Fundamentals of Physics

Teacher Edition

Oak Meadow

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Teacher Edition Introduction

This full-year course is an in-depth exploration into introductory physics. In addition to textbook reading and questions, it includes analytical problem-solving, research, and hands-on activities and labs. Many lessons include activities that students can choose from. This course is designed to help them learn the concepts of physics through multiple lenses to keep them engaged, help them build on their strengths and weaknesses, and improve their skills and abilities as lifelong learners and critical thinkers.

At the end of each lesson, students are reminded to share their work with their teacher. If you would prefer to see their work more or less frequently, you can clarify your expectations with them.

In this teacher edition, answers are shown in **orange** along with the full text of the student coursebook. When assessing student work, it is important to look for conceptual understanding and to make sure the student is putting in an appropriate amount of time and effort. If a student misunderstands a factual question, you can share the correct answer with them to clarify any misconceptions. If they answer many of the factual questions incorrectly, encourage them to review the reading assignments or point them to additional resources.

At the end of units 2–7, students will complete a cumulative unit project that focuses on a variety of STEM (science, technology, engineering, and math) skills, including scientific communication, engineering design, data interpretation, and experiential learning. Each project has its own challenges and encourages your student to grow outside of their comfort zones and try new things. The goal of the unit projects is to practice new skills rather than perform to perfection. Feedback should meet the student where they are individually, with the student's learning goals and progress in mind. Encourage creativity and thinking outside the box when appropriate.

Because students are expected to produce original work, it is best not to share this teacher edition with them. Any indication of plagiarism needs to be taken seriously. Make sure your student is familiar with when and how to attribute sources. These conventions are explained fully in the coursebook appendix. Although high school students should be fully aware of the importance of academic integrity, you are encouraged to review its significance with your student at the start of the course. (Information on this is also found in the appendix.)

We encourage you to join your student in discussing the topics in this course. Taking a special interest in your student's work can result in greater engagement and effort.

A Note About the Workload

Students vary greatly in terms of reading speed, reading comprehension, and writing ability. Some may find the reading in this course takes longer than expected; others may find the writing assignments or math calculations take a great deal of time. In general, students can expect to spend about 5–7 hours a week on this course. For students who need more time to complete the work, you can modify some lessons to focus on fewer assignments or let them complete some of the written assignments orally. Modifications like these will allow students to produce work that is of a higher quality than if they were rushing to get everything done. Each lesson in this course can be customized to suit your student's needs.

Keep an eye on the workload as your student progresses through the course, and make adjustments so they have time for meaningful learning experiences.

Coursebook Introduction

Welcome to *Fundamentals of Physics*! Throughout history, humans have tried to understand how and why the things in the world and broader Universe act the way they do.

We perceive the physical world through our senses and advanced technology. We observe things that act in particular ways, sometimes predictable and sometimes surprising. Our perceptions notice patterns that seem to be relatively consistent and make sense to us. A prediction or hypothesis of what will happen in a particular situation can lead to a statement that describes or explains the patterns noticed in repeated situations. These theories are what make up the core of physics and science in general.

As our recognition of these patterns developed, scientists discovered that the language used to describe them and other physical phenomena is mathematics. Mathematics is a language that we can use to explain and predict the physical happenings in the world. Physics is, at its core, applied mathematics that describes how the world around us works. You may be interested to learn that physics principles are used in engineering, design, scientific research, music, sustainable development, and many more disciplines. Because physics describes how the world works, it can be found all around us.

This physics course will teach you the fundamentals of physics. You'll learn about how and why things move, gravity, energy, light, sound, electricity, magnetism, and modern physics. You'll expand your critical thinking skills as a scientist and improve your ability to communicate clearly. In this course, you will be learning physics through a multitiered approach. You will first practice the math skills you'll need, and then build your conceptual understanding of a new topic through inquiry activities, textbook readings, and research. Next, you will learn the mathematic equations that describe the topic and develop your understanding through conceptual and analytical questions. Once you have a good understanding conceptually and mathematically, you will apply these principles to laboratory experiments and hands-on projects. This multitier approach will help you understand physics better as you learn through multiple lenses.

A note about terminology: In this course, you'll notice the word *Universe* is capitalized when referring to the one we live in (rather than just a generic category), just as *Earth* is capitalized when referring to our planet (rather than the matter that makes up our planet). Specifying our Universe differentiates it from potential other universes or even a multiverse.

Course Materials

In addition to this coursebook, this course uses the following materials:

- *Physics: High School* (OpenStax), available free online at openstax.org/details/books/physics
- Physics Lab Kit
- *Physics Lab Manual*
- Physics Answer Key

Recommended materials:

- Graphing calculator or scientific calculator

For the analytical problem-solving portion of the course, your calculator should be capable of executing trigonometric functions and have the ability to enter numbers in scientific notation. While it is possible to find a calculator app for your phone or access one online for your computer, a handheld calculator is often easier to use.

In your lab kit, you will find the bulk of materials needed to complete the required lab experiments, a lab manual, and an answer key. Some labs require the addition of ordinary household items. These items will be noted in the lab manual for each experiment; a list of materials is also found in the appendix of this coursebook. One of the first labs of the course gives you the chance to familiarize yourself with your lab kit materials. The lab manual also explains how to perform experiments safely. If you are completing this course independently, you can use the answer key to double-check your work. Students who are submitting work to a teacher will have their labs reviewed by their teacher.

This course utilizes the power of technology and the many resources available online. You will be using the internet to conduct research and complete several activities. Links to additional online resources (such as video explanations of some of the material covered) are listed in each lesson and can be easily accessed through Oak Meadow's Curriculum Links page at oakmeadow.com/curriculum-links. Take a moment to locate and bookmark this page for quick access to these online resources.

Your OpenStax textbook has additional student resources available online, including a reading and note-taking guide, a student time management guide, and a student solution guide. The student solution guide has detailed answers to the odd-numbered chapter review problems.

If you do not have internet access at home, you are encouraged to use your local library when conducting online work. If you are unable to use the internet, don't worry—you will still be able to complete the course!

The appendix of this coursebook and the appendix of your textbook contain important material that you will be expected to read and incorporate into your work throughout the year. Take some time to familiarize yourself with the information in the appendices.

How to Read Your Textbook

A science textbook is not a novel, and it requires a different kind of reading. Here are some tips:

- First, look through the key concepts, section headings, and main ideas. Then, read the content. Later in the course, you will find that you are already familiar with some of the content since it is all connected, so you will be able to skim some sections.
- Reading a chapter straight through is not always the best approach. Skip around, go back and forth between sections, and read some parts two or three times. Skim some parts, and read other parts in depth as needed.
- Pay special attention to the images and diagrams. There is a reason that "a picture is worth a thousand words." They might be especially helpful for you if you are a visual learner. It will also be increasingly important for you to understand text descriptions of physics problems and draw an accompanying diagram, so take your time understanding the diagrams drawn in the book.
- As you go through the reading in this course, keep a list of any vocabulary terms that are new to you. The bold terms in the text may be a good start, but there will be others as well. Writing down these terms is one good way to learn them. You will be expected to understand and use the correct terminology. Equally important is pronunciation. Look up any pronunciation you are uncertain of and practice speaking the terms aloud.
- At the end of each chapter are key terms, section summaries, and key equations. You should read through these because they highlight the important takeaways from each section. The key equations often align with the equations you will be defining variables for. Focus on learning the equations included in your coursebook as some of the textbook equations will be skipped.
- If you are using the online version of the textbook, you will find links to external videos that go through sample problems. These can be helpful if you start to feel stuck when answering the conceptual and analytical questions for each lesson.
- If you find yourself struggling to understand a concept explained in the textbook, please refer to the Additional Resources section of the lesson you are working on for links to videos or other websites that explain the concepts presented in the lesson. If you still find yourself struggling to understand, reach out to your teacher. They are eager to help you!

How the Course Is Set Up

In this course, there are 30 lessons divided into 8 units. The first 5 units comprise the first semester of the course and will take approximately 17–18 weeks to complete. The first semester focuses on the language of physics, kinematics in one and two dimensions, force, gravity, rotational motion, and momentum. The final 3 units comprise the second semester of the course and will take approximately 17 weeks to complete. The second semester focuses on energy, heat, thermodynamics, waves, sound, light, electricity, magnetism, and modern physics. You can expect to spend 5–7 hours a week on this course.

This coursebook includes instructions for the readings, assignments, labs, and activities you will be doing for each lesson. Some lessons have lab experiments and some offer several activity options for you to explore—you should choose the activity that interests you the most! Each lesson is designed to engage you as a learner and encourage growth as a student and human being.

Units 2–7 each end with a weeklong project. These projects are cumulative, hands-on experiences that let you explore what it means to be a scientist, engineer, and designer while you demonstrate what you learned in each unit. These projects are designed to broaden your understanding of how physics concepts are utilized in a variety of disciplines. The goal of the unit projects is exploration, learning, and embracing your creativity. The *process* of completing each project is emphasized; engaging fully in the process is more important than producing a perfect end product. Be sure to carefully read through the entire project before you begin, gather any supplies you will need, and set aside specific times to work on the project. The projects will challenge you in different ways. This is a good thing because it means you will grow as a lifelong learner!

This course is designed for independent learning, so hopefully you will find it easy to navigate. However, it is assumed you will have an adult supervising your work and providing support and feedback. This person will be referred to as "your teacher" throughout the course. If you have a question about your work, please ask them for help!

Suggested Course Schedule

Semester 1: Units 1–5, approximately 17.5 weeks

Unit	Lesson	Time to complete
Unit 1 Mathematics and the Language of Physics	Lesson 1A: Mathematical Skills and Concepts Review	0.5 weeks
	Lesson 1B: Introduction to Physics	2 weeks
Unit 2 Introduction to Kinematics and Force	Lesson 2: One-Dimensional Kinematics	1 week
	Lesson 3: Acceleration	1 week
	Lesson 4: Forces and the Laws of Motion	1 week
	Lesson 5: Unit 2 Project: Egg Drop Experiment	1 week
Unit 3 Two-Dimensional and Rotational Motion	Lesson 6: Two-Dimensional Motion	2 weeks
	Lesson 7: Circular and Rotational Motion	1 week
	Lesson 8: Unit 3 Project: Scientific Paper	1 week

Unit	Lesson	Time to complete
Unit 4 Gravity and Momentum	Lesson 9: Gravity	1 week
	Lesson 10: Momentum	1 week
	Lesson 11: Unit 4 Project: Rube Goldberg Machine	1 week
Unit 5 Energy	Lesson 12: Introduction to Work and Energy	1 week
	Lesson 13: Heat	1 week
	Lesson 14: Thermodynamics	1 week
	Lesson 15: Unit 5 Project: Presenting Scientific Research Results	1 week

Semester 2: Units 6–8, approximately 17 weeks

Unit	Lesson	Time to complete
Unit 6 Waves: Light and Sound	Lesson 16: Introduction to Waves	1 week
	Lesson 17: Sound	2 weeks
	Lesson 18: Light	1 week
	Lesson 19: Mirrors and Lenses	1.5 weeks
	Lesson 20: Diffraction and Interference	0.5 weeks
	Lesson 21: Unit 6 Project: Applications of Wave Properties	1 week
Unit 7 Electricity and Magnetism	Lesson 22: Introduction to Electricity	2 weeks
	Lesson 23: Electrical Circuits	1 week
	Lesson 24: Magnetism	1 week
	Lesson 25: Unit 7 Project: Communicating Scientific Ideas	1 week
Unit 8 Modern Physics	Lesson 26: Special Relativity	1 week
	Lesson 27: The Quantum Nature of Light	1 week
	Lesson 28: Quantum Theory of the Atom	1 week
	Lesson 29: Particle Physics	1 week
	Lesson 30: Learning Reflection	1 week

Lesson Structure

In the lessons, you will find the following sections:

An **Assignment Checklist** is included at the beginning of each lesson. You can see all the assignments at a glance, clarify with your teacher which ones are required and which are optional, and check off assignments as you complete them. Assignments are fully explained in the lesson.

The **Learning Objectives** outline the main goals of the lesson and give you an idea of what to expect.

The **Lesson Introduction** provides a brief glimpse into the lesson's topics and themes.

Most lessons include a **Math Prep** section that provides a short review of a math concept relevant to the lesson. This section will help you refresh your math skills before having to use them while analyzing physics problems. You should complete the problems in the Try It! section and submit them as part of the lesson.

The **Real-Life Relevance** section shows how the concepts covered are applied in real-world examples. This section illustrates the importance of what you are learning.

Inquiry Activities give you the opportunity to explore the lesson concepts in a hands-on way, which helps put the rest of the lesson into perspective.

Reading sections list the required reading for the lesson.

Additional Resources complement the required reading for the lesson. These are good to use when you feel like you need a little more explanation of any topics beyond what the textbook reading includes.

Defining Key Equation Variables gives you the opportunity to understand the formulas and equations included in each lesson. Understanding what physical quantities are represented by variables in an equation is an important part of being able to analyze physics problems successfully.

Conceptual Questions are designed to help you solidify key concepts and knowledge. Your answers should be concise while fully explaining or describing your answer.

Analytical Questions apply the knowledge you have learned to solve physics problems using equations and your understanding of each concept. You are encouraged to do these questions by hand on a sheet of paper because you will often be drawing diagrams and solving various equations. Submitting a photo of your work is sufficient for these questions. Be sure your work is organized and clearly labeled.

Activities and Labs are designed to aid in the understanding of the information presented. Some activities will be hands-on, some will be deeper explanations of how to solve problems, and some are a combination of the two. Labs give you the opportunity to learn about physics through hands-on experimentation, where you will practice and hone the ability to collect data, observe phenomena, and analyze results. Be sure to read the directions multiple times to ensure you are completing the activity correctly. Research opportunities let you learn about specific topics in more detail. You should always use legitimate sources, cite them properly, and communicate what you have learned in your own words. Research will be presented as a written paper, presentation, poster, or video.

The **Further Study** section includes activities that are optional and not required to successfully complete the course. If you find a topic fascinating, doing the further study option will give you more exposure to the topic.

The **Share Your Work** section provides reminders and information for students who are submitting their work to a teacher.

When you begin each lesson, scan the entire lesson first. Take a quick look at the number of assignments and amount of reading. Having a sense of the whole lesson will help you manage your time effectively.

Time Management

It is recommended that you establish and stick to a consistent schedule to help you keep on track with your schoolwork. Completing one lesson per week is the recommended pace.

Students vary greatly in terms of reading speed, reading comprehension, and writing ability. Some may find the reading in this course takes longer than expected; others may find the writing assignments, math calculations, or hands-on activities take a great deal of time. To help your teacher gauge and adjust the difficulty of the curriculum, you may want to keep a log of how many hours you spend each week for the first few lessons of this course. If you are regularly completing lessons in substantially less than five hours, you and your teacher may want to increase the length and detail of your responses or the number of assignments you're completing. If you regularly need more time to complete the work, your teacher can help you modify some lessons to focus on fewer assignments or skip activities in some lessons to spend more time on other assignments.

Modifications like these will allow you to produce work of a higher quality. With your teacher's help, you can adjust the requirements of the course to help you better balance your time between your various courses, and between schoolwork and the rest of your life.

Academic Expectations

You are expected to meet your work with integrity and engagement. Your work should be original and give an authentic sense of your thoughts and opinions (rather than merely what you think your teacher wants to hear). When you use other sources, you are required to cite them accurately. Plagiarism—representing another author's words or ideas as your own—and other forms of cheating are not only a serious breach of academic ethics, but they also undercut your own learning and development as a student.

The appendix contains important material that you will need to read and incorporate into your work throughout the year. Take some time to familiarize yourself with the resources in the appendix. You will find information about original work guidelines, tips on how to avoid accidental plagiarism, and details on citing sources and images.

If you become especially interested in any particular topics in the course, let your teacher know. They can help you find relevant information. It is ultimately through you that this course comes alive. So, now is the time to sharpen your senses and expand your mind as you embark on this exciting and challenging journey.

A Note About the Workload

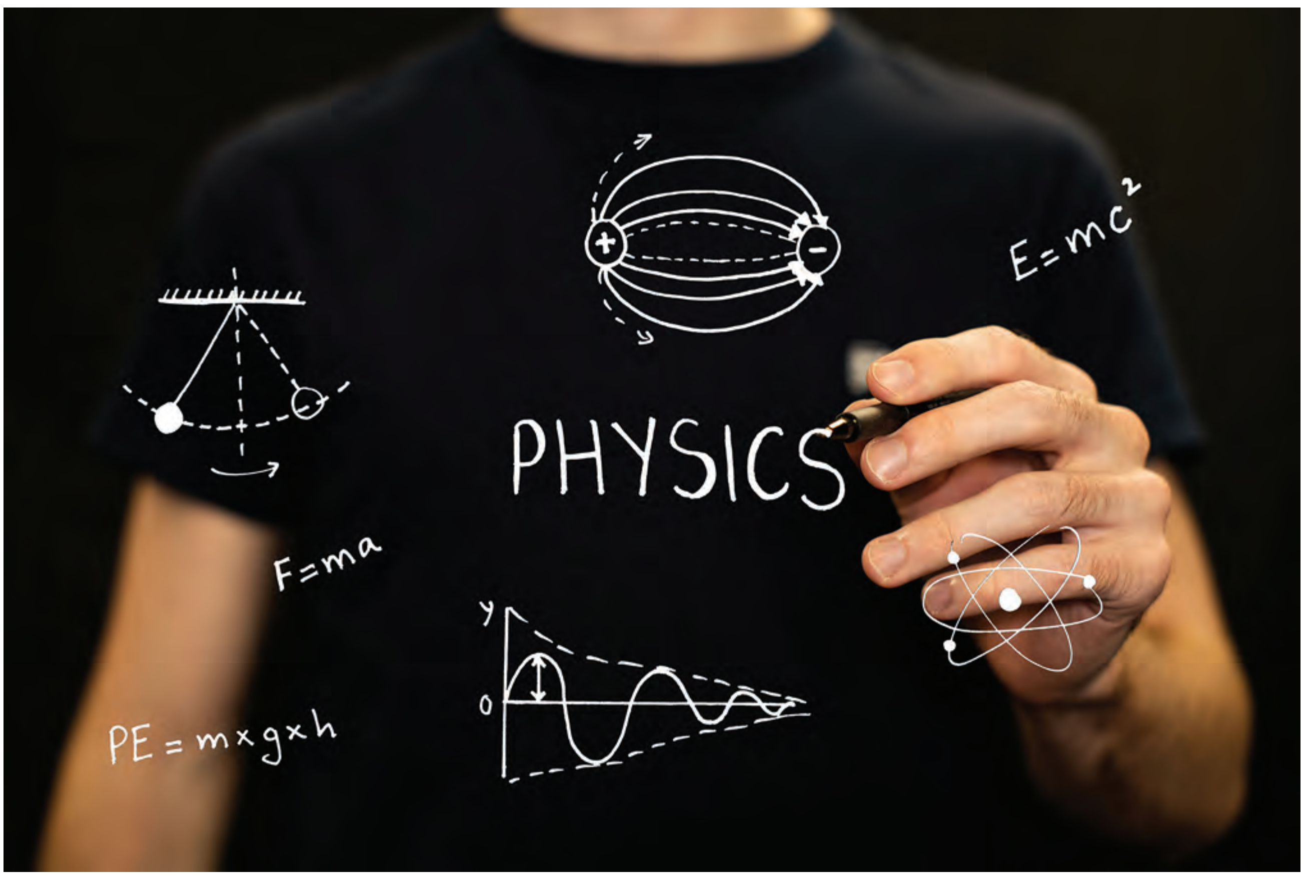
Students vary greatly in terms of reading speed, reading comprehension, and writing ability. Some may find the reading in this course takes less time than expected; others may find the writing assignments take a great deal of time. In general, you can expect to spend about five to seven hours on each weekly lesson.

Keep an eye on the workload as you progress through the course. If you find you are struggling to complete the work, contact your teacher to discuss your options. Your teacher might modify lessons depending on particular learning goals or challenges you are facing.

UNIT 1 Mathematics and the Language of Physics

In Unit 1, we'll review a variety of mathematical skills and concepts you'll be using in this course. Then you will jump into physics with an introduction that discusses what physics is, common terminology, units, scientific notation, uncertainty, and graphing relationships.

Unit 1 consists of two lessons: lesson 1A is a short half-week lesson of math review, and lesson 1B is the introduction to physics!



(Image credit: Preply.com Images)

Lesson

1A Mathematical Skills and Concepts Review

Learning Objectives

In this lesson, you will:

- Review basic algebraic manipulation skills for problem-solving.
- Review graphing basics: plotting, quadrants, axis, slope, and linear equations.
- Review basic trigonometric relationships: sine, cosine, tangent, and right triangles.

ASSIGNMENT CHECKLIST

- [ ] Complete the Math Prep activities.

Lesson Introduction

This lesson is a review of the math skills you'll be using in the rest of the course, such as expression manipulation, graphing, and right triangles. The goal is to have these concepts fresh in your mind as you begin the study of physics. This course was designed for students who have done prior coursework in Algebra I, Algebra II, and Geometry. The goal of this lesson is not to teach these concepts from scratch but to provide a quick refresher.

If any of the information in this lesson is new to you, please reach out to your teacher for further explanation or resources.

This lesson will take approximately half a week.

Math Prep

Rearranging Expressions

Since solving analytical physics problems often involves algebraic manipulation to an existing formula (also referred to as isolating variables), let's review the basics.

Often a physics formula is written in a set way even though the variable we are trying to solve for may be embedded within the formula itself. This happens because what we know in a real-life scenario may vary based on what we are able to measure and what we are looking to find out. Rearranging equations is all about understanding math operations. We will start with addition and subtraction, then multiplication and division, and finally roots.

Much like solving for a single variable, when rearranging equations involving addition and subtraction, we perform the opposite operation of what is present. Check out the following example.

$$a + b = c - d$$

First, let's isolate the variable *b*. To do this, we will need to subtract *a* from both sides since it is currently being added.

$$a - a + b = c - d - a$$

$$b = c - d - a$$

Next, let's isolate the variable *c*. To do this, we will need to add *d* to both sides since it is currently being subtracted.

$$d + a + b = c - d + d$$

$$d + a + b = c$$

While this process may seem simple, the same principle occurs in more complex equations where a given term needs to be eliminated from one side of the equation.

How does this work with multiplication and division? The same principles apply: if the operation currently occurring is multiplication, you will need to divide, and if the current operation is division, you will need to multiply. Look at the next example.

$$ab = \frac{c}{d}$$

First, let's isolate the variable *b*. To do this, we will need to divide both sides by *a* since it is currently being multiplied.

$$\frac{ab}{a} = \frac{c}{da}$$

$$b = \frac{c}{da}$$

Next, let's isolate the variable *c*. To do this, we will need to multiply both sides by *d* as it is currently being divided.

$$ab \cdot d = \frac{c \cdot d}{d}$$

$$abd = c$$

When an equation involves both multiplication and division simultaneously or a fraction is present, the reciprocal fraction is used to rearrange the expression. Check out the following example that uses a reciprocal fraction to isolate the variable *t*.

$$\frac{st}{v} = -4w$$

To isolate the variable t on the left side of the equation, we will need to multiply by $\frac{v}{s}$ since it is the reciprocal to $\frac{s}{v}$, which is currently present in the equation.

$$\frac{st}{v} \cdot \frac{v}{s} = -4w \cdot \frac{v}{s}$$

$$t = \frac{-4wv}{s}$$

The last math operation we will review in this section is simplifying expressions with exponents or roots. Again, the same principles apply. If the current operation is raising a variable to an exponent, the root of the exponent needs to be applied to both sides of the equation. If the current operation is the root of the variable of interest, raising both sides of the equation is necessary. Look at the next example.

$$r^3 = \frac{3\pi}{4}$$

To isolate and solve for the variable r, the cubed root of both sides of the equation must be taken.

$$\sqrt[3]{r^3} = \sqrt[3]{\frac{3\pi}{4}}$$

$$r = \sqrt[3]{\frac{3\pi}{4}}$$

Next, let's start with a square root and isolate the variable under the root.

$$\sqrt{c} = ab - 4d$$

To isolate and solve for the variable c, both sides of the equation must be squared.

$$(\sqrt{c})^2 = (ab - 4d)^2$$

$$c = (ab - 4d)^2$$

All these techniques can be used in tandem to isolate variables in more complex formulas and equations.

Resources for Isolating Variables

If you find the following exercises difficult or are unsure of how to solve them, check out the following videos. If you need additional help, reach out to your teacher.

"Manipulating Formulas: Area"

"Intro to Equations with Variables on Both Sides"

"Manipulating Formulas: Temperature"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Try It! Rearranging Expressions

1. Isolate the variable x in the following equation: $y = 24x - 9$

   Add 9 to both sides and then divide by 24.

   $$x = \frac{y + 9}{24}$$

2. Isolate the variable x in the following equation: $5y - 6x = 48$

   Subtract 5*y* from both sides, then divide by –6.

   $$x = \frac{48 - 5y}{-6}$$

3. Isolate the variable r in the following equation: $A = \pi r^2$

   Divide both sides by π, then apply the square root.

   $$r = \sqrt{\frac{A}{\pi}}$$

4. Isolate the variable n in the following equation: $\frac{h}{n} = \frac{c}{2}$

   Multiply both sides by $\frac{n}{1}$, then by $\frac{2}{c}$.

   $$n = \frac{2h}{c}$$

5. Isolate the variable v in the following equation:

   $$\frac{1}{2}mv^2 = E$$

   Multiply both sides by $\frac{2}{m}$, then apply the square root.

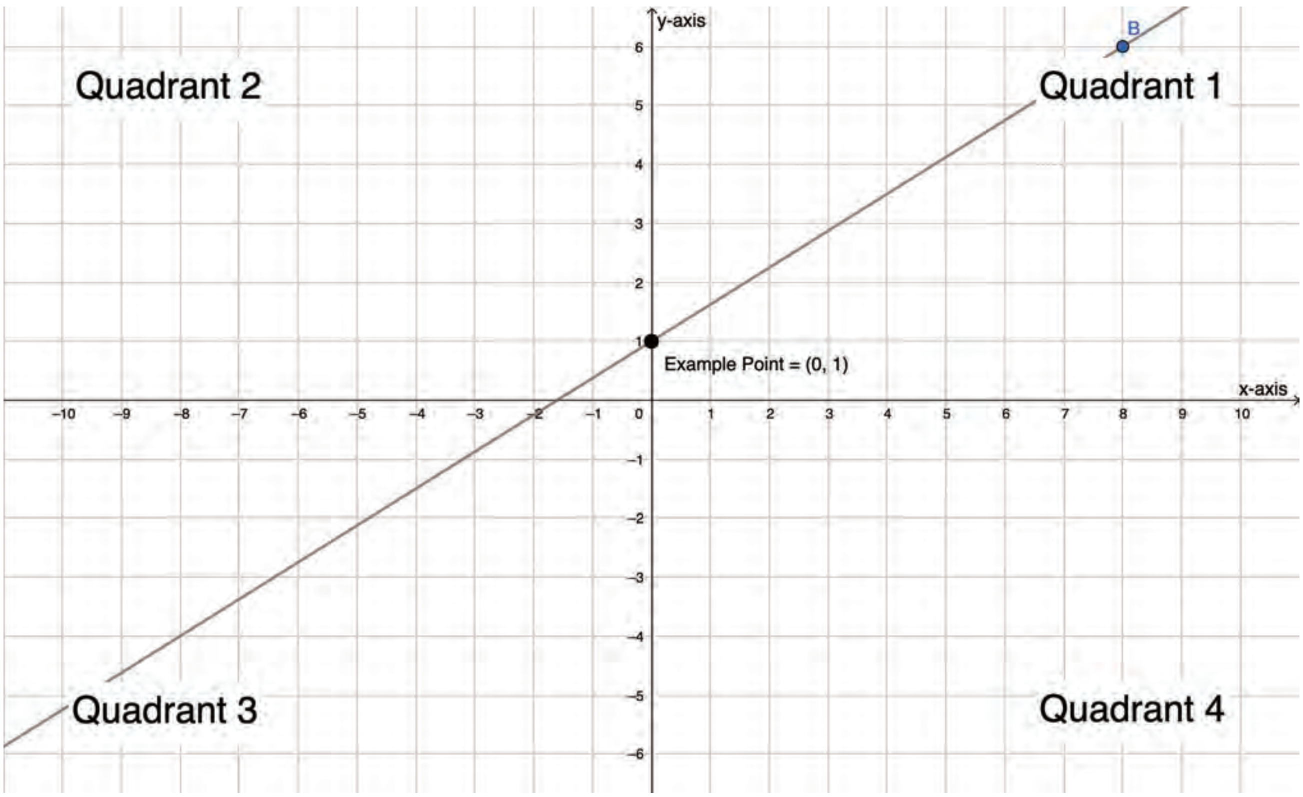
   $$v = \sqrt{\frac{2E}{m}}$$

Graphing Basics

Understanding and being able to interpret graphs is an important skill for you to be familiar with as a physics student. In this section, we'll review graphing linear equations.

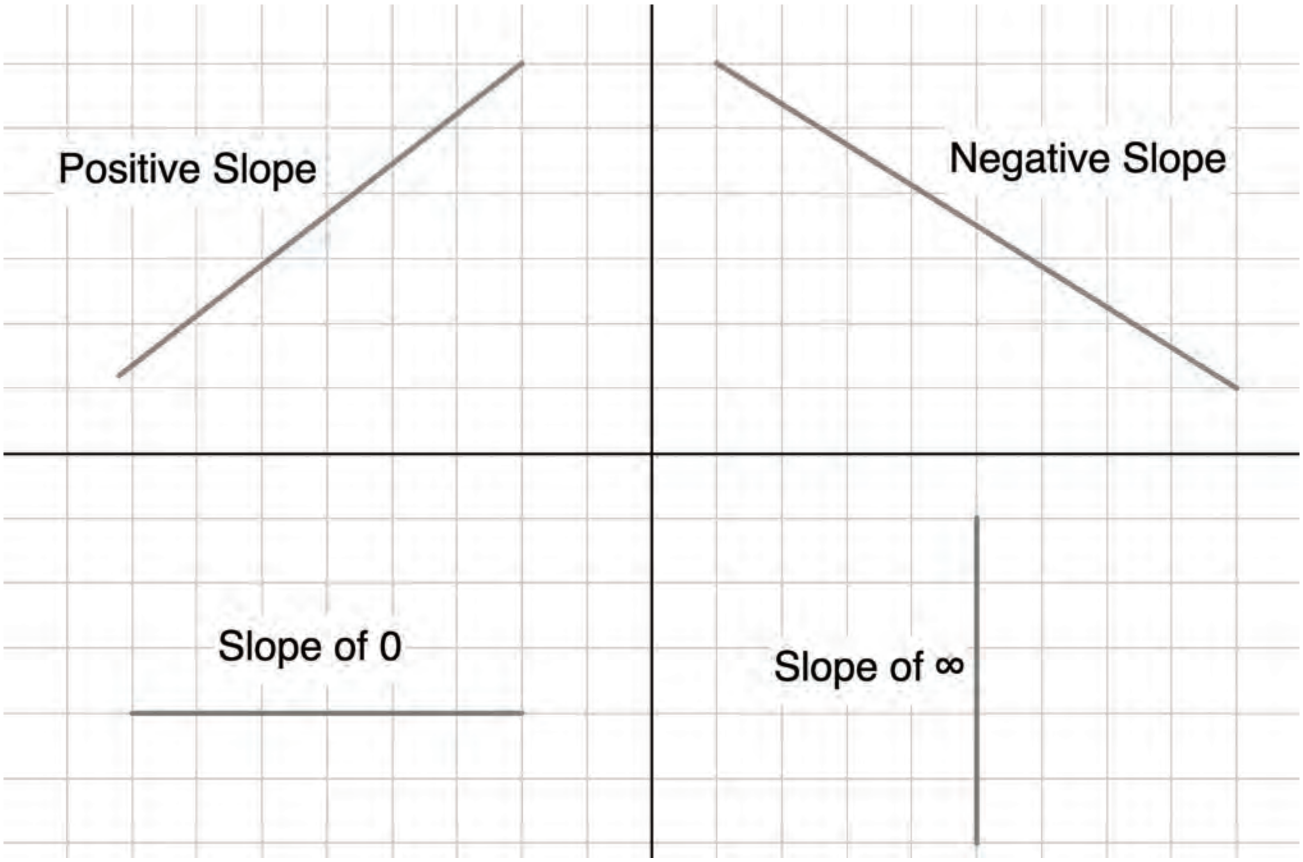
The two-dimensional coordinate plane provides the foundation for graphing linear equations. It is important to remember that the coordinate plane can be broken into four quadrants with a vertical *y*-axis and a horizontal *x*-axis. On the coordinate plane, points are plotted using (x, y) coordinates and linear equations are represented graphically as a line. All these aspects can be seen in the figure below.

Graph: Coordinate Plane



Recall that the slope of a line represents the angle or steepness of the line. A negative slope is a line that slants downward, a positive slope is a line that slants upward, a slope of 0 is a horizontal line, and an infinite slope is a vertical line.

Graph: Types of Slope

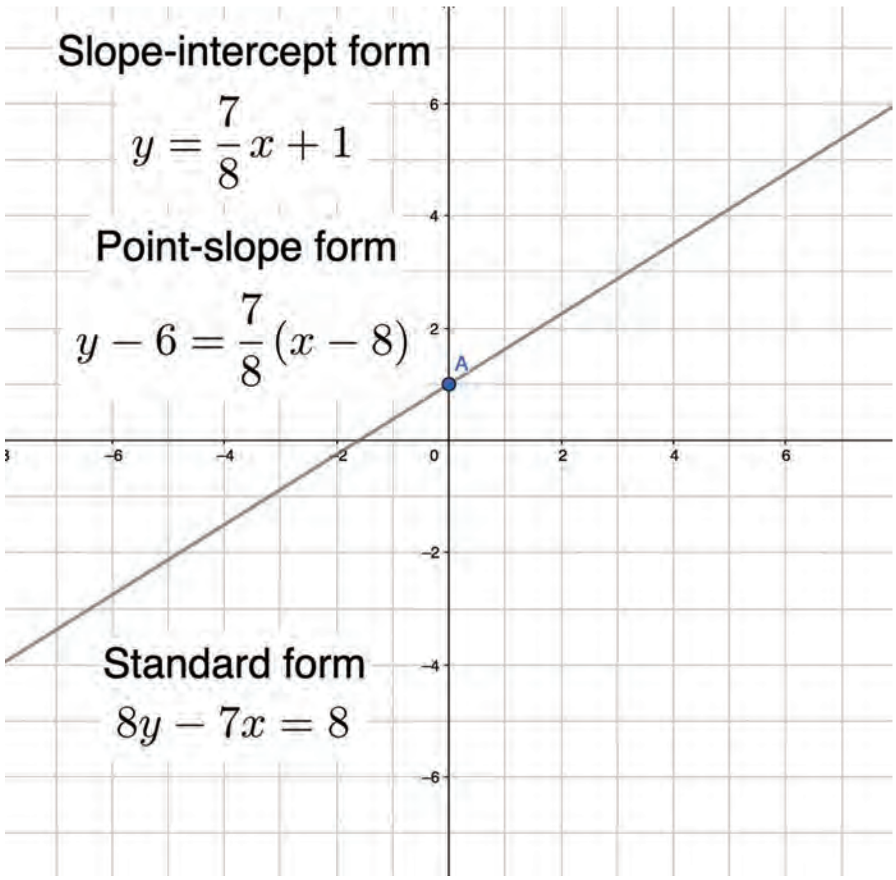


Linear equations are commonly written in slope-intercept form, point-slope form, or standard form.

- In **slope-intercept form**, $y = mx + b$, m is the slope, b is the y-intercept, x is the independent variable, and y is the dependent variable.
- In **point-slope form**, $y - y_1 = m(x - x_1)$, m is the slope, (x_1, y_1) is a specific point on the line, x is the independent variable, and y is the dependent variable.
- In **standard form**, $Ax + By = C$, A, B, and C are integers specific to a given line, x is the independent variable, and y is the dependent variable.

Drawn on the figure below is a linear equation that can be written in slope-intercept form as $y = \frac{7}{8} + 1$, in point-slope form as $y - 6 = \frac{7}{8}(x - 8)$, and in standard form as $8y - 7x = 8$.

Graph: Plotted Line



Resources for Graphing Basics

If you find the following exercises difficult or are unsure of how to solve them, check out the following resources. If you need additional help, reach out to your teacher.

"Slope Review"

"Worked Example: Slope from Graph"

"Intercepts of Lines Review (*x*-Intercepts and *y*-Intercepts)"

"Slope-Intercept Form Review"

"Point-Slope Form Review"

"Standard Form Review"

"Writing Linear Equations in All Forms"

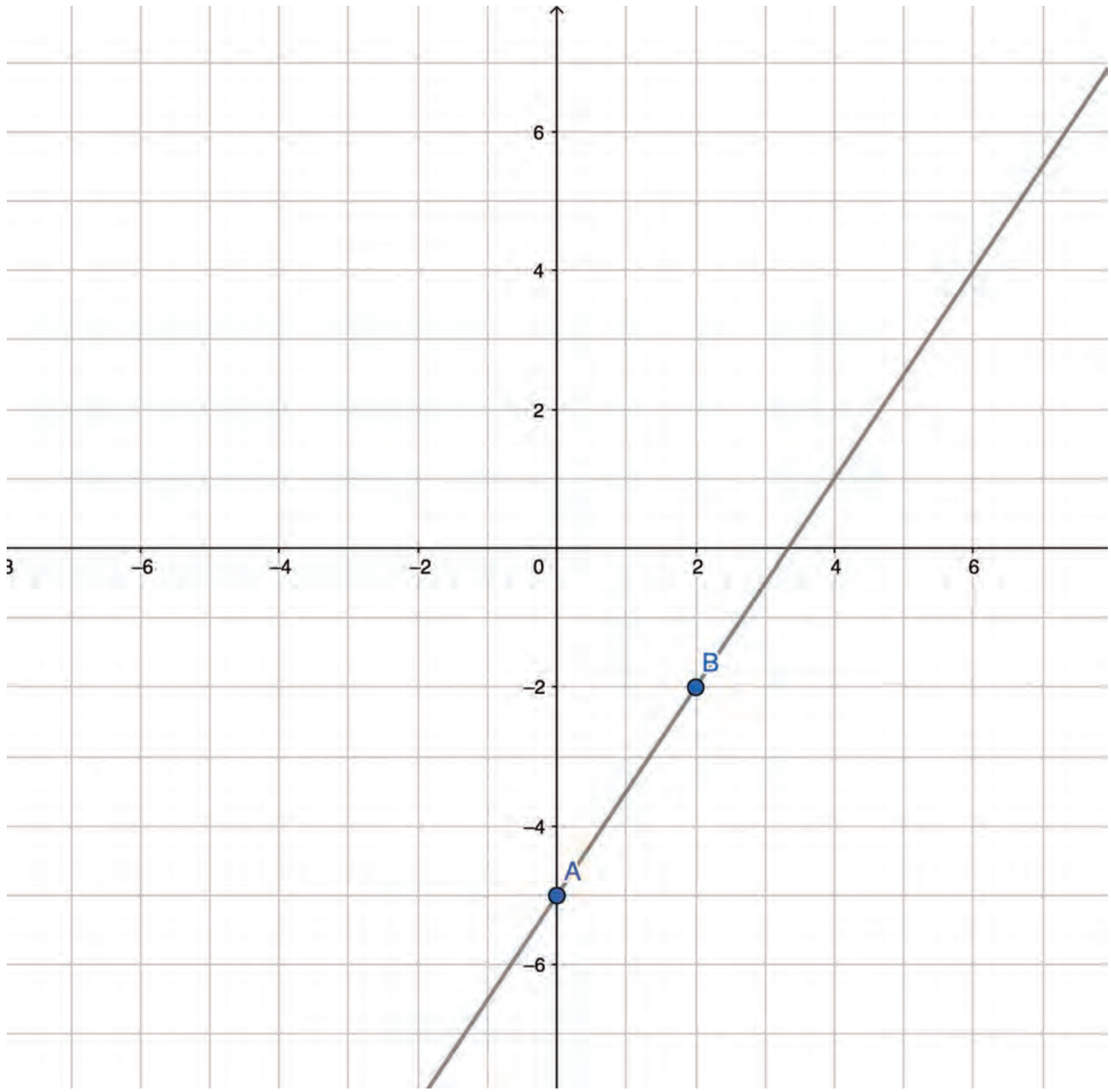
(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Try It! Graphing Basics

For the following graphing problems, draw your graphs by hand on graphing paper or on a self-drawn grid. Graphing calculators and apps should not be used.

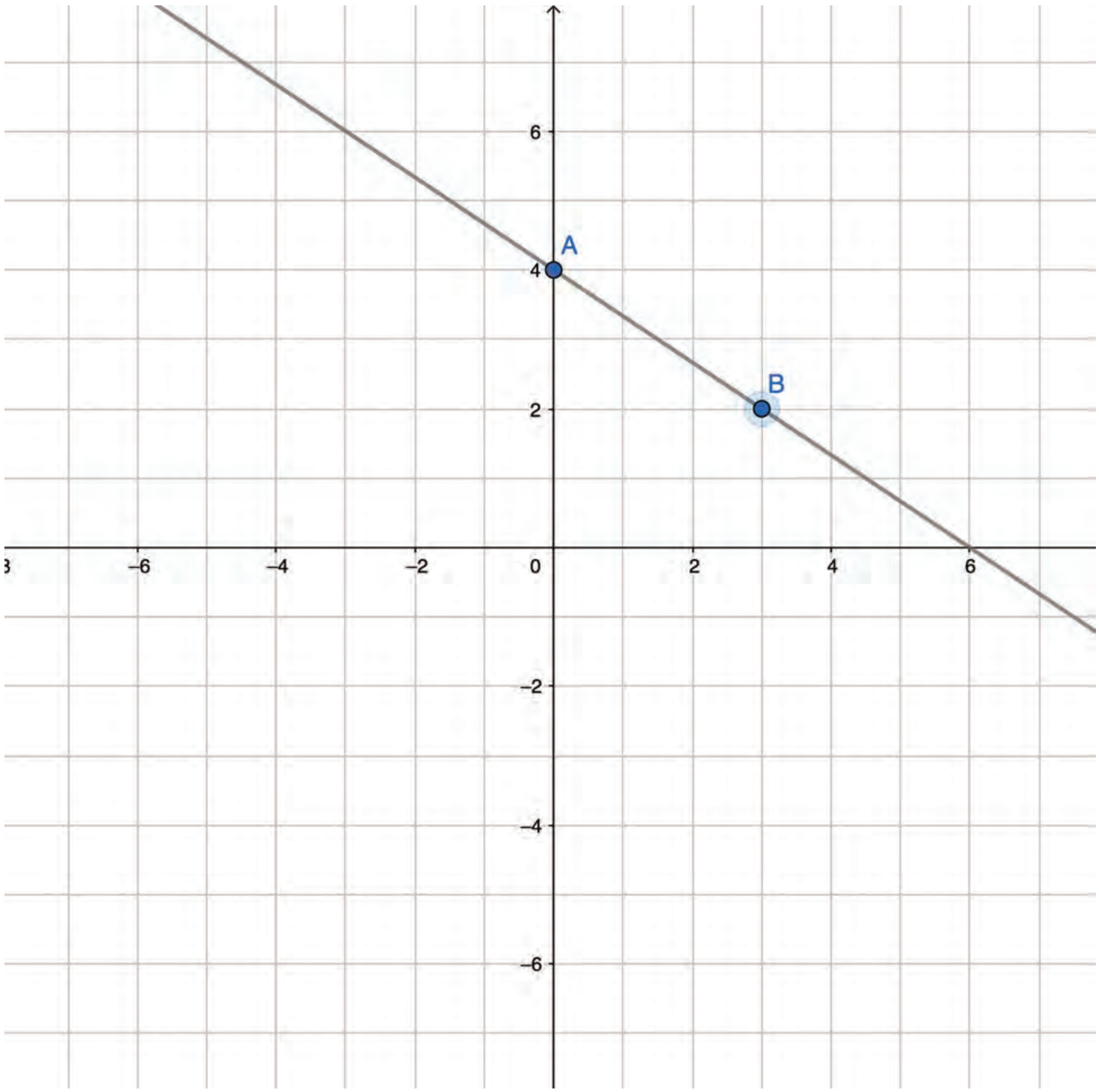
1. Plot the following line: $y = \frac{3}{2}x - 5$

   The solution is shown on the graph below.



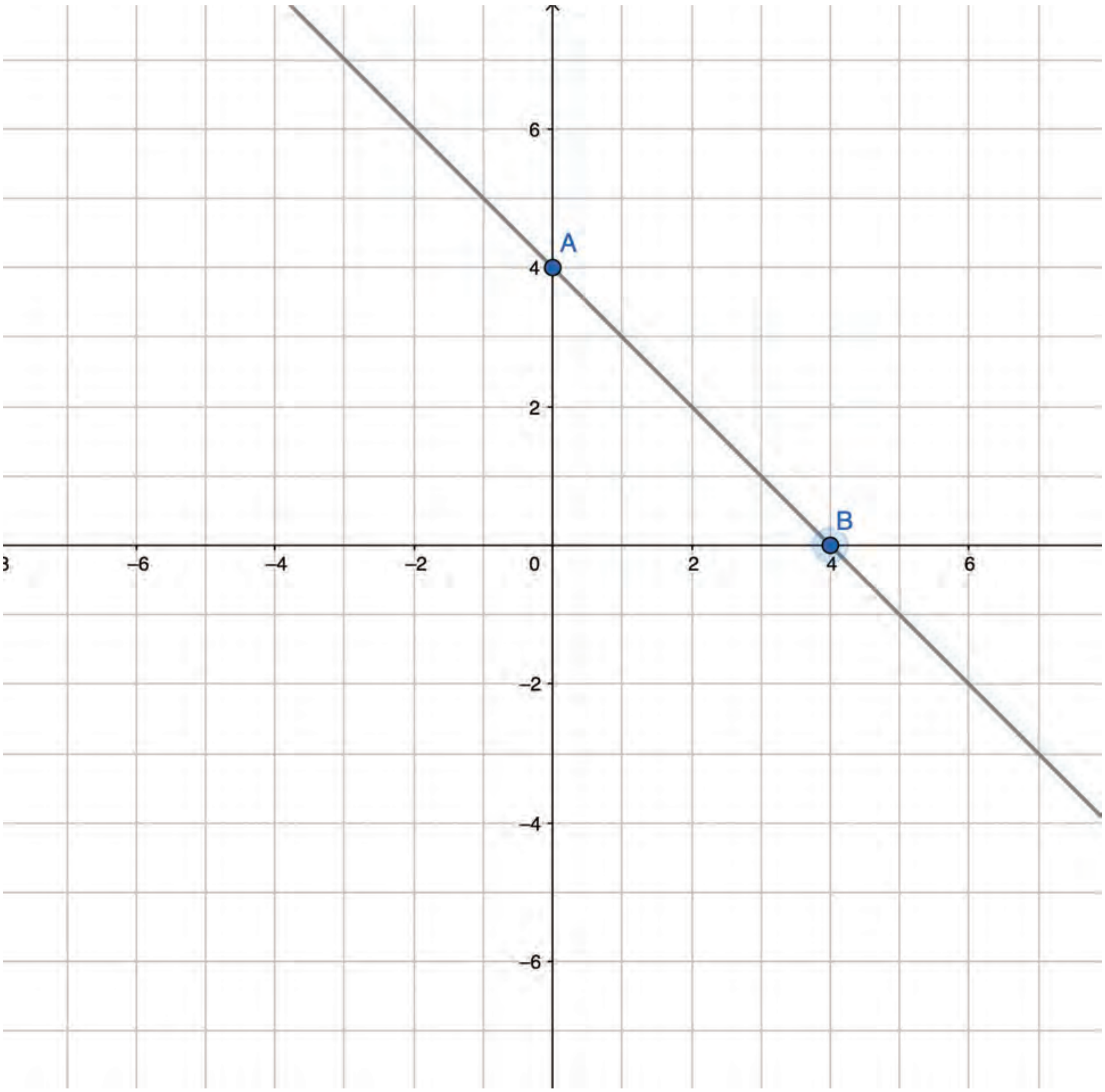
2. Plot the following line: $3y + 2x = 12$

   The solution is shown on the graph below.

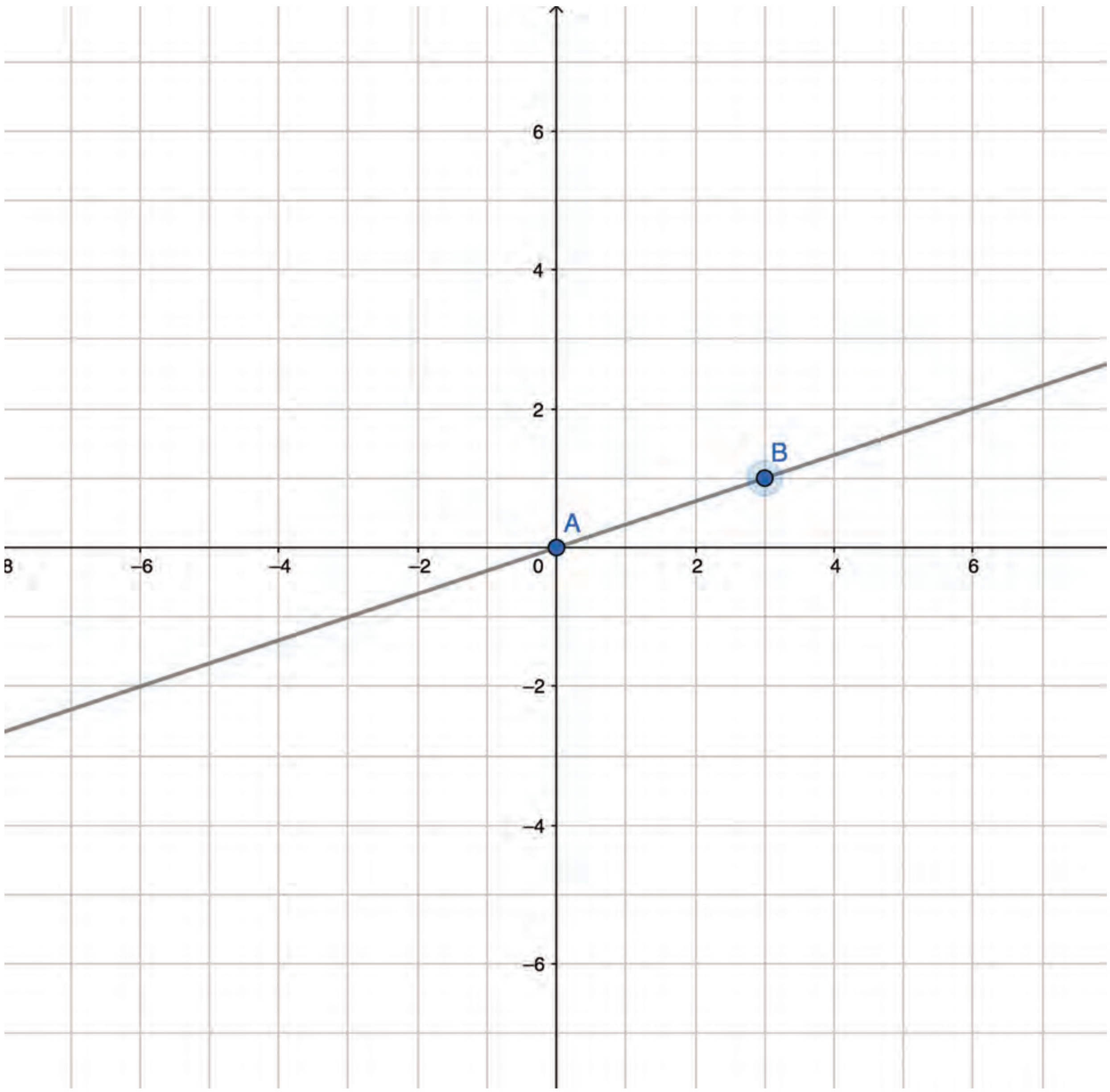


3. Plot the following line: $y - 4 = -(x + 3)$

   The solution is shown on the graph below.



4. Determine the slope of the line below graphically.



Slope = $\frac{1}{3}$

Right Triangles

When working in two-dimensional space, many physics problems involve the use of vectors. Let's review right triangles and basic trigonometry because they are the building blocks for understanding vectors. Later in the course, you will learn what vectors are and how to use them in two-dimensional problem-solving.

Right triangles have one angle of exactly 90°, known as the right angle. The long edge is the hypotenuse. A second angle of the triangle, θ, is often considered to be the angle of interest. In reference to θ, there is the side opposite θ and the side adjacent to θ. Figure 1 illustrates the labeling conventions for right triangles.

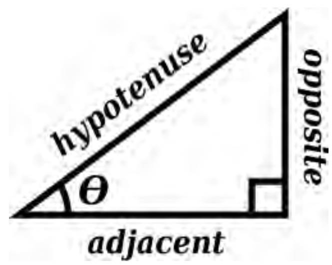


Figure 1: Trigonometric Triangle

Now that the triangle has labels for each side and the angle of interest, the trigonometric relationships of sine, cosine, and tangent can be defined as seen below:

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

The inverse of each trigonometric function can also be defined as follows:

$$\sin^{-1} = \frac{\text{opposite}}{\text{hypotenuse}} = \theta$$

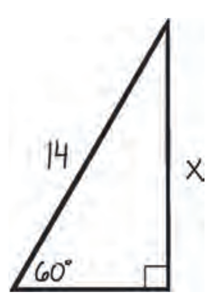
$$\cos^{-1} = \frac{\text{adjacent}}{\text{hypotenuse}} = \theta$$

$$\tan^{-1} = \frac{\text{opposite}}{\text{adjacent}} = \theta$$

These relationships are useful in determining the length of each triangle edge along with the angle of interest. As long as two of the three variables in each relationship are known, the third can be calculated.

Sine

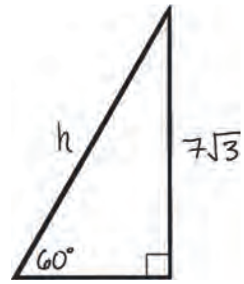
Solving for the opposite side length when θ and the hypotenuse are known:



$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} \rightarrow \text{opposite} = \text{hypotenuse} \cdot \sin\theta$$

$$x = 14 \sin 60^\circ = 7\sqrt{3}$$

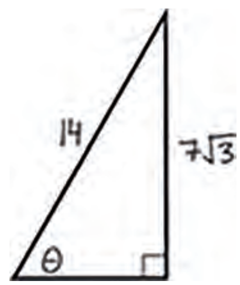
Solving for the hypotenuse length when θ and the opposite side length are known:



$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} \rightarrow \text{hypotenuse} = \frac{\text{opposite}}{\sin\theta}$$

$$h = \frac{7\sqrt{3}}{\sin 60^\circ} = 14$$

Solving for θ when the opposite side length and the hypotenuse are known:

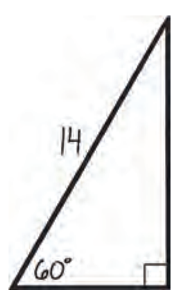


$$\theta = \sin^{-1}\frac{\text{opposite}}{\text{hypotenuse}}$$

$$\theta = \sin^{-1}\frac{7\sqrt{3}}{14} = 60^\circ$$

Cosine

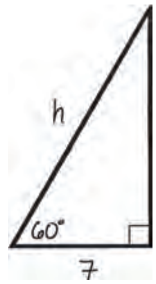
Solving for the adjacent side length when θ and the hypotenuse are known:



$$\sin\theta = \frac{\text{adjacent}}{\text{hypotenuse}} \rightarrow \text{adjacent} = \text{hypotenuse} \cdot \sin\theta$$

$$x = 14\cos 60^\circ = 7$$

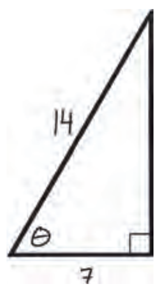
Solving for the hypotenuse length when θ and the adjacent side length are known:



$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} \rightarrow \text{hypotenuse} = \frac{\text{adjacent}}{\cos\theta}$$

$$h = \frac{7}{\sin 60^\circ} = 14$$

Solving for θ when the adjacent side length and the hypotenuse are known:

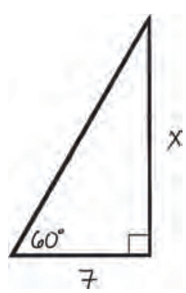


$$\theta = \cos^{-1}\frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\theta = \cos^{-1}\frac{7}{14} = 60^\circ$$

Tangent

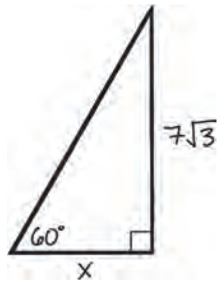
Solving for the opposite side length when θ and the adjacent side length are known:



$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} \rightarrow \text{opposite} = \text{adjacent} \cdot \tan\theta$$

$$x = 7\tan 60^\circ = 7\sqrt{3}$$

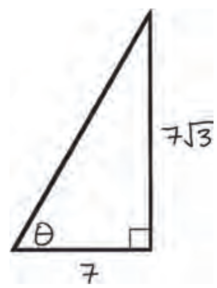
Solving for the adjacent side length when θ and the opposite side length are known:



$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} \rightarrow \text{hypotenuse} = \frac{\text{opposite}}{\tan\theta}$$

$$x = \frac{7\sqrt{3}}{\tan 60^\circ} = 7$$

Solving for θ when the opposite side length and the adjacent side length are known:



$$\theta = \tan^{-1}\frac{\text{opposite}}{\text{adjacent}}$$

$$\theta = \tan^{-1}\frac{7\sqrt{3}}{7} = 60^\circ$$

Resources for Right Triangles

If you find the following exercises difficult or are unsure of how to solve them, check out the following resources. If you need additional help, reach out to your teacher.

"Hypotenuse, Opposite, and Adjacent"

"Trigonometric Ratios in Right Triangles"

"Solving for a Side in Right Triangles with Trigonometry" (article)

"Intro to Inverse Trig Functions"

"Triangle Similarity & the Trigonometric Ratios"

"Trigonometric Ratios in Right Triangles"

"Solving for a Side in Right Triangles with Trigonometry" (video)

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Try It! Right Triangles

For the following problems, be sure to show all your work and each step individually.

1. Solve for the opposite side length when θ = 75° and the hypotenuse = 30.

   Use $\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$ rearranged to opposite = hypotenuse • sin θ = 30 sin 75° = 29.0

2. Solve for the adjacent side length when θ = 75° and the hypotenuse = 30.

   Use $\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$ rearranged to adjacent = hypotenuse • cos θ = 30 sin 75° = 7.8

3. Solve for the opposite side length when θ = 75° and the adjacent side length = 9.

   Use $\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$ rearranged to opposite = adjacent • tan θ = 9 tan 75° = 33.6

4. Solve for the hypotenuse length when θ = 38° and opposite side length = 8.

   Use $\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}} \rightarrow \text{hypotenuse} = \frac{\text{opposite}}{\sin\theta} = \frac{8}{\sin 38°} = 13.0$

5. Solve for the hypotenuse length when θ = 56° and adjacent side length = 45.

   Use $\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}} \rightarrow \text{hypotenuse} = \frac{\text{adjacent}}{\cos\theta} = \frac{45}{\cos 56°} = 80.5$

6. Solve for the adjacent side length when θ = 45° and opposite side length = 12.

   Use $\tan\theta = \frac{\text{opposite}}{\text{adjacent}} \rightarrow \text{adjacent} = \frac{\text{opposite}}{\tan\theta} = \frac{12}{\tan 45°} = 12.0$

7. Solve for θ when the opposite side length = 29 and the hypotenuse = 60.

   Use $\theta = \sin^{-1}\frac{\text{opposite}}{\text{hypotenuse}} = \sin^{-1}\frac{29}{60} = 28.9°$

8. Solve for θ when the adjacent side length = 18 and the hypotenuse = 30.

   Use $\theta = \cos^{-1}\frac{\text{adjacent}}{\text{hypotenuse}} = \cos^{-1}\frac{18}{30} = 53.1°$

9. Solve for θ when the opposite side length = 29 and the adjacent side length = 45.

   Use $\theta = \tan^{-1}\frac{\text{opposite}}{\text{adjacent}} = \tan^{-1}\frac{29}{45} = 32.8°$

SHARE YOUR WORK

At the end of each lesson, you will share your work with your teacher for feedback. (If your teacher prefers a different submission schedule, they will let you know.) You are not necessarily required to complete all the assignments for each lesson, so be sure to check with your teacher at the beginning of the lesson to make sure you understand what you are required to do.

Below is a list of assignments in this lesson, which you can use to organize your work submission:

- Math Prep: Try It! Rearranging Expressions
- Math Prep: Try It! Graphing Basics
- Math Prep: Try It! Right Triangles

Your teacher will let you know the best way to submit your work. If you have any questions about the lesson content, assignments, or how to share your work, contact your teacher.

Lesson

1B Introduction to Physics

Learning Objectives

In this lesson, you will:

- Describe and define physics, both modern and classical, while relating how aspects of physics are used in other fields of study, such as engineering and earth sciences.
- Describe the scientific process of discovery, including the application of the scientific method and the development of physical and mathematical models (hypothesis, theory, and law).
- Understand the importance of physical quantities and their units (specifically related to the International System of Units).
- Perform conversions both with and without scientific notation.
- Understand the uncertainty associated with measurements and determine significant figures for calculations.
- Identify various types of graphing relationships more commonly seen in physics.

ASSIGNMENT CHECKLIST

- ☐ Complete the Math Prep activities.
- ☐ Read chapter 1, "What Is Physics?"
- ☐ Respond to the conceptual questions.
- ☐ Respond to the analytical questions.
- ☐ Activities and Labs:

  Activity: Zeros, Zeros, Everywhere!

  Activity: Significant Digits of Lab Measurement Tools

  Lab: Scientific Analysis

Lesson Introduction

This lesson explains what physics is and why you will be studying physics, and it provides the foundational building blocks that you will use throughout the course. These building blocks include an understanding of fundamental units, derived units, scientific notation, measurement, uncertainty, conversions, the scientific method, and significant figures. You will also learn the difference between classical and modern physics, both of which will be covered in this course.

Some of the material covered in this lesson might overlap with previous science courses you have taken, such as chemistry, while other material may be new to you. Either way, having a good grasp of the basics will help you when more complex topics are introduced later in the course.

This lesson will take approximately two weeks.

Real-Life Relevance

Clear communication is important in our daily lives to ensure we understand one another. In science and technology, clear communication is key to successful research and technological advances. Physics uses specific language called units to describe physical quantities. For example, time is measured in units of seconds. Other units you may be familiar with describe physical quantities such as length (meters or feet) and temperature (degrees Celsius or degrees Fahrenheit). Units come in two varieties commonly referred to as the metric system—also known as the International System of Units or SI—and English units. When working with units, it is important that you stay completely in one system. Mixing and matching unit systems is a lot like speaking French and English at the same time, which can lead to a lot of confusion!

In 1999, when NASA scientists were operating the Mars Climate Orbiter, a multimillion-dollar project, the directions they gave to the Mars Climate Orbiter as it was going into orbit around Mars were in the wrong units. The orbiter spoke the unit language of the metric system, but the directions it was sent were in English units. This discrepancy caused the orbiter to move an incorrect distance, which ultimately ended in its demise—it burned up as it fell into Mars's atmosphere. Years of work, millions of dollars, and the orbiter itself were lost because of a simple miscommunication of units!

To read more about the Mars Climate Orbiter mission and how it failed, check out the following websites:

"Mars Climate Orbiter" (Solar System Exploration/NASA)

"Mars Climate Orbiter" (NASA Space Science Data Coordinated Archive)

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Math Prep

Train Track Method for Conversions

There are many ways in which the process for unit conversions can be organized. In the so-called train track method, conversions are organized on a simple grid that looks a little like a train track. The top row represents the portion of the conversion factor in the numerator of a fraction, and the bottom row represents the portion of the conversion factor in the denominator of a fraction. A conversion factor is two values with different units that represent the same physical quantity. For example, a common conversion factor for time is 1 hour is equal to 60 minutes; the physical quantity is a set length of time that can be described as 1 hour or as 60 minutes. By setting up a grid or track, using conversion factors appropriately becomes simplified, and you are able to keep track of which units cancel each other out as you convert your original unit to your final desired unit. Let's look at a few examples.

Example 1: Using a single conversation factor

Task: Convert 8 feet to inches.

Before starting the conversion, first identify any conversion factors that will be needed. When you are converting from feet to inches, the conversion factor of 12 inches = 1 foot must be used.

Once you have identified any conversion factors, the train track is started by putting the original value and unit into the top left corner of the tracks.

8 ft	

Next, the conversion factor of 12 inches = 1 foot will be put into the second column of the train track. To determine which part of your conversion factor goes on top and which goes on the bottom, look at your original unit, which is in the first column. In this example, the unit is feet, so you will put 1 foot on the bottom of the train track and 12 inches on the top of the train track. This enables you to cancel out the units of feet because it is on both the top and bottom of the train track.

8 ~~ft~~	12 in
	1 ~~ft~~

To finish the conversion, all you need to do is multiply the numbers on top of the train track, then divide by all the numbers on the bottom of the train track. In this case, you would have $\frac{8 \cdot 12}{1} = 96$. The final unit will be the last one left in the tracks, inches, giving you a final answer of 96 inches.

Example 2: Using multiple conversion factors

Task: Convert 8 feet to centimeters.

In this example, you will need to use two conversion factors, one to move from feet to inches (1 foot = 12 inches) and a second to move from inches to centimeters (1 inch = 2.54 centimeters). Thus, you will need another column in your tracks. The beginning of your train track will be set up the same way as example 1.

8 ~~ft~~	12 in	
	1 ~~ft~~	

As you can see, the units that are left are inches. Now, you can use the second conversion factor from inches to centimeters to finish your track setup. As inches are currently on top, you will put 1 in on the bottom and 2.54 cm on the top. Once you have inches on both the top and the bottom of your train tracks, you can cross them out.

8 ~~ft~~	12 ~~in~~	2.54 cm
	1 ~~ft~~	1 ~~in~~

Finally, you can complete your calculation: $\frac{8 \cdot 12 \cdot 2.54}{1 \cdot 1} = 243.84$

This gives you a final answer of 243.84 centimeters.

Example 3: Units that are fractions

Task: Convert 30 miles per hour to feet per second.

For conversion factors, you will need one factor to go from miles to feet (1 mile = 5,280 feet) and two factors to go from hours to seconds (1 hour = 60 minutes and 1 minute = 60 seconds). When your units have the word *per* or exist as a fraction, the part of the unit that is on the bottom of the fraction or after the word *per* will go in the bottom left-hand corner of the train tracks.

30 mi			
h			

Following the same pattern as above, the conversion factor to convert from miles to feet is added next. The final length unit left is feet, as miles are canceled out.

30 ~~mi~~	5,280 ft		
h	1 ~~mi~~		

Now you will convert from hours to seconds. As the original unit of hours is on the bottom of the train track, you will put 1 hour on the top in column 3 and 60 minutes on the bottom. In this way, hours will be on both the top and bottom of the train tracks and will cancel each other out. Similarly, you will use the second conversion factor to go from minutes to seconds, putting 1 minute on the top and 60 seconds on the bottom in column 4. This will cause the units of minutes to cancel out, leaving seconds as the final unit of time.

30 ~~mi~~	5,280 ft	1 ~~h~~	1 ~~min~~
~~h~~	1 ~~mi~~	60 ~~min~~	60 s

Finally, you can complete your calculation: $\frac{30 \cdot 5{,}280 \cdot 1 \cdot 1}{1 \cdot 60 \cdot 60} = 44$

This gives you a final answer of 44 feet per second.

Try It! Train Track Method for Conversions

Convert the following using the train track method.

1. 75 yards to feet

   225 feet

75 ~~yd~~	3 ft
	1 ~~yd~~

2. 5 kilometers to miles

   3.1 miles

5 ~~km~~	1,000 ~~m~~	100 ~~cm~~	1 ~~in~~	1 ~~ft~~	1 mi
	1 ~~km~~	1 ~~m~~	2.54 ~~cm~~	12 ~~in~~	5,280 ~~ft~~

3. 40 miles per hour to meters per second

17.9 meters per second

40 ~~mi~~	5,280 ~~ft~~	12 ~~in~~	2.54 ~~cm~~	1 m	1 ~~h~~	1 ~~min~~
~~h~~	1 ~~mi~~	1 ~~ft~~	1 ~~in~~	100 ~~cm~~	60 ~~min~~	60 s

Reading

In your textbook, read chapter 1, “What Is Physics?” (5–41), which includes the following sections:

- Introduction
- 1.1 Physics: Definitions and Applications
- 1.2 The Scientific Methods
- 1.3 The Language of Physics: Physical Quantities and Units
- Section Summary

Conceptual Questions

Answer the following questions using your own words to describe physics concepts, theories, and laws. You may use a direct quote from the textbook (in quotation marks, with the page number cited) to help support your definition, but do not rely on textbook quotations for your full answer.

1. What are the three conditions under which classical physics approximations are appropriate?

   1. Matter must move at speeds less than 1% of the speed of light.

   2. Objects are large enough to see with the naked eye.

   3. Gravity must be weak, such as that of Earth.

2. Explain the difference between fundamental and derived units. Give an example of each.

   Fundamental units are from measured base physical quantities. There are seven: length (meter, m), mass (kilogram, kg), time (second, s), electric current (ampere, a), temperature (Kelvin, k), amount of a substance (mole, mol), and luminous intensity (candela, cd).

   Derived units are made by mathematically combining fundamental units. An example would be velocity measured as meters per second ($\frac{m}{s}$).

3. How do the rules for significant figures differ from addition/subtraction and multiplication/division?

   For addition and subtraction, the solution will have the same number of decimal places as the least precise starting value. For example, if you add 2.34 and 5.1, the answer will be rounded to the tenths place, 7.4, since 5.1 is the least precise starting value and goes only to the tenths place.

For multiplication and division, the solution will have the same number of significant figures as the starting value with the fewest number of significant figures. For example, if you multiply 58.49 and 0.232, the answer, 13.6, has 3 significant figures because 0.232 has only 3 significant figures while 58.49 has 4 significant figures.

4. Describe a situation in which you can be precise but not accurate.

   An example of when you can be precise but not accurate would be shooting a bow and arrow and having all your arrows land very close together but nowhere near the target. Student examples should have measurements that are very close to one another (precise) but not close to the correct value (not accurate).

5. What is the difference between an independent and a dependent variable?

   An independent variable is the variable that is controlled or manipulated, and a dependent variable changes based on the value of the independent variable. In an experiment, the independent variable is the variable we choose and the dependent variable is the variable we measure.

Analytical Questions

1. Convert 385.6 meters per second to feet per minute. Write your answer with the correct number of significant figures.

   $7.591 \cdot 10^4 \frac{\text{ft}}{\text{min}}$ (4 significant figures)

385.6 ~~m~~	100 ~~cm~~	1 ~~in~~	1 ft	60 ~~s~~
~~s~~	1 ~~m~~	2.54 ~~cm~~	12 ~~in~~	1 min

2. If lengths 8.543 inches, 10.06 inches, and 356.930 inches are added together, how many inches are there? Write your answer with the correct number of significant figures.

   8.543 + 10.06 + 356.930 = 375.533

   rounded to the hundredths: 375.53 inches or $3.7553 \cdot 10^2$ inches

3. A runner completes a half marathon of 21 kilometers in 1 hour, 28 minutes, and 45 seconds. There is an uncertainty of 5 meters in the distance they run and an uncertainty of 1 second in the elapsed time. Calculate the percentage of uncertainty in both the distance and the time.

   Total time 3,600 s + 1,680 s + 45 s = 5,325 s, $\%\text{unc} = \frac{\text{unc}}{\text{total}} \cdot 100 = \frac{1\text{ s}}{5{,}325\text{ s}} \cdot 100 = 0.02\%$

   Total distance 21 km = 21,000 m, $\frac{\text{unc}}{\text{total}} \cdot 100 = \frac{10\text{ m}}{21{,}000\text{ m}} \cdot 100 = 0.04\%$

Activities and Labs

Complete the following:

- Activity: Zeros, Zeros, Everywhere!
- Activity: Significant Digits of Lab Measurement Tools
- Lab: Scientific Analysis

Activity: Zeros, Zeros, Everywhere!

Determining the significant number of digits in a number depends a lot on where the zeros are located. Are they trailing? Are they sandwiched? Are they leading? Below you will find 18 numbers. Your job is to find the secret message hidden by the zeros that count toward significant figures. Highlight the zeros that are significant, and the message will be revealed. Once you have your secret clue, write the significant figures for each of the 18 numbers and write each number in scientific notation.

When you are finished, submit a photo of your completed activity to your teacher.

NUMBERS						SIGNIFICACNT FIGURES	SCIENTIFIC NOTATION
0.	0	0	8	9	1		
6	7	0.	0	0	8		
4	0.	6	7	3	0		
0.	1	0	0	0	2		
0.	0	0	0	0	3		
0.	5	0	2	1	9		
7	3	0.	6	7	8		
4.	0	0	0	0	0		
0.	0	0	6	7	4		
3	0.	0	0	4	0		
2	0.	6	0	1	0		
5	0	0	0.	0	0		
1	2	3	4	5	6		
1	0	0	3.	6	0		
5.	0	0	6	1	0		
6	0	3	0.	5	0		
2	0.	1	0	0	0		
4	0	4.	4	0	0		

The hidden clue is "Zero." This can be seen when the zeros are highlighted and the table is rotated sideways.

NUMBERS						SIGNIFICACNT FIGURES	SCIENTIFIC NOTATION
0.	0	0	8	9	1	3 SF	$8.91 \cdot 10^{2}$
6	7	0.	0	0	8	6 SF	$6.70008 \cdot 10^{2}$
4	0.	6	7	3	0	6 SF	$4.06730 \cdot 10^{1}$
0.	1	0	0	0	2	5 SF	$1.0002 \cdot 10^{-1}$
0.	0	0	0	0	3	1 SF	$3 \cdot 10^{-5}$
0.	5	0	2	1	9	5 SF	$5.0219 \cdot 10^{-1}$
7	3	0.	6	7	8	6 SF	$7.30678 \cdot 10^{2}$
4.	0	0	0	0	0	6 SF	$4.00000 \cdot 10^{0}$
0.	0	0	6	7	4	3 SF	$6.74 \cdot 10^{-3}$
3	0.	0	0	4	0	6 SF	$3.00040 \cdot 10^{1}$
2	0.	6	0	1	0	6 SF	$2.06010 \cdot 10^{1}$
5	0	0	0.	0	0	6 SF	$5.00000 \cdot 10^{3}$
1	2	3	4	5	6	6 SF	$1.23456 \cdot 10^{5}$
1	0	0	3.	6	0	6 SF	$1.00360 \cdot 10^{3}$
5.	0	0	6	1	0	6 SF	$5.00610 \cdot 10^{0}$
6	0	3	0.	5	0	6 SF	$6.03050 \cdot 10^{3}$
2	0.	1	0	0	0	6 SF	$2.01000 \cdot 10^{1}$
4	0	4.	4	0	0	6 SF	$4.04400 \cdot 10^{2}$

Activity: Significant Digits of Lab Measurement Tools

In this activity, you will become familiar with many of the measuring instruments found in your lab kit.

Materials from the Lab Kit

- graduated cylinder
- ruler
- spring scale
- protractor
- thermometer
- stopwatch
- tape measure

In physics, when a measurement is taken, you must also consider the uncertainty of the measurement. To do this, you need to examine the measuring device and determine how precise it is. For devices that are scaled, once you know the smallest increment the device measures, one more place value is estimated generally to half the smallest increment. This gives you the number of significant figures in a measurement taken with that device. For scaled devices, the uncertainty is the last digit that was estimated. For devices with a digital display, the number of digits displayed gives the number of significant figures. For digital devices, the uncertainty is assumed to be ± the smallest increment.

For this activity, you will use two measuring devices together to determine the uncertainty of a device and how many significant figures are in a sample measurement.

Example: A device that is scaled or analog

Take the largest graduated cylinder out of your lab kit, the one with a scale on the side in mL. Looking closely at the scale, we see that it ranges from 10 mL to 100 mL with a step size of 1 mL. When reading this graduated cylinder, a measurement can be estimated to the nearest 0.5 mL because it is half the smallest increment. This means the graduated cylinder has an uncertainty of ±0.5 mL.

An example of a measurement on this graduated cylinder would be 72.0 mL. The 72 comes from reading the graduated cylinder markings and the .0 comes from estimating how close the fluid's meniscus is to the nearest half milliliter. In this case it would have been closest to 72.0 mL, which has 3 significant figures.

Example: A device with a digital display

Take your stopwatch out of your lab kit. Change the mode on the stopwatch until you are in the timer mode. It should read 00:00:00 with the last two zeros being slightly smaller than the first four. This represents minutes:seconds:hundredths of seconds.

To figure out the significant digits on this device, we need to first convert the minutes into seconds and count the significant digits, with the smallest being a hundredth of a second. For example, if the time is 5:34:12 (5 minutes, 34.12 seconds), you would first convert this to 334.12 seconds, which has 5 significant figures. For a time of 45:13.30 (45 minutes, 13.30 seconds), you would convert this to 2713.30 seconds, which has 6 significant figures. The uncertainty of each measurement is ± 0.01 seconds.

Your turn!

Find the uncertainty and the number of significant figures of a sample measurement for the following devices in your lab kit.

1. Small ruler (the centimeter side)

   Uncertainty: ±0.05 cm

   Sample: 5.25 cm

   3 significant figures

2. Tape measure (the centimeter side)

   Uncertainty: ±0.05 cm

   Sample: 5.25 cm

   3 significant figures

3. Spring scale (the Newton side)

   Uncertainty: ±0.0005 N

   Sample: 1.2550 N

   5 significant figures

4. Protractor (angle)

   Uncertainty: ±0.5°

   Sample: 61.5°

   3 significant figures

5. Thermometer

   Uncertainty: ±0.5 °C

   Sample: 37.5 °C

   3 significant figures

Lab: Scientific Analysis

Complete Lab 1: Scientific Analysis, which is found in the *Physics Lab Manual* that came with your lab kit.

Tip: Set up a camera and record the fall in slow motion. This will help you measure the height of the bounce more accurately. The camera should be far enough away from the wall that you can see the entire tape measure.

For this lab, submit the following to your teacher:

- Photos of your setup
- Your completed data tables
- Your completed graphs
- Answers to the lab questions

Solutions are found in the Answer Key that came with your lab kit.

Further Study

If you are interested in further exploring the topics and skills in this lesson, feel free to choose any of the following activities. All are optional.

- Complete the textbook Chapter Review and Test Prep (odd-numbered problems). The solutions are available online via OpenStax, under Student Resources.
- Explore a variety of careers that utilize physics. Pick several of the following job titles to research online.

  Accelerator operator
  Applications engineer
  Astrophysicist
  Data analyst
  Design engineer
  Geophysicist
  High school physics teacher
  Lab technician
  Mechanical engineer
  Optical engineer
  Particle physicist
  Quantum computing
  Software developer

SHARE YOUR WORK

When you have completed your work, share it with your teacher. Remember to check with your teacher at the beginning of each lesson to make sure you understand what you are required to do.

Below is a list of assignments in this lesson, which you can use to organize your work submission:

- Math Prep: Try It! Train Track Method for Conversions
- Conceptual questions
- Analytical questions
- Activity: Zeros, Zeros, Everywhere!
- Activity: Significant Digits of Lab Measurement Tools
- Lab: Scientific Analysis

If you have any questions about the lesson content, assignments, or how to share your work, contact your teacher.

UNIT 2 Introduction to Kinematics and Force

In unit 2, we'll explore the basics of physics, kinematics (or motion) and force as well as acceleration and the laws of motion. Unit 2 consists of three main lessons and one project lesson.

(Image credit: Hippopx)

Lesson

2

One-Dimensional Kinematics

Learning Objectives

In this lesson, you will:

- Describe one-dimensional motion (kinematics) from multiple reference frames.
- Understand the difference between and solve problems involving displacement and distance.
- Understand the difference between and solve problems involving average speed and average velocity.
- Interpret and create position vs. time graphs and velocity vs. time graphs.

Lesson Introduction

Now that you know the basics of what physics entails, it is time to dive in and start learning how the world around us works. First, we'll look at how to describe motion, which is called *kinematics*. While you may be used to everyday language involving speed and distance, physicists have developed more precise language to describe motion conceptually through words, analytically through formulas, and visually through graphs. In this lesson, you will learn how to describe motion in one dimension just as a physicist would.

This lesson will take approximately one week.

ASSIGNMENT CHECKLIST

- ☐ Complete the Math Prep activities.
- ☐ Read chapter 2, "Motion in One Dimension."
- ☐ Complete the exercises in Defining Key Equation Variables.
- ☐ Respond to the conceptual questions.
- ☐ Respond to the analytical questions.
- ☐ Activities and Labs (choose one):

  Activity: Where and How Fast?

  Lab: Graphing Motion

Real-Life Relevance

When a person is injured or experiencing a life-threatening emergency, they often must be transported to the hospital for treatment. Two main modes of medical emergency transportation used in the United States are by ground in an ambulance or by air in a helicopter. Several factors determine which mode is chosen, including the severity of the injury, the distance from the hospital best suited to treat the patient, and the time it would take for the emergency personnel to reach the patient to initiate care.

If we focus solely on the trip from the patient to the hospital, we can analyze which mode of transport would be faster using physics principles, such as distance traveled and the average speed at which transportation takes place. Let's start by analyzing the distance each travels. In an ideal world, the fastest route would be a straight line between the patient and the hospital. The ambulance has to travel on roads that often involve lots of curves and turns, which add to how far it must travel. A helicopter, however, is able to fly in a straight line. This often means the helicopter is able to travel a much shorter distance than the ambulance. In this lesson, you will learn that the distance on a straight line between two points is called *displacement*. In the case of the helicopter, the distance and displacement are almost the same. The speed at which the helicopter can travel is also faster than that of the ambulance because the ambulance must obey traffic laws and operate safely while speeding to its destination. Both the increased distance and the slower rate of travel means it would likely take longer for the ambulance to reach the hospital than the helicopter.

Logically, you may think a helicopter should always be used for any serious injury, yet in real life, this isn't necessarily the case, primarily due to the amount of time it takes for a helicopter crew to prepare for flight and reach the patient versus that of an ambulance crew. Remember, once emergency personnel arrive on scene, they can start the process of caring for the patient. Sometimes getting to the patient quickly to start care is more important than getting the patient to the hospital quickly. Another aspect to consider is the cost of each mode of transportation. A helicopter is much more expensive to operate and requires a more technically trained pilot to fly it. Fortunately, researchers have spent time analyzing all aspects of the ambulance-versus-helicopter conundrum to know when it is ideal to send a helicopter versus a standard ambulance for emergency transport.

Check out the following scientific paper to learn more about the intricacies involved in this critical decision:

> "Cost-Effectiveness of Helicopter versus Ground Emergency Medical Services for Trauma Scene Transport in the United States"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Math Prep

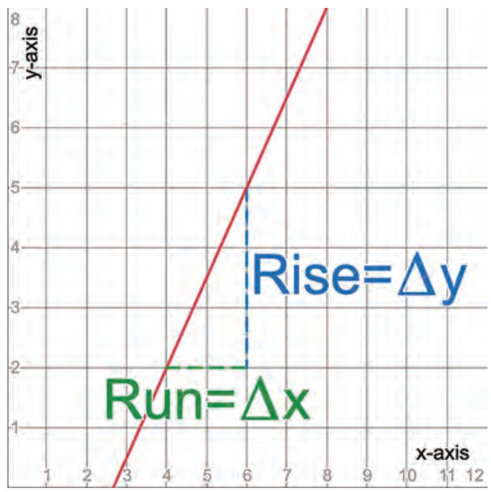
Calculating Slope

To prepare for your work in lesson 2, let's review the basics of calculating slope from two points and estimating the slope of a curve at a single point using a line tangent to the curve.

Recall that the slope of a line is akin to its steepness, meaning it is equivalent to the rise of the line over the run of the line. Rather than using the terms *rise* and *run*, slope is more often defined as the change in the y-direction, Δy, over the change in the x-direction, Δx.

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x}$$

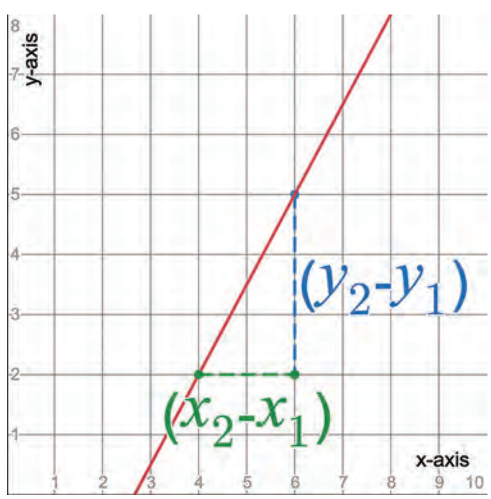
Graph: Rise and Run



Thus, to calculate the slope from two points, (x_1, y_1) and (x_2, y_2), we use the following equation:

$$\text{slope} = \frac{y_2 - y_1}{x_2 - x_1}$$

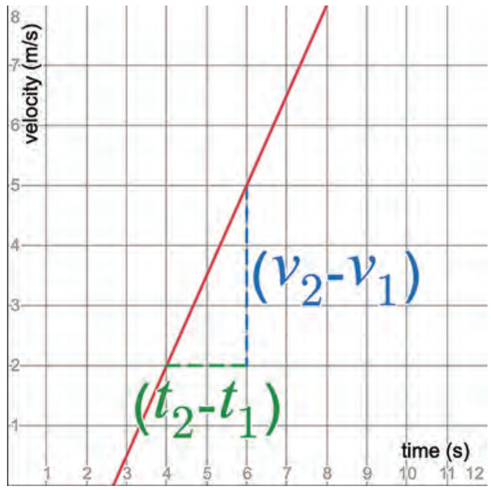
Graph: Calculating Slope



In physics, we often use variables other than *x* and *y*. Often, time is our *x*-axis variable and velocity may be our *y*-axis variable. So, to find the slope of a velocity vs. time graph, we would need to use the following equation:

$$\text{slope} = \frac{v_2 - v_1}{t_2 - t_1}$$

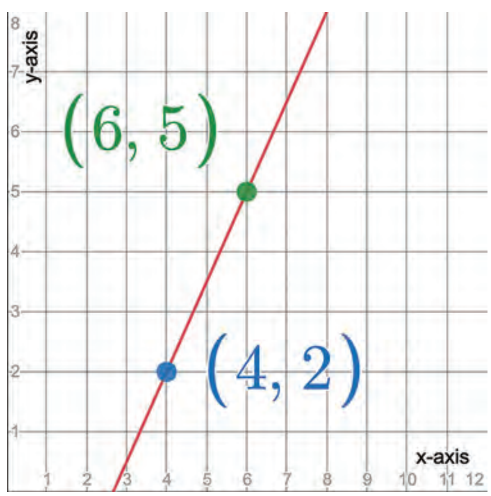
Graph: Calculating Slope as Velocity



Try It! Calculating Slope

1. What is the slope of the line on graph A below?

Graph A: Calculate Slope

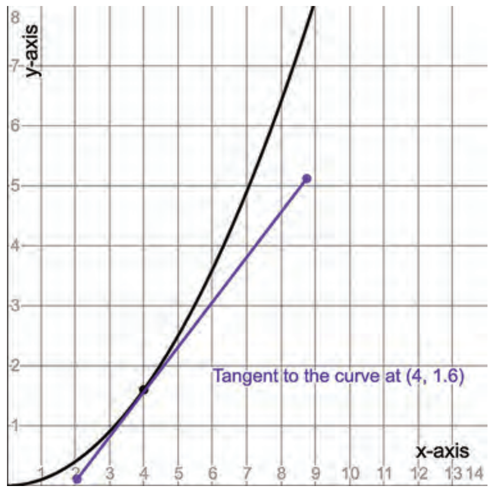


slope $= \frac{5-2}{6-4} = \frac{3}{2} = 1.5$

2. While finding the slope of a line is straightforward, sometimes we need to find the slope of a curve at a given point. We can do this in two ways: by picking two points on the curve very close to the original point or by drawing a tangent line. For the latter, we need to draw a tangent line that just touches the curve at the specified point. Once we have drawn the tangent line, we pick two

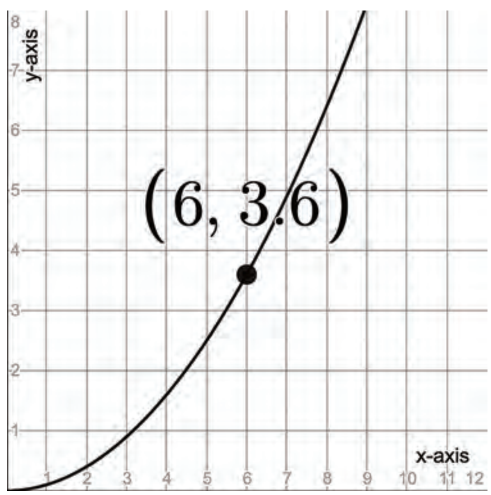
points on the tangent line and follow the method of finding the slope of a straight line. A tangent line is drawn on graph B below at the point (4, 1.6).

Graph B: Tangent to a Curve



On graph C below, estimate the slope of the curve at the point (6, 3.6) using two nearby points on the curve, and then estimate the slope of the curve by drawing a tangent line at (6, 3.6).

Graph C: Finding the Tangent to a Curve



Solutions may vary, depending on the points chosen and the angle of the tangent line. Using the points (5, 2.5) and (7, 5), the slope is approximately 1.3.

Reading

In your textbook, read chapter 2, "Motion in One Dimension" (53–81), which includes the following sections:

- Introduction
- 2.1 Relative Motion, Distance, and Displacement
- 2.2 Speed and Velocity
- 2.3 Position vs. Time Graphs
- 2.4 Velocity vs. Time Graphs
- Section Summary

Resources for "Motion in One Dimension"

Check out the following resources related to topics in chapter 2. If you need additional help, reach out to your teacher.

Note: These videos are meant to supplement, not replace, the textbook reading.

"Motion in a Straight Line: Crash Course Physics #1"

"1D Motion & Kinematics"

"Distance and Displacement Introduction"

"Average Velocity and Average Speed Worked Example"

"Instantaneous Speed and Velocity"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Defining Key Equation Variables

A large part of physics is solving analytical problems to predict physical behavior in the world around us. Doing this involves a familiarity with a wide variety of formulas and equations. To help you understand the physical relationships represented by these equations, you will be defining each variable used *before* you ever have to apply these equations to solve problems.

Once you understand how physical quantities are represented by specific variables, it becomes easier to identify these same quantities while analyzing problems. When you know which physical quantities and corresponding variables are involved, choosing the appropriate equation to use becomes much more manageable.

The key equations you will be defining variables for are shown below. Your task is to identify the physical quantity represented by each variable, the SI units of the variable, and whether it is a scalar or a vector. You may find some variables are used in multiple equations. The first three equations have been done for you to serve as examples.

Equations

1. $\Delta d = d_f - d_i$

   Displacement (without velocity), where Δd is displacement (m, vector), d_f is final position (m, vector), and d_i is initial position (m, vector)

2. $\text{speed}_{\text{avg}} = \dfrac{\text{distance}}{\text{time}}$

   Average speed, where *speedavg* is average speed (m/s, scalar), *distance* is total distance (m, scalar), and *time* is total time (*s*, scalar)

3. $v_{\text{avg}} = \dfrac{d_f - d_i}{t_f - t_i}$

   Average velocity, where v_{avg} is average velocity (m/s, vector), d_f is final position (m, vector), d_i is initial position (m, vector), t_f is final time (s, scalar), and t_i is initial time (s, scalar)

4. $d = d_0 + vt$

   Displacement (with velocity), where d is displacement (m, vector), d_0 is initial position (m, vector), v is velocity (m/s, vector), and t is time (s, scalar)

5. $v = v_0 + at$

   Velocity (with acceleration), where v is velocity (m/s, vector), v_0 is initial velocity (m/s, vector), a is acceleration (m/s^2, vector), and t is time (s, scalar)

6. $a = \frac{\Delta v}{\Delta t} = \dfrac{v_f - v_i}{t_f - t_i}$

   Acceleration, where a is acceleration (m/s^2, vector), Δv is change in velocity (m/s, vector), Δt is change in time (s, scalar), v_f is final velocity (m/s, vector), v_i is initial velocity (m/s, vector), t_f is final time (s, scalar), and t_i is initial time (s, scalar)

Conceptual Questions

Answer the following questions using your own words to describe physics concepts, theories, and laws. You may use a direct quote from the textbook (in quotation marks, with the page number cited) to help support your definition, but do not rely on textbook quotations for your full answer.

1. Explain the difference between a scalar quantity and a vector quantity.

   A scalar quantity has only magnitude while a vector quantity has both magnitude and direction.

2. Describe the difference between distance and displacement. Be sure to use the words *scalar* and *vector* in your answer.

   Distance is a scalar quantity that is the total length of the path traveled. Displacement is a vector quantity defined by the final position minus the initial position.

3. Give one example of when distance and displacement magnitude are equal and one example of when they are not equal.

   When you travel in a straight line, always moving in the same direction, distance and displacement are equal. Examples may vary for when distance and displacement are not equal but should denote a distance that does not follow a straight line.

4. Describe the difference between speed and velocity. Be sure to use the words *scalar* and *vector* in your answer.

   Speed is a scalar quantity defined as the distance an object travels divided by the total time. Velocity is a vector quantity defined as the displacement of an object divided by the total time.

5. Give one example of when speed and velocity magnitude are equal and one example of when they are not equal.

   When walking forward in a straight line, speed and velocity are equal. They are not equal when walking around the curved part of a running track.

6. Why is it useful to have a coordinate system and frame of reference for physics problems?

   Answers may vary but should indicate that a coordinate system imposed within a reference frame lets us know where we are in space and time consistently throughout our analysis of a given scenario.

7. A person riding in a car tosses an apple vertically upward. Describe the motion of the apple from the perspective of someone sitting next to the apple thrower and from someone standing in their driveway as the car drives by.

   From within the car, it looks like the apple only travels upward and downward above the person's hand. From outside the car, it looks like the apple travels upward, downward, and in the direction the car is traveling.

Analytical Questions

1. A plane flies 4 km north and then turns around and flies 6 km south.

   a. What is the plane's displacement? Hint: include direction in your answer.

   Displacement = $d_f - d_i = -2$ km − 0 km = −2 km, or 2 km south

   b. What is the total distance traveled by the plane?

   Distance = 6 km + 4 km = 10 km

c. What is the magnitude of the plane's displacement?

Magnitude of displacement = 2 km

2. If a swimmer takes 20 s to travel 50 m, what is their average speed in m/s?

2.5 m/s

3. If the swimmer in question 2 is in a pool and does a flip turn at 25 m and returns the direction they came, what is their average velocity when they complete 50 m?

0 m/s because displacement is 0 m

4. A bird flies 5.0 m/s. How long does it take the bird to travel 3.0 mi? Hint: make sure your units match.

3.0 mi = 4,828 m, $v_{avg} = \frac{d_f - d_i}{t_f - t_i}$, so time = 970 s or 16 min (2 significant figures)

5. If a person runs 5.1 mph for 2.4 h and then 3.6 mph for 3.2 h in the same direction, what is their average velocity? Hint: you will need to find the total displacement the person runs.

$d1 = d_0 + vt$ = 0 mi + (5.2 mph)(2.4 h) = 12.24 mi

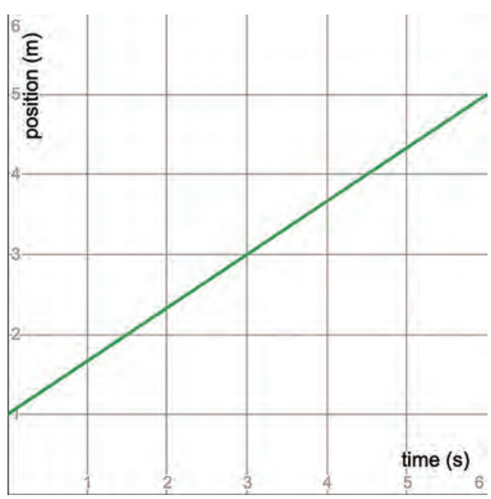
$d2 = d_0 + vt$ = 0 mi + (3.6 mph)(3.2 h) = 11.54 mi

d, total displacement = 24 mi (2 significant figures)

$v_{avg} = \frac{d_f - d_i}{t_f - t_i} = \frac{24 \text{ mi}}{5.6 \text{ h}} = 4.3$ mph

6. Find the average velocity on graph D below from $t = 0$ s to $t = 5$ s. Find the instantaneous velocity at $t = 2.5$ s. Are they the same or different? Why?

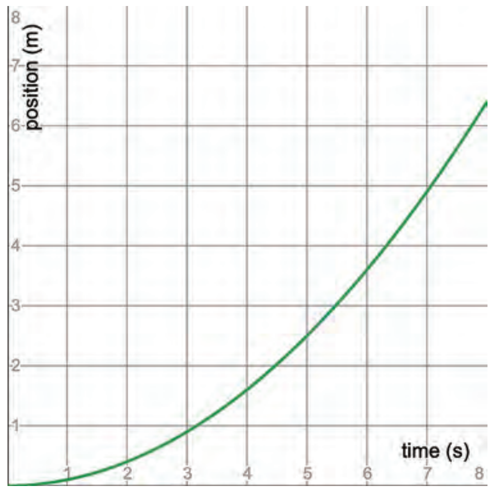
Graph D: Position vs. Time



Answers may vary slightly depending on the position read from the graph at $t = 5$ s. Use points (0 s, 1 m) and (5 s, 4.3 m) and v_{avg} = slope = $\frac{d_f - d_i}{t_f - t_i} = \frac{(4.3 \text{ m} - 1 \text{ m})}{(5 \text{ s} - 0 \text{ s})}$ = 0.67 m/s, which is the same as the instantaneous velocity at 2.5 s because the function is linear (constant slope).

7. Find the average velocity on graph E below from $t = 0$ s to $t = 7.0$ s. Find the instantaneous velocity at $t = 2.5$ s. Are they the same or different? Why?

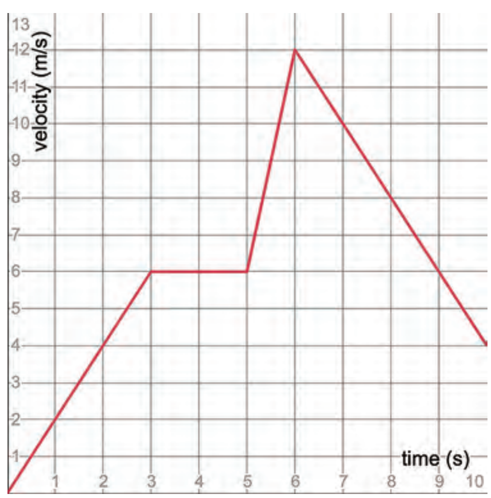
Graph E: Position vs. Time



Use points (0 s, 0 m) and (7.0 s, 5.0 m) and *vavg* = slope = $\frac{d_f - d_i}{t_f - t_i} = \frac{(5.0\text{ m} - 0\text{ m})}{(7\text{ s} - 0\text{ s})}$ = 0.71 m/s; the instantaneous is velocity 0.46 m/s using a drawn tangent line at 2.5 s. (This answer may vary slightly depending on how well the student draws the tangent line.) Average velocity divides displacement by total time from 0 s to 7 s, and instantaneous velocity is the slope of the tangent line at 2.5 s.

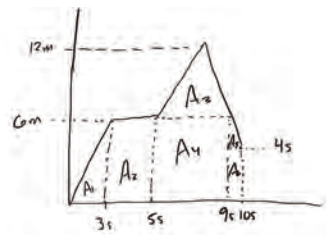
8. Use graph F below to calculate the displacement from $t = 0$ s to $t = 5$ s and from $t = 5$ s to $t = 10$ s.

Graph F: Velocity vs. Time



For $t = 0$ s to 5 s, split the area under the curve from 0 s to 5 s to give a displacement of 21 m.

For t = 5 s to 10 s, calculate the area under the curve from 5 s to 10 s to give a displacement of 41 m. See the diagram below.



Displacement: 0s to 5s

$D = A_1 + A_2 = 9m + 12m = \boxed{21m}$

Displacement: 5s to 10s

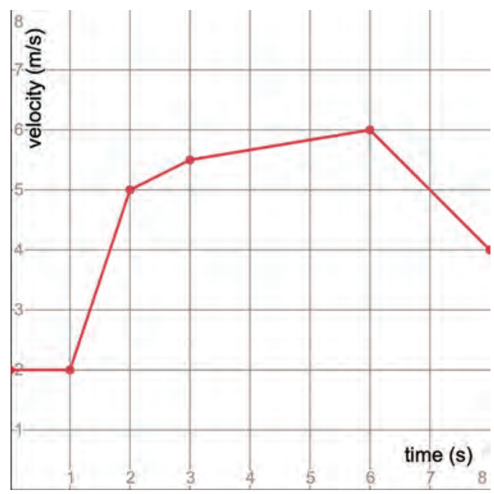
$D = A_3 + A_4 + A_5 + A_6$

$= 12m + 24m + 1m + 4m$

$\boxed{D = 41m}$

9. Use graph G below to answer the following questions.

Graph G: Velocity vs. Time



a. Over what time interval is the magnitude of acceleration the greatest?

Greatest = 1 s to 2 s (slope with the greatest absolute value)

b. Over what time interval is the magnitude of acceleration the least?

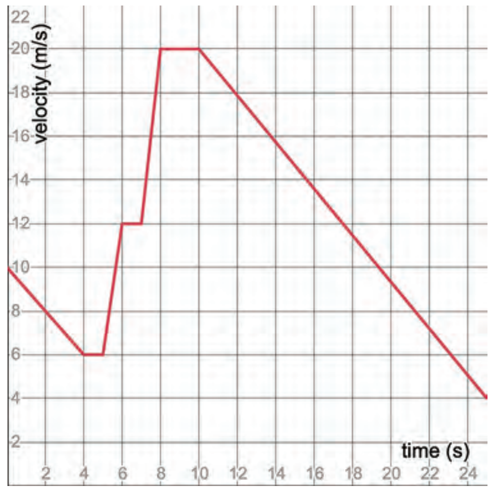
Least = 0 s to 1 s (slope with the lowest absolute value)

c. Over what time interval is the acceleration negative?

Negative = 6 s to 8 s (negative slope)

10. Find the average acceleration on the graph below from $t = 10$ s to $t = 25$ s.

Graph H: Velocity vs. Time



Average acceleration from $t = 10$ s to $t = 25$ s is $a = \frac{v_f - v_i}{t_f - t_i} = \frac{(4 \text{ m/s} - 20 \text{ m/s})}{(25 \text{ s} - 10 \text{ s})} = -1.1 \text{ m/s}^2$

Activities and Labs

Choose one of the following to complete:

- Activity: Where and How Fast?
- Lab: Graphing Motion

Activity: Where and How Fast?

In this activity, you will be learning how to make a velocity vs. time graph and a position vs. time graph. First, you will be guided through the process with a moose-watching scenario, and then you will create your own scenario.

Scenario: Moose Watching

Kelly is driving down a dirt road at 45 km/h. After 4 minutes of driving, Kelly thinks she spots a moose in the woods and decides she wants to check it out. She comes to a complete stop in 30 seconds with a constant rate of negative acceleration. Not wanting to miss such an opportunity, Kelly sits and takes photos for 2 minutes. She then decides to drive backward to get a better view. It takes Kelly 1 minute to reach her maximum reverse driving speed of 20 km/h (assume constant acceleration). Assuming her car is capable, without pausing, she instantaneously stops and then accelerates forward at 1,300 km/h^2 until she is driving 45 km/h again.

Goal #1: Draw a velocity vs. time graph for Kelly's moose-watching adventure.

To start, we first need to decide what units we want to work in. In the description, Kelly's velocity and acceleration are given in km/h and km/h^2, and her time moving or stopped is given in minutes or seconds. We want our units of length and time to be the same. Since time is given in the smallest increment of seconds, let's use the meter as our unit of length and the second as our unit of time.

Step 1: Convert all velocities to m/s, all accelerations to m/s^2, and all times to s.

45 km/h = 12.5 m/s

4 min = 240 s

2 min = 120 s

1 min = 60 s

20 km/h = 5.6 m/s

1,300 km/h^2 = 0.1 m/s^2

Next, we need to find all of Kelly's transition points. These points are where Kelly goes from one state of motion to another. For example, the first transition point is simply her starting velocity at time 0 s. The next transition point, point 2, is when she starts to slow down after 4 minutes of driving. Point 3 is when she first comes to a complete stop. Point 4 is when she starts to drive backward. Point 5 is when she instantaneously switches to driving forward again. Kelly's last and final point, point 6, is her final driving speed of 45 km/h after accelerating at 1,300 km/h^2 to get to that speed.

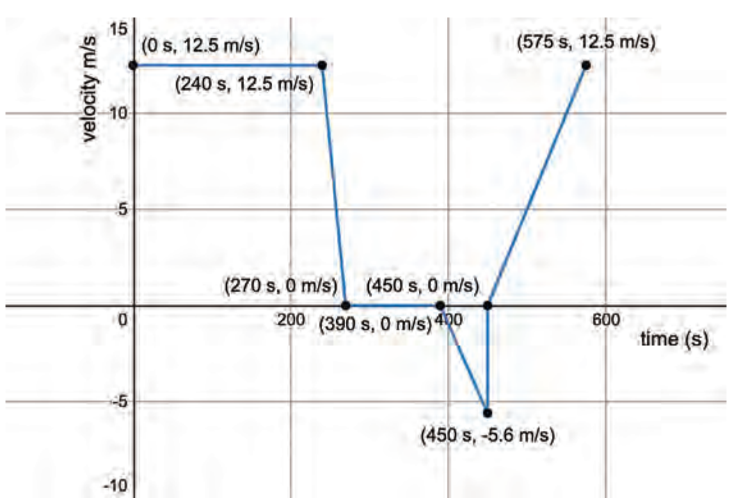
Step 2: Determine all six transition points. Note: To find point 6, you will need to figure out how long it takes her to accelerate at 1,300 km/h^2 from 0 km/h to 45 km/h. To do this, use $v = v_0 + at$.

12.5 m/s = 0 m/s + 0.1 m/s^2 t

***t* = 125 s**

Step 3: Plot all six transition points on a graph of velocity vs. time where velocity is the *y*-axis variable and time is the *x*-axis variable. Connect the six transition points with straight lines. We are able to use all straight lines because acceleration is assumed to be constant throughout. Remember, the slope of a velocity vs. time graph is acceleration.

Graph solution: Velocity vs. Time Graph for Traveling Car



Goal #2: Draw a position vs. time graph for Kelly's moose-watching adventure.

We first need to calculate the displacement for each segment of Kelly's moose-watching experience. The first displacement point is the start of Kelly's journey at 0 m. Her next displacement point is the distance she has traveled after 4 minutes, and the third displacement occurs as Kelly comes to a stop. We need to remember that she stays stationary for 2 minutes, taking photos, to a fourth displacement point. Next, Kelly travels in reverse back toward her starting point for 1 minute to a fifth displacement point. Finally, we need to calculate her displacement as she accelerates forward until she reaches a maximum speed of 45 km/h.

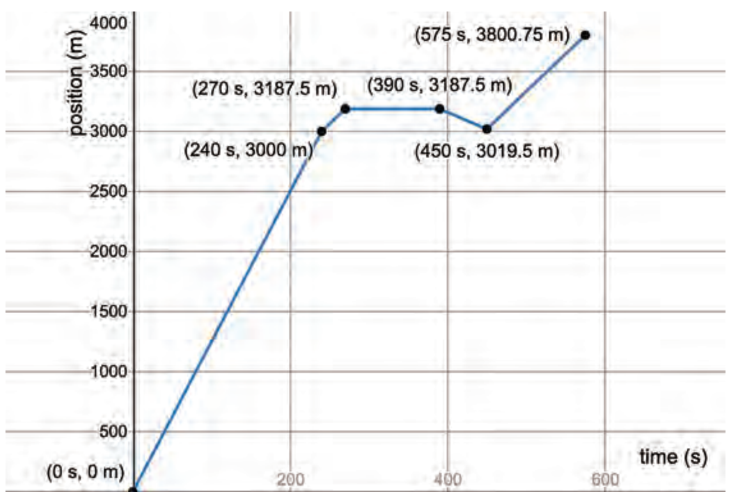
Step 1: Calculate all displacement points. Note: The displacement of an object over a given time interval is the area between the curve and the *x*-axis for that time interval. When the area is above the *x*-axis, add the displacement to the previous displacement. When the area is below the *x*-axis, this means Kelly was driving backward, so you need to subtract the displacement from the previous displacement. If you do this correctly, your final displacement should be 3,800.75 m.

See the final graph below.

Step 2: Plot all six points on the graph. For simplicity, connect your points using straight lines. Note that in reality, velocity is not constant over the time intervals Kelly was accelerating, so these segments would have slight curves to them as she accelerates.

This will likely be very challenging for students to do.

Graph solution: Position vs. Time Graph for Traveling Car



Goal #3: Create your own scenario, describe it, and draw a velocity vs. time graph for it. Your scenario should include forward movement, backward movement, and five displacement points.

Graphs will vary depending on the scenario the student comes up with. Look for clearly labeled graphs with velocity on the *y*-axis and time on the *x*-axis. The description should match the graph.

Lab: Graphing Motion

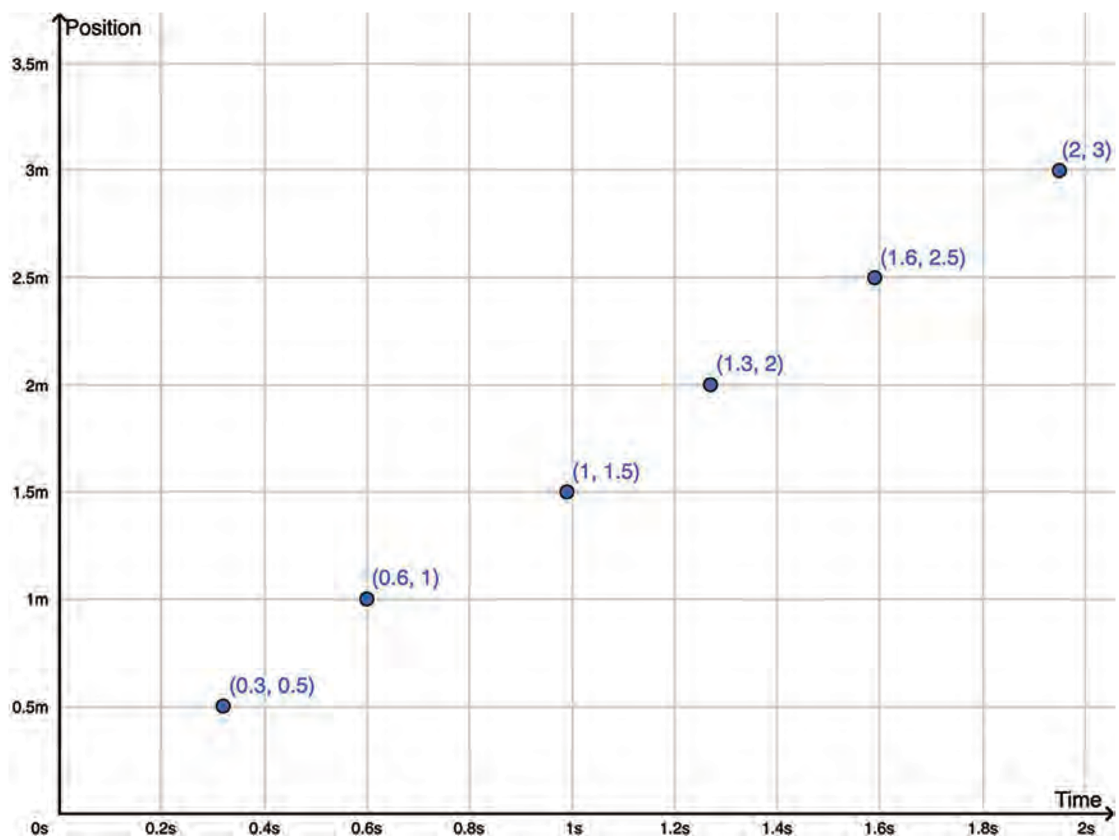
In this lab, you will be completing the Snap Lab on page 69 of your textbook. Be sure to read through the entire lab experiment before you start. If you are doing this without a partner, you will want to start by creating a data table consisting of two columns (distance and time). For distances, you should use 0 m, 0.5 m, 1.0 m, 1.5 m, 2.0 m, 2.5 m, and 3.0 m. For times, you will record the time it takes for the ball to travel from the bottom of the ramp, 0 m, to each distance you have premarked with tape.

See the sample table and graph below. Note that in this example, the ball did not lose much speed before reaching the 3.0 m mark, so the graph is completely linear.

Table: Lab Data

Distance (m)	Time trial 1 (s)	Time trial 2 (s)	Time trial 3 (s)	Average time (s)
0.50	0.32	0.32	0.32	0.32
1.00	0.62	0.60	0.57	0.60
1.50	0.97	1.00	1.00	0.99
2.00	1.22	1.28	1.31	1.27
2.50	1.53	1.66	1.59	1.59
3.00	1.97	1.97	1.91	1.95

Graph: Rolling Ball Position Through Time



Once you have completed the lab experiment and your position vs. time graph, answer the questions below.

1. Is your graph linear or curved? Why do you think it is the way it is?

   Students may observe several different things on their graph. If they had a steep ramp and the ball did not lose much speed by the time it reached 3.0 meters, then the graph is likely linear with a constant slope. If the ramp was less steep and the ball started to decrease in speed by the time it reached 3.0 meters, then the student will observe the slope decrease as the distance increases due to a decrease in the ball's velocity as it loses energy and experiences a negative acceleration. Look for the student to understand the idea that a constant slope, or linear graph, has constant velocity while a slope that decreases over time indicates that the velocity of the ball is decreasing.

2. What is the average velocity of the ball from 0 m to 3.0 m? Is this the same as average speed?

   Students should use the slope of the line between 0 m and 3.0 m to calculate the average velocity. From the data above, slope = $v_{avg} = \frac{x_f - x_i}{t_f - t_i} = \frac{3\text{ m} - 0\text{ m}}{1.95\text{ s} - 0\text{ s}} = 1.54$ m/s. Average velocity and average speed are the same because the ball is traveling in a straight line, and displacement is equal to distance.

3. Estimate the instantaneous velocity at 1.5 m by calculating the slope between your point at 1.0 m and your point at 2.0 m.

   A sample calculation from data is shown below:

   $$\text{slope} = v_{inst} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{2\text{ m} - 1\text{ m}}{1.27\text{ s} - 0.60\text{ s}} = 1.54\text{ m/s}$$

4. Estimate the instantaneous velocity at 1.5 m by drawing a tangent line at 1.5 m and estimating the slope of the line.

   Since the sample graph was linear, the tangent line will have the same slope as question 3. If the student did not have linear graphs, their answer will be based on drawing a tangent line at 1.5 m.

5. How do your instantaneous velocities from question 3 and 4 compare with one another?

   The answer is dependent on their position vs. time graph. If their graph is linear, it should be the same; if the graph is nonlinear, it will be different.

For this lab, submit the following to your teacher:

- Photos of your setup
- Completed data table
- Position vs. time graph
- Answers and work for all questions

Further Study

If you are interested in further exploring the topics and skills in this lesson, feel free to choose any of the following activities. All are optional.

- Complete the textbook Chapter Review and Test Prep (odd-numbered problems). The solutions are available online via OpenStax, under Student Resources.
- Complete the video simulation "Name That Motion." The link can be accessed at oakmeadow.com/curriculum-links.

SHARE YOUR WORK

When you have completed your work, share it with your teacher. Remember to check with your teacher at the beginning of each lesson to make sure you understand what you are required to do.

Below is a list of assignments in this lesson, which you can use to organize your work submission:

- Math Prep: Try It! Calculating Slope
- Defining Key Equation Variables
- Conceptual questions
- Analytical questions
- Activity or lab completed

If you have any questions about the lesson content, assignments, or how to share your work, contact your teacher.

UNIT 3 Two-Dimensional and Rotational Motion

In unit 3, you will be applying the concepts you have learned about one-dimensional motion to two-dimensional motion as well as circular and rotational motion. Unit 3 consists of two main lessons and one project lesson.

(Image credit: Wallpaper Flare)

Lesson 6

Two-Dimensional Motion

Learning Objectives

In this lesson, you will:

- Describe and use both analytical and graphical methods of vector addition and subtraction to solve physics problems.
- Describe and analyze projectile motion through the application of kinematic equations in two dimensions.
- Describe and analyze static and kinetic friction in one and two dimensions.
- Analyze problems involving inclined planes and friction.
- Describe and analyze the concepts behind Hooke's Law and simple harmonic motion, including periodic motion, oscillations, amplitude, frequency, and period.

Lesson Introduction

So far, you have focused on applying concepts of force and kinematics to one-dimensional problems. In lesson 6, you will learn how to analyze motion in two dimensions. To do this, you will use the *x*- and *y*-components of vectors to describe motion separately in the *x*- and the *y*-directions. Once you know how to use vectors, you will explore projectile motion, friction on an inclined surface, and simple harmonic motion. The world we live in is three-dimensional, and understanding physics in two dimensions is the first step to fully understanding how the world around us behaves.

This lesson will take approximately two weeks.

ASSIGNMENT CHECKLIST

- ☐ Complete the Math Prep activities.
- ☐ Inquiry Activity: Juggling
- ☐ Read chapter 5, "Motion in Two Dimensions."
- ☐ Complete the exercises in Defining Key Equation Variables.
- ☐ Respond to the conceptual questions.
- ☐ Respond to the analytical questions.
- ☐ Activities and Labs:

  Activity: Vector Addition—Graphical and Analytical Methods

  Activity: Design a Mini-Project

Real-Life Relevance

Figure 1. World Cup Ladies Ski Jumping, May 2, 2017, Hinzenbach, Austria (Image credit: Ailura)

Ski jumping is an impressive event in the winter Olympics where athletes launch themselves off large jumps to see who can travel the longest distance with the best form. The sport of ski jumping originated in Norway in 1808 and has become a recognized Olympic event, with athletes from various nations coming together to compete. The jumping technique and the equipment have evolved—the ski jumping hills are larger and the skis and uniforms are specialized to increase lift.

Figure 2. Ski jumping hill (Image credit: Hanna Sörensson)

The desire to jump farther distances required an understanding of the underlying physics principles, several of which you have already encountered in this course, such as kinematics and force. A skier launching off a jump must be analyzed in both the forward and downward directions to accurately predict where they will land and how far they may travel. To increase the distance of a jump, the skier aims to increase their launch velocity. As you can see in figure 2, the height of the ramp and the downward pull of gravity causes the skier to accelerate and build up speed as they descend on the ramp. Because the ramp is at an angle, the acceleration downward will always be less than the acceleration due to gravity. Special ski wax is used and the snow and ice on the ramp's surface is carefully controlled to decrease the amount of friction experienced between the skis and the ramp. Friction is a force that inhibits motion between two surfaces that are in contact with each other. Reducing friction helps the skier accelerate faster and thus have a faster launch speed. The final launch speed can be up to 62 miles (100 km) per hour! Other aspects that increase the distance of the jump include how the skier positions their body in the air, the length of their skis, and the material their suits are made from. The starting height of the skier on the ramp can be lowered if necessary to ensure the skier does not travel beyond the safe landing zone.

You can learn more about ski jumping at the resource below:

"Ski Jumping"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Math Prep

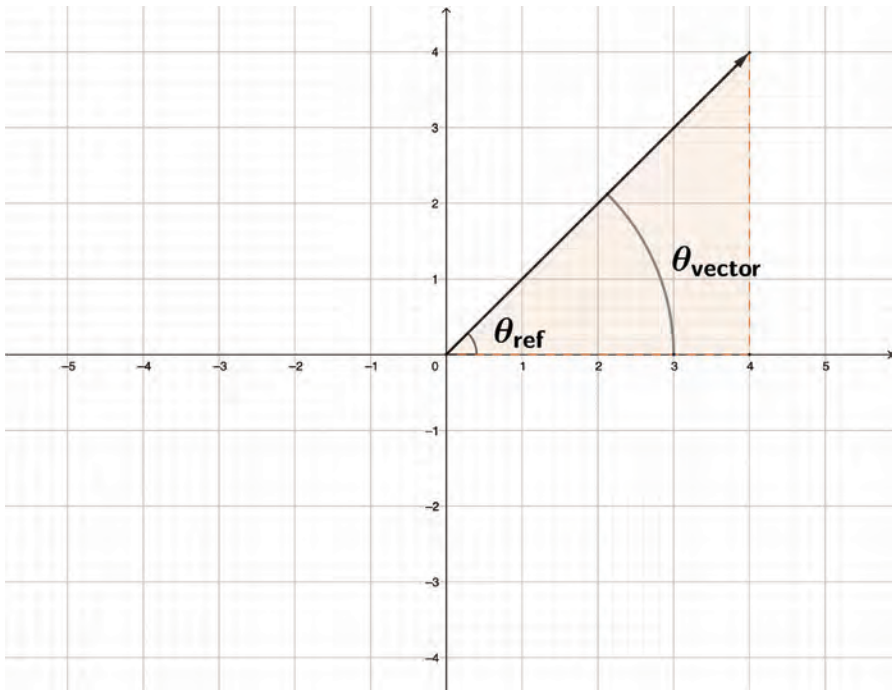
Right Triangles: Reference Angles and Vector Angles

Understanding the trigonometric relationships of right triangles is pivotal to manipulating vector quantities throughout the rest of the course. To prepare for the work in lesson 6, you will briefly review the basics of right triangles. To do this, please return to lesson 1A and read the section on right triangles.

Later in this lesson, you will learn what a vector is and when we would use one in physics. For now, all you need to know is that a vector is a straight arrow drawn from the origin, (0, 0), outward. We will focus on the angle of a vector (straight-line arrow) on a coordinate plane. When we look at vector angles on a coordinate plane, they are measured from the positive *x*-axis in a counterclockwise direction. To determine what the angle is of a given vector, you can use a reference triangle and trigonometric relationships. The reference triangle is always drawn with one edge touching the *x*-axis and the reference angle, θ_{ref}, is the vertex that originates at the origin, (0, 0). Once you have determined your reference angle, calculating the vector angle, θ_{vector}, depends on which quadrant you are in.

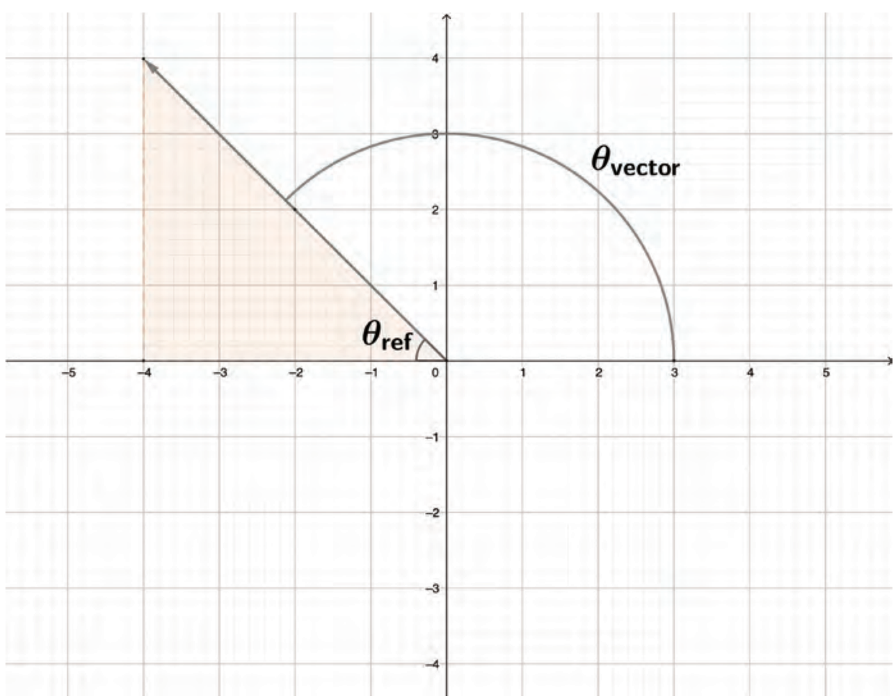
Quadrant 1: The vector angle is the same as the reference angle.

Graph: Vector Angle and Reference Angle in Quadrant 1



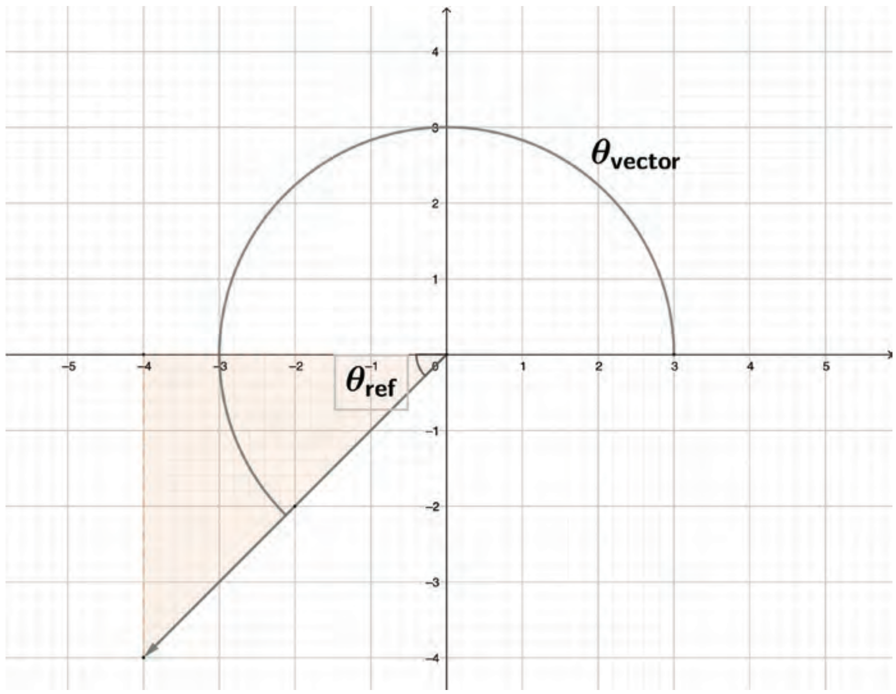
Quadrant 2: The vector angle is 180° – θ_{ref}.

Graph: Vector Angle and Reference Angle in Quadrant 2



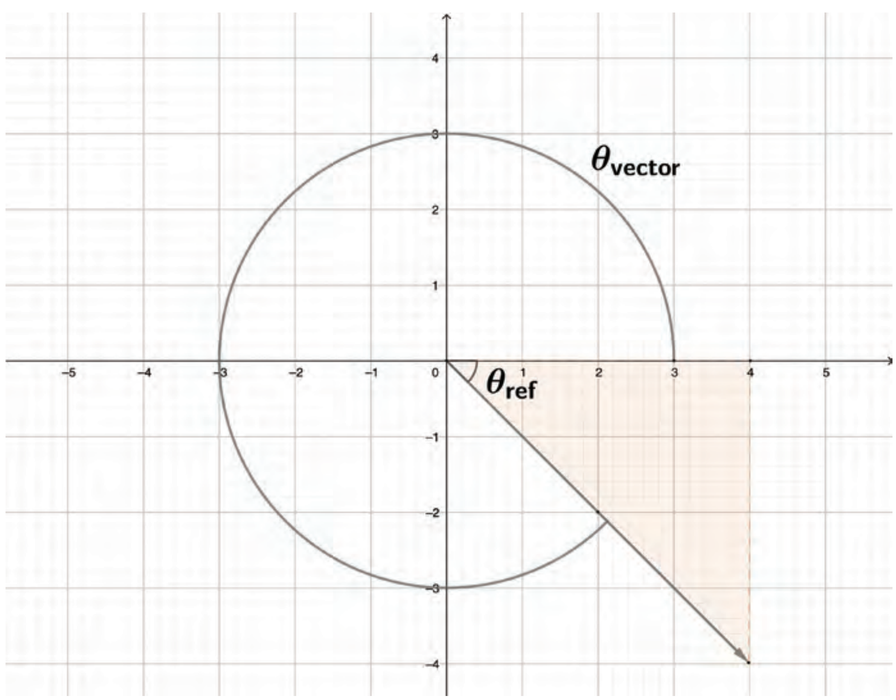
Quadrant 3: The vector angle is 180° + θ_{ref}.

Graph: Vector Angle and Reference Angle in Quadrant 3



Quadrant 4: The vector angle is 360° – θ_{ref}.

Graph: Vector Angle and Reference Angle in Quadrant 4

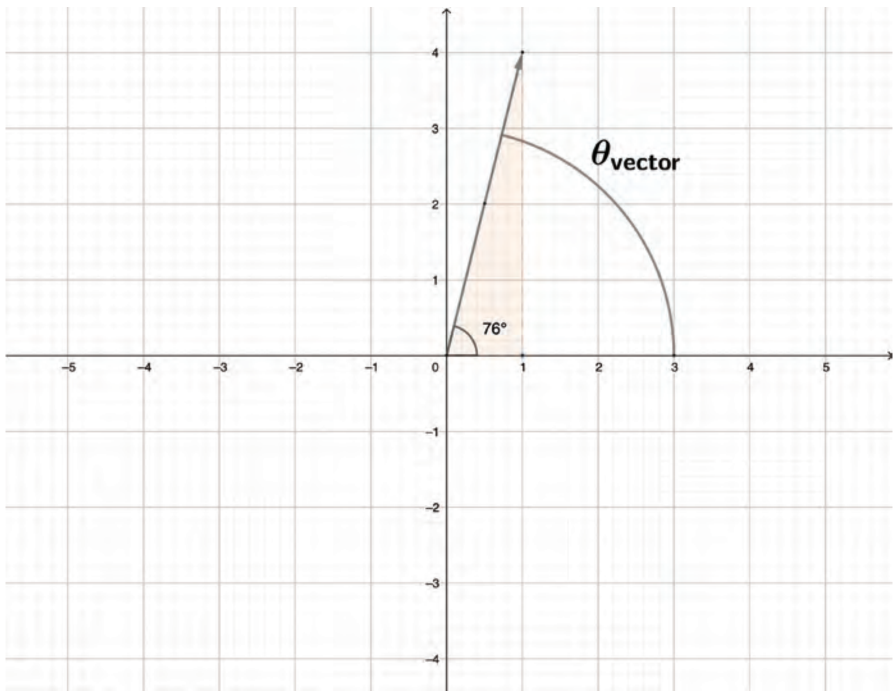


Try It! Right Triangles: Reference Angles and Vector Angles

For the following reference triangles, calculate the vector angle. Remember, the vector angle always starts at the positive *x*-axis in a counterclockwise direction.

1.

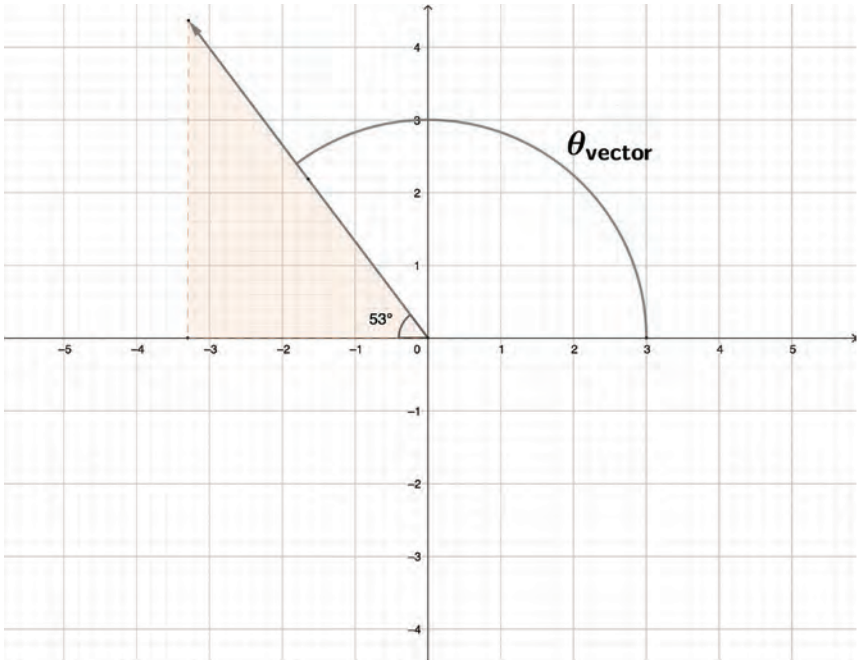
Graph: Vector Angle in Quadrant 1



$\theta_{vector} = \theta_{ref} = 76°$

2.

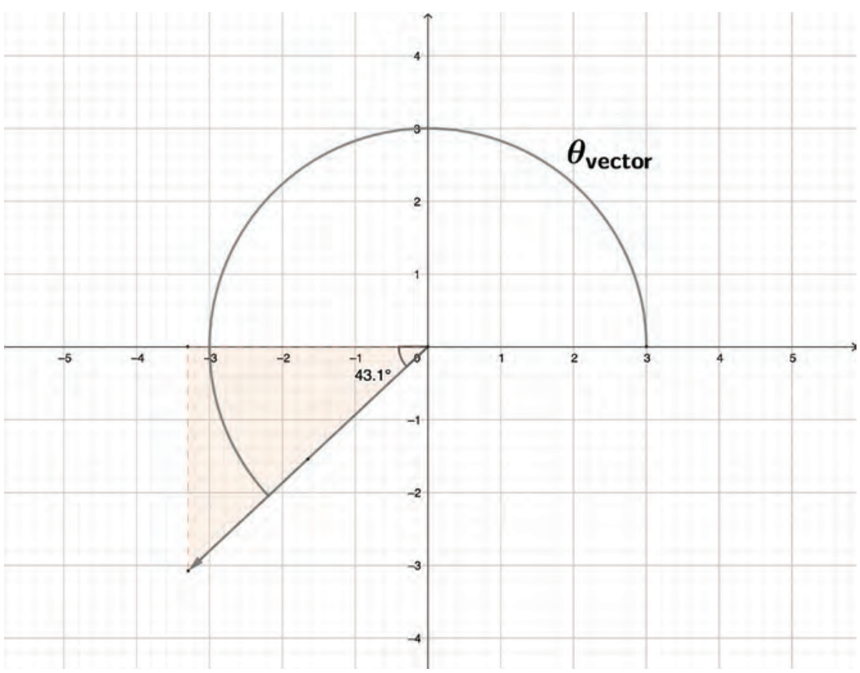
Graph: Vector Angle in Quadrant 2



$\theta_{vector} = 180° - \theta_{ref} = 180° - 53° = 127°$

3.

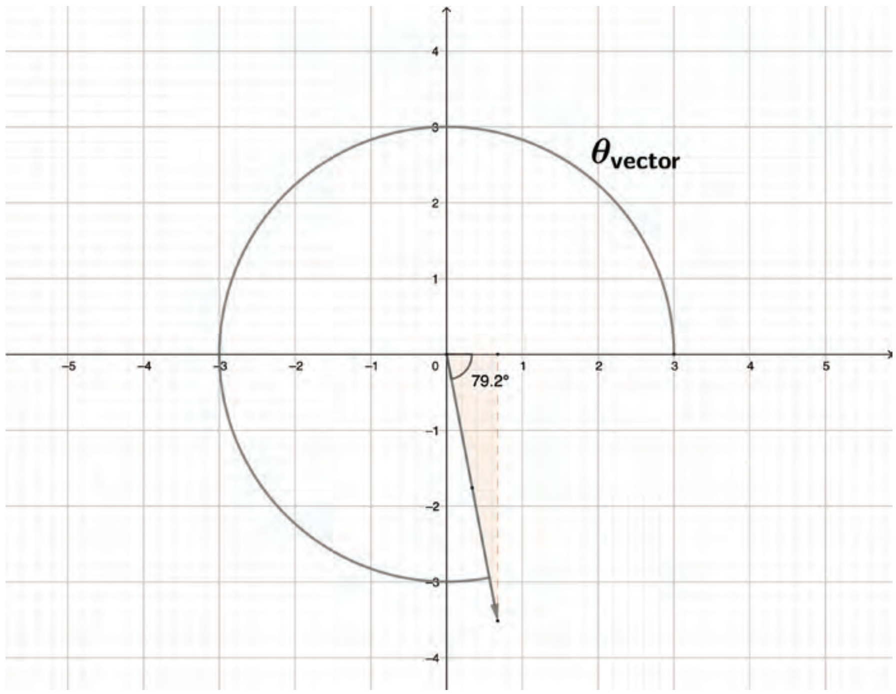
Graph: Vector Angle in Quadrant 3



$\theta_{vector} = 180° + \theta_{ref} = 180° + 43.1° = 223.1°$

4.

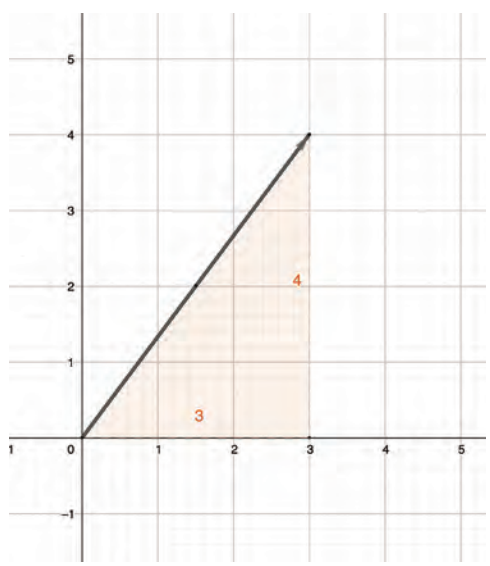
Graph: Vector Angle in Quadrant 4



$\theta_{vector} = 360° - \theta_{ref} = 360° - 79.2° = 280.2°$

5. Use the tangent function to find the reference angle, and then calculate the vector angle.

Graph: Reference Angle in Quadrant 1

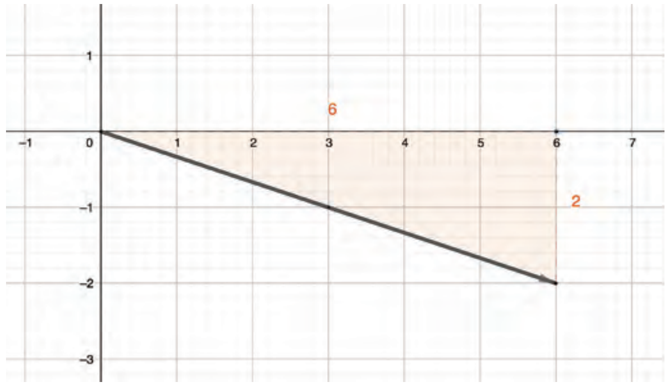


$\theta_{ref} = \tan^{-1}\left(\frac{4}{3}\right) = 53.1°$

$\theta_{vector} = \theta_{ref} = 53.1°$

6. Use the tangent function to find the reference angle, and then calculate the vector angle.

Graph: Reference Angle in Quadrant 4



$$\theta_{ref} = \tan^{-1}\left(\frac{2}{6}\right) = 33.7°$$

$$\theta_{vector} = 360° - \theta_{ref} = 360° - 33.7° = 326.3°$$

Inquiry Activity: Juggling

To complete this inquiry activity, you try to juggle! You will need to find three balls and a location with enough room for you to juggle. If you are indoors, you'll want a place with high ceilings and no breakable items.

Materials

- 3 small balls of equal size, such as tennis balls, hacky sacks, juggling balls, lacrosse balls, etc.

Procedure

1. When you are ready, try to juggle. Keep trying for at least ten minutes.
2. Afterward, write at least three observations about your experience, including one about the shape of the path the balls followed in the air.
3. Next, watch the following video:

   "Why It's Almost Impossible to Juggle 15 Balls"

   (All online resources can be accessed at oakmeadow.com/curriculum-links.)
4. Afterward, try to juggle again for five to ten minutes.
5. Write down at least three observations about what you did differently after watching the video. Did you change your rhythm or how high you threw the balls?

   The goal of this inquiry activity is to get students to start thinking about motion in two dimensions. The balls have to travel up and down but also from one hand to the other. Variables that are important to this process are the angle of release, the speed the ball is

thrown, and where the balls are relative to one another. Students may also mention how the force of gravity pulls the balls downward toward Earth after they are thrown upward. Look for descriptive observations, three before the video, and three after the video.

Reading

In your textbook, read chapter 5, "Motion in Two Dimensions" (143–187), which includes the following sections:

- Introduction
- 5.1 Vector Addition and Subtraction: Graphical Methods
- 5.2 Vector Addition and Subtraction: Analytical Methods
- 5.3 Projectile Motion
- 5.4 Inclined Planes
- 5.5 Simple Harmonic Motion
- Section Summary

Resources for "Motion in Two Dimensions"

Check out the following resources related to topics in chapter 5. If you need additional help, reach out to your teacher.

Note: These resources are meant to supplement, not replace, the textbook reading.

"Vectors and 2D Motion: Crash Course Physics #4"

"Simple Harmonic Motion: Crash Course Physics #16"

"Trig Review for Physics—Common Math Tools"

"2D Motion"

"Friction"

"Simple Harmonic Motion: A Special Periodic Motion"

"Vectors—Motion and Forces in Two Dimensions"

"Breaking Down Forces for Free Body Diagrams"

"Inclined Plane Force Components"

"Period of a Pendulum"

"Definition of Amplitude and Period"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Defining Key Equation Variables

For lesson 5, the key equations you will be defining variables for are shown below.

For each equation, include the variable, quantity, SI Units, and whether it is a scalar or vector. Remember, some variables are used in multiple equations.

1. $A = \sqrt{A_x^2 + A_y^2}$

   Magnitude of a vector A, where A is the magnitude of vector A (units depend on physical quantity, magnitude only of a vector), A_x is the x-component of vector A (units depend on physical quantity, scalar), and A_y is the y-component of vector A (units depend on physical quantity, scalar)

2. $\theta_{ref} = \tan^{-1}\left(\frac{|A_y|}{|A_x|}\right)$

   Reference angle, where θ_{ref} is the reference angle for a given vector (°, direction only of a vector), A_x is the x-component of vector A (units depend on physical quantity, scalar), and A_y is the y-component of vector A (units depend on physical quantity, scalar)

3. $\theta = \theta_{ref}$

   Vector direction in quadrant 1, where θ is the direction of a given vector in quadrant 1 and θ_{ref} is the reference angle for the same vector

4. $\theta = 180° - \theta_{ref}$

   Vector direction in quadrant 2, where θ is the direction of a given vector in quadrant 2 and θ_{ref} is the reference angle for the same vector

5. $\theta = 180° + \theta_{ref}$

   Vector direction in quadrant 3, where θ is the direction of a given vector in quadrant 3 and θ_{ref} is the reference angle for the same vector

6. $\theta = 360° - \theta_{ref}$

   Vector direction in quadrant 4, where θ is the direction of a given vector in quadrant 4 and θ_{ref} is the reference angle for the same vector

7. $A_x = A \cos\theta$

   The x-component of vector A, where A_x is the x-component of vector A (units depend on physical quantity, scalar), A is a given vector (units depend on the physical quantity, vector), and θ is the direction of vector A

8. $A_y = A \sin\theta$

   The y-component of vector A, where A_y is the y-component of vector A (units depend on physical quantity, scalar), A is a given vector (units depend on the physical quantity, vector), and θ is the direction of vector A

9. $h = \frac{v_{0y}^2}{2g}$

   Maximum projectile height, where *h* is the maximum height of the projectile (m, vector), v_{0y} is the *y*-component of the initial velocity (m/s, scalar), and *g* is the acceleration due to gravity (m/s^2, vector)

10. $R = \frac{v_0^2 \sin 2\theta_0}{g}$

    Projectile range, where *R* is the range of the projectile (m, vector), v_0 is the initial velocity (m/s, vector), θ_0 is the initial angle of the projectile (°, scalar), and *g* is the acceleration due to gravity (m/s^2, vector)

11. $f_s \leq \mu_s N,\ f_s \leq \mu_s F_N$

    Force of static friction, where f_s is the force of static friction (N, vector), μ_s is the coefficient of static friction (dimensionless, scalar), and *N* or F_N is the normal force (N, vector)

12. $f_k \leq \mu_k N,\ f_k \leq \mu_k F_N$

    Force of kinetic friction, where f_k is the force of kinetic friction (N, vector), μ_k is the coefficient of kinetic friction (dimensionless, scalar), and *N* or F_N is the normal force (N, vector)

13. $w\perp = w \cos \theta,\ F_{gy} = F_g \cos \theta$

    Perpendicular component of the force of gravity (weight) on an inclined plane, where $w\perp$ and F_{gy} are the force of gravity (weight) of the object perpendicular to the inclined plane (N, scalar), *w* and F_g are the force of gravity (weight) of the object (N, vector), and θ is the angle of the inclined plane (°, scalar)

14. $w\| = w \sin \theta,\ F_{gx} = F_g \sin \theta$

    Parallel component of force of the gravity (weight) on an inclined plane, where $w\|$ and F_{gx} are the force of gravity (weight) of the object parallel to the inclined plane (N, scalar), *w* and F_g are the force of gravity (weight) of the object (N, vector), and θ is the angle of the inclined plane (°, scalar)

15. $F = -kx$

    Hooke's law, where *F* is the restoring force (N, vector), *k* is the deformation force constant (N/m, vector), and *x* is the amount of deformation (displacement) produced by the restoring force (m, vector)

16. $T = 2\pi\sqrt{\frac{m}{k}}$

    Period in simple harmonic motion, where *T* is the period of simple harmonic motion (s, scalar), *m* is the mass (kg, scalar), and *k* is the force constant (N/m, vector)

17. $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

    Frequency in simple harmonic motion, where *f* is the period of simple harmonic motion (1/s, scalar), *m* is the mass (kg, scalar), and *k* is the force constant (N/m, vector)

18. $T = 2\pi\sqrt{\frac{L}{g}}$

    Period of a simple pendulum, where *T* is the period of the simple pendulum (s, scalar), *L* is the length of the pendulum (m, scalar), and *g* is the acceleration due to gravity (m/s^2, vector)

Conceptual Questions

Answer the following questions using your own words to describe physics concepts, theories, and laws. You may use a direct quote from the textbook (in quotation marks, with the page number cited) to help support your definition, but do not rely on textbook quotations for your full answer.

1. Why does a projectile follow the path of an arc?

   A projectile follows an arc due to how motion works in the *x*- and *y*-directions. In the *x*-direction, the projectile has an initial horizontal velocity and is assumed to experience no acceleration, causing it to continue forward at this constant forward velocity. In the *y*-direction, the projectile has an initial vertical velocity, and it experiences acceleration due to the force of gravity. This means that if the projectile is initially moving upward, it will slowly decrease in velocity until it stops completely before changing directions and increasing in velocity as it travels downward. The constant horizontal motion happens at the same time as the upward and then downward vertical motion, creating an arc-shaped path. Students may draw a diagram to illustrate this concept.

2. Why will a projectile launched at an angle of 75° or at an angle of 15° land in the same location?

   The range, *R*, of a projectile can be calculated using $R = \frac{v_0^2 \sin 2\theta}{g}$, where v_0 is the initial velocity, θ is the launch angle, and *g* is the acceleration due to gravity. If you substitute $\theta = 15°$ or $\theta = 75°$ into the formula with the same initial velocity, you will get the same value for the range. This is because $\sin 2\theta = 0.5$ for both angles.

3. What is the difference between static friction and kinetic friction?

   Static friction is the friction that occurs between two surfaces when an object is stationary. Kinetic friction is the friction that occurs between two surfaces when an object is moving. Kinetic friction is lower than static friction. Students may also include the equations for the force of static friction ($f_s \leq \mu_s N, f_s \leq \mu_s F_N$) and the force of kinetic friction ($f_k \leq \mu_k N, f_k \leq \mu_k F_N$).

4. Describe periodic motion in your own words using an example.

   Periodic motion is motion that regularly repeats. A swinging pendulum is one example of periodic motion.

5. What is the restoring force?

   The restoring force is the force that causes an object to return to its equilibrium position.

Analytical Questions

1. You are standing 10.0 m from a tree and want to throw an apple up to your friend, who is sitting on a branch 3.5 m above the ground. You release the apple at an angle of 25°. What does the initial velocity of the apple need to be in order for your friend to catch the apple at its maximum height? How long does it take? Assume you throw the apple from 1.0 m above the ground.

   v_0 = 15 ms, t = 0.75 s

   First calculate the initial velocity using the following kinematic equation in the y-direction $v_{y0}^2 = v_y^2 + 2a(y - y_0)$ rearrange to solve for v_{y0}, $v_{y0} = \sqrt{v_y^2 - 2a(y - y_0)}$, recall that $v_{y0} = v_0 \sin\theta$, substitute this into the previous equation and solve for v_0, $v_0 = \frac{\sqrt{v_y^2 - 2a(y - y_0)}}{\sin\theta} = \frac{\sqrt{(0\text{ m/s})^2 - 2 \bullet -9.8\text{ m/s}^2 \bullet (3\text{ m} - 1\text{ m})}}{\sin 25°} = 14.8\text{ m/s} = 15\text{ m/s}$.

   Next calculate the time using the position equation in the x-direction, $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$ as $x_0 = 0$ m and $a_x = 0\text{ m/s}^2$, the position equation becomes $x = v_{x0}t \rightarrow t = \frac{x}{v_{x0}}$ substitute in $v_{x0} = v_0 \cos\theta$ to get $t = \frac{x}{v_0 \sin\theta} = \frac{10\ m}{14.8\text{ m/s} \sin 25°} = 0.75$ s

2. A person pushes a 12.5 kg box with a horizontal force. The coefficient of static friction between the box and the floor is 0.50. What is the minimum force the person must push with to get the box to move?

   $F_p = 61\ N$

   $F_{net} = F_p - f_s$ substitute in $f_s = \mu_s F_N$ and $F_{net} = 0$ and $F_N = mg$ to get $0 = F_p - \mu_s mg \rightarrow F_p = \mu_s mg = 0.50 \bullet 12.5\text{ kg} \bullet 9.8\text{ m/s}^2 = 61\ N$

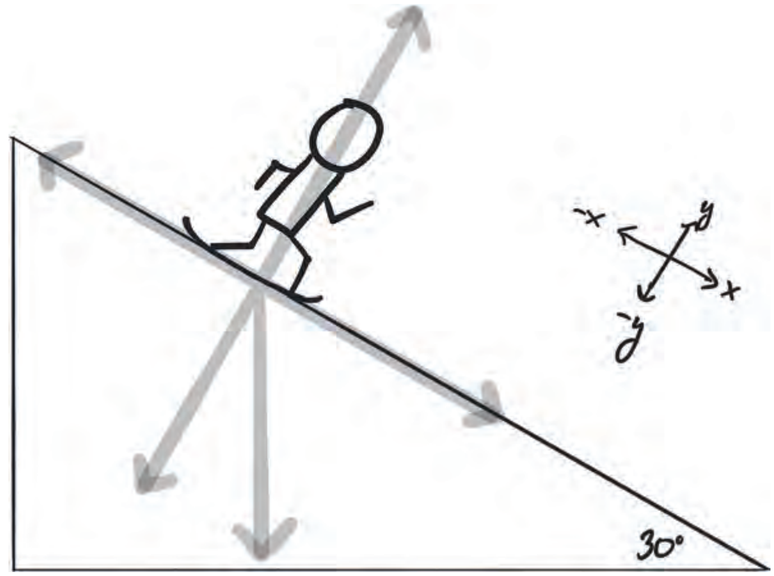
3. If the person keeps pushing the box with the same force and the coefficient of kinetic friction is 0.30, what is the acceleration of the box?

   $a = 1.9\text{ m/s}^2$

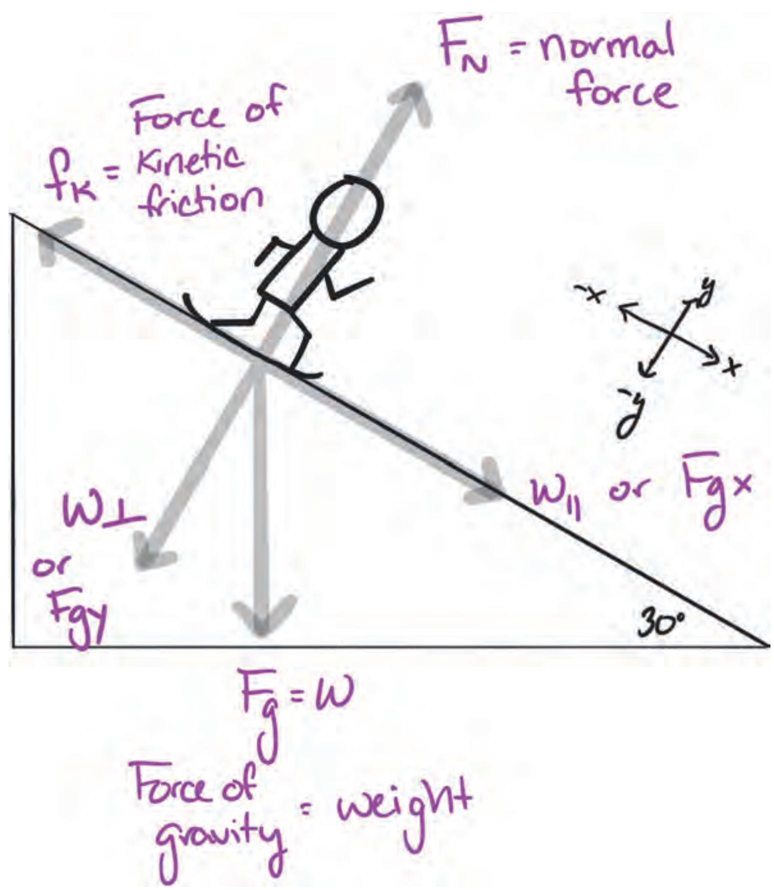
   $F_{net} = F_p - f_k$ substitute in $f_k = \mu_k F_\mathrm{N} = \mu_k mg$, $F_{net} = ma$ and rearrange to solve for a, $a = \frac{F_p - \mu_k mg}{m} = \frac{61\ N - (0.30) \bullet 12.5\text{ kg} \bullet 9.8\text{ m/s}^2}{12.5\text{ kg}} = 1.9\text{ m/s}^2$

4. On the free-body diagram below, label the forces for a snowboarder sliding down a hill.

Diagram: Free-Body Diagram of a Snowboarder

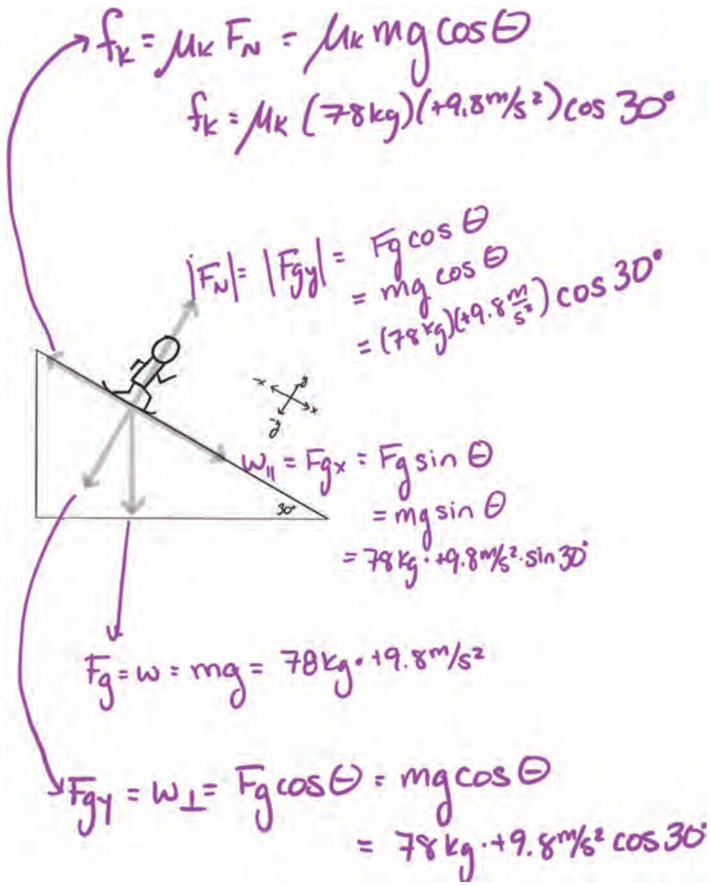


The student's diagram should be labeled as shown below.



5. For the previous free-body diagram, calculate the coefficient of kinetic friction, μ_k, for a 78 kg snowboarder accelerating at 3.2 m/s^2 down a 30° slope. Hint: write out the equations and values of the forces that are known to start.

   $\mu_k = 0.20$



   Sum of forces in the *x*-direction: $F_{net} = ma = F_{gx} - f_k = mg\sin\theta - \mu_k mg\cos\theta$.

   Rearrange to solve for the coefficient of kinetic friction:

   $$\mu_k = \frac{a - g\sin\theta}{-g\cos\theta} = \frac{3.2\text{ m/s}^2 - 9.8\text{ m/s}^2\sin 30°}{-9.8\text{ m/s}^2\cos 30°} = 0.20$$

6. What is the length of a pendulum that has a period of 2.45 s?

   $T = 1.49$ m

   $$T = 2\pi\sqrt{\frac{L}{g}} \rightarrow L = g\left(\frac{T}{2\pi}\right)^2 = 9.8\text{ m/s}^2\left(\frac{2.45\text{ s}}{2\pi}\right)^2 = 1.49\text{ m}$$

7. A mass of 50 g is hung from a spring, causing the spring to stretch 15 cm. What is the spring constant, *k*?

   $$F = -kx \rightarrow k = \frac{F}{-x} = \frac{0.05\text{ kg}\bullet(-9.8\text{ m/s}^2)}{-0.15\text{ m}} = 3.3\ \frac{N}{\text{m}}$$

Activities and Labs

Complete the following activities:

- Activity: Vector Addition—Graphical and Analytical Methods
- Activity: Design a Mini-Project

Activity: Vector Addition—Graphical and Analytical Methods

In this activity, you will be comparing the processes of adding vectors graphically and analytically. As you have learned, a vector is a physical quantity that has both magnitude and direction. Vectors are broken down into their components based on the number of dimensions they are considered to have. In this activity, you will be working on vectors of two dimensions that have an *x*-component in the positive or negative *x*-direction, and a *y*-component in the positive or negative *y*-direction.

The first step to analyzing vectors is to break them down into their dimensions. The *x*-component of a vector can be found using $A_x = A \cos \theta$, where A_x is the *x*-component of vector *A*, *A* is a given vector, and θ is the direction of vector *A*. Similarly, the *y*-component can be found using $A_y = A \sin \theta$, where A_y is the *y*-component of vector *A*. After a vector has been broken down into its *x*- and *y*-components, each component is added separately to other vectors that have also been broken down into their components. Once the new components have been determined for the resultant vector, the vector can be reconstructed from its components. Magnitude *A* is given by $A = \sqrt{A_x^2 + A_y^2}$ and the direction, θ can be found using $\theta_{ref} = \tan^{-1}\left(\frac{|A_y|}{|A_x|}\right)$ and appropriately calculating θ from the reference angle based on the quadrant in which vector *A* is located in.

Materials from the Lab Kit

- ruler
- protractor
- graph paper

Additional Materials

- pencil
- eraser

Part 1: Graphical Method

1. Pick three integer values between 50 units and 300 units. Assign each of the three values their own unique angle between 0° and 360°. The angles 0°, 90°, 180°, and 270° should not be used, nor should the angles you choose differ by these amounts. Write down and label your three values and corresponding angles. These will be the three vectors you will be adding together.

2. Draw a coordinate plane on your graph paper and choose a scale to use that will appropriately represent the values you chose in step 1 (for example 10 units = 1 cm).
3. Using the head-to-tail method described in your textbook, graphically add the three vectors together. Be sure to draw the vectors to the appropriate length using the scale you chose. (For example, given the scale in step 2, a value of 200 units would be 20 cm.) You may find you need to tape multiple pieces of graph paper together as you complete the diagram. Hint: the angle chosen for each vector is relative to the *x*-axis (0°).
4. After graphically adding your three values, calculate the magnitude and direction of the resultant vector. To do this, you will need to draw a line from the origin to the head of the third vector you drew. Measure the length of this new vector to determine its magnitude, and measure the angle of it with your protractor. Write down these values.

Part 2: Analytical Method

1. Using the same three vectors you chose in part 1, determine the *x*- and *y*-components for each vector using the appropriate trigonometric function.
2. Add all three *x*-components to calculate the *x*-component of the resultant vector.
3. Add all three *y*-components to calculate the *y*-component of the resultant vector.
4. Determine the magnitude of the resultant vector using the appropriate equation.
5. Determine the angle of the resultant vector using the tangent trigonometric function and your reference triangle.

Part 3: Comparison

1. Compare the magnitude and direction of your resultant vector determined from graphically adding your three original vectors in part 1 to the magnitude and direction of your resultant vector determined from analytically adding your three original vectors in part 2.
2. As the analytical method of graphing vectors is more accurate, what is the percent error of your graphical calculations for both magnitude and direction? To find the percent error for each part of the resultant vector, use the equation % error = $\frac{|graphical - analytical|}{analytical} \cdot 100$.

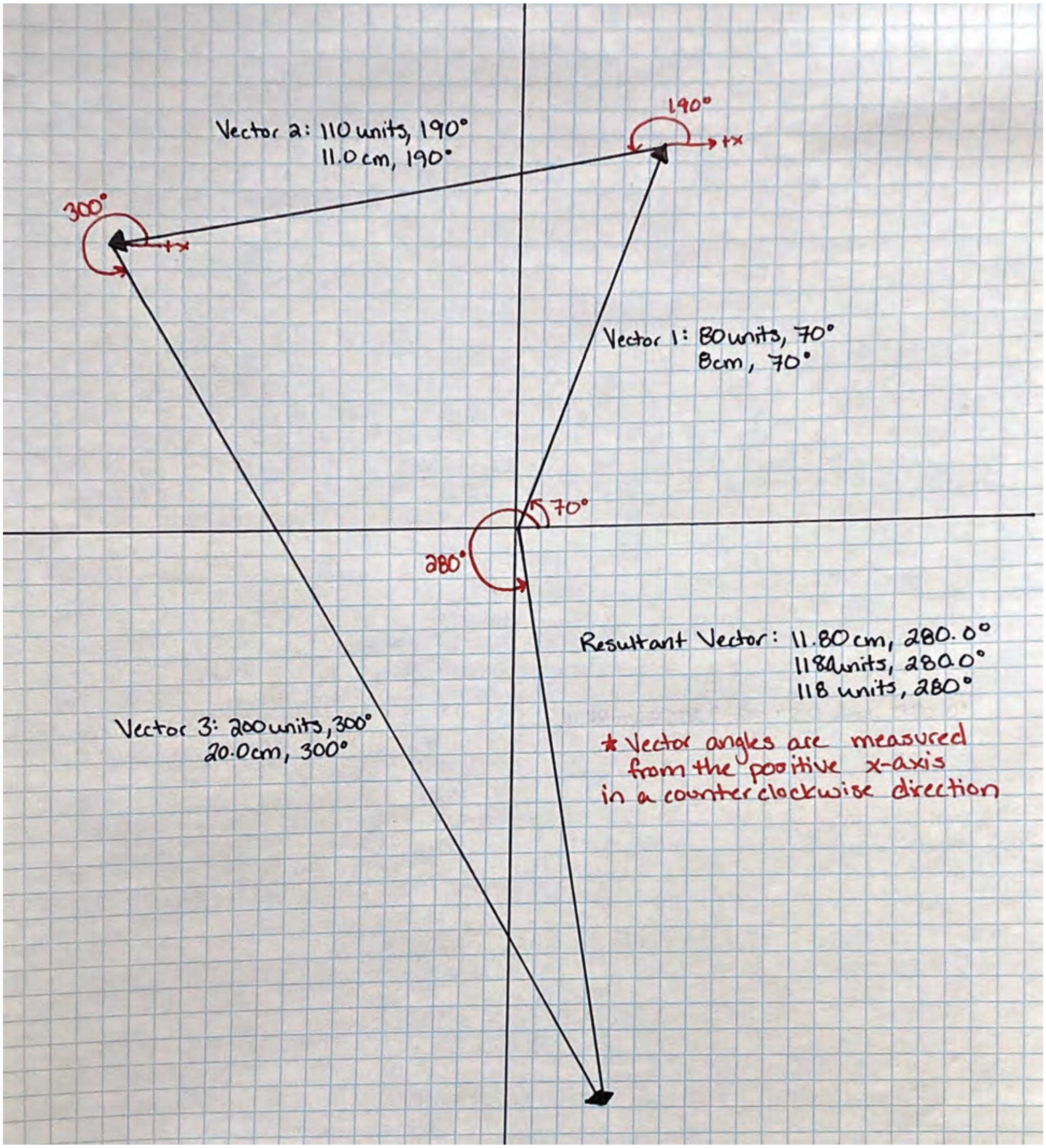
   A sample response is shown below. For student work, check that each vector is drawn at the correct angle and the length of each vector correctly represents its magnitude. Check the measurements for the magnitude and angle of the resultant vector. Analytically, check that the appropriate equations were used.

   Vector 1: 80 units at 70°

   Vector 2: 110 units at 190°

   Vector 3: 200 units at 300°

Part 1: See the graph below. The scale is 10 units = 1 cm. Students should include their scale on their graph.



Part 2: Breaking down vectors into components:

$V_{1x} = V_1 \cos\theta = 80 \cos 70 = 27.4$ units

$V_{1y} = V_1 \sin\theta = 80 \sin 70 = 75.2$ units

$V_{2x} = V_2 \cos\theta = 110 \cos 190 = -108.3$ units

$V_{2y} = V_2 \sin\theta = 110 \sin 190 = -19.1$ units

$V_{3x} = V_3 \cos\theta = 200 \cos 300 = 100.0$ units

$V_{3y} = V_3 \sin\theta = 200 \sin 300 = -173.2$ units

Adding *x*-components: $R_x = 27.4 + (-108.3) + 100.0 = 19.1$ units

Adding *y*-components: $R_y = 75.2 + (-19.1) + (-173.2) = -117.1$ units

Magnitude of resultant vector: $R = \sqrt{R_x^2 + R_y^2} = \sqrt{19.1^2 + (-117.1)^2} = 118.6$ units

Angle of resultant vector: $\theta_{ref} = \tan^{-1}\left(\frac{|R_y|}{|R_x|}\right) = \theta_{ref} = \tan^{-1}\left(\frac{|-117.1 \text{ units}|}{|19.1 \text{ units}|}\right) = 80.7°$

The resultant vector is in quadrant 4 because the *x*-component is positive and the *y*-component is negative; thus, $\theta = 360° - \theta_{ref} = 360° - 80.7° = 279.3°$.

Percent error magnitude: $\% \text{ error} = \frac{|118 - 118.6|}{118.6} \cdot 100 = 0.5\%$

Percent error angle: $\% \text{ error} = \frac{|280° - 279.3°|}{279.3°} \cdot 100 = 0.3\%$

Activity: Design a Mini-Project

In this activity, you will be redesigning a process involving projectile motion or simple harmonic motion. As you go through the design process, you will be demonstrating your understanding of either projectile motion or simple harmonic motion. The final product will be a diagram or a model of your new product!

Innovation is critical for creating and bringing to market products that are sustainable while fulfilling their desired purpose. The process of innovation or design can be broken down into several steps: gathering background information, developing new ideas or design features, refining those ideas, creating a schematic or model, testing the model, refining further, and final production. In this activity, you will go through the first four steps of the design process.

Brainstorm what to innovate.

First, you will brainstorm several existing scenarios where there is a situational need for projectile motion or simple harmonic motion. For example, to increase the distance a ball can be thrown while playing fetch with a dog, the Chuck It was created. The situational need was to throw the ball farther, and the solution was the Chuck It. Similarly, to allow multiple people to drink from the same water source without contaminating the spigot (situational need), the drinking fountain was created with an arc-shaped path of projectile motion (solution). An example of simple harmonic motion is using a rope tied to a branch to swing across a small stream to reach the other side without getting wet.

To brainstorm your project, come up with a list of day-to-day occurrences where a situational need for projectile motion or simple harmonic motion exists, and then decide if any of them could be improved. The scenario you think of could be useful or silly. Feel free to be as creative as you wish. The final stage will be creating a diagram or simple model of your solution. As you will not actually be building or implementing your design, you do not need to worry about having the ability to do it. List two or three scenarios.

Step 1: Gather background information.

Choose one of your scenarios and start gathering background information. Useful background information can include researching how the process currently happens and asking others what they might do to improve or fulfill the need you identified. Make notes about what you have learned.

Step 2: Develop new ideas or design features.

Write down every single idea that comes to mind on how to fulfill your chosen situational need. Include even the outlandish ideas—they may eventually inspire your final product.

Step 3: Refine your ideas.

Review all the ideas you came up with in step 2. Organize your ideas based on what is reasonable, what is cost-effective, what would actually work, and which one you like best. You may take parts of several ideas and mesh them together.

Step 4: Create a schematic or model of your product solution.

Sketch the design of your new product. Your schematic should be labeled and include multiple viewpoints to showcase all parts of your design. If you want, you may build a model of your design (although you are not required to).

Presentation

Create a digital slideshow or video to present your idea. You might like to present your design to a group of friends, family members, or other students.

Your presentation should include the following:

- Description of the situational need your design fulfills
- At least one slide per design step, including explanations of your decision-making process
- The schematic/diagram of your product from step 4
- Explanation of how the solution applies projectile motion or simple harmonic motion
- Explanation of why your design is an improvement on the existing process
- Ideas and thoughts on how your product could be manufactured for use
- References or sources used throughout the design process

Encourage students to get creative with this activity! It is an opportunity for students who may be less math-inclined to showcase their understanding of either projectile motion or simple harmonic motion. While no calculations are required, some students may present sample calculations. As is emphasized in the activity description, the focus is more on the design process and conceptual understanding than the actual feasibility of what the students come up with. The presentation should be well organized and include all the required elements listed above.

Further Study

If you are interested in further exploring the topics and skills in this lesson, feel free to choose any of the following activities. All are optional.

- Complete the textbook Chapter Review and Test Prep (odd-numbered problems). The solutions are available online via OpenStax, under Student Resources.
- Try pendulum art! Follow the instructions below to apply physics principles to the creation of art.

Activity: Pendulum Art

Art as a creative expression often draws inspiration from and utilizes scientific principles. Through his artwork, artist Tom Shannon explores the principles and theories of physics, including gravity, magnetism, and pendulums.

Begin by watching the following video. As you watch, take a few notes about the different physics principles the artist explores and how he uses them to express his own artistic ideas.

"The Painter and the Pendulum"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Now, it is time to make some of your own artwork!

Materials

- string (found in lab kit)
- scissors
- several small plastic bottles
- several plastic cups
- acrylic paint, several colors
- canvas or paper
- newspaper, cardboard, or protective plastic sheet
- drill
- tripod, art easel, or ladder

Procedure

Please read through all the steps before starting. It may take a few tries to perfect the release-and-catch technique, so try it first with smaller amounts of paint.

1. Spread out the newspaper or protective plastic sheet and set up the tripod, art easel, or ladder on top of it. Cut a length of string long enough to hang one of the bottles but short enough that the bottle does not touch the art surface. Tie it to the tripod.
2. Prepare the bottle by drilling a small hole in the center of the bottom of it. Tie the hanging end of the string around the neck of the bottle just below where the lid screws on.
3. In one of the cups, mix the paint with a small amount of water, adding more as needed to make the paint thinner. The paint mixture should be thin enough that it will easily pour out of the hole in the bottle.
4. Place the canvas or paper below the pendulum.
5. With a finger, cover the hole in the bottom of the bottle, then pour the paint into the bottle. Position the bottle, being sure to keep the string taut. The bottle should be just above and to the side of the canvas. You want the bottle to be able to swing without hitting the legs of the tripod, so do not pull it too high to the side.
6. Once the bottle is in starting position, you will simultaneously let go of the bottle, giving it a slight push to the side, and uncover the hole to allow the paint to pour out. As the bottle swings, paint should flow out in a steady stream, creating a pattern on your canvas.
7. To end the painting, take a second empty cup and prepare to catch the bottle and put the cup under it to catch any remaining paint. Quickly stop the bottle and place the cup below it to end the painting process.
8. If desired, repeat the process with another color.
9. Let the painting dry before moving it or the paint may run.

Conclusions

If you are submitting this project to your teacher for extra credit, please include a photo of your finished artwork and answer the following questions.

1. How does the release height and angle impact the paint pattern?

   The height and angle changes the radius of the pendulum and the velocity of the pendulum, resulting in different patterns.

2. What happens to the period of the pendulum as the painting progresses?

   As the painting progresses, the period of the pendulum decreases as it loses momentum. Eventually, the pendulum comes to a rest directly below the point it is hung from.

SHARE YOUR WORK

When you have completed your work, share it with your teacher. Remember to check with your teacher at the beginning of each lesson to make sure you understand what you are required to do.

Below is a list of assignments in this lesson, which you can use to organize your work submission:

- Math Prep: Try It! Right Triangles: Reference Angles and Vector Angles
- Inquiry Activity: Juggling
- Defining Key Equation Variables
- Conceptual questions
- Analytical questions
- Activity: Vector Addition—Graphical and Analytical Methods
- Activity: Design a Mini-Project

If you have any questions about the lesson content, assignments, or how to share your work, contact your teacher.

Lesson

17

Sound

Learning Objectives

In this lesson, you will:

- Describe a sound wave and how they are created and propagate through various mediums.
- Describe and solve problems involving the speed, frequency, and wavelength of sound.
- Describe the Doppler effect of sound waves and sonic booms.
- Understand sound intensity, how it is measured using the decibel scale, and analyze problems associated with intensity.
- Understand resonance, beats, fundamental frequency, and harmonic series.
- Solve and analyze problems involving harmonic series and beat frequency.
- Understand how the human ear receives sound.

Lesson Introduction

Welcome to lesson 17, where you will learn all about the physics of sound! In the previous lesson, you learned the basics of waves and their properties. In this lesson, you will explore how sound is a wave and how it travels through different materials. You will also explore the doppler effect and sonic booms, how the human ear receives sound, and various means of measuring and quantifying sound.

This lesson will take approximately two weeks.

ASSIGNMENT CHECKLIST

- ☐ Complete the Math Prep activities.
- ☐ Inquiry Activity: The Cup-and-String Telephone
- ☐ Read chapter 14, "Sound."
- ☐ Complete the exercises in Defining Key Equation Variables.
- ☐ Respond to the conceptual questions.
- ☐ Respond to the analytical questions.
- ☐ Activities and Labs:

  Research: How We Hear

  Lab: The Speed of Sound in Air

Math Prep

Is Your Solution Logical?

One of the great advantages of physics is that it is applied math, so we are able to check to see if our answer logically makes sense based on the physical phenomena we are studying. For example, if you heard that someone ran 2,600 miles per hour, you might instinctively realize such a speed is beyond unreasonable for a human being to run. Likewise, as you become more familiar with each topic, you will start to gain a feel for whether or not the answers you calculated are reasonable.

The human ear can hear sounds with frequencies between 20 to 20,000 Hz while dogs can hear up to 110,000 Hz. If you were determining the frequency of a sound that both a dog and a human heard and calculated an answer of 5 Hz or 80,000 Hz, neither answer would be correct because humans and dogs cannot hear lower than 20 Hz, and although a dog can hear 80,000 Hz, a human cannot.

Below, you will be given a set of facts about certain physical phenomena. Without doing any calculations, you will practice picking the most reasonable answer. When you are solving actual physics problems, always check to make sure your answer is reasonable and makes sense, including both the value you calculate and the units of your solution.

Try It! Is Your Solution Logical?

1. The speed of light is $3 \cdot 10^8$ m/s. If you are calculating the speed of light in a vacuum, which of the following answers is reasonable?

   a. $2.99 \cdot 10^7$ m/s

   b. $3.01 \cdot 10^9$ m/s

   c. $3.01 \cdot 10^8$ m/s

   d. $2.99 \cdot 10^9$ m/s

   c. $3.01 \cdot 10^8$ m/s

   Note that all the other answers are raised to the incorrect power of 10.

2. The wavelength of visible light, or the light we can see with our eyes, ranges from 400–700 nm. If you are calculating the average wavelength that one sees in a rainbow, which answer would be the most reasonable?

   a. 2,084 nm

   b. 512 nm

   c. $4.5 \cdot 10^3$ nm

   d. 340 nm

   b. 512 nm

   This is the only value that falls within the range of visible light.

3. A Subaru Outback's speedometer has a range of 0 mph to 150 mph. When calculating the average speed of a two-hour trip along winding roads with a lot of curves, which answer would make the most sense?

   a. 28 mph

   b. 115 mph

   c. 180 mph

   d. –45 mph

   a. 28 mph

   While 115 mph is still within the range of the speedometer, it is too high of an average speed for winding roads with many curves, so it isn't reasonable. The other two answers are outside the speedometer's range.

4. Generally speaking, the voltage range of household wires is 115 volts to 125 volts. When calculating the voltage of the wiring in a house, which of the following answers is reasonable?

   a. 120 amps

   b. 160 volts

   c. 120 volts

   d. 95 amps

   c. 120 volts

   Note that 120 amps is incorrect because while the value falls between 115 and 125, the units are amps and not volts, and thus it is a measure of electric current not voltage.

Inquiry Activity: The Cup-and-String Telephone

It is known that sound can travel through more than just air. For this inquiry activity, you will be exploring how sound travels through string! You may have done this activity as a kid, and after completing lesson 17, you will understand how it works.

You will need a partner for this activity.

Materials

- string (found in lab kit)
- 2 plastic or paper cups
- scissors

Procedure

1. Using your scissors, poke a small hole in the bottom of each cup.

2. Push the string through the hole from the outside of the cup to the inside.
3. Tie a knot in the string inside the cup to keep the string from being pulled through the hole.
4. Repeat steps 2 and 3 with the other end of your string and the other cup.
5. Stand far enough apart from your partner that the string between the cups is taut (fully stretched out).
6. Place your cup against your ear and have your partner speak into their cup.
7. Observe what you were able to hear.
8. Have your partner increase and decrease the volume of their voice. Record your observations.
9. Repeat steps 6–8 without holding the string taut.

Follow-Up Questions

1. Were you able to hear your partner speak?
2. Did the string need to be taut or loose to hear your partner speaking? Explain what you think may be happening to the sound waves.

   Students should include their observations about how well they were able to hear their partner speak. For the cup-and-string telephone to work, the string must be taut to allow sound waves to propagate through it without dissipating. With the string taut, students should be able to hear their partner speak both softly and loudly as if they were right next to them.

For this activity, submit the following to your teacher:

- All your observations
- Answers to the follow-up questions

Reading

In your textbook, read chapter 14, "Sound" (415–444), which includes the following sections:

- Introduction
- 14.1 Speed of Sound, Frequency, and Wavelength
- 14.2 Sound Intensity and Sound Level
- 14.3 Doppler Effect and Sonic Booms
- 14.4 Sound Interference and Resonance
- Section Summary

Resources for "Sound"

Check out the following resources related to topics in chapter 14. If you need additional help, reach out to your teacher.

Note: These resources are meant to supplement, not replace, the textbook reading.

"Sound: Crash Course Physics #18"

"The Physics of Music: Crash Course Physics #19"

"Waves, Light and Sound" (watch the second half)

"Production of Sound"

"Sound Properties: Amplitude, Period, Frequency, Wavelength"

"Speed of Sound"

"Standing Waves in Open Tubes"

"Standing Waves in Closed Tubes"

"Introduction to Sound Review"

"Beat Frequency"

"Beats an Interference of Sound Waves Review"

"Doppler Effect Introduction"

"Doppler Effect Review"

"Sound Waves and Music"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Defining Key Equation Variables

For lesson 17, the key equations you will be defining variables for are shown below.

For each equation, include the variable, quantity, SI Units, and whether it is a scalar or vector. Remember, some variables are used in multiple equations.

1. $v = f\lambda$

   Speed of sound, where *v* is the speed of sound (m/s, scalar), *f* is the frequency (Hz, scalar), and λ is the wavelength (m, scalar)

2. $I = \frac{P}{A}$

   Intensity, where *I* is the intensity (W/m^2, scalar), *P* is the power through a given area (W, scalar), and *A* is the area (m^2, scalar)

3. $I = \frac{(\Delta P)^2}{2\rho v_w}$

   Sound intensity, where *I* is the intensity (W/m², scalar), Δρ is the pressure variation (Pa or N/m², scalar), ρ is the density of the material in which the sound wave travels (kg/m³, scalar), and v_w is the speed of sound in the medium (m/s, scalar)

4. $\beta(\text{dB}) = 10 \log_{10}\left(\frac{I}{I_0}\right)$

   Sound intensity level, where β is the sound intensity level (dB, scalar), *I* is the sound intensity (W/m², scalar), and I_0 is the reference intensity for normal human hearing (10^{-12} W/m², scalar)

5. $f_{obs} = f_s\left(\frac{v_w}{v_w \pm v_s}\right)$

   Doppler effect observed frequency (moving source), where f_{obs} is the observed frequency (Hz, scalar), f_s is the frequency of sound from a source (Hz, scalar), v_w is the speed of sound (m/s, scalar), and v_s is the speed of the source along a line joining the source and observer (m/s, scalar)

6. $f_{obs} = f_s\left(\frac{v_w \pm v_{obs}}{v_w}\right)$

   Doppler effect observed frequency (moving observer), where f_{obs} is the observed frequency (Hz, scalar), f_s is the frequency of sound from a source (Hz, scalar), v_w is the speed of sound (m/s, scalar), and v_{obs} is the speed of the observer along a line joining the source and observer (m/s, scalar)

7. $f_B = |f_1 - f_2|$

   Beat frequency, where f_b is the beat frequency (Hz, scalar) and f_1 and f_2 are the frequencies of the original waves (Hz, scalar)

8. $f_n = n\frac{v}{4L}, n = 1, 3, 5 \ldots$

   Resonant frequencies of a closed-pipe resonator, where f_n are the resonant frequencies of a closed-pipe resonator (Hz, scalar), *n* are natural frequencies (dimensionless, scalar), *v* is the speed of sound (m/s, scalar), and *L* is the length of the closed tube (m, scalar)

9. $f_n = n\frac{v}{2L}, n = 1, 2, 3 \ldots$

   Resonant frequencies of an open-pipe resonator, where f_n are the resonant frequencies of an open-pipe resonator (Hz, scalar), *n* are natural frequencies (dimensionless, scalar), *v* is the speed of sound (m/s, scalar), and *L* is the length of the open tube (m, scalar)

Conceptual Questions

Answer the following questions using your own words to describe physics concepts, theories, and laws. You may use a direct quote from the textbook (in quotation marks, with the page number cited) to help support your definition, but do not rely on textbook quotations for your full answer.

1. What is a sound wave? On what two variables does the speed of sound depend?

   A sound wave is a wave that is created from a disturbance of matter that is transmitted from its source outward by longitudinal waves. In other words, when a disturbance is

created, the particles surrounding it will experience simple harmonic motion and pass the disturbance on to the particles next to it via a longitudinal wave. The speed of sound depends on both the density and the rigidity of the medium it is traveling through. The more dense and rigid the medium, the quicker the sound waves will travel through it. In table 14.1 on page 418 of the textbook, you can see that sound travels much faster in glass (5,640 m/s) than in air (331 m/s).

2. All the strings of a guitar are roughly the same length. If the guitar is in tune, why does each string sound a different note?

   A guitar in tune will make a different sound for each string based on the tension or rigidity of the string and the mass of the string. Tuning a guitar is done by tightening or loosening the tension on the strings.

3. What type of motion do particles of a medium experience when a sound wave passes through it?

   Particles will experience simple harmonic motion.

4. What is the decibel scale? Why do we use it?

   The decibel scale is based on how the human ear perceives sound, which is closer to the logarithm of the intensity of a sound rather than pure intensity. The lowest intensity of sound a human can hear is $10^{-12}\frac{\text{W}}{\text{m}^2}$, which corresponds to 0 decibels (dB). The decibel level will increase with an increase in sound intensity. The formula for sound intensity level in decibels is $\beta(\text{dB}) = 10\log_{10}\left(\frac{I}{I_0}\right)$, where β is the sound intensity level (dB), I is the sound intensity (W/m²), and I_0 is the reference intensity for normal human hearing ($10^{-12}\frac{\text{W}}{\text{m}^2}$).

5. Why does a boat whistle sound different when it is stationary, when the boat is moving toward you, and when it is moving away from you?

   A boat whistle will sound different when it is stationary, when moving toward a person, and when moving away from a person due to the Doppler effect. When both the boat and the person are stationary, sound waves will travel toward the person at a given velocity that corresponds to a specific frequency for the boat whistle. When the boat is moving toward a person, it causes the sound waves to be closer together, which corresponds to a higher frequency or a higher-pitched sound. When the boat is moving away from a person, it causes the sound waves to be farther apart from one another, which corresponds to a lower frequency or a lower-pitched sound.

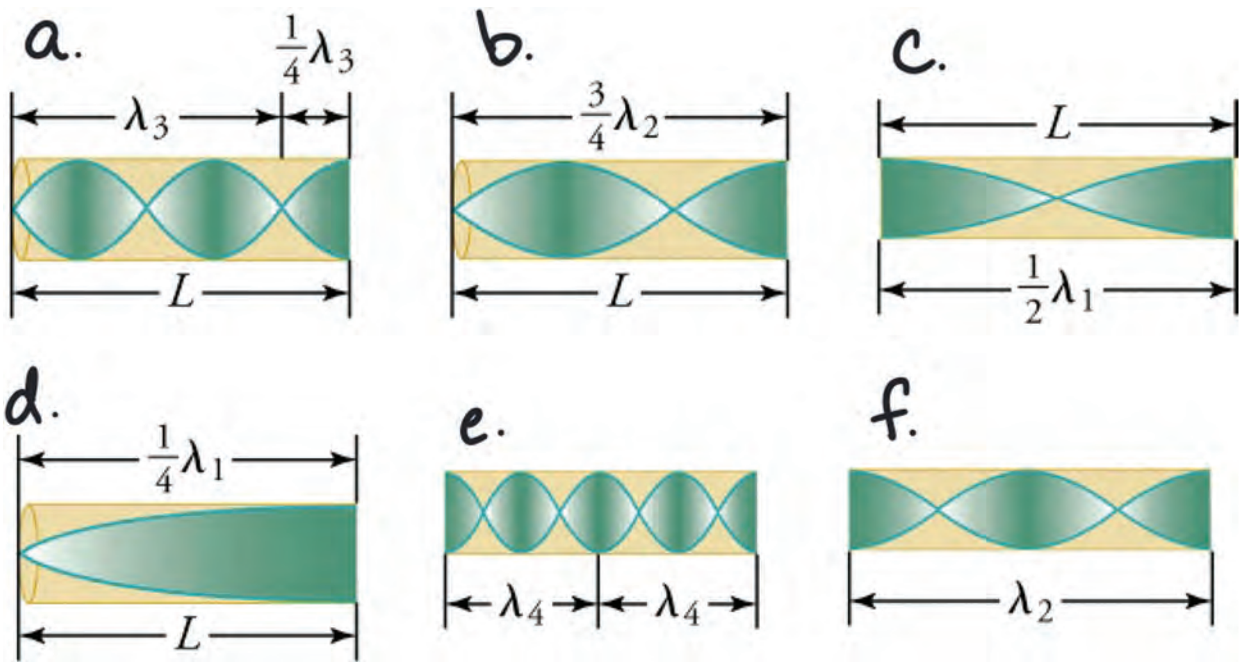
6. What does it mean when a system is said to resonate? Use an example as part of your explanation.

   When a system is said to resonate, it means that it is driven at its natural frequency, which is the frequency at which a system would oscillate if no other forces acted on it. For example, if a child is on a swing and we want the swing system to resonate, we would drive the system by giving the child repeated pushes so that they always swing to the same height or amplitude. In a world without friction, air resistance, and other motion resistive forces, we would not have to push the child each time for them to continue to reach the

same amplitude because it would be oscillating at its natural frequency for that amplitude. The same phenomena can occur with sound waves.

7. Label the diagram with the correct open- or closed-pipe resonator resonant frequency:
   - fundamental for open-pipe
   - fundamental for closed-pipe
   - first overtone for open-pipe
   - first overtone for closed-pipe
   - second overtone for closed-pipe
   - third overtone for open-pipe

Diagram: Various Resonant Frequencies for Open- and Closed-Pipe Resonators



a. second overtone for closed-pipe

b. first overtone for closed-pipe

c. fundamental for open-pipe

d. fundamental for closed-pipe

e. third overtone for open-pipe

f. first overtone for open-pipe

Analytical Questions

1. Dogs can hear frequencies of up to 45 kHz. What is the wavelength of a sound wave with this frequency traveling in air at 0 °C?

   The wavelength is 7.4 m, From table 14.1, page 418, the speed of sound in air at 0 °C is 331 m/s. Use $v_w = f\lambda \rightarrow \lambda = \frac{v_w}{f} = \frac{331\text{ m/s}}{45\text{ Hz}} = 7.4$ m.

2. What is the sound intensity level in W/m^2 and the pressure amplitude in Pa for a sound wave traveling in air at 0 °C and an intensity of 95.0 dB? Note that the speed of sound in air at 0 °C is 331 m/s and the density of air at 0 °C and atmospheric pressure is 1.29 kg/m^3.

   The sound intensity level is $3.16 \cdot 10^{-3}$ W/m^2 and the pressure amplitude is 1.64 Pa.

   First solve for the sound intensity level using $\beta(\text{dB}) = 10\log_{10}\left(\frac{I}{I_0}\right) \rightarrow I = I_0 10^{\left(\frac{\beta(\text{dB})}{10}\right)} = 10^{-12}10^{\left(\frac{(95.0\text{dB})}{10}\right)} = 10^{-2.5} = 3.16 \cdot 10^{-3}$ W/m^2. Next use $I = \frac{(\Delta P)^2}{2\rho v_w} \rightarrow \Delta P = \sqrt{I 2\rho v_w} = \sqrt{(3.16 \cdot 10^{-3})2(1.29\text{ kg/m}^3)(331\text{ m/s})} = 1.64$ Pa.

3. A train is moving at a speed of 28.0 m/s in still air on a day when the speed of sound is 335 m/s. If it has a 175 Hz horn, what frequencies are observed by a stationary person at the side of the tracks as the train approaches and after it passes?

   Approaching f_{obs} = 191 Hz, receding f_{obs} = 162 Hz

   For an approaching train the minus sign is used in
   $$f_{obs} = f_s\left(\frac{v_w}{v_w \pm v_s}\right), f_{obs} = f_s\left(\frac{v_w}{v_w - v_s}\right) = (175\text{ Hz})\left(\frac{(335\text{ m/s})}{(335\text{ m/s}) - (28.0\text{ m/s})}\right) = 191\text{ Hz}$$

   For a train receding the addition sign is used in
   $$f_{obs} = f_s\left(\frac{v_w}{v_w \pm v_s}\right), f_{obs} = f_s\left(\frac{v_w}{v_w - v_s}\right) = (175\text{ Hz})\left(\frac{(335\text{ m/s})}{(335\text{ m/s}) + (28.0\text{ m/s})}\right) = 162\text{ Hz}$$

4. A tube open at both ends and a tube closed at one end have the same fundamental frequency of 205 Hz. What is the frequency of the third overtone for each tube? What is the beat frequency produced by the superposition of the two third overtone sound waves made by each tube?

   Open both ends, the third overtone is 820 Hz. Closed one end, the third overtone is 1435 Hz. The beat frequency from the superposition of the two third overtones is 615 Hz.

   For the tube open on both ends, the resonant frequencies are $f_n = n\frac{v}{2L}$, $n = 1, 2, 3 \ldots$

   For the fundamental frequency $n = 1$, for the third overtone $n = 4$, thus $f_1 = 1\frac{v}{2L} = \frac{v}{2L}$ and $f_4 = 4\frac{v}{2L} = 4(f_1) = 4(205\text{ Hz}) = 820$ Hz

   For the tube closed on one end, the resonant frequencies are $f_n = n\frac{v}{4L}$, $n = 1, 3, 5 \ldots$ For the fundamental frequency $n = 1$, for the third overtone $n = 7$, thus $f_1 = 1\frac{v}{4L} = \frac{v}{4L}$ and $f_7 = 7\frac{v}{4L} = 7(f_1) = 7(205\text{ Hz}) = 1{,}435$ Hz

   For beat frequency use $f_B = |f_1 - f_2| = |(1{,}435\text{ Hz}) - (820\text{ Hz})| = 615$ Hz

Activities and Labs

Complete the following:

- Research: How We Hear
- Lab: The Speed of Sound in Air

Research: How We Hear

In this research activity, you will have the chance to explore how the human ear receives sound waves. Before you begin to conduct your own research, watch the video below:

"What Is up with Noises? (The Science and Mathematics of Sound, Frequency, and Pitch)"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

You will notice that the video goes through the information very fast. If you do not catch every little piece of information, that is fine as long as you feel you understand the overall message.

After you have watched the video, write a brief reflection that is one or two paragraphs long. This will be submitted along with your research paper.

Next, choose one of the following topics to learn more about:

- How the ear and the brain work to interpret sound and auditory overstimulation
- Hearing loss and the physiological changes to the structures within the ear, and how hearing aids work

Use at least three different sources for your research. You might want to include images with your writing. Google Scholar can be a great place to start your research.

When writing your two-page research paper, be sure to put what you have learned into your own words. Be careful not to rely too heavily on your sources when organizing your ideas—this should be your own original work. Use in-text citations for specific pieces of information or direct quotes.

For this activity, submit the following to your teacher:

- reflection on the video
- research paper
- your cited sources

In their research paper, the student should clearly explain the topic they learned about (two choices are listed above), using their own words to create an original work. Students should use at least three credible sources, include in-text citations for specific facts and direct quotes, and cite any photos or images that are used.

Lab: The Speed of Sound in Air

Complete Lab 12: The Speed of Sound in Air, which is found in the *Physics Lab Manual* that came with your lab kit.

Tip: Do not strike the tuning fork on metal as this will damage the tuning fork.

For this lab, submit the following to your teacher:

- Photos of your setup
- Your completed data tables
- Answers to the lab questions
- All the work you did for your calculations

Solutions are found in the Answer Key that came with your lab kit.

Further Study

If you are interested in further exploring the topics and skills in this lesson, you can choose to complete the textbook Chapter Review and Test Prep (odd-numbered problems). The solutions are available online via OpenStax, under Student Resources. This activity is optional.

SHARE YOUR WORK

When you have completed your work, share it with your teacher. Remember to check with your teacher at the beginning of each lesson to make sure you understand what you are required to do.

Below is a list of assignments in this lesson, which you can use to organize your work submission:

- Math Prep: Try It! Is Your Solution Logical?
- Inquiry Activity: The Cup-and-String Telephone
- Defining Key Equation Variables
- Conceptual questions
- Analytical questions
- Research: How We Hear
- Lab: The Speed of Sound in Air

If you have any questions about the lesson content, assignments, or how to share your work, contact your teacher.

Lesson

23

Electrical Circuits

Learning Objectives

In this lesson, you will:

- Understand the differences between direct current and alternating current.
- Describe and apply Ohm's law to solve analytical problems.
- Understand and analyze the differences between resistors in series and in parallel.
- Understand basic circuit elements and how to draw a circuit diagram.
- Describe and solve problems involving electric power with the electric power equation for circuits of resistors in a variety of arrangements.

ASSIGNMENT CHECKLIST

- ☐ Inquiry Activity: Circuit Breakers
- ☐ Read chapter 19, "Electrical Circuits."
- ☐ Complete the exercises in Defining Key Equation Variables.
- ☐ Respond to the conceptual questions.
- ☐ Respond to the analytical questions.
- ☐ Activities and Labs:

  Activity: Circuit Bugs

  Lab: Ohm's Law

Lesson Introduction

Electrical circuits range from simple circuits, such as the ones that turn a light bulb on and off, to complicated circuits like those found in advanced electronics. In this lesson, you will learn about circuits, including how to draw a circuit diagram and the various components that can make up a circuit, such as resistors, capacitors, and transformers. You will familiarize yourself with the concepts of electric current and electric power as well.

This lesson will take approximately one week.

Inquiry Activity: Circuit Breakers

Has there ever been a time when the electricity goes out in part of your home but remains on in the rest? Have you ever heard someone say that the circuit breaker has been "tripped," perhaps after an intense thunder and lightning storm? Both scenarios have something in common: a circuit breaker. Found in homes and other buildings, circuit breakers regulate the current flowing through the electrical wiring of the building. They are a safety mechanism meant to disconnect the power when the current goes above a specified threshold. Interrupting the circuit under these conditions ensures the electrical wires do not overheat and potentially cause a fire. Circuit breakers in houses are usually located in discreet places, such as in a closet, laundry room, or garage.

House circuit breaker (Image credit: Stephanie Lieblappen)

Electricians use circuit breakers to turn off the electricity in the part of the building they are working on. For example, if they are installing new lights and outlets in a bedroom, they will switch off the breaker that corresponds to that part of the house. This is useful because it allows the rest of the house to retain electrical power.

For this inquiry activity, you will locate the circuit breaker in the building that you live in. When you find it, take a photo of it to submit along with a brief description of how many circuits are on it and where it is located. If you cannot locate the circuit breaker in your home, try to see if you can find one elsewhere, such as a local business or a friend's house.

To learn more about circuit breakers, check out the following website:

"How Circuit Breakers Work"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Students will submit a photo of their circuit breaker along with a description of it and where it is located.

Reading

In your textbook, read chapter 19, "Electrical Circuits" (603–639), which includes the following sections:

- Introduction
- 19.1 Ohm's Law
- 19.2 Series Circuits
- 19.3 Parallel Circuits
- 19.4 Electric Power
- Section Summary

Resources for "Electrical Circuits"

Check out the following resources related to topics in chapter 19. If you need additional help, reach out to your teacher.

Note: These resources are meant to supplement, not replace, the textbook reading.

"Electric Current: Crash Course Physics #28"

"DC Resistors & Batteries: Crash Course Physics #29"

"Circuit Analysis: Crash Course Physics #30"

"Capacitors and Kirchhoff: Crash Course Physics #31"

"Circuits, Voltage, Resistance, Current"

"Introduction to Circuits and Ohm's Law"

"Resistivity and Conductivity"

"Current, Resistance, and Resistivity Review"

"Electric Potential Difference and Ohm's Law Review"

"Electric Power"

"DC Circuit and Electrical Power Review"

"Series Resistors"

"Parallel Resistors (Part 1)"

"Parallel Resistors (Part 3)"

"Resistors in Series and Parallel Review"

"Voltmeters and Ammeters"

"DC Ammeters and Voltmeters Review"

"Electric Circuits"

(All online resources can be accessed at oakmeadow.com/curriculum-links.)

Defining Key Equation Variables

For lesson 23, the key equations you will be defining variables for are shown below.

For each equation, include the variable, quantity, SI Units, and whether it is a scalar or vector. Remember, some variables are used in multiple equations.

1. $I = \frac{\Delta Q}{\Delta t}$

   Electric current, where I is the electric current (A, scalar), ΔQ is the change in charge (C, scalar), and Δt is the change in time (s, scalar)

2. $V = IR$

   Ohm's law, where V is the voltage (V, scalar), I is the electric current (A, scalar), and R is the resistance ($\frac{V}{A}$ or Ω, scalar)

3. $R_{equiv} = R_1 + R_2 + \cdots + R_N$

   Resistors in series, where R_{equiv} is the equivalent resistance of resistors in series (Ω, scalar), and R_1, R_2, etc., are the resistors in series (Ω, scalar)

4. $R_{equiv} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}}$

   Resistors in parallel, where R_{equiv} is the equivalent resistance of resistors in parallel (Ω, scalar), and R_1, R_2, etc., are the resistors in parallel (Ω, scalar)

5. $P = IV$

   Power for a current flowing through a potential difference, where P is the electric power (W, scalar), I is the electric current (A, scalar), and V is the voltage (V, scalar)

6. $P = I^2R$

   Power for a current flowing through a resistance, where P is the electric power (W, scalar), I is the electric current (A, scalar), and R is the resistance (Ω, scalar)

7. $P = \frac{V^2}{R}$

   Power for a voltage difference across a resistor, where P is the electric power (W, scalar), V is the voltage (V, scalar), and R is the resistance (Ω, scalar)

Conceptual Questions

Answer the following questions using your own words to describe physics concepts, theories, and laws. You may use a direct quote from the textbook (in quotation marks, with the page number cited) to help support your definition, but do not rely on textbook quotations for your full answer.

1. What is the definition of electric current? What unit is it generally measured in?

   Electric current is the rate at which electric charge moves. Flow direction is conventionally said to be the direction a positive charge would flow if it were able to. In metal wires, it is the negative charge that moves, so the electric current in a wire is opposite the flow of electrons. The SI unit for electric current is the ampere (A), which is defined as one coulomb per second: $1\ \mathrm{A} = 1\ \frac{\mathrm{C}}{\mathrm{s}}$

2. Describe and give at least two examples of both direct current and alternating current.

   Direct current (DC) is current that only flows in one direction. Direct current is used in computers, cell phones, flashlights, and cars. A battery also provides a direct current between its terminals.

   Alternating current (AC) is current that alternates directions back and forth at regular time intervals. This back-and-forth transition is typically smooth and not immediate. The power coming from a wall socket is from an alternating current, which is why the DC devices listed above all have a transformer as part of what you plug into the wall. Devices that use AC current include vacuum cleaners, fans, power tools, and hair dryers.

3. An ohm is a measure of resistance of a material. Use Ohm's law to define an ohm.

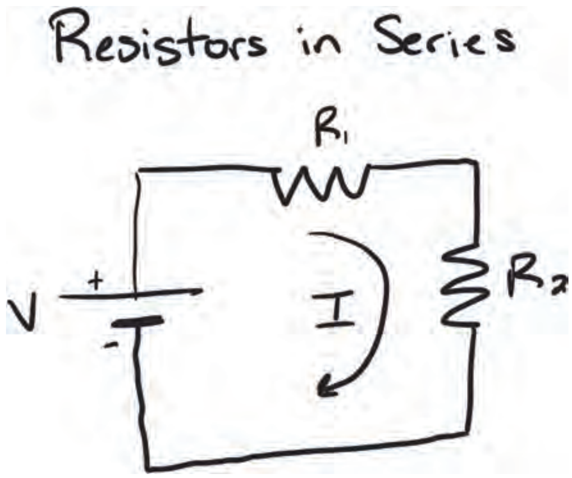
   Ohm's law states that $V = IR$, where V is the voltage, I is the electric current, and R is the resistance. This shows that when a voltage is applied, the resulting current produced from this voltage depends on the resistance found in the circuit. Resistance has the SI unit of an ohm (Ω), which is a derived unit of $\frac{V}{A}$, which comes directly from rearranging Ohm's law to $R = VI$.

4. What does it mean to have resistors in series? Draw a diagram to accompany your explanation and include the direction of the current.

   When resistors are in series, they are connected one after another, and the total resistance of the circuit is the sum of the resistance of each resistor added together. This means the more resistors you have in a circuit, the lower the current will be for a given voltage.

   See the diagram below for an example of resistors in series. Students may have more than two resistors in series; if so, be sure that they come one after another.

Sample Diagram: Two Resistors in Series

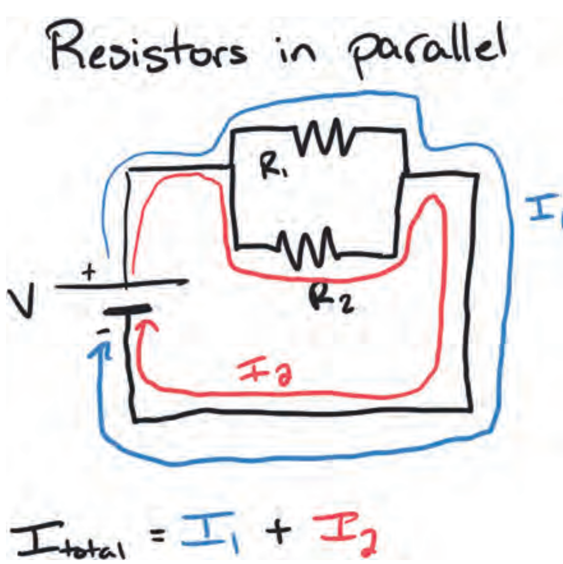


5. What does it mean to have resistors in parallel? Draw a diagram to accompany your explanation and include the direction of the current.

When resistors are in parallel, both sides of each resistor are connected together to the same wire, and the total resistance or equivalent resistance of the circuit comes from the equation $\frac{1}{\frac{1}{R_1}+\frac{1}{R_3}+\cdots+\frac{1}{R_N}}$, where R_{equiv} is the equivalent resistance of resistors in parallel (Ω) and R_1, R_2, etc., are the resistors in parallel (Ω). The total current in a circuit with parallel resistors is the sum of the current across each resistor.

See the diagram below for an example of resistors in parallel. Students may have more than two resistors in parallel; if so, be sure that they are in parallel. The worked example on page 623 of the textbook gives an example of three resistors in parallel drawn in three different ways.

Sample Diagram: Two Resistors in Parallel



Analytical Questions

1. A lightning strike lasts approximately 1.8 ms and transfers 10^{20} electrons from the cloud to the ground. What is the average electric current in the lightning? Is the electric current positive or negative? What does the sign of the current tell us?

   The average current is –8.9 kA. Since we know that electrons carry a negative charge from the cloud to the ground, the direction of positive current flow is from the ground to the sky, and the direction of negative current flow is from the cloud to the ground. Use $I = \frac{\Delta Q}{\Delta t} = \frac{-16.0\ C}{1.8 \bullet 10^{-3}_{s}} = -8.9 \bullet 10^{3}\ A = -8.9$ kA. Note that $\delta Q = ne = 10^{2}(-1.6 \bullet 10^{-19} C) = -16.0$ C. This comes from the number of electrons multiplied by the charge of a single electron.

2. The current through a 15 Ω resistor is 0.040 A. What is the voltage drop across the resistor?

   The voltage is 0.60 V. Use $V = IR = (0.040\ A)(15\ \Omega) = 0.60$ V

3. A circuit is arranged with three resistors of 2.0 Ω, 5.0 Ω, and 12 Ω connected in series. What is the equivalent resistance across the circuit?

   The equivalent resistance is 17 Ω. Use $R_{eq} = R_1 + R_2 + R_3 = 2.0\ \Omega + 5.0\ \Omega + 12\ \Omega = 17\ \Omega$.

4. If the three resistors from question 3 are connected in parallel, what is the equivalent resistance across the circuit? How does this compare to the value you calculated in question 3?

   The equivalent resistance is 1.3 Ω. Use $\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}} = \frac{1}{\frac{1}{2.0\ \Omega}+\frac{1}{5.0\ \Omega}+\frac{1}{12\ \Omega}} = 1.3\ \Omega$.

5. What is the voltage drop across the three resistors from questions 3 and 4 if they are in series with 0.72 A of current running through the entire circuit? What is the voltage drop if they are in parallel with 0.72 A of current running through the entire circuit?

   In series, the voltage is 12 V, and in parallel, the voltage is 0.94 V. This makes sense because the total voltage drop across resistors in parallel should be less than that of resistors in series. This is because, with the resistors in parallel, the current has more paths it can travel down, requiring less electric potential. For series, use $V = IR_{eq} = (0.72\ A)(17\ \Omega) = 12$ V. For parallel, use $V = IR_{eq} = (0.72\ A)(1.3\ \Omega) = 0.94$ V.

6. The voltage supplied by household sockets is typically 120 V. If you have a 40 W light bulb, what is the current that flows through the light bulb?

   The current flow through the light bulb is 0.33 A with 360 Ω. Use $P = IV \rightarrow I = \frac{P}{V} = \frac{40\ W}{120\ W} = 0.33$ A.

Activities and Labs

Complete the following:

- Activity: Circuit Bugs
- Lab: Ohm's Law

Activity: Circuit Bugs

For this activity, you will be creating your own circuit bug! First, you will connect the circuit in parallel, and then you will connect the circuit in series.

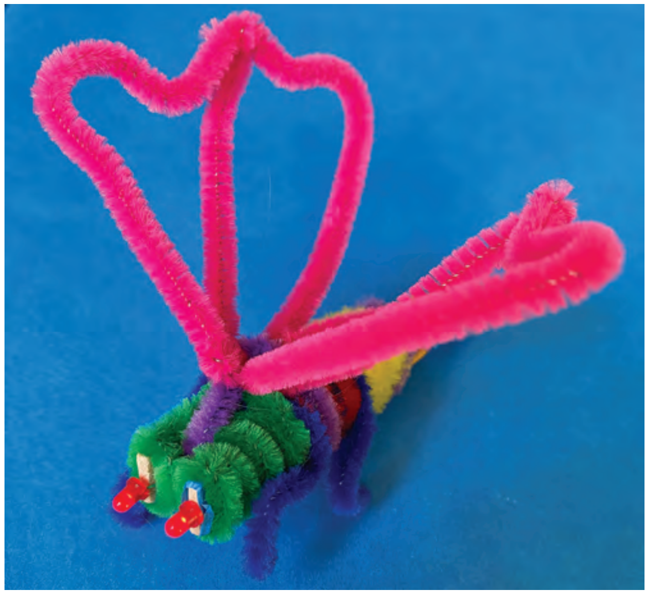


Figure 1: Circuit bug

Note: If you choose to do Lab 20: Diodes for your option in lesson 25, you will need to use the LEDs again, so your circuit bug will not be a permanent creation (unless you put it back together at the end of unit 7). If you choose not to do Lab 20, you may keep your circuit bug assembled.

Safety note: Use care when handling the stripped wires as the ends will be sharp.

Materials from the Lab Kit

- He-Ne laser/LED light
- clothespin
- pliers, needle-nose
- wire, enameled
- 2 light-emitting diodes (LEDs)
- pipe cleaners

Additional Materials

- masking tape
- scissors (or wire strippers)
- craft supplies

Procedure

1. Using the wire-cutting portion of your pliers, cut four lengths of wire approximately 1.5 centimeters longer than the length of the clothespin. Put the remaining wire back into your lab kit.
2. Use wire strippers or carefully use your scissors to cut through just the plastic around the wire by twirling the wire in circles between partially closed scissor blades. You want this cut to be at least a half centimeter from the end of the wire. When you have cut all the way through the plastic, you can pull the end plastic piece off the wire to leave a half centimeter of wire exposed. This is called stripping the wire. Do this to all eight wire ends.

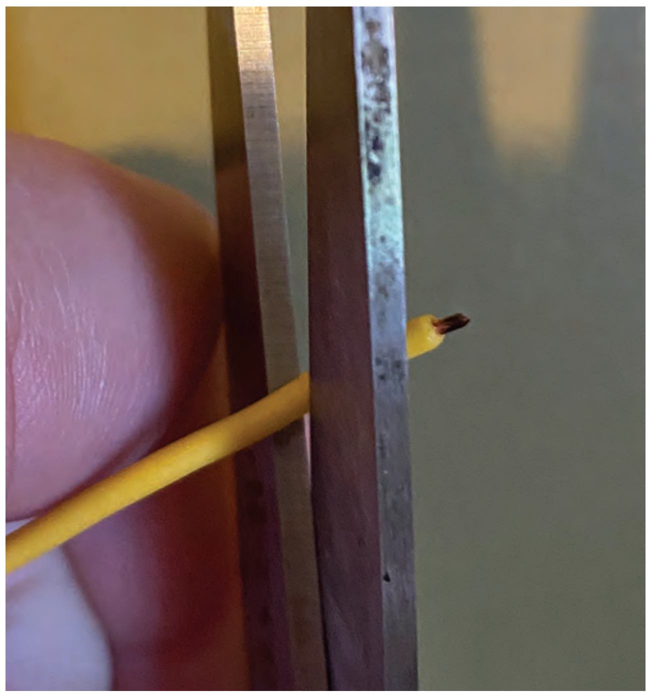


Figure 2: Stripping wire with scissors

3. Carefully remove two batteries from the laser pointer and tape them together in a stack, being careful to leave the top and the bottom fully exposed.

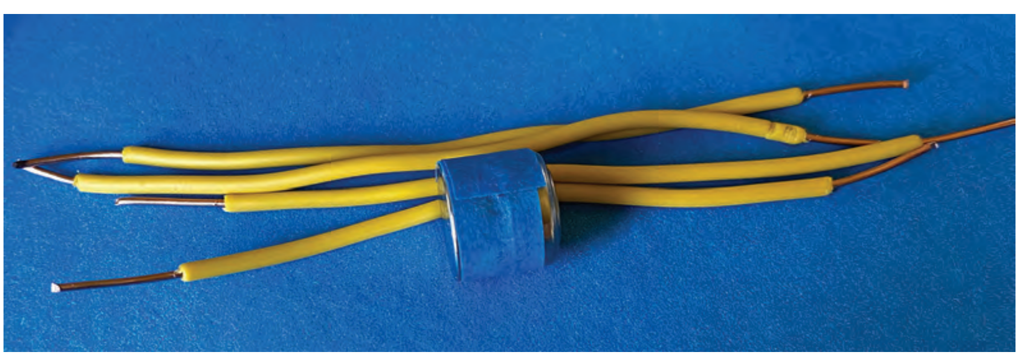


Figure 3: Batteries taped together and the coated wire lengths with stripped ends

4. Test your LEDs with the batteries to confirm that the long wire of the LED is the positive pin (anode) and the short wire is the negative pin (cathode). To do this, place the long wire on the flat positive side of the battery stack and the short wire on the negative side of the battery stack. The LEDs should light up.

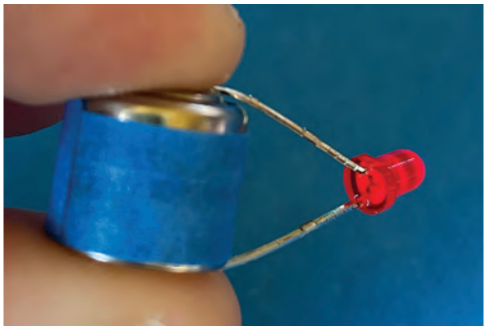


Figure 4: Testing an LED

5. Using the pliers, bend the wire legs of the LEDs. This will make attaching the other wire easier.

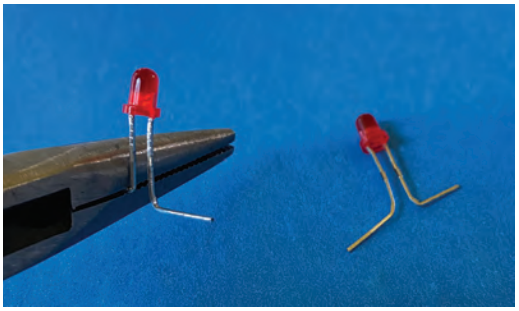


Figure 5: Bending LED legs

6. Using the pliers, twist the exposed copper wire around each LED leg. To start, create a small bend in the wire that can hook around the LED leg. Pinch this tightly onto the LED leg with the pliers, and twist the wire with your other hand. You want as tight a twist as you can get to ensure a good connection. Each LED leg will have its own length of wire connected to it.

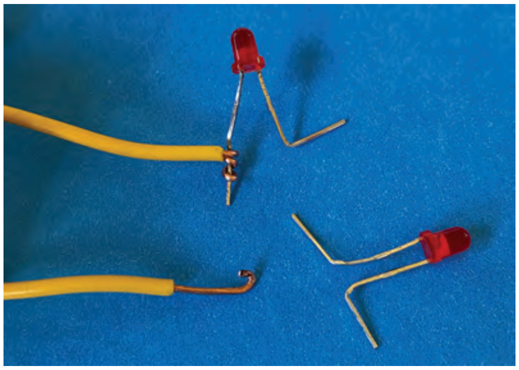


Figure 6: Small hook and attached wire

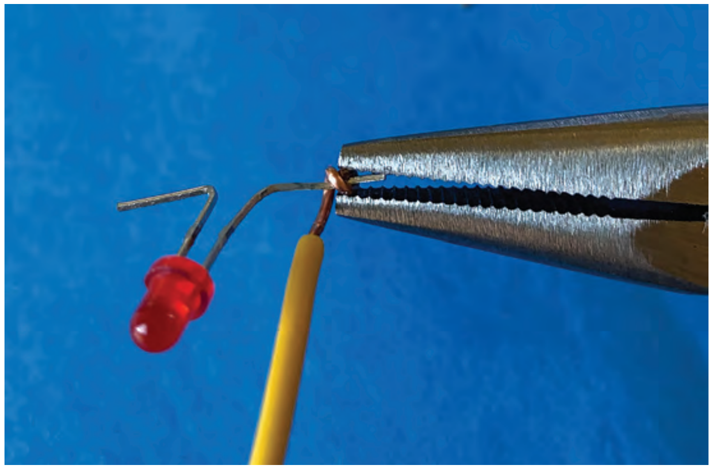


Figure 7: Pinching the hook around the LED leg and twisting

7. Retest that the LED lights up and make note of which wire connects to the negative side of the battery and which connects to the positive side of the battery. If your LED does not light up, switch battery sides with the wires. If it still does not light up, try to twist the LED wire connection tighter.

Figure 8: Retesting the LED with wires attached

8. Tape the LEDs and attach wires to the open end of the clothespin, as shown in figure 9.

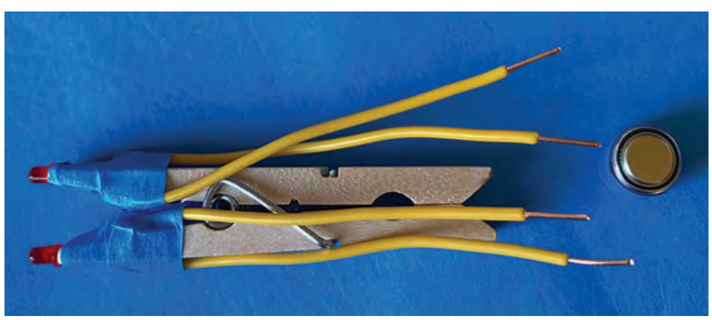


Figure 9: LEDs and wires taped to the clothes pin

Connecting the Circuit in Parallel

1. Using the pliers, wrap the negative wire from each LED together. Do the same for the positive wires. Make the twists as tight as possible for a good connection.

Figure 10: Positive and negative wires twisted together

2. Test your connections with the battery stack. Both LEDs should light up. If they do not, check that your wires are in contact with the correct side of the battery. If they still do not light up, check to make sure your connections are twisted tight enough.
3. Decorate your bug with the pipe cleaners. Leave room for the battery stack to be taped between the wires. You can make any type of creature you wish with the pipe cleaners, though the bug is the easiest. If you have extra pipe cleaners or other craft materials at home, feel free to use them.

Figure 11: Decorated bug

4. Connect the wires to the battery stack and tape them together to keep the eyes of your bug lit.
5. Take a photo of your bug, and observe the brightness of the two LED lights. Write down your observations.

Connecting the Circuit in Series

1. Remove the tape holding the battery in place.
2. Untwist the negative wires and the positive wires using your pliers.
3. To connect the circuit in series, use the pliers to twist the positive wire from one LED with the negative wire from the other LED.
4. Connect the untwisted negative wire to the negative side of the battery stack, and connect the untwisted positive wire to the positive side of the battery stack. You may notice the LEDs are very dim, or they may not be lit at all.
5. Remove a third battery from the laser pointer and add it to your battery stack.

6. Connect the untwisted negative wire to the negative side of the battery stack, and connect the untwisted positive wire to the positive side of the battery stack.
7. Take a photo of your bug, and observe the brightness of the two LED lights. Write down your observations.

Follow-Up Questions

1. What did you observe about the brightness of the LEDs when the bug was connected in parallel?

   Both lights should be of equal brightness and fully lit when the circuit bug is connected in parallel.

2. What did you observe about the brightness of the LEDs with two batteries when the bug was connected in series?

   When the circuit bug is connected in series with two batteries, there is likely not enough voltage to power the LEDs, so the student would observe that the LEDs do not light up.

   A photo of the circuit bug connected in parallel, and a photo of the circuit bug connected in series should be submitted.

3. What did you observe about the brightness of the LEDs with three batteries when the bug was connected in series?

   When the circuit bug is connected in series with three batteries, the students will likely observe that the LEDs are of equal brightness and fully lit.

4. Why was it necessary to add a third battery to the circuit when the LEDs were in series to get the LEDs to light up?

   It was necessary to add a third battery to the circuit when the LEDs were in series because there is only one circuit and current flow used to power both LEDs, so this requires more voltage. Adding another battery increases the voltage. When the circuit bug is set up in parallel, each LED has its own circuit and the voltage for each LED is the same and lower than that of two LEDs.

5. If you were setting up a string of lights to decorate your room, would you want the lights to be in series or parallel? What are the advantages and disadvantages of each setup?

   Students may argue for either series or parallel because there are pros and cons to both setups. In parallel, it requires less voltage, but it does require more wire because each light bulb must be its own circuit with its own wires. An advantage of connecting the lights in series is that it requires less wiring. If a single light goes out when the lights are in parallel, the rest will stay lit. If a single light goes out when the lights are in series, all the bulbs will go out.

For this lab, submit the following to your teacher:

- A photo of your circuit bug connected in parallel
- A photo of your circuit bug connected in series
- Answers to all questions

Lab: Ohm's Law

Complete Lab 17: Ohm's Law, which is found in the *Physics Lab Manual* that came with your lab kit.

Tip: You will need values from lab 15 that you completed in lesson 22. Also pay close attention to where the resistors are in parallel and where they are in series.

For this lab, submit the following to your teacher:

- Photos of your setup
- Your completed data tables
- Answers to the lab questions
- All the work you did for your calculations

Solutions are found in the Answer Key that came with your lab kit.

Further Study

If you are interested in further exploring the topics and skills in this lesson, you can choose to complete the textbook Chapter Review and Test Prep (odd-numbered problems). The solutions are available online via OpenStax, under Student Resources. This activity is optional.

SHARE YOUR WORK

When you have completed your work, share it with your teacher. Remember to check with your teacher at the beginning of each lesson to make sure you understand what you are required to do.

Below is a list of assignments in this lesson, which you can use to organize your work submission:

- Inquiry Activity: Circuit Breakers
- Defining Key Equation Variables
- Conceptual questions
- Analytical questions
- Activity: Circuit Bugs
- Lab: Ohm's Law

If you have any questions about the lesson content, assignments, or how to share your work, contact your teacher.

Appendix

Materials List

Materials Included in the Lab Kit

ball, bouncy

ball, ping-pong

battery, 9 volt

battery connector

board, support

card holder

cards, white

clothespins (2)

compass

cord, nylon

cord, white

cotton swabs (3)

cover for cup, blue foam

cylinder, graduated, 100 ml

diffraction grating (525 lines/mm)

electrolytic capacitors, 100 µf (3)

electronic breadboard

Hall's carts (2)

He-Ne laser/LED light

jumper wires

lens, concave

lens, convex, 50 mm

lens, convex, 150 mm

light-emitting diodes (LED)

magnets (2)

marble

mass set, slotted, 250 g

mirror/lens holder

multimeter

paper, graph (within the manual)

paper clip, large

pencil, wide diameter

pipe cleaners (5)

pliers, needle-nose

protractor

resistors: 2.2, 4.7, and 10.0 kΩ

rubber stopper

ruler

spring scale

spring toy

stopwatch

straws, drinking (plastic)

string, 20 ft

tape measure, metric

thermometer

thumbtacks (4)

tube, clear plastic with scale, 20 cm

tube, clear plastic without scale, 15 cm (2)

tube, small plastic

tuning fork, 1,024 Hertz (cycles/s)

washers

wire, bare 18 gauge, 12 cm

wire, enameled, 100 cm

Materials Not Included in the Lab Kit

balloon

balls of equal size (3)

bathroom scale

battery (AA, C, or D)

bicycle or ball

board

board, 1″ × 6″ × 3′

books

building materials, assorted

candle

canvas or paper

cardboard box

cardboard, heavy corrugated

coins, assorted (100)

colored paper, glitter, or very small beads

colored pencil

craft supplies, assorted

dish soap

drill

duct tape

eggs, raw

eraser

glass of water

hair dryer or fan

household items, assorted

ice cubes

insulated cup

knife or razor blade

marker

matches or lighter

newspaper, cardboard, or protective plastic sheet

notebook

paint, acrylic paper

paper towels

pen

pencil

plastic or paper bowls

plastic bottles

plastic or paper cups

polarized sunglasses (1 or 2 pairs)

pot

reusable plastic bag or bowl

sand or soil

scissors

tape, cellophane

tape, masking

teaspoon

textbook

tongs

tripod, art easel, or ladder

tub filled with water

ziplock bags (2)

Materials Needed for Each Lesson

(Note: Students might not complete every activity.)

LESSON	ACTIVITY/LAB	MATERIALS IN LAB KIT	ADDITIONAL MATERIALS NEEDED
1B	Activity: Significant Digits of Lab Measurement Tools	graduated cylinder ruler spring scale protractor thermometer stopwatch tape measure	
	Lab: Scientific Analysis	ball, bouncy ball, ping-pong paper, graph tape measure	
2	Lab: Graphing Motion	ball, bouncy stopwatch tape measure paper, graph	board books tape, masking pencil
3	Lab: Measuring Acceleration on a Slope	stopwatch tape measure	bicycle or ball
4	Inquiry Activity: The Normal Force		bathroom scale textbook
	Lab: Newton's Second Law	cord, white Hall's cart paper clip, large washers	book countertop
5	Project: Egg Drop Experiment	stopwatch tape measure	building materials eggs, raw notebook pen
6	Inquiry Activity: Juggling		3 balls of equal size
	Activity: Vector Addition—Graphical and Analytical Methods	ruler protractor paper, graph	pencil eraser
	Activity: Pendulum Art	string	scissors plastic bottles, small plastic cups paint, acrylic canvas or paper newspaper, cardboard, or protective plastic sheet drill tripod, art easel, or ladder

LESSON	ACTIVITY/LAB	MATERIALS IN LAB KIT	ADDITIONAL MATERIALS NEEDED
7	Inquiry Activity: Tornado in a Bottle		2 bottles (such as plastic soda bottles) candle matches or lighter duct tape dish soap water colored paper, glitter, or very small beads
	Lab: Centripetal Force	cord, nylon mass set, slotted, 250 g rubber stopper stopwatch tape measure tube, small plastic	pen
8	Lab Option A: Friction	spring scale support board washers	colored pencil two surfaces to test friction
	Lab Option B: Projectile Motion	marble stopwatch tape measure tube, clear plastic without scale ruler	book nickel or quarter pennies (2) tape, masking teaspoon
	Lab Option C: A Pendulum	support board mass set, slotted, 250 g stopwatch string tape measure	books
10	Inquiry Activity: Impulse and Momentum	cotton swabs (2) straws, plastic (2) tape measure	marker scissors tape, masking
	Lab: Hand Movement and Impulse	ball, bouncy	tub filled with water
	Lab: Ice Cubes and Elastic Collisions		ice cubes smooth surface
11	Project: Rube Goldberg Machine		assorted building materials

LESSON	ACTIVITY/LAB	MATERIALS IN LAB KIT	ADDITIONAL MATERIALS NEEDED
12	Inquiry Activity: The Energy of a Ball	ball, bouncy	
	Lab: Work and Power	mass set, slotted, 250 g stopwatch string tape measure tube, clear plastic without scale	stairs tape, masking
	Activity: Wind Turbines	protractor ruler 5 g slotted mass thumbtack pipe cleaner washers (2) pliers, needle-nose back cover of lab manual lab kit box pencil, wide diameter stopwatch string	scissors tape hair dryer or fan
13	Inquiry Activity: Heat Transfer	thermometer	assorted household items
	Lab: Specific Heat Capacity	cover for cup, blue foam thermometer 5–7 washers 3 20 g slotted masses graduated cylinder spring scale	insulated cup pot water tongs
	Lab: Latent Heat of Fusion	cover for cup, blue foam thermometer graduated cylinder	insulated cup pot ice cubes water
15	Lab: Mechanical Advantage of a Simple Machine	Hall's cart spring scale string tape measure	board, 1" × 6" × 3' books tape, masking
	Lab: Energy	Hall's cart spring scale stopwatch tape measure washers	board, 1" × 6" × 3' books
	Lab: Conservation of Energy and Momentum	ball, bouncy ball, ping-pong tape measure	tape, masking

LESSON	ACTIVITY/LAB	MATERIALS IN LAB KIT	ADDITIONAL MATERIALS NEEDED
16	Inquiry Activity: Slinky Waves	spring toy	
17	Inquiry Activity: The Cup-and-String Telephone	string	plastic or paper cups scissors
	Lab: The Speed of Sound in Air	graduated cylinder tube, clear plastic with scale tube, clear plastic without scale tuning fork	paper towels tape, masking
18	Inquiry Activity: Polarized Light		1 or 2 pairs of polarized sunglasses
	Lab: Wavelength of Light	card holder diffraction grating He-Ne laser/LED light mirror/lens holder	box, cardboard tape, masking
19	Inquiry Activity: Focusing the Sun's Energy	convex lens concave lens ruler	glass of water paper
	Lab: Lenses	card holder card, white He-Ne laser/LED light lens, concave lens, convex, 50 mm lens, convex, 150 mm mirror/lens holder tape measure	tape, masking
22	Inquiry Activity: What Can You Pick Up with a Balloon?		balloon household items
	Lab: An Electronic Breadboard	electronic breadboard multimeter pliers, needle-nose resistors: 2.2 kΩ, 4.7 kΩ, and 10.0 kΩ	
	Lab: Capacitors	battery connector batter, 9 volt electrolytic capacitors, 100 μf electronic breadboard jumper wires light-emitting diode (LED) resistor, 10.0 kΩ stopwatch	

LESSON	ACTIVITY/LAB	MATERIALS IN LAB KIT	ADDITIONAL MATERIALS NEEDED
23	Activity: Circuit Bugs	He-Ne laser/LED light clothespin pliers, needle-nose wire, enameled 2 light-emitting diodes (LEDs) pipe cleaners	tape, masking scissors (or wire strippers) craft supplies
	Lab Ohm's Law	battery connector battery, 9 volt electronic breadboard jumper wires multimeter pliers, needle-nose	
24	Inquiry Activity: Finding Iron—Sand or Soil	magnet	2 plastic or paper bowls or 2 ziplock bags sand or soil
	Activity: Wait, Which Way Is North?	magnet compass protractor	paper
	Lab: Magnetic Fields	compass magnets (2) ruler	paper tape, masking
25	Lab: Electric Motors	magnet thumbtacks (4) tube, clear plastic without scale wire, bare wire, enameled	battery (AA, C, or D) cardboard, heavy corrugated knife or razor blade scissors tape, cellophane
	Lab: Diodes	Batter connector battery, 9 volt electronic breadboard jumper wires light-emitting diode (LED) resistor, 10.0 kΩ	
28	Lab: Radioactive Decay Coin Toss		100 coins reusable plastic bag or bowl paper pen or pencil