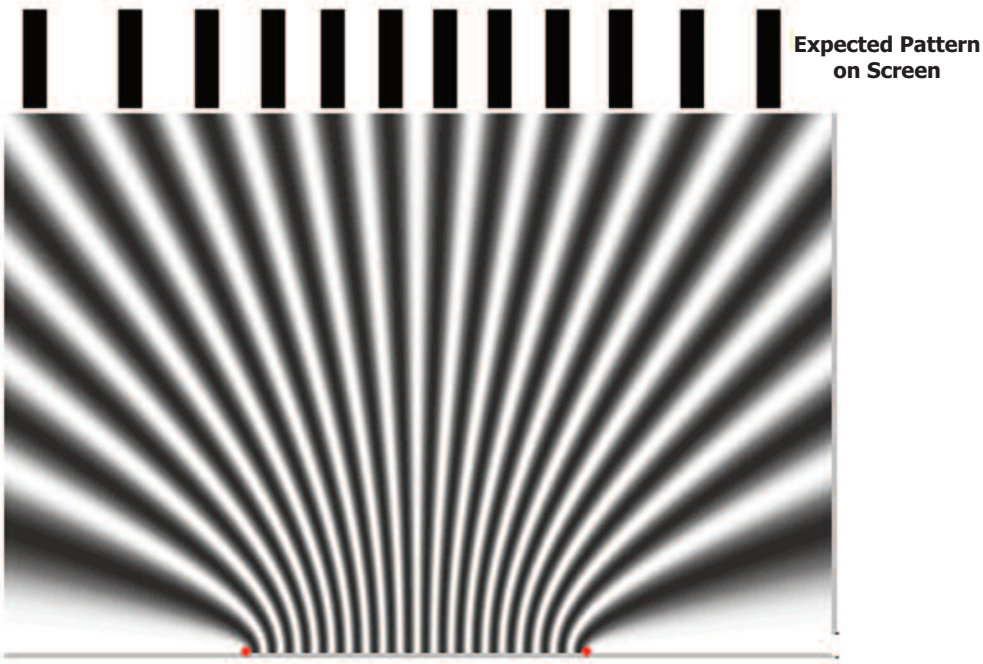
Ripple Tank Pattern of Displacement on Water's Surface Showing Lines of Nodes and Antinodes

This is the ripple tank pattern of light intensity showing the dark lines of nodes and the bright lines of antinodes.

If light has wave properties, then two sources of light waves should produce a result similar to that for waves in a ripple tank.



The light from two sources of light placed side by side should interfere and cast on a screen a pattern of alternating bright and dark lines.



As more nodal lines appear in the interference pattern, the lines become more evenly spaced apart.

The interference pattern expected to appear on a screen far from the light sources (much farther than indicated in the illustration) is a pattern of equally spaced bright and dark lines, as indicated below.

You can observe this pattern if you place your index finger and middle finger close together (in fact, touching in some places), leaving a tiny slit (less than a millimetre) somewhere between them. Look at a bright light source (a fluorescent lamp) through this tiny slit. You should see a pattern of closely spaced bright and dark lines running down the length of this opening.

In Newton's time, many scientists attempted to observe the interference of light. In most cases, they placed two sources of light side by side. The light from the two sources, falling on a nearby screen, was carefully examined, but no interference was observed.

The scientists conducting these experiments did not know that the wavelength of light is extremely small, as we have discussed already. We have, in fact, seen that in a ripple tank, as the frequency of the sources goes up (and so the wavelength goes down), we get more and more nodes and antinodes, which then become more closely spaced. If the **wavelength** is sufficiently **small**, the **distance between two adjacent nodal lines** will be **too small** to see. In the early experiments with light, any interference pattern would have been way too small to notice, but that's not the only problem with these experiments.

There was also a second more basic problem. In order for the interference pattern to be visible at all, we need two sources that are producing waves with *the same frequency*. But white light is a blend of different colours, and a source of white light would be a source of many frequencies. We should not even expect an interference pattern in this case. We need two sources of light that are **monochromatic**—that is, of only one colour (and therefore of one frequency). Even better would be two monochromatic light sources that produce waves *in phase*. In a ripple tank, the nodal line pattern is most easily observed when the two vibrating sources are **in phase**—that is, vibrating at the same time. If the phase of the vibrating sources is altered, the interference pattern will shift.

When two incandescent light sources are used side by side, the light is emitted randomly by the atoms in each source—in bursts and not necessarily in phase. When light strikes the screen, a **constantly varying interference pattern** is produced and no single pattern is observed.

Young's Experiment

Today, we can achieve this effortlessly with the use of a laser, but long before the invention of lasers, in the years 1802 to 1804, Thomas Young (1773–1829) performed a number of experiments, seeking to produce our much-needed interference pattern. Instead of using two sources, he used regular sunlight in a very clever way. He sent a beam of sunlight through a single slit. When this light then spread out a little, he placed a second barrier in the way that had two very small slits, placed very close together, cut into it. The light coming from the original slit then struck the following two slits at the same time, and continued through them. Since the first slit is acting as the source for both of them, the light emerging from the two new slits is necessarily in phase. If monochromatic light is used, then we have exactly what we should properly expect to produce a standing wave interference pattern.

A light source sends out light waves towards a single slit in a barrier.

The single slit acts as a point source sending out wave fronts that arrive at the two slits at the same time (in phase).

The two slits act as two point sources producing the usual interference pattern.

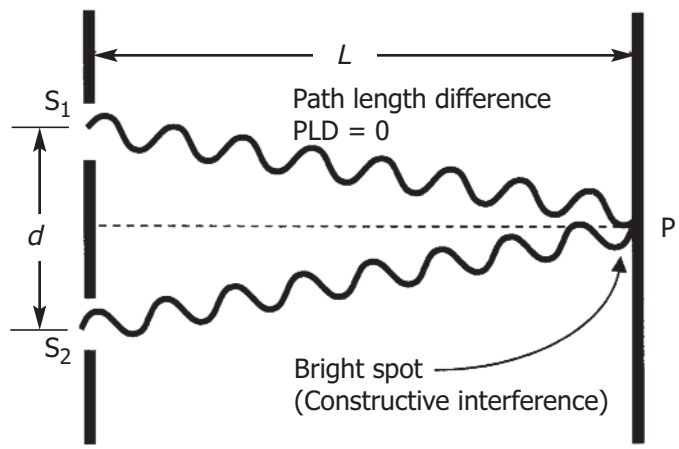
The two major problems in observing the interference of light were solved. In Young's experiment, the two sources were in phase, and the distance between sources was small enough that a series of bright and dark bands, called **interference fringes**, were created on a screen placed in the path of the light. This experiment, now commonly called **Young's experiment**, provided very strong evidence for the wave theory of light.

Young's Experiment: Interference at Three Angles

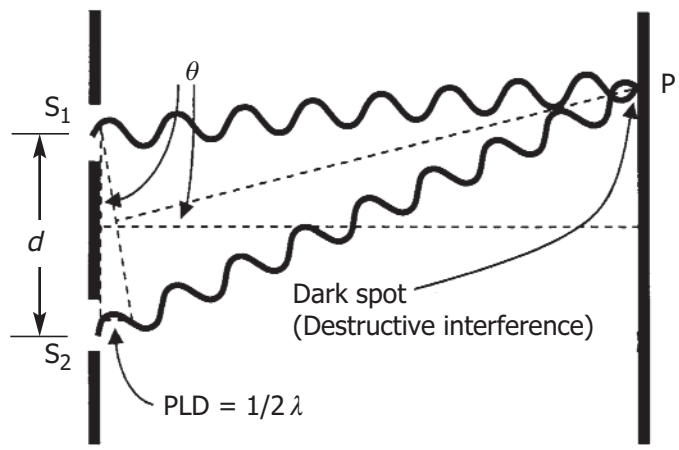
We will look at interference in Young's experiment at three different angles.

In the diagrams below, light waves in phase are passing through the slits S_1 and S_2, which are a distance d apart. The waves spread out in all directions through the slits.

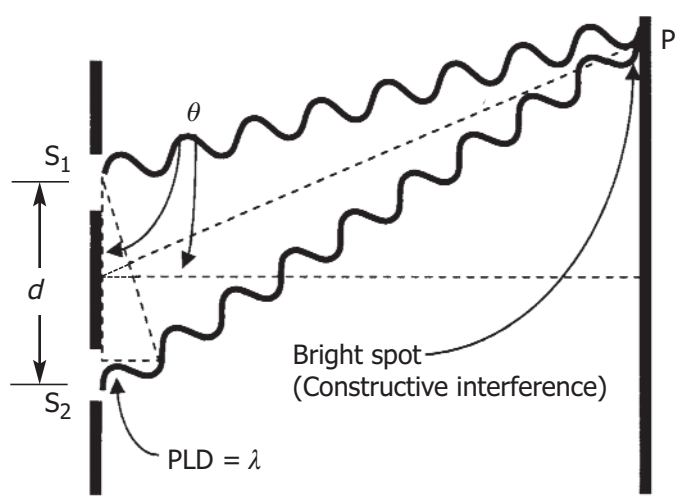
In the left diagram below, both waves that reach the **centre of the screen** are in phase because they travel the same distance. **Constructive interference** occurs and there is a **bright spot** on the screen.



In the diagram on the left, both waves that reach the **centre of the screen** are in phase because they travel the same distance. **Constructive interference** occurs and there is a **bright spot** on the screen.



In the diagram on the left, the waves from S_2 travel an extra $1/2\,\lambda$ (**PLD** = $1/2\,\lambda$) to reach the screen. When they do so, they are exactly out of phase. This means that the crest from the wave of S_1 meets the trough from the wave of S_2. **Destructive interference** occurs and the screen is **dark** at this point. This corresponds to a nodal point on nodal line $n = 1$.



In the diagram on the left, we are moving farther away from the centre of the screen. We reach a point where the path difference is one wavelength and the two waves are once again in phase. This is because the waves from S_2 are one whole wavelength behind those of S_1 and **constructive interference** occurs. This causes a **bright spot** to form here.

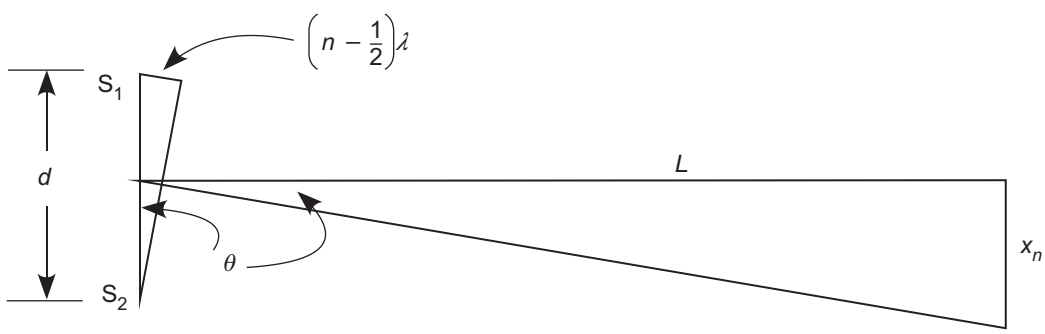
You will recall that if we number the nodal lines starting from the centre line (the perpendicular bisector of S_1S_2), there is a pattern for the path length difference to the nth nodal line given by PLD = $\left(n - \frac{1}{2}\right)\lambda$.

Young's Experiment and Deriving a Useful Equation

From our work on wave interference in water, we learned that the difference in path length from the point P on a nodal line (destructive interference) to the two sources S_1 and S_2 is equal to $\left|PS_1 - PS_2\right| = n - \frac{1}{2}\lambda$.

From the diagram below that shows destructive interference, it can be shown that the difference in path length, $n - \frac{1}{2}$, is also equal to $d \sin\theta$. Therefore, we can write $d \sin\theta = \left(n - \frac{1}{2}\right)\lambda$.

The diagram below shows the two triangles from the diagrams above. In this diagram, x is the distance of the nodal line from the centre line on the screen, and L is the distance from the midpoint between the two slits S_1 and S_2 to the screen. In the two triangles, the angle θ is identical. For very long distances, the distance L is almost identical to the length of the hypotenuse. Therefore, another way to write $\sin\theta$ is $\sin\theta = \frac{x}{L}$. In place of x, we can write x_n, which is the distance to the nth nodal line measured from the right bisector. Our new equation becomes $d\frac{x}{L} = \left(n - \frac{1}{2}\right)\lambda$ or $\lambda = \frac{d\left(\frac{x}{L}\right)}{n - \frac{1}{2}}$.



The distance from the centre line to the first nodal line (x_1) can be given by $x_1 = \frac{\lambda L\left(1-\frac{1}{2}\right)}{d} = \frac{\lambda L}{2d}$. The distance x_2 is given by $x_2 = \frac{\lambda L\left(2-\frac{1}{2}\right)}{d} = \frac{3\lambda L}{2d}$.

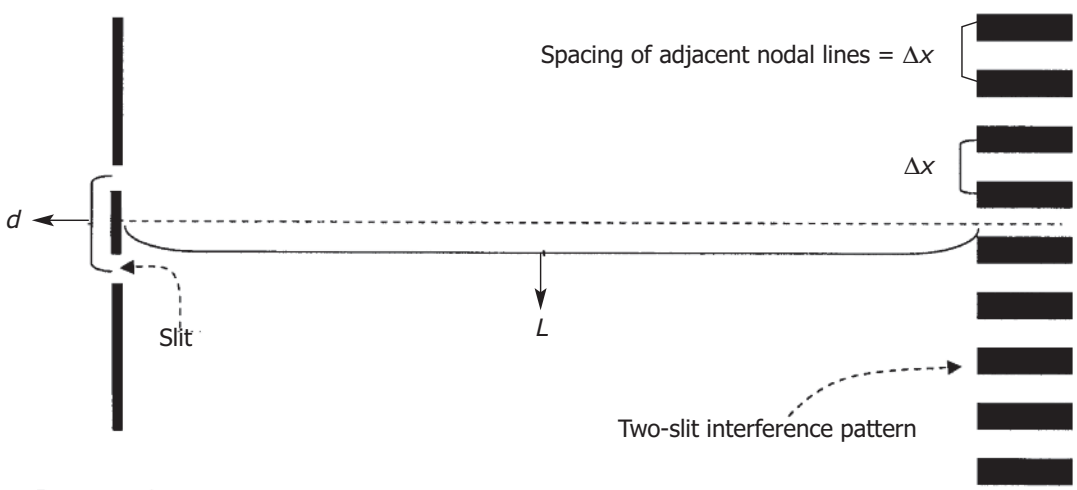
The distance between x_2 and x_1 is $\Delta x = \frac{3\lambda L}{2d} - \frac{\lambda L}{2d} = \frac{\lambda L}{d}$. In general, we can say that $\Delta x = \frac{\lambda L}{d}$, where Δx is the distance between adjacent nodal lines on a screen, d is the separation between the slits, and L is the perpendicular distance from the slits to the screen.

Young's Equation: For a two-slit interference pattern, the spacing of adjacent nodal lines, Δx, is given by the product of the wavelength of the light, λ, and the distance from the slits to the screen, L, divided by the separation of the slits, d.

$$\Delta x = \frac{\lambda L}{d}$$

Quantity	Symbol	Unit
Separation of adjacent nodal lines	Δx	metres (m)
Wavelength of light	λ	metres (m)
Distance from slits to screen	L	metres (m)
Separation of slits	d	metres (m)

Again, make certain that you can link these quantities to the physical situation that is Young's experiment.



Interpreting Young's Equation

In the equation $\Delta x = \frac{\lambda L}{d}$, you can see that the spacing of the nodal lines in a two-slit interference pattern varies with each of the other three quantities—wavelength, distance of screen to slits, and the separation of the slits.

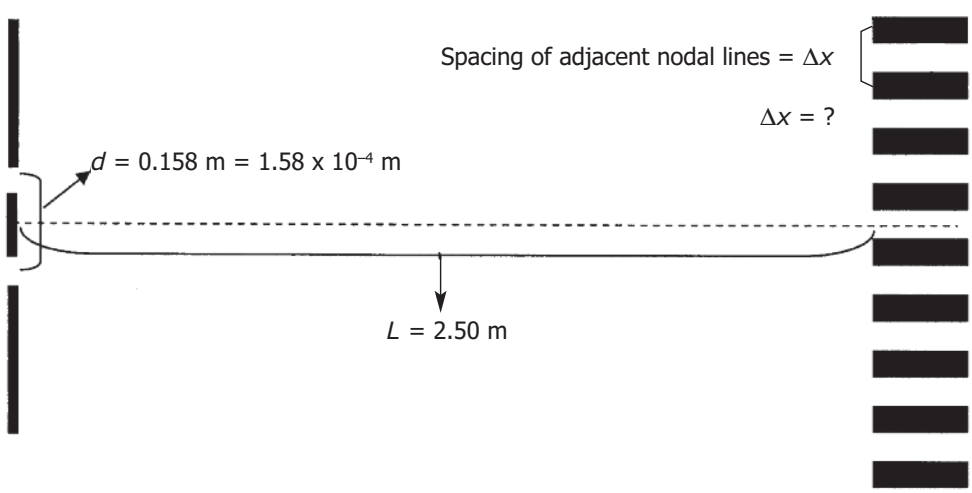
The **spacing** of the nodal lines **varies directly** with the **wavelength**. If a longer wavelength is used in the light source, the nodal line will be farther apart.

The **spacing** of the nodal lines **varies directly** with the **distance from the slits to the screen** where the pattern is viewed. If the distance to the screen increases, so does the spacing of the nodal lines.

Finally, the **spacing** of the nodal lines **varies inversely** with the **distance between the slits**. If the slits are placed farther apart, the spacing between the nodal lines decreases. This is the identical effect you observed when we moved the point sources in the ripple tank apart. This enabled more waves to fit into the pattern, which gave more points of interference, which, in turn, pushed the nodal lines closer together.

Example 1: Young's Experiment—Calculating the Spacing of Nodal Lines

In a typical Young's experiment, red light of wavelength 6.12×10^{-7} m is used. The pattern is viewed at a distance of 2.50 m with a viewer that had the slits separated by 0.158 mm. What is the spacing of the nodal lines?



Equation: $$\Delta x = \frac{\lambda L}{d}$$

Substitute and solve: $$\Delta x = \frac{\lambda L}{d} = \frac{\left(6.12 \times 10^{-7}\ \text{m}\right)\left(2.50\ \text{m}\right)}{\left(1.58 \times 10^{-4}\ \text{m}\right)} = 0.00968\ \text{m}$$

The spacing of the nodal lines will be 0.00968 m or about 1 cm.

Example 2: Young's Experiment—Effect of Wavelength on Nodal Line Spacing

What would the spacing be for the nodal lines in the example above if only blue light (wavelength 4.52×10^{-7} m) instead of red light was used with the same apparatus?

The only change is that $\lambda = 4.52 \times 10^{-7}$ m.

Equation: $$\Delta x = \frac{\lambda L}{d}$$

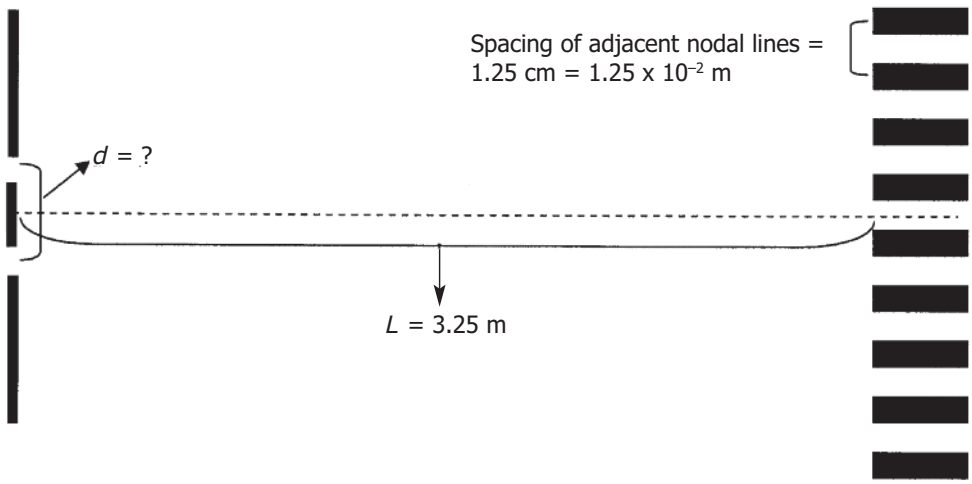
Substitute and solve: $$\Delta x = \frac{\lambda L}{d} = \frac{\left(4.52 \times 10^{-7}\ \text{m}\right)\left(2.50\ \text{m}\right)}{\left(1.58 \times 10^{-4}\ \text{m}\right)} = 0.00715\ \text{m}$$

The spacing is less than for red light.

This should make sense. The spacing of nodal lines is directly related to the wavelength. So if wavelength decreases, then so does the spacing of the nodal lines.

Example 3: Young's Experiment —Calculating the Separation of the Slits

Suppose we use red light, 6.12×10^{-7} m, to view a pattern from two slits at a distance of 3.25 m. The spacing of the nodal lines is 1.25 cm. What is the separation of the slits?



Equation: $\Delta x = \frac{\lambda L}{d}$ rearranged to $d = \frac{\lambda L}{\Delta x}$

Substitute and solve: $d = \frac{\lambda L}{\Delta x} = \frac{(6.12 \times 10^{-7}\ \text{m})(3.25\ \text{m})}{(1.25 \times 10^{-2}\ \text{m})} = 1.59 \times 10^{-4}\ \text{m}$

The separation of the slits is 1.59×10^{-4} m or 0.159 mm.

Electromagnetic Theory of light

At the end of the 1800s, a man by the name of James Clerk Maxwell combined electricity, magnetism, and light into one masterful theory. He called his theory the **electromagnetic theory of light**.

> According to Maxwell, light was an electromagnetic wave with the same properties as other electromagnetic waves that we introduced in the previous module (such as radio waves). Light was, in fact, shown to be nothing more than electromagnetic waves of a particular frequency.

Physicists during this time became so confident in their physics that they felt that they had everything worked out except for a few small details. Newton's physics from the 1600s appeared to be able to explain motion entirely, and Maxwell's electromagnetic theory appeared to be able to explain all there is to know about such things as light, radio waves, etc.

One of these "small details" that still needed to be worked out was the **photoelectric effect**, which we shall explain in another lesson. Jumping ahead just a little bit though, a man named Albert Einstein came along and revealed a surprisingly rejuvenated particle model of light that was stronger than ever before and perhaps even the wave model's equal. Einstein pointed out that there is one play remaining in this game between the wave model and the particle model of light, and that is the photoelectric effect.

Although Maxwell's theory was a fabulous theory all around in that it could explain much about light, it was not able to explain all the properties of light, including one called the photoelectric effect. In 1900, Max Planck proposed the **quantum hypothesis**, which suggested that light was transmitted and absorbed in small bundles of energy called "quanta." Albert Einstein agreed with Planck's theory and explained the photoelectric effect using the particle model of light. The theory of **quantum mechanics**, developed over several years in the early 1900s, combines the two major theories, suggesting that light can behave as a particle and/or a wave.

Recall from the last module the discussion of scientific models and theories. Their function is to explain the known properties of a phenomenon, and to predict new behaviour or new properties. As we study the theories of light, keep in mind these characteristics of theories and how they are illustrated in this history.

Learning Activity 10.5

Young's Experiment

1. When a screen is illuminated by two closely spaced, parallel, single-filament light sources, no interference is observed. What major condition for interference has not been satisfied?
2. If Young's experiment was done completely in glass, how would the interference pattern change from that observed in air, using the same equipment and experimental set-up?

(continued)

Learning Activity 10.5: Young's Experiment (continued)

3. A student is measuring the wavelength of light produced by a sodium vapour lamp. The light is directed through two slits with a separation of 0.150 mm. The interference pattern was created on the screen 3.00 m away. The student found that the distance between the first and the eighth consecutive dark lines was 8.00 cm. What was the wavelength emitted by the sodium vapour lamp?

4. An interference pattern is formed on a screen when a helium-neon laser light (λ = 6.328 x 10^{-7} m) is directed towards it through two slits. If the slits are 43 μm apart and the screen is 2.5 m away, what will be the separation of adjacent nodal lines (μ = micro = 10^{-6})?

5. Two slits have green light of wavelength 5.25 x 10^{-7} m passing through them. The interference pattern is observed at a distance of 1.75 m. The distance from 1 dark line to the 8th dark line is 10.2 cm.
   a) What is the spacing of the nodal lines?
   b) What is the separation of the slits?

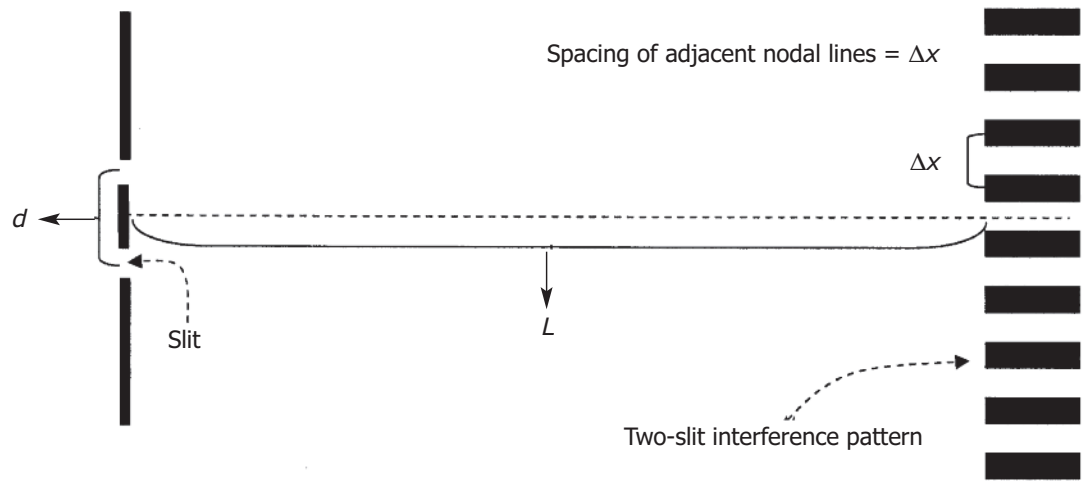
Lesson Summary

In Newton's time, scientists attempted to observe the interference of light. They were not successful for two major reasons. The frequency of light is very high (the wavelength is very small) and it is difficult to observe the nodal lines associated with interference. Also, if two incandescent light sources are used, the light is emitted randomly, resulting in a constantly varying interference pattern with no single pattern observed.

In **Young's experiment**, Thomas Young was able to observe interference effects in light. A series of bright and dark bands called **interference fringes** were produced. He was able to see interference because the pinholes in his experiment were close together, allowing the nodal line pattern to be seen. Also since the light came from a single source, the light passing through the two pinholes was in phase.

If the path difference from the sources to the screen is an odd whole number multiple of half wavelengths, then destructive interference will occur and a dark spot will form on the screen. If the path difference is an even number of half wavelengths, then constructive interference will occur and a bright spot will form on the screen.

For the interference of light from two point sources, the equation $\Delta x = \frac{\lambda L}{d}$ can be used. In this equation, λ is the wavelength of the light, Δx is the distance between adjacent nodal lines on a screen, d is the separation between the slits, and L is the perpendicular distance from the slits to the screen.



NOTES

Assignment 10.3, Part D

Young's Experiment (7 MARKS)

A student is measuring the wavelength of a narrow, monochromatic light source. The double slit has a separation of 0.150 mm. A second student places markers on a screen 2.00 m in front of the slits at the positions of successive dark bands in the patterns. The student finds that the dark bands are 0.560 cm apart.

a) The student has met two important conditions for interference to occur. What are they?

b) Calculate the wavelength of the light source.

c) Calculate the spacing of the dark bands if a source of wavelength 600.0 nm were used. (A "nm" is a nanometre, or 10^{-9} m.)

(continued)

Assignment 10.3, Part D: Young's Experiment (continued)

d) If a student wants the spaces between the dark bands in an interference pattern to be wider apart, should the spacing between the slits increase or decrease? Explain why.

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Method of Assessment

The total of seven marks for this assignment will be determined as follows:

- 2 marks for the two parts of question (a)
- 1 mark for expressing the equation correctly in question (b)
- 1 mark for calculating the wavelength correctly in question (b)
- 1 mark for expressing the wavelength in metres correctly in question (c)
- 1 mark for calculating the spacing correctly in question (c)
- 1 mark for the explanation in question (d)

Lesson 6: The Photoelectric Effect and Wave-Particle Duality (1.5 hours)

Learning Outcomes

When you have completed this lesson, you should be able to

- ❑ define the term "photoelectric effect"
- ❑ explain how the photoelectric effect can be demonstrated using a photocell
- ❑ define the term "threshold frequency"
- ❑ explain how the frequency of light and the amplitude (brightness) of light are related to current flow in the photoelectric effect
- ❑ describe the different kinds of predictions made by the wave theory and the photon theory to explain the photoelectric effect
- ❑ explain what is meant by the wave-particle duality and the Principle of Complementarity
- ❑ discuss the kinds of situations in which the wave theory provides a good explanation for the behaviour of light, and the situations where the particle (photon) theory is better

Key Words

photoelectric effect	threshold frequency	photocell
current	photon theory	wave theory
wave-particle duality	Principle of Complementarity	photoelectrons
cathode	anode	

Introduction

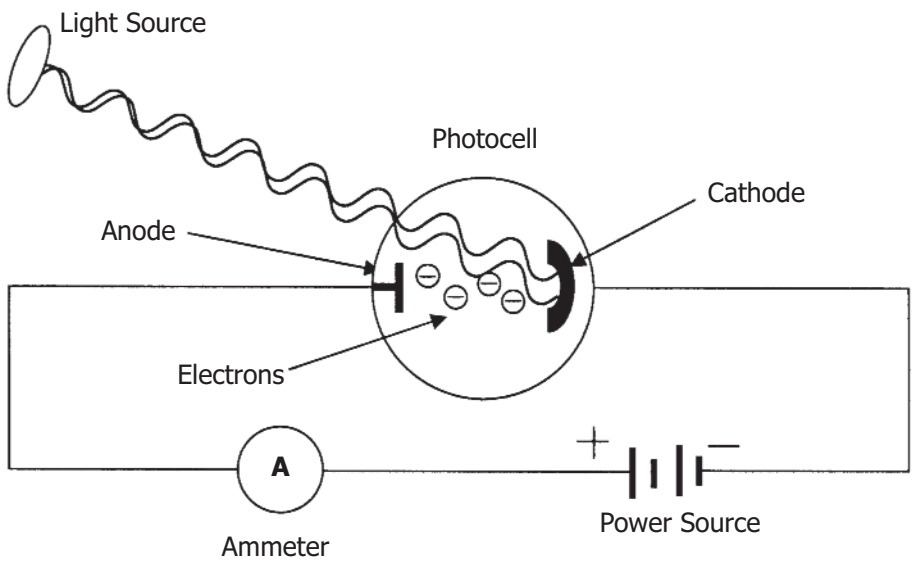
In this final lesson, we discuss the **photoelectric effect.** The wave theory and the particle theories of light make different predictions about the effects of the frequency and the intensity of light on this effect. Albert Einstein proposed the idea that light is made up of **photons**, and we will see that his theory explained the photoelectric effect very well. The lesson concludes with a discussion of the wave-particle duality and the Principle of Complementarity. This discussion will show that to explain fully the behaviour of light we need to use both the wave and the particle (photon) theories. Both Maxwell's electromagnetic theory and Newton's corpuscular theory provided excellent models for our understanding of light, and the wave-particle model was built on the contributions of these and other great scientists.

The Photoelectric Effect and the Photocell

In 1887, the German physicist Heinrich Hertz (1857–1894) was testing Maxwell's Theory of Electromagnetic waves. Hertz noticed that when he directed ultraviolet waves at certain metallic surfaces, they lose their negative charges. For example, a negatively charged zinc plate was discharged when ultraviolet radiation fell on it, but it remained charged when ordinary light fell on it. But a positively charged plate was never discharged. The incident light somehow caused the metal to liberate electrons. Both light and electricity are involved so the term **photoelectric effect** was given to this phenomenon of emitting electrons when electromagnetic radiation falls on an object.

> The **photoelectric** effect is the ejection of electrons from the surface of a metal by ultraviolet light.

The photoelectric effect can be studied using a **photocell** such as the one shown below. The cell has two metal electrodes sealed in an evacuated tube. The air has been removed to keep the metal surface clean and to keep electrons from being stopped by the air molecules. The large electrode, the **cathode**, is usually coated with cesium or some other alkali metal. The second electrode, the **anode**, is made of a thin wire so it does not block any radiation. The tube is often made of quartz to permit ultraviolet wavelengths to pass through. A power source is connected to the anode and the cathode in such a way that the **negative side** of the source is attached to the **cathode** and the **positive side** is connected to the **anode**. An **ammeter** can measure if there is a current flowing through the circuit.



When no radiation falls on the cathode, the current does not flow in the circuit. When radiation does fall on the cathode, a current is produced in the circuit and this is indicated by the ammeter. The current is a result of electrons, called **photoelectrons**, being ejected from the cathode by the radiation. The electrons then move to the positive electrode, the anode.

The Photoelectric Effect and the Wave Theory

Not all radiation that falls on the cathode in a photoelectric cell results in current flow.

> Electrons are ejected only if the frequency of the radiation is above a certain minimum value called the **threshold frequency**, f_0.

The threshold frequency varies with the metal. For example, all wavelengths of light except red will eject electrons from cesium, but ultraviolet light must be used with zinc. Radiation of a frequency below f_0 does not eject any electrons from the metal no matter how bright it is. Even if it is very dim, radiation at or above the threshold frequency causes electrons to leave the metal immediately, and the greater the intensity of this radiation, the larger the flow of photoelectrons.

The **electromagnetic wave theory cannot explain these effects**. The wave theory says that a more intense radiation, regardless of frequency, has stronger electric and magnetic fields. According to the wave theory, the electric field accelerates and ejects the electrons from the metal. With very faint light shining on the metal, electrons would require a very long time before they gained enough energy to be ejected.

When the photoelectric effect occurs, the light energy is absorbed by an electron instantaneously, and does not need to "accumulate" energy to a point where the electron can be liberated. The classical wave theory predicts that electrons can be ejected even for very dim light but there must be a long time for this to occur.

Another way of looking at the photoelectric effect using the classical wave theory is to consider that the light wave shakes the atom until it loses an electron. According to the wave theory, the amplitude and time duration of the wave would determine whether sufficient energy had been transferred to the atom that ejects an electron. The **amplitude** is related to the **brightness**, or **intensity**, of the light. Thus, **more intense beams** of light, even of lower frequency, should **eject more electrons**. But **this is not the case**. Higher frequency beams are necessary in most cases.

The Photoelectric Effect and Einstein

In 1905, Albert Einstein published a revolutionary theory that explained the photoelectric effect. Einstein made the radical proposal that the energy of light and other forms of electromagnetic radiation is not transmitted as a continuous wave. Rather it is concentrated in discrete bundles of energy called **photons**.

> A photon is a quantum of light or electromagnetic radiation.

He proposed that the **amount of energy** in each of these bundles was a discrete, fixed amount that **depended directly** on the **frequency** of the light. The higher the frequency, the greater the energy contained in the photon.

Einstein's theory explained the existence of a threshold frequency. A photon must have a minimum energy to eject an electron from a metal. This minimum energy depends on the threshold frequency, f_0, of the light. If the photon has a frequency below f_0, then it does not have the energy needed to eject an electron. Light with a frequency greater than f_0 has more energy than needed to eject the electron. The excess energy makes the electron move, and is converted to kinetic energy of the moving electron.

Einstein thus predicted why there was a threshold frequency. The electron must have a minimum amount of energy to escape the attractive force holding it to the metal. When the frequency of the incident light is too low, the photon does not give the absorbing electron sufficient energy and it remains bound to the surface. The intensity (brightness) of the light is only a measure of the rate at which the photons strike the surface, not the energy of

the photon. This explains why the kinetic energy of the emitted photoelectrons and the threshold frequency do not depend on the intensity of the incident light.

Notice that an electron cannot simply accumulate photons until it has enough energy. Only one photon interacts with one electron. The photon either has enough energy to eject the electron or it does not. Thus, **the photon behaves more like a particle than a wave**.

A Comparison of the Wave Model and the Particle Model of Light

Let's review what we have learned about light and how its behaviour can be explained using the wave model and the particle model of light. As a method of comparing the models, let's keep score of which is the better model.

The Wave Theory and Reflection

Light reflects from surfaces in such a way that the angle of incidence is equal to the angle of reflection. In our studies of waves in two dimensions, we learned that water waves also reflect from surfaces so that the angle of incidence is equal to the angle of reflection. This means that the wave model of light has no difficulty in explaining the behaviour of the reflection of light. As an added bonus, the wave theory can, in fact, explain something that troubled the particle theory, which is that when light strikes a surface such as water or glass, the light does reflect from it but it also transmits into it—the light only partially reflects. Newton could not give an adequate explanation for why only some of his particles would reflect off of the "hard surface" while some would happily enter it. Of course, we know that when a wave encounters a new medium, there is a partial reflection and a partial refraction, which is exactly what light does when it encounters a new medium. This means that the wave model "wins" over the particle model, as it more completely explains the reflection of light.

- 1 point for wave model; 0 points for particle model

The Wave Theory and Refraction

This is another automatic win for the wave theory of light. We have already seen that waves can refract upon entering a new medium that supports it at a different speed. In fact, if light waves travel slower in water, then the fact that it refracts towards the normal would be simple to explain. Recall that Newton's particle model required that light go faster in water. When it became possible to measure the speed of light accurately, it was found that light does indeed go slower in water. That's another point for the wave model.

- 2 points for wave model; 0 points for particle model

The Wave Theory and Diffraction

Newton actually criticized the wave model by saying that if light was a wave, then light waves should act like waves. In particular, they should be able to bend around corners. This actually makes sense. If someone is around a corner, you have no trouble hearing them—the sound waves do in fact bend around the corner. But you cannot see them—the light does not seem to bend around the corner. Might this be a point for the particle theory?

No! In our earlier work in diffraction of water waves, we observed that there is considerable diffraction only when the size of the opening (or obstacle) is of approximately the same size as the wavelength of the waves or smaller. If the openings or obstacles are larger than the wavelength, then the effects of diffraction can be safely ignored.

At the time of Huygens and Newton, the wavelength of visible light was not known. Upon further investigation, however, it was discovered that with a sufficiently tiny (very tiny!) opening (in the form of a narrow slit carved into a barrier), light very much does in fact diffract. This suggested (correctly) that the wavelengths of light are very, very small—so small, in fact, that in any ordinary situation, the diffraction of light can be ignored. Of course, with the right size opening, light diffracts exactly as it should.

- 3 points for wave model; 0 points for particle model

While the wave model is ahead by three points, the particle model at this point is still in the game. After all, let's remember that it does at least offer some explanation of reflection, refraction, and the rectilinear propagation of light (although the wave model actually beats it on all three accounts). The next item that we will turn to however is worth a lot more than one point. In fact, the next item could be described as being worth 100 points. We now turn our attention to interference.

The Interference of Light

Interference, or more particularly *destructive interference*, is something that waves can do and particles, as we usually think of them, simply cannot. Simply put, if I throw a marble towards the wall at the same time that you throw a marble towards the wall, then there is just no way that the marbles (being rather like particles) will somehow "cancel" out, disappearing as a result. If light can be shown to be capable of interference, then you may as well pound in the last of the nails into the particle model's coffin. Of course, if light cannot do this trick, you may as well toss out the wave model of light, as it could not possibly be correct in that case.

The interference of light was, in fact, initially considered to be a point against the wave model for the simple reason that light doesn't seem to do this! If a flashlight is pointed at a wall, then the wall gets lit up. The particle model would declare that the flashlight is sending a stream of light particles to the wall, which is why it is lit up. The wave model would declare that the flashlight is sending light waves towards the wall, which is why it is lit up—this is no problem for either model.

If a second flashlight is then also pointed at the wall, then the wall gets more brightly lit up. This is true regardless of the positioning of the flashlights. Supporters of the particle model have no problem with this—there are simply twice as many particles of light hitting the wall now, which is why it gets brighter. But they might then smugly point out to the supporters of the wave model that we should expect to see an interference pattern—places of constructive (brighter) interference as well as places of destructive interference (less bright). Essentially, we should see places where light + light = dark!

Perhaps overconfident with their three-point lead, the supporters of the wave model took a hard fall. The particle model supporters are, of course, correct. The wave model does require that light do this. If light cannot interfere in this way, then light cannot be a wave, no matter what the score is so far. As I said earlier, this one is worth a *lot of points*.

In our studies of waves in two dimensions, we learned that waves generated by two point sources in a ripple tank interfere with each other to produce areas of constructive and destructive interference, resulting in nodes and antinodes. If light has wave properties, then two sources of light waves should produce a result similar to that for waves in a ripple tank. In Newton's time, many scientists attempted to observe the interference of light. In most cases, they placed two sources of light side by side. The light from the two sources, falling on a nearby screen, was carefully examined, but no interference was observed. Things are starting to look bleak for the wave model.

Young allowed sunlight to shine through an opening in a barrier, and then let the light that passed through the opening shine unto two small openings very close together on a second barrier. The first opening acted as a point source of light, which sent out waves. A single wave would reach the second barrier, hitting the two slits simultaneously. This had the effect of producing two point sources that were in phase.

With the apparatus carefully constructed and the light going through the first single slit, he moved on to the double-slit arrangement, and then finally to a screen where it could be viewed. Do we or do we not see an interference pattern? Do we see nodes and antinodes? Is it possible that light + light = dark when the geometry of wave interference calls for it? The crowd hushes down to a near silence while the referee steps in to have a close look at the screen to make a game-deciding call.

Yes! The crowd goes wild! With only one second left, the wave model gains 100 points.

- 103 points for wave model; 0 points for particle model

Totally defeated, the remains of the particle model of light are swept into its coffin, the nails are banged in and it's buried 1.83 metres deep.

I'm sure glad that Mr. Young did his experiment. That should remove any doubt—103 points to zero! After all, there's no way that particles interfere. Only waves can do that. Mind you, there were those details that we mentioned. One of these "small details" was Einstein and the **photoelectric effect**. He called for us to dig up the particle model's coffin and open it up to reveal a surprisingly rejuvenated, stronger version of the particle model of light that was perhaps even the wave model's equal. Einstein pointed out that there is one play remaining in this game, and that it is the photoelectric effect. Freakishly enough, this play is worth 103 points!

Photoelectric Effect

Not all radiation that falls on the cathode in a photoelectric cell results in current flow.

> Electrons are ejected only if the frequency of the radiation is above a certain minimum value called the **threshold frequency**, f_0.

Even if it is very dim, radiation at or above the threshold frequency causes electrons to leave the metal immediately, and the greater the intensity of this radiation, the larger the flow of photoelectrons.

The **electromagnetic wave theory** cannot explain these effects. The wave theory says that a more intense radiation, regardless of frequency, has stronger electric and magnetic fields. According to the wave theory, the electric field accelerates and ejects the electrons from the metal. With very faint light shining on the metal, electrons would require a very long time before they gained enough energy to be ejected.

When the photoelectric effect occurs, the light energy is instantaneously absorbed by an electron, and does not need to "accumulate" energy to a point where the electron can be liberated. The classical wave theory predicts that electrons can be ejected even for very dim light, but it takes a long time for this to occur.

Einstein made the radical proposal that the energy of light and other forms of electromagnetic radiation is not transmitted as a continuous wave. Rather, it is concentrated in discrete bundles of energy called **photons**.

> A photon is a quantum of light or electromagnetic radiation.

He proposed that the **amount of energy** in each of these bundles was a discrete, fixed amount that **depended directly** on the **frequency** of the light. The higher the frequency, the greater the energy contained in the photon.

Einstein was able to explain that even one photon with a frequency above the threshold frequency could eject an electron from a metal's surface. So very dim light could eject electrons! Also, more intense light simply means more photons, which in turn can eject more electrons.

So what is the final score?

- 103 points for wave model; 103 points for particle model

It's a tie!

The Principle of Complementarity and Light

It has become obvious that light is not just a wave and not just a particle. It has a dual nature, a property referred to by physicists as a **wave-particle duality**. We can come to this conclusion because both theories of light have been shown to be valid based on very strong experimental evidence. It is clear that light is a much more complex phenomenon than just a beam of particles or just a simple wave.

The great Danish physicist, Neils Bohr (1885–1962) clarified the situation by proposing the **Principle of Complementarity**. He stated that "To understand a specific experiment, one must use either the wave or the photon theory, but not both."

> **Principle of Complementarity:** Understanding both the wave and the particle properties of light is essential if one is to have a full understanding of light. In other words, the two aspects of light complement one another.

If we return to Young's experiment and the photoelectric effect, we can illustrate how this principle is applied. To understand how light interferes after it passes through two parallel slits, we must use the wave theory, not the particle theory. To understand why the photoelectric effect occurs, we must use the photon, or particle nature of light, not the wave theory.

As a general rule, when light passes through **space** or through a **medium**, its **behaviour** is best explained using its **wave properties**. But when light **interacts with matter**, its behaviour is more like that of a **particle**.

The Wave-Particle Duality and Models

One of the reasons we have trouble understanding the dual nature of light is that it is very difficult if not impossible for us to visualize this duality. We cannot draw pictures or create images of a wave-particle combination. We are restricted to creating wave images in some applications and particle images in other applications, but never both at the same time.

Also, most of the laws and principles of physics we are familiar with are based on experiments that involve direct observations. In the study of light, particularly as it transfers energy from place to place, we base our knowledge on indirect experiments. We cannot see directly how light energy is transmitted as a wave or particle. All we can observe are the results of the interaction of light and matter. Our knowledge is limited to indirect information, and therefore we cannot use visual means to describe light's dual nature. Quantum mechanics utilizes mathematical models, not visual models, but this method constitutes a part of quantum mechanics that is much beyond the scope of this course.

The wave-particle model of light that we use today is much more subtle than Newton's corpuscular theory or Maxwell's electromagnetic theory. Both of these theories were important in their time and contributed much to our understanding of the behaviour of light. But these models were inadequate in themselves for explaining all of the properties of light. Like all models or theories, they can be replaced by better models when new information becomes available. This is the case with the two classical models of light. They have been superseded by the wave-particle model of light, the only theory that we find acceptable today for a full understanding of the nature of light.

Learning Activity 10.6

The Photoelectric Effect and Wave-Particle Duality

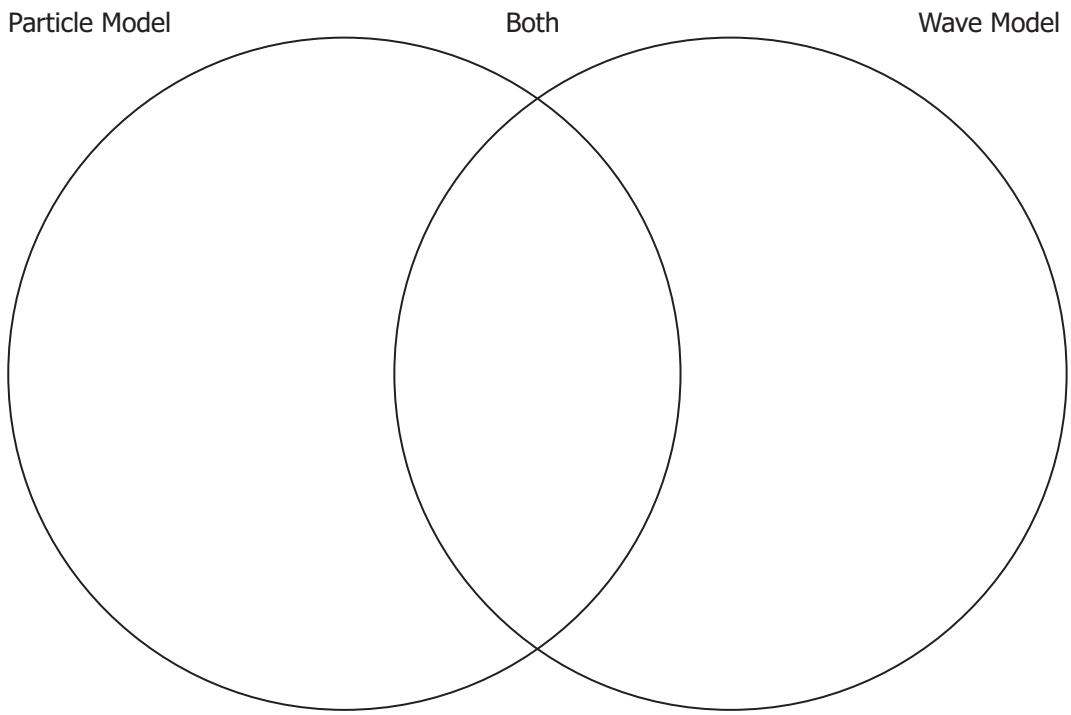
1. The physical construction of the photocell was discussed in the lesson. If the following changes were made, what effect would there be on the current?
   a) If the photocell tube did not have the air inside evacuated, would there be more of a current or less?
   b) If the glass making up the photocell was not made up of quartz, but ordinary glass, would this result in more of a current in the photocell or less?
   c) If the cathode was made up of a harder metal such as steel, would there be a larger current or less?
2. Suppose that ultraviolet light is required before an electric current is produced in a photocell. The wave theory and the photon theories predict different effects if very bright orange light shining for a long time is used instead. What does each theory predict and which theory makes the correct prediction?
3. Einstein's photon theory was able to explain why light with only a minimum frequency is necessary to dislodge an electron, and that light below this frequency will not, no matter how bright the light is. How was he able to explain this?
4. The Principle of Complementarity states that to understand the behaviour of light, we need to use both the wave theory and the photon theory. In general, where is the wave theory best applied, and where is the photon theory best applied?

(continued)

Learning Activity 10.6: The Photoelectric Effect and Wave-Particle Duality (continued)

5. On the diagram below, write in the names of the behaviours of light that can be explained using the particle model on the outside edge of the circle entitled "Particle Model." Write in the names of the behaviours of light that can be explained using the wave model on the outside edge of the circle entitled "Wave Model." In the section of the diagram where the two circles overlap, write the behaviours that can be explained using both theories.

The Current Model of Light: Wave-Particle Duality
(Sometimes I feel like a nut and sometimes I don't!)



Lesson Summary

The **photoelectric effect** refers to the ejection of electrons from the surface of a metal when it is exposed to electromagnetic radiation.

In a **photocell**, high-frequency light falls on the negatively charged cathode. Electrons are ejected and are attracted towards the anode. An ammeter in the circuit can measure the current flow.

Electrons are ejected from a metal only if the frequency of the radiation is above a certain minimum value called the **threshold frequency**, f_0. The threshold frequency varies with the metal.

Radiation of a frequency below f_0 does not eject any electrons from the metal no matter how bright it is. Even if it is very dim, radiation at or above the threshold frequency causes electrons to leave the metal immediately, and the greater the intensity of this radiation, the larger the flow of photoelectrons.

The electromagnetic wave theory cannot explain these effects. The classical wave theory predicts that electrons can be ejected even for very dim light but there must be a long time for this to occur.

According to the wave theory, the amplitude and time duration of the wave would determine whether sufficient energy had been transferred to the atom that ejects an electron.

Albert Einstein proposed that the energy of light and other forms of electromagnetic radiation is concentrated in discrete bundles of energy called **photons**. He proposed that the amount of energy in each of these bundles is a discrete, fixed amount that depended on the frequency of the light.

Einstein's theory explained the photoelectric effect and the existence of a threshold frequency. A photon must have a minimum energy to eject an electron from a metal. This minimum energy depends on the metal and the threshold frequency, f_0. Any excess energy makes the electron move, and is converted to kinetic energy of the moving electron. The intensity (brightness) of the light is only a measure of the rate at which the photons strike the surface, not the energy of the photon.

Light behaves like both a wave and a particle. It has a **wave-particle duality**. This model supersedes both Newton's corpuscular theory and Maxwell's electromagnetic theory.

The **principle of complementarity** states that "To understand a specific experiment, one must use either the wave or the photon theory but not both." In general the wave theory best explains the behaviour of light when it passes through space or a medium. When light interacts with matter, its behaviour is more like that of a particle.

NOTES

Assignment 10.4

The Photoelectric Effect and Wave-Particle Duality (5 MARKS)

In the visible spectrum, violet light has the highest frequency and red light has the lowest frequency. Suppose that the threshold frequency for a metal requires that a frequency not lower than that produced by blue light be used.

a) Suppose that very bright red light was used instead. What effect would this have on the current flow as compared with that produced by the blue light? Explain.

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_____

_____

b) Suppose that very bright violet light was used. What effect would this have on the current flow as compared with that produced by the blue light? Explain.

_____

_____

_____

_____

c) Suppose that very bright blue light was used. What effect would this have on the current flow as compared with that produced by the very dim blue light? Explain.

_____

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_____

(continued)

Assignment 10.4: The Photoelectric Effect and Wave-Particle Duality (continued)

d) Suppose that very bright yellow light shone on the metal for one hour. Compare this to shining blue light for one second. What effect would this yellow light have on the current flow as compared with that produced by the blue light? Explain.

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_____

e) Suppose that ordinary sunlight was used. What effect would this have on the current flow as compared with that produced by the very dim blue light? Explain.

_____

_____

_____

_____

Method of Assessment

The total of five marks for this assignment will be determined as follows:

- 1 mark for each of parts (a) to (e)

Module 10 Summary

Congratulations on completing Module 10.

Submitting Your Assignments

It is now time for you to submit Assignment 9.1 to 9.3 from Module 9 and Assignments 10.1 to 10.4 from Module 10 to the Distance Learning Unit so that you can receive some feedback on how you are doing in this course. Remember that you must submit all the assignments in this course before you can receive your credit.

Make sure you have completed all parts of your Module 9 and Module 10 assignments and organize your material in the following order:

- Modules 9 and 10 Cover Sheet (found at the end of the course Introduction)
- Assignment 9.1, Part A: The Nature of Sound
- Assignment 9.1, Part B: Beats and Resonance
- Assignment 9.1, Part C: The Doppler Effect
- Assignment 9.2: Video laboratory Activity: Resonance and the Speed of Sound
- Assignment 9.3: Music and Noise
- Assignment 10.1: The Scientific Method, Laws, Theories, and Models
- Assignment 10.2: Video Laboratory Activity: The Particle Model of Light
- Assignment 10.3, Part A: The Nature of Light and Newton's Corpuscular Theory
- Assignment 10.3, Part B: Determining the Speed of Light
- Assignment 10.3, Part C: Wave Theory of Light
- Assignment 10.3, Part D: Young's Experiment
- Assignment 10.4: The Photoelectric Effect and Wave-Particle Duality

For instructions on submitting your assignments, refer to How to Submit Assignments in the course Introduction.

Final Examination

Congratulations, you have finished Module 10 in the course. The final examination is out of 100 marks and worth 30% of your final mark. In order to do well on this examination, you should review all of your learning activities and assignments from Modules 1 to 10. Please note that 25% of your final mark is based on Modules 7 to 10 and 5% of your final mark is based on Modules 1 to 6.

You will complete this examination while being supervised by a proctor. You should already have made arrangements to have the examination sent to the proctor from the Distance Learning Unit. If you have not yet made arrangements to write it, then do so now. The instructions for doing so are provided in the Introduction to this module.

You will be allowed to use a calculator to write your examination. The calculator that you bring with you should be a graphing or scientific calculator. In addition, you will be supplied with an equation sheet and any constants that may be required.

A maximum of 2.5 hours is available to complete your final examination. When you have completed it, the proctor will then forward it for assessment. Good luck!

Final Practice Examination and Answer Key

To help you succeed in your examination, a practice examination can be found in the learning management system (LMS). The final practice examination is very similar to the actual examination that you will be writing. The answer key is also included so that, when you have finished writing the practice examination, you can check your answers. This will give you the confidence that you need to do well on your examination. If you do not have access to the Internet, contact the Distance Learning Unit at 1-800-465-9915 to get a copy of the practice examination and the answer key.

Grade 11 Physics (30S)

Module 10: Models, Laws, and Theories, and the Nature of Light

Learning Activity Answer Keys

Module 10: Models, Laws, and Theories, and the Nature of Light

Learning Activity 10.1: The Scientific Method, Laws, Theories, and Models

1. In doing the black box experiment, you are told that there is one object in the box, but you are not given any information about what that object is. At first, you move, tilt, and shake the box, and you can see that there is indeed what appears to be one object in the box. You then proceed more slowly and carefully. You tilt the box slowly and you hear a sliding sound. You never hear a rolling sound. It does not matter if you tilt the box slowly or rapidly. You never hear a rolling sound, but if you tilt the box rapidly you may hear a tumbling sound of the kind that a cube might make.

   a) If you were to state that object inside the black box was a cube, would this be an observation or an inference? Justify your answer.

      Answer:

      This would not be an observation. An observation is a fact that is noticed either qualitatively or quantitatively. Stating that the object is a cube is not a fact. It is an inference. We can define an inference as a deduction, conclusion, or interpretation based on the facts made during the observation.

   b) If you were to state that when you tilt the box in any of the front-to-back or back-to-front ways, the object inside slides and does not roll, would this be a statement of theory or a statement of a scientific law?

      Answer:

      This would a statement of a scientific law.

      A law is a concise but general statement about how nature behaves. It is a summary of the results of our observations. It is a description of nature without an explanation of why nature behaves that way. The statement above describes how the object inside the box behaves but does not provide an explanation for the behaviour.

c) If you were to state that the object inside the box must be a cube, could we say that this statement is an example of a scientific model? Explain your reasoning.

Answer:

Yes, we could say that this statement is an example of a scientific model. A scientific model is a mental picture that helps us understand something we cannot see or experience directly. Stating that the object is a cube is a mental picture of the object.

d) What would make it necessary to change the law or theory developed for the object inside the black box in this example?

Answer:

It would become necessary to change the law or theory if a new observation was made that could not be explained by the existing laws and theories. For example, if a rolling sound was heard, it would show that the object inside the black box could not be a cube.

2. What are the characteristics of a good theory?

Answer:

Good theories have the following characteristics:

A good theory explains phenomena accurately and its predictions are accurate.

It consistently explains a wide range of phenomena; it has a wide scope.

The theory is simple, or less complex.

It can quantitatively predict phenomena.

3. Distinguish between:

a) observation and conclusion

Answer:

An observation is a fact that is noticed either qualitatively or quantitatively during an experiment. No meaning is attached to an observation.

A conclusion is a statement expressing a judgment or opinion formed as a result of analyzing the experimental data. Conclusions attempt to draw meaning from observations.

b) theory and model

Answer:

A scientific model is a mental picture that helps us understand something we cannot see or experience directly. Models can suggest new experiments to perform and can provide ideas about what other related phenomena can occur. Scientific models change as new discoveries are made.

A theory provides a general explanation for the observations. Theories are inspirations that come from a creative human mind to explain observations. Early attempts at forming theories may be speculative, first attempts to explain phenomena. New observations or laws may not be explained by a theory, so it needs to be modified. A theory that can explain a greater range of phenomena may be referred to as robust.

c) law and inference

Answer:

A law is a concise but general statement about how nature behaves. It is a summary of the results of our observations. It is a description of nature without an explanation of why nature behaves that way.

An inference is a deduction, conclusion, or interpretation based on the facts made during the observation.

4. Why are theories changed?

Answer:

New observations or laws may not be explained by a theory, so it needs to be modified.

5. If a friend said that Levi's jeans are the best, what kind of evidential arguments would support this statement?

Answer:

The kind of evidential argument would be based on what the person meant by the best. If the person meant that these jeans are the most durable under normal conditions, some data could be provided to support that claim. If the person meant that they are the most popular fashion, data could be provided to support that statement.

Learning Activity 10.2: The Nature of Light and Newton's Corpuscular Theory

1. When a "particle" such as a steel ball strikes a hard surface, its speed is usually reduced. If the speed of light were reduced, how would the light appear to be different after the reflection as compared to the incoming light beam? (You will need to use your knowledge from your work on waves to explain how the speed of light, the wavelength of light, and the frequency are related.)

   Answer:

   When light leaves a source, the frequency of the light is fixed. From the equation $v = f\lambda$, we can see that if the speed of the light is less, then the wavelength of the light must also be less. This means that there would be a colour change in the light.

2. We can think of momentum as the amount of push a moving mass has. A more precise definition of momentum will be given later in the course. People such as Benjamin Franklin rejected the corpuscular theory of light on the basis of momentum considerations. Suggest an argument he may have used.

   Answer:

   Even though the speed of light was not known at the time of Newton, it was at least known that it was very great. So even a particle with a tiny mass would carry an appreciable amount of momentum and the number of such particles in a beam must also be very large. Yet we never feel the "force" of light. No one at that time conceived the idea that particles might be massless. Yet light does exert pressure and has momentum.

3. From the brief descriptions given above of Planck's quantum hypothesis, how does it compare with Newton's corpuscular theory?

   Answer:

   Planck's quantum hypothesis suggests that light comes in small bundles of energy called quanta. This is very similar to Newton's idea that light consists of small particles.

4. We know now that Newton's corpuscular theory had limitations and that light really does not consist of particles. What can we learn about placing too great a belief in a theory and the kind of evidence needed to support the theory?

   Answer:

   We can learn that we must not believe a theory only on the basis that it comes from an eminent person. There must be strong supporting experimental evidence.

5. Briefly describe how Newton's corpuscular theory was able to explain each of the following behaviours of light. Include a diagram where appropriate.

   a) rectilinear propagation

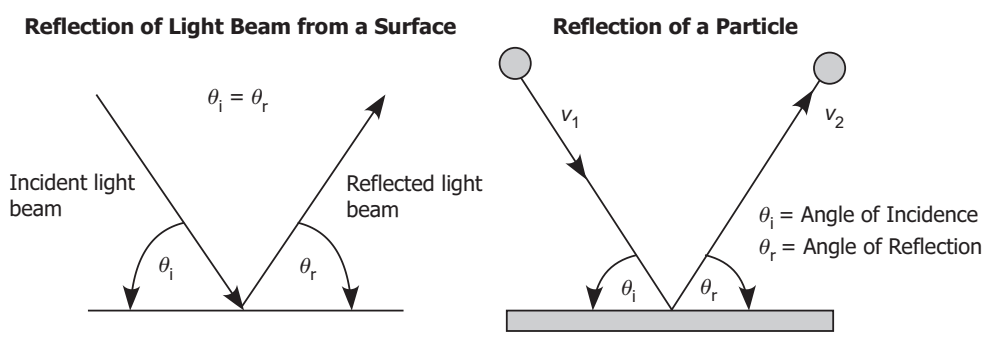
      Answer:

      Rectilinear propagation of light is light travelling in straight lines. We can see this effect in sharp shadows cast by sunlight. Newton argued that the speed of light must be very high because the path of light has no noticeable curve.

   b) reflection

      Answer:

      Newton's corpuscular theory was able to explain reflection of light by showing that, in the ideal case, very hard spheres reflect from a surface so that the angle of incidence is equal to the angle of reflection, and that the reflected speed of the spheres equals the incident speed.

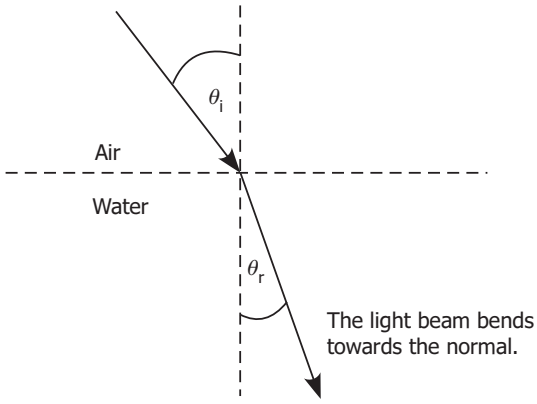


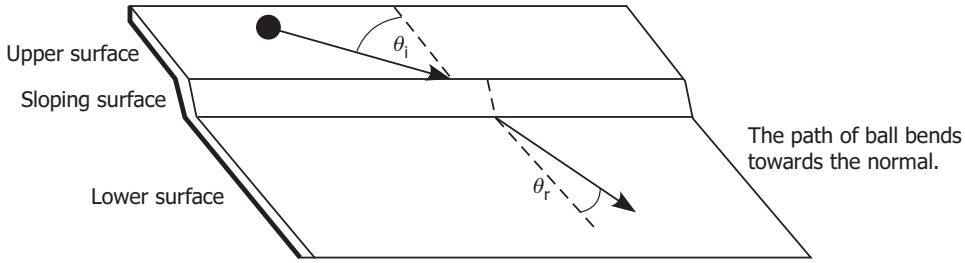
c) refraction

Answer:

Newton's corpuscular theory demonstrated that when light refracts towards the normal in moving towards a denser medium, this is analogous to a ball rolling from a higher horizontal surface to a lower one and also bending towards the normal. As particles of light pass from air to water, the water particles attract the light particles, causing them to accelerate and change their direction of motion.

Light Beam Moving from Air to Water

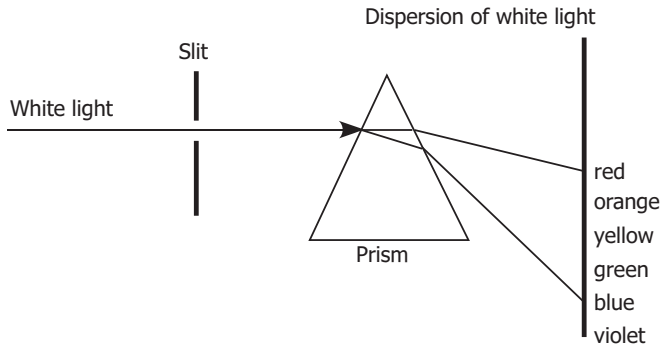




d) dispersion

Answer:

Dispersion occurs when white light passes through a prism and is refracted by different amounts, resulting in the formation of the spectrum of colours. Newton's corpuscular theory was able to explain dispersion by assuming that each particle of the spectrum has a different mass. Violet particles have the smallest mass and so are refracted the most, while red particles have the greatest mass and are refracted the least.



Learning Activity 10.3: Determining the Speed of Light

1. Galileo attempted to measure the speed of light using lanterns on two hilltops. Explain why this technique might have worked if he were attempting to find the speed of sound, but not the speed of light.

   Answer:

   The speed of sound is much slower than the speed of light, so it is possible to measure the time of travel between two hilltops. The speed of light is too great for the time of travel to be accurately measured using this method.

2. What technique allowed Fizeau to measure time accurately enough to determine the speed of light much better than Galileo?

   Answer:

   Fizeau shone a light between the teeth of a rapidly rotating toothed wheel. There were over a hundred teeth in the wheel. The wheel rotated at hundreds of times a second. Therefore, a thousandth of a second was easy to measure.

3. What was it about Michelson's technique that allowed him to measure the speed of light so accurately?

   Answer:

   Michelson was able to determine the large distance between his mirrors very accurately. He was also able to determine the speed of rotation of his eight-sided mirror very accurately.

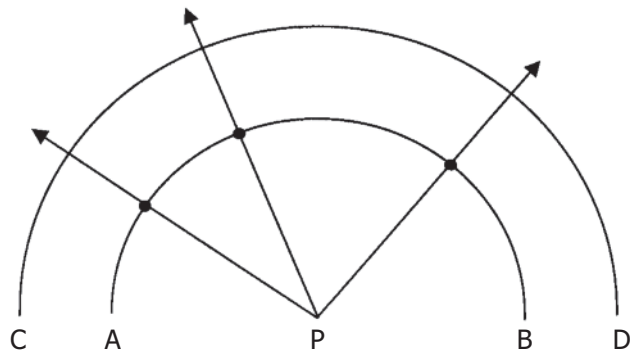
4. After doing his experiments on two mountains, Michelson did another series of experiments in a long evacuated tube. What improvements did this new method have?

   Answer:

   The experiments were done in an evacuated tube one mile (1.6 km) long to eliminate the problems of haze and variations in air density. This allowed Michelson to determine the speed of light even more accurately.

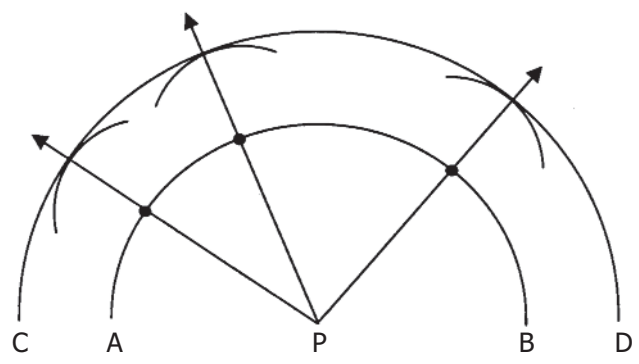
Learning Activity 10.4: Wave Theory of Light

1. A source of light is at the point P. The diagram shows three of the light rays that may be travelling out from this point. The wave theory would predict that the light source is sending out circular waves. One of those waves is labelled AB. At the places where the light rays cross the wave, there are dots representing new sources of wavelets. When the wave AB expands to become wave CD, draw the wavelets at each of the places where the light rays intersect with the wave CD.



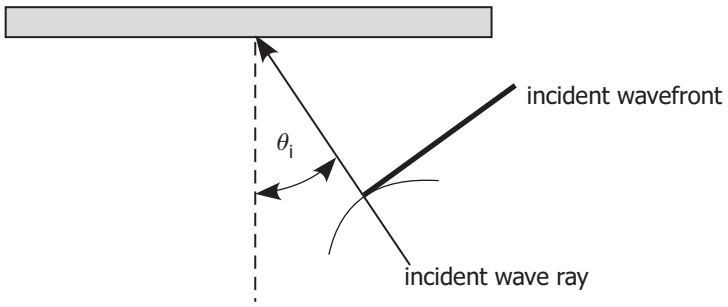
Answer:

The wavelets are drawn tangent to the wavefront at the places where the light rays intersect the circle.



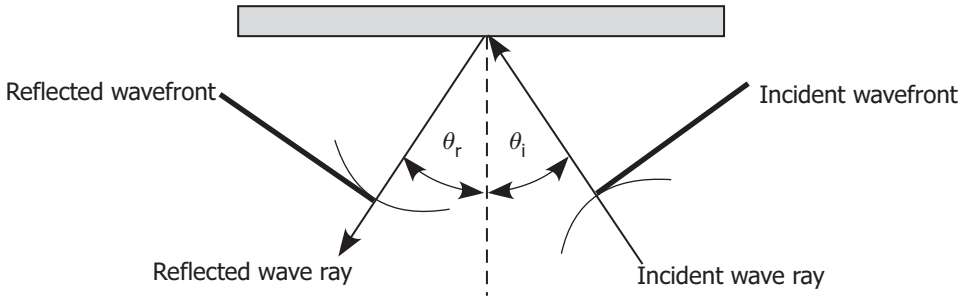
2. The diagram below shows a wavefront and the associated wavelet approaching a barrier. The wave ray indicates the direction of motion of the wavelet. The angle of incidence is also shown. Show the wavelet at some later time after reflection has occurred. In your diagram, include the following:
   a) the wave ray indicating the direction of motion of the reflected wavelet
   b) a possible location of the wavefront
   c) the correct location of the wavelet in relation to the wavefront

d) the angle of reflection



Answer:

The direction of motion of the wavelet is shown moving away from the barrier so that the angle of incidence is equal to the angle of reflection. The wavefront is drawn perpendicular to the wave ray. The wavelet is tangent to the wavefront at the location where the wavefront intersects the wave ray.



3. The wave theory provides a good model for describing refraction.

   a) When waves move from deep water to shallow water, what does the wave theory show about the change to the wavelength of the wave and the speed of the wave in the shallow water?

   Answer:

   The wave theory shows that the wavelength will be less and the speed of the wave will also be less in the shallow water.

b) How does the wave theory prediction about the speed of light in an optically denser medium compare with the corpuscular theory?

Answer:

The wave theory predicts that the speed of light will be less in the denser material while the corpuscular theory predicts it will be greater.

4. If we wanted to observe the diffraction of light as it passes through an opening, how large should the opening be in order to observe the effect?

Answer:

The opening must be very small. It should be approximately the same size as the wavelength of the light used.

Learning Activity 10.5: Young's Experiment

1. When a screen is illuminated by two closely spaced, parallel, single-filament light sources, no interference is observed. What major condition for interference has not been satisfied?

   Answer:

   The two light sources are placed closely together so the distance condition for two sources is satisfied. However, the two sources are not in phase and therefore interference cannot occur.

2. If Young's Experiment was done completely in glass, how would the interference pattern change from that observed in air, using the same equipment and experimental set-up?

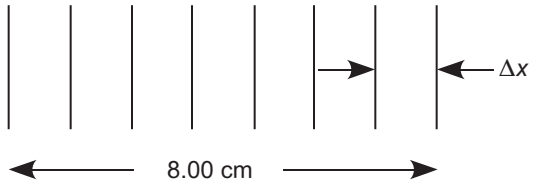
   Answer:

   Glass is a denser material than air, so light refracts (bends) in glass to a greater extent than in air. This would cause the distance between the nodes in an interference pattern to be closer together. The speed of light in glass is less than in air, and thus the wavelength is less.

3. A student is measuring the wavelength of light produced by a sodium vapour lamp. The light is directed through two slits with a separation of 0.150 mm. The interference pattern was created on the screen 3.00 m away. The student found that the distance between the first and the eighth consecutive dark lines was 8.00 cm. What was the wavelength emitted by the sodium vapour lamp?

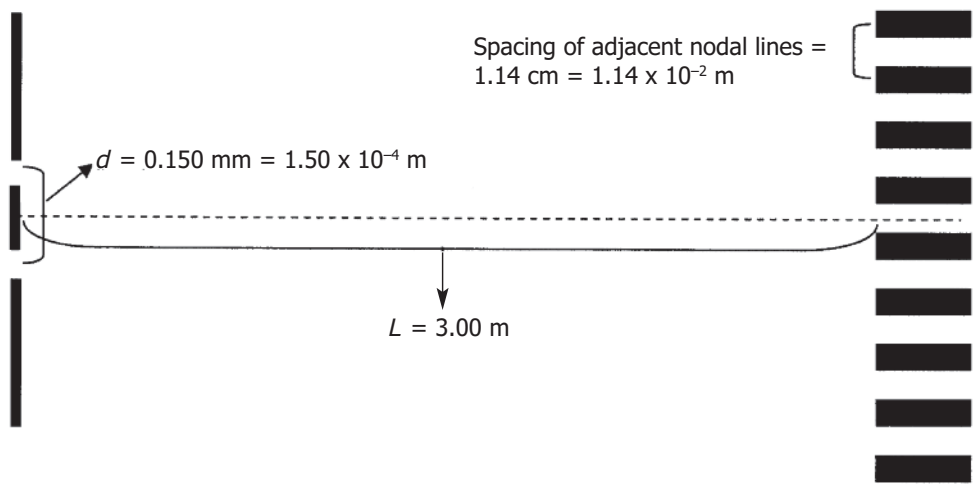
   Answer:

   The diagram below shows the eight lines. Δx represents the distance between two of the lines.



   If there are 8 nodal lines, then there are 7 spaces. The distance between each space must be $\Delta x = \dfrac{8.00\text{ cm}}{7} = 1.14\text{ cm} = 1.14 \times 10^{-2}\text{ m}$.

The distance between the slits is 0.150 mm = 1.50 x 10^{-4} m.



Equation: $\Delta x = \frac{\lambda L}{d}$ rearranged to $\lambda = \frac{\Delta x d}{L}$

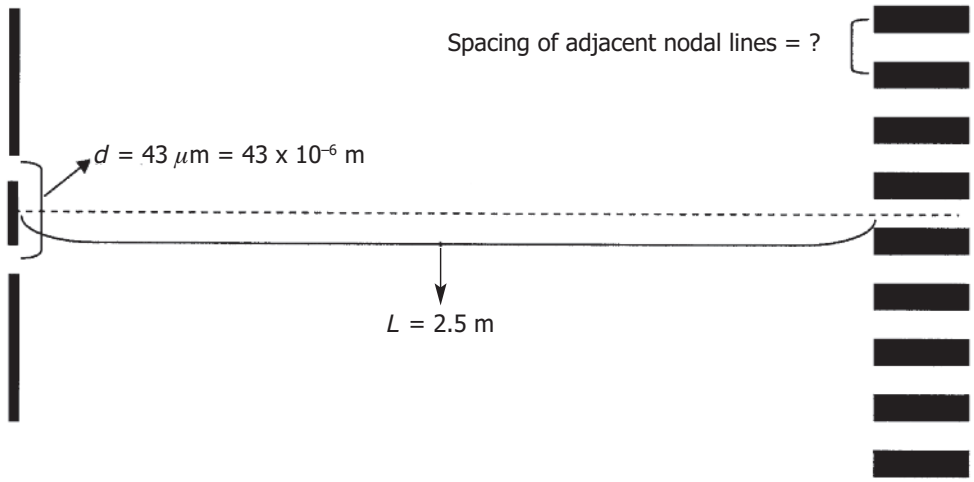
Substitute and solve: $\lambda = \frac{\Delta x d}{L} = \frac{(1.14 \times 10^{-2}\ \text{m})(1.50 \times 10^{-4}\ \text{m})}{3.00\ \text{m}}$

$= 5.70 \times 10^{-7}\ \text{m}$

The wavelength is 5.70 x 10^{-7} m.

4. An interference pattern is formed on a screen when a helium-neon laser light (λ = 6.328 x 10^{-7} m) is directed towards it through two slits. If the slits are 43 μm apart and the screen is 2.5 m away, what will be the separation of adjacent nodal lines? (μ = micro = 10^{-6})

   Answer:



   Wavelength $\lambda = 6.328 \times 10^{-7}$ m

   Unknown: Spacing of adjacent nodal lines Δx = ?

   Equation: $$\Delta x = \frac{\lambda L}{d}$$

   Substitute and solve: $$\Delta x = \frac{\lambda L}{d} = \frac{(6.328 \times 10^{-7}\ \text{m})(2.5\ \text{m})}{43 \times 10^{-6}\ \text{m}}$$
   $$= 3.7 \times 10^{-2}\ \text{m} = 0.037\ \text{m}$$

   The spacing of adjacent nodal lines is 0.037 m or 3.7 cm.

5. Two slits have green light of wavelength 5.25 x 10^{-7} m passing through them. The interference pattern is observed at a distance of 1.75 m. The distance from 1 dark line to the 9th dark line is 10.2 cm.

   a) What is the spacing of the nodal lines?

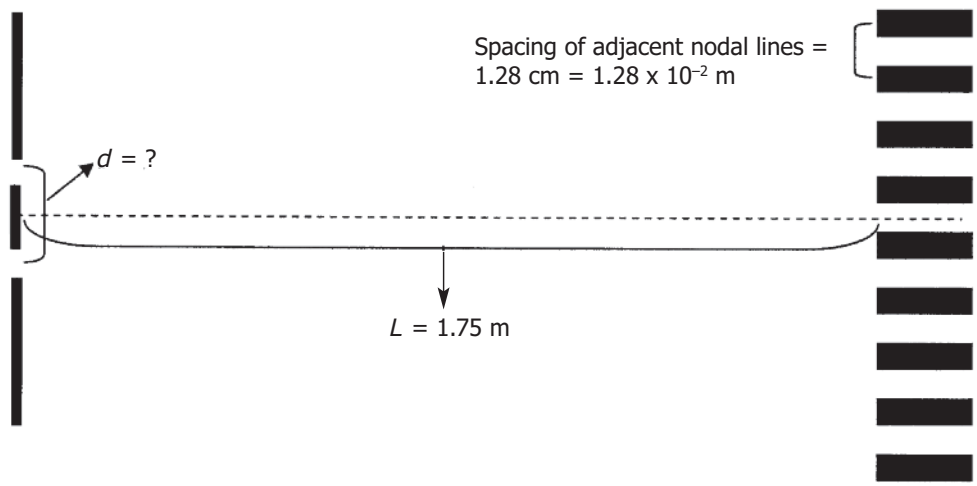
      Answer:

      There are 8 spaces between the 9 nodal lines.

      $$\Delta x = \frac{10.2\ \text{cm}}{8} = 1.28\ \text{cm} = 1.28 \times 10^{-2}\ \text{m}$$

b) What is the separation of the slits?

Answer:



Wavelength $\lambda = 5.25 \times 10^{-5}$ m

Unknown: Spacing of adjacent nodal lines $d = ?$

Equation: $\Delta x = \dfrac{\lambda L}{d}$ rearranged to $d = \dfrac{\lambda L}{\Delta x}$

Substitute and solve: $d = \dfrac{\lambda L}{\Delta x} = \dfrac{(5.25 \times 10^{-7}\ \text{m})(1.75\ \text{m})}{1.28 \times 10^{-2}\ \text{m}} = 7.18 \times 10^{-5}\ \text{m}$

The separation of the slits is 7.18×10^{-5} m.

Learning Activity 10.6: The Photoelectric Effect and Wave-Particle Duality

1. The physical construction of the photocell was discussed previously. If the following changes were made, what effect would there be on the current?

   a) If the photocell tube did not have the air inside evacuated, would there be more of a current or less?

      Answer:

      There would be less of a current because some of the motion of the freed electrons would be interfered with by the air molecules.

   b) If the glass making up the photocell was not made up of quartz but instead of ordinary glass, would this result in more of a current in the photocell or less?

      Answer:

      There would be less of a current because ultraviolet light cannot pass through ordinary glass.

   c) If the cathode was made up of a harder metal such as steel, would there be a larger current or less?

      Answer:

      There would be less of a current because it would be more difficult to remove electrons from a harder metal such as steel.

2. Suppose that ultraviolet light is required before an electric current is produced in a photocell, The wave theory and the photon theories predict different effects if very bright orange light that is shining for a long time is used instead. What does each theory predict and which theory makes the correct prediction?

   Answer:

   The wave theory predicts that electrons will be ejected using the orange light. The more intense radiation has stronger electric and magnetic fields and should eject the electrons. If it shines for a long time, then eventually the electrons should gain enough energy to be ejected. The photon theory predicts that orange light will not eject the electron because the frequency of this light is below the threshold frequency. The photon theory makes the correct predictions.

3. Einstein's photon theory was able to explain why light with only a minimum frequency is necessary to dislodge an electron, and that light below this frequency will not, no matter how bright the light is. How was he able to explain this?

   Answer:

   An electron must have a minimum amount of energy to escape the attractive force holding it to the metal. The energy contained in a photon depends on the frequency of the photon. If the frequency is too low, then there is not enough energy contained in the photon. If low frequency light is bright, this means that there are more photons striking the surface in a given time, but these photons do not have sufficient energy.

4. The Principle of Complementarity states that to understand the behaviour of light, we need to use both the wave theory and the photon theory. In general, where is the wave theory best applied, and where is the photon theory best applied?

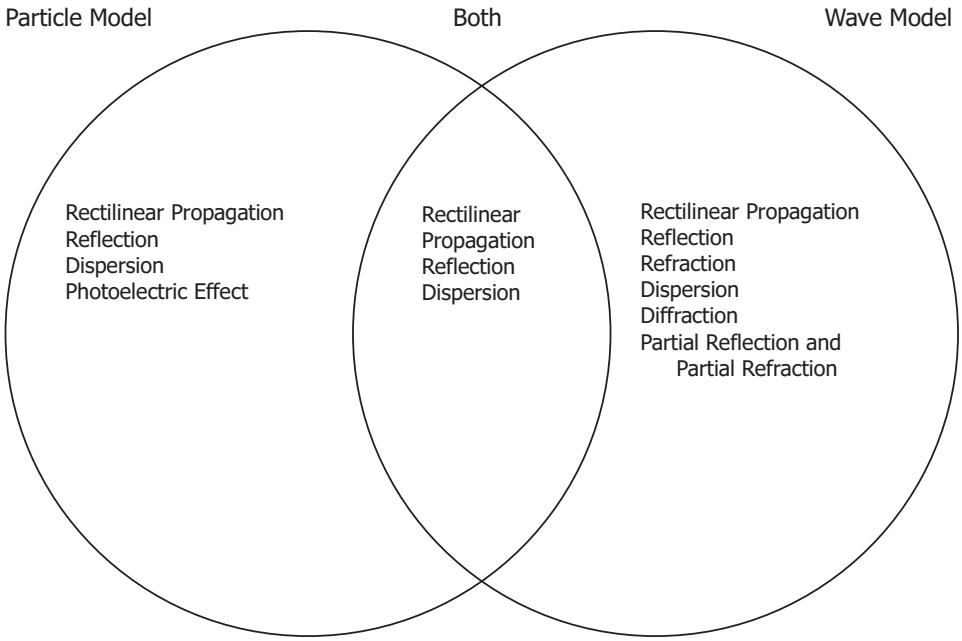
   Answer:

   The wave theory is best applied when light passes through space or a medium. But when light interacts with matter, its behaviour is more like that of a particle.

5. On the diagram below write in the names of the behaviours of light that can be explained using the particle model on the outside edge of the circle entitled "Particle Model". Write in the names of the behaviours of light that can be explained using the wave model on the outside edge of the circle entitled "Wave Model". In the section of the diagram where the two circles overlap, write the behaviours that can be explained using both theories.

   Answer:

The Current Model of Light: Wave-Particle Duality
(Sometimes I feel like a nut and sometimes I don't!)



Grade 11 Physics (30S)

Module 10: Models, Laws, and Theories, and the Nature of Light

Learning Activity Answer Keys

Module 10: Models, Laws, and Theories, and the Nature of Light

Learning Activity 10.1: The Scientific Method, Laws, Theories, and Models

1. In doing the black box experiment, you are told that there is one object in the box, but you are not given any information about what that object is. At first, you move, tilt, and shake the box, and you can see that there is indeed what appears to be one object in the box. You then proceed more slowly and carefully. You tilt the box slowly and you hear a sliding sound. You never hear a rolling sound. It does not matter if you tilt the box slowly or rapidly. You never hear a rolling sound, but if you tilt the box rapidly you may hear a tumbling sound of the kind that a cube might make.

   a) If you were to state that object inside the black box was a cube, would this be an observation or an inference? Justify your answer.

      Answer:

      This would not be an observation. An observation is a fact that is noticed either qualitatively or quantitatively. Stating that the object is a cube is not a fact. It is an inference. We can define an inference as a deduction, conclusion, or interpretation based on the facts made during the observation.

   b) If you were to state that when you tilt the box in any of the front-to-back or back-to-front ways, the object inside slides and does not roll, would this be a statement of theory or a statement of a scientific law?

      Answer:

      This would a statement of a scientific law.

      A law is a concise but general statement about how nature behaves. It is a summary of the results of our observations. It is a description of nature without an explanation of why nature behaves that way. The statement above describes how the object inside the box behaves but does not provide an explanation for the behaviour.

c) If you were to state that the object inside the box must be a cube, could we say that this statement is an example of a scientific model? Explain your reasoning.

Answer:

Yes, we could say that this statement is an example of a scientific model. A scientific model is a mental picture that helps us understand something we cannot see or experience directly. Stating that the object is a cube is a mental picture of the object.

d) What would make it necessary to change the law or theory developed for the object inside the black box in this example?

Answer:

It would become necessary to change the law or theory if a new observation was made that could not be explained by the existing laws and theories. For example, if a rolling sound was heard, it would show that the object inside the black box could not be a cube.

2. What are the characteristics of a good theory?

Answer:

Good theories have the following characteristics:

A good theory explains phenomena accurately and its predictions are accurate.

It consistently explains a wide range of phenomena; it has a wide scope.

The theory is simple, or less complex.

It can quantitatively predict phenomena.

3. Distinguish between:

a) observation and conclusion

Answer:

An observation is a fact that is noticed either qualitatively or quantitatively during an experiment. No meaning is attached to an observation.

A conclusion is a statement expressing a judgment or opinion formed as a result of analyzing the experimental data. Conclusions attempt to draw meaning from observations.

b) theory and model

Answer:

A scientific model is a mental picture that helps us understand something we cannot see or experience directly. Models can suggest new experiments to perform and can provide ideas about what other related phenomena can occur. Scientific models change as new discoveries are made.

A theory provides a general explanation for the observations. Theories are inspirations that come from a creative human mind to explain observations. Early attempts at forming theories may be speculative, first attempts to explain phenomena. New observations or laws may not be explained by a theory, so it needs to be modified. A theory that can explain a greater range of phenomena may be referred to as robust.

c) law and inference

Answer:

A law is a concise but general statement about how nature behaves. It is a summary of the results of our observations. It is a description of nature without an explanation of why nature behaves that way.

An inference is a deduction, conclusion, or interpretation based on the facts made during the observation.

4. Why are theories changed?

Answer:

New observations or laws may not be explained by a theory, so it needs to be modified.

5. If a friend said that Levi's jeans are the best, what kind of evidential arguments would support this statement?

Answer:

The kind of evidential argument would be based on what the person meant by the best. If the person meant that these jeans are the most durable under normal conditions, some data could be provided to support that claim. If the person meant that they are the most popular fashion, data could be provided to support that statement.

Learning Activity 10.2: The Nature of Light and Newton's Corpuscular Theory

1. When a "particle" such as a steel ball strikes a hard surface, its speed is usually reduced. If the speed of light were reduced, how would the light appear to be different after the reflection as compared to the incoming light beam? (You will need to use your knowledge from your work on waves to explain how the speed of light, the wavelength of light, and the frequency are related.)

   Answer:

   When light leaves a source, the frequency of the light is fixed. From the equation $v = f\lambda$, we can see that if the speed of the light is less, then the wavelength of the light must also be less. This means that there would be a colour change in the light.

2. We can think of momentum as the amount of push a moving mass has. A more precise definition of momentum will be given later in the course. People such as Benjamin Franklin rejected the corpuscular theory of light on the basis of momentum considerations. Suggest an argument he may have used.

   Answer:

   Even though the speed of light was not known at the time of Newton, it was at least known that it was very great. So even a particle with a tiny mass would carry an appreciable amount of momentum and the number of such particles in a beam must also be very large. Yet we never feel the "force" of light. No one at that time conceived the idea that particles might be massless. Yet light does exert pressure and has momentum.

3. From the brief descriptions given above of Planck's quantum hypothesis, how does it compare with Newton's corpuscular theory?

   Answer:

   Planck's quantum hypothesis suggests that light comes in small bundles of energy called quanta. This is very similar to Newton's idea that light consists of small particles.

4. We know now that Newton's corpuscular theory had limitations and that light really does not consist of particles. What can we learn about placing too great a belief in a theory and the kind of evidence needed to support the theory?

   Answer:

   We can learn that we must not believe a theory only on the basis that it comes from an eminent person. There must be strong supporting experimental evidence.

5. Briefly describe how Newton's corpuscular theory was able to explain each of the following behaviours of light. Include a diagram where appropriate.

   a) rectilinear propagation

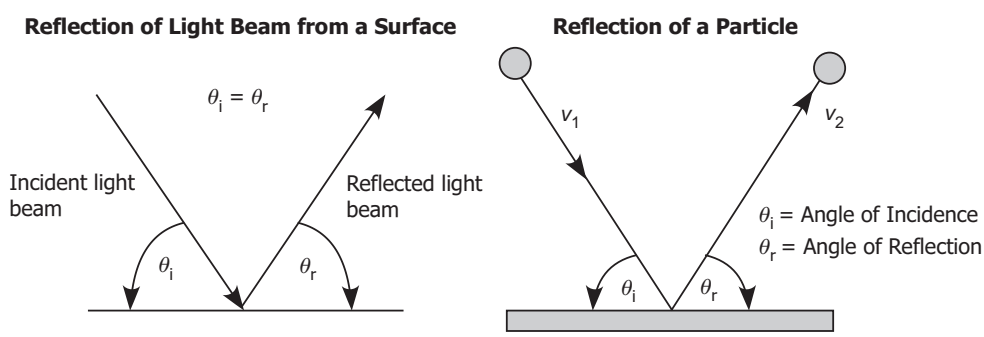
      Answer:

      Rectilinear propagation of light is light travelling in straight lines. We can see this effect in sharp shadows cast by sunlight. Newton argued that the speed of light must be very high because the path of light has no noticeable curve.

   b) reflection

      Answer:

      Newton's corpuscular theory was able to explain reflection of light by showing that, in the ideal case, very hard spheres reflect from a surface so that the angle of incidence is equal to the angle of reflection, and that the reflected speed of the spheres equals the incident speed.

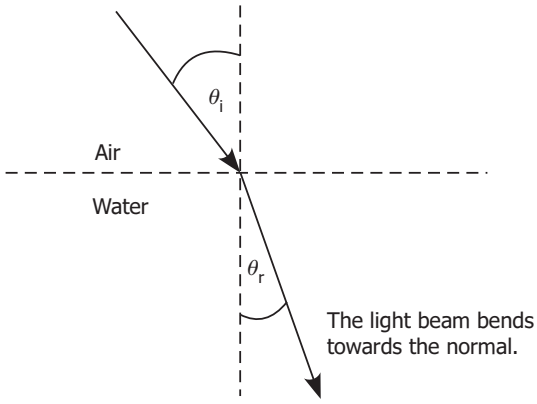


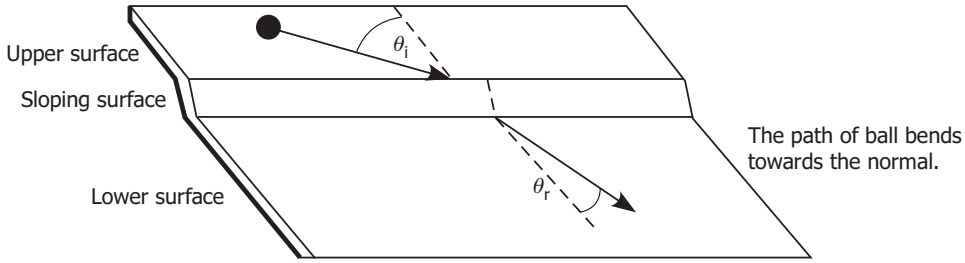
c) refraction

Answer:

Newton's corpuscular theory demonstrated that when light refracts towards the normal in moving towards a denser medium, this is analogous to a ball rolling from a higher horizontal surface to a lower one and also bending towards the normal. As particles of light pass from air to water, the water particles attract the light particles, causing them to accelerate and change their direction of motion.

Light Beam Moving from Air to Water

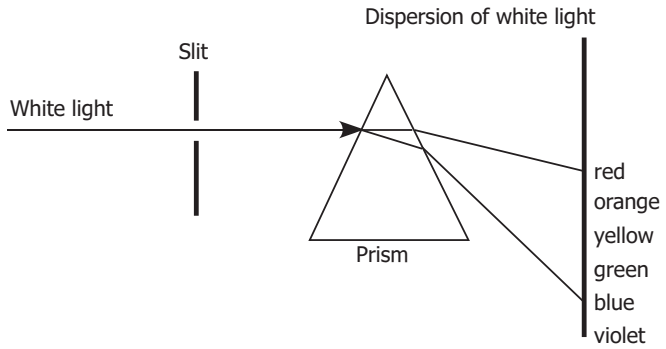




d) dispersion

Answer:

Dispersion occurs when white light passes through a prism and is refracted by different amounts, resulting in the formation of the spectrum of colours. Newton's corpuscular theory was able to explain dispersion by assuming that each particle of the spectrum has a different mass. Violet particles have the smallest mass and so are refracted the most, while red particles have the greatest mass and are refracted the least.



Learning Activity 10.3: Determining the Speed of Light

1. Galileo attempted to measure the speed of light using lanterns on two hilltops. Explain why this technique might have worked if he were attempting to find the speed of sound, but not the speed of light.

   Answer:

   The speed of sound is much slower than the speed of light, so it is possible to measure the time of travel between two hilltops. The speed of light is too great for the time of travel to be accurately measured using this method.

2. What technique allowed Fizeau to measure time accurately enough to determine the speed of light much better than Galileo?

   Answer:

   Fizeau shone a light between the teeth of a rapidly rotating toothed wheel. There were over a hundred teeth in the wheel. The wheel rotated at hundreds of times a second. Therefore, a thousandth of a second was easy to measure.

3. What was it about Michelson's technique that allowed him to measure the speed of light so accurately?

   Answer:

   Michelson was able to determine the large distance between his mirrors very accurately. He was also able to determine the speed of rotation of his eight-sided mirror very accurately.

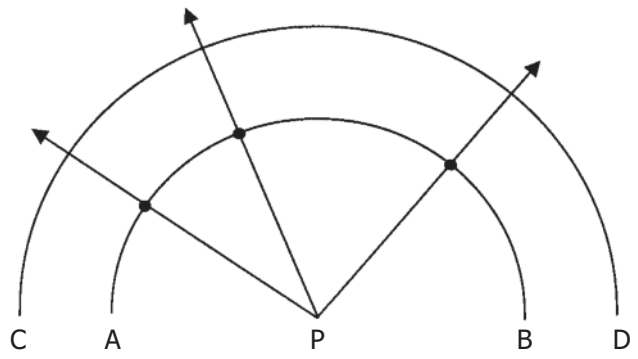
4. After doing his experiments on two mountains, Michelson did another series of experiments in a long evacuated tube. What improvements did this new method have?

   Answer:

   The experiments were done in an evacuated tube one mile (1.6 km) long to eliminate the problems of haze and variations in air density. This allowed Michelson to determine the speed of light even more accurately.

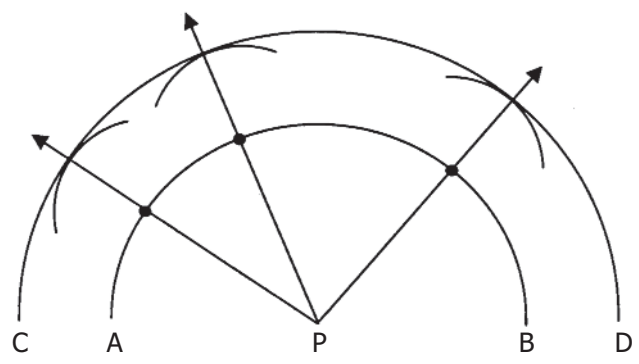
Learning Activity 10.4: Wave Theory of Light

1. A source of light is at the point P. The diagram shows three of the light rays that may be travelling out from this point. The wave theory would predict that the light source is sending out circular waves. One of those waves is labelled AB. At the places where the light rays cross the wave, there are dots representing new sources of wavelets. When the wave AB expands to become wave CD, draw the wavelets at each of the places where the light rays intersect with the wave CD.



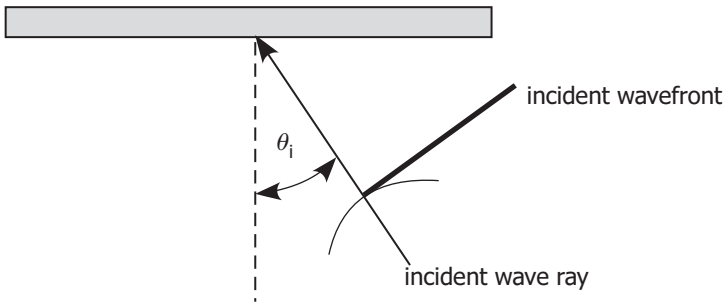
Answer:

The wavelets are drawn tangent to the wavefront at the places where the light rays intersect the circle.



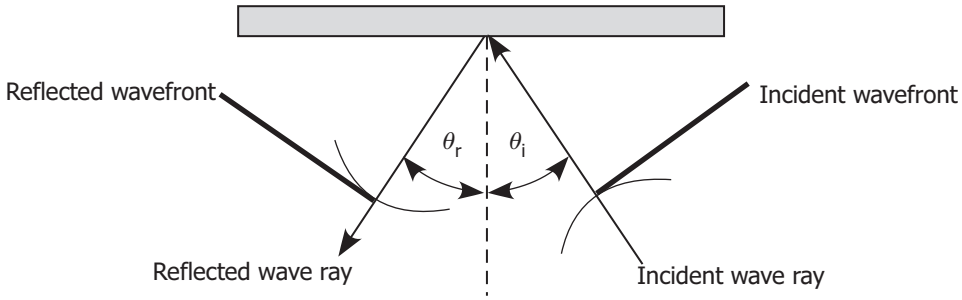
2. The diagram below shows a wavefront and the associated wavelet approaching a barrier. The wave ray indicates the direction of motion of the wavelet. The angle of incidence is also shown. Show the wavelet at some later time after reflection has occurred. In your diagram, include the following:
   a) the wave ray indicating the direction of motion of the reflected wavelet
   b) a possible location of the wavefront
   c) the correct location of the wavelet in relation to the wavefront

d) the angle of reflection



Answer:

The direction of motion of the wavelet is shown moving away from the barrier so that the angle of incidence is equal to the angle of reflection. The wavefront is drawn perpendicular to the wave ray. The wavelet is tangent to the wavefront at the location where the wavefront intersects the wave ray.



3. The wave theory provides a good model for describing refraction.

   a) When waves move from deep water to shallow water, what does the wave theory show about the change to the wavelength of the wave and the speed of the wave in the shallow water?

   Answer:

   The wave theory shows that the wavelength will be less and the speed of the wave will also be less in the shallow water.

b) How does the wave theory prediction about the speed of light in an optically denser medium compare with the corpuscular theory?

Answer:

The wave theory predicts that the speed of light will be less in the denser material while the corpuscular theory predicts it will be greater.

4. If we wanted to observe the diffraction of light as it passes through an opening, how large should the opening be in order to observe the effect?

Answer:

The opening must be very small. It should be approximately the same size as the wavelength of the light used.

Learning Activity 10.5: Young's Experiment

1. When a screen is illuminated by two closely spaced, parallel, single-filament light sources, no interference is observed. What major condition for interference has not been satisfied?

   Answer:

   The two light sources are placed closely together so the distance condition for two sources is satisfied. However, the two sources are not in phase and therefore interference cannot occur.

2. If Young's Experiment was done completely in glass, how would the interference pattern change from that observed in air, using the same equipment and experimental set-up?

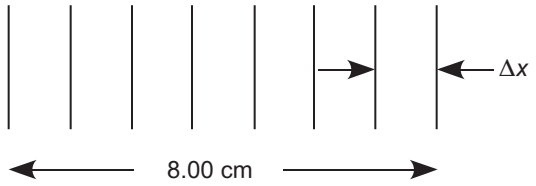
   Answer:

   Glass is a denser material than air, so light refracts (bends) in glass to a greater extent than in air. This would cause the distance between the nodes in an interference pattern to be closer together. The speed of light in glass is less than in air, and thus the wavelength is less.

3. A student is measuring the wavelength of light produced by a sodium vapour lamp. The light is directed through two slits with a separation of 0.150 mm. The interference pattern was created on the screen 3.00 m away. The student found that the distance between the first and the eighth consecutive dark lines was 8.00 cm. What was the wavelength emitted by the sodium vapour lamp?

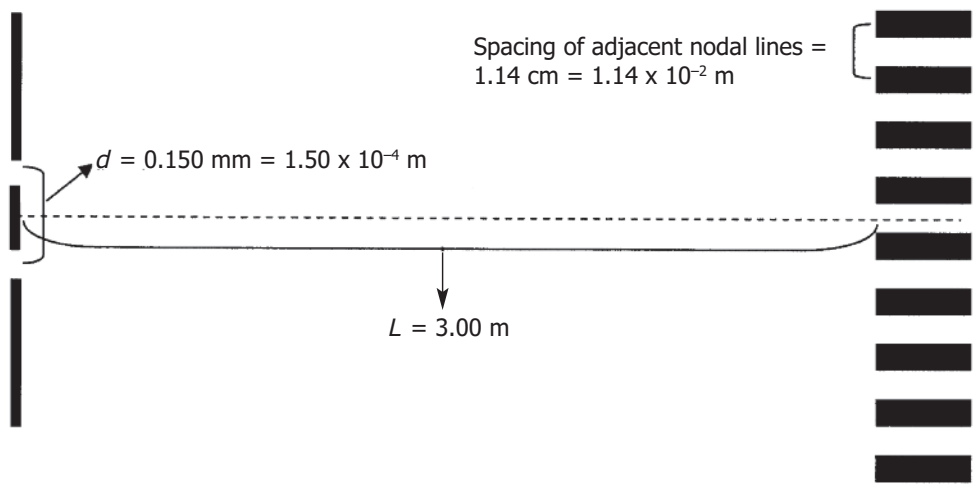
   Answer:

   The diagram below shows the eight lines. Δx represents the distance between two of the lines.



   If there are 8 nodal lines, then there are 7 spaces. The distance between each space must be $\Delta x = \dfrac{8.00\text{ cm}}{7} = 1.14\text{ cm} = 1.14 \times 10^{-2}\text{ m}$.

The distance between the slits is 0.150 mm = 1.50 x 10^{-4} m.



Equation: $\Delta x = \frac{\lambda L}{d}$ rearranged to $\lambda = \frac{\Delta x d}{L}$

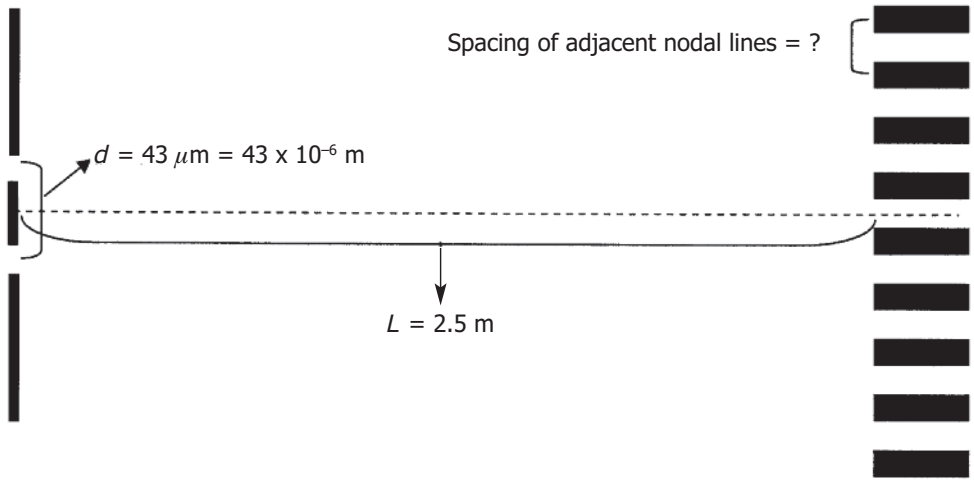
Substitute and solve: $\lambda = \frac{\Delta x d}{L} = \frac{(1.14 \times 10^{-2}\ \text{m})(1.50 \times 10^{-4}\ \text{m})}{3.00\ \text{m}}$

$= 5.70 \times 10^{-7}\ \text{m}$

The wavelength is 5.70 x 10^{-7} m.

4. An interference pattern is formed on a screen when a helium-neon laser light (λ = 6.328 x 10^{-7} m) is directed towards it through two slits. If the slits are 43 μm apart and the screen is 2.5 m away, what will be the separation of adjacent nodal lines? (μ = micro = 10^{-6})

   Answer:



   Wavelength $\lambda = 6.328 \times 10^{-7}$ m

   Unknown: Spacing of adjacent nodal lines Δx = ?

   Equation: $$\Delta x = \frac{\lambda L}{d}$$

   Substitute and solve: $$\Delta x = \frac{\lambda L}{d} = \frac{(6.328 \times 10^{-7}\ \text{m})(2.5\ \text{m})}{43 \times 10^{-6}\ \text{m}}$$
   $$= 3.7 \times 10^{-2}\ \text{m} = 0.037\ \text{m}$$

   The spacing of adjacent nodal lines is 0.037 m or 3.7 cm.

5. Two slits have green light of wavelength 5.25 x 10^{-7} m passing through them. The interference pattern is observed at a distance of 1.75 m. The distance from 1 dark line to the 9th dark line is 10.2 cm.

   a) What is the spacing of the nodal lines?

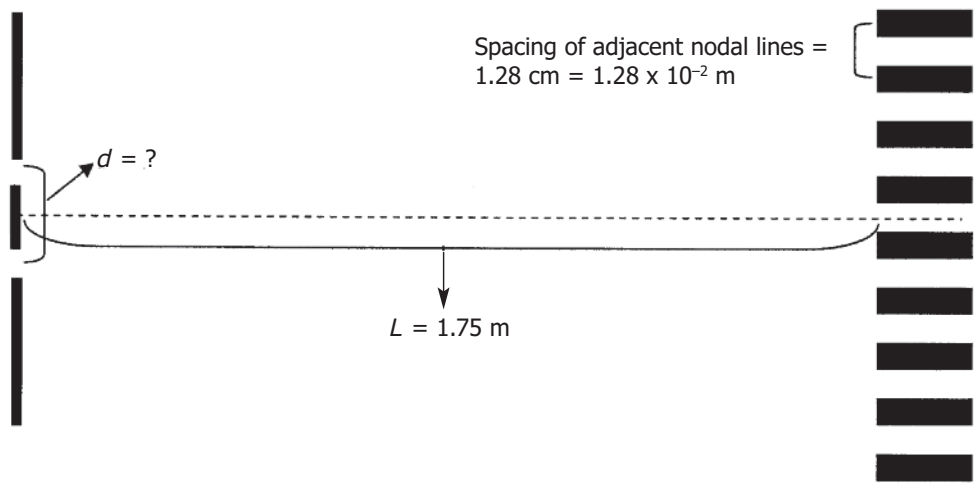
      Answer:

      There are 8 spaces between the 9 nodal lines.

      $$\Delta x = \frac{10.2\ \text{cm}}{8} = 1.28\ \text{cm} = 1.28 \times 10^{-2}\ \text{m}$$

b) What is the separation of the slits?

Answer:



Wavelength $\lambda = 5.25 \times 10^{-5}$ m

Unknown: Spacing of adjacent nodal lines $d = ?$

Equation: $\Delta x = \dfrac{\lambda L}{d}$ rearranged to $d = \dfrac{\lambda L}{\Delta x}$

Substitute and solve: $d = \dfrac{\lambda L}{\Delta x} = \dfrac{(5.25 \times 10^{-7}\ \text{m})(1.75\ \text{m})}{1.28 \times 10^{-2}\ \text{m}} = 7.18 \times 10^{-5}\ \text{m}$

The separation of the slits is 7.18×10^{-5} m.

Learning Activity 10.6: The Photoelectric Effect and Wave-Particle Duality

1. The physical construction of the photocell was discussed previously. If the following changes were made, what effect would there be on the current?

   a) If the photocell tube did not have the air inside evacuated, would there be more of a current or less?

      Answer:

      There would be less of a current because some of the motion of the freed electrons would be interfered with by the air molecules.

   b) If the glass making up the photocell was not made up of quartz but instead of ordinary glass, would this result in more of a current in the photocell or less?

      Answer:

      There would be less of a current because ultraviolet light cannot pass through ordinary glass.

   c) If the cathode was made up of a harder metal such as steel, would there be a larger current or less?

      Answer:

      There would be less of a current because it would be more difficult to remove electrons from a harder metal such as steel.

2. Suppose that ultraviolet light is required before an electric current is produced in a photocell, The wave theory and the photon theories predict different effects if very bright orange light that is shining for a long time is used instead. What does each theory predict and which theory makes the correct prediction?

   Answer:

   The wave theory predicts that electrons will be ejected using the orange light. The more intense radiation has stronger electric and magnetic fields and should eject the electrons. If it shines for a long time, then eventually the electrons should gain enough energy to be ejected. The photon theory predicts that orange light will not eject the electron because the frequency of this light is below the threshold frequency. The photon theory makes the correct predictions.

3. Einstein's photon theory was able to explain why light with only a minimum frequency is necessary to dislodge an electron, and that light below this frequency will not, no matter how bright the light is. How was he able to explain this?

   Answer:

   An electron must have a minimum amount of energy to escape the attractive force holding it to the metal. The energy contained in a photon depends on the frequency of the photon. If the frequency is too low, then there is not enough energy contained in the photon. If low frequency light is bright, this means that there are more photons striking the surface in a given time, but these photons do not have sufficient energy.

4. The Principle of Complementarity states that to understand the behaviour of light, we need to use both the wave theory and the photon theory. In general, where is the wave theory best applied, and where is the photon theory best applied?

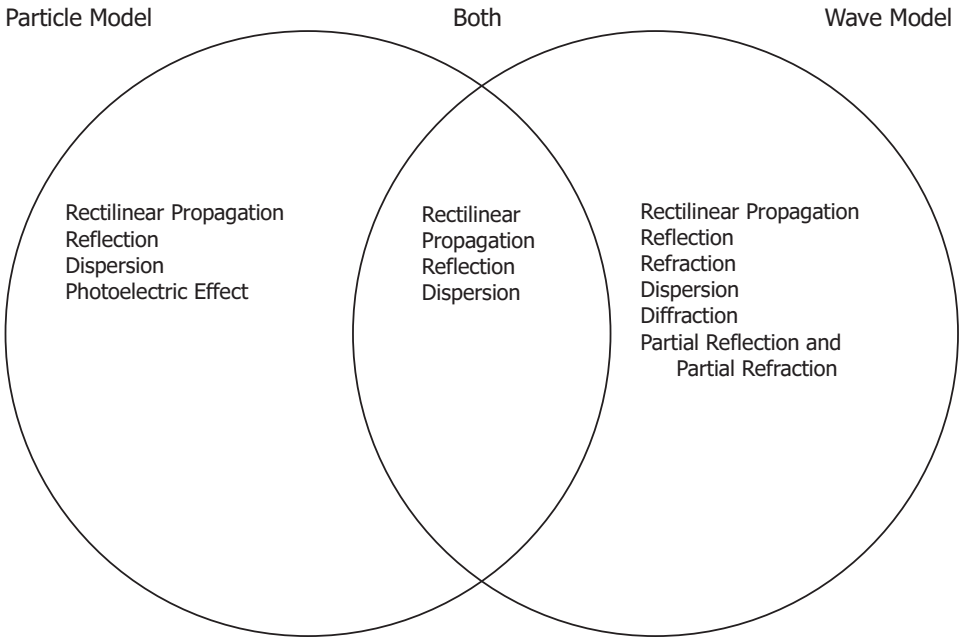
   Answer:

   The wave theory is best applied when light passes through space or a medium. But when light interacts with matter, its behaviour is more like that of a particle.

5. On the diagram below write in the names of the behaviours of light that can be explained using the particle model on the outside edge of the circle entitled "Particle Model". Write in the names of the behaviours of light that can be explained using the wave model on the outside edge of the circle entitled "Wave Model". In the section of the diagram where the two circles overlap, write the behaviours that can be explained using both theories.

   Answer:

The Current Model of Light: Wave-Particle Duality
(Sometimes I feel like a nut and sometimes I don't!)



Topic 4 - Audio/Videos

Module 10

1. The Scientific Method, Theories, Laws, and Models
2. What's the difference between a scientific law and theory? - Matt Anticole
3. Newton's Corpuscular Theory | Physics Animation
4. Physics - Newton's corpuscular theory of light - Science
    a. This video introduces Newton's Corpuscular Theory of Light. It demonstrates that this theory can explain the reflection of light and the refraction of light.
    b. Newton's corpuscular theory of light could not explain the interference of light and the diffraction of light. The theory also predicted incorrectly that particle of light speed up when they pass through the boundary between a less dense medium and a denser medium. As always scientific theories must be able to explain all of the observations of the phenomenon that these theories attempt to explain. If not the theory must be amended to explain the new observation. If the theory cannot be successfully amended, then the theory is incorrect.
5. Light: Particle or a Wave?
    a. The website compares the particle and wave models of light with good animations and explanations.
    b. There are side by side animations of the behaviour of light as a particle and light as a wave.
    c. The website provides an explanation and animation for the behaviour of light as a particle and light
6. Grade 11 Physics Track 7 The Particle Model of Light Mod 10 A10.2
7. Modern Physics 2-1: Measuring the Speed of Light (Eclipses of Io)
8. Classroom Aid - Fizeau measures the speed of light
9. Modern Physics 2-2: Measuring the Speed of Light (Foucault Experiment)
    a. Watch from 0 to 3:50.
    b. The instructor provides a description of the Foucault experiment to measure the speed of light. The apparatus is similar to that of Fizeau. Fizeau used a rotating notched wheel to measure the time of travel of light. Foucault replaces the notched wheel with a rotating multi-sided mirror.
    c. Light is emitted by a source. The light bounces off a face of the rotating mirror. The light travels to a distant mirror where it reflects back to the rotating mirror and the light strikes the rotating mirror. Since the rotating mirror has moved while the light traveled to the distant mirror and back again, the light reflects off the rotating mirror and travels not back to the source but along a slightly different path. The angle to this new path is measured and is used to determine the time that elapsed. Finally speed = distance/time is used to determine the speed of light.
10. Velocity of Light: Michelsons's Method
11. How did Scientists Determine the Speed of Light?
12. Huygens Principle | He's Dutch! | Doc Physics

a. This video provides an introduction to Huygen's Principle which states that each point on a wave front serves as a point source of the wave. Each of these point sources sends out circular wavelets. The constructive interference of these wavelets produce the wave front an instant later. This is how wave fronts propagate or reproduce themselves as they travel along.
b. If a straight wave front passes through an opening in a barrier, the part of the wave front that strikes the opening then serves as point sources which then produces a circular wave.
c. If a straight wave front strikes a barrier with one opening a circular wave front is produced behind the barrier. If this circular wave front then strikes a second barrier with two openings each opening becomes a new source of wave fronts that are also circular in shape. What has been created is a situation of two point sources of waves that are generated in phase. These periodic waves will then interfere constructively to produce antinodes and destructively to produce nodes. This is Young's Experiment.

13. Reflection and Refraction of Light Waves (Explanation by Huygens' Principle)
    a. This animation shows the refraction and reflection of waves according to Huygen's Principle.
    b. The animation is initially set for an index of refraction n = 1.00 in the incident (top) medium and n = 2.00 in the refracted (bottom) medium. You can change these values for n.
    c. There is a window that briefly describes what is happening in the animation.
    d. There are 5 steps to the animation.
    e. Step 1 shows a straight wave front traveling from the upper left corner towards the lower right corner. Remember the direction of motion of the wave front is the wave ray which is perpendicular to the wave front.
    f. Step 2 shows the wave front approaching the boundary between the two media. Along the boundary are found point sources for the wave. The reflected wave fronts move back up into the first medium. The refracted wave fronts move into the bottom or refracted medium.
    g. Step 3 repeats step 2 but adds the wave fronts for the incident wave, the reflected wave and the refracted wave.
    h. Step 4 adds the wave ray to each wave front (incident wave front, reflected wave front, and refracted wave front). The angles of incidence, reflection and refraction as also drawn where the respective wave rays meet at the boundary.
    i. Step 5 illustrates a series of wave fronts undergoing reflection and refraction according to Huygen's principle.
    j. This animation solves one of the shortcomings of the Corpuscular Theory of Light, mainly that there is partial transmission and partial reflection of light from a surface. Waves are able to partially transmit and partially reflect from a surface.
14. Light Is Waves: Crash Course Physics #39
15. The Double Slit Experiment: Light As A Wave
16. Young's double slit introduction | Light waves | Physics | Khan Academy
    a. This is a nice introduction to the classic Young's Experiment.

b. Light wave fronts from a source are allowed to fall unto a barrier with two very narrow slits placed very close to each other. The light is monochromatic. Two different parts of a given wave front will pass through the openings. Since the same part of the wave front, say the crest, reaches each of the slits at the same time the slits will now act as two point sources that are in phase. The circular waves generated by the two point sources form an interference pattern when the light is projected unto a screen.
c. This interference pattern will be like two point sources generating waves in phase in a ripple tank.

17. Young's Double Slit
    a. This interactive animation illustrates Young's Experiment.
    b. Light is shone unto a screen with 2 slits. The interference pattern is projected unto a second screen.
    c. By moving the slider on the Distance Between Slits bar you can adjust the distance between the slits (d) and view the effect on the spacing of the lines (Δx) in the pattern on the second screen. When done, move the slider completely to the left.
    d. By moving the slider on the Slit Screen Distance bar you can adjust the distance of the first screen with the slits to the second screen (L). Increase and then decrease the distance between the first and second screens and view the effect on the spacing of the lines (Δx) in the interference pattern. When done, move the slider completely to the left.
    e. By moving the slider on the Wavelength bar you change the wavelength (λ) and color of the light. Increase and then decrease the wavelength and view the effect of the change in wavelength on the spacing of the lines (Δx) in the pattern seen on the second screen.
18. Young's Experiment Physics Classroom
    a. Click on Launch Interactive.
    b. In this interactive the goal is to calculate the wavelength of the red, green and blue laser light shining on the double slits using the equation for Young's Experiment.
    c. Open the interactive in full screen by clicking on the icon in the upper left hand corner.
    d. Choose a value for the slit width, d, and the distance to the screen (L). Choose a wavelength
    e. On the pattern of equally spaced dark and bright lines select two dark lines and using the scale beneath these lines record the position of each dark line. Determine the distance (y) in metres between the positions of the 2 chosen dark lines. Count the number of spaces, n, between the two dark lines selected. Each of the spaces corresponds to a bright line in the pattern.
    f. Then determine the spacing of the adjacent dark lines (Δx) using the relationship
    g. (Δx) = y/n.
    h. Repeat the measurement of (Δx) twice more using a different number of spaces.

i. Finally using the average value of (Δx) determine the value of the wavelength, λ, using
j. $\lambda/d = \Delta x/L$.
k. Determine the wavelength of the red, green and blue light.

19. Wave-Particle Duality and the Photoelectric Effect
    a. This video introduces the photoelectric effect.
    b. Electromagnetic radiation contains radiation of many different frequencies. Radio waves have a low frequency and carry relatively little energy. Gamma rays have very high frequencies and carry a relatively great amount of energy. Visible light has frequencies and energies between radio waves and gamma rays.
    c. The photoelectric effect occurs when electromagnetic radiation, such as visible light, of a given frequency, called the threshold frequency, falls on the surface of a metal, an electron is ejected from the metal. Light below this threshold frequency could not eject electrons. Light above that threshold frequency for the metal could eject electrons from the metal's surface. This phenomenon could not be explained using the wave model of light.
    d. A new theory was postulated. To explain this new effect the theory of light was amended to account for the photoelectric effect. This new theory said that light consisted of photons, tiny particles of light.
    e. In the end the theory of light was changed to reflect the fact light had wave properties and it had particle properties. The new theory of light is called the Wave-Particle Duality.
20. The Photoelectric Effect: Light As A Particle
    a. The video outlines the discovery of the photoelectric effect and the reasoning that lead to the conclusion that light has a particle nature as well as a wave nature.
    b. The video illustrates the apparatus that was used in the experiment and the events that occur during the effect. Tossing fruits and vegetables (photons of light of different frequencies) at a watermelon (an electron stuck in a metal) is used to illustrate why only light with a frequency above the threshold frequency possesses enough energy to eject electrons from the surface.
    c. In addition the video shows that if the light has a frequency above the threshold frequency and thus can eject electrons, increasing the intensity of the light (more photons per second) will result in more electrons being ejected from the surface of the metal. If more electrons are ejected per second this will increase the current moving toward the positive terminal across the gap.
    d. Once more the photoelectric effect proves that light (electromagnetic radiation) has a particle nature. Light can be thought of as consisting of particles called photons.
    e. The new theory of light that emerged is called the Wave-Particle Duality of Light.
21. Quantum Theory Made Easy [1]
    a. This video deals with the work of many famous physicists around the year 1900.
    b. Starting at around 14:00 the video presents the photoelectric effect which demonstrates that there is a minimum energy required by light to eject electrons from the surface of the metal. Electrons are ejected instantly as soon as the light

is shone on the metal. Electrons are ejected only if the frequency of the light is high enough and the light has enough energy (threshold energy) to do the work of ejecting the electron from the metal. The brightness of the light for a frequency below the threshold level does not enable light with a frequency below the threshold level to eject electrons.

c. Aside from the photoelectric effect, there are many equations and concepts presented in this video that are beyond the scope of this course.
d. Then why watch this video? The best reason is that this video presents a history of a series of discoveries which illustrate how science works. These discoveries showed that the current theory of light at that time (light is a wave) could not explain certain observations. These new observations were more consistent with the behavior of particles (light is a particle).
e. According to the way science works, a new theory should be able to explain all the old observations and also include the new observations. So the particle theory of light if it was correct should be able to explain old observations (interference, diffraction, dispersion and partial reflection and refraction) and the new observations of the photoelectric effect and the quantum theory.
f. The wave theory could explain interference, diffraction, dispersion and partial reflection and refraction but it could not explain the photoelectric effect.
g. So which theory is correct? The only way to reconcile the observations was the light had both wave properties and particle properties. Science itself had to adapt its ways in order to explain the observations for the behavior of light.
h. At 28:34 there is a graphic that depicts the 3 aspects of the wave-particle duality of light. Light can act like waves or light can act like a particle and a wave or light can act like a particle.
i. The second reason to watch the video is to pique your interest. According to the macroscopic everyday world we live in, the world of quantum physics is a somewhat weird place where crazy events occur. So sit back and enjoy.

Grade 11 Physics (30S)

Final Practice Exam

Grade 11 Physics (30S)

Final Practice Exam

Instructions

The final exam will be weighted as follows:

Modules 1–6	15–20%
Modules 7–10	80–85%

The format of the examination will be as follows:

Part A: Multiple Choice	40 x 1 = 40 marks
Part B: Short Explanations	5 x 3 = 15 marks
Part C: Diagrams	15 marks
Part D: Problems	1 x 6 = 6 marks
Part E: Problems	4 x 6 = 24 marks

The following instructions are meant to assist you when you are writing your final examination.

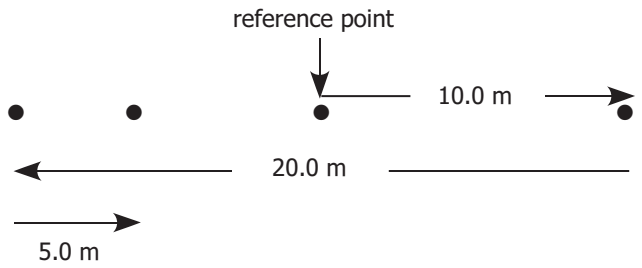
- Show your work for the problems.
- Include directions with all vector answers.
- Round off answers to the correct number of significant digits.

Part A: Multiple Choice (40 x 1 = 40 Marks)

Circle the letter of the choice that best completes each statement.

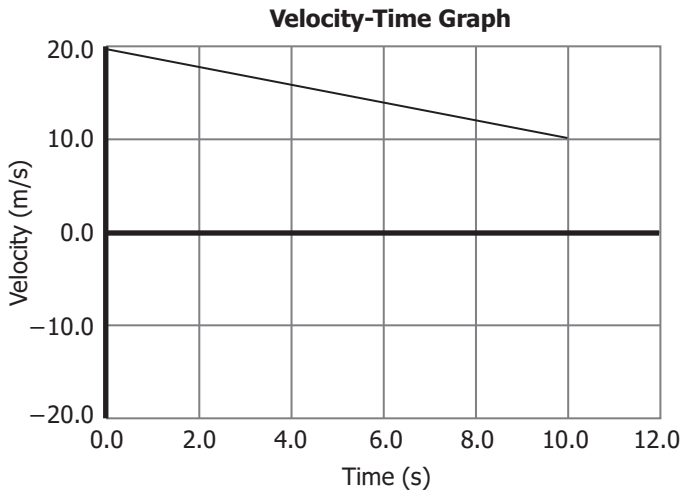
1. Those two quantities that are vectors are
   a) acceleration and electric charge
   b) mass and gravitational field
   c) force and velocity
   d) speed and time interval

2. An object moves to the right 10.0 m from the starting point in a time of 1.0 s, then to the left 20.0 m in a time of 3.0 s, and then to the right 5.0 m in a time of 1.0 s. The diagram below represents this motion.



   The average speed of the object over the whole time interval is best written as
   a) –1.2 m/s
   b) 0.8 m/s
   c) 1.2 m/s
   d) 7.0 m/s

3. The graph below is a velocity-time graph for the motion of an object.



The acceleration of this object is

a) –2.0 m/s^2

b) –1.0 m/s^2

c) +1.0 m/s^2

a) +2.0 m/s^2

4. If an object is already moving and the sum of all the vector forces on a mass is zero, then the object will

a) move at a constant speed in a straight line

b) accelerate at a constant rate in a straight line

c) come to rest

d) increase its amount of inertia

5. Two forces are acting on a 5.00 kg mass. One of the forces is 10.0 N south and the other is 15.0 N east. The magnitude of the acceleration of the mass is

a) 3.60 m/s^2

b) 5.00 m/s^2

c) 18.0 m/s^2

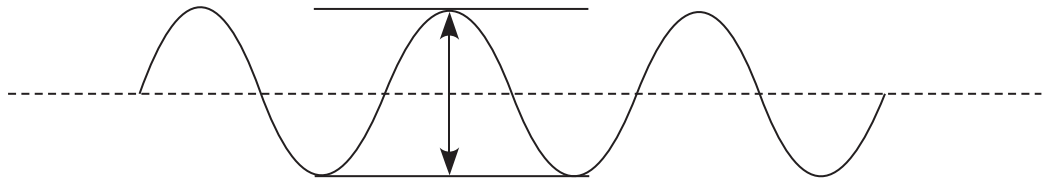
d) 25.0 m/s^2

6. The factors, both of which will increase the magnetic field strength of an electromagnet, are
   a) increased electrical current and fewer coils of wire
   b) increased diameter of coil and an increase in the number of coils
   c) an increase in the electrical current and using a strong ferromagnetic material like iron
   d) using an air core instead of iron and increasing the diameter of the coil

7. On Mars, the gravitational field strength is 3.7 N/kg. An object has a weight of 98 N on the earth. The weight of this object on Mars is
   a) 1.0×10^1 N
   b) 37 N
   c) 98 N
   d) 360 N

8. A 5.0 kg mass is placed in an elevator that is accelerating upwards at 4.0 m/s^2. The apparent weight of this mass is
   a) 20. N
   b) 29 N
   c) 49 N
   d) 69 N

9. The diagram below shows a wave. The arrow is showing the distance from the top of the wave to the bottom of the wave.



   This arrow represents
   a) the amplitude
   b) twice the amplitude
   c) the wavelength
   d) twice the wavelength

10. A 50.0 kg crate rests on the floor of a warehouse. The coefficient of static friction is 0.750 and the coefficient of kinetic friction is 0.450. We want to determine the horizontal force (to the right) required just to start the crate moving. The horizontal force (to the right) required to just get the crate moving along the floor is
    a) 22.5 N
    b) 37.5 N
    c) 221 N
    d) 368 N

11. The magnetic field is
    a) strongest near a pole and the direction at any point in space is tangent to the field line
    b) strongest far from a pole and the direction at any point in space is tangent to the field line
    c) strongest near a pole and the direction at any point in space is perpendicular to the field line
    d) strongest far from a pole and the direction at any point in space is perpendicular to the field line

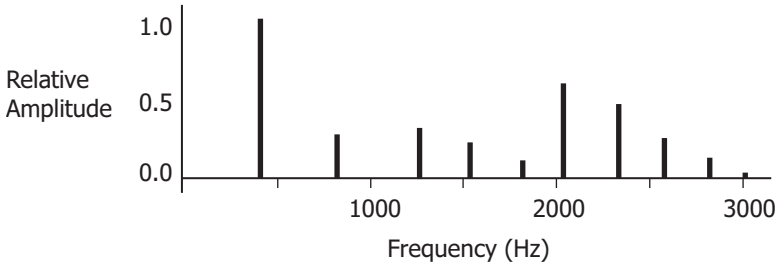
12. A standing wave is formed by waves of frequency 256 Hz. The speed of the waves is 128 m/s. The distance between the nodes must be
    a) 2.00 m
    b) 1.00 m
    c) 0.500 m
    d) 0.250 m

13. Consider the direction in which the magnetic field lines point for a bar magnet with a north pole and a south pole. That situation that would give the same pattern of lines is the
    a) gravitational field line pattern for two neutral masses
    b) electric field line pattern for two positive charges
    c) electric field line pattern for two negative charges
    d) electric field line pattern for two opposite charges

14. When a wave moves from shallow water to deep water, the
    a) frequency decreases, the wavelength increases, and the speed increases
    b) frequency does not change, the wavelength increases, and the speed increases
    c) frequency does not change, the wavelength decreases, and the speed decreases
    d) frequency does not change, the wavelength increases, and the speed decreases

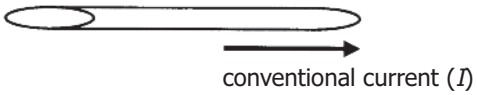
15. The definition of magnetic inclination is the angle between
    a) magnetic north and geographic north
    b) magnetic north and geographic south
    c) the earth's magnetic field at any point and the vertical
    d) the earth's magnetic field at any point and the horizontal

16. The following is a sound spectrum created by an instrument playing a certain note.



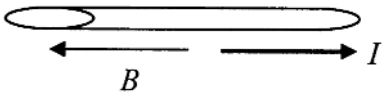
If another instrument were to play the same note, then
    a) the fundamental frequency would be the same, and the number and relative intensity of the harmonics would also be the same
    b) the fundamental frequency would be the same, but the number and relative intensity of the harmonics would be different
    c) the fundamental frequency would be different, but the number and relative intensity of the harmonics would also be the same
    d) the fundamental frequency would be different, and the number and relative intensity of the harmonics would also be different

17. The diagram below shows an electrical current flowing through a straight conductor. The dark arrow shows the electrical current moving to the right. The symbol (*I*) will be used to represent the electric current.

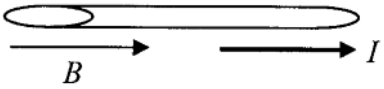


The symbol B will be used to represent the magnetic field. The diagram that shows the direction of the magnetic field produced by the current-carrying wire is

a)



b)



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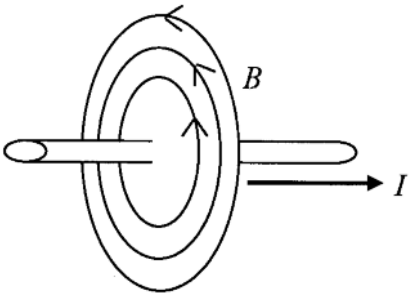

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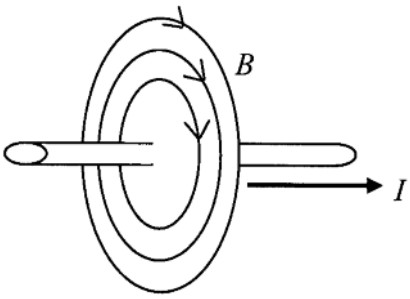


18. A 15,000 Hz sound wave and a 5,000 Hz sound wave approach a small hole in a wall. The degree of "bending" as the waves move through the hole
    a) depends on the speed of the wave
    b) is the same for both waves
    c) is greater for the 5,000 Hz wave
    d) is greater for the 15,000 Hz wave

19. The frequency of middle C is 256 Hz. The frequency of a C note two octaves below middle C is
    a) 64 Hz
    b) 128 Hz
    c) 252 Hz
    d) 254 Hz

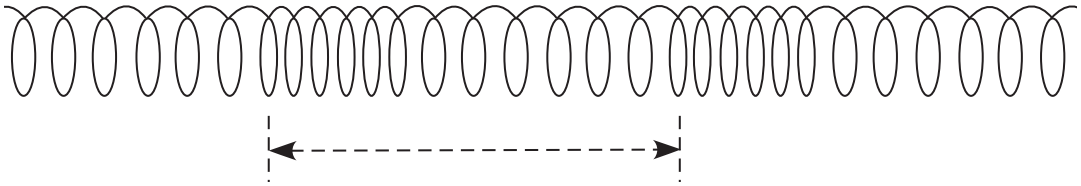
20. An air column that is solid at one end is used to determine the speed of sound. The frequency of an E note tuning fork is 329.6 Hz. The length of the shortest air column producing the resonance is 25.0 cm. The speed of the sound must be
    a) 20.6 m/s
    b) 82.4 m/s
    c) 3.30×10^2 m/s
    d) 3.30×10^4 m/s

21. A pulse on a spring is moving from the right to the left. There is a circle on the right edge of the pulse.

As the pulse moves to the left, the circle on the right edge of the pulse will move
    a) to the left
    b) to the right
    c) upwards
    d) downwards

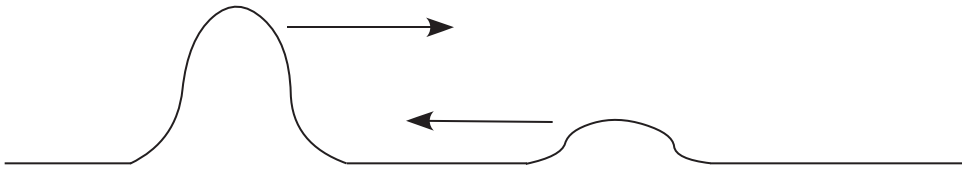
22. If the frequency of a "C" note in the musical scale is 262 Hz, then we can say that the
   a) period will be the inverse of the frequency and the speed of the wave will be changed
   b) period will be the inverse of the frequency and the speed of the wave will be constant
   c) period will be identical to the frequency and the speed of the wave will be changed
   d) period will be identical to the frequency and the speed of the wave will be constant

23. The diagram below shows a longitudinal wave.



The horizontal distance indicated with the double arrow shows
   a) one wavelength
   b) twice one wavelength
   c) one amplitude
   d) twice one amplitude

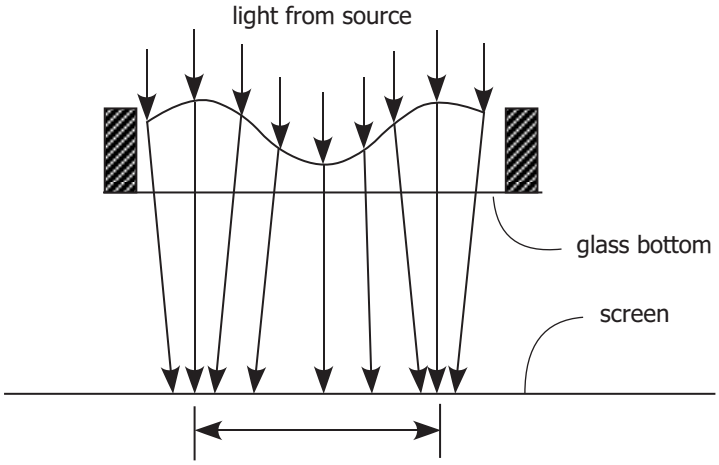
24. The two pulses shown below are about to pass through each other.



When the two pulses interfere with each other, the result is
   a) a standing wave pattern
   b) destructive interference
   c) constructive interference
   d) a constant nodal point

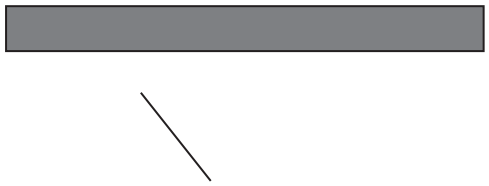
25. A string is plucked producing four loops (antinodes). The length of the string is 12.00 m. The wavelength of the wave must be
    a) 48.0 m
    b) 24.0 m
    c) 6.00 m
    d) 3.00 m

26. A ripple tank is shown below.

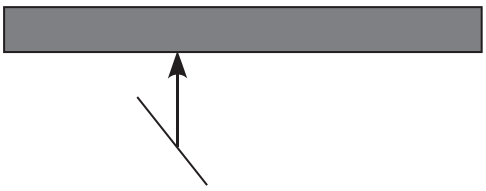


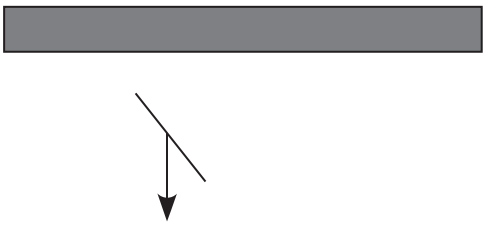
The double arrow at the bottom of the diagram indicates the distance between two
    a) dark spots and is equivalent to one-half a wavelength
    b) dark spots and is equivalent to one full wavelength
    c) bright spots and is equivalent to one-half a wavelength
    d) bright spots and is equivalent to one full wavelength

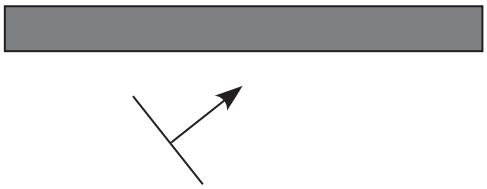
27. The diagram below shows an incident wavefront approaching a straight barrier.

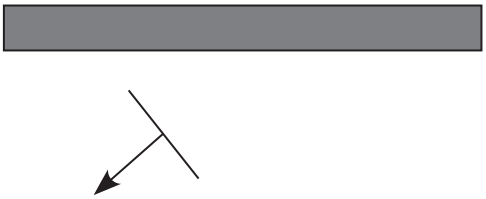


The diagram that shows the wave ray for the wavefront above is

a) 

b) 

c) 

d) 

28. A wave travels at a speed of 10.0 cm/s in shallow water. The wavelength of the wave in the shallow water is 2.0 cm. The speed of the wave in the deep water is 12.0 cm/s. The wavelength of the wave in deep water is

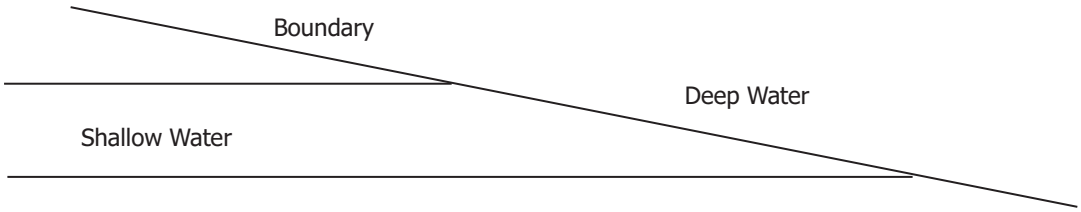
a) 0.42 cm

b) 0.60 cm

c) 1.7 cm

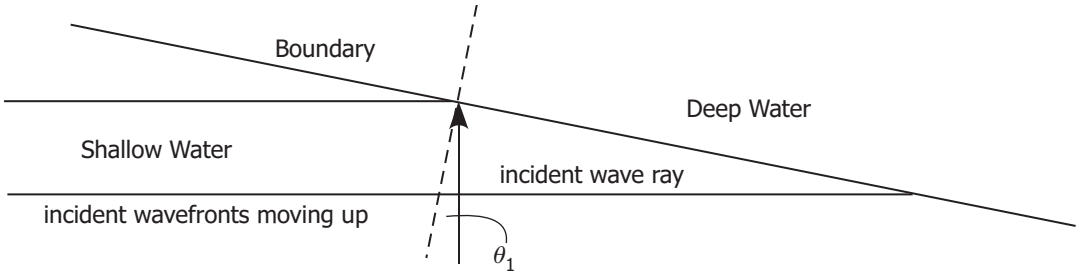
d) 2.4 cm

29. The diagram below shows waves moving from shallow water to deep water.

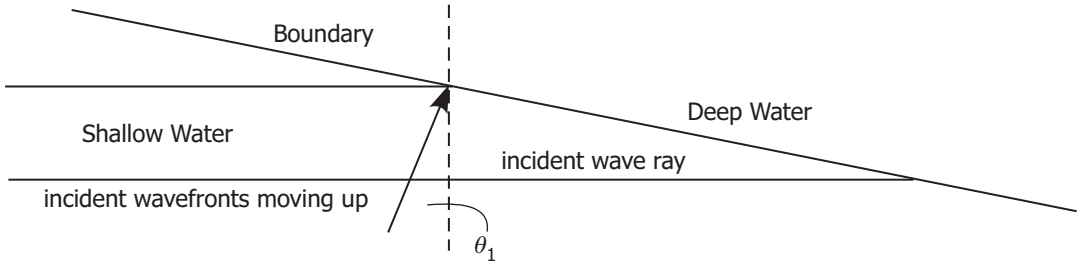


For each of the diagrams below, the dashed line represents a normal and the arrow represents the incident wave ray. The diagram showing the correct incident wave ray and angle of incidence for the incident wave ray is

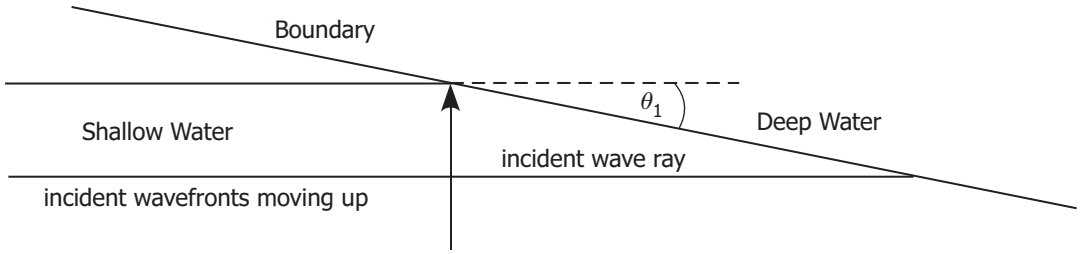
a)



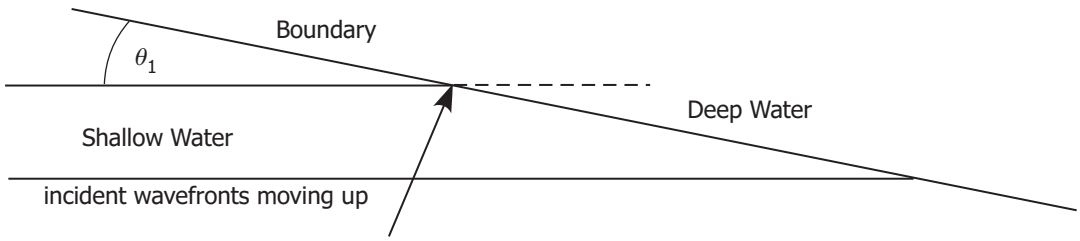
b)



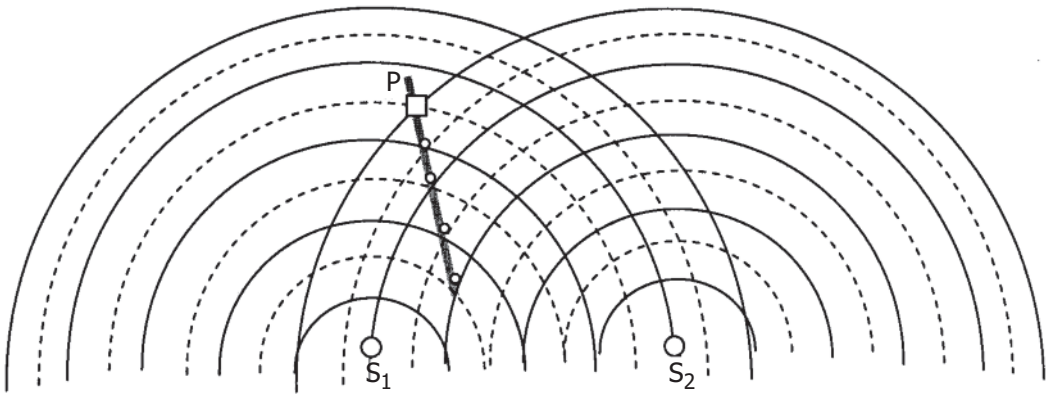
c)



d)



30. In the diagram below, the point P is found on the nodal line as shown below in the square. The distance PS_1 is 10.0 cm and the distance PS_2 is 13.0 cm. The distance between the sources is 8.0 cm.



The wavelength of the waves producing the interference pattern must be

a) 0.12 cm
b) 2.0 cm
c) 3.0 cm
d) 6.0 cm

31. In a sound wave that moves to the right, a vibrating tuning fork creates a rarefaction when the fork moves

a) to the right, creating a momentary fall in air pressure
b) to the left, creating a momentary fall in air pressure
c) to the right, creating a momentary rise in air pressure
d) to the left, creating a momentary rise in air pressure

32. The sound level in a room may be 50 dB. A sound that is twice as loud as a 50 dB sound is

a) 60 dB
b) 100 dB
c) 500 dB
d) 5000 dB

33. If the frequency of one source of sound is 500 Hz and a second sound source is 504 Hz, then when the two waves interfere with each other, the beat frequency will be
    a) 2 Hz
    b) 4 Hz
    c) 8 Hz
    d) 16 Hz

34. For a tube closed at one end, the length of the tube at a frequency of 256 Hz will be
    a) one-quarter the value for a tube open at both ends
    b) one-half the value for a tube open at both ends
    c) twice the value for a tube open at both ends
    d) four times the value for a tube open at both ends

35. The frequency of a G note is 384 Hz. Using the table below, the frequency of the B note must be

C	D	E	F	G	A	B	C′	D′
4	...	5	...	6				
			4	...	5	...	6	
				4	...	5	...	6

    a) 192 Hz
    b) 307 Hz
    c) 480 Hz
    d) 768 Hz

36. A good scientific theory is one which is
    a) simple (less complex), has a wide scope, and is accurate and consistent
    b) simple (less complex), narrow in scope, and is accurate and consistent
    c) more complex, has a wide scope, is accurate and consistent
    d) more complex, narrow in scope, consistent but not accurate

37. When we perform an experiment and form a mental picture without necessarily having a mathematical relationship, this way of representing the experiment can be described as
   a) visual
   b) symbolic
   c) numeric
   d) graphical

38. Those who proposed the idea that light has wave-like properties were
   a) Huygens and Newton
   b) Huygens and Planck
   c) Maxwell and Planck
   d) Maxwell and Huygens

39. At the time of Newton, many scientists tried to produce wave interference effects, but were not successful. The reason for this is that
   a) incandescent light sources are out of phase and the wavelength of light is very large
   b) incandescent light sources are out of phase and the wavelength is very small
   c) incandescent light sources are in phase and the wavelength of light is very large
   d) incandescent light sources are in phase and the wavelength of light is very small

40. If light moves from left to right along the x-axis, then the electric field line vibrates along
   a) the x-axis and the magnetic field also vibrates along the x-axis
   b) the x-axis and the magnetic field vibrates along the y-axis
   c) the y-axis and the magnetic field vibrates along the x-axis
   d) the y-axis and the magnetic field line vibrates along the z-axis

Part B: Short Explanations (5 x 3 = 15 Marks)

Answer any five (5) of the following questions. Be sure to indicate clearly which five questions are to be marked.

Outcome S3P-1-01

1. Distinguish between transverse waves and longitudinal waves.

Outcome S3P-4-23

2. Using the Domain Theory of Magnetism, explain the following.
   a) When placed in a strong magnetic field, a bar of iron becomes a bar magnet. When the field is removed, the piece of iron is no longer a bar magnet.

   b) Over a period of years, the steel girders in a building become magnetized.

Outcome S3P-1-21

3. Distinguish among fundamental frequency, overtone, and harmonic for a string of a guitar.

Outcome S3P-2-07

4. Using a diagram, explain how Newton's Corpuscular Theory explained refraction.

Outcome S3P-1-27

5. Distinguish between the pitch, the intensity, and the quality of sound produced by a musical instrument.

_____

_____

_____

_____

_____

Outcome S3P-1-05

6. A wave crest is travelling along a heavy medium. The wave crest encounters a junction between the heavy medium and a light medium. Using a sketch, describe the situation after the wave crest has passed through the junction.

   Here is a diagram of the situation before the crest hits the junction.

Outcome S3P-2-10, S3P-2-11

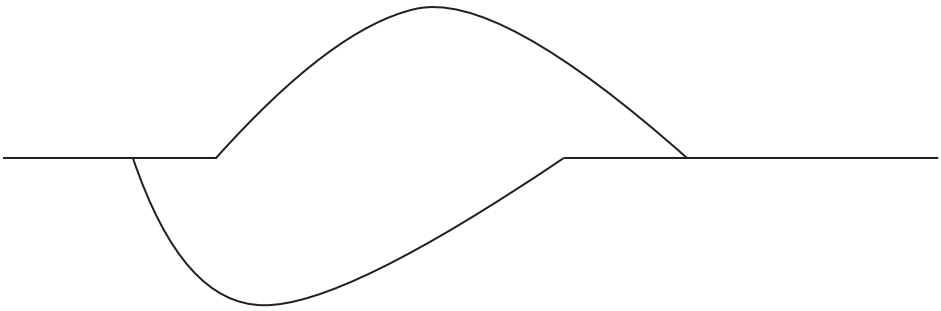
7. Describe two phenomena for the behaviour of light that are explained better using the wave model of light than the particle model of light.

Part C: Diagrams (15 Marks)

Show your work in the space provided.

Outcome S3P-1-06

1. Draw the resultant wave. *(4 marks)*



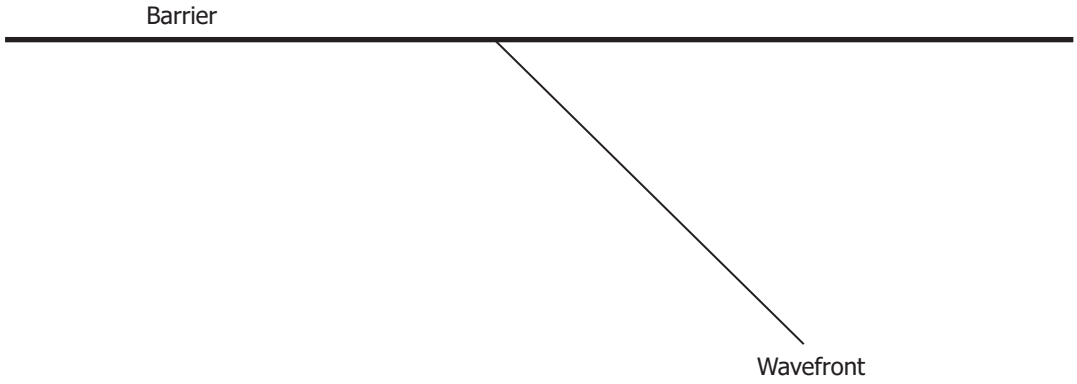
Point	Displacement to Top Wave (cm)	Displacement to Bottom Wave (cm)	Total Displacement (cm)

Outcome S3P-1-10

2. A point source on a ripple tank is located 3.5 cm from a straight barrier. Draw in, using a compass, the circular wave after it has travelled 5.0 cm. Locate the source of the reflected wavefront and draw in the reflected wavefront. Indicate the direction of travel of both the incident and reflected wavefronts. *(3 marks)*

Outcome S3P-1-10

3. The diagram below shows a wavefront travelling towards a straight barrier. Draw in and label the direction of motion, the angle of incidence, the reflected crest, its direction of motion, and the angle of reflection. *(3 marks)*



Outcome S3P-4-21

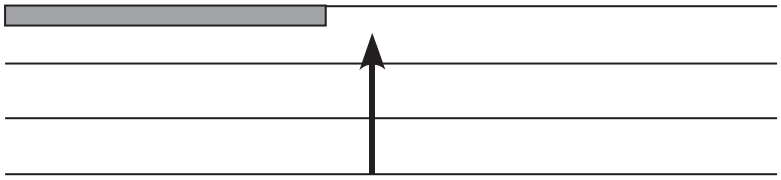
4. Draw the magnetic field around

   a) a wire carrying a current out of the page. *(1 mark)*

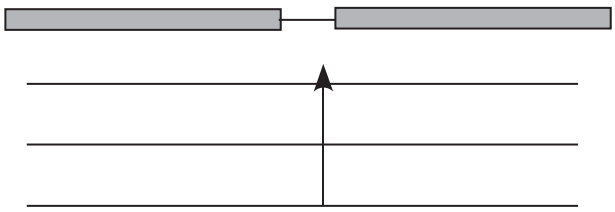
   b) two positive point charges. *(2 marks)*

Outcome S3P-1-14

5. Diagram the diffraction of waves in the following situations:
   a) at the edge of a straight barrier. *(1 mark)*



   b) through the opening in a straight barrier. *(1 mark)*



Part D: Problems (6 Marks)

Do only one question from Part D.

Outcome S3P-4-08

1. A baseball is popped straight upwards at 25.3 m/s. The acceleration of gravity is 9.80 m/s^2 downwards.

   a) Determine the highest point of the flight of the ball. *(3 marks)*

   b) For what length of time would the ball rise from the instant it left the bat? *(3 marks)*

2. A crate of mass 255 kg is pulled along a level floor. The crate rests on a dolly, which has a handle attached to it. The handle is pulled by a person exerting a force of 215 newtons at an angle of 42.0° from the horizontal, and the force of friction is 112 newtons.

Outcome S3P-0-2h

a) Determine the horizontal and vertical components of the applied force acting on the crate. *(2 marks)*

Outcome S3P-3-12

b) Draw a free-body diagram labelling clearly all of the forces acting on the dolly. *(2 marks)*

Outcome S3P-3-12, S3P-3-13

c) Determine the net force acting on the dolly and the acceleration of the dolly. *(2 marks)*

Part E: Problems (24 Marks)

Answer any four (4) problems. If more than four problems are done, the first four will be marked.

1. A 8.25 Hz water wave travels from deep water, where its speed is 42.0 cm/s, to shallow water where its speed is 31.5 cm/s. The angle of incidence is 30.0°. Find the following.

   Outcome S3P-1-04

   a) the wavelengths in the two media *(3 marks)*

Outcome S3P-2-12

b) the angle of refraction in the shallow water *(3 marks)*

2. Two point sources generate identical waves that interfere in a ripple tank. The sources are located 6.50 cm apart, and the frequency of the waves is 9.25 Hz. The waves travel at 12.6 cm/s.

Outcome S3P-1-04

a) What is the wavelength of the waves? *(2 marks)*

Outcome S3P-1-16

b) What is the path length difference to a point P on the third nodal line? *(1.5 marks)*

Outcome S3P-1-16

c) What would happen to the spacing of the nodal lines in the interference pattern if only the distance between the sources was increased? *(1.5 marks)*

Outcome S3P-1-16

d) What would happen to the number of nodal lines in the interference pattern if only the frequency of the waves was increased? *(1 mark)*

3. An air column closed at one end resonates at the second maximum or the second resonant length. The frequency of the sound wave is 1024 Hz. The air temperature is 18.6°C.

Outcome S3P-1-21

a) Draw a diagram of the displacement wave pattern inside the column. *(1 mark)*

Outcome S3P-1-23

b) Calculate the speed of sound in air. *(2 marks)*

Outcome S3P-1-04

c) Calculate the wavelength. *(1.5 marks)*

Outcome S3P-1-21

d) Calculate the length of the closed air column. *(1.5 marks)*

4. In a standing wave pattern on a spring, the distance between the third and seventh nodes is 1.52 m. The source generates 25 crests and 25 troughs in 5.40 seconds.

Outcome S3P-1-03

a) What is the frequency? *(1.5 marks)*

Outcome S3P-1-05

b) What is the wavelength? *(2 marks)*

Outcome S3P-1-04

c) What is the speed of these waves? *(1.5 marks)*

Outcome S3P-1-28

d) What would be the frequency of the wave one octave above the given wave? *(1 mark)*

5. In a Young's Experiment measurement, light of wavelength 5.25×10^{-7} m passed through 2 slits 2.78×10^{-5} m apart.

Outcome S3P-2-14

a) At a distance of 2.75 m, what would be the spacing of the adjacent nodal lines in this pattern? *(3 marks)*

Outcome S3P-2-13

b) What is the spacing of adjacent nodal lines if only light of wavelength 6.75×10^{-7} m was used instead of 5.25×10^{-7} m? *(1.5 marks)*

Outcome S3P-2-13

c) What is the spacing of adjacent nodal lines if only the spacing of the two slits is changed to 3.50×10^{-5} m? *(1.5 marks)*

Outcome S3P-2-14

6. Two slits have green light of wavelength 5.25×10^{-7} m passing through them. The interference pattern is observed at a distance of 1.75 m. The distance from the first dark line to the ninth dark line is 10.2 cm.

   a) What is the spacing of the nodal lines? *(2 marks)*

   b) What is the separation of the slits? *(3 marks)*

c) Should light of a larger or smaller wavelength be used in this situation to produce a pattern of lines that is spaced closer together? Explain why. *(1 mark)*

NOTES

Grade 11 Physics
Formula Sheet

Mathematics

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\text{hypotenuse}^2 = (\text{Leg 1})^2 + (\text{Leg 2})^2$$

Kinematics

$$v = \frac{d}{\Delta t}$$

$$\Delta = \text{second value} - \text{first value}$$

$$\vec{d} = \text{pos}_2 - \text{pos}_1$$

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{\text{pos}_2 - \text{pos}_1}{\Delta t}$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ or } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

Waves

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{1-2}$$

$$PLD = |PS_1 - PS_2| = \left(n - \frac{1}{2}\right)\lambda$$

$$f = \frac{1}{T}$$

$$T = \frac{1}{f}$$

$$v = f\lambda$$

Light

$$\text{PLD} = |\text{PS}_1 - \text{PS}_2|$$

$$\frac{\Delta x}{L} = \frac{\lambda}{d}$$

Sound

$$v = 332 + 0.6\ \text{T}$$

Closed-pipe resonant length

$$L_n = \left(\frac{(2n-1)}{4}\right)\lambda$$

Open-pipe resonant length

$$L_n = \left(\frac{n}{2}\right)\lambda$$

$$f_B = |f_2 - f_1|$$

Dynamics

$$\vec{F}_{\text{NET}} = m\vec{a}$$

$$\vec{F}_{\text{NET}} = \sum \text{Forces}$$

$$F_F = \mu F_N$$

Gravity

$$\vec{F}_g = m\vec{g}$$

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$

Electricity

$$\vec{E} = \frac{\vec{F}_E}{q}$$

$$q = \text{N}e$$

$$E = \frac{V}{d}$$

Magnetism

$$\vec{F}_B = BIL\sin\theta$$

Grade 11 Physics (30S)

Final Practice Exam

Answer Key

Grade 11 Physics (30S)

Final Practice Exam
Answer Key

Instructions

The final exam will be weighted as follows:

Modules 1–6	15–20%
Modules 7–10	80–85%

The format of the examination will be as follows:

Part A: Multiple Choice	40 x 1 = 40 marks
Part B: Short Explanations	5 x 3 = 15 marks
Part C: Diagrams	15 marks
Part D: Problems	1 x 6 = 6 marks
Part E: Problems	4 x 6 = 24 marks

The following instructions are meant to assist you when you are writing your final examination.

- Show your work for the problems.
- Include directions with all vector answers.
- Round off answers to the correct number of significant digits.

Part A: Multiple Choice (40 x 1 = 40 Marks)

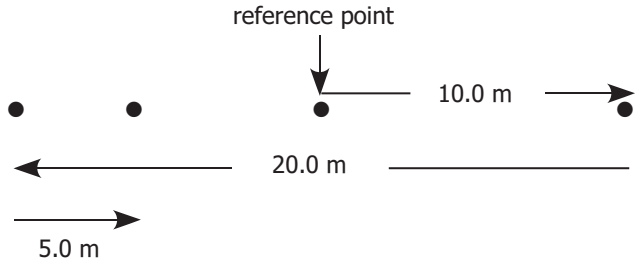
Circle the letter of the choice that best completes each statement.

1. Those two quantities that are vectors are
   a) acceleration and electric charge
   b) mass and gravitational field
   c) force and velocity
   d) speed and time interval

   Answer (c)

   Outcome S3P-3-01, S3P-4-19, S3P-4-01, S3P-4-03, S3P-4-04, S3P-3-03

2. An object moves to the right 10.0 m from the starting point in a time of 1.0 s, then to the left 20.0 m in a time of 3.0 s, and then to the right 5.0 m in a time of 1.0 s. The diagram below represents this motion.

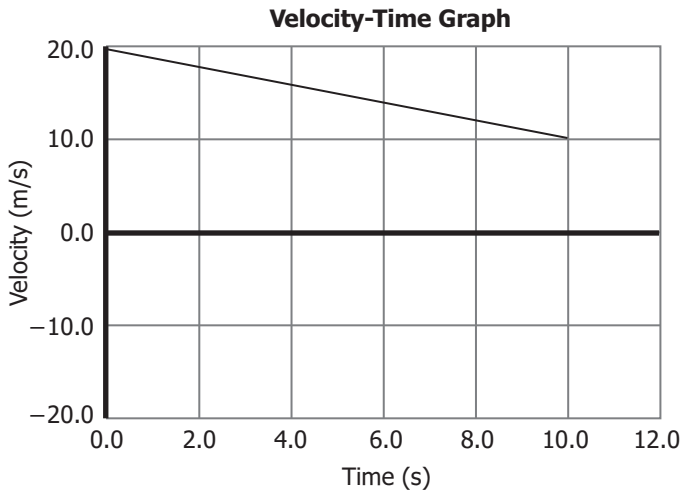


   The average speed of the object over the whole time interval is best written as
   a) –1.2 m/s
   b) 0.8 m/s
   c) 1.2 m/s
   d) 7.0 m/s

   Answer (d)

   Outcome S3P-3-01

3. The graph below is a velocity-time graph for the motion of an object.



The acceleration of this object is

a) –2.0 m/s^2
b) –1.0 m/s^2
c) +1.0 m/s^2
a) +2.0 m/s^2

Answer (b)
Outcome S3P-3-04

4. If an object is already moving and the sum of all the vector forces on a mass is zero, then the object will

a) move at a constant speed in a straight line
b) accelerate at a constant rate in a straight line
c) come to rest
d) increase its amount of inertia

Answer (a)
Outcome S3P-3-11

5. Two forces are acting on a 5.00 kg mass. One of the forces is 10.0 N south and the other is 15.0 N east. The magnitude of the acceleration of the mass is

a) 3.60 m/s^2
b) 5.00 m/s^2
c) 18.0 m/s^2
d) 25.0 m/s^2

Answer (a)
Outcome S3P.3.11

6. The factors, both of which will increase the magnetic field strength of an electromagnet, are
   a) increased electrical current and fewer coils of wire
   b) increased diameter of coil and an increase in the number of coils
   c) an increase in the electrical current and using a strong ferromagnetic material such as iron
   d) using an air core instead of iron and increasing the diameter of the coil

Answer (c)

Outcome S3P-4-24

7. On Mars, the gravitational field strength is 3.7 N/kg. An object has a weight of 98 N on the earth. The weight of this object on Mars is
   a) 1.0×10^1 N
   b) 37 N
   c) 98 N
   d) 360 N

Answer (b)

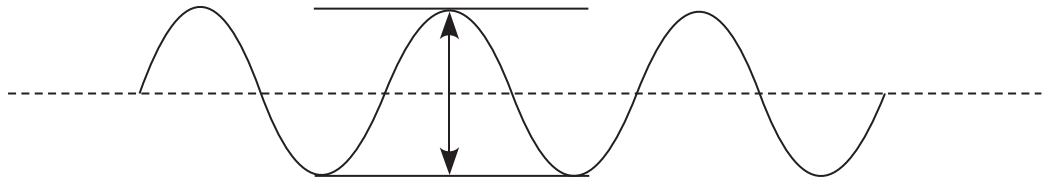
Outcome S3P-4-04

8. A 5.0 kg mass is placed in an elevator that is accelerating upwards at 4.0 m/s^2. The apparent weight of this mass is
   a) 20. N
   b) 29 N
   c) 49 N
   d) 69 N

Answer (d)

Outcome S3P-4-05

9. The diagram below shows a wave. The arrow is showing the distance from the top of the wave to the bottom of the wave.



   This arrow represents
   a) the amplitude
   b) twice the amplitude
   c) the wavelength
   d) twice the wavelength

Answer (b)

Outcome S3P-1-02

10. A 50.0 kg crate rests on the floor of a warehouse. The coefficient of static friction is 0.750 and the coefficient of kinetic friction is 0.450. We want to determine the horizontal force (to the right) required just to start the crate moving. The horizontal force (to the right) required to just get the crate moving along the floor is

a) 22.5 N

b) 37.5 N

c) 221 N

d) 368 N

Answer (d)

Outcome S3P-4-11, S3P-4-13

11. The magnetic field is

a) strongest near a pole and the direction at any point in space is tangent to the field line

b) strongest far from a pole and the direction at any point in space is tangent to the field line

c) strongest near a pole and the direction at any point in space is perpendicular to the field line

d) strongest far from a pole and the direction at any point in space is perpendicular to the field line

Answer (a)

Outcome S3P-4-17

12. A standing wave is formed by waves of frequency 256 Hz. The speed of the waves is 128 m/s. The distance between the nodes must be

a) 2.00 m

b) 1.00 m

c) 0.500 m

d) 0.250 m

Answer (d)

Outcome S3P-1-06

13. Consider the direction in which the magnetic field lines point for a bar magnet with a north pole and a south pole. That situation that would give the same pattern of lines is the

a) gravitational field line pattern for two neutral masses

b) electric field line pattern for two positive charges

c) electric field line pattern for two negative charges

d) electric field line pattern for two opposite charges

Answer (d)

Outcome S3P-4-17

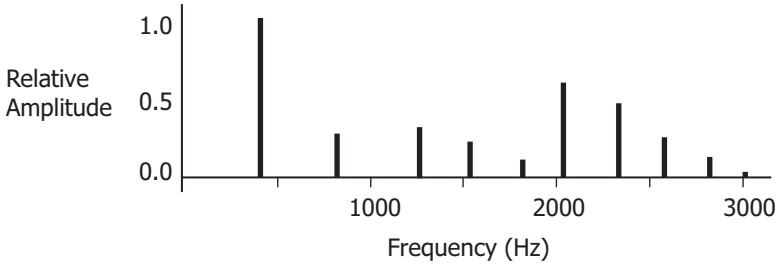
14. When a wave moves from shallow water to deep water, the
   a) frequency decreases, the wavelength increases, and the speed increases
   b) frequency does not change, the wavelength increases, and the speed increases
   c) frequency does not change, the wavelength decreases, and the speed decreases
   d) frequency does not change, the wavelength increases, and the speed decreases

Answer (b)
Outcome S3P-1-11

15. The definition of magnetic inclination is the angle between
   a) magnetic north and geographic north
   b) magnetic north and geographic south
   c) the earth's magnetic field at any point and the vertical
   d) the earth's magnetic field at any point and the horizontal

Answer (d)
Outcome S3P.4.20

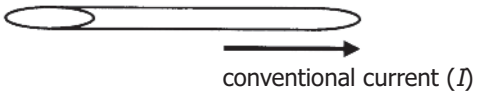
16. The following is a sound spectrum created by an instrument playing a certain note.



If another instrument were to play the same note, then
   a) the fundamental frequency would be the same, and the number and relative intensity of the harmonics would also be the same
   b) the fundamental frequency would be the same, but the number and relative intensity of the harmonics would be different
   c) the fundamental frequency would be different, but the number and relative intensity of the harmonics would also be the same
   d) the fundamental frequency would be different, and the number and relative intensity of the harmonics would also be different

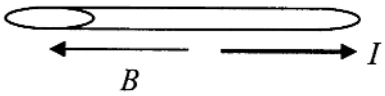
Answer (b)
Outcome S3P-1-17, S3P-1-27

17. The diagram below shows an electrical current flowing through a straight conductor. The dark arrow shows the electrical current moving to the right. The symbol (*I*) will be used to represent the electric current.

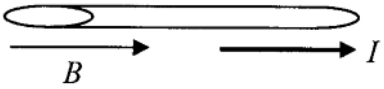


The symbol B will be used to represent the magnetic field. The diagram that shows the direction of the magnetic field produced by the current-carrying wire is

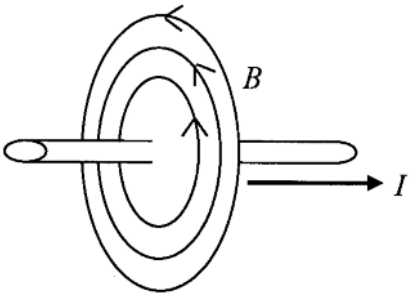
a)



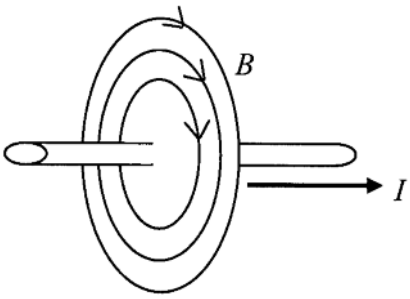
b)



c)



d)



Answer (d)

Outcome S3P-4-22

18. A 15,000 Hz sound wave and a 5,000 Hz sound wave approach a small hole in a wall. The degree of "bending" as the waves move through the hole

a) depends on the speed of the wave

b) is the same for both waves

c) is greater for the 5,000 Hz wave **Answer (c)**

d) is greater for the 15,000 Hz wave Outcome S3P-1-14

19. The frequency of middle C is 256 Hz. The frequency of a C note two octaves below middle C is

a) 64 Hz

b) 128 Hz

c) 252 Hz **Answer (a)**

d) 254 Hz Outcome S3P-1-28

20. An air column that is solid at one end is used to determine the speed of sound. The frequency of an E note tuning fork is 329.6 Hz. The length of the shortest air column producing the resonance is 25.0 cm. The speed of the sound must be

a) 20.6 m/s

b) 82.4 m/s

c) 3.30×10^2 m/s **Answer (c)**

d) 3.30×10^4 m/s Outcome S3P-1-22

21. A pulse on a spring is moving from the right to the left. There is a circle on the right edge of the pulse.

As the pulse moves to the left, the circle on the right edge of the pulse will move

a) to the left

b) to the right

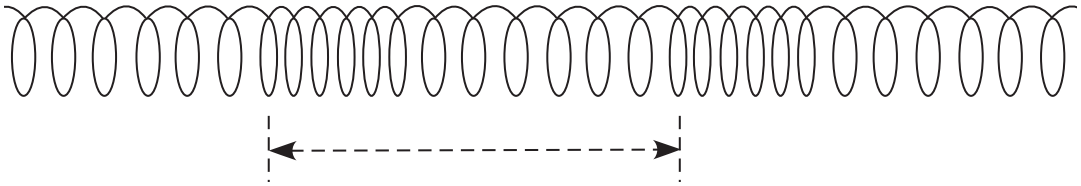
c) upwards **Answer (d)**

d) downwards Outcome S3P-1-01

22. If the frequency of a "C" note in the musical scale is 262 Hz, then we can say that the
   a) period will be the inverse of the frequency and the speed of the wave will be changed
   b) period will be the inverse of the frequency and the speed of the wave will be constant
   c) period will be identical to the frequency and the speed of the wave will be changed
   d) period will be identical to the frequency and the speed of the wave will be constant

Answer (b)
Outcome S3P-1-03

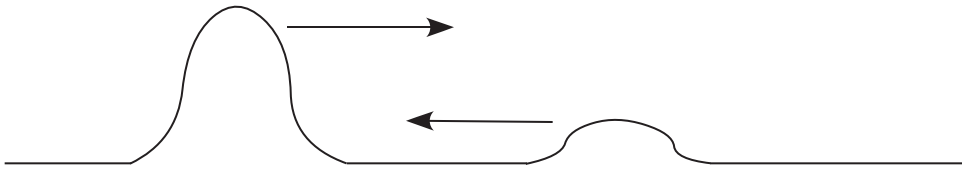
23. The diagram below shows a longitudinal wave.



The horizontal distance indicated with the double arrow shows
   a) one wavelength
   b) twice one wavelength
   c) one amplitude
   d) twice one amplitude

Answer (a)
Outcome S3P-1-02

24. The two pulses shown below are about to pass through each other.



When the two pulses interfere with each other, the result is
   a) a standing wave pattern
   b) destructive interference
   c) constructive interference
   d) a constant nodal point

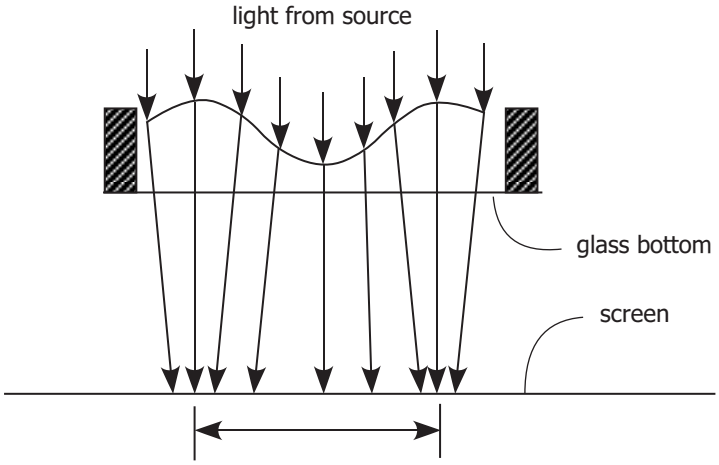
Answer (c)
Outcome S3P-1-06

25. A string is plucked producing four loops (antinodes). The length of the string is 12.00 m. The wavelength of the wave must be

a) 48.0 m
b) 24.0 m
c) 6.00 m
d) 3.00 m

Answer (c)
Outcome S3P-1-06

26. A ripple tank is shown below.

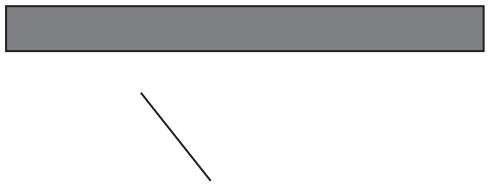


The double arrow at the bottom of the diagram indicates the distance between two

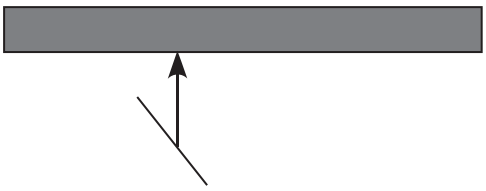
a) dark spots and is equivalent to one-half a wavelength
b) dark spots and is equivalent to one full wavelength
c) bright spots and is equivalent to one-half a wavelength
d) bright spots and is equivalent to one full wavelength

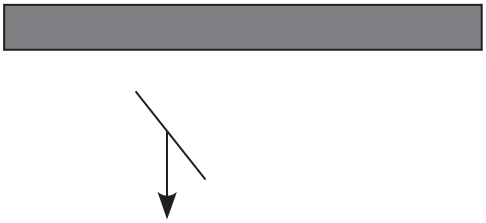
Answer (d)
Outcome S3P-1-08

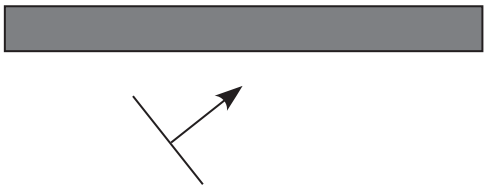
27. The diagram below shows an incident wavefront approaching a straight barrier.

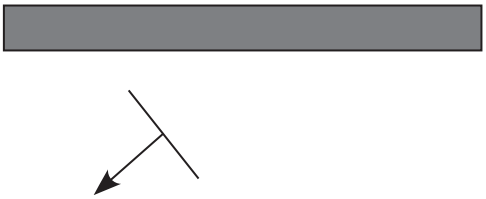


The diagram that shows the wave ray for the wavefront above is

a) 

b) 

c) 

d) 

Answer (c)

Outcome S3P-1-10

28. A wave travels at a speed of 10.0 cm/s in shallow water. The wavelength of the wave in the shallow water is 2.0 cm. The speed of the wave in the deep water is 12.0 cm/s. The wavelength of the wave in deep water is

a) 0.42 cm

b) 0.60 cm

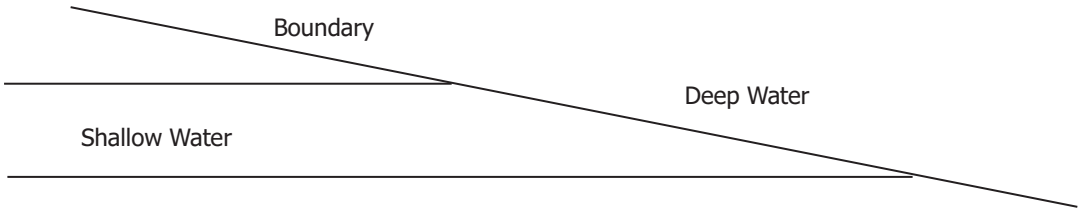
c) 1.7 cm

d) 2.4 cm

Answer (d)

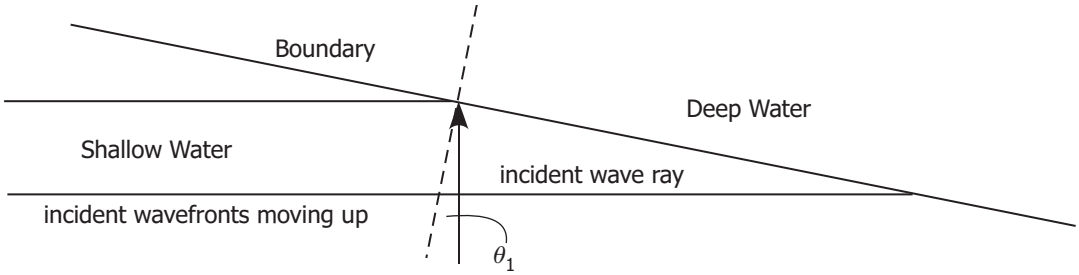
Outcome S3P-1-11, S3P-1-12, S3P-1-13

29. The diagram below shows waves moving from shallow water to deep water.

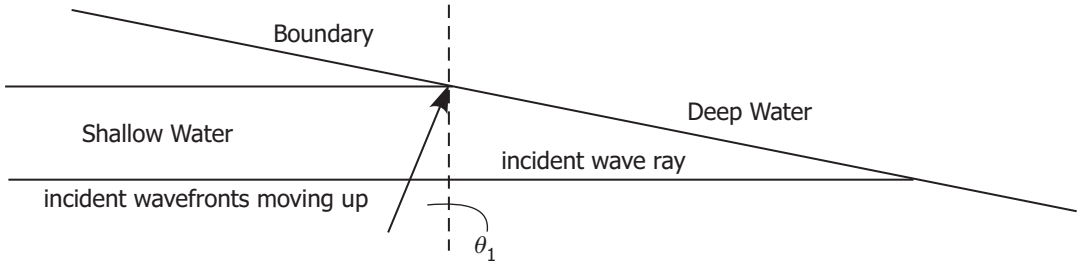


For each of the diagrams below, the dashed line represents a normal and the arrow represents the incident wave ray. The diagram showing the correct incident wave ray and angle of incidence for the incident wave ray is

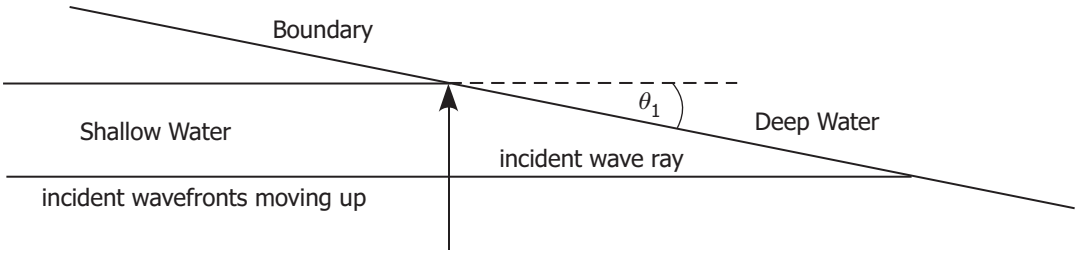
a)



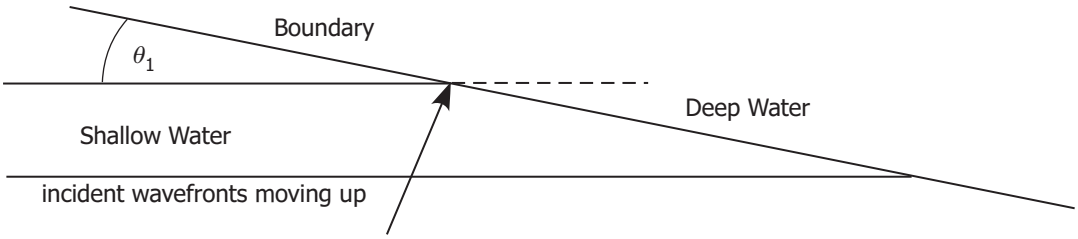
b)



c)



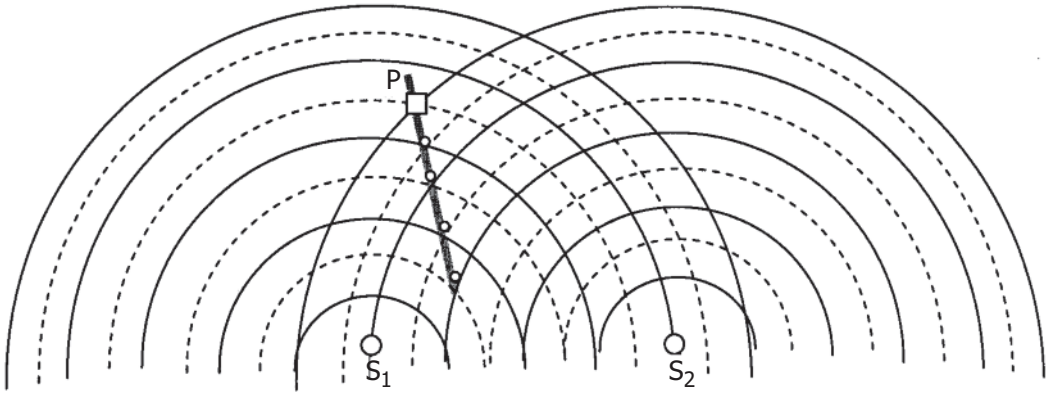
d)



Answer (a)

Outcome S3P-1-11

30. In the diagram below, the point P is found on the nodal line as shown below in the square. The distance PS_1 is 10.0 cm and the distance PS_2 is 13.0 cm. The distance between the sources is 8.0 cm.



The wavelength of the waves producing the interference pattern must be

a) 0.12 cm
b) 2.0 cm
c) 3.0 cm
d) 6.0 cm

Answer (b)
Outcome S3P-1-16

31. In a sound wave that moves to the right, a vibrating tuning fork creates a rarefaction when the fork moves

a) to the right, creating a momentary fall in air pressure
b) to the left, creating a momentary fall in air pressure
c) to the right, creating a momentary rise in air pressure
d) to the left, creating a momentary rise in air pressure

Answer (b)
Outcome S3P-1-17

32. The sound level in a room may be 50 dB. A sound that is twice as loud as a 50 dB sound is

a) 60 dB
b) 100 dB
c) 500 dB
d) 5000 dB

Answer (a)
Outcome S3P-1-25

33. If the frequency of one source of sound is 500 Hz and a second sound source is 504 Hz, then when the two waves interfere with each other, the beat frequency will be

a) 2 Hz
b) 4 Hz
c) 8 Hz
d) 16 Hz

Answer (b)
Outcome S3P-1-20

34. For a tube closed at one end, the length of the tube at a frequency of 256 Hz will be

a) one-quarter the value for a tube open at both ends
b) one-half the value for a tube open at both ends
c) twice the value for a tube open at both ends
d) four times the value for a tube open at both ends

Answer (b)
Outcome S3P-1-20

35. The frequency of a G note is 384 Hz. Using the table below, the frequency of the B note must be

C	D	E	F	G	A	B	C′	D′
4	...	5	...	6				
			4	...	5	...	6	
				4	...	5	...	6

a) 192 Hz
b) 307 Hz
c) 480 Hz
d) 768 Hz

Answer (c)
Outcome S3P-1-28

36. A good scientific theory is one which is

a) simple (less complex), has a wide scope, and is accurate and consistent
b) simple (less complex), narrow in scope, and is accurate and consistent
c) more complex, has a wide scope, is accurate and consistent
d) more complex, narrow in scope, consistent but not accurate

Answer (a)
Outcome S3P-2-05

37. When we perform an experiment and form a mental picture without necessarily having a mathematical relationship, this way of representing the experiment can be described as

a) visual
b) symbolic
c) numeric
d) graphical

Answer (a)
Outcome S3P-2-02

38. Those who proposed the idea that light has wave-like properties were

a) Huygens and Newton
b) Huygens and Planck
c) Maxwell and Planck
d) Maxwell and Huygens

Answer (d)
Outcome S3P-2-06

39. At the time of Newton, many scientists tried to produce wave interference effects, but were not successful. The reason for this is that

a) incandescent light sources are out of phase and the wavelength of light is very large
b) incandescent light sources are out of phase and the wavelength is very small
c) incandescent light sources are in phase and the wavelength of light is very large
d) incandescent light sources are in phase and the wavelength of light is very small

Answer (b)
Outcome S3P-2-14

40. If light moves from left to right along the x-axis, then the electric field line vibrates along

a) the x-axis and the magnetic field also vibrates along the x-axis
b) the x-axis and the magnetic field vibrates along the y-axis
c) the y-axis and the magnetic field vibrates along the x-axis
d) the y-axis and the magnetic field line vibrates along the z-axis

Answer (d)
Outcome S3P-2-15

Part B: Short Explanations (5 x 3 = 15 Marks)

Answer any five (5) of the following questions. Be sure to indicate clearly which five questions are to be marked.

Outcome S3P-1-01

1. Distinguish between transverse waves and longitudinal waves.

   Answer:

   Transverse waves are waves in which the direction of motion of the medium is perpendicular to the direction of motion of the disturbance. In longitudinal waves, the direction of motion of the medium is parallel to the direction of motion of the disturbance.

Outcome S3P-4-23

2. Using the Domain Theory of Magnetism, explain the following.

   a) When placed in a strong magnetic field, a bar of iron becomes a bar magnet. When the field is removed, the piece of iron is no longer a bar magnet.

      Answer:

      When the bar of iron is placed in a strong magnetic field, the magnetic domains within the piece of iron align themselves with the magnetic field. The bar of iron then acts like a bar magnet. When the magnetic field is removed, the magnetic domains return to their original random arrangement. The piece of iron is no longer a bar magnet.

   b) Over a period of years, the steel girders in a building become magnetized.

      Answer:

      Over a period of years, the magnetic domains within the steel girders align themselves with the Earth's magnetic field, thus becoming magnetized.

Outcome S3P-1-21

3. Distinguish among fundamental frequency, overtone, and harmonic for a string of a guitar.

   Answer:

   The fundamental frequency of the guitar string is the lowest frequency at which the guitar string can vibrate (for example, 100 Hz).

   An overtone is a frequency, which is a whole number multiple of the fundamental frequency. The first overtone has the frequency of twice the fundamental frequency (200 Hz).

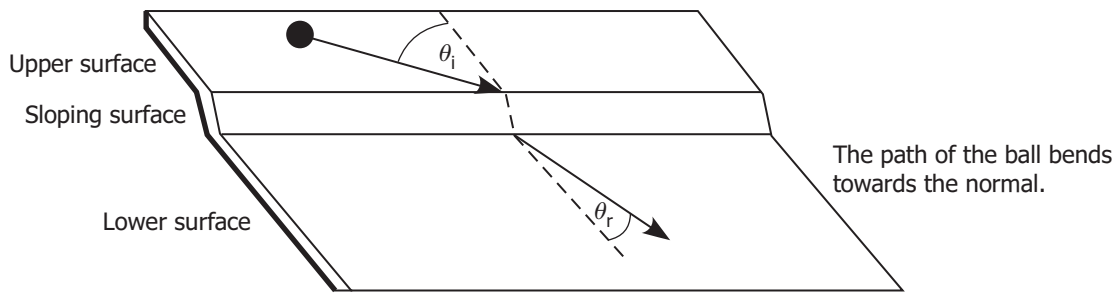
   A harmonic is a frequency, which is also a whole number multiple of the fundamental frequency. The first harmonic has a frequency equal to the fundamental frequency (100 Hz).

Outcome S3P-2-07

4. Using a diagram, explain how Newton's Corpuscular Theory explained refraction.

   Answer:

   Newton used two level surfaces, one slightly higher than the other, with a ramp joining the higher surface to the lower surface. As a particle rolled across the upper surface, it travelled in a straight-line path like light does in a uniform medium. When the particle reached the ramp or sloping surface, it received a pull from gravity, changing the direction of its path. This change in direction corresponded to refraction. On the lower level, the particle again travelled in a straight line.



Outcome S3P-1-27

5. Distinguish between the pitch, the intensity, and the quality of sound produced by a musical instrument.

   Answer:

   Pitch refers to the frequency of the sound. A sound with a high frequency has a high pitch.

   Intensity of sound refers to the energy carried by the sound and is most closely linked to the amplitude of the sound waves.

   The quality of the sound refers to the complexity of the sound wave. The more complex the sound wave, the better the quality of the sound.

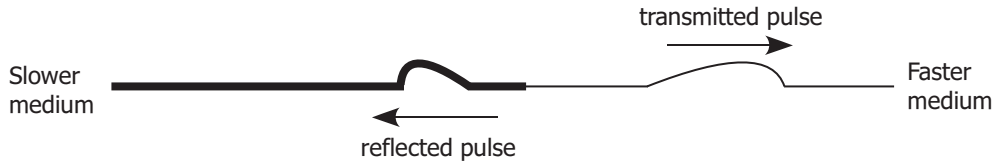
Outcome S3P-1-05

6. A wave crest is travelling along a heavy medium. The wave crest encounters a junction between the heavy medium and a light medium. Using a sketch, describe the situation after the wave crest has passed through the junction.

   Here is a diagram of the situation before the crest hits the junction.

   Answer:

   The diagram below is how the medium would appear a short while after the incident pulse has hit the boundary. The reflected pulse and the transmitted pulse are both shown.



   Again, there are several details to make note of:

Reflected Pulse	Transmitted Pulse
Returns as a crest—reflected upright from a free end	Transmitted as a crest
Smaller in amplitude—energy is transmitted	Larger in amplitude—light to medium is easier to move
Same length as original crest—speed is the same	Longer in length than the original crest—speed is larger in the transmitted section
Closer to the boundary	Farther from the boundary since the crest is moving more quickly

Outcome S3P-2-10, S3P-2-11

7. Describe two phenomena for the behaviour of light that are explained better using the wave model of light than the particle model of light.

   Answer:

   1. Refraction

      The particle model predicts that particles of light will speed up as they pass through the boundary between air and water. The wave model correctly predicts that light will slow down as it passes through the boundary between air and water.

   2. Partial reflection and partial refraction

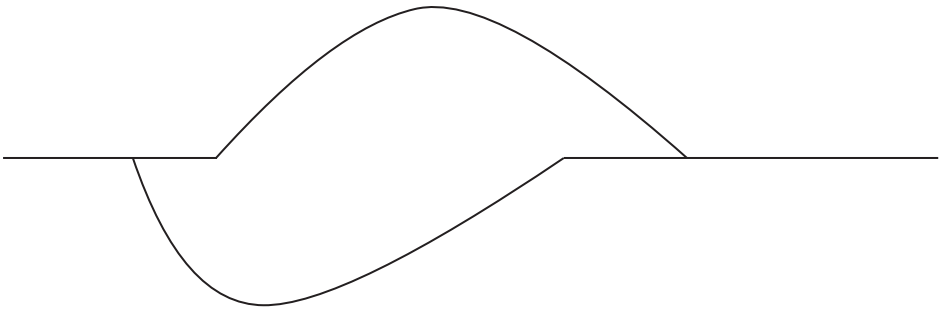
      The particle model could not fully explain why some particles would reflect off the boundary between two media and some particles would be transmitted through the boundary. The wave model of light demonstrates that waves incident on to the boundary between two media can partially be reflected and partially be transmitted.

Part C: Diagrams (15 Marks)

Show your work in the space provided.

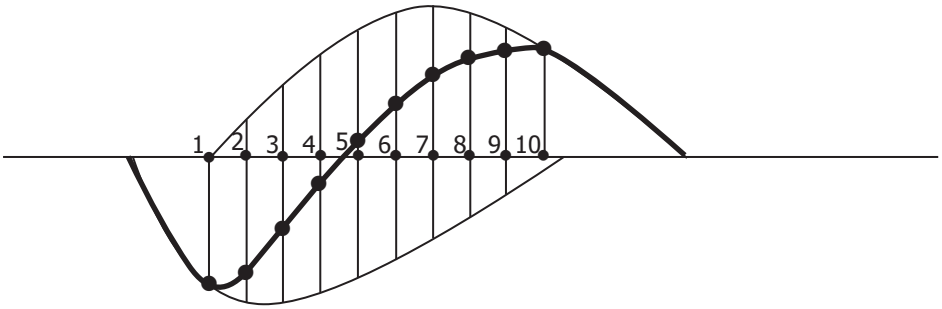
Outcome S3P-1-06

1. Draw the resultant wave. *(4 marks)*



Point	Displacement to Top Wave (cm)	Displacement to Bottom Wave (cm)	Total Displacement (cm)
1	0	–1.7	–1.7
2	0.4	–1.9	–1.5
3	0.9	–1.9	–1.0
4	1.3	–1.7	–0.4
5	1.6	–1.5	0.1
6	1.9	–1.2	0.7
7	2.0	–1.0	1.0
8	1.9	–0.8	1.1
9	1.8	–0.4	1.4
10	1.5	–0.1	1.4

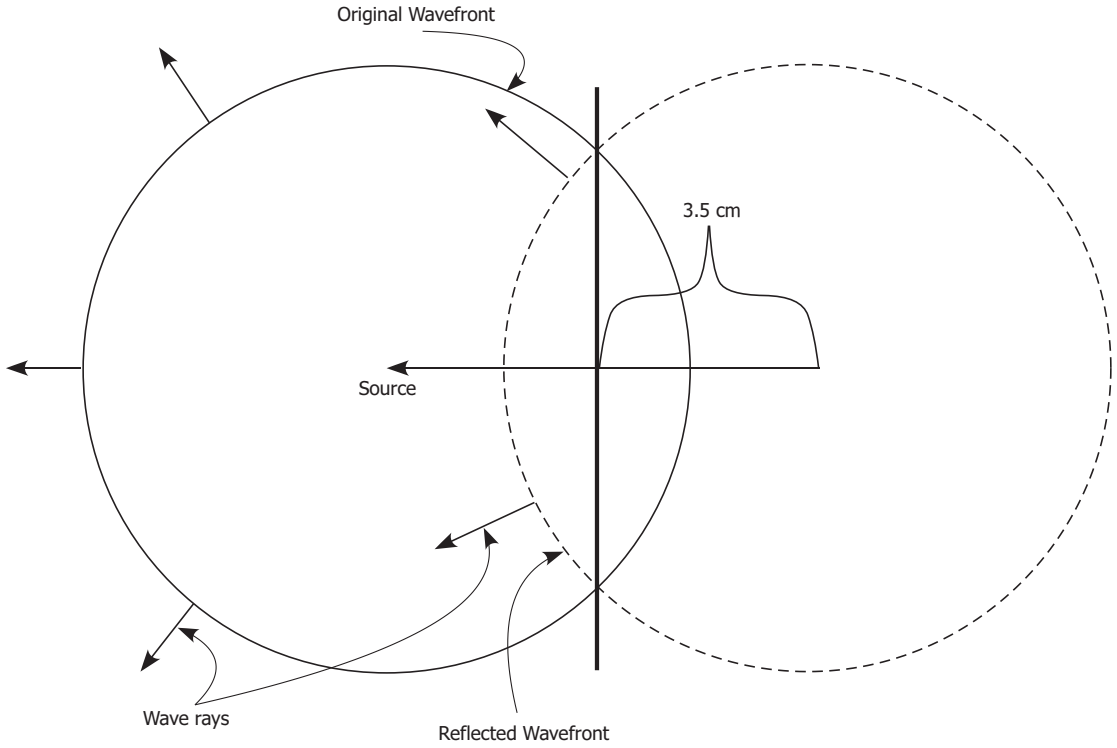
Answer:



Outcome S3P-1-10

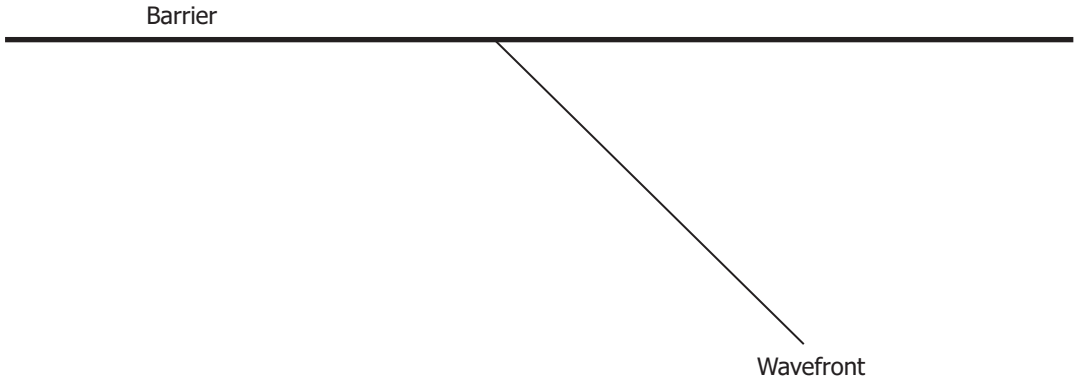
2. A point source on a ripple tank is located 3.5 cm from a straight barrier. Draw in, using a compass, the circular wave after it has travelled 5.0 cm. Locate the source of the reflected wavefront and draw in the reflected wavefront. Indicate the direction of travel of both the incident and reflected wavefronts. *(3 marks)*

Answer:

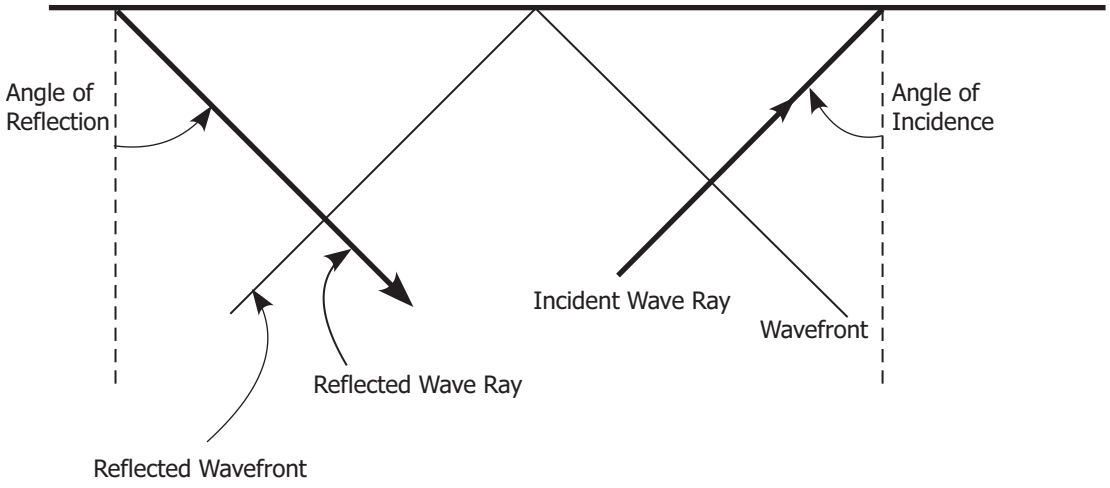


Outcome S3P-1-10

3. The diagram below shows a wavefront travelling towards a straight barrier. Draw in and label the direction of motion, the angle of incidence, the reflected crest, its direction of motion, and the angle of reflection. *(3 marks)*



Answer:



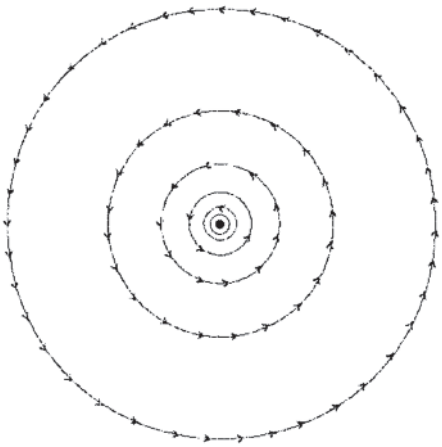
Outcome S3P-4-21

4. Draw the magnetic field around

   a) a wire carrying a current out of the page. *(1 mark)*

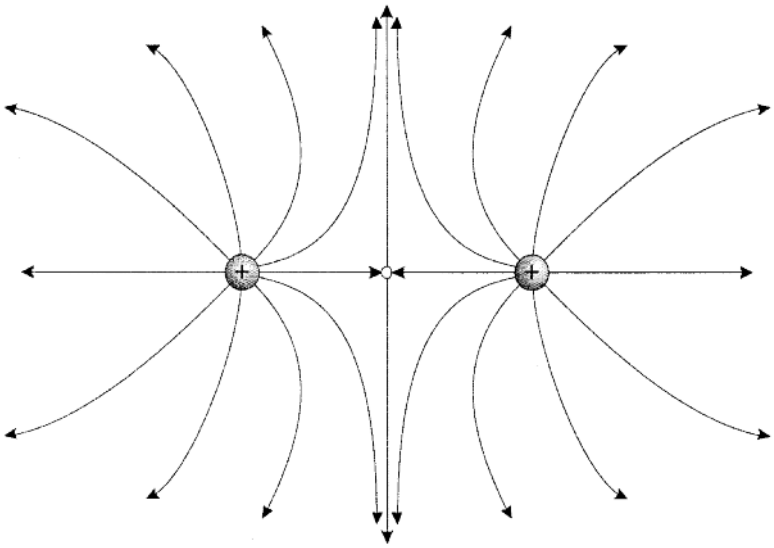
Answer:

Magnetic Field around a Wire Carrying a Current OUT of the Page



   b) two positive point charges. *(2 marks)*

Answer:

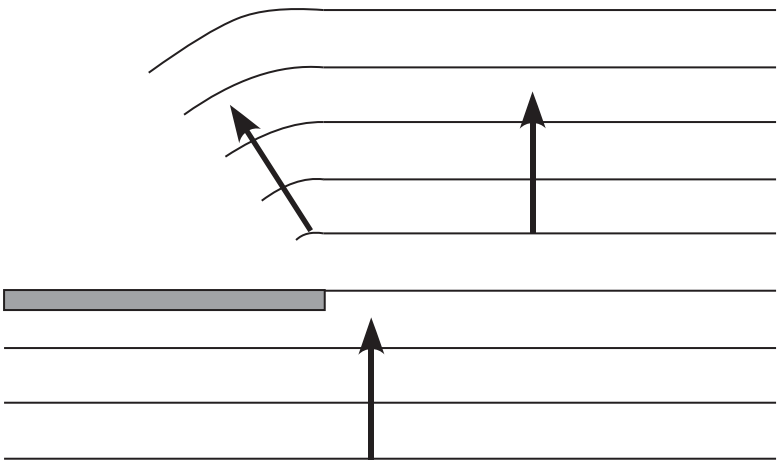


Outcome S3P-1-14

5. Diagram the diffraction of waves in the following situations:

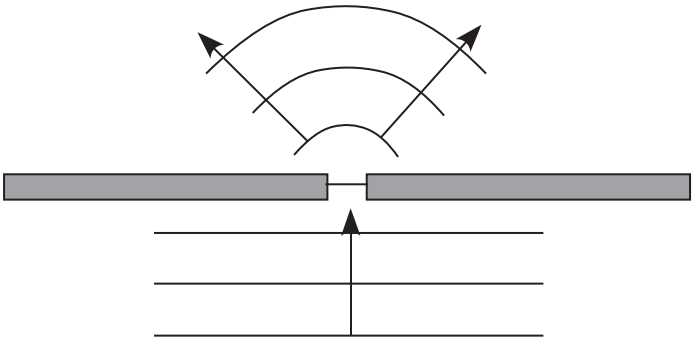
   a) at the edge of a straight barrier. *(1 mark)*

   Answer:



   b) through the opening in a straight barrier. *(1 mark)*

   Answer:



Part D: Problems (6 Marks)

Do only one question from Part D.

Outcome S3P-4-08

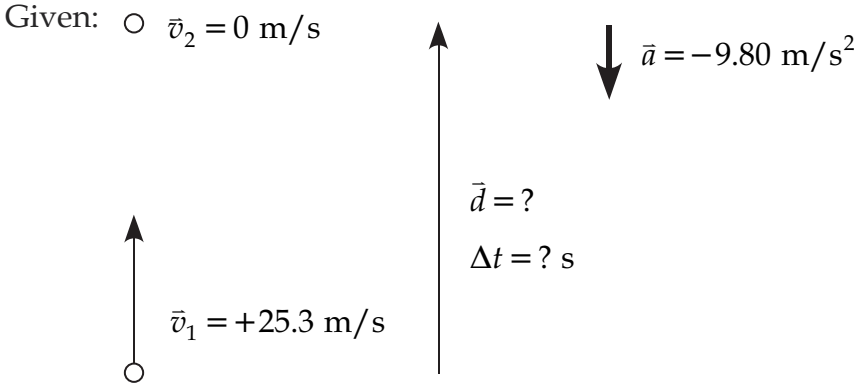
1. A baseball is popped straight upwards at 25.3 m/s. The acceleration of gravity is 9.80 m/s^2 downwards.

   a) Determine the highest point of the flight of the ball. *(3 marks)*

   Answer:

   Let down be negative.

   Given:



   Unknown: Maximum height $\vec{d} = ?$

   Equation: $v_2^2 = v_1^2 + 2ad$ rearranged to $d = \dfrac{v_2^2 - v_1^2}{2a}$

   Substitute and solve: $d = \dfrac{v_2^2 - v_1^2}{2a} = \dfrac{(0 \text{ m/s})^2 - (+25.3 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = +32.6 \text{ m}$

   The maximum height is 32.6 m.

   b) For what length of time would the ball rise from the instant it left the bat? *(3 marks)*

   Answer:

   Unknown: Time interval $\Delta t = ?$

   Equation: $\vec{d} = \dfrac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$ rearranged to $\Delta t = \dfrac{2\vec{d}}{\vec{v}_1 + \vec{v}_2}$

   Substitute and solve: $\Delta t = \dfrac{2d}{\vec{v}_1 + \vec{v}_2} = \dfrac{2(+32.6 \text{ m})}{(+25.3 \text{ m/s}) + (0)} = 2.58 \text{ s}$

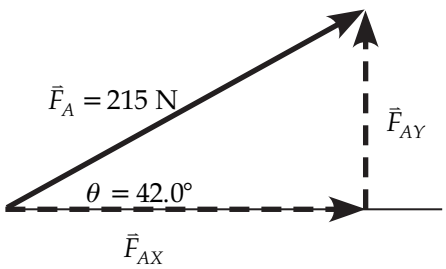
   It takes the ball 2.58 seconds to reach its maximum height.

2. A crate of mass 255 kg is pulled along a level floor. The crate rests on a dolly, which has a handle attached to it. The handle is pulled by a person exerting a force of 215 newtons at an angle of 42.0° from the horizontal, and the force of friction is 112 newtons.

Outcome S3P-0-2h

a) Determine the horizontal and vertical components of the applied force acting on the crate. *(2 marks)*

Answer:



$$\vec{F}_{AX} = \cos\ 42.0°\ (\vec{F}_A)$$
$$\vec{F}_{AX} = \cos\ 42.0°(215\ \text{N})$$
$$\vec{F}_{AX} = 160\ \text{N}$$
$$\vec{F}_{AX} = 1.60 \times 10^2\ \text{N}$$

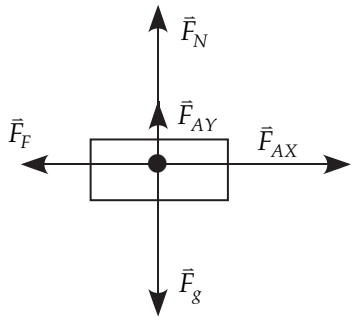
$$\vec{F}_{AY} = \sin\ 42.0°\ (\vec{F}_A)$$
$$\vec{F}_{AY} = \sin\ 42.0°(215\ \text{N})$$
$$\vec{F}_{AY} = 144\ \text{N}$$

The vertical component of the applied force is 144 N and the horizontal component is 1.60×10^2 N.

Outcome S3P-3-12

b) Draw a free-body diagram labelling clearly all of the forces acting on the dolly. *(2 marks)*

Answer:



Outcome S3P-3-12, S3P-3-13

c) Determine the net force acting on the dolly and the acceleration of the dolly. *(2 marks)*

Answer:

The net force is the sum of the force of friction and the horizontal component of the applied force.

$$\vec{F}_{\text{NET}} = \vec{F}_F + \vec{F}_{AX} = 112\text{ N [left]} + 160\text{ N [right]} = 48\text{ N [right]}$$

The acceleration is found using Newton's Second Law.

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{48\text{ N[right]}}{255\text{ kg}} = 0.19\text{ m/s}^2\text{[right]}$$

The acceleration is 0.19 m/s/s [right].

Part E: Problems (24 Marks)

Answer any four (4) problems. If more than four problems are done, the first four will be marked.

1. A 8.25 Hz water wave travels from deep water, where its speed is 42.0 cm/s, to shallow water where its speed is 31.5 cm/s. The angle of incidence is 30.0°. Find the following.

   Outcome S3P-1-04

   a) the wavelengths in the two media *(3 marks)*

   Answer:

   Given: Frequency $f = 8.25$ Hz

   Speed in deep water $v_D = 42.0$ cm/s

   Speed in shallow water $v_S = 31.5$ cm/s

   Angle in deep water $\theta = 30.0°$

   Unknown: Wavelength in deep water $\lambda_D = ?$

   Equation: $v = f\lambda$ rearranged to $\lambda_D = \frac{v_D}{f}$

   Substitute and solve: $\lambda_D = \frac{v_D}{f} = \frac{42.0 \text{ cm/s}}{8.25 \text{ Hz}} = 5.09 \text{ cm}$

   Similarly, for shallow water, the wavelength is calculated as

   $\lambda_S = \frac{v_S}{f} = \frac{31.5 \text{ cm/s}}{8.25 \text{ Hz}} = 3.82 \text{ cm.}$

Outcome S3P-2-12

b) the angle of refraction in the shallow water *(3 marks)*

Answer:

Unknown: Angle in shallow water $\theta_S = ?$

Equation: Snell's Law: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

Here medium 1 is deep water and medium 2 is shallow water.

Substitute and solve:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$$

$$\frac{\sin 30.0°}{\sin\theta_S} = \frac{42.0\text{ cm/s}}{31.5\text{ cm/s}}$$

$$\sin\theta_S = \frac{(\sin 30.0°)(31.5\text{ cm/s})}{42.0\text{ cm/s}} = 0.375$$

$$\theta_S = 22.0°$$

The angle of refraction in shallow water is 22.0°.

2. Two point sources generate identical waves that interfere in a ripple tank. The sources are located 6.50 cm apart, and the frequency of the waves is 9.25 Hz. The waves travel at 12.6 cm/s.

Outcome S3P-1-04

a) What is the wavelength of the waves? *(2 marks)*

Answer:

Given: Frequency $f = 9.25$ Hz

Speed of waves $v = 12.6$ cm/s

Distance between sources $d = 6.50$ cm

Unknown: wavelength $\lambda = ?$

Equation: $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$

Substitute and solve: $\lambda = \frac{v}{f} = \frac{12.6 \text{ cm/s}}{9.25 \text{ Hz}} = 1.36 \text{ cm}$

The wavelength is 1.36 cm.

Outcome S3P-1-16

b) What is the path length difference to a point P on the third nodal line? *(1.5 marks)*

Answer:

Given: number of nodal line $n = 3$

Unknown: Path length difference PLD = ?

Equation: $\left|\overline{P_nS_1} - \overline{P_nS_2}\right| = \left(n - \frac{1}{2}\right)\lambda$

Substitute and solve:

$$\left|\overline{P_nS_1} - \overline{P_nS_2}\right| = \left(n - \frac{1}{2}\right)\lambda$$

$$= \left(3 - \frac{1}{2}\right)(1.36 \text{ cm}) = 3.40 \text{ cm}$$

The path length difference is 3.40 cm.

Outcome S3P-1-16

c) What would happen to the spacing of the nodal lines in the interference pattern if only the distance between the sources was increased? *(1.5 marks)*

Answer:

If the spacing between the sources was to increase, this would place more points in the pattern within the same space. This would lead to a greater number of nodal lines. In turn, the nodal line must be spaced closer together.

Outcome S3P-1-16

d) What would happen to the number of nodal lines in the interference pattern if only the frequency of the waves was increased? *(1 mark)*

Answer:

If the frequency of the waves was increased, this would decrease the distance between points of interference in the pattern. This, in turn, would increase the number of nodal lines.

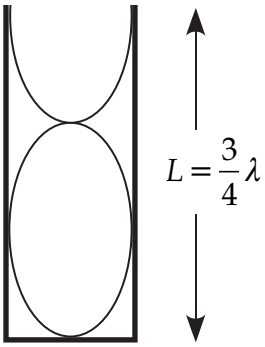
3. An air column closed at one end resonates at the second maximum or the second resonant length. The frequency of the sound wave is 1024 Hz. The air temperature is 18.6°C.

Outcome S3P-1-21

a) Draw a diagram of the displacement wave pattern inside the column. *(1 mark)*

Answer:

The length of the closed air column at the second maximum is $\frac{3}{4}\lambda$.



Outcome S3P-1-23

b) Calculate the speed of sound in air. *(2 marks)*

Answer:

Given: Air temperature	T = 18.6°C
Unknown: Speed of sound	v = ?
Equation:	v = 332 m/s + (0.60 m/s/°C)T
Substitute and solve:	v = 332 m/s + (0.60 m/s/°C)(18.6°C)
	v = 332 + 11.16 = 343 m/s

The speed of sound is 343 m/s.

Outcome S3P-1-04

c) Calculate the wavelength. *(1.5 marks)*

Answer:

Given: Frequency $f = 1024$ Hz

Speed $v = 343$ m/s

Unknown: wavelength $\lambda = ?$

Equation: $v = f\lambda$ rearranged to $\lambda = \frac{v}{f}$

Substitute and solve: $\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{1024 \text{ Hz}} = 0.335 \text{ m}$

The wavelength is 0.335 m.

Outcome S3P-1-21

d) Calculate the length of the closed air column. *(1.5 marks)*

Answer:

The length of the closed air column is $\frac{3}{4}\lambda$ or $\frac{3}{4}(0.335 \text{ m}) = 0.251$ m.

4. In a standing wave pattern on a spring, the distance between the third and seventh nodes is 1.52 m. The source generates 25 crests and 25 troughs in 5.40 seconds.

Outcome S3P-1-03

a) What is the frequency? *(1.5 marks)*

Answer:

25 waves are generated in 5.40 seconds.

$$f = \frac{\text{number of events}}{\text{time}} = \frac{25}{5.40\ \text{s}} = 4.6\ \text{Hz}$$

Outcome S3P-1-05

b) What is the wavelength? *(2 marks)*

Answer:

The distance between the 3rd and 7th nodes is 2 wavelengths.

$2\lambda = 1.52\ \text{m}$

$\lambda = 0.760\ \text{m}$

The wavelength is 0.760 m.

Outcome S3P-1-04

c) What is the speed of these waves? *(1.5 marks)*

Answer:

$v = f\lambda = (4.6\ \text{Hz})(0.760\ \text{m}) = 3.5\ \text{m/s}$

Outcome S3P-1-28

d) What would be the frequency of the wave one octave above the given wave? *(1 mark)*

Answer:

One octave above a given frequency is twice the given frequency. So, one octave above 4.6 Hz is 9.2 Hz.

5. In a Young's Experiment measurement, light of wavelength 5.25×10^{-7} m passed through 2 slits 2.78×10^{-5} m apart.

Outcome S3P-2-14

a) At a distance of 2.75 m, what would be the spacing of the adjacent nodal lines in this pattern? *(3 marks)*

Answer:

Given: Wavelength $\lambda = 5.25 \times 10^{-7}$ m

Separation of slits $d = 2.78 \times 10^{-5}$ m

Distance to pattern $L = 2.75$ m

Unknown: Spacing of nodal lines $\Delta x = ?$

Equation: $\lambda = \frac{\Delta x d}{L}$ rearranged to $\Delta x = \frac{\lambda L}{d}$

Substitute and solve:

$$\Delta x = \frac{\lambda L}{d} = \frac{(5.25 \times 10^{-7}\text{ m})(2.75\text{ m})}{2.78 \times 10^{-5}\text{ m}}$$
$$= 5.19 \times 10^{-2}\text{ m}$$

The spacing of adjacent nodal lines is 5.19×10^{-2} m.

Outcome S3P-2-13

b) What is the spacing of adjacent nodal lines if only light of wavelength 6.75×10^{-7} m was used instead of 5.25×10^{-7} m? *(1.5 marks)*

Answer:

Only the wavelength changes to 6.75×10^{-7} m.

$$\Delta x = \frac{\lambda L}{d} = \frac{(6.75 \times 10^{-7}\text{ m})(2.75\text{ m})}{2.78 \times 10^{-5}\text{ m}} = 6.68 \times 10^{-2}\text{ m}$$

The new spacing is 6.68×10^{-2} m.

Outcome S3P-2-13

c) What is the spacing of adjacent nodal lines if only the spacing of the two slits is changed to 3.50×10^{-5} m? *(1.5 marks)*

Answer:

Only the separation of the slits is changed from the original situation to 3.50×10^{-5} m.

$$\Delta x = \frac{\lambda L}{d} = \frac{(5.25 \times 10^{-7}\text{ m})(2.75\text{ m})}{3.50 \times 10^{-5}\text{ m}} = 4.12 \times 10^{-2}\text{ m}$$

The new spacing of the nodal lines is 4.12×10^{-2} m.

Outcome S3P-2-14

6. Two slits have green light of wavelength 5.25×10^{-7} m passing through them. The interference pattern is observed at a distance of 1.75 m. The distance from the first dark line to the ninth dark line is 10.2 cm.

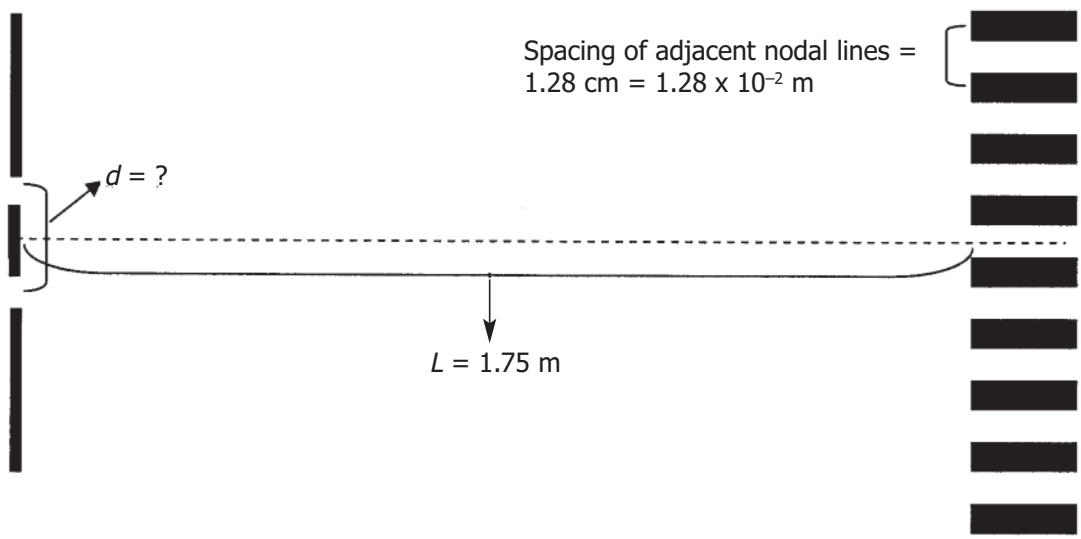
   a) What is the spacing of the nodal lines? *(2 marks)*

   Answer:

   There are 8 spaces between the 9 nodal lines.

$$\Delta x = \frac{10.2 \text{ cm}}{8} = 1.28 \text{ cm} = 1.28 \times 10^{-2} \text{ m}$$

   b) What is the separation of the slits? *(3 marks)*



Answer:

Given: Wavelength $\lambda = 5.25 \times 10^{-7}$

Unknown: Separation of slits $d = ?$

Equation: $\Delta x = \frac{\lambda L}{d}$ rearranged to $d = \frac{\lambda L}{\Delta x}$

Substitute and solve: $d = \frac{\lambda L}{\Delta x} = \frac{(5.25 \times 10^{-7} \text{ m})(1.75 \text{ m})}{1.28 \times 10^{-2} \text{ m}} = 7.18 \times 10^{-5} \text{ m}$

The separation of the slits is 7.18×10^{-5} m.

c) Should light of a larger or smaller wavelength be used in this situation to produce a pattern of lines that is spaced closer together? Explain why. *(1 mark)*

Answer:

According to the relationship for Young's Experiment, $\Delta x = \frac{\lambda L}{d}$, the spacing of the lines varies directly with the wavelength. For the lines to be spaced closer together, a smaller wavelength must be used.

NOTES

Grade 11 Physics
Formula Sheet

Mathematics

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\text{hypotenuse}^2 = (\text{Leg 1})^2 + (\text{Leg 2})^2$$

Kinematics

$$v = \frac{d}{\Delta t}$$

$$\Delta = \text{second value} - \text{first value}$$

$$\vec{d} = \text{pos}_2 - \text{pos}_1$$

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{\text{pos}_2 - \text{pos}_1}{\Delta t}$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ or } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

Waves

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{1-2}$$

$$PLD = |PS_1 - PS_2| = \left(n - \frac{1}{2}\right)\lambda$$

$$f = \frac{1}{T}$$

$$T = \frac{1}{f}$$

$$v = f\lambda$$

Light

$$\text{PLD} = |\text{PS}_1 - \text{PS}_2|$$

$$\frac{\Delta x}{L} = \frac{\lambda}{d}$$

Sound

$$v = 332 + 0.6\ \text{T}$$

Closed-pipe resonant length

$$L_n = \left(\frac{(2n-1)}{4}\right)\lambda$$

Open-pipe resonant length

$$L_n = \left(\frac{n}{2}\right)\lambda$$

$$f_B = |f_2 - f_1|$$

Dynamics

$$\vec{F}_{\text{NET}} = m\vec{a}$$

$$\vec{F}_{\text{NET}} = \sum \text{Forces}$$

$$F_F = \mu F_N$$

Gravity

$$\vec{F}_g = m\vec{g}$$

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$

Electricity

$$\vec{E} = \frac{\vec{F}_E}{q}$$

$$q = \text{N}e$$

$$E = \frac{V}{d}$$

Magnetism

$$\vec{F}_B = BIL\sin\theta$$

Grade 11 Physics (30S)

Appendices

- Appendix A: Equation Sheet
- Appendix B: Glossary
- Appendix C: Kinematics Graphs Transformation Organizer
- Appendix D: List of SLOs Found in Each Lesson

Appendix A: Equation Sheet

Mathematics

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\text{hypotenuse}^2 = (\text{Leg } 1)^2 + (\text{Leg } 2)^2$$

Kinematics

$$v = \frac{d}{\Delta t}$$

$$\Delta = \text{second value} - \text{first value}$$

$$\vec{d} = \overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1$$

$$\vec{v} = \frac{\vec{d}}{\Delta t} = \frac{\overrightarrow{\text{pos}}_2 - \overrightarrow{\text{pos}}_1}{\Delta t}$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} \text{ or } \vec{a} = \frac{\vec{v}_2 - \vec{v}_1}{\Delta t} \text{ or } \vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$$

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$$

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

Waves

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{1-2}$$

$$PLD = |PS_1 - PS_2| = \left(n - \frac{1}{2}\right)\lambda$$

$$f = \frac{1}{T}$$

$$T = \frac{1}{f}$$

$$v = f\lambda$$

Light

$$PLD = |PS_1 - PS_2|$$

$$\frac{\Delta x}{L} = \frac{\lambda}{d}$$

Sound

$$v = 332 + 0.6T$$

Closed-pipe resonant length

$$L_n = \left(\frac{(2n-1)}{4}\right)\lambda$$

Open-pipe resonant length

$$L_n = \left(\frac{n}{2}\right)\lambda$$

$$f_B = |f_2 - f_1|$$

Dynamics

$$\vec{F}_{\text{NET}} = m\vec{a}$$

$$\vec{F}_{\text{NET}} = \sum \text{Forces}$$

$$F_F = \mu F_N$$

Gravity

$$\vec{F}_g = m\vec{g}$$

$$\vec{F}_N + \vec{F}_g = \vec{F}_{\text{NET}} = m\vec{a}$$

Electricity

$$\vec{E} = \frac{\vec{F}_E}{|q|}$$

$$q = \text{N}e$$

$$E = \frac{V}{d}$$

Magnetism

$$\vec{F}_B = BIL\sin\theta$$

NOTES

Appendix B: Glossary

A

Acceleration is the time rate change of velocity, which is found by taking the change in velocity over the change in time. It is a vector quantity.

Air friction is friction due to the motion of an object through air; it is proportional to the object's velocity.

Amplitude modulation involves encoding a signal in radio waves by varying the amplitude but keeping the frequency constant.

Amplitude is the distance measured from the normal rest position of the medium to the highest point on a crest or to the lowest point on a trough.

Angle of incidence is the angle between the normal and the ray representing the incoming wave or light.

Angle of reflection is the angle between the normal and the ray representing the reflected wave or light reflected from a surface, such as a mirror.

Angle of refraction is the angle that the refracted light ray or wave makes with the normal of the surface or boundary.

Antinodes occur midway between the nodes, and are areas where double crests and double troughs occur when positive and negative pulses of equal amplitude and length travel in opposite directions and interfere.

Apparent weight is the weight measured by a scale.

Apparent weightlessness is a state where a scale will measure the weight as 0 N because the object, the scale, and the surroundings are freely falling.

Applied force is the force exerted on an object by an outside agent.

Audio spectrum is the range of audible frequencies for a healthy person 20 Hz to 20 kHz.

Auroras are commonly called the northern or southern lights, and are caused by high energy particles from the solar wind that are trapped in the Van Allen belts of the Earth's magnetic field.

Average velocity is defined as the displacement of an object divided by the elapsed time. It is a vector quantity.

B

Balanced forces are forces that are acting on a given object so that their sum is 0 N.

Beat frequency is the number of times that the loudness rises and falls every second. The beat frequency is the absolute value of the difference between the two sound frequencies.

Beats are the periodic variations in loudness resulting from the interference of sound waves with slightly different frequencies.

Boundary is the interface between two different media.

C

Chord is a straight line segment joining two points on a graph.

Closed air column (see closed-pipe column).

Closed-pipe column is an air column that is closed at one end and open at the other.

Coefficient of friction is the ratio of frictional force to the normal force between two object surfaces.

Coefficient of kinetic friction is the ratio of the kinetic frictional force and the normal force.

Coefficient of static friction is the ratio of the maximum static frictional force and the normal force.

Components are two vectors that point along the major axes and whose sum is the resultant vector.

Compression is a place where the medium is compressed (closer together than usual).

Conclusion is a judgment or opinion formed as a result of analyzing the experimental data.

Constant is a quantity that is kept at the same value, and that does not change.

Constructive interference is the situation when a combined or resultant wave has a larger amplitude than its component waves.

Contact force is the force exerted by an object in direct contact with another object.

Conventional current is the motion of positive charges around the circuit.

Cosine is a trigonometric function calculated by the ratio of the length of the adjacent side over the length of the hypotenuse.

Coulomb is the SI unit for charge (e.g., 1 C = 6.24×10^{18} *e*).

Crest is the part of a transverse wave found above the normal rest position.

Cycle is, for a wave, one complete grouping of a single crest and a single trough.

D

Delta (Δ) is the symbol representing change, and is calculated as the final value minus the initial value.

Dependent variable is the responding variable in an experiment. It may change due to changes in the independent variable.

Destructive interference is the situation when a combined or resultant wave has a smaller amplitude than its component waves.

Diatonic scale is a musical scale that consists of three sets of major triads.

Diffraction is the bending of waves around an object in their path.

Direct variation is a mathematical relationship where, as one variable increases, so does the other.

Dispersion occurs when white light passes through a prism and is refracted by different amounts, resulting in the formation of the spectrum of colours.

Displacement antinode is the location of the region of the maximum amplitude for a standing wave in a column.

Displacement node is the location of the region of the minimum amplitude for a standing wave in a column.

Displacement represents the change in position of an object. Displacement is calculated by subtracting as follows: final position minus initial position.

Distance is the length of a path travelled by an object; it has no direction and is therefore a scalar quantity.

Doppler effect is a change in the observed frequency of a sound due to motion of the source or the observer.

Dynamics is the study of the causes of motion.

E

Electric current is the quantity of positive charge passing a given point during a particular time interval in a circuit, measured in amperes.

Electric dipole consists of two point charges that are opposite in sign but equal in magnitude.

Electric field is a region of space around a charge where an electric charge experiences a force caused by one or more other charges. It is calculated as the quotient of the electric force on an amount of charge and the magnitude of the charge located at that point.

Electromagnet is a magnet created by placing an iron core inside a solenoid.

Electromagnetic theory is Maxwell's theory of light, which states that light is an electromagnetic wave with the same properties as other electromagnetic waves.

Electromagnetism is a phenomenon associated with moving electrons producing a magnetic field and a changing magnetic field causing electrons to move.

Elementary charge is the amount of charge on a single proton or electron ($e = 1.60 \times 10^{-19}$ C).

Emission theory was proposed by the Pythagoreans who believed that objects send out light beams or particles that would ricochet off objects and enter the eye.

Experiment is a carefully devised procedure for making observations and gathering data.

External force is any force exerted by an object that is not part of the system on an object within the system.

F

Ferromagnetism is the property of materials that readily show strong attractions to nearby magnets, and may become magnetized.

Fixed end is where the medium ends and cannot move.

Force is an action, like a push or a pull, that causes a change in the motion of an object.

Frame of reference is a subset of the physical world defined by an observer in which positions or motions can be discussed and compared.

Free-body diagram is the diagram used to aid in solving dynamics problems in which all of the forces acting on an object are shown as acting on a point representing the object.

Free end is when the medium ends and is free to move.

Free fall describes the situation in which the only force acting on the falling object is the force of gravity.

Frequency modulation involves encoding a signal in radio waves by varying the frequency but keeping the amplitude constant.

Frequency is a measure of how many cycles are produced per unit of time.

Friction is a force opposing the relative motion of two objects that are in contact.

Fundamental frequency is the lowest natural frequency that will produce resonance in a standing wave pattern.

G

Graphical mode is a "picture" or graph of data or measurements.

Graphical technique is when you draw the vectors carefully with a ruler, to scale, and place them "tip to tail."

Gravitational field constant is a number associated with the gravitational field intensity at the surface of the Earth. Its symbol is "g", and its value is 9.8 N/kg.

Gravitational field intensity is the quotient of the gravitational force and the magnitude of the test mass at a given point in the field.

Gravitational field lines are imaginary directed lines that indicate the path a tiny test mass would take if free to move in the gravitational field.

Gravitational field is the region around a mass where another mass would experience a gravitational force.

Gravitational force is an attraction between two objects because of their mass.

GUESS method is a mnemonic used to help one remember the steps in problem solving. It stands for Given, Unknown, Equation, Substitute, and Solve.

H

Harmonic is a frequency that is a whole number multiple of the fundamental frequency.

Harmonic frequency (see natural frequency).

Hypothesis is a plausible solution to a problem, an answer to a question, or an unproven explanation of the facts.

I

In phase is the periodic motion of two individual systems vibrating with the same frequency. They are phase if they each reach the same amplitude at the same time.

Independent variable is a variable under the control of the experimenter; it is changed by the experimenter.

Indirect variation is a mathematical relationship where, as one variable increases, the other variable decreases.

Inertia is the ability of an object to resist changes in its state of motion.

Inference is a deduction, conclusion, or interpretation based on the facts noted during the observation.

Infrasonic sound waves are those sound waves with a frequency below the range of normal human hearing. These frequencies occur below 20 Hz.

Instantaneous acceleration is the acceleration at a given instant. It is found by taking the slope of the tangent to the curve on a velocity-time graph.

Instantaneous position can be defined as the position of an object at a specific or instantaneous time.

Instantaneous time is the time a time piece such as a clock reads at any particular instant and that lasts zero seconds.

Instantaneous velocity is the velocity at a given instant, found by taking the slope of the tangent to the curve on a position-time graph.

Intensity of a sound wave is the energy that is transported past a given area per unit of time.

Interference fringes is a series of bight and dark bands seen in the interference pattern of light passing through two narrow slits that are very close together.

Interference occurs when two or more waves act simultaneously on the same particles of a medium, resulting in a new displacement.

J

K

Kinematics is the study of motion of bodies without reference to mass or force.

Kinetic friction is a frictional force that acts to slow the motion of an object.

Knowledge claim is a declaration of conviction consisting of a sentence of the type "I know that ..." or "I believe that." Knowledge claims can be supported by evidence that depends on the training and experience of the claimer.

L

Law is a concise but general statement about how nature behaves. It is a description of nature without an explanation of why nature behaves that way.

Law of Magnetic Poles states that unlike poles attract each other, and like poles repel.

Law of Refraction (see Snell's Law).

Line of best fit is a line drawn through data points on a graph that best represents the trend of the plotted data points.

Longitudinal wave is a wave in which the particles of the medium vibrate parallel to the direction of motion of the wave.

Loops (see antinodes).

Loudness is a subjective characteristic of sound that depends primarily on the amplitude of the wave.

M

Magnetic declination is the measured angle between the direction to true north (the location of the north geographical pole) and the direction that a compass will point (towards the magnetic north pole—the south pole of Earth's magnetism).

Magnetic inclination is the angle between the Earth's magnetic field at any point and the horizontal measured at the surface of the Earth.

Magnetic field is the region around a magnet or current-carrying wire where another magnet or current-carrying wire experiences a force.

Magnetosphere is the region of the upper atmosphere beyond approximately 200 km in which the motion of charged particles from space is governed by the magnetic field of the Earth.

Magnitude represents the size of a quantity.

Major triad is a collection of three notes with frequencies in the ratio 4:5:6.

Mass is the "amount of matter" present in an object measured in kilograms.

Mechanical wave is a wave that travels through a medium as a disturbance in that medium.

Medium is a substance such as air or water or a solid through which a wave disturbance travels.

N

Net force is the sum of all forces acting on an object.

Newton is defined as the force that causes a 1 kg mass to accelerate at $1\ m/s^2$; $1\ kg \cdot m/s^2$.

Node or nodal point is the point that remains at rest when positive and negative pulses of equal amplitude and length travel in opposite directions and interfere.

Noise is a sound produced by irregular vibrations or frequencies in a manner that is unpleasant to the listener.

Non-contact force is the force that acts even though objects are separated by a distance, such as attraction or repulsion between magnets.

Normal force is a force that acts in a direction perpendicular to the common contact surface between two objects.

Normal is the straight line perpendicular to a surface or a barrier.

North magnetic pole is the magnetic pole due to the Earth's magnetic field that is found near the north geographic pole. It is the Earth's magnetic pole towards which the north pole of a compass will point.

North pole is the end of a magnet that points towards the north.

Numerical mode uses data or measurements to represent a relationship or phenomenon.

O

Observation is a fact, or information, gathered by using one or more of the five senses.

Octave consists of the interval between a given musical tone and one with double or half the frequency.

Open-air column (see open-pipe column).

Open-pipe column is an air column that is open at both ends.

Overtones are all-natural frequencies higher than the fundamental frequency in a standing wave pattern.

P

Particle or corpuscular theory is Newton's theory, which states that light consists of particles that travel in straight lines.

Path length difference (PLD) is where the difference between two point sources, S_1 and S_2, and a point of interest, P, is given by the absolute value of the difference in length between the path length form S_1 to P and S_2 to P.

$$PLD = \left| PS_1 - PS_2 \right|$$

Period is the amount of time that the source takes to produce one full cycle (crest and trough) or the amount of time it takes one wavelength to pass a given point.

Periodic wave is the wave produced by the motion of an object in a repeated pattern over regular time intervals.

Photocell is an electrical device where high-frequency light falls on the negatively charged cathode; electrons are ejected and are attracted towards the anode.

Photoelectric effect refers to the ejection of electrons from the surface of a metal when it is exposed to electromagnetic radiation.

Photons are bundles in which the energy of light and other forms of electromagnetic radiation are concentrated. The amount of energy depends on the frequency of the radiation.

Pitch is an attribute of a sound that determines its position in a musical scale. Pitch is measured in frequency, but depends also on the loudness and quality of the sound.

Point charge is an idealized charged particle with no real size or spatial extent.

Point source is a small object disturbing the surface of the water at a single point, thus creating circular waves.

Position is the location of an object as measured from the origin of a frame of reference.

Principle of Complementarity states that "To understand a specific experiment with light, one must use either the wave or the photon theory but not both."

Principle of Superposition states that the resultant displacement of a given particle is equal to the sum of the displacements that would have been produced by each wave independently.

Proton is a positively charged particle found in the nucleus of all atoms.

Pulse is a single disturbance that travels through the medium.

Pure tone is a sound with a single frequency. Push-button telephones use pure tones.

Q

Qualitative observation is a verbal description of an object or phenomenon.

Quality is an attribute of a sound that is used to distinguish between sounds that are the same pitch and loudness.

Quantitative observation is a numerical description of an object or phenomena; quantitative observations typically involve measurements of a particular quantity.

Quantity is the measurable, countable, or comparable property or aspect of a thing. For example, the mass of an object is a quantity.

Quantum hypothesis was suggested by Max Planck who proposed that light was transmitted and absorbed in small bundles of energy called "quanta."

Quantum mechanical theory was developed by several scientists in the early 1900s. It combines the two major theories of light, suggesting that light does not always behave as a particle and light does not always behave as a wave.

R

Rarefactions (also called expansions) are sections where the medium is expanded (further apart than usual).

Real weightlessness occurs at a point in space where the gravitational field intensity is 0 N/kg.

Rectilinear propagation of light is light travelling in straight lines.

Reference points are points in a reference system from which quantities are measured. An example is the origin on the number line.

Reflection is the bouncing of a wave or light back into the medium in which it is travelling when the wave or light encounters a boundary between two media.

Refraction is the change in the speed and direction of a wave or light ray due to its travelling from one medium to another.

Resonance is a phenomenon that occurs when energy is added to a vibrating system at the same frequency as its natural frequency. During resonance, the amplitudes of the vibrations of the object become very large.

Resonant lengths are the specific lengths in a column in which resonance occurs, typically measured in fractions of wavelength.

Rest position is the position of an object, such as a simple pendulum or a mass on a spring, when it is allowed to hang freely and is not moving. This is sometimes called equilibrium position.

Resultant vector is the vector representing the sum of two or more vectors.

S

Scalar is a quantity that is specified in terms of magnitude only.

Scientific method is an orderly and systematic approach to gathering knowledge.

Scientific model is a mental picture that helps us understand something we cannot see or experience directly; it helps to explain observations.

Secondary wavelets are every point on a wavefront that can be considered as a point source of tiny secondary wavelets that spread out in front of the wave at the same speed as the wave itself.

Significant figures consist of those digits in a measurement that are known for certain, plus one uncertain digit.

Sine is a trigonometric function calculated by the ratio of the length of the opposite side over the length of the hypotenuse.

Slope is the steepness of a line, calculated as rise over run.

Solar wind consists mainly of protons and electrons emitted by the sun.

Solenoid is a closely wound helix of wire that acts as a magnet when current runs through the wire.

Sound spectrum is a plot of relative intensity versus frequency for the various frequencies that make up a sound.

South magnetic pole is the magnetic pole due to the Earth's magnetic field that is found near the south geographic pole. It is the Earth's magnetic pole towards which the south pole of the compass will point.

South pole is the end of the magnet that points towards the south.

Speed is a measure of how fast an object is travelling. Speed is calculated by the distance travelled over the time interval.

Standing wave is a stationary wave consisting of nodes and antinodes, formed when two equal waves travelling in opposite directions in a linear medium such as a rope or string pass through one another.

Static friction is a frictional force that acts to keep an object at rest.

Strong nuclear force is an attractive force that holds protons and neutrons in the nucleus of an atom.

Surface envelope is a tangent to all the secondary wavelets of a wavefront, and constitutes the new wavefront.

Symbolic mode uses symbols in the form of an equation to represent a relationship or phenomenon.

T

Tactile theory is a theory of the light based on the ability of the eye to "touch objects." Plato thought that light consisted of "streamers" or filaments, emitted by the eye, and that when these streamers came in contact with an object, it was possible to see the object.

Tangent is a line that intersects a curve at only one particular point. It is a trigonometric function calculated by the ratio of the length of the opposite side over the length of the adjacent side.

Terminal velocity is the constant velocity of a falling object at which the drag force of air resistance is equal in magnitude to the force of gravity.

Tesla is the unit for magnetic field (i.e., 1 tesla = 1 T = 1 N/A · m).

Theory provides a general explanation for the observations. It is a collection of ideas, validated by many scientists, that fit together to explain and predict a natural phenomenon.

Threshold frequency is when, in the photoelectric effect, electrons are ejected from a metal only if the frequency of the radiation is above a certain minimum value. This is called the threshold frequency, f_0.

Timbre refers to the sound quality or tone colour, and this depends on the spectrum of sound frequencies that produce a complex wave.

Time interval is the difference between two clock readings or, in other words, two instantaneous times: $\Delta t = t_2 - t_1$.

Transmission is the passing of a wave or light through the boundary between two media.

Transverse waves are waves in which the particles of the medium vibrate at right angles to the direction of motion of the disturbance.

Trigonometry is the mathematics of the relationships in triangles between the length of the sides and the angles.

Troughs are the parts of a transverse wave found below the normal rest position.

U

Ultrasonic sound waves are those sound waves with a frequency above the range of normal human hearing and therefore are above 20 kHz.

Unbalanced force occurs when a force in a given direction is not opposed by another force of the same magnitude but opposite direction acting on the same object.

Uniformly accelerated motion is a motion during which the acceleration is constant.

Unit current element consists of a straight wire of length 1 metre carrying a current of 1 ampere (1 A).

V

Variables are quantities or conditions that can affect the outcome of an experiment.

Vector is a quantity specified using both magnitude and direction.

Velocity is the rate of change of position. Velocity is calculated by the displacement over the time interval.

Visual mode uses a visual (picture or graphic) to represent a relationship or phenomenon.

W

Wavefront is a continuous crest or trough. It is a group of adjacent points in a two-dimensional wave that all have the same phase, usually indicated by the curve or line drawn across the crests.

Wave ray is a line at right angles to the wavefront indicating the direction of travel of the wavefront.

Wave theory is the theory of light, supported principally by Christiaan Huygens, which states that light behaves as a wave.

Wave is a disturbance that transfers energy through a medium.

Wavelength is the distance from a point on a wave to the same point on an adjacent wave.

Wave-particle duality is the theory that light behaves both as a particle and as a wave.

Weak nuclear force acts between certain subatomic particles, and is partly responsible for radioactivity.

Weight is the force that gravity exerts on an object because of its mass. It is calculated as the product of the mass of the object and the gravitational field intensity at that point.

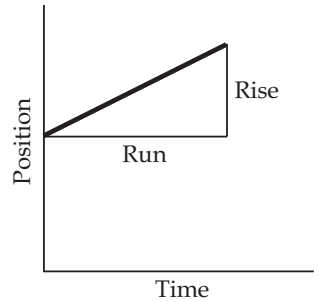
X

Y

Z

Appendix C: Kinematics Graphs Transformation Organizer

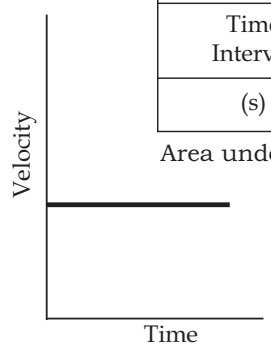
Going Down:
Take Slopes



Run	Rise	Slope
Time Interval	Displacement	Velocity
(seconds)	(metres)	(metres/second)

	Area : $\vec{d} = \vec{v}\Delta t$	$\overrightarrow{\text{Pos}}_2 = \overrightarrow{\text{Pos}}_1 + \vec{d}$
Time Interval	Displacement	Position at End of Interval
(s)	(m)	(m)

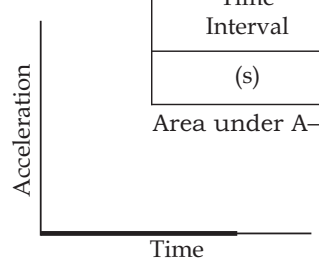
Area under V–T gives P–T graph.



Run	Rise	Slope
Time Interval	Change in Velocity	Acceleration
(seconds)	(metres)	(metres/second)^2

	Area: $\Delta\vec{v} = \vec{a}\Delta t$	$\vec{v}_2 = \vec{v}_1 + \Delta\vec{v}$
Time Interval	Change in Velocity	Velocity at End of Interval
(s)	(m/s)	(m/s)

Area under A–T gives V–T graph.



Going Up:
Take Areas

NOTES

Appendix D: List of SLOs Found in Each Lesson

This appendix has been developed for classroom teachers who are interested in knowing which specific learning outcomes are taught in each lesson in this Independent Study course.

Module 1

Lesson 2

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-2-02: Plan and perform an experiment to identify a linear pattern between two variables and state the pattern as a mathematical relationship (law).
Include: visual, numeric, graphical, and symbolic modes of representation

Lesson 3

S3P-0-2d: Estimate and measure accurately, using Système International (SI) units.

S3P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data collection methods.
Include: discrepancies in data and sources of error

S3P-3-01: Differentiate between, and give examples of, scalar and vector quantities.
Examples: distance, speed, mass, time, temperature, volume, weight, position, displacement, velocity, acceleration, force…

Lesson 4

S3P-3-01: Differentiate between, and give examples of, scalar and vector quantities.
Examples: distance, speed, mass, time, temperature, volume, weight, position, displacement, velocity, acceleration, force…

S3P-3-02: Differentiate among position, displacement, and distance.

S3P-3-03: Differentiate between the terms "an instant" and "an interval" of time.

Lesson 5

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-3-04: Analyze the relationships among position, velocity, acceleration, and time for an object that is accelerating at a constant rate.
Include: transformations of position-time, velocity-time, and acceleration-time graphs using slopes and areas

S3P-3-05: Compare and contrast average and instantaneous velocity for nonuniform motion.
Include: slopes of chords and tangents

Lesson 6

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-3-04: Analyze the relationships among position, velocity, acceleration, and time for an object that is accelerating at a constant rate.
Include: transformations of position-time, velocity-time, and acceleration-time graphs using slopes and areas

Lesson 7

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2f: Record, organize, and display data, using an appropriate format. Include: labelled diagrams, tables, graphs.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-3-04: Analyze the relationships among position, velocity, acceleration, and time for an object that is accelerating at a constant rate.
Include: transformations of position-time, velocity-time, and acceleration-time graphs using slopes and areas

Lesson 9

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-2f: Record, organize, and display data, using an appropriate format. Include: labelled diagrams, tables, graphs.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-3-06: Illustrate, using velocity-time graphs of uniformly accelerated motion, that average velocity can be represented as $\vec{v}_{\text{avg}} = \frac{\vec{d}}{\Delta t}$ and that displacement can be calculated as $\vec{d} = \frac{(\vec{v}_1 + \vec{v}_2)}{2}\Delta t$.

Lesson 10

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-3-07: Solve problems, using combined forms of:

$$\vec{v}_{\text{avg}} = \frac{\vec{v}_1 + \vec{v}_2}{2},\ \vec{v}_{\text{avg}} = \frac{\vec{d}}{\Delta t},\ \vec{a}_{\text{avg}} = \frac{\Delta \vec{v}}{\Delta t}$$

Module 2

Lesson 1

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-3-01: Differentiate between, and give examples of, scalar and vector quantities.
Examples: distance, speed, mass, time, temperature, volume, weight, position, displacement, velocity, acceleration, force…

Lesson 2

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-3-01: Differentiate between, and give examples of, scalar and vector quantities.
Examples: distance, speed, mass, time, temperature, volume, weight, position, displacement, velocity, acceleration, force…

Lesson 3

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-3-01: Differentiate between, and give examples of, scalar and vector quantities.
Examples: distance, speed, mass, time, temperature, volume, weight, position, displacement, velocity, acceleration, force…

Lesson 4

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data collection methods.
Include: discrepancies in data and sources of error

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

Module 3

Lesson 1

S3P-3-08: Identify the four fundamental forces of nature.

Lesson 2

S3P-3-10: Define the unit of force as the newton.

S3P-3-11: Define $\vec{F}_{\text{NET}}$ as the vector sum of all forces acting on a body.
Include: force of friction, normal force, gravitational force, applied forces

Lesson 3

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-3-09: Perform an experiment to demonstrate Newton's Second Law $\vec{F}_{\text{NET}} = m\vec{a}$.

Lesson 4

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-3-12: Construct free-body diagrams to determine the net force for objects in various situations.
Include: balanced and unbalanced forces, inclined planes

Lesson 5

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-3-12: Construct free-body diagrams to determine the net force for objects in various situations.
Include: balanced and unbalanced forces, inclined planes

S3P-3-13: Solve problems, using Newton's Second Law and the kinematics equations from S3P-3-07.
Include: forces applied along a straight line and perpendicular forces

Lesson 6

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-3-11: Define $\vec{F}_{NET}$ as the vector sum of all forces acting on a body.
Include: force of friction, normal force, gravitational force, applied forces

S3P-3-12: Construct free-body diagrams to determine the net force for objects in various situations.
Include: balanced and unbalanced forces, inclined planes

S3P-3-13: Solve problems, using Newton's Second Law and the kinematics equations from S3P-3-07.
Include: forces applied along a straight line and perpendicular forces

Module 4

Lesson 1

S3P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-4-01: Define the gravitational field qualitatively as the region of space around a mass where another point mass experiences a force.

S3P-4-02: Diagram the Earth's gravitational field, using lines of force.

S3P-4-03: Define the gravitational field quantitatively as a force per unit mass.

Lesson 2

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-4-04: Compare and contrast the terms "mass" and "weight."

S3P-4-05: Describe, qualitatively and quantitatively, apparent weight changes in vertically accelerating systems.
Examples: elevators, spacecraft…

Lesson 3

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2d: Estimate and measure accurately, using Système International (SI) units.

S3P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data collection methods.
Include: discrepancies in data and sources of error

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-4-07: Perform an experiment to calculate $\vec{g}$ near the surface of the Earth.

Lesson 4

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-4-08: Solve free-fall problems.

Lesson 5

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-4-09: Describe terminal velocity, qualitatively and quantitatively

Lesson 6

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-4-10: Define the coefficient of friction (μ) as the ratio of the force of friction and the normal force.

S3P-4-11: Distinguish between static and kinetic friction.

S3P-4-12: Compare the effects of the normal force, materials involved, surface area, and speed on the force of friction.

S3P-4-13: Solve problems with the coefficient of friction for objects on a horizontal surface.

Module 5

Lesson 1

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-4-14: Define the electric field qualitatively as the region of space around a charge where a positive test charge experiences a force.

S3P-4-15: Diagram electric fields using lines of force with respect to a positive test charge.
Include: single point charges (positive and negative), near two like charges, near two unlike charges, between a single charge and a charged plate, between two oppositely charged parallel plates

S3P-4-16: Define the electric field quantitatively as a force per unit charge $\vec{E} = \frac{\vec{F}}{q}$ and solve problems using the unit field concept $\left(\vec{F} = q\vec{E}\right)$.

Lesson 2

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-4-16: Define the electric field quantitatively as a force per unit charge $\left(\vec{E} = \frac{\vec{F}}{q}\right)$ and solve problems using the unit field concept $\left(\vec{F} = q\vec{E}\right)$.

S3P-4-19: Define the elementary charge and convert between elementary charges and coulombs.
Include: $q = Ne$

Lesson 3

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-1a: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-4-16: Define the electric field quantitatively as a force per unit charge $\left(\vec{E} = \frac{\vec{F}}{q}\right)$ and solve problems using the unit field concept $\left(\vec{F} = q\vec{E}\right)$.

S3P-4-17: Solve problems for the motion of charges between parallel plates where $\vec{F}_{\text{NET}} = \vec{F}_e + \vec{F}_g$.

Lesson 4

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-1a: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

S3P-0-2h: Analyze problems, using vectors.
Include: adding and subtracting vectors in straight lines and at right angles, vector components

S3P-4-16: Define the electric field quantitatively as a force per unit charge $\left(\vec{E} = \frac{\vec{F}}{q}\right)$ and solve problems using the unit field concept $\left(\vec{F} = q\vec{E}\right)$

S3P-4-17: Solve problems for the motion of charges between parallel plates where $\vec{F}_{\text{NET}} = \vec{F}_e + \vec{F}_g$.

S3P-4-18: Describe a simplified version of Millikan's experiment for the determination of the elementary charge (solve for charge when $\vec{F}_e = \vec{F}_g$).

S3P-4-19: Define the elementary charge and convert between elementary charges and coulombs.
Include: $q = \text{N}e$

Module 6

Lesson 1

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-4-20: Define the magnetic field as the region of space around a magnet where another magnet will experience a force.

S3P-4-21: Demonstrate and diagram magnetic fields, using lines of force.
Include: bar magnet, horseshoe magnet, between like poles, between unlike poles

S3P-4-22: Describe the concept of magnetic poles and demonstrate that like poles repel and unlike poles attract.

Lesson 2

S3P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-4-23: Describe magnetism, using the domain theory.
Include: ferromagnetic materials, the attraction of iron objects to north and south poles

S3P-4-24: Investigate the influence and effects of the magnetic field of the Earth.
Include: auroras, magnetic declination and inclination

Lesson 3

S3P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

S3P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as a result of new innovations in technology.

S3P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

S3P-4-25: Describe and demonstrate the phenomenon of electromagnetism.

S3P-4-26: Diagram and describe qualitatively the magnetic field around a current-carrying wire.
Include: direction and intensity of the field

S3P-4-27: Diagram and describe qualitatively the magnetic field of a solenoid.
Include: direction and intensity of the field

S3P-4-28: Describe and demonstrate the function of an electromagnet.
Include: common applications of electromagnets

Lesson 4

S3P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data collection methods.
Include: discrepancies in data and sources of error

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-4-29: Perform a lab to demonstrate that $\vec{B} \; \alpha \; I$ for an electromagnetic field.

Lesson 5

S3P-4-30: Describe the force on a current-carrying conductor in a magnetic field.
Include: $\vec{F}_B = \vec{B}IL \sin\theta$

S3P-4-31: Define the magnetic field quantitatively as a force per unit current element (i.e., $\vec{B} = \frac{\vec{F}_B}{IL}$, where IL is a current element).

S3P-4-32: Solve problems, using $\vec{F}_B = \vec{B}IL$.

Lesson 6

This lesson is a review of the entire module. Therefore, it refers to each SLO in Module 6.

Module 7

Lesson 1

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2c: Formulate operational definitions of major variables or concepts.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-1-01: Describe a wave as a transfer of energy.
Include: medium, mechanical wave, pulse, periodic wave

S3P-1-02: Describe, demonstrate, and diagram the characteristics of transverse and longitudinal waves.
Include: crest, trough, amplitude, wavelength, compression, rarefaction

S3P-1-03: Compare and contrast the frequency and period of a periodic wave.
Include: $T = \frac{1}{f}$

S3P-1-04: Derive and solve problems, using the wave equation ($v = f\lambda$).

Lesson 2

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-1-05: Describe, demonstrate, and diagram the transmission and reflection of waves travelling in one dimension.
Include: free and fixed ends, different media

Lesson 3

S3P-0-2d: Estimate and measure accurately, using Système International (SI)units.

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs.

S3P-1-06: Use the principle of superposition to illustrate graphically the result of combining two waves.
Include: constructive and destructive interference, nodes, antinodes, standing waves

Lesson 4

S3P-1-06: Use the principle of superposition to illustrate graphically the result of combining two waves.
Include: constructive and destructive interference, nodes, antinodes, standing waves

S3P-1-07: Investigate the historical development of a significant application of communications technology that uses waves.
Examples: telephone, radio, television, cell phone, communications satellite, motion detectors, remote controls…

Module 8

Lesson 1

S3P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

S3P-0-2f: Record, organize, and display data, using an appropriate format.
Include: labelled diagrams, tables, graphs.

S3P-0-2i: Select and integrate information obtained from a variety of sources.
Include: print, electronic, and/or specialist sources, resource people.

S3P-0-3c: Identify social issues related to science and technology, taking into account human and environmental needs and ethical considerations.

S3P-1-08: Describe and give examples of two-dimensional waves.

S3P-1-09: Compare and contrast a wavefront and a wave ray.

S3P-1-10: Describe, demonstrate, and diagram the reflection of plane (straight) and circular waves.
Include: linear and parabolic reflectors

Lesson 2

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-1-11: Describe, demonstrate, and diagram the refraction of plane (straight) waves.

S3P-1-12: Derive Snell's Law using the relationships between wavelength, velocity, and the angles of incidence and refraction.

Lesson 3

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-1-14: Describe, demonstrate, and diagram diffraction of water waves.

Lesson 4

S3P-0-2f: Record, organize, and display data, using an appropriate format. Include: labelled diagrams, tables, graphs.

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-1-15: Describe, demonstrate, and diagram how constructive and destructive interference produce an interference pattern from two point sources.

S3P-1-16: Derive the path difference relationship for the interference pattern from two point $\left|\overline{P_nS_1} - \overline{P_nS_2}\right| = \left(n - \frac{1}{2}\right)\lambda$.

Lesson 5

S3P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

S3P-0-2i: Select and integrate information obtained from a variety of sources. Include: print, electronic, and/or specialist sources, resource people

S3P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as a result of new innovations in technology.

S3P-2-15: Describe light as an electromagnetic wave.

S3P-1-07: Investigate the historical development of a significant application of communications technology that uses waves.
Examples: telephone, radio, television, cell phone, communications satellite, motion detectors, remote controls…

Module 9

Lesson 1

S3P-0-2i: Select and integrate information obtained from a variety of sources. Include: print, electronic, and/or specialist sources, resource people.

S3P-0-3a: Analyze, from a variety of perspectives, the risks and benefits to society and the environment when applying scientific knowledge or introducing technology.

S3P-0-4d: Develop a sense of personal and shared responsibility for the impact of humans on the environment, and demonstrate concern for social and environmental consequences of proposed actions.

S3P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

S3P-1-17: Investigate to analyze and explain how sounds are produced, transmitted, and detected, using examples from nature and technology.
Examples: production of sound by a vibrating object, drums, guitar strings, cricket, hummingbird, dolphin, piezocrystal, speakers…

S3P-1-23: Compare the speed of sound in different media, and explain how the type of media and temperature affect the speed of sound.

S3P-1-26: Describe the diverse applications of sound waves in medical devices, and evaluate the contribution to our health and safety of sound-wave-based technologies.
Examples: hearing aid, ultrasound, stethoscope, cochlear implants…

Lesson 2

S3P-1-20: Describe and explain in qualitative terms what happens when sound waves interact (interfere) with one another.
Include: production of beats

S3P-1-21: Experiment to analyze the principle of resonance and identify the conditions required for resonance to occur.
Include: open- and closed-column resonant lengths

Lesson 3

S3P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

S3P-1-23: Compare the speed of sound in different media, and explain how the type of media and temperature affect the speed of sound.

S3P-1-24: Explain the Doppler effect, and predict in qualitative terms the frequency change that will occur for a stationary and a moving observer.

Lesson 4

S3P-0-2d: Estimate and measure accurately, using Système International (SI) units.

S3P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data collection methods.
Include: discrepancies in data and sources of error

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

S3P-1-22: Experiment to calculate the speed of sound in air.

Lesson 5

S3P-0-3c: Identify social issues related to science and technology, taking into account human and environmental needs and ethical considerations.

S3P-0-3d: Use the decision-making process to address an STSE issue.

S3P-0-4c: Demonstrate confidence in carrying out scientific investigations and in addressing STSE issues.

S3P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

S3P-1-18: Use the decision-making process to analyze an issue related to noise in the environment.
Examples: sonic boom, traffic noise, concert halls, loudspeakers, leaf blowers…

S3P-1-25: Define the decibel scale qualitatively, and give examples of sounds at various levels.

S3P-1-27: Explain in qualitative terms how frequency, amplitude, and wave shape affect the pitch, intensity, and quality of tones produced by musical instruments.
Include: wind, percussion, stringed instruments

S3P-1-28: Examine the octave in a diatonic scale in terms of frequency relationships and major triads.

Module 10

Lesson 1

S3P-0-1a: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

S3P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

S3P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

S3P-0-1e: Differentiate between how scientific theories explain natural phenomena and how scientific laws identify regularities and patterns in nature.

S3P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as a result of new innovations in technology.

S3P-2-01: Use a mystery container activity to outline the relationships among observations, inferences, models, and laws.

S3P-2-03: Describe the relationships among knowledge claims, evidence, and evidential arguments.
Include: atomic model of matter, a relevant advertising claim

S3P-2-04: Outline the tentative nature of scientific theories.
Include: speculative and robust theories

S3P-2-05: Describe the characteristics of a good theory.
Include: accuracy, simplicity, and explanatory power

Lesson 2

S3P-2-06: Outline several historical models used to explain the nature of light.
Include: tactile, emission, particle, wave models

S3P-2-07: Summarize the early evidence for Newton's particle model of light.
Include: propagation, reflection, refraction, dispersion

S3P-2-08: Experiment to show the particle model of light predicts that the velocity of light in a refractive medium is greater than the velocity of light in an incident medium ($v_r > v_i$).

Lesson 3

S3P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

S3P-2-09: Outline the historical contribution of Galileo, Roemer, Huygens, Fizeau, Foucault, and Michelson to the development of the measurement of the speed of light.

Lesson 4

S3P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

S3P-2-11: Summarize the evidence for the wave model of light.
Include: propagation, reflection, refraction, partial reflection/refraction, diffraction, dispersion

S3P-2-12: Compare the velocity of light in a refractive medium predicted by the wave model with that predicted in the particle model.

Lesson 5

S3P-2-13: Outline the geometry of a two-point-source interference pattern, using the wave model.

S3P-2-15: Describe light as an electromagnetic wave.

Lesson 6

S3P-0-1a: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

S3P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

S3P-0-1d: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

S3P-2-16: Discuss Einstein's explanation of the photoelectric effect qualitatively.

S3P-2-17: Evaluate the particle and wave models of light and outline the currently accepted view.
Include: the principle of complementarity

Grade 11 Physics EQUATION SHEET

MATHEMATICS

$$\sin\theta = \frac{Opp}{Hyp}$$

$$\cos\theta = \frac{Adj}{Hyp}$$

$$\tan\theta = \frac{Opp}{Adj}$$

$$Hyp^2 = (Leg\,1)^2 + (Leg\,2)^2$$

KINEMATICS

$$v = \frac{d}{\Delta t}$$

$$\Delta = 2^{nd}\ value - 1^{st}\ value$$

$$d = pos_2 - pos_1$$

$$\vec{v} = \frac{d}{\Delta t} = \frac{pos_2 - pos_1}{\Delta t}$$

$$\vec{a} = \frac{\Delta v}{\Delta t} \text{ or } \vec{a} = \frac{v_2 - v_1}{\Delta t} \text{ or}$$

$$\vec{v}_2 = \vec{v}_1 + \vec{a}\,\Delta t$$

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\,\Delta t$$

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

WAVES

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{1-2}$$

$$PLD = |PS_1 - PS_2|$$

f = 1/T

T = 1/f

v = fλ

LIGHT

$$PLD = |PS_1 - PS_2|$$

$$\frac{\Delta x}{L} = \frac{\lambda}{d}$$

SOUND

v = 332 + 0.6 T

Closed-pipe resonant length

$$L_n = \left(\frac{(2n-1)}{4}\right)\lambda$$

Open-pipe resonant length

$$L_n = \left(\frac{n}{2}\right)\lambda$$

$$f_B = |f_2 - f_1|$$

DYNAMICS

$$F_{NET} = ma$$

$$F_{NET} = \sum Forces$$

$$F_F = \mu F_N$$

GRAVITY

$$F_G = mg$$

$$F_N + F_G = F_{NET} = ma$$

ELECTRICITY

$$\vec{E} = \frac{F_E}{q}$$

q=Ne

$$E = \frac{V}{d}$$

MAGNETISM

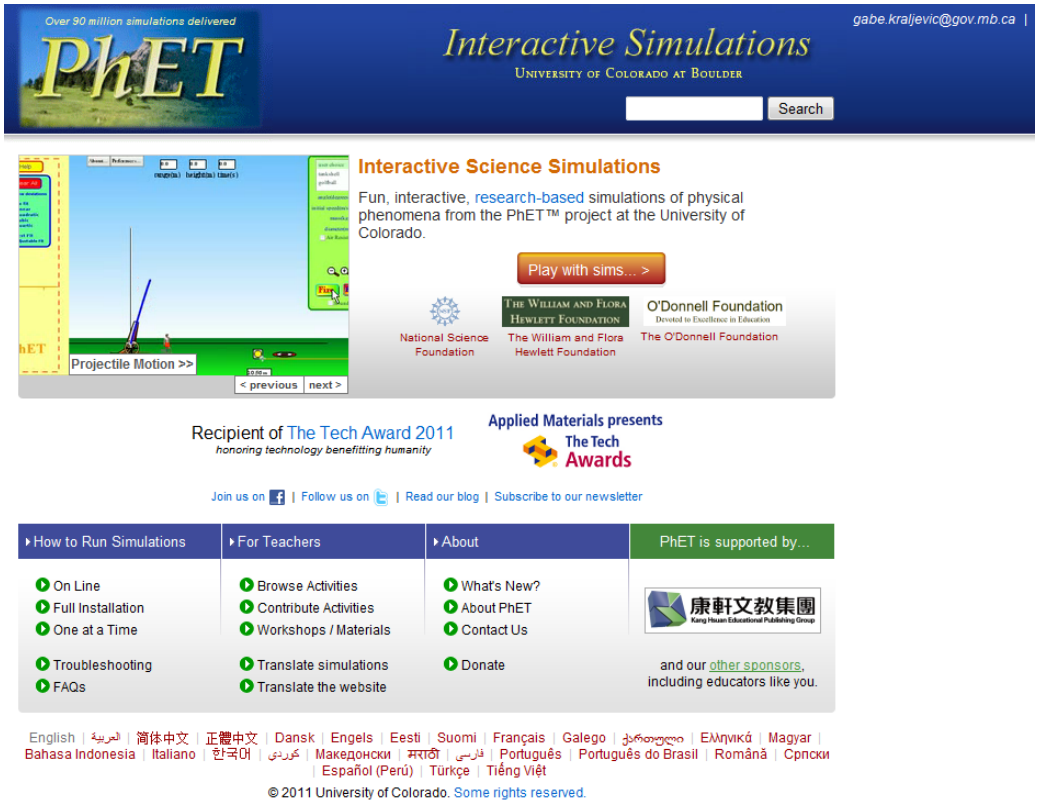
Grade 11 Physics EQUATION SHEET

$F_B = BIL\sin\theta$

Applets and Apps for Physics

PhET (Physics Education Technology) Project - University of Colorado at Boulder

Hundreds of Java applets and Flash animations on a wide variety of physics and chemistry topics. Teachers have developed and posted lessons, worksheets, activities and clicker questions that go along with many of the simulations. Many of these shared resources are in Word format.



Most of the simulations are translated into French and many other languages.

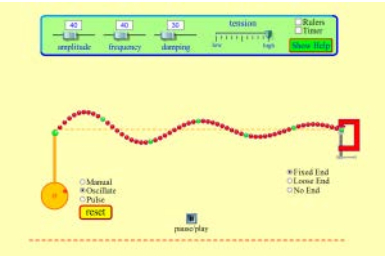
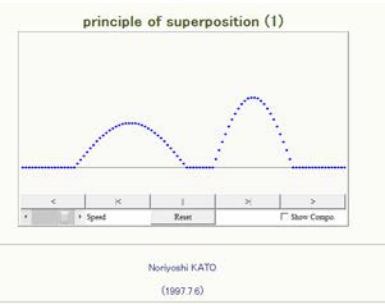
Download the simulations, run them off their website or embed them directly into your own websites or html pages.

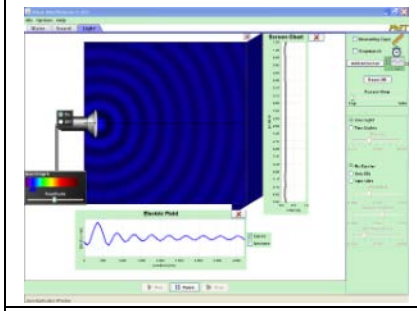
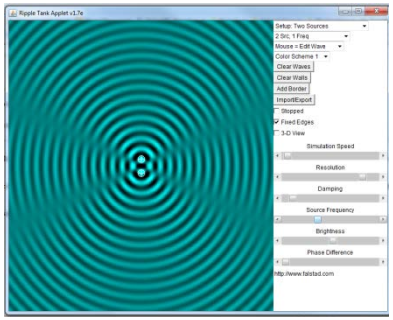
Source codes are free and open.

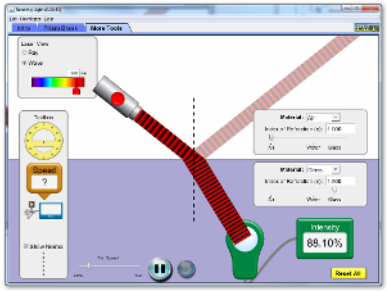
Continually updated.

Topic 1: Waves

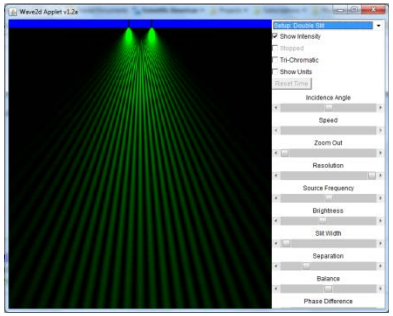
Topic 1.1: Waves in One Dimension

PhET: Waves on a String 	https://phet.colorado.edu/en/simulation/wave-on-a-string http://tinyurl.com/9omeqf7	*"Watch a string vibrate in slow motion. Wiggle the end of the string and make waves, or adjust the frequency and amplitude of an oscillator. Adjust the damping and tension. The end can be fixed, loose, or open." –PhET website*	***French available***	
Superposition of Waves 1 	http://www2.biglobe.ne.jp/~norimari/science/JavaEd/e-wave2.html http://tinyurl.com/2rx343	Investigate superposition of waves. Simple simulation with only one choice of wave form.		

	http://www2.swgc.mun.ca/physics/physlets/wave.html http://tinyurl.com/9k7g65m	Very simple depiction of a transverse wave.		
Topic 1.2: Waves in Two Dimensions				
PhET: Wave Interference 	https://phet.colorado.edu/en/simulation/wave-interference http://tinyurl.com/8c37ube	This applet provides a complete ripple tank environment. Add barriers, slits. Measure time, wavelength. Adjust frequency, amplitude, one- or two-sources.	***French available***	
Falstad: Ripple Tank 	http://www.falstad.com/ripple/ http://tinyurl.com/5kjov	Full control of a simulated ripple tank. Change the mouse menu to "Mouse=Edit Walls" to add barriers and investigate reflection, refraction, etc. Be sure to check 3D to get a full sense of interference. The 3D screen can be spun around using the mouse.		***iPad version available***

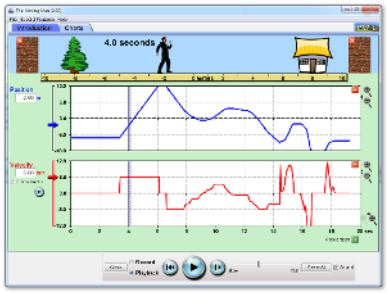
PhET: Bending Light 	https://phet.colorado.edu/en/simulation/bending-light http://tinyurl.com/8k6o3pv	A complete Snell's law simulation. Control angle of incidence, indices of refraction, measure angles, wavelengths. In another tab of this applet, you can add prisms of different shapes.	***French available***	
Topic 1.3: Sound				
The Soundry	http://library.thinkquest.org/19537/ http://tinyurl.com/2cdtox	Click on the "Sound Lab" button on the home page to access several Java applets that allow students to investigate harmonics, beats and the effect of wave shape on sound. The "Doppler effect" applet was not useful and the "Sound Scene" applet didn't work at all in Firefox or IE8.		
PhET: Wave Interference	https://phet.colorado.edu/en/simulation/wave-interference http://tinyurl.com/8c37ube	Use the "Sound" tab of this simulation to investigate sound waves.	***French available***	

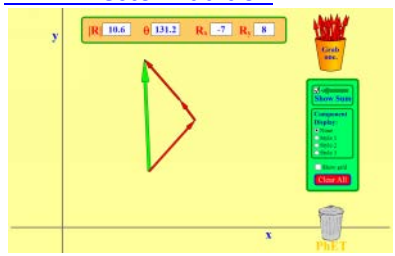
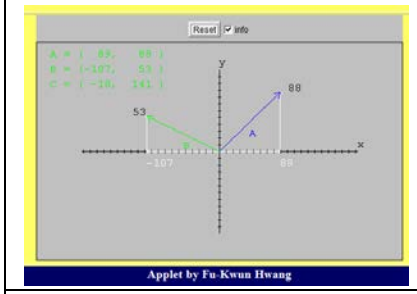
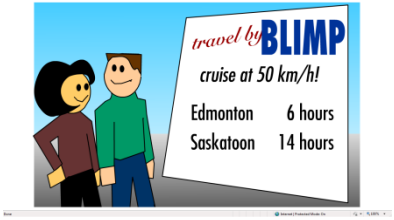
PhET: Sound	https://phet.colorado.edu/en/simulation/sound http://tinyurl.com/9rmpxjf	Change frequency, amplitude of sound waves with audible tones. Investigate how removing air will effect the transmission of waves. Interference and reflection of sound waves can also be investigated.	***French available***	
Topic 2: The Nature of Light				
Topic 2.1: Models, Laws, and Theories				
Topic 2.2: Particle and Wave Models of Light				
PhET: Wave Interference	https://phet.colorado.edu/en/simulation/wave-interference http://tinyurl.com/8c37ube	Play with Young's double slit experiment in the "Light" tab of this simulation	***French available***	

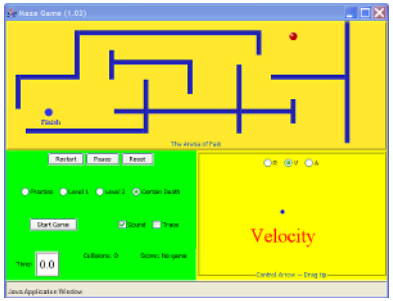
Falstad: 2D Wave Simulation 	http://www.falstad.com/wave2d/ http://tinyurl.com/bo8hlnd	Another Young's double slit experiment with many, many options and variable controls.		

Topic 3: Mechanics

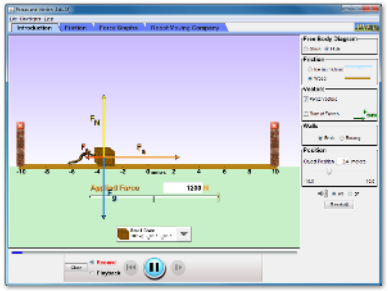
Topic 3.1: Kinematics

Phet: Moving Man 	https://phet.colorado.edu/en/simulation/moving-man http://tinyurl.com/9nf677z	Manually manipulate the man's position on the 'number line' or set values (positive or negative) for velocity, initial position and acceleration. x-t, v-t and a-t graphs will automatically be generated. You can replay the motion and watch the graphs change as the man goes through his moves. Clicking on the "Show Vectors" boxes will show how the velocity vector will change with constant acceleration. This would work for grade 10 physics units.	***French available***	***Useful for Grade 10***

PhET: Vector Addition 	https://phet.colorado.edu/sims/vector-addition/vector-addition_en.html http://tinyurl.com/cpsykbk	This applet will resolve any vector you draw into its x- and y-components. Clicking on the 'styles' buttons will show different methods of indicating component vectors. The "Show Sum" was acting funny in IE8. A little disappointing, considering the other applets at PhET.	***French available***	
Vector Addition 	http://ephysics.physics.ucla.edu/ntnujava/vector/evector_addition.htm http://tinyurl.com/9gymuu9	This applet has the user draw two vectors and it then animates the addition using parallelogram method. This may help students visualize the addition better.		
	http://canu.ucalgary.ca/map/content/vectors/basic/glimpse/ http://tinyurl.com/9qxseeq	Cute video that explains vector addition.		

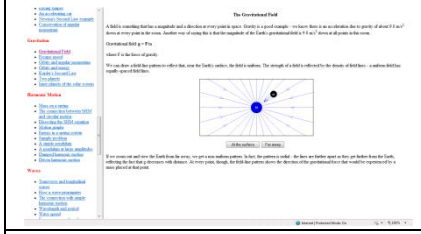
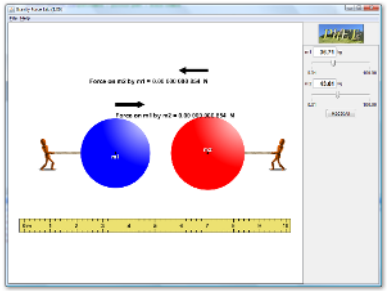
PhET: Maze Game 	https://phet.colorado.edu/en/simulation/maze-game http://tinyurl.com/9m5p4yj	By stretching a position, velocity or acceleration vector, you manipulate a small red dot through a maze to end up on a blue dot. The student is to develop a better understanding of the vector nature of motion. This one is a little weak.	***French available***	
Boston University: Pre-labs for Introductory Physics Experiments	http://physics.bu.edu/~duffy/semester1/semester1.html http://tinyurl.com/8zyfqnq	There are several, simple simulations that deal with motion, graphs, forces, vectors, friction, etc. In general, these are quite simple but they include content and may be worth your while.		
Minds•on Physics Simulations	http://users.hal-pc.org/~clement/Simulations/Physlets/MOP/minds_on_physics_physlets.html http://tinyurl.com/d2hhhlu	Several, simple simulations involving different situations of moving objects with associated graphs generated as you watch the motion.		

Topic 3.2: Dynamics

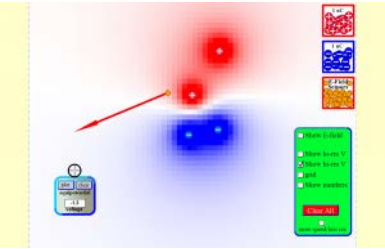
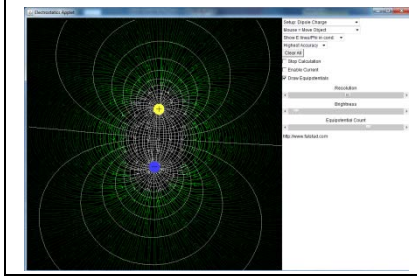
PhET: Vector Addition	https://phet.colorado.edu/sims/vector-addition/vector-addition_en.html http://tinyurl.com/cpsykbk	This applet will resolve any vector you draw into its x- and y-components. Clicking on the 'styles' buttons will show different methods of indicating component vectors. The "Show Sum" was acting funny in IE8. A little disappointing, considering the other applets at PhET.	***French available***	
PhET: Forces and Motion 	https://phet.colorado.edu/en/simulation/forces-and-motion http://tinyurl.com/9smvn5v	*"Explore the forces at work when you try to push a filing cabinet. Create an applied force and see the resulting friction force and total force acting on the cabinet. Charts show the forces, position, velocity, and acceleration vs. time. View a Free Body Diagram of all the forces (including gravitational and normal forces)."*	***French available***	***Grade 10***

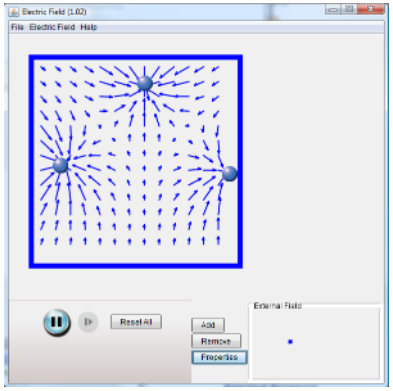
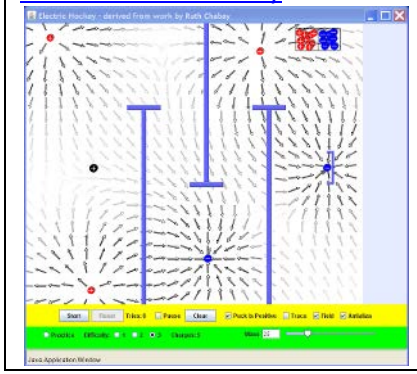
Topic 4: Fields

Topic 4.1: Gravitational Fields

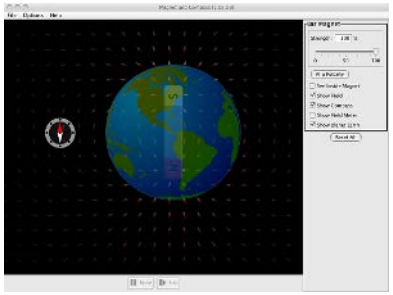
Gravitational Fields 	http://physics.bu.edu/~duffy/semester1/semester1.html http://tinyurl.com/5yap6	Click on "Gravitational Field" to get a small simulation of the force of gravity near to the Earth's surface and further away in space. A bit of content included. Not much.		
PhET: Gravity-Force Lab 	https://phet.colorado.edu/en/simulation/gravity-force-lab http://tinyurl.com/9tdyjzs	Not really in depth. More of a visualization of gravitational attraction.	***French available***	

Topic 4.1: Electric Fields

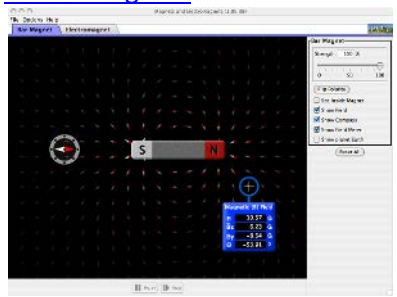
PhET: Charges and Fields 	https://phet.colorado.edu/en/simulation/charges-and-fields http://tinyurl.com/c7v4z58	This is an excellent applet that allows students to qualitatively and quantitatively investigate electrostatic fields around charges and groups of charges. Measure potential and plot equipotential lines with the volt meter, visualize and quantify the field strength using "E field sensors." Be sure to check off "Show numbers."	***French available***	
Falstad: Electrostatics Simulation 	http://www.falstad.com/emstatic/index.html http://tinyurl.com/cylbqom	Show field lines, equipotential lines and much more in this high-end electrostatics simulation. Use "Setup: Dipole Charge" to get opposite charges.		

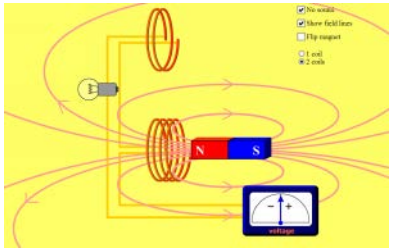
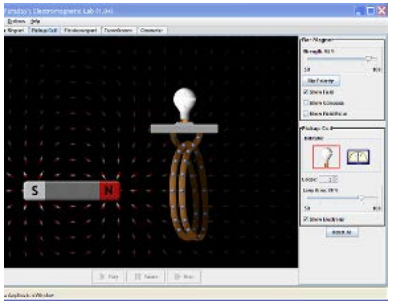
Phet: Field of Dreams 	https://phet.colorado.edu/en/simulation/efield http://tinyurl.com/9jgmagp	What happens to charged masses as they are let go? What if we impose an external field to the area? Use the "Electric Field" menu to increase or decrease the number of field lines. To change the charge and mass of objects click on the "Properties" button before you click on "Add". If you pause the action before you add your objects you can visualize the changes in electric fields as you move the objects closer and further apart.	***French available***	
PhET: Electric Hockey 	https://phet.colorado.edu/en/simulation/electric-hockey http://tinyurl.com/968n8jc	Add negative and positive charges to a playing field to manoeuvre a charged 'puck' through a maze. More fun than anything. Your students might end up spending all their time playing with this one! If you need to delete a charge drag it off the edge of the 'rink'.	***French available***	

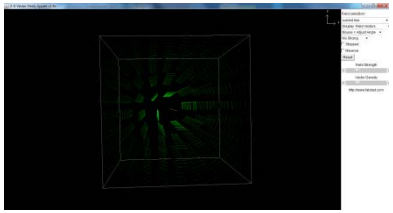
Topic 4.1: Magnetic Fields

Phet: Magnet and Compass 	https://phet.colorado.edu/en/simulation/magnet-and-compass http://tinyurl.com/8e82mkb	Examine the magnetic fields around a bar magnet or planet Earth (as an example of a bar magnet). A virtual magnetometer will give you values for B. Increasing the size and spacing of the needles under the "Options" menu will help show field lines better. This simulation is exactly the same as the first tab of the Magnets and Electromagnets and simulation, which you may just want to go to directly.	***French available***	

Topic 4.1: Electromagnetism

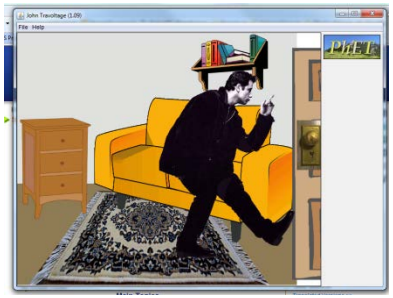
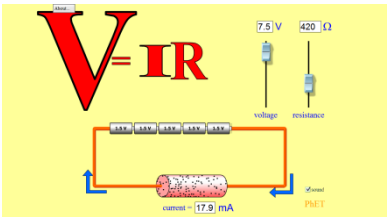
PhET: Magnets and Electromagnets 	https://phet.colorado.edu/en/simulation/magnets-and-electromagnets http://tinyurl.com/9uhjhvq	The first tab is exactly the same as Magnet and Compass simulation and almost entirely the same as the first tab of Faraday's Electromagnetic Lab. In the "Electromagnet" tab you can visualize the fields around loops of wire with either DC or AC current. Note the little slider on the battery that allows you to manipulate the voltage. You can adjust the number of loops as well. A magnetometer can be used to measure field strength at various points. In AC, you may want to play with the x-axis of the sine curve to slow down the simulation. The pause and step features help with visualization and reading the field strengths.	***French available***	

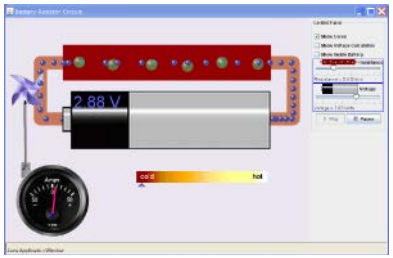
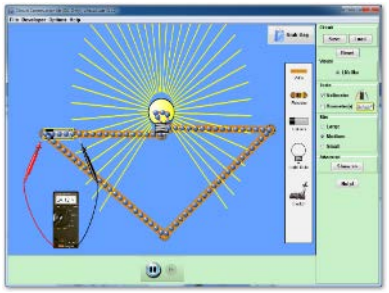
PhET: Faraday's Law 	https://phet.colorado.edu/en/simulation/faradays-law http://tinyurl.com/9cpg94a	A qualitative demo of moving a bar magnet through loops of wire. The number of loops and speed that you move the magnet through them affect the brightness of the bulbs. The visualization of the field lines crossing the wires is probably the best feature of this simulation, which can easily be done hands on instead.	***French available***	
PhET: Faraday's Electromagnetic Lab 	https://phet.colorado.edu/en/simulation/faraday http://tinyurl.com/8ea8nj3	This is a more full-featured simulation compared to Faraday's Law simulation. Change variables like field strength, number of loops and loop area in a simple transformer and generator. Although you can measure field strength, this is primarily a qualitative simulation.	***French available***	

Falstad: 3D Magnetostatic Fields 	http://www.falstad.com/vector3dm/ http://tinyurl.com/3znjc74	Choose "Display: Field Lines" and play with the vector density to show magnetic fields around straight conductors, solenoids, paired conductors and many more combinations and orientations. This simulation requires pretty good 3d visualization skills. One criticism: Field strength is indicated by the brightness of the vectors, not the number or length. Because of this, it is sometimes difficult to see changes to the field strength when playing with variables. Use the mouse to rotate the simulation.		

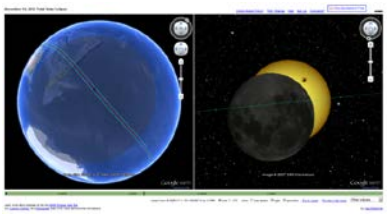
PhET Applets that just don't cut it:

Unit 3: Nature of Electricity

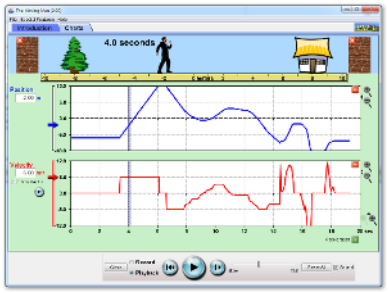
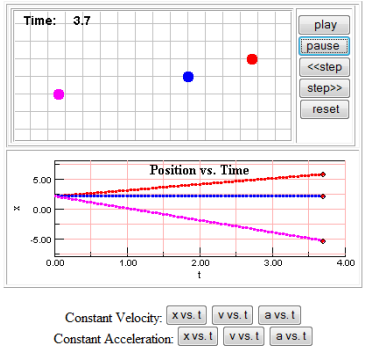
PhET: John Travoltage 	https://phet.colorado.edu/en/simulation/travoltage http://tinyurl.com/99emwp6	Cheesy look at what happens when you get a static shock.		
PhET: Ohm's Law 	https://phet.colorado.edu/sims/ohms-law/ohms-law_en.html http://tinyurl.com/9h85uwg	Simple, yet visual way of looking at Ohm's law.		

PhET: Battery – Resistor Circuit 	https://phet.colorado.edu/en/simulation/battery-resistor-circuit http://tinyurl.com/9b5ln97	Look at resistance from a particle point of view. Also investigate the effects of resistance on current, heat, voltage.		
PhET: Circuit Construction Kit 	https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab http://tinyurl.com/9owd7jd	Excellent simulator that allows you to create DC circuits, use virtual voltmeters and ammeters. You can even investigate short circuits. The brightness of light bulbs changes with voltage and current. Flip between schematic Right clicking on objects and junctions is useful here.	**French Available**	

Unit 4: Exploration of the Universe

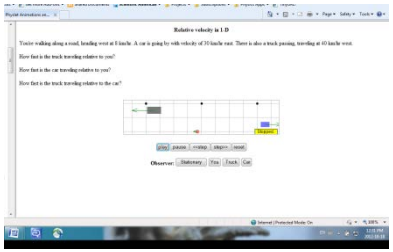
HeyWhatsThat 	http://www.heywhatsthat.com/eclipses.html http://tinyurl.com/26ozdtg	Shows the view of sun from different locations during an eclipse. It gives a good idea of how large the shadow Requires Google Earth to be installed on your computer.		
The Scale of the Universe 2	http://htwins.net/scale2/lang.html http://tinyurl.com/85sbjp2	Starting at the scale of 'metres', the user can slide downward or upward in size to visualize the full scale of objects in the universe. This is stunning.	***Available in French***	
	http://www.atlasoftheuniverse.com/ http://tinyurl.com/3rv3c4		***Available in French***	

Cluster 3: In Motion

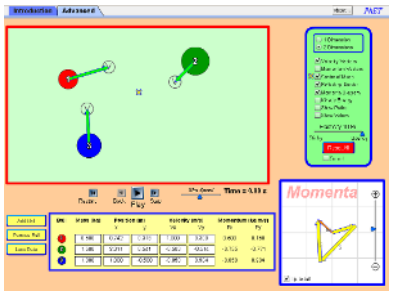
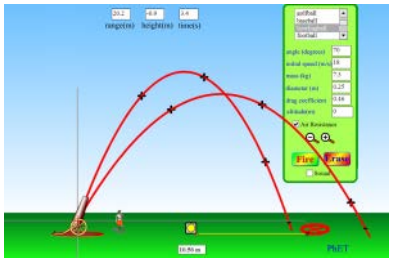
Phet: Moving Man 	https://phet.colorado.edu/en/simulation/moving-man http://tinyurl.com/9nf677z	Manually move the man around or set values (positive or negative) for velocity, initial position and acceleration. x-t, v-t and a-t graphs will automatically be generated. You can replay the motion and watch the graphs change as the man goes through his moves. Clicking on the "Show Vectors" boxes will show how the velocity vector will change with constant acceleration.	***French available***	
Constant Velocity, Constant Acceleration 	http://physics.bu.edu/~duffy/semester1/c01_motion.html http://tinyurl.com/c7rebfv	Simple and clear simulation that draws graphs as you watch 3 circles move in different directions and with different velocities.		

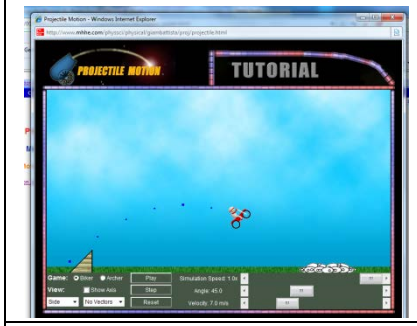
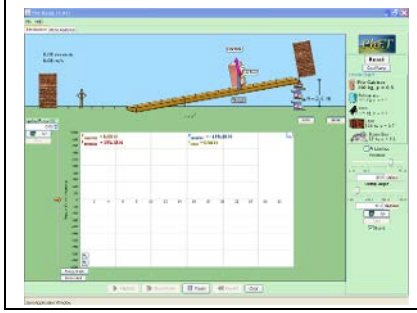
Topic 1: Mechanics

Topic 1.1: Kinematics

Boston University: Physics Applets 	http://physics.bu.edu/~duffy/semester1/semester1.html Click on “Relative Velocity in 1D” and “Mia and Brandy”	Simple demonstration of relative velocity. You can see depictions of the motion of 3 objects from different frames of reference.		

Topic 1.2: Dynamics

Topic 1.3: Momentum				
PhET: Collision Lab 	https://phet.colorado.edu/sims/collision-lab/collision-lab_en.html http://tinyurl.com/98afe8l	Investigate collisions in either "Basic" (1-D, 2 objects only) tab or "Advanced" (2-D, 2^+ objects). Be sure to click on "More Data" and "Show Values" to allow you to change variables. One criticism: In 2D collisions you can't enter angles – you stretch a velocity vector and can see the x- and y-values for the velocity.	***French available***	
Topic 1.4: Projectile Motion				
PhET: Projectile Motion 	https://phet.colorado.edu/sims/projectile-motion/projectile-motion_en.html http://tinyurl.com/8ra82s2	Get your calculators out and work out the settings to hit a target with your choice of projectiles. Cannon and target can be moved vertically and horizontally.	***French available***	

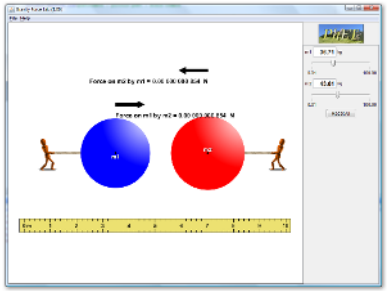
Physics: Principles and Problems Projectile Motion Applet 	http://www.mhhe.com/physsci/physical/giambattista/proj/projectile.html Linking page: http://glencoe.mcgraw-hill.com/sites/0078458137/student_view0/chapter6/projectile_motion_applet.html	Change angle and initial velocity to land your bike on a target. Not **as** full featured as the PhET applet.		
Topic 1.5: Circular Motion				
Boston University: Physics Applets	http://physics.bu.edu/~duffy/semester1/semester1.html Look under "Uniform Circular Motion" for several links.	Several simple simulations available here.		
Topic 1.6: Work and Energy				
PhET: The Ramp 	https://phet.colorado.edu/en/simulation/the-ramp http://tinyurl.com/8cybz3x	*"Explore forces, energy and work as you push household objects up and down a ramp. Lower and raise the ramp to see how the angle of inclination affects the parallel forces acting on the file cabinet. Graphs show forces, energy and work"* – PhET website	***French available***	

PhET: Energy Skate Park	https://phet.colorado.edu/en/simulation/energy-skate-park http://tinyurl.com/9lotd6f	This is the ultimate energy playground! Build tracks, change gravity (even use 0 g), set your zero potential line, and have your choice of skater dude grind your track. Be sure to zoom out to have more room to draw bigger tracks. This simulation also produces graphs and allows quantitative experimentation.	***French available***	

Topic 2: Fields

Topic 2.1: Exploration of Space

Topic 2.2: Low Earth Orbit

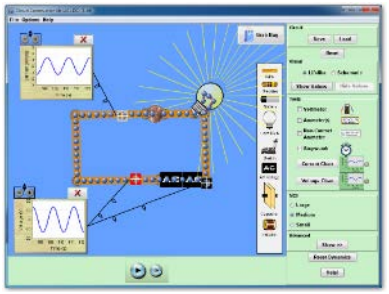
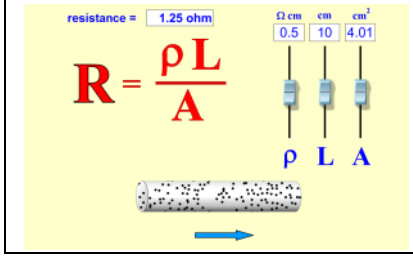
PhET: Gravity-Force Lab 	https://phet.colorado.edu/en/simulation/gravity-force-lab http://tinyurl.com/9tdyjzs	Not really in depth. More of a visualization of gravitational attraction.	***French available***	

Topic 2.3: Electric and Magnetic Fields

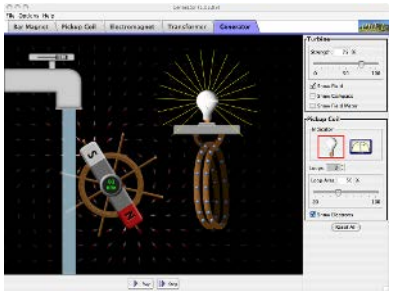
See Physics 30S				

Topic 3: Electricity

Topic 3.1: Electric Circuits

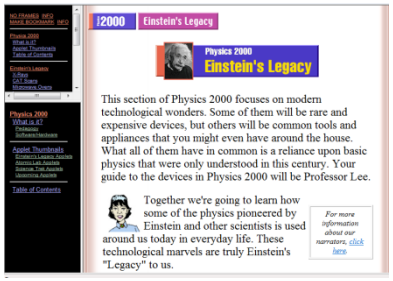
PhET: Circuit Construction Kit (AC and DC) 	https://phet.colorado.edu/en/simulation/circuit-construction-kit-ac http://tinyurl.com/963nem8		***French available***	
PhET: Resistance in a Wire 	https://phet.colorado.edu/en/simulation/resistance-in-a-wire http://tinyurl.com/8dmprca		***French available***	

Topic 3.1: Electromagnetic Induction

PhET: Generators 	https://phet.colorado.edu/en/simulation/generator http://tinyurl.com/93k6ovo	Investigate generators, transformers and the variables that affect them.	***French available***	

Topic 4: Medical Physics

Topic 4.1: Medical Physics

Physics 2000: Einstein's Legacy 	http://www.colorado.edu/physics/2000/index.pl http://tinyurl.com/ejp7k	'Mini simulations' scattered throughout good content help explain how x-rays, CT-scans work, on both theoretical and practical aspects.		

Physics 11 – Independent Study Option Course

Special Instructions for Assignments

As students submit assignments for evaluation it has become apparent that for some assignments additional instructions must be provided. This document will provide additional instructions for the correct completion of assignments.

GENERAL INSTRUCTIONS FOR ALL ASSIGNMENTS:

1. Correct Use of Significant Digits
Please round off your answer to the correct number of significant digits. In most cases this will be three (3) significant digits. Please review the lesson on significant digits: Module 1 Lesson 2: Working with Vectors, Scalars and Significant Digits pages 21-32.

Marks will be deducted if answers are not rounded off at the rate of 0.5 marks for every two incorrectly rounded off answers per assignment.

2. Correct Statement of a Vector Answer
A vector is a quantity that has magnitude and direction. Therefore every answer that involves a vector must include the direction for that vector.
For example: The final velocity is 12.5 m/s.
In this case, since velocity is a vector quantity a direction must be attached to this answer.
A correctly stated answer might be: The final velocity is 12.5 m/s [East].

Marks will be deducted at the rate of 0.5 marks for every instance where an answer does not include a direction for a vector quantity.

If you are using a symbol for a vector it must be written with the vector arrow above the symbol for the quantity. For example use $\vec{A}$ not A.

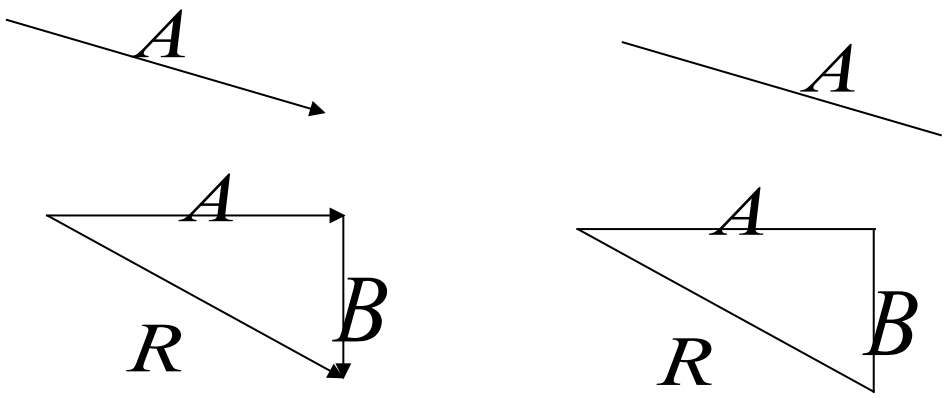
A comparable situation occurs in English. You have learned capitalization and punctuation. You are expected to employ capitalization and punctuation at all times. In Physics you are expected to employ significant digits and directions for vectors when stating the answer.

3. Showing your work in problem solving.
You are expected to show your work. Please follow the "GUESS" method of problem solving as outlined in Module 1 Lesson 8: Constant Velocity and Acceleration: Problem Solving pages 134 and 135.
Using the "GUESS" method will simplify problem solving for you. It will also enable you to communicate to the tutor-marker the work that you performed to solve the problem.

4. Drawing Vectors

When drawing a vector always use a **labelled directed** line segment – an arrow – to represent that specific vector quantity. A line segment without the arrow head does not communicate the direction of the vector.

Acceptable **Unacceptable**



5. Lack of Room to Write the Answer

Many times there may be insufficient room provided for you to show all of your work. If this should occur please feel free to write your answer on a separate sheet of paper. Clearly label the answer to the question. Attach the sheet to the remainder of the assignment from which the question is taken.

SPECIAL INSTRUCTIONS FOR SPECIFIC ASSIGNMENTS:

1. Assignment 1.2 – Video Laboratory Activity – Kinematics

Since this is your first report, here are some specific instructions for analyzing the motion of the car in the video. These can be printed and used as the Data and Calculations section of your report.

Data and Calculations:

In the table record the time for which the car is at each of the following positions.

Position (cm)	Time (s)

Graph Position versus Time on the grid below.

Calculation of Instantaneous Velocity at the Midpoint of a Time Interval:

Use the Position- Time graph above to determine the average velocity of each interval of time on the graph. The slope of the position-time graph for each interval gives the instantaneous velocity for that time interval. Record the midpoint of the time interval and the instantaneous velocity for that interval in the table below.
Sample calculation:

Instantaneous Velocity at Midpoint (cm/s)	**Midpoint of Time Interval(s)**

From the Velocity-Time graph calculate the average acceleration for the car. Show your work in the space below.

Method of Assessment:

Purpose	1 mark
Apparatus and Procedure	2 marks
Completed Position-Time Table and Position-Time graph	4 marks
Sample Instantaneous Velocity Calculation	2 marks
Completed Velocity-Time Table and Velocity-Time Graph	6 marks
Calculation of Average Acceleration	2 marks
Discussion	2 marks
Conclusion	1 mark

Total = 20 marks

2. Assignment 2.2 – Vector Journey

Additional Instructions:
Draw your scale diagrams on a separate sheet of paper. The larger the diagrams are, the more accurate they will be. Graph paper is useful in drawing these scale diagrams.
Please draw each vector as a **LABELLED DIRECTED LINE SEGMENT. Each vector should look like an arrow.**
The question asking you to draw a scale diagram requires that you **add the vectors in the order given** for the scale diagram. Draw

$d_1, then\ d_2\ on\ the\ head\ of\ d_1, then\ d_3\ on\ the\ head\ of\ d_2\ and\ so\ on.$

3. Assignment 3.1: Video Laboratory : Dynamics

Read the introduction to the activity carefully (Module 3 Lesson 3 Pages 28-30. This information will guide you through the calculations.

Data and Calculations:

1. For each of the ticker tapes make a table of time and position. There should be 5 tables, one for each different height of release.

2. Sample calculation of instantaneous velocity.

3. For each of the ticker tapes make table of time and instantaneous velocity. There should be 5 tables, one for each different height of release.
For each table make a graph of velocity-time.

4. Sample calculation of average acceleration

5. Make one chart of Force and Acceleration.
Plot one graph of Acceleration versus Force.

Method of Assessment:

Purpose	1 mark
Apparatus and Procedure	2 marks
Completed Position-Time Data Tables	4 marks
Sample Instantaneous Velocity Calculation	1 marks
Completed Velocity-Time Table and Velocity-Time Graph	4 marks
Calculation of Average Acceleration	1 mark
Force-Acceleration Graph	2 marks
Discussion	4 marks
Conclusion	1 mark

Total = 20 marks

Time Interval	Position (cm)

(s)	
0	0
0.1	0 + displacement for 1st 6 dots = pos 2 (0 + 1.85 cm = 1.85 cm)
0.2	Pos 2 + displacement for 2nd 6 dots = pos 3(1.85 cm + 3.35 cm = 5.2 cm)
0.3	Pos 3 + displacement for 3rd 6 dots = pos 4 (5.2 cm + 5.0 cm = 10.2 cm)
0.4	
0.5	

Velocity calculation:

V =(Pos 2 – Pos 1) / time interval
V = (1.85 cm – 0 cm) / 0/1 s = 18.5 cm/s

Make a new chart:

Midpoint of Time interval (s)	Velocity (cm/s)
0.5	18.5
0.15	33.5

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www.edu.gov.mb.ca/k12

RE: Grade 11 Physics Equation Sheet

Dear students;

On the following page, you will find an **Equation Sheet** for this course. You need to be aware of the following with regard to the equation sheet:

1. You do not have to memorize it.
2. Do not try to learn all of the equations at once. You will learn their significance as you work through the course.
3. The equation sheet can be used when you work on assignments, write practice tests and practice exams.
4. You will be provided with a copy of this equation sheet during the midterm and final exams. You **cannot** bring in your own copy of the equation sheet with you when you write your exams. A new one will be included with the exam.
5. Although you do not have to memorize the equations, you must know:

    - when to use each equation
    - what the variables in each equation represent
    - the units for each variable
    - how to arrange the basic equations on the sheet into a working equation to solve specific problems (in other words, rearrange the equations to isolate each variable from the equations)

Please keep in mind that using algebraic equations to solve problems is just one aspect of physics. You are trying to develop an understanding of the concepts discussed in this course. With this in mind, if you use the equation list as you work through the course, you will find that it is a good summary of the course.

Good luck with your Physics course.

Independent Study Option

Grade 11 Physics EQUATION SHEET

MATHEMATICS

$$\sin\theta = \frac{Opp}{Hyp}$$

$$\cos\theta = \frac{Adj}{Hyp}$$

$$\tan\theta = \frac{Opp}{Adj}$$

$$Hyp^2 = (Leg\,1)^2 + (Leg\,2)^2$$

KINEMATICS

$$v = \frac{d}{\Delta t}$$

$$\Delta = 2^{nd}\ value - 1^{st}\ value$$

$$d = pos_2 - pos_1$$

$$\vec{v} = \frac{d}{\Delta t} = \frac{pos_2 - pos_1}{\Delta t}$$

$$\vec{a} = \frac{\Delta v}{\Delta t} \text{ or } \vec{a} = \frac{v_2 - v_1}{\Delta t} \text{ or}$$

$$\vec{v}_2 = \vec{v}_1 + \vec{a}\,\Delta t$$

$$\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\,\Delta t$$

$$\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}\Delta t^2$$

$$v_2^2 = v_1^2 + 2ad$$

WAVES

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = n_{1-2}$$

$$PLD = |PS_1 - PS_2|$$

f = 1/T

T = 1/f

v = fλ

LIGHT

$$PLD = |PS_1 - PS_2|$$

$$\frac{\Delta x}{L} = \frac{\lambda}{d}$$

SOUND

v = 332 + 0.6 T

Closed-pipe resonant length

$$L_n = \left(\frac{(2n-1)}{4}\right)\lambda$$

Open-pipe resonant length

$$L_n = \left(\frac{n}{2}\right)\lambda$$

$$f_B = |f_2 - f_1|$$

DYNAMICS

$$F_{NET} = ma$$

$$F_{NET} = \sum Forces$$

$$F_F = \mu F_N$$

GRAVITY

$$F_G = mg$$

$$F_N + F_G = F_{NET} = ma$$

ELECTRICITY

$$\vec{E} = \frac{F_E}{q}$$

q=Ne

$$E = \frac{V}{d}$$

MAGNETISM

Grade 11 Physics EQUATION SHEET

$F_B = BIL\sin\theta$

All Supporting Videos for Grade 11 Physics

Topic 1 - Audio/Videos

Multimedia Physics Studio - A collection of animations on all physics topics.
Physics at Internet4Classrooms
Relative Motion - A simulation of relative motion.

Module 1

1. The Scientific Method, Theories, Laws, and Models
2. Experiments and Variables
3. Significant Figures Made Easy!
4. Introduction to Physics - Lesson 9 - Using Sig Figs
5. High School Physics: Vectors and Scalars
6. Describing Motion
7. Position Distance & Displacement - Average Speed & Velocity Word Problems & Graphs - Physics
8. Understanding and Walking Position as a function of Time Graphs
9. Position vs. time graphs | One-dimensional motion | Physics | Khan Academy
10. Position vs. Time Graph: Constant Velocity
11. Match That Graph
    a. Click on the link Launch Concept Builder. Follow the instructions to load the program.Start with the Apprentice Level questions. For more challenging questions move on to the Master Level and the Wizard Level. This interactive concept builder requires the student to match position-time and velocity-time graphs. If you make an error click on the Help Me button to receive some helpful explanations and hints which will help you understand the concepts.
12. Velocity vs. Time Graph: Part 1
13. Walking Position, Velocity and Acceleration as a Function of Time Graphs
14. Velocity Time Graphs
15. Motion with Constant Acceleration
    a. In this animation you set the initial velocity and the acceleration. Then the animation draws in real time the graph of position-time, velocity-time and acceleration time one beneath the other.

       For non-accelerated motion with constant velocity use the following settings.
       Press RESET.
       Initial Position = 0 m; Velocity = 2.00 m/s; Acceleration = 0.00 m/s/s
       Press Reset
       Initial Position = 25 m; Velocity = -2.00 m/s; Acceleration = 0.00 m/s/s
       For accelerated motion (non-constant velocity) use the following setting.
       Initial Position = 0 m; Velocity = 2.00 m/s; Acceleration = 2.00 m/s/s

Press Reset
Initial Position = 25 m; Velocity = -2.00 m/s; Acceleration = -1.00 m/s/s
Press Reset
Initial Position = 10 m; Velocity = +2.00 m/s; Acceleration = -1.00 m/s/s

16. Graphing the Drop of a Ball from 2.0 Meters - An Introductory Free-Fall Acceleration Problem
17. Grade 11 Physics Track 1 Mod A1.2 Kinematics
18. Velocity Time Graphs Part 4 Area Kinematics Physics Tutorial
19. Velocity time graph area under curve is displacement
20. Acceleration Time Graphs Area Kinematics Physics Tutorial
21. Graphing Summary Kinematics High School & College Physics Tutorial
22. Physics - Analysing Motion Graphs
23. Introduction to Uniformly Accelerated Motion with Examples of Objects in UAM
24. Kinematics 6: Uniform Accelerated Motion
25. Constant Velocity compared to Constant Acceleration
26. Position vs. Time Graph: Constant Velocity and Acceleration
27. A Basic Acceleration Example Problem and Understanding Acceleration Direction
28. Relating the Motion of an Object to the Sign of the Acceleration (II)
29. Uniformly Accelerated Motion Examples
30. High School Physics: Kinematic Equations
31. 1D KINEMATIC MOTION PRACTICE - Acceleration Example Problem

Module 2

1. Introduction to Vectors
2. How to use Cardinal Directions with Vectors
3. An Introduction to Vectors and Scalars 1
4. An Introduction to Vectors and Scalars 2: Scalars, Vectors, and Vector Operations
5. Drawing Vector Diagrams
    a. Watch the start of this video to observe how vectors are drawn to scale on a vector diagram using a ruler and protractor. What is missing from the procedure is the conversion of the real length of 6 miles to the scale length using a scaling factor. The scaling factor is 1 cm = 1 mile. The calculation to convert the magnitude to the scale length is: (6 miles) x (1 cm/ 1 mile) = 6 cm
    b. Watch the remainder of this video to observe how 2 vectors are added together using the tip to tail method by drawing the vector accurately to scale on a vector diagram using a ruler and protractor. The instructor does not use symbols to label the vector. Call the 12.0 m [N] the vector A (A with an arrow over top). Call the 8.0 m [E] the vector B (B with an arrow over top). Call the resultant vector R (R with an arrow over top). The equation is Vector R = Vector A + Vector B. Vector A and vector B are converted to their scale lengths using a scaling factor of 1 cm = 1 m. Vector R is converted to its actual length using the same scaling factor.
6. Introduction to Vector Components
7. Resolution of Vectors into Components
8. Visually adding and subtracting vectors

9. Head-to-Tail Method of Vector Addition
10. Drawing Vector Diagrams
    a. Watch this video from 6:37 to 14:00. Watch this video to observe how 2 vectors are added together using the tip to tail method by drawing the vector accurately to scale on a vector diagram using a ruler and protractor. The instructor does no use symbols to label the vector.
       Call the 12.0 m [N] the vector A (A with an arrow over top).
       Call the 8.0 m [E] the vector B (B with an arrow over top).
       Call the resultant vector R (R with an arrow over top).
       The equation is Vector R = Vector A + Vector B.
       Vector A and vector B are converted to their scale lengths using a scaling factor of 1 cm = 1 m.
       Vector R is converted to its actual length using the same scaling factor.
11. Introductory Tip-to-Tail Vector Addition Problem
12. How to Find the Distance Between Two Points - How to Use the Distance Formula
13. Distance and Displacement

Module 3

1. The four fundamental forces of nature - Michio Kaku
2. Strong Interaction: The Four Fundamental Forces of Physics #1a
3. Weak Interaction: The Four Fundamental Forces of Physics #2
4. Introduction to Newton's First Law of Motion
5. High School Physics - Newton's 1st Law of Motion
6. STEMonstrations: Newtons 2nd Law of Motion
7. STEMonstrations: Newton's Third Law of Motion
8. Newton's First Law of Motion - Second & Third - Physics Practice Problems & Examples
9. Newton's 3 Laws of Motion for Kids: Three Physical Laws of Mechanics for Children - FreeSchool
10. Dynamics: What are Forces?
11. Watch a Video for Assignment 3.1 - Go to Track 2
12. Introduction to Free Body Diagrams or Force Diagrams
13. Breaking the Force of Gravity into its Components on an Incline
14. Concept Builder - Free Body Diagrams
    a. Work through each of the 12 situations by drawing the correct free body diagram for the situation that is described.
15. Common Free-Fall Pitfalls
16. Free-Body Diagrams
17. Free Body Diagrams Physics Mechanics Problems, Tension, Friction, Inclined Planes, Net Force
18. Introduction to Newton's Second Law of Motion with Example Problem
19. Introductory Newton's 2nd Law Example Problem and Demonstration
    a. This video show how kinematics and dynamics are related through Newton's Second Law. This is a more complicated example of the Dynamics-Newton's

Second Law-Kinematics relationship. A cart is placed on a track that is almost frictionless. The cart is accelerated from rest by a falling mass that is attached to the cart by a string. There are kinematics quantities (displacement, initial velocity, time) that are measured along with the applied force of the string pulling the cart. The question is to find the force of friction (a dynamics quantity). The analysis requires a list of the given quantities, a free body diagram, and finding the net force as the sum of the forces acting on the cart. From the kinematics side the measured quantities allow acceleration to be calculated. Then the link over to dynamics is Fnet = ma where the net force is calculated. In turn knowing the net force allows the force of friction to be calculated. See page 64 for a graphic illustrating the link between Dynamics <-> Newton's Second Law <-> Kinematics.

20. Kinematics (Part 9: Force and Acceleration Example)
21. Newton's Second Law of Motion - Science of NFL Football
22. Newton's second law of motion | Forces and Newton's laws of motion | Physics | Khan Academy
23. More on Newton's second law | Physics | Khan Academy
    a. This video from Khan Academy shows that if several forces act on an object the analysis of the forces to determine the net force can be accomplished using the property of vectors that components of vectors are independent of each other or what happens in the x direction does not affect what happens in the y direction.
    b. So we can find the sum of the horizontal or x components of the forces by themselves. Then we can add the vertical or y components of the forces by themselves.
    c. Then the sum of the x-components plus the sum of the y components of the forces can be added using the component method to give the net force that is acting.
    d. If a force is acting in neither the vertical direction nor the horizontal direction, that force must be resolved into its horizontal and vertical components which are then added with the forces in the x direction or in the y direction.

Topic 2 - Audio/Videos

Module 4

1. Gravitational Field Introduction
    a. This video uses the concept that the force of gravity acting on an object is given by
    b. Force of gravity = (mass of the object)(gravitational field intensity) or
    c. Fg = mo g.
    d. Then gravitational field intensity = (Force of gravity) / (mass of the object) or g = Fg / mo.
    e. Gravitational field lines are introduced to represent the concept of the strength and direction of a constant gravitational field at the Earth's surface and the

strength and direction of a non-constant gravitational field far from the Earth's surface.

2. Weight and Mass are Not the Same
3. Would you weigh less in an elevator? - Carol Hedden
4. Do You Feel Your Weight?
    a. Weight is introduced as the force of gravity. Weight though is measured by standing on a scale. What we feel as our weight is the normal force of the scale (or whatever we are standing on).
    b. Our weight does not change. What we feel as our weight can change (heavier than normal or lighter than normal). If we stand on a scale in an elevator we can feel heavier than normal when the elevator accelerates upwards, lighter than normal when the elevator accelerates downwards, or normal when the elevator is not accelerating.
    c. What we feel as our weight (the apparent weight) is the normal force of the scale pushing up on us.
5. Elevator Ride
    a. This interactive activity illustrates when a person riding in an elevator experiences having a normal weight or feel lighter than normal or feels heavier than normal.
    b. A free body diagram located by the passenger shows the force of gravity and the normal force acting on the passenger. Using the values for these forces determine the net force when the passenger experiences having a normal weight or feel lighter than normal or feels heavier than normal.
6. Video 222 - Calculating Gravity using a Pendulum
    a. Watch this video from 8:56 to 10:51.
    b. This part of the video illustrates how to isolate the gravitational field intensity (g) from the equation for the period of a pendulum.
7. O Level Physics Notes
    a. This website provides a method of measuring the period of a pendulum with increased accuracy. A method to calculate the period is outlined.
8. Dropping Dictionaries Doesn't Defy Gravity, Duh!
9. Introduction to Free-Fall and the Acceleration due to Gravity
10. Dropping a Ball from 2.0 Meters - An Introductory Free-Fall Acceleration Problem
    a. This video solves a problem using the equations of motion for the motion of a medicine ball that is dropped from rest over a distance of 2.0 metres.
    b. Note in this video that the subscript "y" is added to the symbols of velocity and acceleration and that displacement in the vertical direction is referred to as delta y (Δy).
    c. Pay attention to some of the common errors made with vector directions.
11. Free Fall
    a. Click on the link Launch Concept Builder.
    b. Attempt each of the 3 activities- Describing Free Fall, Speedometer, It's About Time.

    c. This simulation uses a value of 10.0 m/s/s [down] for the acceleration of gravity.
    d. The simulation relates the sizes and directions of the velocities and acceleration during different parts of the journey of an object thrown straight up into the air.
12. GCSE Physics Revision: Forces on a skydiver
    a. As a skydiver falls to the Earth the force of gravity and the force of air friction both act on the skydiver. The two forces will add to produce the net force on the skydiver at a given instant in time. The skydiver will accelerate in the direction of the net force. This video describes how the forces change to create the net force and enable for you to predict the acceleration of the skydiver and the accompanying change in velocity.
13. Physics Ch.2.1 Part 2 Air resistance and terminal velocity
14. Brian Cox visits the world's biggest vacuum chamber - Human Universe: Episode 4 Preview - BBC Two
    a. This video shows a visit to a large vacuum chamber. The structure and operation of the vacuum chamber is reviewed. A large ball and some feathers are dropped from the same height simultaneously when the chamber is filled with air to observe the effect of air resistance. The feathers accelerate from rest picking up speed as they fall. The rate of acceleration for the feather slows until the feathers fall at a constant velocity, the terminal velocity. The ball accelerates constantly increasing its speed s it falls.
    b. The air is then evacuated from the chamber leaving a vacuum inside the chamber. The ball and the feathers are dropped again. How do the motions of the ball and feather compare when they fall without air resistance?
15. Introduction to Static and Kinetic Friction by Bobby
16. Introduction to the Coefficient of Friction
17. Understanding the Force of Friction Equation
    a. This video examines the force of friction equation. The application of the equation for kinetic friction results in a constant value as long as the object is moving.
    b. However for the force of static friction the value of the force of static friction varies according to the external force applied to the object force. The force of static friction will have the same magnitude as the applied force acting on the objet.
    c. Once the applied force exceeds the maximum force of static friction, the object begins to move and the force of kinetic friction appears. The force of static friction then drops to 0 N.
18. Does the Book Move? An Introductory Friction Problem
    a. A book rests on a level horizontal table. A horizontal force is applied to the book. The question is will the book move? If the book moves what will be its acceleration?
    b. The approach to this problem follows the Dynamics – Newton's Second Law – Kinematics approach with the new factor of the forces of kinetic friction and static friction.
19. Static Friction and Kinetic Friction Physics Problems With Free Body Diagrams
20. Physics - What is Friction?

Module 5

1. Electric Charge and Electric Fields
2. Electric Fields: Crash Course Physics #26
3. Electric Field Due to a Point Charge - Physics Practice Problems
4. Electric Field Physics Problems - Point Charges, Tension Force, Conductors, Square & Triangle
5. Capacitor Lab: Basics
    a. This is an interactive animation of the charged parallel plate apparatus or capacitor.
    b. There is a window with 4 variables that can be displayed. Be sure that Plate Charge and Electric Field are checked.
    c. You can also change the area of the plates and the separation of the plates by dragging on the green arrows.
    d. The voltage can be measured using the meter marked voltage. Place the point of the red probe on the wire at the top of the battery and the black probe on the wire just below the battery.
    e. Finally you can drag the yellow rectangle on the battery to change the voltage. You can change the size of the voltage and the polarity which changes which plate is positive and which plate is negative.
    f. Select a voltage of 1.00 volts, an area of 400 mm2, and a plate separation of 5.00 mm. The electric field intensity will be displayed as the density of the electric field lines.
    g. Adjust the apparatus changing voltage only and observe the effect on the electric field.
    h. Adjust the apparatus changing area of the plates only and observe the effect on the electric field.
    i. Adjust the apparatus changing separation of plates only and observe the effect on the electric field.
6. Parallel Plate Apparatus
    a. This video describes through aanimation how a parallel plate apparatus works. The importance of this apparatus is that the electric field between the plates of of the apparatus is uniform, both in magnitude and direction.
    b. This electric field can be calculated by the ratio of the potential difference between the plates measured in volts divided by the separation of the plates in metres. The electric field between the charged plates will always point from the positive plate to the negative plate.
    c. Between the charged plates the electric force on a charged particle is found by multiplying the electric field by the electric charge on the particle. The direction of the electric force is found by determining to which plate the charge on the particle will be attracted.
7. Electric Field of Parallel Plates
    a. This video illustrates the electric field between two charged parallel plates. It illustrates how the electric field is calculated. We will use the

electric field between charged parallel plates is the ratio of the potential difference between the plates expressed in volts divided by the separation of the plates expressed with units of metres.

b. Again the electric force on a charges particle between the charged plates is found using the electric charge on the particle expressed in Coulombs divided by the separation of the plates expressed in metres.
c. Charged particles are shot into the space between the plates traveling in a direction parallel to to the charged plates. These particles follow a path much like a ball thrown horizontally at the surface of the Earth.

8. Electric Field Strength Parallel Plates Example - Physics
    a. This video solves a problem about charges particles within the electric field between two charge parallel plates and the force on an electron between the plates and also the force on a proton between the plates.
    b. The electric field between the plates is calculated from the voltage across the plates and the separation between the plates using
    c. Electric Field = Voltage/ Separation of the plates.
    d. Once electric field is found in part a, this value is used to calculate the electric force on an electron in part b and the electric force on a proton in part c.
    e. Note you must include directions with the electric field and the electric force.
9. Uniform Electric Field (1 of 9) Motion of Charged Particles Parallel to the Field
10. Millikan Oil Drop Experiment Animation
    a. When the oil drop is motionless the force of gravity downwards is balanced by the electric force upwards and the net force on the droplet is 0N.
    b. So in the vertical or y direction Fnet = Fe – Fg = 0N
    c. And Fe = Fg.
    d. But Fe = qE and Fg = mg so
    e. qE = mg and
    f. q = mg/E.
    g. The final result was that there was a smallest charge that q could have called the unit elementary charge e.
11. Millikan's Oil Drop Experiment
12. Elementary Charge
    a. In this video animation of the Millikan Experiment is used to describe how Millikan's experiment worked. Millikan was able to isolate oil drops as they fell between charged parallel plates where the electric field was controlled by the voltage. Millikan was able to observe an oil droplet with a microscope. The oil drops where exposed to X-rays which ionized molecules to produce a net charge on the droplets. The droplets fell with a terminal velocity which depends on the size of the droplet. Oil droplets falling with the same terminal velocity would have the same size and mass. Millikan selected oil droplets that fell with the same terminal

velocity which ensured that the drops had the same mass and force of gravity acting on each droplet.

b. Millikan then changed the charge by exposing the oil droplets to X-rays. Millikan then adjusted the voltage to hold an oil droplet motionless. Knowing the size of the oil drop and the density of oil, the mass of the oil drop (m) could be calculated.
c. Then the force of gravity on the oil drop is found using Fg = mg.
d. When the oil drop is motionless the force of gravity downwards is balanced by the electric force upwards and the net force on the droplet is 0N.
e. So in the vertical or y direction Fnet = Fe – Fg = 0N
f. And Fe = Fg.
g. But Fe = qE and Fg = mg so
h. qE = mg and
i. q = mg/E.
j. The final result was that there was a smallest charge that q could have called the unit elementary charge e.
k. The charge on a given oil drop was always found to be a multiple of e.
l. All the values of q were found to be
m. Charge on the oil droplet = (integer)(unit elementary charge)
n. Or q = Ne.
o. In other words charge is quantized, that is, it comes in discrete units or packages with a smallest possible amount of e = 1.602 x 10-19 Coulombs.

13. Millikan's oil drop calculation
    a. This video solves a typical problem based on Millikan's Oil Drop Experiment.
    b. The force of gravity on the oil drop is found using Fg = mg.
    c. When the oil drop is motionless the force of gravity downwards is balanced by the electric force upwards and the net force on the droplet is 0N.
    d. So in the vertical or y direction Fnet = Fe – Fg = 0N
    e. And Fe = Fg.
    f. But Fe = qE and Fg = mg so
    g. qE = mg.
    h. So you can solve for any of these variables using qE = mg or E = Voltage/ Plate Separation or E = V/d.

Module 6

1. Introduction to magnetism | Physics | Khan Academy
2. Magnetic Field | #aumsum #kids #education #science #learn
3. Magnetic lines of force - edutree(full HD)
4. Magnets and Magnetic Fields
5. Magnetic Domains

6. Physics & Electromagnetism : The Domain Theory of Magnetism
7. Electromagnetism - Magnetic Force: The Four Fundamental Forces of Physics #4b
8. Oersted's Experiment
9. Physics-Magnetic Field Due a Current Carrying Wire
10. GCSE Science Physics (9-1) Electromagnets
    a. A current in a wire produces a magnet field around the wire which can be detected using a compass. A wire can be wound into a coil to create a solenoid. The solenoid also produces a magnetic field that has the same shape as the magnetic field for a bar magnet and which is strongest inside the core of the solenoid. Introducing an iron core into the core of the solenoid constructs an electromagnet. The strength of the electromagnet is affected by the size of the current, the number of turns in the coil and the insertion of a ferromagnetic coil into the core of the solenoid.
11. Three Right Hand Rules of Electromagnetism - Magnetic Force
    a. This video illustrates the 3 Right Hand Rules for the directions of current, magnetic field and magnetic force.
    b. The first rule (curled right hand) relates the direction of motion of the current in a wire (positive charge motion) and the direction of the magnetic field given by the direction that the curled fingers point around the wire.
    c. The second rule (flat right hand) relates the direction of the magnetic field given by direction the fingers point, the direction of the current or the direction of motion of a positively charged particle given by the direction the thumb points and the direction of the magnetic force on the wire or charged particle given by the direction the palm points.
    d. The third right hand rule relates the direction the current flows in the wires of a solenoid to the direction of the magnetic field inside the solenoid. The rule given in the course materials is a bit different. The thumb points along a wire in the direction the current is flowing. The curled fingers are placed inside the solenoid. The fingers then point towards the end of the solenoid where the North pole is found.
    e. Note that there are variations of the Right Hand Rules. Please use the one presented in the course materials.
12. Tangent Galvanometer
13. Grade 11 Physics Track 3 Tangent Galvanometer Mod 6 A6.2
14. Force on a current carrying conductor in a magnetic field - Physics
15. Force on a Current Carrying Wire in a Magnetic field
16. Magnetic Force on a Current-Carrying Conductor
    a. This webpage addresses the concept of how to determine the magnetic force (both magnitude and direction) on a current-carrying conductor in a magnetic field.
    b. The direction of the magnetic force on the current carrying wire is found using the flat right hand rule.
    c. For the magnitude of the magnetic force the equation used is $F_B = ILB\sin\Theta$.
    d. An explanation of the theory is presented in the first section of the webpage.

e. In a colored text box the calculation is done for the magnitude. The right hand rule (flat hand) is used to determine the direction of the magnetic force.
f. Scroll down to Problems and Exercises.
g. Do the first 3 questions relating the directions of the magnetic force, current and magnetic field. Diagrams and answers are provided.

17. Finding Magnetic Force on a Current Carrying Wire
18. Grade 11 Physics Track 4 Magnetic Field and Solenoid Mod 6 A6.3

Topic 3 - Audio/Videos

Module 7

1. Transverse and Longitudinal Waves
2. GCSE Science Physics (9-1) Transverse and Longitudinal Waves
    a. This video introduces waves. It describes what waves are. It also compares waves on water (transverse waves) to waves of sound (longitudinal) waves. For each type of wave the video illustrates the direction of motion of a point on the medium compared to the direction of motion of the wave disturbance. The video notes that transverse waves require a medium to transmit the disturbance
3. Transverse Waves
    a. A simulation of transverse waves. This illustrates a transverse wave on the surface of water with a duck floating on the surface of the water as waves move across the surface of the water.
    b. A diagram of transverse waves illustrates some of the characteristics of transverse waves.
4. Longitudinal Wave
    a. This applet animates the motion of longitudinal waves and allows you to change some parameters to make it interactive. Have some fun.
    b. The applet demonstrates how a longitudinal wave travels in a medium of points marked by dots. As the wave moves to the right the dots side to side
    c. Click on the animation area to switch the animation to dots.
    d. Select “Progressive Wave”. Set amplitude to “Low” and frequency to “Low”.
    e. Observe the motion of the particles and note how far the particles travel horizontally from the normal rest position. This is the amplitude. You can control the animation step by step by resting the cursor on the line after start and using the switches that appear.
    f. Select “Progressive Wave”. Set amplitude to “High” and frequency to “Low”.
    g. Repeat the steps above and compare the maximum distance a point moves from the normal undisturbed position.
    h. Select “Progressive Wave”. Set amplitude to “Low” and frequency to “Low”.
    i. Observe and note the number of waves made each second by timing for 10 seconds and counting the back and forth motions of the piston. Calculate the frequency using
    j. f = (number of cycles) / time.

    k. Reset amplitude to “Low” and frequency to “High”.
    l. Again count the number of cycles the piston makes in 10 seconds.
    m. Calculate the frequency.
    n. Change the wave type to “Pulsed Rarefaction” and observe how the spacing of the points on the medium changes.
    o. Finally change the wave type to “Pulsed Compression” and observe how the spacing of the points on the medium changes.
5. Wave Speed
6. Longitudinal versus Traverse Waves
7. Transverse Wave - Reflection & Transmission
    a. This animation does an excellent job of illustrating the reflection and transmission of waves at an end or at a junction between two different media.
    b. For reflection there is only the incident wave and the reflected wave.
    c. For transmission there will be an incident wave, a partially reflected wave in the first medium and a partially transmitted wave in the second medium. Both of these must be described.
    d. The waves that are reflected and transmitted are described using 4 characteristics:
    e. 1. Orientation – upright or inverted compared to the incident wave
    f. 2. Speed –faster or slower that the incident wave
    g. 3. Wavelength – longer or shorter than the incident wave
    h. 4. Amplitude – larger or smaller that the incident wave
    i. Start with the Free End Reflection. Describe the reflected wave using the 4 characteristics.
    j. Change the animation to Fixed End Reflection and repeat the analysis of the reflected wave.
    k. Change the animation to a Thinner to Thicker and describe both transmitted and reflected waves.
    l. Finally change the animation to Thicker to Thinner and do the analysis one more time.
    m. If you hover your cursor in the lowest part of the animation a control bar appears by which you can control the speed of the animation including step by step.
8. Wave Superposition
9. Wave interference | Mechanical waves and sound | Physics | Khan Academy
    a. The narrator uses ideal waves (squares, rectangles and triangles) to illustrate the principle of superposition.
    b. There is a link on the left side of the screen “Practice: Predicting Wave Interference Patterns”. When you click on that link you will be presented with 4 problems to practice the Principle of Superposition.
10. Standing Waves
    a. This video illustrates the production of standing waves as the result of superposition of two waves traveling in the same medium.
    b. An animation shows the superposition of a wave in blue with its reflected wave in white to produce a standing wave in black. The standing wave has places called

nodes where the medium does not move. The two waves are constantly canceling each other out. In between the nodes are antinodes, that is locations which are constantly in motion.

c. Examples of standing waves are provided in baseball bats, guitar strings (two fixed ends), and wind instruments such as a trumpet (one fixed and 1 open end column) and a pan flute (a two open end column). This is a precursor to musical instruments and how they work.

11. Transverse Wave Addition
    a. This animation shows superposition and standing waves.
    b. Part 1. Select Animation 11. Set the animation to Gaussian Pulse with Equal Amplitude and In Phase.
    c. Start the animation. Observe the waves before they interact, while they interact and after they interact.
    d. Before the interaction, the red pulse moves to the right and the white pulse moves to the left. During the interaction the interaction the two pulses interfere constructively to produce the yellow pulse.
    e. Stop the animation when the largest yellow pulse is formed. At each dot, the displacement for the yellow wave is the sum of the displacement of the red wave plus the displacement of the white wave.
    f. Continue the animation. After the passing through each other the red and with pulses continue to move as before with the same shape and size.
    g. Part 2. Repeat part 1 with the two pulses having Unequal Amplitudes.
    h. Part 3. Back up 1 page in your browser so that you see choices of Animation 11 and Animation 111. Switch the animation to Animation 111. Set Wavelength to Small.
    i. A continuous pair of waves, blue moving left and white moving right, pass through each other and interfere with each other. Together a yellow wave is produced by the principle of superposition.
    j. Stop the animation when the blue wave and white wave are at the same position. Again observe that the displacement of the yellow wave is the sum of the displacements of the blue wave and white wave.
    k. Start the animation.
    l. Notice that there are nodes (points that do not move) and antinodes (the points that move from the bottom of the screen to the top of the screen) formed.
    m. The distance from a node to the adjacent node is one half of a wavelength (½λ).
12. The Physics of Music: Crash Course Physics #19
    a. This video introduces music. Music is produced by standing waves in strings in string instruments or standing waves in columns of air in wind instruments.
    b. The video covers the fundamental frequency, harmonics and overtones and the relationships between these. The narrator speaks very rapidly so you may have to pause the video or repeat sections to catch all the information being conveyed.
    c. For a string vibrating at its fundamental frequency f0 the string has a node at each end and an antinode in the middle of the string. The length of the string is ½λλ. The fundamental frequency is also the frequency of the first harmonic, n=1.

d. If the frequency in this same string is doubled a standing wave with a node at each end plus a node in the middle of the string is formed. This pattern then has 2 antinodes. This is the pattern for the second harmonic. The frequency of the second harmonic f2 is 2x f0.
e. So a pattern of harmonic numbers and fundamental frequency emerges.
f. For a given harmonic, n, the frequency of the harmonic, fn, is given by fn = n x f0 .
g. We tie this in with the universal wave equation, $v = f\lambda$. We can, knowing the length of the string and the fundamental frequency, determine the wavelength using $L = \frac{1}{2}\lambda$. Then knowing the fundamental frequency, f0, and λ we use $v = f\lambda$ to determine the speed.
h. There is a nice comparison using animation for the fundamental frequency or first harmonic in a string with 2 fixed ends and in a pipe or column of air with two open ends. In a string fixed at both ends there is a node at each end with an antinode in the middle of the string. In a pipe with to open ends there is an antinode at each end and a node in the middle of the air column.
i. For a column of air in a pipe closed at one end, the fundamental frequency is not $\frac{1}{2}\lambda$ but $\frac{1}{4}\lambda$. This fact results in there being no harmonic at even numbered harmonics.

13. AP Physics 1: Mechanical Waves Review

Topic 3 - Audio/Videos

Module 8

1. Waves in 2d Includes basic reflection
    a. This video presents an introduction to waves in two dimensions on the surface of water.
    b. A point source is shown to generate circular waves. The waves on the diagram are represented by lines. The lines would represent the crests on the surface of the water. In a ripple tank pattern the wave crests appear as bright lines.
    c. The space between two lines or crests would be a trough. A trough appears as a dark line in a ripple tank pattern.
    d. A point source generates circular waves. The circular lines that represent the waves are called wave fronts. The wave front is the crest moving along the surface of the water.
    e. To show the direction of motion of a point on the wave front we use arrows called wave rays. Wave rays are drawn perpendicularly to the wave front at the point in question. A wave ray and wave fronts form a 90° angle.
    f. A circular wave has each point of the wave front starting at the source and moving away from the source. The motion of a particular wave front is an ever expanding circle.
    g. The narrator then shifts to describing how straight or planar waves travel across the surface of the water. These wave fronts are produced by a straight source,

like a ruler, dipping into the water. Again the wave front has a direction of motion given by the wave ray drawn perpendicularly to the wave front at each point on the wave front. In a uniform medium all of the points on the wave front travel at the same speed and in the same direction so the straight wave front remains straight as it travels.

h. If these straight wave fronts are incident unto a barrier the wave fronts reflect (bounce off) the barrier. A diagram of wave rays is used to plot the path of the wave rays using the law of reflection. The direction of the incident wave ray is measured from the normal to the surface of the barrier to form the angle of incidence. The angle of reflection is equal to the angle of incidence. The angle of reflection is measured from the normal to the surface to the reflected wave ray. Once the reflected wave ray is drawn on the diagram, then reflected wave fronts are drawn perpendicularly to the reflected wave ray.
i. Finally a photograph of straight wave fronts reflected from a straight barrier is analyzed to illustrate the law of reflection for actual waves on the water's surface in a ripple tank.

2. Ripple Tank Simulation - Circular Waves
    a. This website contains a virtual ripple tank.
    b. On the left side is a green area which represents the surface of a ripple tank.
    c. On the right side are found several popups. The top popup selects the type of source. If you click on the arrow a list of possible sources will appear.
    d. The second popup sets the Waves = Sound. Leave this one as is.
    e. The third popup sets the color scheme. Use Color Scheme 1.
    f. The next button Clear Waves will clear all the waves and structures in the ripple tank. Always start with a blank ripple tank.
    g. The next selection is Stopped. At the start have this set to Stopped. Once you have selected the Source and other structures like barriers, you begin the simulation by unchecking Stopped.
    h. For the sliders the only one you might change will be the Frequency of the waves.
    i. Circular Waves I
    j. Generating a single circular wave front.
    k. Select "Single Source", clear any waves and select "STOPPED".
    l. Right click on the single source at the top of the ripple tank. Delete this point source.
    m. Then move the cursor to the centre of the ripple tank and left click. This will generate a single circular wave which starts and travels away from the point that you clicked on with the cursor.
    n. Circular Waves II
    o. Generating a periodic circular wave.
    p. For this simulation select "Single Source".
    q. If the simulation does not react, uncheck Stopped. You may also have to select a different example and then "Single Source".

r. Observe the motion of circular wave fronts. Identify the wave fronts and remember that the wave rays begin at the point source and radiated outwards.
s. Circular Waves III
t. Clear the waves and check Stopped.
u. Right click on the point source at the top of the ripple tank and select DELETE from the menu. This will delete the point source.
v. On the menu bar at the top of the ripple tank, click on ADD.
w. From the menu that appears select "Add point source". A dot should appear in the ripple tank.
x. Uncheck Stopped to run the simulation which now shows the completed circular pattern of waves that are formed.

3. Ripple Tank Simulation - Straight Waves
    a. This simulation will produce a straight wave front on the surface of the water in the ripple tank.
    b. Clear Waves and check STOPPED.
    c. From the first popup select Example:Plane Wave.
    d. Uncheck STOPPED. A train of straight waves will travel form the top to the bottom of the ripple tank.
    e. Imagine the wave rays drawn perpendicularly to the wave fronts. All of these will be parallel to each other and pointing towards the bottom of the page.
    f. Check STOPPED. Slide the FREQUENCY bar to the right to increase the frequency. Uncheck STOPPED and compare the wavelength of the high frequency waves to the wavelength of the low frequency waves.
4. Ripple Tank Simulation - Reflection of Circular Waves from a Straight Barrier
    a. Start with an empty ripple tank.
    b. Set the first popup to "Single Source". Clear Waves and check STOPPED.
    c. If the single point source is creating waves, right click on the point source and from the menu click on "DELETE". This will delete the point source.
    d. Go to ADD and select "ADD WALL". Drag the ends of the wall to position the wall about 2/3 of the way down the page and parallel to the bottom of the page. The wall should extend completely across the ripple tank.
    e. Place your cursor about 4 cm above the wall and left click. Uncheck "STOPPED".
    f. A single circular pulse will be generated. Observe how it reflects from the straight barrier. Where does the reflected circular pulse originate?
    g. To check this run the simulation again. Stop the simulation after the incident pulse has reflected
5. Ripple Tank Simulation – Reflection of Circular Waves from a Circular Barrier
    a. CLEAR all waves and check STOPPED.
    b. In the first popup select "Example: Circle:.
    c. Uncheck STOPPED. The simulation will show a circular wave starting at the centre of a circular barrier.

    d. Observe the reflection of the wave front from the barrier and watch it travel back to the source. The wave front passes through the centre of the circle and continues to repeat the motion.
6. Ripple Tank Simulation – Reflection of Straight Waves from a Parabolic Barrier
    a. CLEAR all waves and check STOPPED.
    b. In the first popup select "Example: Parabolic Mirror 2".
    c. Uncheck STOPPED. A circular wave is generated at the focus of the parabolic barrier. The circular wave travels outwards from the source, reflects from the parabolic barrier and then becomes a straight wave traveling away from the parabolic reflector with the wave ray pointing along the axis of the parabolic reflector.
    d. The last two simulations are just the opposite of each other.
    e. In **Reflection of Straight Waves from a Parabolic Barrier** a straight wave is traveling towards the parabolic barrier with the wave ray pointing towards the parabolic barrier along the axis of the parabolic barrier. All of the points on the straight wave reflect and meet at the focus.
    f. In **A Circular Wave Generated at the Focal Point of a Parabolic Barrier Reflects from the Barrier** a circular wave front starts at the focus of the parabolic barrier. Each point on the part of the circular wave front that travels towards the parabolic barrier reflects from the barrier and travels away from the barrier moving with wave rays that point along the principal axis of the parabolic barrier. All of the points join up to form a straight wave front traveling parallel to the principal axis of the parabolic barrier.
7. Huygen's Principle - Reflection & Refraction
    a. This applet shows the reflection and refraction of wave fronts using Huygen's Principle.
    b. In the text box found in the upper right hand corner of the applet select "Refraction".
    c. The angle of incidence is set to 45 degrees.
    d. Click/tap at the left edge to change the mode (single wavefront/multiple wavefronts). Set the mode to multiple wave fronts.
    e. Start the applet.
    f. Wave fronts will descend towards the barrier along the blue section on the left. The moving white lines are the incident wave fronts. The line along the middle of the blue section represents the wave ray for the incident wave fronts.
    g. At the boundary between two different media each point represents a point source.
    h. When a part of the incident wave front strikes a point that point generates a circular wave in the second medium. A circular wave is generated by each point source in succession as the incident wave front strikes it.
    i. These circular waves again combine to form the refracted wave front which is now traveling in the second medium.
    j. The wave ray in the second medium for these refracted wave fronts no longer points in the same direction as the incident wave ray. The path of the wave

fronts has been changed, bent towards the normal to the boundary in the second medium.

k. The angle of incidence is smaller than the angle of refraction in the second medium.
l. Things to notice.
m. The wave fronts travel faster in medium 1.
n. You can see that the wave fronts are separated by a distance equal to their wavelength. Since the speed of the wave fronts is larger in medium 1 and the frequency of the wave fronts is the same in both media it follows that the wavelength in medium 1 must be larger than the wavelengths in medium 2.
o. Change the angle of incidence and repeat the refraction of the waves. The angle of refraction in medium 2 is always smaller than the angle of incidence and the refracted wave ray is bent towards the normal.

8. Geophysics: Lecture 2. Wave Theory, refraction and reflection
    a. (Start the video at 22:20. The section on Wave Propagation ends at 26:04.)
    b. This part of the video deals with the propagation of waves according to Huygen's Principle.
    c. Understanding how waves propagate or reproduce themselves will also help you understand how the reflection of waves occurs as a waves strikes a barrier and how waves refract as they pass through the boundary or interface between two different media.
9. All the circular wave fronts generated by the point sources combine to form .Huygen's Principle - Reflection & Refraction
    a. This applet shows the reflection and refraction of wave fronts using Huygen's Principle.
    b. In the text box found in the upper right hand corner of the applet select "Reflection".
    c. The angle is set to 45 degrees.
    d. Click/tap at the left edge to change the mode (single wavefront/multiple wavefronts). Set the mode to single wave front.
    e. Start the applet.
    f. Wave fronts will descend towards the barrier along the blue section on the left. The moving white line is the incident wave front. The line along the middle of the blue section represents the wave ray for the incident wave front.
    g. At the boundary each yellow point represents a point source.
    h. When a part of the incident wave front strikes a yellow point that yellow point generates a circular wave. A circular wave is generated by each yellow point source in succession as the incident wave front strikes it.
    i. The circular waves generated have different sizes. The first yellow point struck has the largest circular wave front. The last yellow point source struck has the smallest circular wave front.
    j. All the circular wave fronts generated by the point sources combine to form the reflected wave front.
    k. This reflected wave front travels up to the right.

l. The line along the centre of the right blue section represents the wave ray for the reflected wave fronts.
m. The angle of incidence will equal the angle of reflection.
n. Change the angle of incidence to 30 degrees and observe. What is the angle of reflection?
o. Change the angle of incidence to 60 degrees and observe. What is the angle of reflection?

10. PHet Simulation - Refraction - Bending Light
    a. This simulation illustrates refraction, the bending of the path of light as the ray passes from one medium into a second medium.
    b. Be sure the simulation selected is INTRO. You will see two different media represented by 2 layers of different colours. The line between the two media is the boundary or interface.
    c. Each media has a control box which is used to set the substance that is that media. If you click on the button next to MATERIAL you can select the material for the upper medium. There is a similar control to select the material for the lower level.
    d. There is a light source in the upper medium (medium 1). You can set the angle of incidence by moving this light source.
    e. In medium 1 has another control which selects whether the light is given as a wave ray or as waves.
    f. In the lower left hand side in found a tool box. You will be using the protractor which can be moved by clicking in the protractor and dragging it to a new location.
    g. Trial I: Measuring the Angle of Incidence, the angle of reflection and the angle of refraction.
    h. Choose air for medium 1. Use RAY for the light. Choose water for medium 2. Move the light source about midway between the normal and the boundary.
    i. Click and drag the protractor and position it so that the crosshairs are at the intersection of the normal and the boundary.
    j. Measure each of the angle of incidence, angle of reflection and the angle of refraction.
    k. Check the index of refraction for medium 1 and compare the size of the index of refraction to the size of the angle of incidence. Compare the index of refraction for medium 2 to the size of the angle of refraction.
    l. Trial II: Measuring the Angle of Incidence, the angle of reflection and the angle of refraction.
    m. Repeat the simulation in trial 1. Change only the upper medium to water and the lower medium to air.
    n. Trail III: Comparing the Speed of the Waves and Wavelength for Each Medium to the Index of Refraction
    o. Set the simulation to the same parameters as Trial I except select WAVE instead of RAY.

p. This time focus on the speed of the wave in each medium. Compare the speed of the wave in medium I to the index of refraction for medium I. Repeat this for medium 2.
q. Next focus on the wavelength in each medium. Compare the wavelength in medium I to the index of refraction for medium I. Repeat this for medium 2.
r. Complete this chart. Enter Large or Small in the empty cells.

Index of Refraction	Angle Size	Speed	Wavelength
Large			
Small			

s. A useful way of remembering the speed and direction changes of light during refraction is **'FAST': Faster - Away / Slower - Towards**.

11. AP Physics 1: Waves 7: Refraction 2: 2-Dimensional Waves and the Law of Refraction
12. Lesson 54: Snell's Law
    a. This webpage makes use of Snell's Law in the form

$$\frac{\sin\theta_1}{\sin\theta_2}=\frac{n_2}{n_1}=\frac{\lambda_1}{\lambda_2}=\frac{v_1}{v_2}$$

    b. where θ = angle measured from normal
    c. n = index of refraction for medium
    d. λ = wavelength of light
    e. v = velocity of light.
    f. These terms are defined. The index of refraction is a new term found in the video lab in this lesson.
    g. Three problems are presented. Each problem is solved. The solution is accompanied with an explanation of the strategy to use.
13. Grade 11 Physics Track 5 Snell's Law Part A Mod 8 A8.2
14. Ripple Tank Simulation – Diffraction I
    a. Diffraction I : Low Frequency (Large Wavelength) Waves Passing by the Edge of a Barrier
    b. CLEAR all waves and check STOPPED.
    c. In the first popup select "Example: Half Plane".
    d. Set the frequency to a low value by sliding the control to a spot near the left end of the slider.
    e. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) near the top of the ripple tank.

f. The part of the wave that hits the barrier will reflect and travel back towards the top of the ripple tank, interfere with the incoming waves and form a standing wave.
g. The part of the wave that misses the barrier continues to travel towards the bottom of the ripple tank.
h. However the waves that passed by the edge of the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
i. The bending of the wave fronts as they pass by the edge of a straight barrier is called **diffraction**.

15. Ripple Tank Simulation – Diffraction II
    a. Diffraction II: High Frequency (Small Wavelength) Waves Passing by the Edge of a Barrier
16. CLEAR all waves and check STOPPED.
    a. In the first popup select "Example: Half Plane".
    b. Set the frequency to a high value by sliding the frequency control to a spot near the right end of the slider.
    c. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) near the top of the ripple tank.
    d. The waves that passed by the edge of the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
    e. The bending of the wave fronts as they pass by the edge of a straight barrier is called **diffraction**.
    f. Compare the amount of diffraction for low frequency (large wavelength) waves to that of high frequency (small wavelength) waves.
17. Ripple Tank Simulation: Diffraction III
    a. Diffraction III: High Frequency (Small Wavelength) Waves Passing Around the Edges of a Barrier
18. CLEAR all waves and check STOPPED.
    a. In the first popup select "Example: Half Plane".
    b. Set the frequency to a high value by sliding the control to a spot near the right end of the slider.
    c. Click on the barrier and drag the barrier to the centre of the ripple tank. CLEAR all waves if necessary.
    d. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) in the middle of the ripple tank.
    e. The waves that missed the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
    f. The bending of the wave fronts as they pass by the edge of a straight barrier is called diffraction.
    g. Note the extent of the **diffraction**.

19. Ripple Tank Simulation - Diffraction IV
    a. **Diffraction IV: Low Frequency (Large Wavelength) Waves Passing Around the Edges of a Barrier**
    b. CLEAR all waves and check STOPPED.
    c. In the first popup select "Example: Half Plane".
    d. Set the frequency to a low value by sliding the control to a spot near the left end of the slider.
    e. Click on the barrier and drag the barrier to the centre of the ripple tank. CLEAR all waves if necessary.
    f. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank. There is a wall (barrier) in the middle of the ripple tank.
    g. The waves that missed the barrier begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
    h. The bending of the wave fronts as they pass by the edge of a straight barrier is called **diffraction**.
    i. Note the extent of the diffraction.
    j. **Compare the amount of diffraction for low frequency (large wavelength) waves to that of high frequency (small wavelength) waves.**
20. Ripple Tank Simulation - Diffraction V
    a. **Diffraction V: Low Frequency (Large Wavelength) Waves Passing Through an Opening in a Barrier**
    b. CLEAR all waves and check STOPPED.
    c. In the first popup select "Example: Half Plane".
    d. Set the frequency to a low value by sliding the control to a spot near the left end of the slider.
    e. Click on the barrier and drag the barrier down to the centre of the ripple tank. CLEAR all waves if necessary.
    f. Right click on the surface of the ripple tank. In the menu that pops up select ADD WALL. A short wall with controls on each end will pop up in the ripple tank. Click on one of the end controls and stretch the wall so that it is about the same size as the original barrier.
    g. Click on this wall and move it next and parallel to the first wall so that the two walls form one horizontal line. Separate the walls by about 0.5 cm.
    h. CLEAR all waves if necessary.
    i. Uncheck STOPPED. The simulation will show straight waves starting at the top of the ripple tank and traveling towards the bottom of the ripple tank.
    j. Some parts of the wave will travel through the opening in the barrier, begin to curve and bend and start to travel in a different direction from the original motion towards the bottom of the ripple tank.
    k. The bending of the wave fronts as they pass through an opening in a straight barrier is called **diffraction**.
    l. Note the extent of the diffraction.
    m. CLEAR all waves and select STOPPED.

n. Move one of the barriers to create an opening of about 1 cm then run the simulation.
o. Repeat the steps above using openings of 1.5 cm, 2.0 cm, and 4 cm.
p. Compare the amount of diffraction as the width of the opening in the barrier increases.
q. Extension: Repeat the simulation using high frequency waves with short wavelengths.

21. Interference of Waves | Superposition and Interference in light and water waves | Physics
22. Ripple Tank
    a. Interference 1: Setting Up the Ripple Tank for the Interference of Waves from 2 Point Sources
    b. CLEAR all waves and check STOPPED.
    c. In the first popup select "Example: Two Sources". Two point sources will appear in the middle of the ripple tank. Drag each source up to the top of the ripple tank and place the point sources about 2 cm apart.
    d. Using the “SOURCE FREQUENCY’ slider set the frequency to a low value by sliding the control to a spot under the letter “F” near the left end of the slider.
    e. Using the BRIGHTNESS slider set the brightness slider to a position about ¾ of the way to the right.
    f. If necessary CLEAR all waves.
    g. Uncheck STOPPED.
    h. Circular waves begin to travel form each source. These circular waves interfere. There are points where crests from source 1 meet troughs from source 2. This results in destructive interference. The crest and the trough cancel out and a node results. A node appears as the same color as the undisturbed medium.
    i. In the pattern the nodes appear to form a line (nodal line) that becomes straight at a great distance from the sources.
    j. In other places a crest from source 1 meets a crest from source 2 to form a larger, double crest. This appears as a bright area in the pattern. Also a trough from source 1 meets a trough from source 2 to form a larger, double trough. This appears as dark area in the pattern. This results in constructive interference. Where constructive interference occurs a line of antinodes appears in the pattern.
    k. If you image the perpendicular bisector of the line joining the 2 sources, S1S2, you will notice that a line of antinodes lies on the perpendicular bisector of S1S2. This line of antinodes lies between 2 nodal lines.
    l. We number the nodal lines in a quadrant starting from the perpendicular bisector of S1S2 . The first nodal line to the right of the perpendicular bisector of S1S2 is n=1.
    m. Count the number of nodal lines in the right hand quadrant.
23. Interference II
    a. Use the same setup as in Interference I.
    b. Use the cursor to drag the right hand source horizontally by 2 cm to double the separation of the source.

c. If necessary CLEAR all waves.
d. Uncheck STOPPED.
e. Again count the number of nodal lines in the right hand quadrant.
f. Check STOPPED and CLEAR all waves.
g. Move the right hand source horizontally a further 2cm.
h. Uncheck STOPPED.
i. Again count the number of nodal lines in the right hand quadrant.
j. What is the effect of increasing the separation of the point sources on the number of nodal lines in a given quadrant?

24. Interference III
    a. Use the same setup as in Interference I.
    b. Using the “SOURCE FREQUENCY’ slider set the frequency to a low value by sliding the control to a spot under the letter “F” near the left end of the slider.
    c. If necessary CLEAR all waves.
    d. Uncheck STOPPED.
    e. Again count the number of nodal lines in the right hand quadrant.
    f. Check STOPPED and CLEAR all waves.
    g. Using the “SOURCE FREQUENCY’ slider set the frequency to a higher value by sliding the control to a spot under the letter “q”.
    h. Uncheck STOPPED.
    i. Again count the number of nodal lines in the right hand quadrant.
    j. Check STOPPED and CLEAR all waves.
    k. Using the “SOURCE FREQUENCY’ slider set the frequency to a higher value by sliding the control to a spot under the letter “c”.
    l. Uncheck STOPPED.
    m. Again count the number of nodal lines in the right hand quadrant.
    n. What is the effect of increasing the frequency and this decreasing the wavelengths of the waves produced by the point sources on the number of nodal lines in a given quadrant?
25. Interference IV
    a. The 2 sources in the first 3 simulations had the 2 sources generating waves fronts in phase. This means that the two point sources generate crests at the same time. They also generated troughs at the same time.
    b. You will adjust the phase of one of the sources in this new simulation to have the two sources generate waves out of phase. Source 1 and source 2 will make their crests at different times.
    c. So the question is how does changing the phase delay between 2 sources affect the pattern of nodal lines?
    d. Once the applet opens you must then open a different version of the applet.
    e. Below the ripple tank window scroll down 6 lines to this line: This is the WebGL version. You can also still access the old javascript version, and the even older Java Version.
    f. Click on javascript version. This will open a slightly different applet where you will be able to change the phase of the sources.

g. Adjust the parameters as follow.
h. Move the 2 sources to the top of the ripple tank and place them about 3 cm apart.
i. Set the top line to SETUP: Two Sources
j. Set the second line to 2Scr, 1Freq
k. CLEAR waves if necessary.
l. Move the PHASE DIFFERENCE slider completely to the left. This gives a phase delay of 0 which means the two sources make crests at the same time.
m. Run the simulation and note the position of the first nodal line relative to the perpendicular bisector of S1S2.
n. Stop the simulation by checking STOPPED.
o. CLEAR the waves.
p. Change only the phase delay by sliding the slider halfway across to the right. This setting has source 1 generating a crest. Then one quarter of a period later source 2 generates a crest. The crest from source 1 has traveled ¼ of a wavelength before the crest is generated by source 2.
q. Note the position of the first nodal line relative to the position of the perpendicular bisector.
r. Stop the simulation by checking STOPPED.
s. CLEAR the waves.
t. Change only the phase delay by sliding the slider all the way across to the right. This setting has source 1 generating a crest. Then one half of a period later source 2 generates a crest. The crest from source 1 has traveled ½ of a wavelength before the crest is generated by source 2.
u. Note the position of the first nodal line relative to the position of the perpendicular bisector.
v. What is the effect of changing the phase delay on the positions of the nodal lines and the lines of antinodes in the interference patterns?

26. Wave interference | Mechanical waves and sound | Physics | Khan Academy
27. Introduction to Electromagnetic Waves
    a. This video has a nice review of wave basics: wavelength, frequency, and speed. These of course are related by the Universal Wave Equation: $v = f\lambda$. In the video c is used as the symbol for speed instead of v.
    b. The video introduces a new equation: energy of a wave = constant x frequency. Symbolically the equation is $E = hf$.
    c. The video then switches to electromagnetic radiation. A graphic of the electromagnetic spectrum is introduced. Trends in frequency, energy and wavelength are described for the electromagnetic spectrum.
28. Electromagnetic Wave
    a. This animation illustrates the propagation of an electromagnetic wave.
    b. The vectors of the fluctuating electric field in red vibrate parallel to the x-axis. The vectors of the fluctuating magnetic field in blue vibrated parallel to the y-axis. The EM wave travels along the z-axis.
29. Electromagnetic Waves(HD)

a. This video provides a qualitative look at how electromagnetic (EM) radiation is generated. It briefly reviews the history of the scientific discoveries that lead to a theory that explains EM radiation.
b. The video also reviews some of the properties of EM radiation such as the electric disturbance occurs in the vertical plane and the magnetic disturbance occurs in the horizontal plane. The two disturbances are coupled, that is they travel in lock step with the changing electric field producing the magnetic disturbance and the changing magnetic field producing the electric disturbance. All the while the EM radiation moves in a direction perpendicular to both the electric disturbance and the magnetic disturbance.
c. Because EM occurs in the electric and magnetic fields EM radiation can travel through a vacuum. Thus EM radiation is not a mechanical wave.

30. Accelerating Charges Emit Electromagnetic Waves - "Light" - Radio Antennas! | Doc Physics
31. The Electromagnetic Spectrum

Topic 4 - Audio/Videos

Module 9

1. THE NATURE OF SOUND - SYMPHONY OF SCIENCE
2. Longitudinal Wave
3. The Nature of Sound
4. Explain That Stuff- Sound
    a. Scroll down to the UNDERSTANDING AMPLITUDE AND FREQUENCY text box.
    b. There are 4 waves drawn as transverse wave to represent 4 sound waves.
    c. You can listen to each sound by pressing the start button. The sounds generated are tones – sound of a single frequency.
    d. Listen to each of the 4 tones and describe the effect of changing the frequency on the tone and also of changing the amplitude on the tone.
    e. Scroll down to WHY INSTRUMENTS SOUND DIFFERENT.
    f. Here you will read about why musical instruments sound different even though they are playing the same tone or frequency.
5. Introduction to the Intensity of Sound and Human Hearing
6. Beats Animation
    a. This animation allows you to control the frequencies of 2 waves and then view the interference pattenr that is produced by the two waves. Beats are produced as the waves from the 2 sources overlap. In some spots waves overlap to produce constructive interference which is a loud sound. In other places wave overlap to produce destructive interference or no sound.
    b. You can vary the frequency of both of the waves by sliding the control button.
    c. This animation does not produce any sounds.

d. Begin the animation with the following settings. Use the IN PHASE setting.
e. **Trial 1:** Top wave: 14 HZ Bottom Wave: 14 Hz
f. The two waves are producing the same tone. Describe the resultant wave that appears.
g. **Trial 2:** Top Wave: 14 Hz Bottom Wave: 15 Hz
h. **Trail 3:** Top Wave: 14 HZ Bottom Wave: 13 HZ
i. **Trial 4:** Top Wave: 14 Hz Bottom Wave: 16 HZ
j. **Trial 5:** Top Wave: 14 HZ Bottom Wave: 17 Hz
k. In each case identify the difference in the frequencies and the number of beats produced.

7. Demonstration of Beats
8. Beat frequency | Physics | Khan Academy
9. MIT Physics Demo Tuning Forks Resonance & Beat Frequency 720
    a. An apparatus consisting of a tuning fork attached to the top of a wooden box which is open at one end is used in this demonstration. When the tuning fork is struck the the tuning fork vibrates which causes the top of the box to which the tuning fork is attached to vibrate also. The large surface of the top of the box causes the air inside the box to vibrate and the amplified sound exits the box through the open end. So this is an apparatus that amplifies sound.
    b. Two of these pieces of apparatus are used. Each tuning fork vibrates at the same frequency.
    c. When both tuning forks are struck, you hear the same tone.
    d. When one tuning fork is struck and then the tines are prevented from vibrating, the other tuning fork is hear to be vibrating and producing sound. This demonstrates resonance. Each object like a tuning fork has a natural frequency at which it vibrates. Since the two tuning forks have the same frequency if one is vibrating the second tuning fork will also begin to vibrate at its resonant or fundamental frequency. Remember the boxes serve to amplify the sound and the effect.
    e. The final demonstration shows the production of beats. A weight is attached to the tine of one tuning fork. This causes the tuning fork to vibrate at a different frequency. When both tuning forks are struck beats are heard. These beats are alternating loud and soft sounds rather than a steady tone.
10. Standing wave in pipe open at both ends at the fundamental frequency or first harmonic
    a. This short video shows the standing wave for the displacement of points on the medium in a pipe open at both ends for the fundamental frequency or the first harmonic.
    b. Note for the first harmonic there is one node at the centre of the pipe. There is an antinode at each end of the pipe.
    c. The length of the pipe is ½ λ.
    d. This follows the formula for the length of a pipe open at each end.

e. $L_n = (n/2)\ \lambda$
f. where n = the number of the harmonic or resonant length, L = the length of the pipe and λ = wavelength.

11. Standing wave in pipe open at both ends - 2nd Harmonic
    a. This short video shows the standing wave for the displacement of points on the medium in a pipe open at both ends for the second harmonic where the frequency is 2 x the fundamental frequency.
    b. There are 2 nodes in this standing wave pattern. There is an antinode at each end of the pipe plus one antinode between the 2 nodes.
    c. The length of this pipe is 1λ.
    d. This follows the formula for the length of a pipe open at each end.
    e. $L_n = (n/2)\ \lambda$
    f. where n = the number of the harmonic or resonant length, L = the length of the pipe and λ = wavelength.
12. Standing Waves in Air Columns for a Pipe Open at Both Ends - Waves & Sound
    a. This website illustrates the interference of longitudinal waves in a tube open at both ends using a displacement pattern. Vertical lines are used for the purpose of representing points on the medium. When the lines are close together we have a compression. When the lines are far apart we have a rarefaction. If you look carefully there are lines that do not move. That line is at a displacement node. At either end of the tube the lines are continually moving. These lines represent a displacement antinode. The lines represent the displacement pattern for a standing longitudinal sound wave.
    b. We are familiar with transverse waves and the nodes and antinodes found on a standing transverse wave.
    c. A transverse standing wave is superimposed on the air column. You can clearly see the antinodes at each end of the tube and the node in the center of the tube.
    d. In the first tube the website shows the length of the tube (½ λ) at the first resonant frequency or fundamental frequency ($\mathbf{f_0}$) or the first harmonic.
    e. In the second tube the website shows the length of the tube at the second resonant frequency ($\mathbf{2f_0}$) or second harmonic.
    f. A tube with a standing wave with a frequency of the third harmonic ($\mathbf{3f_0}$) is the final example shown.
    g. Click on the "Next Page" link at the bottom of the page. This will bring you to another page that repeats the animation of standing waves found in a pipe closed at one end.

h. In the first tube the animation shows the length of the tube (¼ λ) at the first resonant frequency or fundamental frequency (**f_0**) or the first harmonic.
i. In the second tube we do not have a standing wave for the second harmonic. Instead the next standing wave in the sequence is for the third harmonic (**$3f_0$**).
j. The last tube has the standing wave for the fifth harmonic **($5f_0$).**

13. Doppler Effect
    a. In this video the perceived frequency of a sound as heard by an observer depends both on the motion of the source and the motion of the observer.
    b. Using animation the video shows that if the source of sound is moving the wave fronts pile up in front the source creating a higher frequency (higher pitch). Also behind the moving source the wave fronts are spread apart creating a lower frequency (lower pitch).
    c. As a moving source of sound moves towards you and then passes by you hear first the higher pitched sound as the source approaches you and then a lower pitched sound as the source moves away from you.
    d. This effect also is created when the source is stationary and the observer moves relative to the source.
    e. Examples of the Doppler Effect are given.
14. Sound Waves, Intensity level, Decibels, Beat Frequency, Doppler Effect, Open Organ Pipe - Physics
15. The Doppler Effect: solving for the speed of the source
16. Introduction to Supersonic Speeds and the Sonic Boom
17. Resonance and the Sounds of Music
18. Grade 11 Physics Track 6(1) Resonance the speed of sound part 1 Mod 9 A9.2
19. Grade 11 Physics Track 6(2) Resonance the speed of sound part 2 Mod 9 A9.2
20. Speed of Sound Lab
    a. This video an instructor performing the experiment to determine the speed of sound using resonance in a tube closed at one end.
    b. The instructor explains the Physics behind the experiment and reviews the calculations that must be performed to determine the speed of sound.
    c. The calculations presented are a bit different that our video lab.
    d. First the temperature is not measured or included in the calculation of the speed of sound.
    e. Secondly the diameter of the tube is not measured or included in the calculation of the speed of sound.
    f. Thirdly, the length of the resonating tube is measured for n = 1, 2, 3, 4, 5. Our activity only measures the length of the tube for n =1.
21. Science - Sound - Music or Noise - English
22. Sound Waves, Intensity level, Decibels, Beat Frequency, Doppler Effect, Open Organ Pipe - Physics
    a. (Duration 29:00 to 32:50)

b. Intensity is defined as power/area, that is how much energy in Joules is reaching 1 m2 of area in 1 second.
c. This video constructs a table of sound intensity in watts/m2, Level in decibels (dB) and Loudness compared to the threshold level.
d. As the intensity of the sound increases by 101 , the level in decibels increases by 10 dB. Also the loudness doubles from the previous loudness value.
e. As the intensity increase observe how the level in decibels increases and the loudness compared to the threshold energy increases.

23. Learn about sound and musical frequencies - Black Book Lesson One
24. Resonance and the Sounds of Music
    a. This video covers resonance as the main concept. In addition to defining resonance the presenter demonstrates many applications of this phenomenon. This is a long video that switches topics along the way. A description of the topics is provided below.
    b. In all there is a nice connection between resonance and music. This video serves nicely to tie together this module on sound.
    c. 0-10:00 Resonance on a String
        i. This section contains a definition of resonance and applies this to resonance on a string. There is a demonstration of resonance using a rubber tube.
    d. 10:00 – 26:00 Resonance and Musical Instruments
        i. This section of the video shows how resonance is used in how a string instrument and a wind instrument plays music.
    e. 26:20 – 31:00 Introduction of the Apparatus to Detect and Display Sound Waves on an Oscilloscope
        i. A 440 Hz tuning fork generates a tone that is displayed on an oscilloscope as a regular sine wave.
    f. 31:00- 39:30
        i. Five different instruments are used to illustrate the 440 HZ sound wave that is generated by each instrument.
        ii. This part of the video shows the connection between resonance and string instruments (violin and guitar) and wind instruments (clarinet, saxophone and bassoon) . Each instrument plays a 440 Hz note and the sound wave along with its harmonics produce a complex wave. The number of the harmonics and their amplitudes produced as the instrument resonates interfere to form a complex wave. Even though the instruments all play the same note, the instruments sound different. Each instrument has its own timbre (a different complex wave). These complex waves are displayed on an oscilloscope which displays a sine wave picture of the sound disturbance.
    g. 39:30—49:00 Everyday Examples of Resonance
        i. Many examples of resonance are mentioned. A demonstration of resonance on a wine glass shows that the wine glass actually moves as it

resonates. A copper tube and a square metal plate are also made to resonate.

h. 49:00-53:00 Destructive Resonance
    i. A video shows the Tacoma Narrows Bridge collapsing in 1940 when it is set in motion (made to resonate) by a 40 miles per hour (67 km/hour) wind. The swinging becomes so violent that the bridge breaks apart.
i. 53:00-56:30 Using Sound and Resonance to Break a Wine Glass
    i. The idea here is that sound is made to cause resonance in a wine glass. In the end the wine glass shatters.
j. 56:30 – End Resonance and the Human Voice
    i. The presenter breathes in helium. Helium conducts sound at a different speed that air thus changing the resonant frequency of the presenter's throat and mouth. Listen to how speaking with helium sounds.

25. The Basics of the Physics of a Guitar

Module 10

1. The Scientific Method, Theories, Laws, and Models
2. What's the difference between a scientific law and theory? - Matt Anticole
3. Newton's Corpuscular Theory | Physics Animation
4. Physics - Newton's corpuscular theory of light - Science
    a. This video introduces Newton's Corpuscular Theory of Light. It demonstrates that this theory can explain the reflection of light and the refraction of light.
    b. Newton's corpuscular theory of light could not explain the interference of light and the diffraction of light. The theory also predicted incorrectly that particle of light speed up when they pass through the boundary between a less dense medium and a denser medium. As always scientific theories must be able to explain all of the observations of the phenomenon that these theories attempt to explain. If not the theory must be amended to explain the new observation. If the theory cannot be successfully amended, then the theory is incorrect.
5. Light: Particle or a Wave?
    a. The website compares the particle and wave models of light with good animations and explanations.
    b. There are side by side animations of the behaviour of light as a particle and light as a wave.
    c. The website provides an explanation and animation for the behaviour of light as a particle and light
6. Grade 11 Physics Track 7 The Particle Model of Light Mod 10 A10.2
7. Modern Physics 2-1: Measuring the Speed of Light (Eclipses of Io)
8. Classroom Aid - Fizeau measures the speed of light
9. Modern Physics 2-2: Measuring the Speed of Light (Foucault Experiment)
    a. Watch from 0 to 3:50.

b. The instructor provides a description of the Foucault experiment to measure the speed of light. The apparatus is similar to that of Fizeau. Fizeau used a rotating notched wheel to measure the time of travel of light. Foucault replaces the notched wheel with a rotating multi-sided mirror.
c. Light is emitted by a source. The light bounces off a face of the rotating mirror. The light travels to a distant mirror where it reflects back to the rotating mirror and the light strikes the rotating mirror. Since the rotating mirror has moved while the light traveled to the distant mirror and back again, the light reflects off the rotating mirror and travels not back to the source but along a slightly different path. The angle to this new path is measured and is used to determine the time that elapsed. Finally speed = distance/time is used to determine the speed of light.

10. Velocity of Light: Michelsons's Method
11. How did Scientists Determine the Speed of Light?
12. Huygens Principle | He's Dutch! | Doc Physics
    a. This video provides an introduction to Huygen's Principle which states that each point on a wave front serves as a point source of the wave. Each of these point sources sends out circular wavelets. The constructive interference of these wavelets produce the wave front an instant later. This is how wave fronts propagate or reproduce themselves as they travel along.
    b. If a straight wave front passes through an opening in a barrier, the part of the wave front that strikes the opening then serves as point sources which then produces a circular wave.
    c. If a straight wave front strikes a barrier with one opening a circular wave front is produced behind the barrier. If this circular wave front then strikes a second barrier with two openings each opening becomes a new source of wave fronts that are also circular in shape. What has been created is a situation of two point sources of waves that are generated in phase. These periodic waves will then interfere constructively to produce antinodes and destructively to produce nodes. This is Young's Experiment.
13. Reflection and Refraction of Light Waves (Explanation by Huygens' Principle)
    a. This animation shows the refraction and reflection of waves according to Huygen's Principle.
    b. The animation is initially set for an index of refraction n = 1.00 in the incident (top) medium and n = 2.00 in the refracted (bottom) medium. You can change these values for n.
    c. There is a window that briefly describes what is happening in the animation.
    d. There are 5 steps to the animation.
    e. Step 1 shows a straight wave front traveling from the upper left corner towards the lower right corner. Remember the direction of motion of the wave front is the wave ray which is perpendicular to the wave front.
    f. Step 2 shows the wave front approaching the boundary between the two media. Along the boundary are found point sources for the wave. The reflected wave fronts move back up into the first medium. The refracted wave fronts move into the bottom or refracted medium.

g. Step 3 repeats step 2 but adds the wave fronts for the incident wave, the reflected wave and the refracted wave.
h. Step 4 adds the wave ray to each wave front (incident wave front, reflected wave front, and refracted wave front). The angles of incidence, reflection and refraction as also drawn where the respective wave rays meet at the boundary.
i. Step 5 illustrates a series of wave fronts undergoing reflection and refraction according to Huygen's principle.
j. This animation solves one of the shortcomings of the Corpuscular Theory of Light, mainly that there is partial transmission and partial reflection of light from a surface. Waves are able to partially transmit and partially reflect from a surface.

14. Light Is Waves: Crash Course Physics #39
15. The Double Slit Experiment: Light As A Wave
16. Young's double slit introduction | Light waves | Physics | Khan Academy
    a. This is a nice introduction to the classic Young's Experiment.
    b. Light wave fronts from a source are allowed to fall unto a barrier with two very narrow slits placed very close to each other. The light is monochromatic. Two different parts of a given wave front will pass through the openings. Since the same part of the wave front, say the crest, reaches each of the slits at the same time the slits will now act as two point sources that are in phase. The circular waves generated by the two point sources form an interference pattern when the light is projected unto a screen.
    c. This interference pattern will be like two point sources generating waves in phase in a ripple tank.
17. Young's Double Slit
    a. This interactive animation illustrates Young's Experiment.
    b. Light is shone unto a screen with 2 slits. The interference pattern is projected unto a second screen.
    c. By moving the slider on the Distance Between Slits bar you can adjust the distance between the slits (d) and view the effect on the spacing of the lines (Δx) in the pattern on the second screen. When done, move the slider completely to the left.
    d. By moving the slider on the Slit Screen Distance bar you can adjust the distance of the first screen with the slits to the second screen (L). Increase and then decrease the distance between the first and second screens and view the effect on the spacing of the lines (Δx) in the interference pattern. When done, move the slider completely to the left.
    e. By moving the slider on the Wavelength bar you change the wavelength (λ) and color of the light. Increase and then decrease the wavelength and view the effect of the change in wavelength on the spacing of the lines (Δx) in the pattern seen on the second screen.
18. Young's Experiment Physics Classroom
    a. Click on Launch Interactive.

b. In this interactive the goal is to calculate the wavelength of the red, green and blue laser light shining on the double slits using the equation for Young's Experiment.
c. Open the interactive in full screen by clicking on the icon in the upper left hand corner.
d. Choose a value for the slit width, d, and the distance to the screen (L). Choose a wavelength
e. On the pattern of equally spaced dark and bright lines select two dark lines and using the scale beneath these lines record the position of each dark line. Determine the distance (y) in metres between the positions of the 2 chosen dark lines. Count the number of spaces, n, between the two dark lines selected. Each of the spaces corresponds to a bright line in the pattern.
f. Then determine the spacing of the adjacent dark lines (Δx) using the relationship
g. (Δx) = y/n.
h. Repeat the measurement of (Δx) twice more using a different number of spaces.
i. Finally using the average value of (Δx) determine the value of the wavelength, λ, using
j. $\lambda/d = \Delta x/L$.
k. Determine the wavelength of the red, green and blue light.

19. Wave-Particle Duality and the Photoelectric Effect
    a. This video introduces the photoelectric effect.
    b. Electromagnetic radiation contains radiation of many different frequencies. Radio waves have a low frequency and carry relatively little energy. Gamma rays have very high frequencies and carry a relatively great amount of energy. Visible light has frequencies and energies between radio waves and gamma rays.
    c. The photoelectric effect occurs when electromagnetic radiation, such as visible light, of a given frequency, called the threshold frequency, falls on the surface of a metal, an electron is ejected from the metal. Light below this threshold frequency could not eject electrons. Light above that threshold frequency for the metal could eject electrons from the metal's surface. This phenomenon could not be explained using the wave model of light.
    d. A new theory was postulated. To explain this new effect the theory of light was amended to account for the photoelectric effect. This new theory said that light consisted of photons, tiny particles of light.
    e. In the end the theory of light was changed to reflect the fact light had wave properties and it had particle properties. The new theory of light is called the Wave-Particle Duality.
20. The Photoelectric Effect: Light As A Particle
    a. The video outlines the discovery of the photoelectric effect and the reasoning that lead to the conclusion that light has a particle nature as well as a wave nature.
    b. The video illustrates the apparatus that was used in the experiment and the events that occur during the effect. Tossing fruits and vegetables (photons of light of different frequencies) at a watermelon (an electron stuck in a metal) is

used to illustrate why only light with a frequency above the threshold frequency possesses enough energy to eject electrons from the surface.

c. In addition the video shows that if the light has a frequency above the threshold frequency and thus can eject electrons, increasing the intensity of the light (more photons per second) will result in more electrons being ejected from the surface of the metal. If more electrons are ejected per second this will increase the current moving toward the positive terminal across the gap.
d. Once more the photoelectric effect proves that light (electromagnetic radiation) has a particle nature. Light can be thought of as consisting of particles called photons.
e. The new theory of light that emerged is called the Wave-Particle Duality of Light.

21. Quantum Theory Made Easy [1]
    a. This video deals with the work of many famous physicists around the year 1900.
    b. Starting at around 14:00 the video presents the photoelectric effect which demonstrates that there is a minimum energy required by light to eject electrons from the surface of the metal. Electrons are ejected instantly as soon as the light is shone on the metal. Electrons are ejected only if the frequency of the light is high enough and the light has enough energy (threshold energy) to do the work of ejecting the electron from the metal. The brightness of the light for a frequency below the threshold level does not enable light with a frequency below the threshold level to eject electrons.
    c. Aside from the photoelectric effect, there are many equations and concepts presented in this video that are beyond the scope of this course.
    d. Then why watch this video? The best reason is that this video presents a history of a series of discoveries which illustrate how science works. These discoveries showed that the current theory of light at that time (light is a wave) could not explain certain observations. These new observations were more consistent with the behavior of particles (light is a particle).
    e. According to the way science works, a new theory should be able to explain all the old observations and also include the new observations. So the particle theory of light if it was correct should be able to explain old observations (interference, diffraction, dispersion and partial reflection and refraction) and the new observations of the photoelectric effect and the quantum theory.
    f. The wave theory could explain interference, diffraction, dispersion and partial reflection and refraction but it could not explain the photoelectric effect.
    g. So which theory is correct? The only way to reconcile the observations was the light had both wave properties and particle properties. Science itself had to adapt its ways in order to explain the observations for the behavior of light.
    h. At 28:34 there is a graphic that depicts the 3 aspects of the wave-particle duality of light. Light can act like waves or light can act like a particle and a wave or light can act like a particle.
    i. The second reason to watch the video is to pique your interest. According to the macroscopic everyday world we live in, the world of quantum physics is a somewhat weird place where crazy events occur. So sit back and enjoy.