Student Edition

Inspire Physical Science

McGraw Hill

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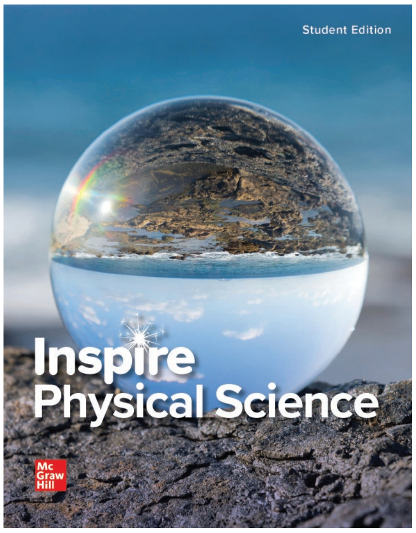

Phenomenon: Refraction and Reflection

Light bends when it travels through the crystal ball, showing an inverted image of the coast.

Fun Fact

The distance between the coast and the crystal ball determines the size of the image as well as whether or not the image is flipped.

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STEM

McGraw-Hill is committed to providing instructional materials in Science, Technology, Engineering, and Mathematics (STEM) that give all students a solid foundation, one that prepares them for college and careers in the 21st century.

Welcome to

Inspire Physical Science

Explore Our Phenomenal World

The Inspire High School Series brings phenomena to the forefront of learning to engage and inspire students to investigate key science concepts through their three-dimensional learning experience.

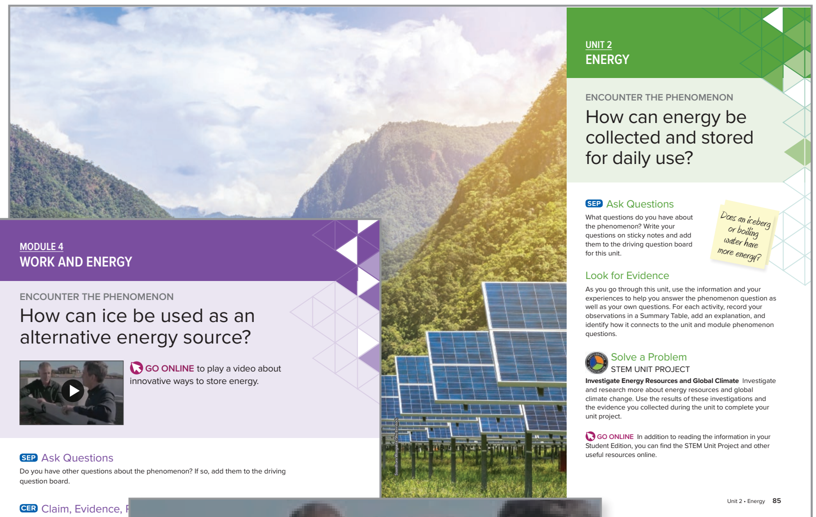
Start exploring now!

Inspire Curiosity • Inspire Investigation • Inspire Innovation

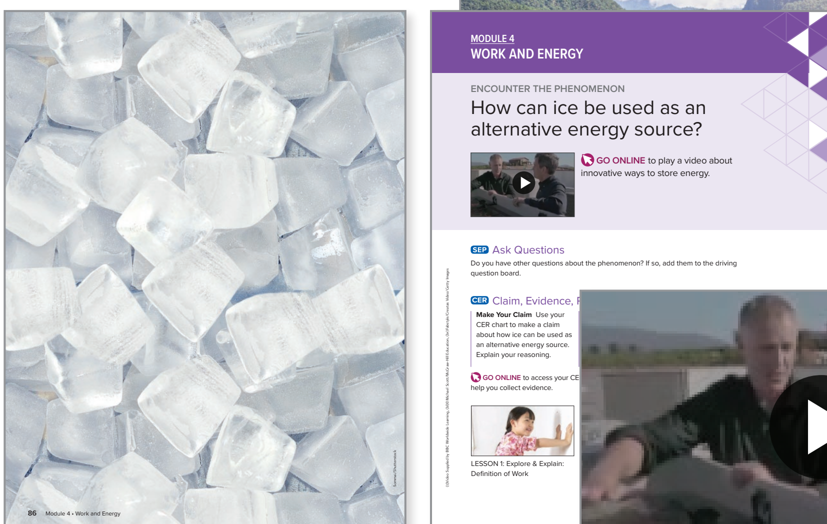
Owning Your Learning

1 Encounter the Phenomenon

Every day, you are surrounded by natural phenomena that makes you wonder.

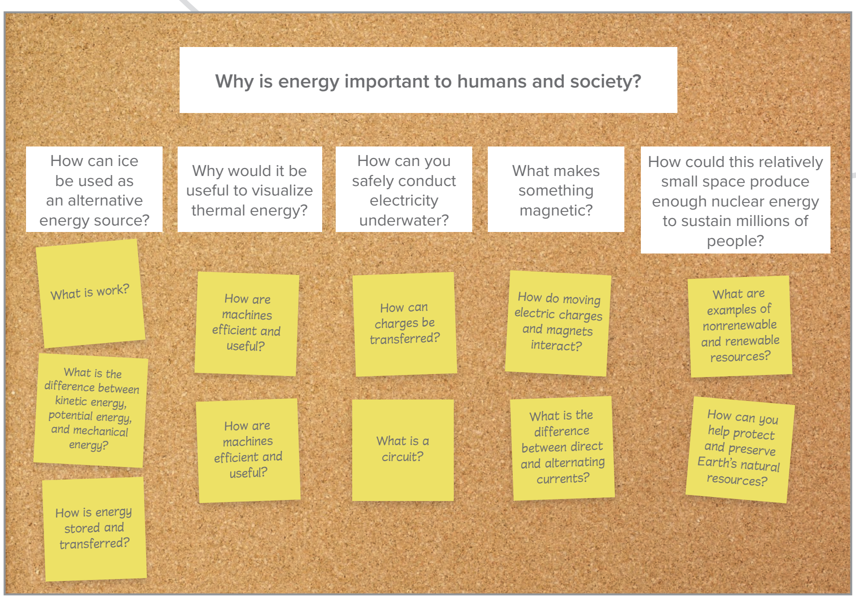


Unit Opener



Module Opener

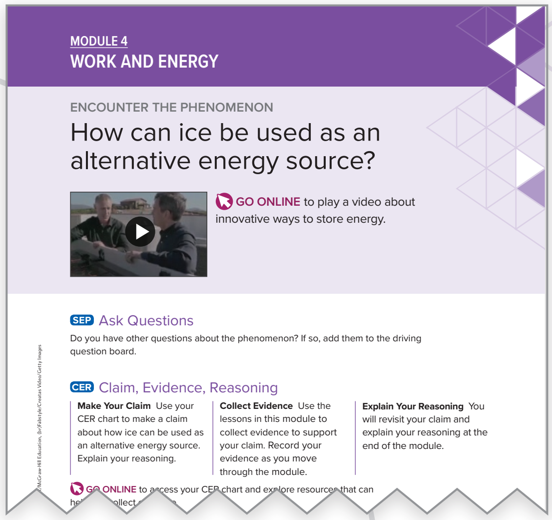
Phenomenon Video



2 Ask Questions

At the beginning of each unit and module, make a list of the questions you have about the phenomenon. Share your questions with your classmates.

(t)Video Supplied by BBC Worldwide Learning, (b)moi/amanaimagesRF/Getty Images



MODULE 4
WORK AND ENERGY

ENCOUNTER THE PHENOMENON

How can ice be used as an alternative energy source?

GO ONLINE to play a video about innovative ways to store energy.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about how ice can be used as an alternative energy source. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can

3 Claim, Evidence, Reasoning

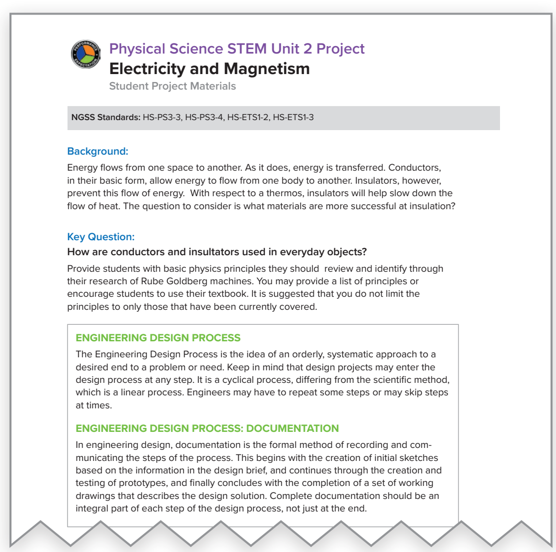
As you investigate each phenomenon, you will write your claim, gather evidence by performing labs and completing reading assignments and Applying Practices, and explain your reasoning to answer the unit and module phenomena.

SUMMARY TABLE

Activity Model	Observation Evidence	Explanation Reasoning	Connection to Phenom	Questions Answered	New Questions
Applying Practices: Modeling Changes in Energy	Energy within a system can change forms and be transferred between parts of the system.	The kinetic energy of the molecules in a cup of hot water can be transferred to ice cubes, which causes them to melt.	Unit: Electrical energy can be collected and stored in batteries. Module: Ice can be used as a heat sink to convert heat into mechanical energy.	How is energy stored and transferred?	What other types of energy can be transformed into usable forms?

4 Summarize Your Work

When you collect evidence, you can record your data in a summary table and use the data to collaborate with others to answer the questions you had.



Physical Science STEM Unit 2 Project
Electricity and Magnetism
Student Project Materials

NGSS Standards: HS-PS3-3, HS-PS3-4, HS-ETS1-2, HS-ETS1-3

Background:

Energy flows from one space to another. As it does, energy is transferred. Conductors, in their basic form, allow energy to flow from one body to another. Insulators, however, prevent this flow of energy. With respect to a thermos, insulators will help slow down the flow of heat. The question to consider is what materials are more successful at insulation?

Key Question:

How are conductors and insultators used in everyday objects?

Provide students with basic physics principles they should review and identify through their research of Rube Goldberg machines. You may provide a list of principles or encourage students to use their textbook. It is suggested that you do not limit the principles to only those that have been currently covered.

ENGINEERING DESIGN PROCESS

The Engineering Design Process is the idea of an orderly, systematic approach to a desired end to a problem or need. Keep in mind that design projects may enter the design process at any step. It is a cyclical process, differing from the scientific method, which is a linear process. Engineers may have to repeat some steps or may skip steps at times.

ENGINEERING DESIGN PROCESS: DOCUMENTATION

In engineering design, documentation is the formal method of recording and communicating the steps of the process. This begins with the creation of initial sketches based on the information in the design brief, and continues through the creation and testing of prototypes, and finally concludes with the completion of a set of working drawings that describes the design solution. Complete documentation should be an integral part of each step of the design process, not just at the end.

5 Apply Your Evidence and Reasoning

At the end of the unit, modules, and lessons, you can use all of the data you collected to help complete your STEM Unit Project.

KEY PARTNERS

Smithsonian

Smithsonian

Following the mission of its founder James Smithson for "an establishment for the increase and diffusion of knowledge," the Smithsonian Institution today is the world's largest museum, education, and research complex. To further their vision of shaping the future, a wealth of Smithsonian online resources are integrated within this program.

SPONGELAB
A GLOBAL SCIENCE COMMUNITY

SpongeLab Interactives

SpongeLab Interactives is a learning technology company that inspires learning and engagement by creating gamified environments that encourage students to interact with digital learning experiences.

Students participate in inquiry activities and problem-solving to explore a variety of topics using games, interactives, and video while teachers take advantage of formative, summative, or performance-based assessment information that is gathered through the learning management systems.

PhET
INTERACTIVE SIMULATIONS
University of Colorado Boulder

PhET Interactive Simulations

The PhET Interactive Simulations project at the University of Colorado Boulder provides teacher and students with interactive science and math simulations. Based on extensive education research, PhET sims engage students through an intuitive, game-like environment where students learn through exploration and discovery.

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UNIT 1

MOTION AND FORCES

ENCOUNTER THE PHENOMENON

Why did the person jump backward over the bar?

INTRODUCTION TO PHYSICAL SCIENCE

This module introduces the nature of science, what physical science is, and provides tools for the study of science.

MODULE 1: THE NATURE OF SCIENCE

MODULE 2: MOTION

MODULE 3: FORCES AND NEWTON'S LAWS

UNIT 2

ENERGY

ENCOUNTER THE PHENOMENON

How can energy be collected and stored for daily use?

UNIT 3

WAVES

ENCOUNTER THE PHENOMENON

How do waves interact with our senses?

MODULE 9: INTRODUCTION TO WAVES

MODULE 10: SOUND

MODULE 11: ELECTROMAGNETIC WAVES

MODULE 12: LIGHT

MODULE 13: MIRRORS AND LENSES

UNIT 4

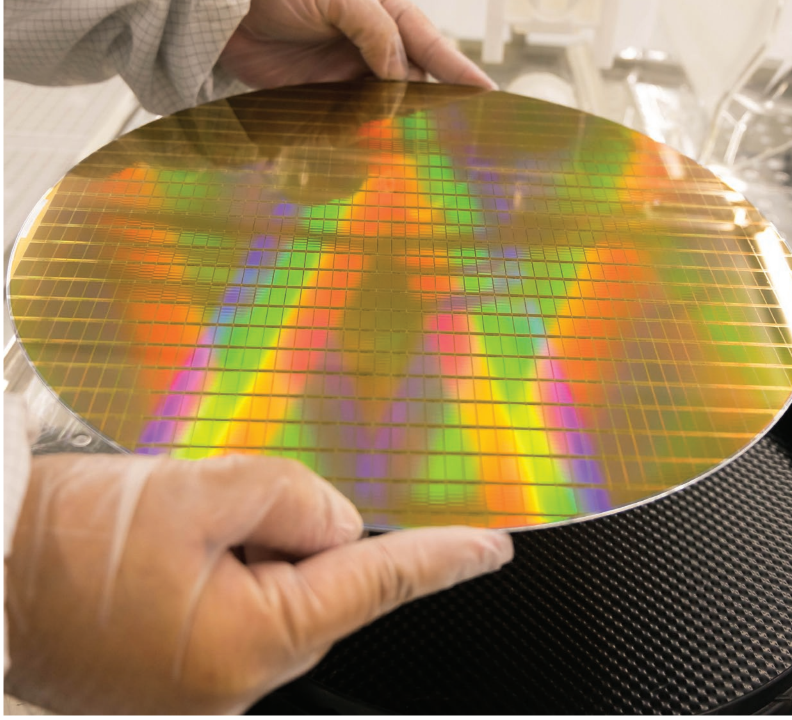
MATTER

ENCOUNTER THE PHENOMENON

Why can dry ice go directly from a solid to a gas?

UNIT 5
REACTIONS

Emil O/Shutterstock



UNIT 6

APPLICATIONS OF CHEMISTRY

ENCOUNTER THE PHENOMENON

How are advancements in chemistry related to technology?

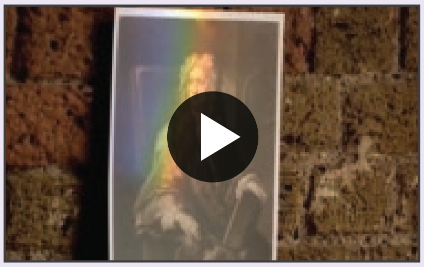

WeatherVideoHD.TV

MODULE 1

THE NATURE OF SCIENCE

ENCOUNTER THE PHENOMENON

How do we know how rainbows form?



GO ONLINE to play a video about the way Newton studied light.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim how rainbows form. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 1: Explore & Explain: What is science?

LESSON 4: Explore & Explain: Global Technological Needs

Smithsonian

Additional Resources

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LESSON 1
THE METHODS OF SCIENCE

FOCUS QUESTION

What are the steps of the methods of science?

What is science?

Science is not just a subject in school. It is a method for studying the natural world. After all, science comes from the Latin word *scientia*, which means "knowledge." Science is a process based on inquiry that helps develop explanations about events in nature.

Nature follows a set of rules. Many rules, such as those concerning how the human body works, are complex. Other rules, such as the fact that Earth rotates about once every 24 hours, are much simpler. Scientists, such as the one shown in **Figure 1,** ask questions and make observations to learn about the rules that govern the natural world.

Major categories of science

Science covers many different topics that can be classified according to three main categories: (1) Life science deals with living things. (2) Earth science investigates Earth and space. (3) Physical science studies matter and energy. Sometimes, though, a scientific study will overlap the categories. One scientist, for example, might study how to build better artificial limbs. Is this scientist studying energy and matter or how muscles operate? She is studying both life science and physical science.

Figure 1 This scientist is monitoring water quality from a solar-powered field laboratory.

Observe *In the photograph, what evidence do you see of the three main branches of science?*

Tdub303/E+/Getty Images

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Virtual Investigation: The Nature of Science
Carry out an investigation to determine how color affects heat absorption.

Laboratory: Relationships
Carry out an investigation to determine the patterns that exist between variables in an experiment.

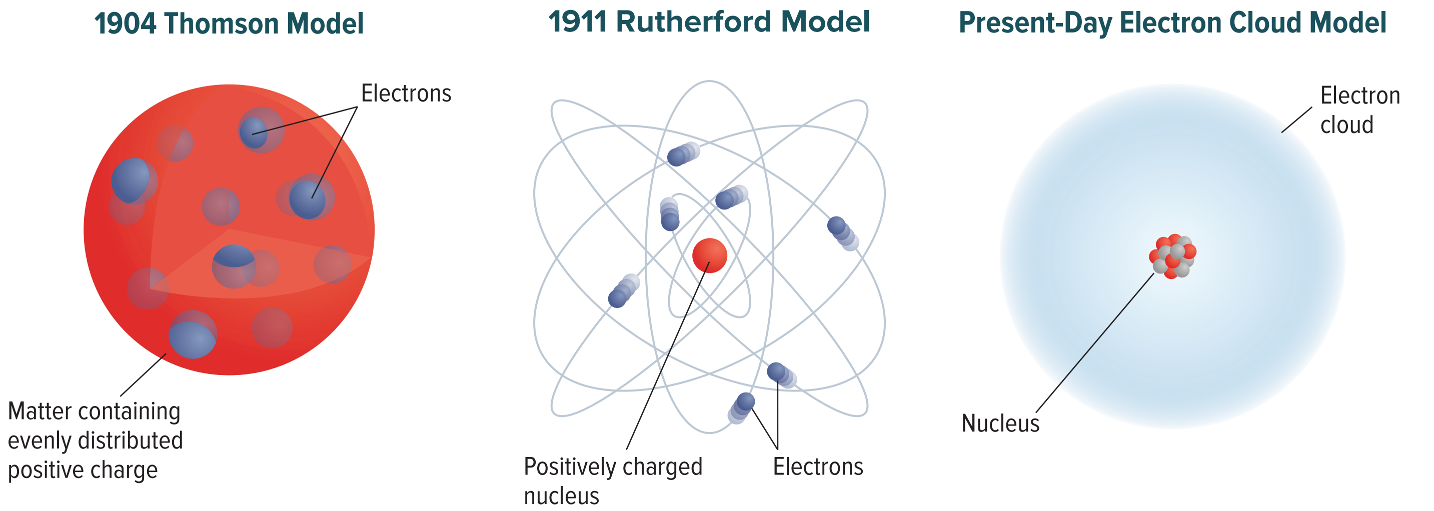


Figure 2 Our understanding of the atom has changed over time.

Science changes

Scientific explanations help us understand the natural world. Sometimes these explanations must be modified. As more is learned, earlier explanations might be found to be incomplete, or new technology might provide more accurate answers.

For example, scientists have been studying the atom for more than two centuries. Throughout this time, they have revised their thinking on what atoms might look like, how they interact, and even how they combine to form other substances.

In the early 1900s, British physicist J.J. Thomson created a model of the atom that consisted of electrons embedded in a ball of positive charge. Several years later, physicist Ernest Rutherford created a model of the atom based on new research. As shown in **Figure 2,** his model was different from Thomson's model. Instead of a solid ball, the atom consisted of a nucleus with electrons orbiting it like the planets orbit the Sun.

Later in the 20th century, scientists discovered the nucleus is not a solid ball but is made of protons and neutrons. This improved our understanding of the atom and its behavior. The present-day model of the atom is a nucleus made of protons and neutrons surrounded by an electron cloud. The electron cloud represents the space containing rapidly moving electrons.

The electron cloud model is the result of scientists pulling together evidence from many investigations. They came to an agreement that it is the best model for the information available at the time. Because it is the nature of science to be open to change, investigations into the model of the atom continue today.

Investigations

Scientists learn new information about the natural world by performing investigations. Some investigations involve simply observing something that occurs and recording the observations. Other investigations involve setting up experiments with a control to test the effect of one thing on another.

Modeling Sometimes an investigation involves building a model that resembles something, such as a model of a new space vehicle, and then testing the model to see how it acts. Other models represent processes or objects that cannot be seen with the unaided eye, such as the models of the atom. Often, a scientist will use information from several types of investigations when attempting to learn about the natural world.

Scientific Methods

Although scientists do not always follow a rigid set of steps, investigations often follow a general pattern. The pattern of investigation procedures is called the **scientific methods.** Six common steps found in the scientific methods are shown in **Figure 3.** A scientist might add new steps, repeat some steps many times, or skip steps altogether.

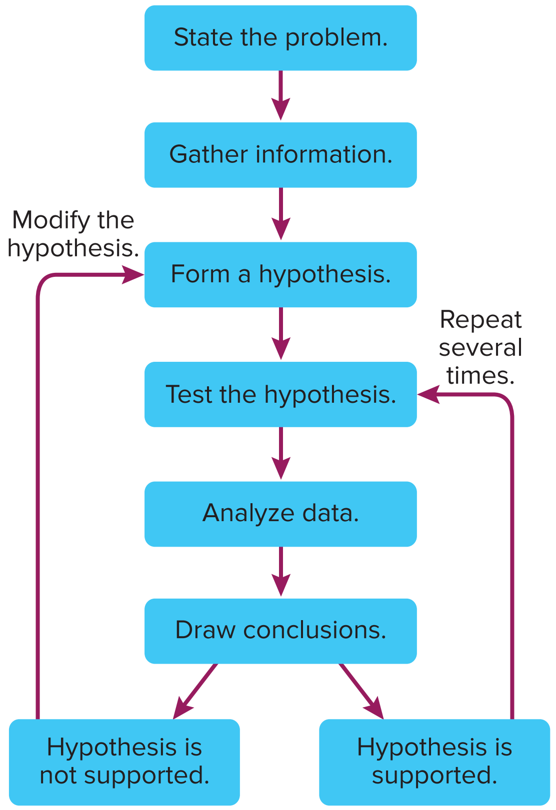


Figure 3 The series of procedures shown here is one way to use scientific methods to solve a problem.

State the problem

To begin the process, a scientist must state what he or she is going to investigate. Many investigations begin when someone observes an event in nature and wonders why or how it occurs. The question of "why" or "how" is the problem.

Scientists once posed questions about why objects fall to Earth, what causes day and night, and how to generate electricity for daily use. Many times, a statement of a problem arises when an investigation is complete and its results lead to new questions. For example, once scientists understood why we experience day and night, they wanted to know why Earth rotates.

Sometimes a new question is posed when an investigation runs into trouble. For example, some early work on guided missiles found the instruments in the nose cone did not always work properly. The original problem statement involved how to guide missiles during flight. The new statement involved how to protect the instruments in the nose cone.

Get It?

Identify What is the first step in a scientific investigation, and what form does it usually take?

Research and gather information

Before beginning an investigation, scientists research what is already known about the problem. They gather and examine observations and interpretations from reliable sources. This background helps scientists fine-tune their question and form a hypothesis.

Form a hypothesis

A **hypothesis** is a possible answer to a question or a possible solution to a problem based on what you know and what you observe. When trying to find a better material to protect the space shuttle, NASA scientists looked to other materials that were used in similar situations. Scientists knew that a ceramic coating had been found to solve the guided missile problem. They hypothesized that a ceramic material might work on the space shuttle also.

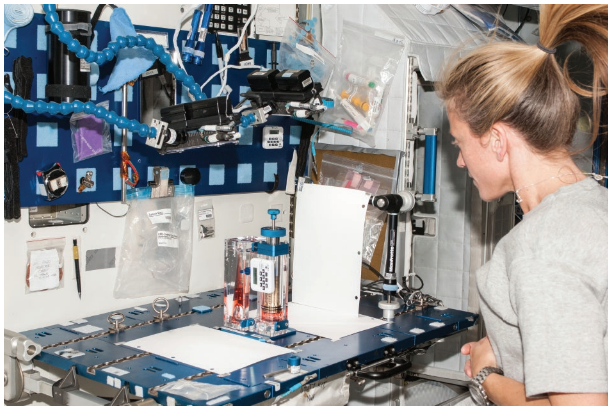


Figure 4 An astronaut aboard the *International Space Station* conducts an experiment session with the Capillary Flow Experiment (CFE). CFE observes the flow of fluid, in particular capillary phenomena, in microgravity.

Test a hypothesis

Some hypotheses can be tested by making observations. Others can be tested by building a model and relating it to real-life situations. One common way to test a hypothesis is to perform an experiment. An **experiment** tests the effect of one thing on another using a control.

Variables An experiment usually contains at least two variables. A **variable** is a quantity that can have more than a single value. **Table 1** summarizes the types of variables. For example, numerous experiments aboard space shuttles and the *International Space Station* (ISS) have studied the effects of microgravity on plants. Before these experiments could begin, scientists had to think of every factor that might affect plant growth. Each of these factors is a variable.

Independent and dependent variables In the microgravity experiment, plant growth is the **dependent variable** because its value changes according to the changes in the other variables. The variable that is changed to see how it will affect the dependent variable is called the **independent variable.** The microgravity is the independent variable. Scientists on the ISS are using microgravity as an independent variable in other experiments as well, as shown in **Figure 4.**

Constants To be sure they were testing to see how microgravity affects growth, mission specialists kept the other possible factors the same. A factor that does not change is called a **constant.** The microgravity experiments used the same soil and type of plant. Additionally, each plant was given the same amount of light and water and was kept at the same temperature. Type of soil, type of plant, amount of light, amount of water, and temperature were constants for this experiment.

Table 1 Types of Variables

Dependent Variable	changes according to the changes of the independent variable
Independent Variable	the variable that is changed to test the effect on the dependent variable
Constant	a factor that does not change when other variables change
Control	the standard by which the test results can be compared

Controls A **control** is the standard by which test results can be compared. After the mission specialists gathered their data on the plants grown in microgravity, they compared their results with the same types of plants grown on Earth's surface with the same constants. This comparison allowed them to analyze the data and form a conclusion about whether microgravity has an effect on plant growth.

Get It?
Identify What is the purpose of a control in an experiment?

Analyze the data

An important part of every investigation includes recording observations and organizing the test data into easy-to-read tables and graphs. Later in this module, you will study ways to display data. When you are making and recording observations, you should include all results, even unexpected ones. Many important discoveries have been made from unexpected results.

Scientific inferences are based on observations made using scientific methods. All possible scientific explanations must be considered. If the data are not organized in a logical manner, wrong conclusions can be drawn. When a scientist communicates and shares data, other scientists will examine that data, consider how it is analyzed, and compare it to the work of others. Scientists share their data through reports and conferences. In **Figure 5,** a scientist is presenting his data.

Draw conclusions

Based on the analysis of the data, the next step is to decide whether the hypothesis is supported. For the hypothesis to be considered valid and widely accepted, the experiment must result in the exact same data every time it is repeated. If the experiment does not support the hypothesis, the hypothesis must be reconsidered. Perhaps the hypothesis needs to be revised, or maybe the experiment's procedure needs to be refined.

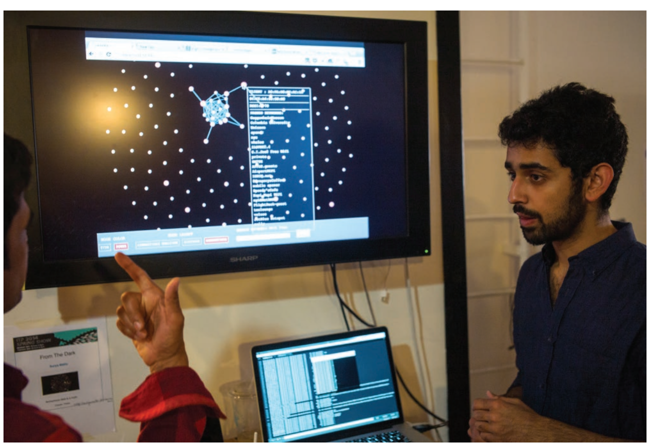


Figure 5 An exciting and important part of an investigation is sharing your ideas with others.

ACADEMIC VOCABULARY
Infer
to come to a logical conclusion based on observations and evidence
After observing a trail of ants in his kitchen, Joe inferred that he had spilled some sugar.

Figure 6 In order for medicine to be approved for use on humans, scientists have to run multiple trials to prove the results are objective.

Peer review

Before it is made public, science-based information is reviewed by scientists' peers—scientists who are in the same field of study. Peer review is a process by which the procedures and results of an experiment are evaluated by other scientists who are in the same field as those who are conducting similar research. Reviewing other scientists' work is a responsibility that many scientists have.

Being objective

Scientists also have a responsibility to minimize bias in their investigations. **Bias** occurs when a scientist's expectations change how the results are analyzed or conclusions are formed. Bias might cause a scientist to select a result from one trial over those from other trials. An example of bias would be presenting positive test results to promote a product and withholding unfavorable results.

Scientists can reduce bias by running as many trials as possible and by keeping accurate notes of each observation made. **Figure 6** shows a scientist who is researching a medication's effectiveness. One way to reduce bias in this case would be to conduct the experiment so that the researchers didn't know which group was the study group and which group was the control. This is called a blind experiment.

Valid experiments must also have data that are measurable. For example, a scientist performing a global warming study must base his or her data on accurate measures of global temperature. This allows others to compare the results to data they obtain from similar experiments. Most importantly, the experiment must be repeatable. Findings are supportable when other scientists around the world perform the same experiment and get the same results.

Get It?

Define What is bias in science?

Visualizing with Models

Sometimes scientists cannot see everything that they are testing. They might be observing something that is too large or small, takes too much time to see completely, or is hazardous. In these cases, scientists use models. A **model** represents an idea, event, or object to help people better understand it.

Models in history

Models have been used throughout history. Lord Kelvin, a scientist who lived in England in the 1800s, was famous for making models. To model his idea of how light moves through space, he put balls into a bowl of jelly and encouraged people to move the balls around with their hands. Recall the models of the atom in **Figure 2**. Scientists used models of atoms to represent their current understanding because of the atom's small size.

High-tech models

Scientific models don't always have to be something you can touch. Another type of model is a computer simulation, like the one shown in **Figure 7**. A computer simulation uses a computer to test a process or procedure and to collect data. Computer software is designed to safely and conveniently mimic the processes under study. Today, many scientists use computers to build models.

Computer simulations, such as the one shown in **Figure 7**, enable pilots to practice all aspects of flight without ever leaving the ground. In addition, the computer simulation can simulate harsh weather conditions or other in-flight challenges that pilots might face.

Figure 7 This is a computer simulation of an aircraft landing on a runway. The image on the screen in front of the pilots mimics what they would see if they were landing a real plane.

Identify *models in your classroom.*

Santofilme/iStock/Getty Images

Scientific Theories and Laws

A scientific **theory** is an explanation based on knowledge gained from many observations and investigations. It is not a guess. If scientists repeat an investigation and the results always support the hypothesis, the hypothesis can be called a theory. As new information becomes available, theories can be modified.

A **scientific law** is a statement about what happens in nature and that seems to be true all the time. Laws describe specific relationships under given conditions. They don't explain why or how something happens. Gravity is an example of a scientific law. The law of gravity states that any one mass will attract another mass.

A theory can be used to explain a law, but theories do not become laws. For example, many theories have been proposed to explain how the law of gravity works. Even so, there are few accepted theories in science and even fewer laws.

Figure 8 Science can't answer all questions, like questions about opinions and values. This piece of art might look very beautiful to one person but not to another.

Discuss *Can anyone prove that a piece of art is beautiful? Explain.*

The Limitations of Science

Science can help you explain many things, but science cannot explain or solve every question. It is scientists' job to develop hypotheses that can be tested and verified. Questions that cannot be tested and verified, such as those about opinions and values, are not scientific. You might take a survey to gather opinions about a piece of art, such as the painting in **Figure 8**, but it would not prove the opinions to be true or false.

Check Your Progress

Summary

- Scientists ask questions and perform investigations to learn more about the natural world.
- Scientists use scientific methods to test their hypotheses.
- Models help scientists visualize concepts.
- A theory is a possible explanation for observations, while a scientific law describes a pattern but does not explain why things happen.

Demonstrate Understanding

1. **Define** Summarize the steps you might use to carry out an investigation using scientific methods.
2. **Explain** what a law is, what a theory is, and why a theory cannot become a law.

Explain Your Thinking

3. **Analyze** What is the dependent variable in an experiment that shows how the volume of a gas changes with changes in temperature?
4. **MATH Connection** An experiment to determine how many breaths a squirrel takes per minute yields this data: minute 1: 65 breaths; minute 2: 73 breaths; minute 3: 67 breaths; minute 4: 71 breaths; minute 5: 62 breaths. Calculate the average number of breaths per minute.

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

LESSON 2

STANDARDS OF MEASUREMENT

FOCUS QUESTION

Which units are used when measuring length, volume, mass, electricity, and temperature?

Units and Standards

Suppose you and a friend want to find out whether a desk will fit through a doorway. You have no ruler, so you decide to use your hands as measuring tools. Using the width of his hands, your friend measures the doorway and says it is eight hands wide. Using the width of your hands, you measure the desk and find it is $7\frac{3}{4}$ hands wide. Will the desk fit through the doorway? You can't be sure. Even though you both used hands to measure, you didn't check to see whether your hands were the same width as your friend's hands. In other words, because you didn't use a measurement standard, you can't compare the measurements. A **standard** is an exact quantity that people agree to use to compare measurements.

Measurement Systems

Suppose the label on a ball of string says that the length of the string is 1. Is the length 1 meter (m), 1 foot (ft), or 1 centimeter (cm)? For a measurement to make sense, it must include a number and a unit, as shown in **Figure 9.**

Your family might buy lumber by the foot, milk by the gallon, and potatoes by the pound. These units are part of the U.S. customary system of measurement, which comes from units used in the former British Empire. Most countries other than the United States now use the metric system, which is based on multiples of ten.

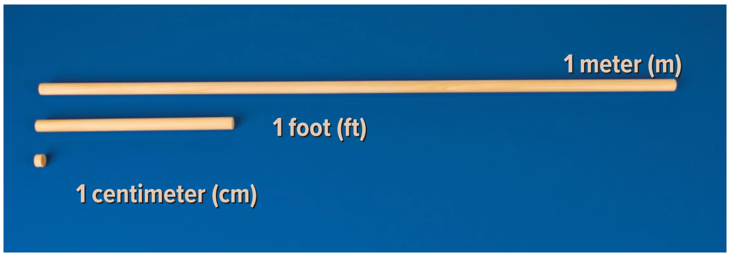


Figure 9 For data collected in an investigation or experiment, you need appropriate and consistent standards of measurement. It is important that you always use a number and a unit when describing length.

3D THINKING · DCI Disciplinary Core Ideas · CCC Crosscutting Concepts · SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Determine the Density of a Pencil

Carry out an investigation to determine the density of a pencil based on its physical properties.

CCC **Identify Crosscutting Concepts**

Create a table of the crosscutting concepts and fill in examples you find as you read.

International System of Units

In 1960, an improved version of the metric system was devised. Known as the International System of Units, this system is often abbreviated **SI,** from the French *Le Systeme Internationale d'Unites*. All SI standards are universally accepted and understood by scientists throughout the world.

All of the units in SI are based on fundamental physical constants that are the same throughout the universe. For example, the standard meter equals the exact distance that light travels through a vacuum in 1/299,792,458 seconds.

Table 2 SI Base Units

Quantity Measured	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Intensity of light	candela	cd

A base unit in SI is one that is based on a universal physical constant. There are seven base units in SI. The names and symbols for the seven base units are shown in **Table 2.** All other SI units are derived from these seven units. The base unit of mass, the kilogram, was recently redefined to be based on a constant known as the Planck constant.

SI prefixes

The SI system is easy to use because it is based on multiples of ten. Prefixes are used with the names of the units to indicate what multiple of ten should be used with the units. For example, the prefix *kilo-* means "1000," which means that one kilometer equals 1000 meters. Likewise, one kilogram equals 1000 grams. Because *deci-* means "one-tenth," one decimeter equals one-tenth of a meter. A decigram equals one-tenth of a gram. The most frequently used prefixes are shown in **Table 3.**

Table 3 Common SI Prefixes

Prefix	Symbol	Multiplying Factor
Kilo-	k	1,000
Deci-	d	0.1
Centi-	c	0.01
Milli-	m	0.001
Micro-	µ	0.000 001
Nano-	n	0.000 000 001

Get It?

Calculate How many meters is 1 km? How many grams is 1 dg?

Converting between SI units

Sometimes quantities are measured using different units. A conversion factor is a ratio that is equal to 1. It is used to change one unit to another. For example, there are 1000 mL in 1 L, so 1000 mL = 1 L. If both sides in this equation are divided by 1 L, the equation becomes:

$$\frac{1000 \text{ mL}}{1 \text{ L}} = 1$$

To convert units, multiply by the appropriate conversion factor. For example, to convert 1.255 L to mL, multiply 1.255 L by a conversion factor. Use the conversion factor with new units (mL) in the numerator and the old units (L) in the denominator.

$$1.255 \text{ L} \times \frac{1000 \text{ mL}}{1 \text{ L}} = 1255 \text{ mL}$$

EXAMPLE Problem 1

CONVERT UNITS How long, in centimeters, is a 3075-mm rope?

Identify the Unknown:	**rope length in cm**
List the Knowns:	**rope length in mm = 3075 mm** 1 m = 100 cm = 1000 mm
Set Up the Problem:	**length in cm = length in mm** $\times \frac{100 \text{ cm}}{1000 \text{ mm}}$
Solve the Problem:	**length in cm = 3075 mm** $\times \frac{100 \text{ cm}}{1000 \text{ mm}}$ = **307.5 cm**
Check the Answer:	Millimeters are smaller than centimeters, so make sure your answer in mm is greater than the measurement in cm. Because SI is based on tens, the answer in mm should differ from the length in cm by a factor of ten.

PRACTICE Problems

ADDITIONAL PRACTICE

5. If your pencil is 11 cm long, how long is it in millimeters?

6. CHALLENGE Some birds migrate 20,000 miles. If 1 mile equals 1.6 kilometers, calculate the distance these birds fly in kilometers.

Measuring Length

The word *length* is used in many ways. For example, the length of a novel is the number of pages or words it contains. In scientific measurement, however, length is the distance between two points. That distance might be the diameter of a hair or the distance from Earth to the Moon. The SI base unit of length is the meter (m). A baseball bat is about 1 m long. Metric rulers and metersticks are used to measure length. **Figure 10** compares a meter and a yard.

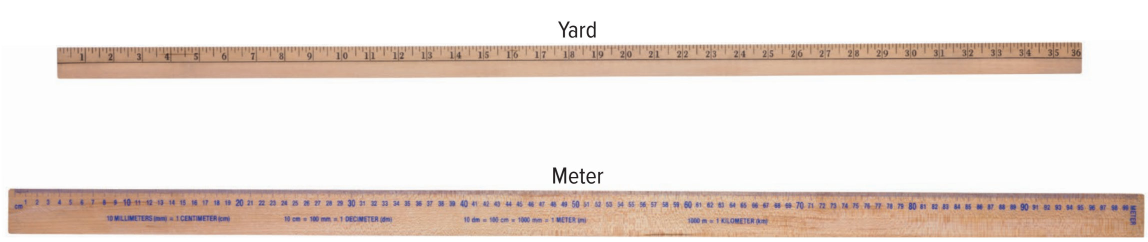


Figure 10 One meter is slightly longer than 1 yard, and 100 m is slightly longer than a football field.

Predict *whether your time for a 100-m dash would be slightly more or less than your time for a 100-y dash.*

STEM CAREER Connection

Computer Systems Analyst

Computer systems analysts study an organization's current computer systems and procedures and design solutions to help the organization operate more efficiently and effectively.

Siede Preis/Photodisc/Getty Images

Figure 11 The size of the object being measured determines the appropriate unit to use. A tape measure measures in meters. A micrometer measures very small lengths.

Choosing a unit of length

As shown in **Figure 11,** the unit with which you measure will depend on the size of the object being measured. For example, the diameter of a shirt button is about 1 cm. You would most likely measure the length of your pencil in centimeters but the length of your classroom in meters. What unit would you use to measure the distance from your home to school? You would probably want to use a unit larger than a meter. The kilometer (km), which is 1000 m, is used to measure these kinds of distances.

By choosing an appropriate unit, you avoid large-digit numbers and numbers with many decimal places. It is easier to read and calculate 21 km than 21,000 m. And 13 mm is easier to use than 0.013 m.

Measuring Volume

The amount of space occupied by an object is called its **volume.** If you want to know the volume of a solid rectangle, such as a brick, you measure its length, width, and height and multiply the three numbers and their units together: $V = l \times w \times h$. For a brick, your length measurements would most likely be in centimeters. The volume would then be expressed in cubic centimeters (cm^3) because when you multiply, you add the exponents. To find out how large of a load a moving van can carry, your length measurements would probably be in meters, and the volume would be expressed in cubic meters (m^3).

Sometimes, liquid volumes, such as doses of medicine, are expressed in cubic centimeters. One cubic centimeter and one milliliter are the same volume.

$$1 \text{ mL} = 1 \text{ cm}^3$$

Suppose you wanted to convert a measurement in liters to cubic centimeters. You use conversion factors to convert L to mL and then mL to cm^3.

$$1.5 \text{ L} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1 \text{ cm}^3}{1 \text{ mL}} = 1500 \text{ cm}^3$$

SCIENCE USAGE v. COMMON USAGE

volume

Science usage: the amount of space occupied by an object
To measure the volume of the cube, Raul submerged it in a beaker of water.

Common usage: the degree of loudness
Alisa couldn't hear the radio, so she turned up the volume.

Table 4 Densities of Some Materials at 20°C

Material	Density (g/cm^3)
Hydrogen	0.00009
Oxygen	0.0014
Water	1.0
Aluminum	2.7
Iron	7.9
Gold	19.3

Measuring Mass and Density

Matter is anything that takes up space and has mass. A table-tennis ball and a golf ball have about the same volume. If you pick them up, you notice a difference. The golf ball has more mass. **Mass** is a measurement of the quantity of matter in an object. The mass of a golf ball is about 45 g. It is almost 18 times the mass of a table-tennis ball, which is about 2.5 g. A bowling ball has a mass of about 5000 g. This makes its mass roughly 100 times greater than the mass of the golf ball and 2000 times greater than the table-tennis ball's mass.

Density

A cube of polished aluminum and a cube of silver that are the same size look similar and have the same volume, but they have different masses. The mass and volume of an object can be used to find the density of the material of which the object is made. **Density** is the mass per unit volume of a material. You find density by dividing an object's mass by the object's volume. For example, the density of an object having a mass of 10 g and a volume of 2 cm^3 is 5 g/cm^3. **Table 4** lists the densities of some familiar materials.

Derived units

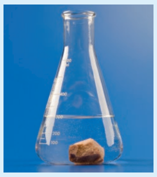
The measurement unit for density, g/cm^3, is a combination of SI units. A unit obtained by combining different SI units is called a derived unit. An SI unit multiplied by itself also is a derived unit. Thus, the liter, which is based on the cubic decimeter, is a derived unit. A cubic meter, m^3, is another example of a derived unit.

Measuring Time and Temperature

It is often necessary to keep track of how long it takes for something to happen. Time is the interval between two events. The SI unit for time is the second. In the laboratory, you will use a stopwatch or a clock with a second hand to measure time.

Another type of measurement common to science is temperature. You will learn the scientific meaning of the word *temperature* in a later module, but for now, think of temperature as a measure of how hot or how cold something is. **Table 5**, on the next page, summarizes SI measurements, including time and temperature.

Table 5 **SI Dimensions**

Unit	Example	
Millimeters		A dime is about 1 mm thick.
Meters		A football field is about 91 m long.
Kilometers		The distance from your house to the store can be measured in kilometers.
Milliliters		A teaspoonful of medicine is about 5 mL.
Liters		This carton holds 1.89 L of milk.
Grams/cm^3		This stone sinks because it is denser—has more grams per cubic centimeter—than water.
Meters/second		The speed of a roller-coaster car can be measured in meters per second.
Kelvin		Water boils at 373 K and freezes at 273 K.
Grams		The mass of a paper clip can be measured in grams.

(t to b)Sven Kahns/McGraw-Hill Education, Ahturner/Shutterstock, Alita Xander/123RF, Brazzo/iStock/Getty Images, Ingram Publishing, Matt Meadows/McGraw-Hill Education, Rarpia/iStock/Getty Images, Matt Meadows/McGraw-Hill Education, Matt Meadows/McGraw-Hill Education

Comparing Temperature Scales

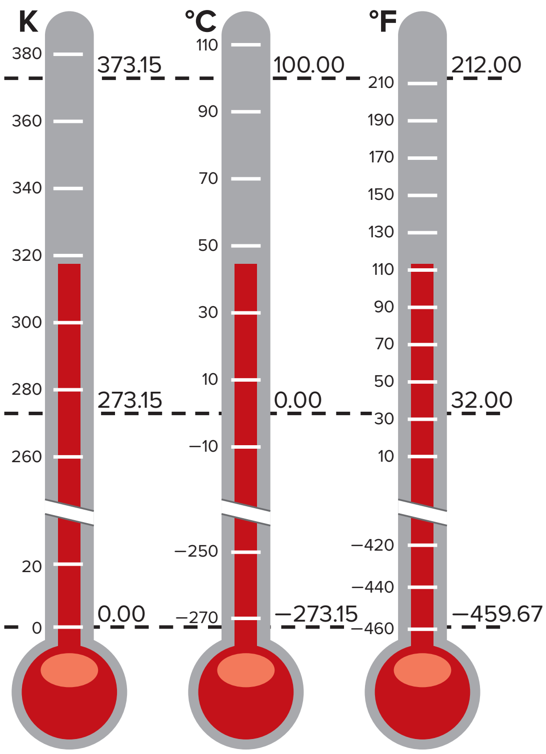


Figure 12 These three thermometers illustrate the three most common temperature scales. The dotted lines show absolute zero, the freezing point of water, and the boiling point of water.

State *the boiling point of water on the three scales.*

Celsius

Look at **Figure 12.** For much scientific work, temperature is measured on the Celsius (C) scale. On this scale, the freezing point of water is 0°C, and the boiling point of water is 100°C. Between these points, the scale is divided into 100 equal divisions. Each one represents 1°C. On the Celsius scale, average human body temperature is 37°C, and a typical room temperature is between 20°C and 25°C.

Kelvin and Fahrenheit

The SI unit of temperature is the kelvin (K). Zero on the Kelvin scale (0 K) is the coldest possible temperature, also known as absolute zero. Absolute zero is roughly equal to −273°C, which is 273°C below the freezing point of water.

Most laboratory thermometers are marked only with the Celsius scale. Because the divisions on the Celsius and Kelvin scales are the same size, the Kelvin temperature can be found by adding 273 to the Celsius reading. So, on the Kelvin scale, water freezes at 273 K and boils at 373 K. Notice that degree symbols are not used with the Kelvin scale.

The temperature measurement with which you are probably most familiar is the Fahrenheit scale. On the Fahrenheit scale, the freezing point of water is 32°F, and the boiling point is 212°F. A temperature difference of 1° on the Fahrenheit scale is 5/9° on the Celsius scale.

Check Your Progress

Summary

- The International System of Units, or SI, was established to provide a standard of measurement and to reduce confusion.
- Conversion factors are used to change one unit to another and involve using a ratio equal to 1.
- The size of an object determines which unit you will use to measure it.

Demonstrate Understanding

7. **Explain** why it is important to have exact standards of measurement.
8. **Make a Table** Organize the following measurements from smallest to largest and include the multiplying factor for each: kilometer, nanometer, centimeter, meter, and micrometer.

Explain Your Thinking

9. **Explain** why density is a derived unit.
10. **MATH Connection** Make the following conversions: 27°C to kelvins, 20 dg to milligrams, and 3 m to decimeters.
11. **MATH Connection** What is the density of an unknown metal that has a mass of 158 g and a volume of 20 mL? Use **Table 4** to identify this metal.

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LESSON 3
COMMUNICATING WITH GRAPHS

FOCUS QUESTION
When would you use a bar graph instead of a line graph?

A Visual Display

Scientists often graph the results of their experiments to make it easier to detect patterns in the data. A **graph** is a visual display of information or data. **Figure 13** is a graph that shows the time and distance from home as a girl walked her dog. The horizontal axis, called the *x*-axis, measures time. Time is the independent variable, because as it changes, it affects the measure of another variable. The distance from home that the girl and the dog walk is the other variable. It is the dependent variable and is measured on the vertical axis, called the *y*-axis.

Graphs are useful for displaying numerical information in business, science, sports, advertising, and many everyday situations. Graphs make it easier to understand patterns by displaying data in a visual manner.

Scientists often graph their data to detect patterns that would not have been evident in a table. Businesspeople may graph sales dollars to determine trends. Different kinds of graphs—line, bar, and circle—are appropriate for displaying different types of information. Additional information on making and using graphs can be found in the Math Skill Handbook in the back of this book.

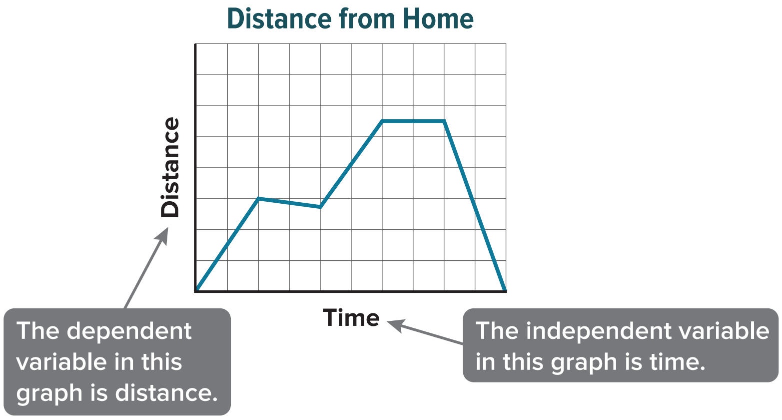

Figure 13 This graph tells the story of the motion that takes place when a girl takes her dog for a 10-minute walk. The dependent variable is on the *y*-axis, and the independent variable is on the *x*-axis.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE
Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE
GO ONLINE to find these activities and more resources.

Lab: Who contributes carbon dioxide?
Carry out an investigation to calculate the quantity of carbon dioxide produced per person in different countries.

Teaching Activity: Reading Graphs
Analyze a graph to determine how they make it easier to understand and detect patterns within data.

Line Graphs

A line graph can show any relationship in which the dependent variable changes due to a change in the independent variable. Line graphs often show how one or more variables change over time. In this case, time is the independent variable. You can use a line graph to track many things, such as how certain stocks perform or how the population changes over any period of time—a month, a week, or a year.

Displaying data on line graphs

You can show more than one event on the same graph as long as the relationship between the variables is identical. Suppose a builder had to choose one thermostat from among three different kinds for a new school. He tested them to find out which was the best brand to install throughout the building. He installed different thermostats in classrooms A, B, and C. He set each thermostat at 20°C. He turned on the furnace and checked the temperatures in the three rooms every 5 min for 25 min. He recorded his data in **Table 6.**

The builder then plotted the data on the graph in **Figure 14.** He could see from the table that the data did not vary much for the three classrooms. So, he chose small intervals for the *y*-axis and left out part of the scale (the part between 0°C and 15°C). This allowed him to spread out the area on the graph where the data points lie.

You can easily see the contrast in the colors of the three lines and their relationship to the black horizontal line. The black line represents the thermostat setting and is the control. The control is what the resulting room temperature of the classrooms should be if the thermostats are working efficiently.

Table 6 Room Temperature

Time*(min)	Classroom Temperature (°C)		
	A	B	C
0	16	16	16
5	17	17	16.5
10	19	19	17
15	20	21	17.5
20	20	23	18
25	20	25	18.5

*minutes after turning on heat

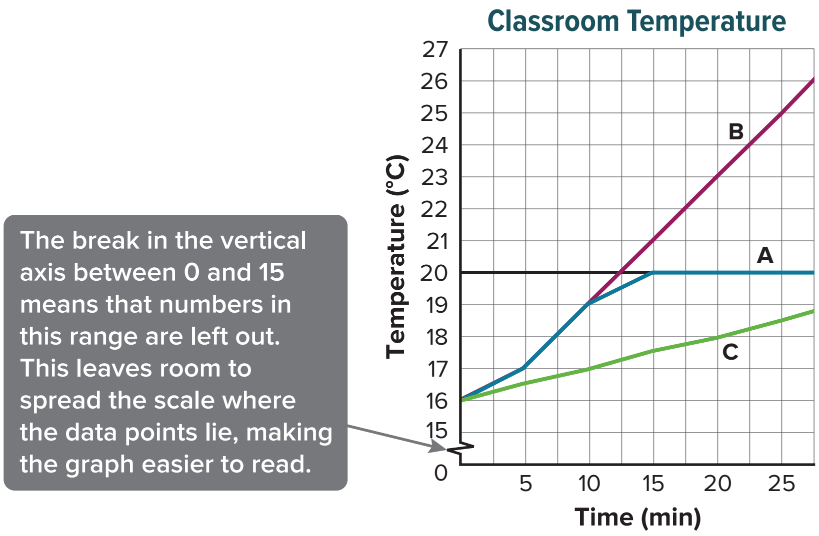

Figure 14 The builder's graph compares the time the furnace has been running with the temperature in each of three rooms, A, B, and C. The black line at $y = 20$°C shows the thermostat setting.

Identify *the thermostat that reached 20°C first.*

Constructing line graphs

In addition to choosing a scale that makes a graph readable, other factors are involved in constructing useful graphs. The most important factor in making a line graph is always using the *x*-axis for the independent variable. The *y*-axis is always used for the dependent variable. Recall that the dependent variable changes in response to the changes that you make to the independent variable, and the independent variable is the variable that you change to see how it will affect the dependent variable.

Another factor in constructing a graph involves units of measurement. You must use consistent units when graphing data. For example, you might use a Celsius thermometer for one part of your experiment and a Fahrenheit thermometer for another. But you must first convert your temperature readings to the same unit of measurement before you make your graph.

Once the data is plotted as points, a straight line or a curve is drawn based on those points. This should not be done like a connect-the-dots game. Instead, a best-fit line or a most-probable smooth curve is placed among the data points, as shown in **Figure 15.**

In the past, graphs had to be made by hand, with each point plotted individually. Today, scientists, mathematicians, and students use a variety of tools, such as computer programs and graphing calculators, to help them draw and interpret graphs.

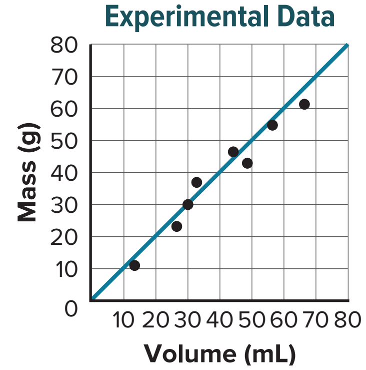

Figure 15 Generally, the line or curve that you draw will not intersect all of your data points.

APPLY SCIENCE

Make and Use Graphs

Line graphs are useful tools for showing the relationship between an independent and a dependent variable. In an experiment, you checked the air temperature at certain hours of the day and recorded it in the data table shown here.

Time	Temperature
8:00 A.M.	27°C
12:00 P.M.	32°C
4:00 P.M.	30°C

Identify the Problem

time = independent variable

temperature = dependent variable

Temperature is the dependent variable because it varies with time. Graph time on the *x*-axis and temperature on the *y*-axis. Mark equal increments on the graph and include all measurements. Plot each point on the graph by finding the time on the *x*-axis and moving up until you find the recorded temperature on the *y*-axis. Continue placing points on the graph. Then, connect the points from left to right.

Solve the Problem

1. Based on your graph, what was the temperature at 10:00 A.M.? What was the temperature at 2:00 P.M.?
2. What is the relationship between time and temperature?
3. Why is a line graph a useful tool for viewing this data?
4. For what other types of data might a line graph be useful?

Table 7 Classroom Size

Number of Students	Number of Classrooms
20	1
21	3
22	3
23	2
24	3
25	5
26	5
27	3

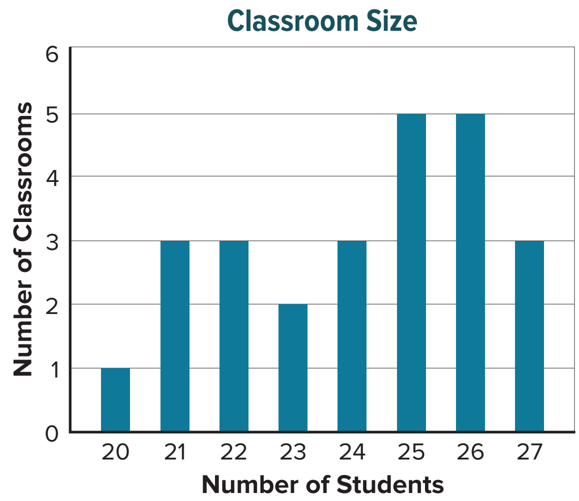

Figure 16 The height of each bar corresponds to the number of classrooms having a particular number of students.

Bar Graphs

A bar graph is useful for comparing information or displaying data that do not change continuously. Suppose you counted the number of students in every classroom in your school and organized your data in **Table 7.** You could show these data in a bar graph like the one in **Figure 16.** Notice you can easily determine which classrooms have the greatest and least numbers of students. You can also easily see that there are the same numbers of classrooms with 21 and 22 students and with 25 and 26 students.

Bar graphs can be used to compare oil or crop production, to compare costs of different products, or as data in promotional materials. Similar to a line graph, the independent variable is plotted on the *x*-axis, and the dependent variable is plotted on the *y*-axis.

Recall that you might need to place a break in the scale of the graph to better illustrate your results. For example, if your data set included the points 1002, 1010, 1030, and 1040 and the intervals on the scale were every 100 units, you might not be able to see the difference from one bar to another. If you had a break in the scale and started your data range at 1000 with intervals of ten units, you could make a more accurate comparison.

Get It?

Describe possible data for which using a bar graph would be better than using a line graph.

Circle Graphs

A circle graph, sometimes called a pie chart, is used to show how some fixed quantity is broken into parts. The circular pie represents the total. The slices represent the parts and usually are represented as percentages of the total.

Figure 17 illustrates how a circle graph could be used to show the percentage of buildings in a neighborhood using each of a variety of heating fuels. You easily can see that more buildings use gas heat than any other kind of system. What other information does the graph provide?

To create a circle graph, start with the total of what you are analyzing. Suppose the survey of heating fuels counted 72 buildings in the neighborhood. For each type of heating fuel, you divide the number of buildings using each type of fuel by the total (72). Then multiply that decimal by 360° to determine the angle that the decimal makes in the circle. For example, 18 buildings use steam. Therefore, $18 \div 72 = 0.25$, and $0.25 \times 360° = 90°$ on the circle graph. You then would measure 90° on the circle with your protractor. You can also calculate that if this graph shows 50 percent of the buildings use gas, then 36 of the buildings use gas ($0.50 \times 72 = 36$).

When you create a graph, think carefully about which type of graph you will use and how you will present your data. In addition, consider the conclusions you may draw from your graph. Make sure your conclusions are based on sound information and that you present your information clearly.

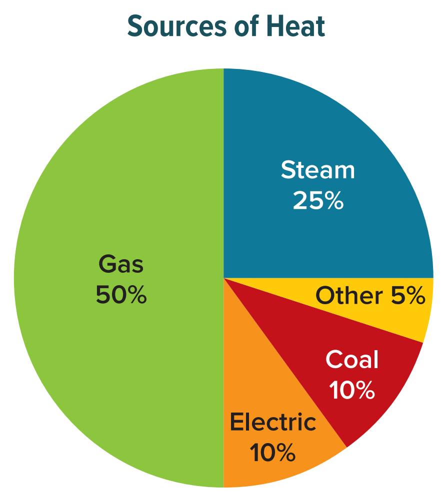

Figure 17 A circle graph shows the different parts of a whole quantity.

Check Your Progress

Summary

- Graphs are a visual representation of data.
- Scientists often graph their data to detect patterns.
- A line graph shows a relationship between an independent and a dependent variable.
- Bar graphs are best used to compare information collected by counting.
- A circle graph shows how a fixed quantity is broken down into parts.

Demonstrate Understanding

12. **Identify** the kind of graph that would best show the results of a survey of 144 people, of which 75 ride a bus, 45 drive cars, 15 carpool, and 9 walk to work.
13. **State** which type of variable is plotted on the x-axis and which type is plotted on the y-axis.
14. **Compare and Contrast** How are line, bar, and circle graphs similar? How are they different?

Explain Your Thinking

15. **Explain** why the points in a line graph can be connected.
16. **MATH Connection** In a survey, it was reported that 56 out of 245 people would rather drink orange juice than coffee in the morning. Calculate the percentage of a circle graph that orange-juice drinkers would occupy.

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LESSON 4

SCIENCE AND TECHNOLOGY

FOCUS QUESTION

How does society affect the technology that we use?

What is technology?

The terms *science* and *technology* often are used interchangeably. However, these terms have very different definitions. Science is an exploration process. Scientific processes are used to gain knowledge to explain and predict natural occurrences. Scientists often pursue scientific knowledge for the sake of learning new information. There may or may not be a plan to use the knowledge.

When scientific knowledge is used to solve a human need or problem, as shown in **Figure 18,** the result is referred to as technology. **Technology** is the application of scientific knowledge to benefit people. Given this definition, is an aspirin tablet technology? Is a car technology? What about the national highway system? Although these examples appear to be very different, they all represent examples of technology. Technology can be

- any human-made object (such as a radio, computer, or pen),
- methods or techniques for making any object or tool (such as the process for making glass or ceramics),
- knowledge or skills needed to operate a human-made object (such as the skills needed to pilot an airplane), or
- a system of people and objects used to do a particular task (such as the Internet, a system for sharing information).

Figure 18 The prosthetic leg in this image is a technological object. The knowledge needed to interpret this image is also technology.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Quick Investigation: Research the Past

Carry out an investigation to ask a senior citizen what types of technologies existed when they were teenagers.

LabA: Care Package

Carry out an investigation to model which materials work best in the packaging of foods, and construct an explanation for how the packaging design may reduce consumer costs.

Technological objects

The value of a technological object changes through time, as shown in **Figure 19.** What is considered new technology today might be considered an antique tomorrow. For example, special feathers called quills were used long ago to write with ink. The quill pen was the height of technology for over 1000 years. Then, in the middle of the nineteenth century, metallic pens and writing points came into use. The modern ballpoint pen was not widely used until the 1940s.

Technological methods or techniques

Just as writing instruments have changed over time, so have techniques for performing various tasks. Long ago, people would sit for hours and copy each page of a book by hand. Books were expensive and could be bought by only the very rich. Today, books can be created in different ways. They can be made on a computer, printed with a computer printer, and bound with a simple machine. Modern printing presses, like those shown in **Figure 20,** are used to produce the majority of books used today, including your textbook.

The methods used for printing books have changed over time. Each technique has its own technology. Other techniques that characterize technology include using a compact disc to store information, using a refrigerator to preserve food, and using e-mail to correspond with friends.

Technological knowledge or skills

Technology also can be the knowledge or skills needed to perform a task. For example, computer skills are needed to run the software that is used to make books and other documents. Printing press operators must use their skills to print books successfully. Any time a complex machine is used to perform a task, technological skills must be used by the operator.

Sundial

Digital wristwatch

Figure 19 Technology changes through time. A sundial was once the common method used to tell time. Today, we often rely on wristwatches or digital clocks.

Figure 20 Hundreds of years ago, books had to be written and published by hand. Now, printing presses can generate thousands of pages an hour.

Technological systems

A network of people and objects that work together to perform a task is also technology. One example of this technology is the Internet. The Internet is a collection of computers and software that is used to exchange information. A technological system is a collection of various types of technology that are combined to perform a specific function. The airline industry is an example of a technological system. This industry is a collection of objects, methods, systems, knowledge, and procedures. The airports, pilots, fuel, and ticketing process form a technological system that is used to move people and goods.

Get It?

Identify another example of a technological system. Explain why it fits into this category.

Global Technological Needs

The value of technology may vary for different people and at different times. The technology that is needed in the United States is not necessarily needed in other parts of the world. Developing countries have different needs for technology than do industrialized countries.

Developing countries

The people of some countries work hard to meet basic needs such as food, shelter, clothing, safe drinking water, and health care. For example, the family shown in **Figure 21** lives without electricity and running water in their home. Instead of going to the grocery store for the food their family eats, they might grow most of it themselves. Children might walk to school instead of taking the school bus.

Figure 21 The technological needs of this family might be different from those of a family in another location. All people need safe water, food supplies, health care, education, and a safe place to work, but the technology involved in meeting these needs can differ from location to location.

Compare and contrast *these needs with the needs of your family.*

Meeting basic needs Technological solutions in developing countries are often limited to supplying a family's basic needs. Technology that would supply adequate and safe drinking water and food supplies would be valued before technology such as access to the Internet. Increasing the accessibility of basic health care would improve the quality of life and increase the life expectancy in developing countries. The technology valued by rural people in developing countries contrasts with the technology valued by people in those countries' industrialized cities.

Figure 22 The basic needs for survival are available to most people in industrialized countries. Value is placed on technology that improves the quality of life, such as devices that make tasks easier and devices that provide entertainment.

Describe *three technological objects that you value that would likely be of less value to a family in a developing country.*

Industrialized countries

The United States is considered an industrialized country. Technology gives people the ability to clean polluted waters. Improving the quality of the food supply is also valued. But the level of urgency and focus differs from those in developing countries.

Most areas of the United States have adequate and safe water and food supplies. Because the needs for survival are met in industrialized nations, money often is spent on different types of technology. The technology used in industrialized countries is designed to improve people's quality of life.

Look at the home in **Figure 22,** and compare it to the home on the previous page. Most homes in the United States have electricity and running water. Quality health care is available to many people. The life expectancy for Americans is in the late-seventies, generally higher than life expectancy in developing countries. Most homes in the United States contain many different types of technology, including computers, telephones, and televisions. Money is spent on such medical procedures as cosmetic surgery to remove wrinkles and eye surgery to eliminate the need for wearing glasses.

Contrasting needs As you can see, the human needs in developing countries and industrialized countries are very different. Both developing and industrialized countries value technologies that meet basic human needs, but the actual technology required in each type of country may be very different.

Get It?

Compare and contrast the technological needs of developing and industrialized countries.

Figure 23 Consumers often decide which technologies will be developed. If consumers do not purchase a product, additional money usually will not be spent on the production or improvement of the product.

Social Forces That Shape Technology

Science and society are closely connected. **Society** is a group of people that share similar values and beliefs. Discoveries in science and technology bring about changes in society. In turn, society affects how new technologies develop. The development of technology is affected by society and its changing values, politics, and economics.

In the past 100 years, attitudes about automobiles have changed in the United States. Many people became able to own cars due to the changes in technology and manufacturing. As car ownership increased, so did fossil fuel consumption. With rising gasoline prices, some consumers began buying more fuel-efficient cars. The automotive industry has researched and developed technologies that make cars more fuel-efficient. Today, hybrid cars use both gasoline and electricity.

Personal values

People will support the development of technologies that agree with their personal values, directly and indirectly. Purchasing technology is a direct way in which people support the development of technology. For example, if consumers continue to purchase fuel-efficient cars, like the one shown in **Figure 23,** additional money will be spent on improving the technology. If consumers fail to buy a product, companies usually will not spend additional money on that type of technology. People also support the development of technology directly when they give their money to organizations that are committed to a specific project, such as cancer research.

There are also many ways to indirectly support technologies that agree with one's personal values. For example, people vote for a congressional candidate based on the candidate's views on various issues. This is an indirect way in which people's personal values influence whether technology projects receive funding and support.

Economic Forces That Shape Technology

Many factors influence how much money is spent on technology. Before funding is given for a project, several questions should be answered. What is the benefit of this product? What is the cost? Who will buy this product? All of these questions should be answered before money is invested in a project. Various methods exist to fund new and existing technology.

Federal government

One way in which funds are allocated for research and development of technology is through the federal government. Every year, Congress and the president place large amounts of money in the federal budget for scientific research and development. These funds are reserved for specific types of research, such as agriculture, defense, energy, and transportation. This money is given to companies and institutions in the form of contracts and grants to do specific types of research. Citizens can affect how the government funds technology by voting, as shown in **Figure 24**, and other political activities.

Private foundations

Some scientific research is funded using money from private foundations. Funds are raised for various types of disease research, such as breast cancer and muscular dystrophy, through events such as races and telethons. Many private foundations focus on research for a specific cause.

Private industries

Research and development is also funded by private industries. Industries budget a portion of their profits for research and development. Investing in research and development can make money for the company in the long-term. Bringing new products to the marketplace is one way companies make profits.

Figure 24 Participating in the political process is one way that people can influence which technologies are developed and which are not.

Explain *how voting for members of Congress influences which technologies will be developed.*

WORD ORIGINS

technology

comes from the Greek word *technologia*, which means “an ordered treatment of an art”

Technology helps our everyday lives.

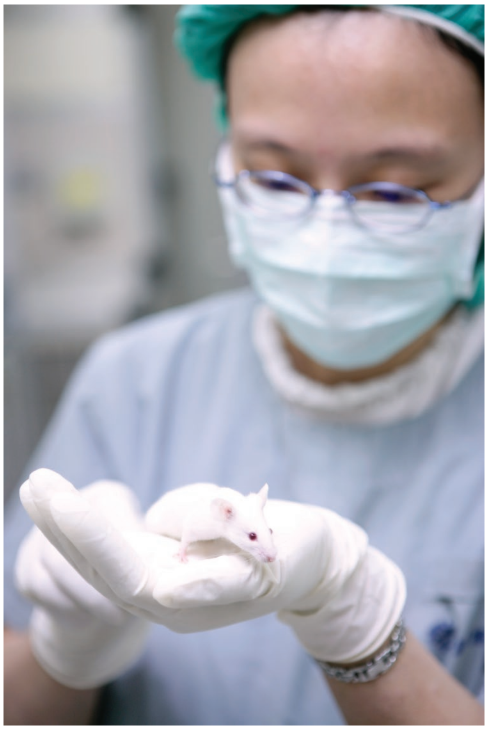


Figure 25 Scientists must be aware of ethical issues when testing on animal subjects. Although animals are still used in some scientific testing, today there are laws and guidelines to regulate this testing.

Moral and Ethical Issues

When people need to distinguish between right and wrong, what is fair, and what is in the best interest of all people, moral and ethical issues are raised. Ethics help scientists establish standards that they agree to follow when they collect, analyze, and report data. Scientists are expected to conduct investigations honestly and openly.

Some ethical questions in science concern the use of animals, such as the mouse shown in **Figure 25,** as well as humans. The inhumane treatment of humans and animals in past experiments has led to public outcry. For example, human test subjects have been put through experiments against their will or without being informed of the risks associated with the research or the true nature of the experiments. Ethical questions about these practices helped to create laws and guidelines to prevent unethical treatment of both humans and animals in scientific research.

Biotechnology

Any technological application using living things or living systems is called biotechnology. Breeding animals for certain traits, using fermentation to obtain cheese or wine, and baking with yeast are biotechnologies that humans have used for many years. Today, biotechnology includes diverse areas of research, such as stem cells and genetically engineered crops. Some of these research areas are controversial because they challenge society's values and beliefs. All areas must be examined for their impact on individuals, society, and the environment.

Check Your Progress

Summary

- Technology can be an object, a technique, a skill, or a system.
- Societal and economic forces influence which technologies will be developed and used around the world.
- The development of new technology is influenced by voting and buying habits.
- The federal government, private foundations, and private industries fund the research and development of technology.

Demonstrate Understanding

17. **Classify** the types of technology, and give at least two examples of each type.
18. **Explain** why the types of technology that are valued can vary.
19. **Describe** how private citizens have a voice in which projects the federal government will fund.

Explain Your Thinking

20. Evaluate Would cell-phone technology be of use in a developing country? Explain your answer.
21. **MATH Connection** In 2010, the Department of Defense's overall budget was approximately $534 billion. In the same year, the Department of Defense budgeted $79.1 billion for research, development, tests, and evaluations. What percentage of the budget does this represent?

LEARNSMART® Go online to follow your personalized learning path to review, practice, and reinforce your understanding.

Scientific Methods

Abu Ali al-Hasan ibn al-Haytham is sometimes known as the father of the scientific methods, the first true scientist, and the founder of optics. He was born in a.d. 965 in what is now Iraq, but he spent most of his life in Cairo, Egypt. As a young man, he read the works of Aristotle, the third-century b.c. Greek philosopher. He approved of Aristotle's reliance on experience, rather than untested ideas, in pursuit of truth.


Ibn al-Haytham is often regarded as the founder of scientific methods.

In one of his essays, Ibn al-Haytham, whose statue is shown in the photo at right, wrote that "the seeker after truth is . . . the one who submits to argument and demonstration and not to the sayings of a human being whose nature is fraught with all kinds of imperfection and deficiency." Ibn al-Haytham studied and wrote about many scientific disciplines, including mathematics (especially geometry), astronomy, optics, physics, and medicine. He became one of the first scientists to perform experiments to test his hypotheses. In addition, he contributed to the fields of philosophy and psychology.

Experiments with optics

The study of optics is the branch of physics that studies light and vision. Earlier thinkers, such as the second-century a.d. Greek scientist Ptolemy, thought that people could see because rays of light came out of their eyes and fell on the objects they were observing. Ibn al-Haytham performed experiments to test the behavior of light and the workings of the human eye. His observations led him to conclude that people could see because rays of light entered, not exited, their eyes.

A lasting influence

Ibn al-Haytham's insistence on experimentation and on making quantifiable observations helped develop scientific methods as we know them today. Centuries after his death, Ibn al-Haytham's most important work, *Kitab al-Manazir* (*Optics*), influenced European scientists such as Roger Bacon, a 13th-century philosopher who is sometimes credited with laying the foundation for the use of scientific methods.

Because of Ibn al-Haytham's lifelong quest to develop a rational way of exploring his ideas, today's scientists and students of science have scientific methods, a powerful tool for testing hypotheses.

APPLY SCIENTIFIC REASONING AND EVIDENCE

Describe and explain what characterizes science and its methods, what resembles science but does not meet its criteria (pseudoscience), and what is clearly not science. Identify a question you think can be answered through science and a question that is outside its boundaries, and explain your reasoning.

MODULE 1
STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 THE METHODS OF SCIENCE

- Scientists ask questions and perform investigations to learn more about the natural world.
- Scientists use scientific methods to test their hypotheses.
- Models help scientists visualize concepts.
- A theory is a possible explanation for observations, while a scientific law describes a pattern but does not explain why things happen.

- scientific methods
- hypothesis
- experiment
- variable
- dependent variable
- independent variable
- constant
- control
- bias
- model
- theory
- scientific law

Lesson 2 STANDARDS OF MEASUREMENT

- The International System of Units, or SI, was established to provide a standard of measurement and to reduce confusion.
- Conversion factors are used to change one unit to another and involve using a ratio equal to 1.
- The size of an object determines which unit you will use to measure it.

- standard
- SI
- volume
- matter
- mass
- density

Lesson 3 COMMUNICATING WITH GRAPHS

- Graphs are a visual representation of data.
- Scientists often graph their data to detect patterns.
- A line graph shows a relationship between an independent variable and a dependent variable.
- Bar graphs are best used to compare information collected by counting.
- A circle graph shows how a fixed quantity is broken down into parts.

- graph

Lesson 4 SCIENCE AND TECHNOLOGY

- Technology can be an object, a technique, a skill, or a system.
- Societal and economic forces influence which technologies will be developed and used around the world.
- The development of new technology is influenced by voting and buying habits.
- The federal government, private foundations, and private industries fund the research and development of technology.

- technology
- society

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

How do we know how rainbows form?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

GO FURTHER

SEP Data Analysis Lab

Graphing Scientific Data

Interpolation is a method used to approximate values that are between points of a graph. Extrapolation is a method for approximating values that are beyond the range of the data. The data in **Table 1** were obtained from an experiment conducted to find out how the volume of a gas changes when its temperature changes. Use this data to construct and interpret a graph.

Table 1

Temperature (K)	Volume (cm^3)
0	a.
100	71
140	b.
210	155
273	c.
280	195
360	257
400	d.
600	e.

Procedure

1. Draw a graph on a piece of graph paper.
2. Mark the *x*-axis for the independent variable and the *y*-axis for the dependent variable.
3. Plot a point for each temperature/volume set of data in the table. Draw the line that best fits the data points.
4. Extend the line to include all temperatures from 0 K to 600 K.

CER Analyze and Interpret Data

1. **Claim** Use your graph to predict values for the volume of a gas at 0 K, 140 K, 273 K, 400 K, and 600 K, and place these values in the data table.
2. **Evidence and Reasoning** Suppose you had drawn the graph in a "dot-to-dot" fashion. Why would it be difficult to extrapolate from this type of graph?
3. **Claim, Reasoning** Why isn't it necessary for all of the data points to be on the drawn line of the graph?
4. **Claim** Write a sentence that describes the relationship between the temperature and the volume of a gas.

UNIT 1

MOTION AND FORCES

ENCOUNTER THE PHENOMENON

How could this athlete jump higher?

SEP Ask Questions

What questions do you have about the phenomenon? Write your questions on sticky notes and add them to the driving question board for this unit.

What is the relationship between motion and force?

Look for Evidence

As you go through this unit, use the information and your experiences to help you answer the phenomenon question as well as your own questions. For each activity, record your observations in a Summary Table, add an explanation, and identify how it connects to the unit and module phenomenon questions.

Solve a Problem

STEM UNIT PROJECT

Newton's Laws of Motion Investigate and research more about motion and forces. Use the results of these investigations and the evidence you collected during the unit to complete your unit project.

GO ONLINE In addition to reading the information in your Student Edition, you can find the STEM Unit Project and other useful resources online.

Stephen Barnes/Sport/Alamy Stock Photo

MODULE 2
MOTION

ENCOUNTER THE PHENOMENON

Why is this motor bike traveling in an arc?

GO ONLINE to play a video about the projectile motion of a fireball.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

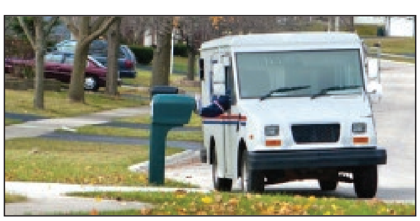
CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about why this motor bike is traveling in an arc. Explain your reasoning.

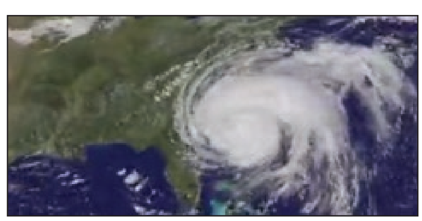
Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.



LESSON 2: Explore & Explain: Motion and Position



LESSON 2: Explore & Explain: Velocity

Smithsonian

Additional Resources

LESSON 1

DESCRIBING MOTION

FOCUS QUESTION

Which factors describe the motion of an object?

Motion and Position

You do not always need to see something move to know that motion has taken place. For example, suppose you look out a window and see a mail truck stopped next to a mailbox, as shown in **Figure 1.** One minute later, you look out again and see the same truck stopped farther down the street. Although you did not see the truck move, you know it moved because its position relative to the mailbox changed.

Reference points

A reference point is needed to determine the position of an object. In **Figure 1,** the reference point might be a mailbox. **Motion** is a change in an object's position relative to a reference point. How you describe an object's motion depends on the reference point that is chosen. For example, the description of the mail truck's motion in **Figure 1** would be different if the reference point were a tree instead of a mailbox.

After a reference point is chosen, a frame of reference can be created. A frame of reference is a coordinate system in which the position of the object is measured. The *x*-axis and *y*-axis of the reference frame are drawn so that they are perpendicular to each other and intersect the reference point.

Figure 1 As the mail truck follows its route, it stops at each mailbox along the street.

Explain *How would you know the mail truck has moved?*

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Virtual Investigation: Describing Motion
Carry out an investigation to determine the relationship between distance, average speed, and time of cars in a race, and to predict the distance the cars will travel.

Quick Investigation: Measure Average Speed
Carry out an investigation to determine the average speed of a toy car and how average speed changes when forces of different magnitude are applied to the system.

Coordinate systems

Figure 2 shows a map of the city where the mail truck is delivering mail. The map has a coordinate system drawn on it. The x-axis is in the east-west direction, the y-axis is in the north-south direction, and each division represents a city block. The post office is located at the origin. The mail truck is located at 3 blocks east ($x = 3$) and 2 blocks north ($y = 2$) of the post office.

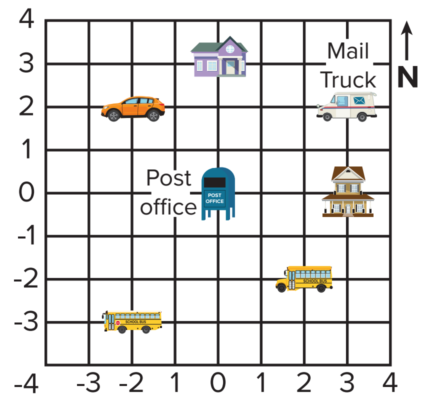


Figure 2 A coordinate system is like a map. The reference point is at the origin, and each object's position can be described with its coordinates.

Identify *the position of the orange car.*

Change in Position

Have you ever run a 50-m dash? Describing how far and in what direction you moved was an important part of describing your motion.

Distance

In a 50-m dash, each runner travels a total distance of 50 m. The SI unit of distance is the meter (m). Longer distances are measured in kilometers (km). One kilometer is equal to 1000 m. Shorter distances are measured in centimeters (cm) or millimeters (mm). One meter is equal to 100 cm and to 1000 mm.

Displacement

Suppose a runner jogs to the 50-m mark and then turns around and runs back to the 20-m mark, as shown in **Figure 3.** The runner travels 50 m in the original direction (east) plus 30 m in the opposite direction (west), so the total distance that she ran is 80 m. How far is she from the starting line? The answer is 20 m. Sometimes, you may want to know the change in an object's position relative to the starting point. An object's **displacement** is the distance and direction of the object's change in position. In **Figure 3,** the runner's displacement is 20 m east.

The length of the runner's displacement and the total distance traveled would be the same if the runner's motion were in a single direction. For example, if the runner ran east from the starting line to the finish line without changing direction, then the distance traveled would be 50 m, and the displacement would be 50 m east.

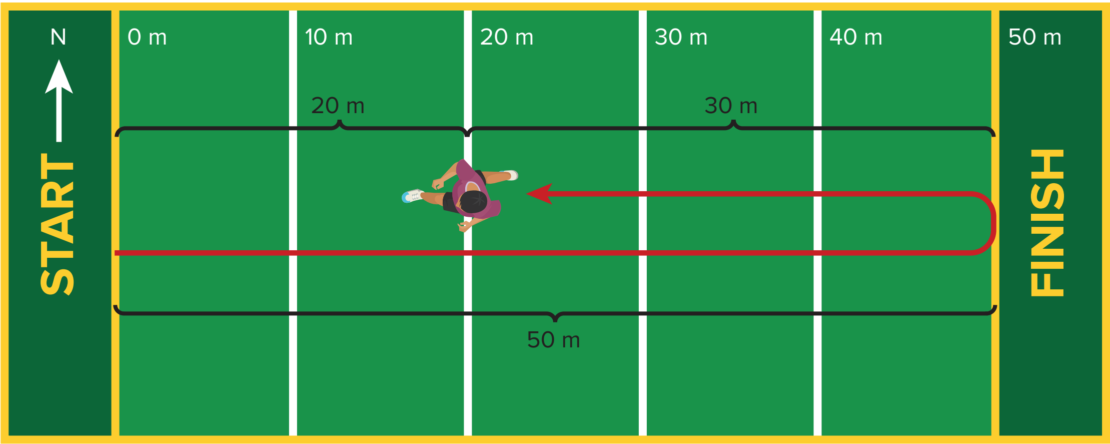
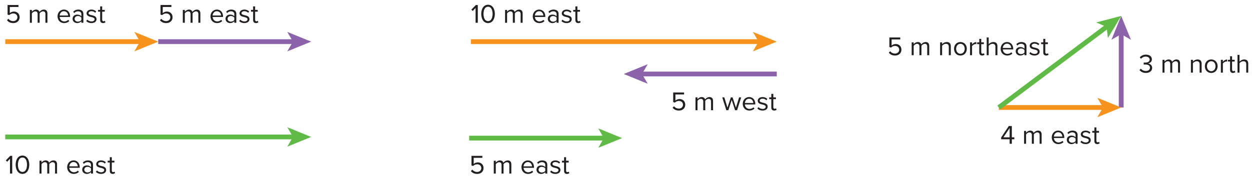


Figure 3 An object's displacement is not the same as the total distance that the object traveled. The runner's displacement is 20 m east of the starting line. However, the total distance the runner traveled is 80 m.

Describe *the difference between the total distance traveled and the displacement.*



Displacements in the same direction can be added.

Displacements in opposite directions can be subtracted.

Displacements that are not in the same direction or opposite directions cannot be directly added or subtracted.

Figure 4 These arrows represent the students' walks. The green arrows show the first part of the walk, and the purple arrows show the second part. The orange arrows show the students' displacements.

Adding displacements

You know that you can add distances to get the total distance. For example, 2 m + 3 m = 5 m. But how would you add the displacements 5 m east and 10 m east? Directions in math problems are much like units: you can add numbers with like directions. For example, suppose a student walks 5 m east, stops at a crosswalk, and then walks another 5 m east, as shown on the left in **Figure 4.** His displacement is

$$5 \text{ m east} + 5 \text{ m east} = 10 \text{ m east}$$

But what if the directions are not the same? Then compare the two directions. If the directions are exactly opposite, the distances can be subtracted. Suppose a student walks 10 m east, turns around, and walks 5 m west, as shown in the center of **Figure 4.** The size of the displacement would be

$$10 \text{ m} - 5 \text{ m} = 5 \text{ m}$$

The direction of the total displacement is always the direction of the larger displacement. In this case, the larger displacement is east, so the total displacement is 5 m east.

Get It?

Determine the total displacement of a dog that runs 15 m north, 6 m south, then 8 m north.

Now suppose the two displacements are neither in the same direction nor in opposite directions, as illustrated on the right in **Figure 4.** Here, the student walks 4 m east and then 3 m north. The student walks a total distance of 7 m, but the displacement is 5 m in a roughly northeast direction. The displacements of 4 m east and 3 m north cannot be directly added or subtracted, and they should be discussed separately. The rules for adding displacements are summarized in **Table 1.**

Table 1 **Rules for Adding Displacements**

1. Add displacements in the same direction.
2. Subtract displacements in opposite directions.
3. Displacements that are not in the same or in opposite directions cannot be directly added together.

SCIENCE USAGE v. COMMON USAGE

position

Science usage: the location of an object in relation to a reference point

The cat's position was 3 meters west of the house.

Common usage: a point of view; a job or rank

After graduation, I accepted a teller position at the bank.

Speed

Think back to the mail truck moving down the street. You could describe the movement by the distance traveled or by the displacement. You might also want to describe how fast the truck is moving. To do this, you need to know how far it travels in a given amount of time. To describe how fast an object moves, scientists use the object's speed. **Speed** is the distance an object travels per unit of time.

Calculating speed

Any change over time is called a rate. For example, you could describe how quickly water is leaking from a tank by stating how many liters are lost each hour. This would be the rate of water leakage. If you think of distance as the change in position, then speed is the rate of change in position. Speed can be calculated from the equation shown below.

Speed Equation

$$\text{speed (in meters/second)} = \frac{\text{distance (in meters)}}{\text{time (in seconds)}}$$

$$s = \frac{d}{t}$$

In SI units, distance is measured in meters, and time is measured in seconds. Therefore, the SI unit for speed is meters per second (m/s). Sometimes, it is more convenient to express speed in other units, such as kilometers per hour (km/h). **Table 2** shows the speeds of some common objects.

Table 2 Common Speeds

Motion	Speed (m/s)
Olympic 100-m dash	10 m/s
Car on city street (35 mph)	16 m/s
Car on interstate highway (65 mph)	29 m/s
Commercial airplane	250 m/s

EXAMPLE Problem 1 ADDITIONAL PRACTICE

CALCULATE SPEED A car traveling at a constant speed covers a distance of 750 m in 25 s. What is the car's speed?

Identify the Unknown: speed: s

List the Knowns: distance: $d = 750\text{ m}$

time: $t = 25\text{ s}$

Set Up the Problem: $s = \frac{d}{t} = \frac{750\text{ m}}{25\text{ s}}$

Solve the Problem: $s = \frac{750\text{ m}}{25\text{ s}} = 30\text{ m/s}$

Check the Answer: 30 m/s is approximately the speed limit on a U.S. interstate highway, so the answer is reasonable.

PRACTICE Problems

1. A passenger elevator travels from the first floor to the 60^{th} floor, a distance of 210 m, in 35 s. What is the elevator's speed?
2. A motorcycle is moving at a constant speed of 40 km/h. How long does it take the motorcycle to travel a distance of 10 km?
3. How far does a car travel in 0.75 h if it is moving at a constant speed of 88 km/h?
4. **CHALLENGE** A long-distance runner is running at a constant speed of 5 m/s. How long does it take the runner to travel 1 km?

Constant speed

Suppose you are in a car traveling on a nearly empty freeway. You look at the speedometer and see that the car's speed hardly changes. If the car neither slows down nor speeds up, the car is traveling at a constant speed. If you are traveling at a constant speed, you can calculate your speed by dividing any distance interval by the time it took you to travel that distance. The speed you calculate will be the same regardless of the interval you choose.

Speed Changing over Distance

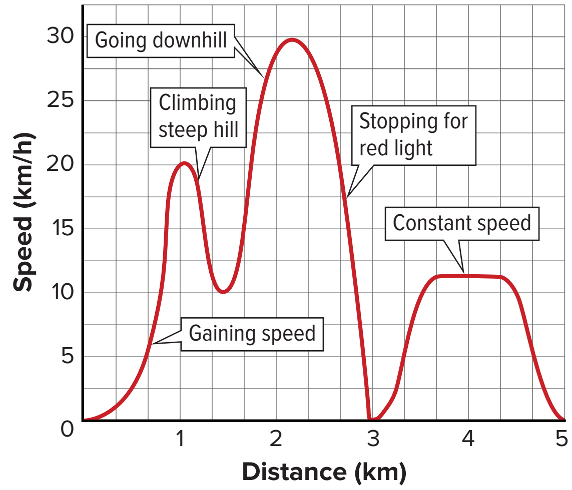


Figure 5 The cyclist's speed varies from 0 km/h to 30 km/h during this trip.

Explain *how you can describe the speed of an object when the speed is changing.*

Changing speed

Usually, speed is not constant. Think about riding a bicycle for a distance of 5 km. The bicycle's speed will vary, as in **Figure 5.** As you start out, your speed increases from 0 km/h to 20 km/h. You slow down to 10 km/h as you pedal up a steep hill and speed up to 30 km/h going down the other side of the hill. You stop for a red light, speed up again, and move at a constant speed for a while. Finally, you slow down and come to a stop.

Checking your watch, you find that the trip took 15 min. How would you express your speed on such a trip? Would you use your fastest speed, your slowest speed, or some speed between the two? Two common ways of expressing a changing speed are average speed and instantaneous speed.

Get It?
Identify two common ways of expressing a changing speed.

Average speed Average speed is one way to describe the speed of the bicycle trip. Average speed is the total distance traveled divided by the total time of travel. It can be calculated using the relationships between speed, distance, and time. For the bicycle trip just described, the total distance traveled was 5 km, and the total time was $\frac{1}{4}$ h, or 0.25 h. Therefore, the average speed was

$$s = \frac{d}{t} = \frac{5\text{ km}}{0.25\text{ h}} = 20\text{ km/h}$$

Get It?
Identify how to calculate average speed.

STEM CAREER Connection

Delivery Truck Driver

With more and more online sales, companies must have a way to get the products to customers' doors. Delivery truck drivers pick up products at a distribution center and drive them to businesses and homes for delivery. Acceleration, velocity, and time are important factors for delivery truck drivers as they try to make their deliveries on a tight schedule.

Instantaneous speed Suppose you watch a car's speedometer, like the one in **Figure 6,** go from 0 km/h to 80 km/h. A speedometer shows how fast a car is going at one point in time, or at one instant. The speed shown on a speedometer is the instantaneous speed. Instantaneous speed is the speed at a given point in time. When something is speeding up or slowing down, its instantaneous speed is changing. The speed is different at different points in time. If an object is moving with constant speed, the instantaneous speed does not change. The speed is the same at every point in time.

Figure 6 A speedometer gives the car's instantaneous speed. Instantaneous speed is the speed at one instant in time.

Get It?

Identify two examples of motion in which an object's instantaneous speed changes.

Graphing Motion

The motion of an object over a period of time can be shown on a distance-time graph. For example, the graph in **Figure 7** shows the distance traveled by three swimmers during a 30-minute workout. Time is plotted along the horizontal axis of the graph, and the distance traveled is plotted along the vertical axis of the graph.

Each axis must have a scale that covers the range of numbers to be plotted. In **Figure 7,** the distance scale must range from 0 to 2400 m, and the time scale must range from 0 to 30 min. Next, the *x*-axis is divided into equal time intervals, and the *y*-axis is divided into equal distance intervals.

Once the scales for each axis are in place, the data points can be plotted. In **Figure 7,** there is a data point plotted for each swimmer every 2.5 minutes. After plotting the data points, a line is drawn to connect the points.

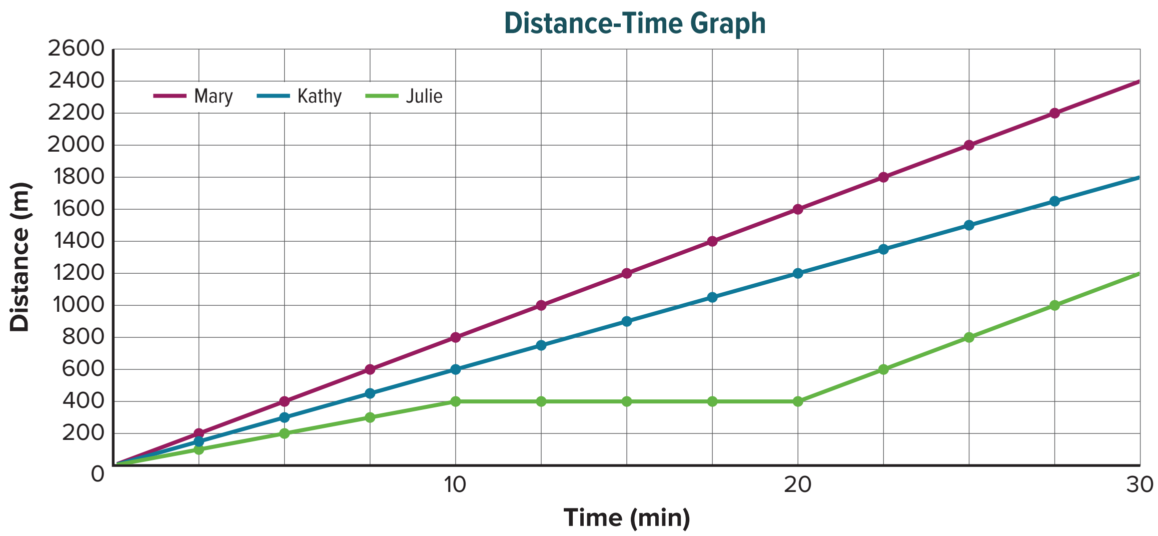


Figure 7 This graph shows how far each girl swam during a 30 minute workout. Time is divided into 2.5-minute intervals along the *x*-axis. Distance swam is divided into 200-m intervals along the *y*-axis.

Examine *the graph and determine which girl swam the farthest during the workout.*

Nik Rogul/Hemera/Getty Images

Speed on distance-time graphs

If an object moves with constant speed, the increase in distance over equal time intervals is the same. As a result, the line representing the object's motion is a straight line. For example, look at the graph of the swimmers' workouts in **Figure 8.** The straight red line represents the motion of Mary, who swam with a constant speed of 80 m/min.

The green line represents the motion of Julie, who did not swim with a constant speed. She swam with a constant speed of 40 m/min for 10 minutes, rested for 10 minutes, and then swam with a constant speed of 80 m/min for 10 minutes.

The graph shows that the line representing the motion of the faster swimmer is steeper. The steepness of a line on a graph is the line's slope. The slope of a line on a distance-time graph equals the object's speed. Because Mary has a greater speed (80 m/min) than Kathy (60 m/min), the line representing her motion has a steeper slope.

Now look at the green line representing Julie's motion. During the time she is resting, her line is horizontal. A horizontal line on a distance-time graph has zero slope and represents an object at rest.

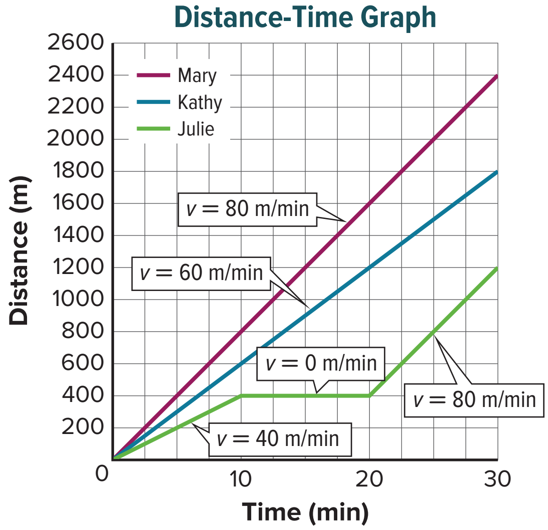


Figure 8 An object's speed is equal to the slope of the line on a distance-time graph.

Identify *the part of the graph that shows one of the swimmers resting for 10 min.*

Check Your Progress

Summary

- Motion occurs when an object changes its position relative to a reference point.
- Displacement is the distance and direction of a change in position from the starting point.
- Speed is the rate at which an object's position changes.
- On a distance-time graph, time is the *x*-axis, and distance is the *y*-axis.
- The slope of a line plotted on a distance-time graph is the speed.

Demonstrate Understanding

5. **Describe** the trip from your home to school using the words *position, distance, displacement,* and *speed*.
6. **Explain** whether an object's displacement could be greater than the distance the object travels.
7. **Describe** the motion represented by a horizontal line on a distance-time graph.
8. **Describe** the difference between average speed and constant speed.

Explain Your Thinking

9. **Explain** During a trip, can a car's instantaneous speed ever be greater than its average speed? Explain.
10. **MATH Connection** Michiko walked a distance of 1.60 km in 30 min. Find her average speed in m/s.
11. **MATH Connection** A car travels at a constant speed of 30.0 m/s for 0.80 h. Find the total distance traveled in km.

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LESSON 2
VELOCITY AND MOMENTUM

FOCUS QUESTION

How does the velocity of an object affect its momentum?

Velocity

You turn on the radio and hear a news story about a hurricane. The storm, traveling at a speed of 20 km/h, is located 500 km east of your location. Should you worry?

Unfortunately, you do not have enough information to answer that question. Knowing only the speed of the storm is not much help. Speed describes only how fast something is moving. To decide whether you need to move to a safer area, you also need to know the direction that the storm is moving. In other words, you need to know the velocity of the storm. **Velocity** includes the speed of an object and the direction of its motion. Velocity has the same units as speed, m/s. If you had been told that the hurricane was traveling straight toward your house at 20 km/h, you would have known to evacuate.

Velocity and speed

Because velocity depends on direction as well as speed, the velocity of an object can change even if the speed of the object remains constant. For example, the race cars in **Figure 9** have constant speeds through a turn. Even though the speeds remain constant, their velocities change because they change direction throughout the turn.

Get It?

Describe how velocity and speed are different.

Figure 9 These cars travel at constant speed, but not with constant velocity. The cars' velocities change because their direction of motion changes.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Lab: Motion Graphs

Carry out an investigation to measure the speed of a toy car and create a distancetime graph to model at what points its speed increased, decreased, or remained constant.

Laboratory: Velocity and Momentum

Carry out an investigation to determine how the relationship between the momentum of an object and how long a force acts on it.

Same speed, different velocities It is possible for two objects to have the same speed but different velocities. For example, the two escalators pictured in **Figure 10** are moving at the same speed but in different directions. The speeds of the two sets of passengers are the same, but their velocities are different because they are moving in different directions. Cars traveling in opposite directions on a road with the same speed also have different velocities.

Figure 10 The two escalators move with a speed of 0.5 m/s. But the closer escalator's velocity is 0.5 m/s downward, and to the left, while the closer escalator's velocity is 0.5 m/s upward and to the left.

Motion of Earth's Crust

Can you think of something that is moving so slowly that you cannot detect its motion, but you can see evidence of its motion over long periods of time? As you look around the surface of Earth from year to year, its basic structure seems the same. Mountains, plains, and oceans seem to remain unchanged. Yet, if you examined geologic evidence of what Earth's surface looked like over the past 250 million years, you would see that large changes have occurred. **Figure 11** shows how, according to the theory of plate tectonics, the positions of landmasses have changed during this time. Changes in the landscape occur constantly as continents drift slowly over Earth's surface.

These moving plates cause geologic changes, such as the formation of mountain ranges, earthquakes, and volcanic eruptions. The movement of the plates changes the size of the oceans. The Pacific Ocean is getting smaller, and the Atlantic Ocean is getting larger. As they collide and spread apart, the plates' movement also changes the shape of the continents.

Plates move so slowly that their speeds are given in units of centimeters per year. Along the San Andreas Fault in California, two plates move past each other with an average speed of about 1 cm per year. The Australian Plate moves faster and pushes Australia north at an average speed of about 17 cm/y. Therefore, the velocity of the Australian plate is 17 cm/y north.

Figure 11 Geologic evidence suggests that Earth's surface is changing. The continents have moved slowly over time and are still moving today.

About 250 million years ago, the continents formed a supercontinent called Pangaea.

Pangaea separated into smaller pieces. About 66 million years ago, the continents looked like the figure above.

hxdbzxy/Shutterstock

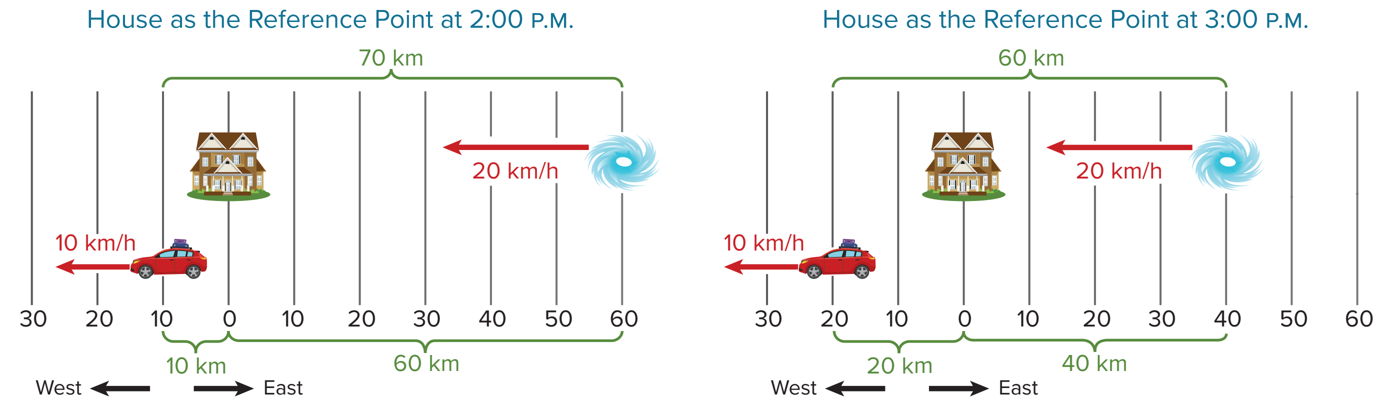

Figure 12 If the house is chosen for the reference point, the car appears to be traveling 10 km/h west, and the hurricane appears to be traveling 20 km/h west.

Relative Motion

Have you ever watched cars pass you on the highway? Cars traveling in the same direction often seem to creep by, while cars traveling in the opposite direction seem to zip by. This apparent difference in speeds is because the reference point—your vehicle—is also moving.

The choice of a moving reference point affects how you describe motion. For example, the motion of a hurricane can be described using a stationary reference point, such as a house. **Figure 12** shows the locations and velocities of a hurricane and a car relative to a house at 2:00 P.M. and 3:00 P.M. The distance between the hurricane and the house is decreasing at a rate of 20 km/h. The distance between the house and the car is increasing at a rate of 10 km/h.

How would the description of the hurricane's motion be different if the reference point were a car traveling at 10 km/h west? **Figure 13** shows the motion of the hurricane and the house relative to the car. A person in the car would say that the hurricane is approaching with a speed of 10 km/h and that the house is moving away at a speed of 10 km/h. It is important to notice that **Figure 12** and **Figure 13** show the same changes, but they use different reference points. Velocity and position always depend on the point of reference chosen.

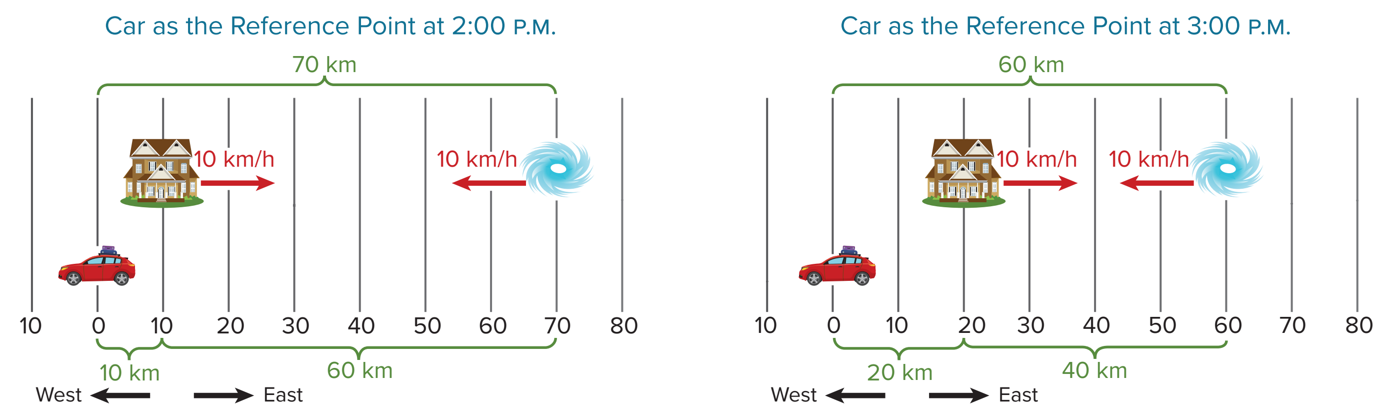

Figure 13 If the car is chosen as the reference point, the hurricane appears to be moving toward the car at 10 km/h, and the house is moving away from the car at 10 km/h.

Momentum

An object is moving at 2 m/s toward a glass vase. Will the vase be damaged in the collision? If the object has a small mass, like a bug, a collision will not damage the vase. But if the object has a larger mass, like a car, a collision will damage the vase.

A useful way of describing both the velocity and mass of an object is to state its momentum. The **momentum** of an object is the product of its mass and velocity. Momentum is usually represented by the symbol *p* and is defined for a particular frame of reference.

Table 3 Typical Momenta

Object	Momentum (kg·m/s)
Tossed baseball	0.15
Person walking	100
Car on interstate	45,000

Momentum Equation

momentum (in kg·m/s) = **mass** (in kg) × **velocity** (in m/s)

$$p = mv$$

The unit for momentum is kg·m/s. Like velocity, momentum has a size and a direction. An object's momentum is always in the same direction as its velocity. **Table 3** shows the momenta of some common objects.

Get It?

Explain how two objects could have the same velocity but different momentums.

EXAMPLE Problem 2

SOLVE FOR MOMENTUM At the end of a race, a sprinter with a mass of 80.0 kg has a velocity of 10.0 m/s east. What is the sprinter's momentum?

Identify the Unknown: momentum: p

List the Knowns: mass: m = 80.0 kg
velocity: v = 10.0 m/s east

Set Up the Problem: $p = mv$ = (80.0 kg) × (10.0 m/s) east

Solve the Problem: p = (80.0 kg)(10.0 m/s) east = 800.0 kg·m/s east

Check the Answer: Our answer makes sense because it is greater than the momentum of a walking person but much less than the momentum of a car on the highway.

PRACTICE Problems

ADDITIONAL PRACTICE

12. What is the momentum of a car with a mass of 1300 kg traveling north at a speed of 28 m/s?

13. A baseball has a momentum of 6.0 kg·m/s south and a mass of 0.15 kg. What is the baseball's velocity?

14. Find the mass of a person walking west at a speed of 0.8 m/s with a momentum of 52.0 kg·m/s west.

15. **CHALLENGE** The mass of a basketball is three times greater than the mass of a softball. Compare the momenta of a softball and a basketball if they are moving at the same velocity.

Figure 14 Both the car and the truck have a velocity of 30 m/s west, but the truck has a much larger momentum.

Comparing momenta

Think about the car and the truck in **Figure 14.** Which has the greater momentum? The truck does because it has more mass. When two objects travel at the same velocity, the object with more mass has a greater momentum. A difference in momenta is why a car traveling at 2 m/s might damage a porcelain vase, but an insect flying at 2 m/s will not.

Now consider two 1-mg insects. One insect flies at a speed of 2 m/s, and the other flies at a speed of 4 m/s. The second insect has a greater momentum. If two objects have the same mass, the object with the greater velocity has the greater momentum.

Check Your Progress

Summary

- The velocity of an object includes the object's speed and its direction of motion relative to a reference point.
- An object's motion is always described relative to a reference point.
- The momentum of an object is defined for a particular frame of reference and is the product of the object's mass and velocity: $p = mv$.

Demonstrate Understanding

16. **Describe** a car's velocity as it goes around a track at a constant speed.
17. **Explain** why streets and highways have speed limits rather than velocity limits.
18. **Identify** For each of the following news stories, determine whether the object's speed or velocity is given: the world record for the 100-meter dash is about 10 m/s; the wind is 30 km/h from the northwest; a 200,000 kg train was traveling north at 70 km/h when it derailed; a car was issued a ticket for traveling at 140 km/h on the interstate.

Explain Your Thinking

19. **Describe** You are walking toward the back of a bus that is moving forward with a constant velocity. Describe your motion relative to the frame of reference of the bus and relative to the frame of reference of a point on the ground.
20. **MATH Connection** What is the momentum of a 100-kg football player running north at a speed of 4 m/s?
21. **MATH Connection** Compare the momenta of a 6300-kg elephant walking 0.11 m/s and a 50-kg dolphin swimming 10.4 m/s.

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LESSON 3
ACCELERATION

FOCUS QUESTION

How does acceleration result in projectile motion?

Velocity and Acceleration

You are in a stopped car when the light turns green. The driver steps on the gas pedal, and the car starts moving faster and faster. Just as speed is the rate of change of position, **acceleration** is the rate of change of velocity. When the velocity of an object changes, the object is accelerating. Remember that velocity includes the speed and direction of an object. Therefore, a change in velocity can be either a change in speed or a change in direction. Acceleration occurs when an object changes its speed, its direction, or both.

When you think of acceleration, you might think of speeding up. However, an object that is slowing down also is accelerating, as is an object that is changing direction. **Figure 15** shows the three ways an object can accelerate. Like velocity and momentum, acceleration has a direction. In **Figure 15,** you can see that when the car is speeding up, its acceleration and velocity are in the same direction. When the car is slowing down, its acceleration is in the opposite direction of its velocity. When the car changes direction, the acceleration is neither in the same direction nor opposite direction as the car's velocity.

Get It?
Identify three ways that an object can accelerate.

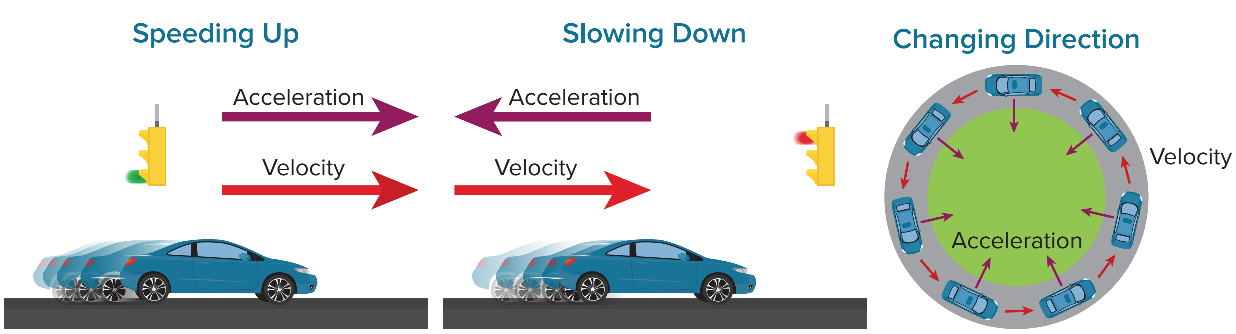

Figure 15 An object, such as this car, is accelerating if it is speeding up, slowing down, or changing direction.

3D THINKING — DCI Disciplinary Core Ideas — CCC Crosscutting Concepts — SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Laboratory: Projectile Motion
Carry out an investigation to analyze and use data on the projectile motion of objects to model and predict different trajectories.

LabA: The Momentum of Colliding Objects
Carry out an investigation to observe and calculate the momentum of different balls, and to compare the results of collisions involving different amounts of momentum.

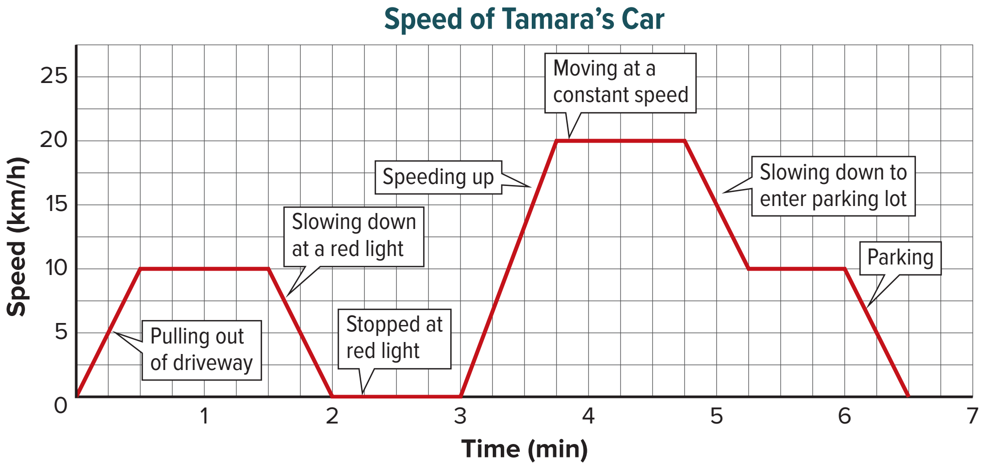

Figure 16 For objects that are speeding up and slowing down, the slope of the line on a speed-time graph is the acceleration.

Identify *the time intervals during which Tamara's car is not accelerating.*

Speed-time graphs and acceleration

When an object travels in a straight line and does not change direction, a graph of speed versus time can provide information about the object's acceleration. **Figure 16** shows the speed-time graph of Tamara's car as she drives to the store. Just as the slope of a line on a distance-time graph is the object's speed, the slope of a line on a speed-time graph is the object's acceleration. For example, when Tamara pulls out of her driveway, the car's acceleration is 0.33 km/min^2, which is equal to the slope of the line from $t = 0$ to $t = 0.5$ min.

Calculating acceleration

Acceleration is the rate of change in velocity. To calculate the acceleration of an object, the change in velocity is divided by the length of the time interval over which the change occurs. The change in velocity is the final velocity minus the initial velocity. If the direction of motion does not change and the object moves in a straight line, the size of the change in velocity can be calculated from the change in speed. Then, the acceleration of an object can be calculated from the following equation.

Acceleration Equation

$$\text{acceleration (in meters/second}^2\text{)} = \frac{\text{change in velocity (in meters/second)}}{\text{time (in seconds)}}$$

$$a = \frac{v_f - v_i}{t}$$

In SI units, velocity has units of m/s and time has units of s, so the SI unit of acceleration is m/s^2. In some cases, your calculations will result in a negative acceleration. The negative sign means *in the opposite direction*. For example, an acceleration of -10 m/s^2 north is the same as 10 m/s^2 south.

CCC CROSSCUTTING CONCEPTS

Systems and System Models Create a table to demonstrate the importance of defining the initial conditions of a system when discussing acceleration. Change the initial conditions of the system's motion to show how a given acceleration can result in different final velocities.

EXAMPLE Problem 3

CALCULATE ACCELERATION A skateboarder has an initial velocity of 3 m/s west and comes to a stop in 2 s. What is the skateboarder's acceleration?

Identify the Unknown: acceleration: a

List the Knowns: initial velocity: v_i = 3 m/s west

final velocity: v_f = 0 m/s west

time: t = 2 s

Set Up the Problem: $a = \frac{(v_f - v_i)}{t} = \frac{(0 \text{ m/s} - 3 \text{ m/s})}{2 \text{ s}}$ west

Solve the Problem: $a = \frac{(0 \text{ m/s} - 3 \text{ m/s})}{2 \text{ s}} = -1.5 \text{ m/s}^2$ west

The acceleration has a negative sign, so the direction is reversed.

$a = 1.5 \text{ m/s}^2$ east

Check the Answer: The magnitude of the acceleration (1.5 m/s²) is reasonable for a skateboard that takes 2 s to slow from 3 m/s to 0 m/s. The acceleration is in the opposite direction of the velocity, so the skateboard is slowing down, as we expected.

PRACTICE Problems

ADDITIONAL PRACTICE

22. An airplane starts at rest and accelerates down the runway for 20 s. At the end of the runway, its velocity is 80 m/s north. What is its acceleration?

23. A cyclist starts at rest and accelerates at 0.5 m/s² south for 20 s. What is the cyclist's final velocity?

24. **CHALLENGE** A ball is dropped and falls with an acceleration of 9.8 m/s² downward. It hits the ground with a velocity of 49 m/s downward. How long did it take the ball to fall to the ground?

Motion in Two Dimensions

So far, we have discussed only motion in a straight line. But most objects are not restricted to moving in a straight line. Recall that we cannot add measurements that are not in the same or opposite directions. So, we will discuss motion in each direction separately. For example, suppose a student walked three blocks north and four blocks east. The trip could be described this way: the student walked north for three blocks at 1 m/s and then walked east for four blocks at 2 m/s.

Recall that objects that change direction are accelerating. For an object that is changing direction, its acceleration is not in the same or opposite direction as its velocity. This means that we cannot use the acceleration equation. Just as with displacement and velocity, accelerations that are not in the same or opposite directions cannot be directly combined.

Get It?

Explain why you cannot use the acceleration equation for an object that changes direction.

Circular motion

Think about a horse's horizontal motion on a carousel, such as the one in **Figure 17.** The horse moves in a circular path. Its speed remains constant, but it is accelerating because its direction of motion changes. The change in the direction of the horse's velocity is toward the center of the carousel. The horse's velocity is perpendicular to the inward acceleration. Acceleration toward the center of a curved or circular path is called **centripetal acceleration.** In the same way, Earth experiences centripetal acceleration as it orbits the Sun in a nearly circular path.

Get It?

Define the term *centripetal acceleration.*

Projectile motion

If you have tossed a ball to someone, you have probably noticed that thrown objects do not travel in straight lines. They curve downward. That is why quarterbacks, dart players, and archers aim above their targets. Anything that is thrown or shot through the air is called a projectile. Earth's gravity causes projectiles to follow a curved path.

Horizontal and vertical motion When you throw or shoot an object, such as the rubber band in **Figure 18,** the force exerted by your hand gives the object a horizontal velocity. For example, after the rubber band is released, its horizontal velocity is constant. The rubber band does not accelerate horizontally. If there were no gravity, the rubber band would move along the straight dotted line in **Figure 18.**

However, when you release a rubber band, gravity causes it to accelerate downward. The rubber band has an increasing vertical velocity. The result of these two motions is that the rubber band travels in a curve, even though its horizontal and vertical motions are completely independent of each other.

Centripetal Acceleration

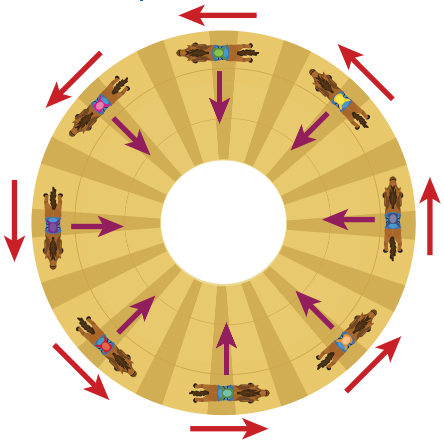

Figure 17 The horizontal speed of the horses in this carousel is constant, but the horses are accelerating because their direction is changing constantly. The acceleration of each horse is toward the center of the circular carousel.

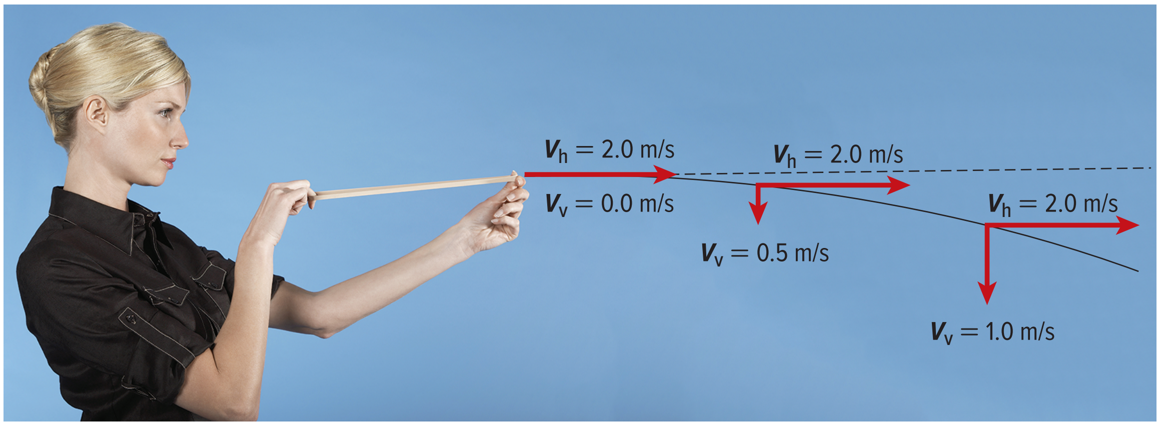

Figure 18 The woman gives the rubber band a horizontal velocity. The horizontal velocity of the rubber band remains constant, but gravity causes the rubber band to accelerate downward. The combination of these two motions causes the rubber band to move in a curved path.

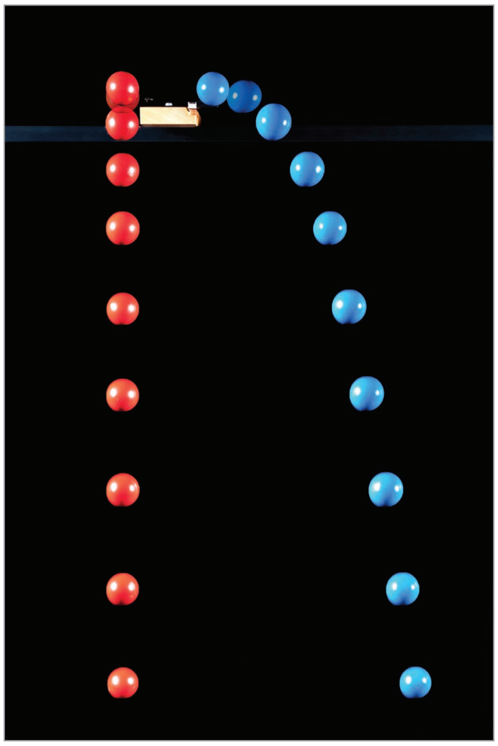

Figure 19 The dropped ball and the thrown ball in this multiflash photograph have the same downward acceleration.

Throwing and dropping If you were to throw a ball as hard as you could in a perfectly horizontal direction, would it take longer to reach the ground than if you dropped a ball from the same height? Surprisingly, it will not. A thrown ball and a dropped ball will hit the ground at the same time. Both balls in **Figure 19** travel the same vertical distance in the same amount of time. However, the ball thrown horizontally travels a greater horizontal distance than the ball that is dropped.

Amusement park acceleration

Riding roller coasters in amusement parks can give you the feeling of danger, but these rides are designed to be safe. Engineers use the laws of physics to design amusement park rides that are thrilling but harmless. Roller coasters are constructed of steel or wood. Because wood is not as strong as steel, wooden roller coasters do not have hills that are as high and as steep as those of some steel roller coasters.

The highest speeds and accelerations are usually produced on steel roller coasters. Steel roller coasters can offer multiple steep drops and inversion loops, which give the riders large accelerations. As riders move down a steep hill or an inversion loop, they will accelerate toward the ground due to gravity. When riders go around a sharp turn, they are also accelerated. This acceleration is due to a change in direction.

Check Your Progress

Summary

- Acceleration is the rate of change of velocity.
- The speed of an object increases if the acceleration is in the same direction as the velocity.
- The speed of an object decreases if the acceleration and the velocity of the object are in opposite directions.
- If an object is moving in a straight line, the change in velocity equals the final speed minus the initial speed.
- Acceleration toward the center of a curved or circular path is called centripetal acceleration.

Demonstrate Understanding

25. **Describe** the acceleration of your bicycle as you ride it from your home to the store.
26. **Determine** the change in velocity of a car that starts at rest and has a final velocity of 20 m/s north.
27. **Analyze** the motion of an object that has an acceleration of 0 m/s^2.

Explain Your Thinking

28. **Compare** Suppose a car is accelerating so that its speed is increasing. First, describe the line that you would plot on a speed-time graph for the motion of the car. Then describe the line that you would plot on a distance-time graph.
29. **MATH Connection** A ball is dropped from a cliff and has an acceleration of 9.8 m/s^2. How long will it take the ball to reach a speed of 24.5 m/s?
30. **MATH Connection** A sprinter leaves the starting blocks with an acceleration of 4.5 m/s^2. What is the sprinter's speed 2 s later?

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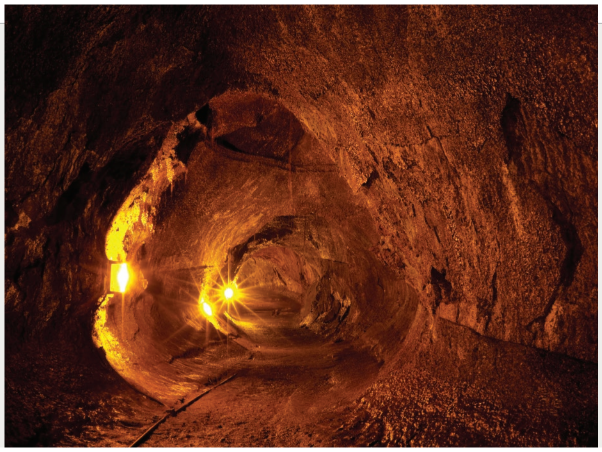
Autonomous Vehicles Go Subterranean

In 2004, the Defense Advanced Research Projects Agency (DARPA) held a competition that opened the door for the development of autonomous vehicles. At the time, driverless cars were the stuff of science fiction, but the DARPA Grand Challenge helped move self-driving technology forward. Today, car companies are testing autonomous cars on rural and urban roads, and these vehicles may soon be part of our everyday lives.



Underground tunnels provide a testing ground for advances in autonomous vehicles.

Physics at the wheel

How can a vehicle operate autonomously? To move safely, it must interpret the environment, evaluate its position relative to the destination, navigate obstacles, and control speed and direction of motion. Light beams emitted by lasers and radio waves given off by a radar unit bounce off surrounding objects and geographical features. Reflection times determine distances between a vehicle and these objects and help evaluate changes in position and terrain.

Additional position data is provided by the Global Positioning System (GPS) and sensors that measure wheel rotation and direction of motion. The vehicle's computer integrates all incoming data, compares it to a map of the route, and makes necessary adjustments in steering, throttling, and braking.

DARPA Subterranean Challenge

The DARPA Subterranean (SubT) Challenge requires competitors to map, navigate, and search underground environments such as natural cave networks and human-made tunnels. Teams of engineers, scientists, and citizens from around the world will compete in the Challenge, developing hardware and software for testing on a variety of courses to conquer tight passages, vertical shafts, underground water, unstable structures, and darkness while not being able to depend on GPS.

The Challenge will not produce the ultimate below-ground autonomous vehicle, but if it advances the technology used to work in underground environments, future vehicles could help save lives.

COMMUNICATE SCIENTIFIC INFORMATION

Brainstorm the potential benefits of using automated vehicles in underground settings. Use your ideas to design a poster advertising an automated underground vehicle service. Share your poster with the class.

MODULE 2

STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 DESCRIBING MOTION

- Motion occurs when an object changes its position relative to a reference point.
- Displacement is the distance and direction of a change in position from the starting point.
- Speed is the rate at which an object's position changes.
- On a distance-time graph, time is the x-axis, and distance is y-axis.
- The slope of a line plotted on a distance-time graph is the speed.

- motion
- displacement
- speed

Lesson 2 VELOCITY AND MOMENTUM

- The velocity of an object includes the object's speed and its direction of motion relative to a reference point.
- An object's motion is always described relative to a reference point.
- The momentum of an object is defined for a particular frame of reference and is the product of the object's mass and velocity: $p = mv$.

- velocity
- momentum

Lesson 3 ACCELERATION

- Acceleration is the rate of change of velocity.
- The speed of an object increases if the acceleration is in the same direction as the velocity.
- The speed of an object decreases if the acceleration and the velocity of the object are in opposite directions.
- If an object is moving in a straight line, the change in velocity equals the final speed minus the initial speed.
- Acceleration toward the center of a curved or circular path is called centripetal acceleration.

- acceleration
- centripetal acceleration

THREE-DIMENSIONAL THINKING

Module Wrap-Up

REVISIT THE PHENOMENON

Why is this motor bike traveling in an arc?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

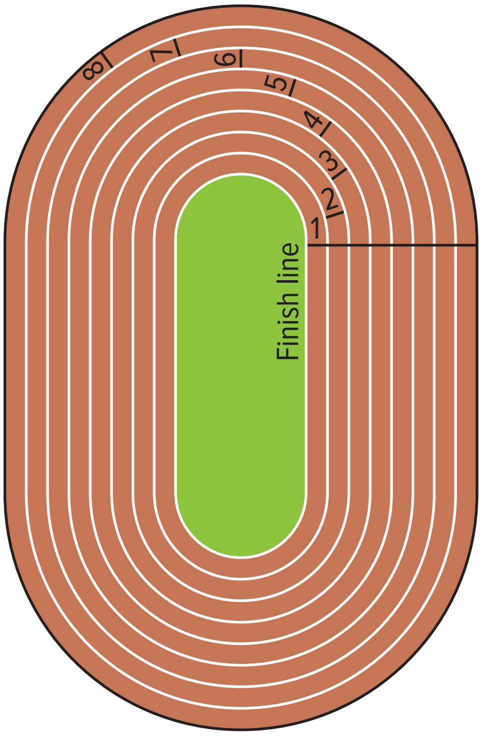
Now that you've completed the module, revisit your STEM unit project. You will summarize your evidence and apply it to the project.

GO FURTHER

SEP Data Analysis Lab

The 400 Meter Dash

The 400-m sprint, or dash, is a footrace that is equal to one lap around a running track. To complete the distance of 400 m on a standard running track, the starting positions of the runners are staggered, with one runner actually starting at the finish line. At the sound of a starting pistol, the athletes take off from their fixed positions and speed up to advance beyond the other runners. Some runners have a strong "kick," or an ability to increase their velocity at the end of the race.



The diagram on the right shows the starting positions for eight racers in a 400-m race. Look at the diagram and answer the questions below.

CER Analyze and Interpret Data

1. **Claim and Evidence** The starting positions indicated on the diagram are typical for a 400-m dash. Why are the runners not all starting together in a straight line?
2. **Claim, Evidence, Reasoning** At the completion of a race, what is the displacement of the runner in lane 1? Is this the same for all the runners? Explain your answer.
3. **Claim, Evidence, Reasoning** If a male runner in the fourth starting position ran the 400-m race in 44.40 s, how would you calculate his average speed? Explain your answer.

Stephen Barnes/Sport/Alamy Stock Photo


format35/iStock/Getty Images

MODULE 3

FORCES AND NEWTON'S LAWS

ENCOUNTER THE PHENOMENON

Why can a car stop faster than a train?

GO ONLINE to play a video about how leaves affect friction on the wheels of a train.

SEP Ask Questions

Do you have other questions about the phenomenon? If so, add them to the driving question board.

CER Claim, Evidence, Reasoning

Make Your Claim Use your CER chart to make a claim about why a car can stop faster than a train. Explain your reasoning.

Collect Evidence Use the lessons in this module to collect evidence to support your claim. Record your evidence as you move through the module.

Explain Your Reasoning You will revisit your claim and explain your reasoning at the end of the module.

GO ONLINE to access your CER chart and explore resources that can help you collect evidence.

LESSON 1: Explore & Explain: Gravity

LESSON 3: Explore & Explain: What happens in a crash?

Smithsonian

Additional Resources

(t)Video Supplied by BBC Worldwide Learning, (bl)Cassini/NASA, (br)TRL Ltd./Science Source

LESSON 1
FORCES

FOCUS QUESTION

How does friction affect motion?

What is force?

Catching a basketball and hitting a baseball with a bat are examples of applying force to an object. A **force** is a push or a pull. In both examples, the applied force changes the movement of the ball. Sometimes it is obvious that a force has been applied. But other forces are not as noticeable. For instance, are you conscious of the force that the floor exerts on your feet? Can you feel the force of the atmosphere pushing against your body or gravity pulling on your body? Think about all of the forces that you exert in a day. Every push, pull, stretch, or bend is a force being applied to an object.

Changing motion

What happens to the motion of an object when you exert a force on it? A force can cause the motion of an object to change. Think of kicking a soccer ball, as shown in **Figure 1.** The player's foot strikes the ball with a force that causes the ball to stop and then move in the opposite direction. If you have played billiards, you know that you can make a ball at rest roll into a pocket by striking it with another ball. The force from the moving ball causes the ball at rest to move in the direction of the force. In each case, the velocity of the ball was changed by a force.

Figure 1 When the player kicks the soccer ball, she is exerting a force on the ball. This kick will cause the ball's motion to change.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Laboratory: Friction Predictions

Carry out an investigation to observe and compare the forces in a system needed to move an object over surfaces with varying degrees of friction.

Quick Investigation: Compare Friction

Carry out an investigation to observe and compare how surfaces with different levels of friction interact in a system to prevent an object from sliding.

Net force

When two or more forces act on an object at the same time, the forces combine to form the net force. The **net force** is the sum of all of the forces acting on an object. Forces have a direction, so they follow the same addition rules as displacement, as listed in **Table 1.** Forces are measured in SI units of newtons (N). A force of about 3 N is needed to lift a full can of soda at a constant speed.

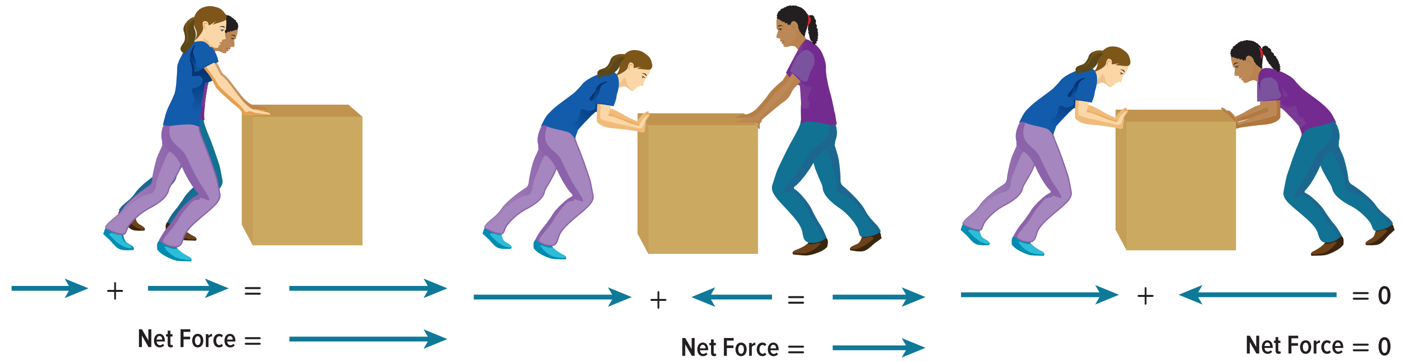
Table 1 **Rules for Adding Forces**

1.	Add forces in the same direction.
2.	Subtract forces in opposite directions.
3.	Forces that are neither in the same direction nor in opposite directions cannot be directly added together.

Unbalanced forces Look at **Figure 2A.** The students are each pushing on the box in the same direction. These forces are combined, or added together, because they are exerted on the box in the same direction. The students in **Figure 2B** are pushing in opposite directions. Here, the direction of the net force is the same as the direction of the greater force. In other words, the student who pushes harder causes the box to move in the direction of that push. The net force is the difference between the two forces because they are in opposite directions. In **Figure 2A** and **Figure 2B,** the net force has a value that is not zero, and the box moves. The forces that the students apply are considered unbalanced forces.

Balanced forces Now suppose that the students are pushing with the same size force but in opposite directions, as shown in **Figure 2C.** The net force on the box is zero because the two forces cancel each other. Forces that are equal in size and opposite in direction are called balanced forces. Unbalanced forces cause changes in motion. Balanced forces do not cause a change in motion.

Figure 2 Forces can be balanced or unbalanced.
Identify *another example of unbalanced forces and another example of balanced forces.*



[A] Two students push on the box in the same direction. These forces are unbalanced. The net force is the sum of the two forces, and the box will move in the direction that the students push.

[B] Two students push on the box with unequal forces in opposite directions. These forces are unbalanced. The net force is the difference of the two forces, and the box will move in the direction of the greater force.

[C] Two students push on the box with equal forces but in opposite directions. These forces are balanced. The net force is zero, and the box does not move.

Friction

Suppose you give a skateboard a push with your hand. After you let go, the skateboard slows down and eventually stops. Because the skateboard's motion is changing as it slows down, there must be a force acting on it. The force that slows the skateboard is called friction. **Friction** is the force that opposes the sliding motion of two surfaces that are touching each other.

Figure 3 The surface of this teapot looks and feels smooth, but it is rough at the microscopic level.

What causes friction?

Would you believe that the surface of a highly polished piece of metal is rough? Surfaces that appear smooth actually have many bumps and dips. These bumps and dips can be seen when the surface is examined under a microscope, as shown in **Figure 3.** If two surfaces are in contact, welding or sticking occurs where the bumps touch each other. These microwelds are the source of friction. To move one surface over the other, a force must be applied to break the microwelds.

Get It?
Describe the source of friction.

The amount of friction between two surfaces depends on the kinds of surfaces and the force pressing the surfaces together. Rougher surfaces have more bumps and can form more microwelds, increasing the amount of friction. In addition, a larger force pushing the two surfaces together will cause more of the bumps to come into contact, as shown in **Figure 4.** The microwelds will be stronger, and a greater force must be applied to break them apart.

Static friction

Suppose you have a cardboard box filled with books, such as the one in **Figure 5,** and you want to move that box. The box is resting on what seems to be a smooth floor, but when you push on the box, it does not budge. The box experiences no change in motion, so the net force on the box is zero. The force of friction cancels your push.

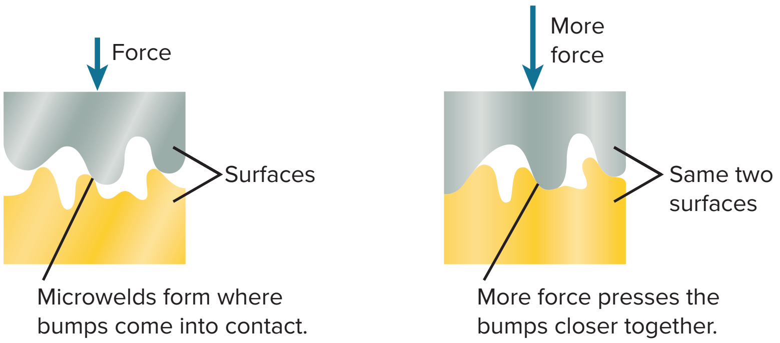


Figure 4 Friction is caused by microwelds that form between two surfaces. Microwelds are stronger when the two surfaces are pushed together with a greater force.
Explain *how the area of contact between the surfaces changes when they are pushed together.*

Static friction balances the applied force. The box remains at rest and does not accelerate.

Sliding friction and the applied force are unbalanced. The box accelerates to the right.

Figure 5 Friction opposes the sliding motion of two surfaces that are touching each other.
Describe *the net force on each box.*

This type of friction is called static friction. Static friction prevents two surfaces from sliding past each other and is due to the microwelds that have formed between the bottom of the box and the floor. Your push is not great enough to break the microwelds, and the box does not move, as shown in **Figure 5.**

Sliding friction

If you and a friend push together, as shown on the right in **Figure 5,** the box moves. Together, you and your friend have exerted enough force to break the microwelds between the floor and the bottom of the box. But if you stop pushing, the box quickly comes to a stop. To keep the box moving, you must continually apply a force. This is because sliding friction opposes the motion of the box as the box slides across the floor. Sliding friction opposes the motion of two surfaces sliding past each other and is caused by microwelds constantly breaking and forming as the objects slide past each other. The force of sliding friction is usually less than the force of static friction.

Rolling friction

You may think of friction as a disadvantage. But wheels, like the ones shown in **Figure 6,** would not work without friction. As a wheel rolls, static friction acts over the area where the wheel and surface are in contact. This special case of static friction is sometimes called rolling friction.

You may have seen a car that was stuck in snow, ice, or mud. The driver steps on the gas, but the wheels just spin without the car moving. The force used to rotate the tires is greater than the force of static friction between the wheels and the ground, so the tires slide instead of gripping the ground. Spreading sand or gravel on the surface increases the friction until the wheels stop slipping and begin rolling. When referring to tires on vehicles, people often use the term *traction* instead of *friction*.

Figure 6 Rolling friction between the bicycle's wheels and the pavement keeps the wheels from slipping.

Gravity

At this moment, you are exerting an attractive force on everything around you—your desk, your classmates, and even the planet Jupiter, millions of kilometers away. This attractive force acts on all objects with mass and is called gravity. **Gravity** is an attractive force between any two objects that depends on the masses of the objects and the distance between them.

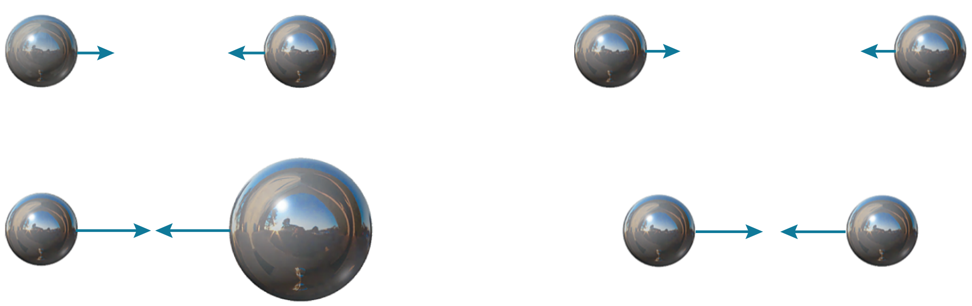
Gravity is one of the four basic forces called the fundamental forces. The other basic forces are the electromagnetic force, the strong nuclear force, and the weak nuclear force. Gravity acts on all objects with mass, and the electromagnetic force acts on all charged particles. Both gravity and the electromagnetic force have an infinite range. The nuclear forces affect only particles in the nuclei of atoms.

The law of universal gravitation

In the 1660s, English scientist Isaac Newton used data on the motions of the planets to find the relationship between the gravitational force between two objects, the objects' masses, and the distance between them. This relationship is called the law of universal gravitation and can be written as the following equation.

$$F = G\frac{m_1 m_2}{d^2}$$

In this equation, G is the universal gravitational constant, and d is the distance between the centers of the two masses, m_1 and m_2. The law of universal gravitation states that the gravitational force increases as the mass of either object increases and as the objects move closer, as shown in **Figure 7.** The force of gravity between any two objects can be calculated if their masses and the distance between them are known.



If the mass of either of the objects increases, the gravitational force between them increases.

If the objects are closer together, the gravitational force between them increases.

Figure 7 The law of universal gravitation states that the gravitational force between two objects depends on their masses and the distance between them.

Gravity and you The law of universal gravitation explains why you feel Earth's gravity but not the Sun's gravity or this book's gravity. While the Sun has much more mass than Earth, the Sun is too far away to exert a noticeable gravitational attraction on you. And while this book is close, it does not have enough mass to exert an attraction that you can feel. Only Earth is both close enough and massive enough that you can feel its gravitational attraction.

The range of gravity According to the law of universal gravitation, the gravitational force between two masses decreases rapidly as the distance between the masses increases. For example, if the distance between two objects increases from 1 m to 2 m, the gravitational force between them becomes one-fourth as large. If the distance increases from 1 m to 10 m, the gravitational force between the objects is one-hundredth as large. However, no matter how far apart two objects are, the gravitational force between them never completely drops to zero. Because the gravitational force between two objects never disappears, gravity is called a long-range force.

Get It?
Explain why gravity is called a long-range force.

The gravitational field Forces that act at a distance, without requiring contact between objects, can be explained using the concept of a field. A **field** is a region of space that has a physical quantity (such as a force) at every point. All objects are surrounded by a gravitational field. **Figure 8** shows that Earth's gravitational field is strongest near Earth and becomes weaker as the distance from Earth increases. The strength of the gravitational field, represented by the letter *g*, is measured in newtons per kilogram (N/kg).

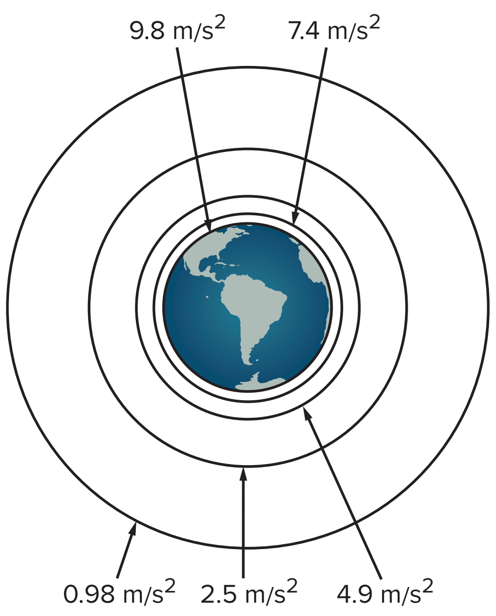


Figure 8 Earth's gravitational field exists at all points in space. It is strongest near the surface and decreases in strength as one moves away from Earth.

Weight The gravitational force exerted on an object is the object's **weight.** The universal law of gravitation can be used to calculate weight, but scientists use a simplified version of this equation that combines m_1, d^2, and G into a single number called the gravitational strength, g.

Weight Equation

weight (N) = **mass** (kg) × **gravitational strength** (N/kg)

$$F_g = mg$$

We use F_g for weight because weight is the force due to gravity. Weight has units of newtons (N) because it is a force. The g in the subscript stands for *gravity*. The gravitational strength, g, has the units N/kg. Recall that 1 N = 1 kg · m/s². So, g can also be written with units of m/s².

Weight and mass Weight and mass are not the same. Weight is a force, and mass is a measure of the amount of matter an object contains. But, according to the weight equation, weight and mass are related. Weight increases as mass increases.

Weight on Earth We often need to know an object's weight on Earth. At Earth's surface, m_1 is Earth's mass, and d is Earth's radius. Using those values in the law of universal gravitation shows that g = 9.8 N/kg near Earth's surface. **Table 2** lists the weights of some objects on Earth.

Table 2 Weight of Common Objects on Earth

Object	Weight
Cell phone	1 N
Backpack full of books	100 N
Jumbo jet	3.4 million N

EXAMPLE Problem 1

SOLVE FOR WEIGHT An elephant has a mass of 5000 kg. What is the elephant's weight?

Identify the Unknown: weight: F_g

List the Knowns: mass: m = **5000 kg**

gravitational strength: g = **9.8 N/kg**

Set Up the Problem: $F_g = mg$

Solve the Problem: F_g = (**5000 kg**)(**9.8 N/kg**) = **49,000 N**

Check the Answer: The gravitational strength is about 10 N/kg, so we would expect the elephant's weight to be about 50,000 N. Our answer (F_g = 49,000 N) makes sense.

PRACTICE Problems

ADDITIONAL PRACTICE

1. A squirrel has a mass of 0.5 kg. What is its weight?
2. A boy weighs 400 N. What is his mass?
3. **CHALLENGE** An astronaut has a mass of 100 kg and has a weight of 370 N on Mars. What is the gravitational strength on Mars?

Weight away from Earth An object's weight usually refers to the gravitational force between the object and Earth. But the weight of an object can change, depending on the gravitational force on the object. For example, the gravitational strength on the Moon is 1.6 N/kg, about one-sixth as large as Earth's gravitational strength. As a result, a person, such as the astronaut in **Figure 9,** would weigh only about one-sixth as much on the Moon as on Earth.

Figure 9 Although the astronaut has the same mass on the Moon, he weighs less than he does on Earth. He can take longer steps and jump higher than on Earth.

Finding other planets

Earth's motion around the Sun is affected by the gravitational pulls of the other planets in the solar system. In the same way, the motion of every planet in the solar system is affected by the gravitational pulls of all of the other planets.

In the 1840s, the most distant planet known was Uranus. The motion of Uranus calculated from the law of universal gravitation disagreed slightly with its observed motion. Some astronomers suggested that there must be an undiscovered planet affecting the motion of Uranus. Using the law of universal gravitation and the laws of motion, two astronomers independently calculated the orbit of this planet. As a result of these calculations, the planet Neptune was found in 1846.

Check Your Progress

Summary

- A force is a push or a pull on an object.
- The net force on an object is the combination of all of the forces acting on the object.
- Unbalanced forces cause the motion of objects to change.
- Friction is the force that opposes the sliding motion of two surfaces that are in contact.
- Gravity is an attractive force between all objects that have mass.

Demonstrate Understanding

4. **Describe** two forces that would change the motion of a bicycle traveling along a road.
5. **Explain** Can there be forces acting on an object if the object is at rest? Must there be an unbalanced force acting on a moving object? Explain your answers.
6. **Explain** Why does coating surfaces with oil reduce friction between the surfaces?
7. **Distinguish** between the mass of an object and the object's weight.

Explain Your Thinking

8. **Predict** Suppose Earth's mass increased but Earth's diameter did not change. Describe how the gravitational force between Earth and an object on its surface would change.
9. **MATH Connection** On Earth, what is the weight of a large-screen TV that has a mass of 75 kg?
10. **MATH Connection** Two students push on a box in the same direction, and one student pushes in the opposite direction. What is the net force on the box if each student pushes with a force of 50 N?

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LESSON 2
NEWTON'S LAWS OF MOTION

FOCUS QUESTION

How do forces affect acceleration?

Isaac Newton and the Laws of Motion

In 1665, Cambridge University in England closed for 18 months because of the bubonic plague. Isaac Newton, a 23-year-old student, used this time to develop the law of universal gravitation, calculus, and three laws describing how forces affect the motion of objects. Newton's laws of motion apply to the motion of everyday objects, such as cars and bicycles, as well as the motion of planets and stars.

Newton's First Law of Motion

Recall that forces change an object's motion. Newton's first law explains the relationship between force and change in motion. **Newton's first law of motion** states that an object moves at a constant velocity unless an unbalanced force acts on it. This means that a moving object will continue to move in a straight line at a constant speed unless an unbalanced force acts on it. If an object is at rest, its velocity is zero, and it stays at rest unless an unbalanced force acts on it. Newton's first law is sometimes called the law of inertia. **Inertia** (ih NUR shuh) is the tendency of an object to resist any change in its motion. **Figure 10** shows a toy car hitting a block and stopping. The block on top of the car is not attached to the car and keeps traveling. The block's forward motion demonstrates the property of inertia.

Figure 10 You might have seen the law of inertia without even knowing it. For example, as the car hits the wooden block and stops, the red block continues to move forward.

Describe *another example of inertia.*

3D THINKING · DCI Disciplinary Core Ideas · CCC Crosscutting Concepts · SEP Science & Engineering Practices

COLLECT EVIDENCE

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INVESTIGATE

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Applying Practices: Newton's Second Law

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Inertia and mass Does a bowling ball have the same inertia as a table-tennis ball? Why is there a difference? Swatting a ball with a table-tennis paddle would not change the motion of a bowling ball much, but it would greatly accelerate a table-tennis ball. A greater force would be needed to change the motion of a bowling ball because it has greater inertia.

Recall that mass is the amount of matter in an object. An object's inertia is related to its mass. The greater an object's mass is, the greater its inertia is. A bowling ball has more mass than a table-tennis ball, so the bowling ball has a greater inertia.

You will sometimes hear people say that when an object begins to move, inertia is overcome. This is not true. The object still has mass when it is moving, so it still has inertia. As long as the mass is the same, the object has the same inertia.

Newton's Second Law of Motion

Newton's first law of motion states that the motion of an object changes only if an unbalanced force acts on the object. Newton's second law of motion describes how the forces exerted on an object, its mass, and its acceleration are related.

Force and acceleration

How are throwing a ball as hard as you can and tossing it gently different? When you throw hard, you exert a greater force on the ball. The ball has a greater velocity when it leaves your hand. The hard-thrown ball has a greater change in velocity, and the change occurs over a shorter period of time. Recall that acceleration equals the change in velocity divided by the time it takes for the change to occur. So, a hard-thrown ball is accelerated more than a gently-thrown ball, as shown in **Figure 11.**

Figure 11 According to Newton's second law of motion, the harder you throw a baseball, the greater its acceleration will be.

Figure 12 If both pitchers apply the same force, the baseball will experience a greater acceleration than the softball because the baseball has less mass.

Mass and acceleration

If you throw a softball and a baseball as hard as you can, as shown in **Figure 12,** why do they not have the same speed? The difference is due to their masses. A softball has a mass of about 0.20 kg, but a baseball's mass is about 0.14 kg. The softball has less velocity after it leaves your hand than the baseball does, even though you exerted the same force. The softball has a lesser final speed because it experienced a lesser acceleration. The acceleration of an object depends on its mass as well as the force exerted on it. Force, mass, and acceleration are related.

Get It?

Identify You apply a force of 2 N to a toy car and to a real car. Which car has the greater acceleration?

Relating force, mass, and acceleration

Newton's second law of motion states that an object's acceleration is in the same direction as the net force on the object and is equal to the net force exerted on it divided by its mass. Newton's second law can be written as the following equation.

The Second Law of Motion Equation

$$\textbf{acceleration} \text{ (in meters/second}^2\text{)} = \frac{\textbf{net force} \text{ (in newtons)}}{\textbf{mass} \text{ (in kilograms)}}$$

$$a = \frac{F_{net}}{m}$$

In the above equation, acceleration has units of meters per second squared (m/s^2), and mass has units of kilograms (kg). Recall that the net force is the sum of all of the forces on an object. Remember that the SI unit for force is a newton (N) and that 1 N = 1 kg·m/s^2. Just like velocity and acceleration, force has a size and a direction.

Calculating net force Newton's second law can also be used to calculate the net force if mass and acceleration are known. To do this, the equation for Newton's second law must be solved for the net force, F_{net}. To solve for the net force, multiply both sides of the above equation by the mass.

$$m \times a = \cancel{m} \times \frac{F_{net}}{\cancel{m}}$$

The mass, m, on the right side cancels.

$$F_{net} = ma$$

For example, when a tennis player hits a ball, the racket and the ball might be in contact for only a few thousandths of a second. Because the ball's velocity changes over such a short period of time, the ball's acceleration could be as high as 5000 m/s^2. The ball's mass is 0.06 kg, so the size of the net force exerted on the ball would be 300 N.

$$F_{net} = ma = (0.06\ \text{kg})(5000\ \text{m/s}^2) = 300\ \text{kg} \cdot \text{m/s}^2 = 300\ \text{N}$$

EXAMPLE Problem 2

CALCULATE ACCELERATION You push a wagon that has a mass of 12 kg. If the net force on the wagon is 6 N south, what is the wagon's acceleration?

Identify the Unknown: acceleration: a

List the Knowns: mass: m = 12 kg net force: F_{net} = 6 N south

Set Up the Problem: $a = \frac{F_{net}}{m}$

Solve the Problem: $a = \frac{6\ \text{N south}}{12\ \text{kg}} = 0.5\ \text{m/s}^2$ south

Check the Answer: The value of the net force (6) is less than the value of the wagon's mass (12), so we would expect the acceleration's value to be less than 1. Our answer (0.5 m/s^2) makes sense.

PRACTICE Problems ADDITIONAL PRACTICE

11. If a helicopter's mass is 4500 kg and the net force on it is 18,000 N upward, what is its acceleration?

12. What is the net force on a dragster with a mass of 900 kg if its acceleration is 32.0 m/s^2 west?

13. A car pulled by a tow truck has an acceleration of 2.0 m/s^2 east. What is the mass of the car if the net force on the car is 3000 N east?

14. **CHALLENGE** What is the net force on a skydiver falling with a constant velocity of 10 m/s downward?

ACADEMIC VOCABULARY

period

a length of time

Each class period is 45 minutes.

CCC CROSSCUTTING CONCEPTS

Cause and Effect With a partner, repeat Example Problem 2 for wagons with different mass. Explain the relationship between acceleration and mass.

Newton's Third Law of Motion

What happens when you push against a wall? If the wall is sturdy, nothing happens. But if you pushed against a wall while wearing roller skates, you would go rolling backward. This is a demonstration of **Newton's third law of motion.** Newton's third law of motion states that when one object exerts a force on a second object, the second object exerts a force on the first that is equal in strength and opposite in direction.

Sometimes, Newton's third law is written as "to every action force there is an equal and opposite reaction force." However, one force is not causing the second force. They occur at the same time. It does not matter which object is labeled Object 1 and which is labeled Object 2. Think about a boat tied to a dock with a taut rope. You could say that the action force is the boat pulling on the rope and the reaction force is the rope pulling on the boat. But it would be just as correct to say that the action force is the rope pulling on the boat and the reaction force is the boat pulling on the rope.

Forces on different objects do not cancel

If these two forces are equal in size and opposite in direction, you might wonder how some things ever happen. For example, if the box in **Figure 13** pushes on the student when the student pushes on the box, why does the box move? According to the third law of motion, action and reaction forces act on different objects. Recall that the net force is the sum of the forces on a single object. The left picture in **Figure 13** shows the forces on the student. The net force is zero, and the student remains at rest. The right picture shows that there is a net force of 20 N to the right on the box, and the box accelerates to the right.

Get It?

Explain why action and reaction forces do not cancel.

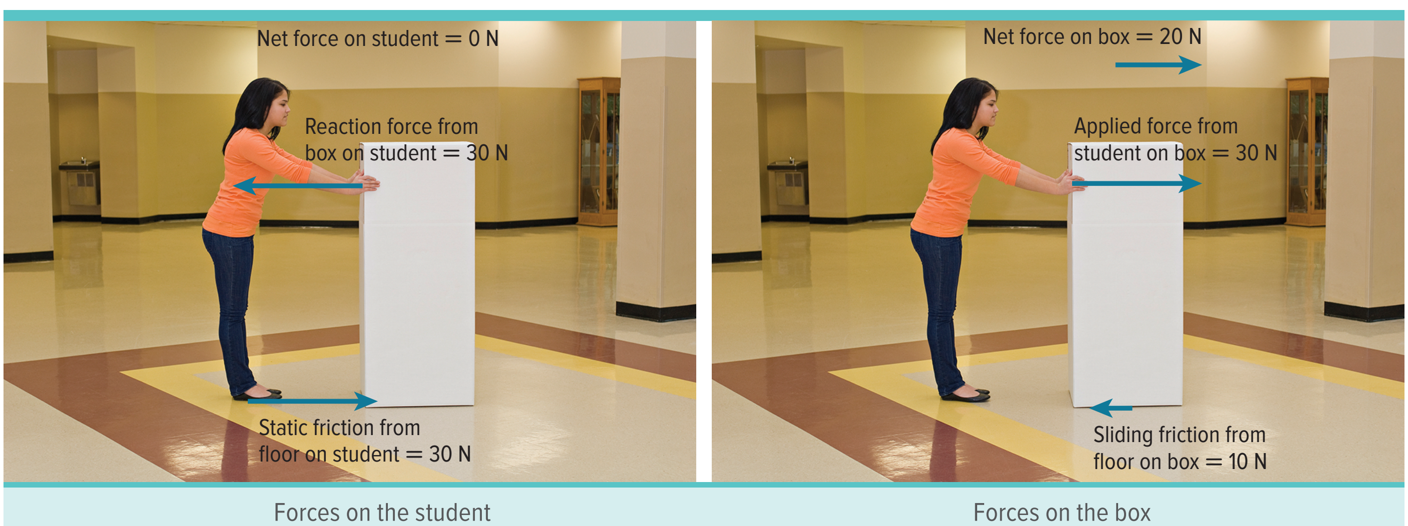

Figure 13 The student pushes on the box, and the box pushes on the student. To understand the motion of each object, the other forces on that object must be examined.

Forces are interactions

Newton's third law depends on a very important fact: forces are interactions between objects. For example, it makes no sense to say "The box has a force of 30 N." Is this force acting on the box? Is the box pushing on something? What is causing this force? However, it does make sense to say "The student applied a force of 30 N to the box."

Furthermore, both objects experience a force from the interaction. Look at the skaters in **Figure 14.** The male skater is pulling upward and to the left on the female skater, while the female skater is pulling downward and to the right on the male skater. The two forces are equal in size but opposite in direction. Both skaters feel a pull of the same size.

Even if the two objects have different masses, they will feel forces of the same size. For example, if a bug flies into the windshield of a truck, the bug and the truck exert forces on each other. According to Newton's third law, the bug and the truck experience forces of the same size even though their masses and accelerations are different.

Figure 14 The skaters exert forces on each other. According to Newton's third law of motion, the two forces are equal in size but opposite in direction. Both skaters feel the same amount of force.

Check Your Progress

Summary

- Newton's first law of motion states that the motion of an object at rest or moving with constant velocity will not change unless an unbalanced force acts on the object.
- Inertia is the tendency of an object to resist a change in motion.
- Newton's second law of motion states that the acceleration of an object depends on its mass and the net force exerted on it.
- According to Newton's third law of motion, when an object exerts a force on a second object, the second object exerts a force on the first object that is equal in strength and opposite in direction.

Demonstrate Understanding

15. **Interpret and Apply** Use Newton's laws of motion to describe what happens when you kick a soccer ball.
16. **Explain** why Newton's first law of motion is sometimes called the law of inertia.
17. **Determine** whether the inertia of an object changes as the object's velocity changes.
18. **Explain** why an object with a smaller mass has a greater acceleration than an object with a larger mass if the same force acts on each.

Explain Your Thinking

19. **Identify** You push a book across a table. The book moves at a constant speed, but you do not move. Identify all of the forces on you. Then, identify all of the forces on the book.
20. **MATH Connection** A student pushes on a 5-kg box with a force of 20 N forward. The force of sliding friction is 10 N backward. What is the acceleration of the box?
21. **MATH Connection** You push yourself on a skateboard with a force of 30 N east and accelerate at 0.5 m/s^2 east. Find the mass of the skateboard if your mass is 58 kg.

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LESSON 3

USING NEWTON'S LAWS

FOCUS QUESTION

How do Newton's three laws explain the change of motion that occurs in a collision?

What happens in a crash?

Newton's first law of motion can explain what happens in a car crash. When a car traveling about 50 km/h collides head-on with something solid, the car crumples, slows down, and stops within approximately 0.1 s. According to Newton's first law, the passengers will continue to travel at the same velocity that the car was moving unless a force acts on them.

This means that within 0.02 s after the car stops, any unbelted passengers will slam into the windshield, dashboard, steering wheel, or the backs of the front seats, as shown on the left in **Figure 15.** These unbelted passengers are traveling at the car's original speed of 50 km/h (about 30 miles per hour).

Even in a low-speed crash, inertia causes the unrestrained dummies to slam into the windshield or seat in front of them.

This crash dummy was restrained safely with a safety belt and cushioned with an airbag in this low-speed crash.

Figure 15 The crash dummies have inertia and resist changes in motion.

3D THINKING DCI Disciplinary Core Ideas CCC Crosscutting Concepts SEP Science & Engineering Practices

COLLECT EVIDENCE

Use your Science Journal to record the evidence you collect as you complete the readings and activities in this lesson.

INVESTIGATE

GO ONLINE to find these activities and more resources.

Applying Practices: Conservation of Momentum

HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

Applying Practices: Egg Heads

HS-PS2-3. Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

Safety belts

Passengers wearing safety belts, also shown in **Figure 15,** will be slowed down by the force of the safety belt. This prevents passengers from being thrown out of their seats. Car-safety experts say that about half of the people who die in car crashes would survive if they wore safety belts. Thousands of others would suffer fewer serious injuries.

The force needed to slow a person's speed from 50 km/h to 0 in 0.1 s is equal to 14 times the force of gravity on the person. Therefore, safety belts are designed to loosen a little as they restrain passengers. The loosening increases the time it takes to slow the person down, resulting in a smaller acceleration and a smaller force on the passenger.

Airbags

Airbags also reduce injuries in car crashes by providing a cushion that reduces the acceleration of the passengers and prevents them from hitting the dashboard. When impact occurs, a chemical reaction occurs in the airbag, producing nitrogen gas. The airbag expands rapidly and then deflates just as quickly as the nitrogen gas escapes out of tiny holes in the bag. The entire process is completed in about 0.04 s.

Newton's Second Law and Gravitational Acceleration

Recall that the gravitational force exerted on an object is equal to the object's mass times the strength of gravity ($F_g = mg$). If gravity is the only force acting on an object ($F_{net} = F_g$), then Newton's second law states that the object's acceleration is the force of gravity divided by the object's mass. Notice that the mass cancels, and the object's acceleration due to gravity is equal to the gravitational strength.

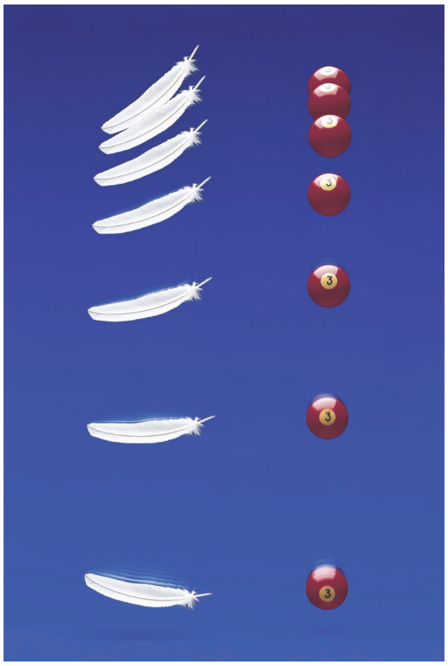
$$a = \frac{F_{net}}{m} = \frac{F_g}{m} = \frac{\cancel{m}g}{\cancel{m}} = g$$

When discussing the acceleration due to gravity, g is written with the units m/s^2. On Earth, any falling object with only gravity acting on it will accelerate at 9.8 m/s^2 toward Earth.

Air resistance

The gravitational force causes objects to fall toward Earth. However, objects falling in the air experience air resistance. **Air resistance** is a friction-like force that opposes the motion of objects that move through the air. Air resistance acts in the direction opposite to the motion of an object moving through air. If the object is falling downward, air resistance exerts an upward force on the object.

The amount of air resistance on an object depends on the size, shape, and speed of the object, as well as the properties of the air. Air resistance, not the object's mass, is the reason feathers, leaves, and pieces of paper fall more slowly than do pennies, acorns, and billiard balls. If there were no air resistance, then all objects, including a feather and a billiard ball, would fall with the same acceleration, as shown in **Figure 16.**



Erich Schrempp/Science Source

Figure 16 In a vacuum, there is no air resistance. As a result, a feather and a billiard ball fall with the same acceleration in a vacuum.

Get It?
Explain why some objects fall faster than others.

Size and shape The more spread out an object is, the more air resistance it will experience. Picture dropping two plastic bags, as shown in **Figure 17.** One is crumpled into a ball, and the other is spread out. When the bags are dropped, the crumpled bag falls faster than the spread-out bag. The downward force of gravity on both bags is the same, but the upward force of air resistance on the crumpled bag is less. As a result, the net downward force on the crumpled bag is greater.

Speed and terminal velocity The amount of air resistance also increases as the object's speed increases. As an object falls, gravity causes it to accelerate downward. But as an object falls faster, the upward force of air resistance increases. So, the net force on the object decreases as it falls, as shown with the skydiver in **Figure 18.**

Eventually, the upward air resistance force becomes large enough to balance the downward force of gravity, and the net force on the object is zero. Then the acceleration of the object is zero, and the object falls with a constant speed called the terminal velocity. **Terminal velocity** is the maximum speed an object will reach when falling through a substance, such as air.

A falling object's terminal velocity depends on its size, shape, and mass. For example, the air resistance on an open parachute is much greater than the air resistance on the skydiver alone. When her parachute opens, the skydiver's terminal velocity will be small enough that she can land safely.

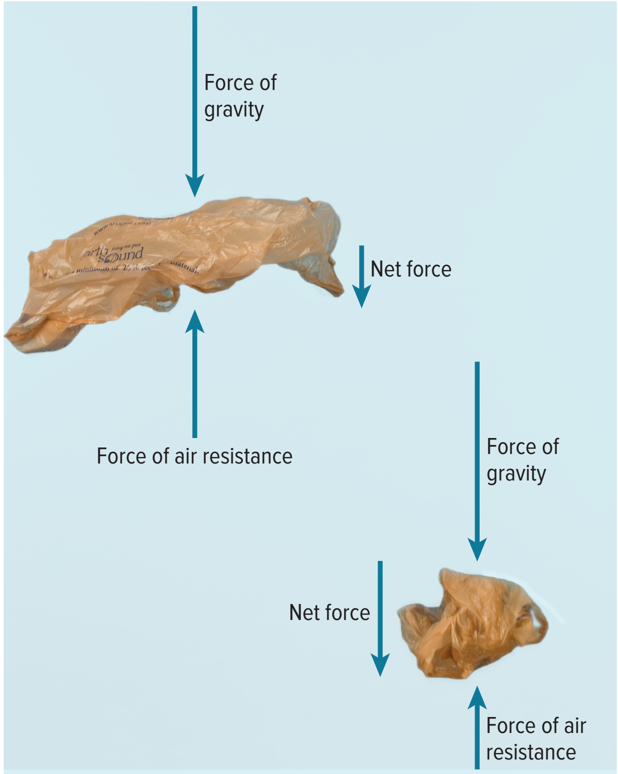


Figure 17 An object's surface size and shape determine how fast it will fall. Because of its greater surface area, the bag on the left has more air resistance acting on it as it falls.

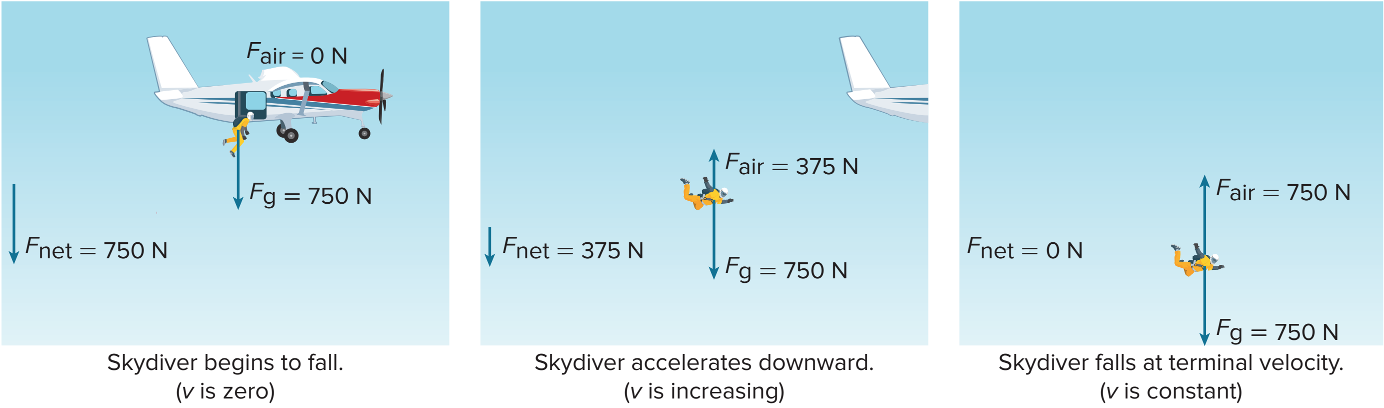


Figure 18 As the skydiver's speed increases, so does the force of air resistance acting on her. At some point, the force of the air resistance equals the force due to gravity, and the skydiver falls at a constant speed called terminal velocity.

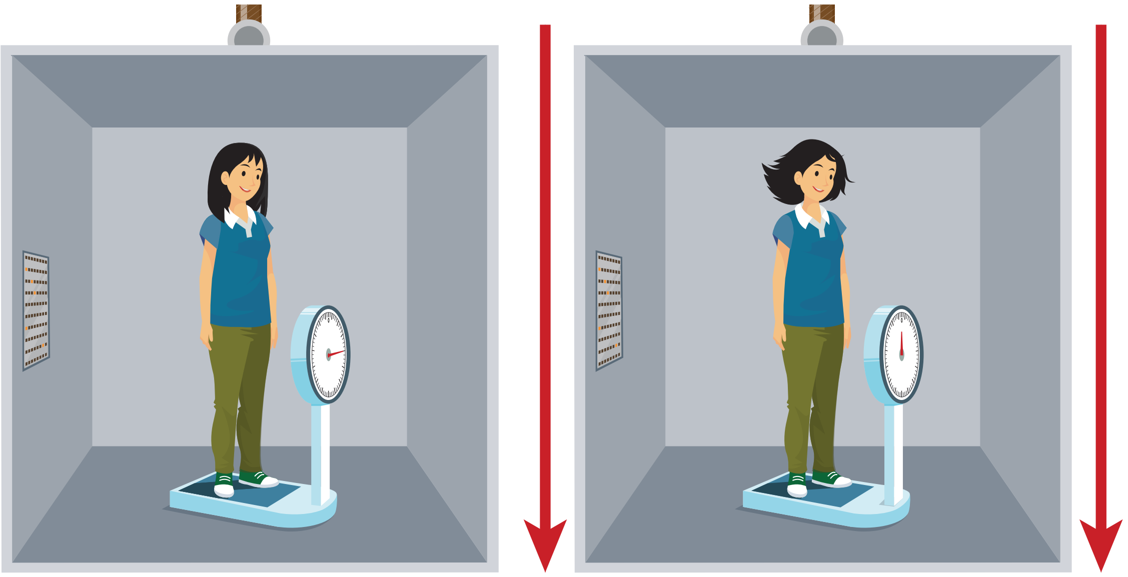
Free fall

Suppose an object were falling and there were no air resistance. Gravity would be the only force acting on the object. If gravity is the only force acting on an object, the object is said to be in **free fall.** For example, the feather and the billiard ball falling in a vacuum, shown in **Figure 16,** are in free fall. Another example is an object in orbit. Earth, for example, is in free fall around the Sun. If Earth did not have a velocity perpendicular to the gravitational force, it would fall into the Sun. Similarly, satellites are in free fall around Earth.

Weightlessness You might have seen pictures of astronauts and equipment floating inside an orbiting spacecraft. They are said to be experiencing weightlessness. But, according to the law of universal gravitation, the strength of Earth's gravitational field at a typical orbiting altitude is about 90 percent of its strength at Earth's surface. So, an 80-kg astronaut would weigh about 700 N in orbit and would not be weightless.

What does it mean to say that something is weightless? Think about how you measure your weight. When you stand on a scale, as shown on the left in **Figure 19,** you are at rest. The net force on you is zero, according to Newton's second law of motion. The scale exerts an upward force that balances your weight. The dial on a scale shows the size of the upward force, which is the same as your weight.

Now suppose you stand on a scale in an elevator that is in free fall, as shown on the right in **Figure 19.** You would no longer push down on the scale at all. The scale dial would read zero, even though the force of gravity has not changed. An orbiting spacecraft is in free fall, and objects in it seem to float because they are all falling around Earth at the same rate.



When the elevator is stationary, the scale shows the girl's weight.

If the elevator were in free fall, the scale would read zero.

Figure 19 The reading on the scale depends on the upward force the scale exerts on the girl. If both the girl and the scale are in free fall, the girl experiences the sensation of weightlessness, even though the force of gravity has not changed.

Figure 20 The riders on this amusement-park ride are traveling in a circle because of the centripetal force acting on them.

Identify *the force that acts as the centripetal force.*

Centripetal Forces

Orbiting objects, such as space shuttles, are traveling in nearly circular paths. According to Newton's first law, this change in motion is caused by a net force acting on the object. Newton's second law states that because the object's acceleration is toward the center of the curved path, the net force is also toward the center. A **centripetal force** is a force exerted toward the center of a curved path.

Anything that moves in a circle is doing so because a centripetal force is accelerating it toward the center. Many different forces can act as a centripetal force. Gravity is the centripetal force that keeps planets orbiting the Sun. On the amusement-park ride in **Figure 20,** the centripetal force is the walls pushing on the people.

When a car rounds a level curve on a highway, friction between the tires and the road acts as the centripetal force. If the road is slippery, the frictional force might not be large enough to keep the car moving around the curve. Then the car will slide in a straight line, as shown in **Figure 21.**

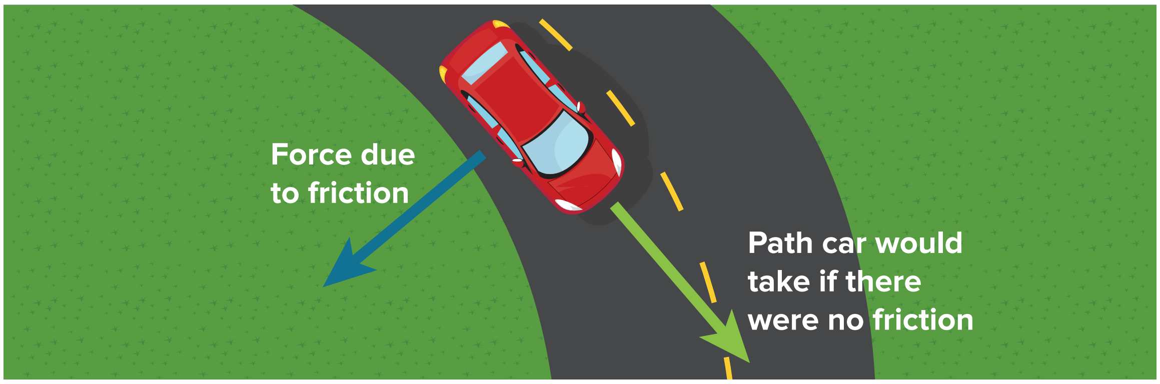


Figure 21 If the inward frictional force is too small, the car will continue in a straight line and not make it around the curve.

STEM CAREER Connection

Civil Engineer

Civil engineers conceive of and design roadways in cities. They must take into account factors such as current and future traffic flows, design of intersections and interchanges, building materials, geometric alignment, and pavement maintenance.

SCIENCE USAGE v. COMMON USAGE

gravity

Science usage: an attractive force between any two objects that depends on their masses and the distance between them *Gravity is the force that keeps Earth orbiting around the Sun.*

Common usage: seriousness

If you understood the gravity of the situation, you would not find it funny.

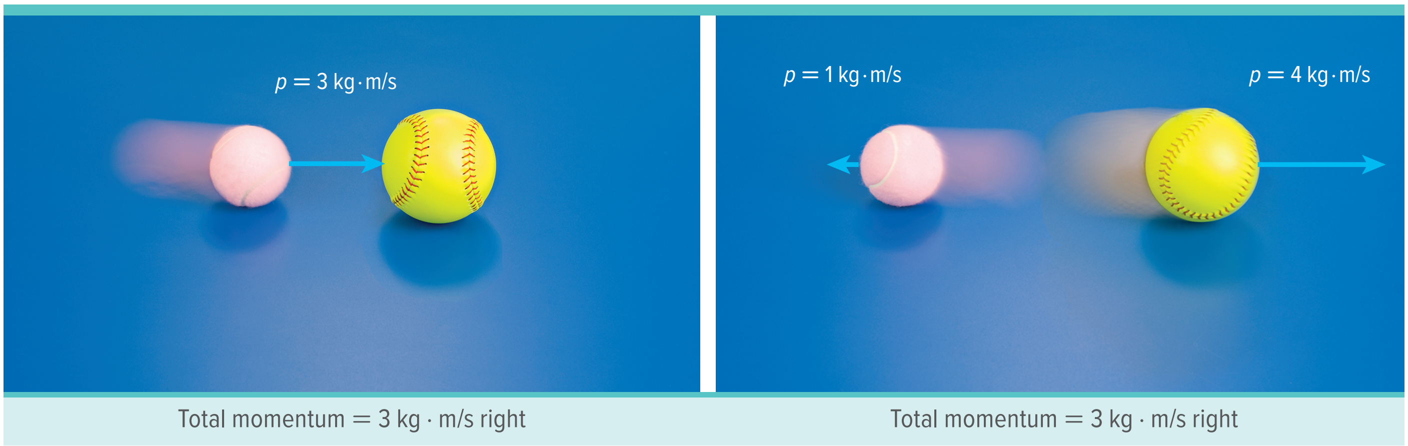


Figure 22 When two objects collide and there are no external forces acting on the objects, momentum is conserved.

Force and Momentum

Recall that acceleration is the difference between the initial and final velocities, divided by the time. Therefore, we can write Newton's second law in the following way.

$$F = ma = m \times \frac{(v_f - v_i)}{t} = \frac{(mv_f - mv_i)}{t}$$

Recall that an object's momentum equals its mass multiplied by its velocity. In the equation above, mv_f is the final momentum, and mv_i is the initial momentum. The equation states that the net force exerted on an object equals the change in its momentum divided by the time over which the change occurs. In fact, this is how Newton originally wrote the second law of motion.

Conservation of momentum

Newton's second and third laws of motion can be used to describe what happens when objects collide. For example, consider the collision of the balls in **Figure 22.** We will assume that friction is too small to cause a noticeable change in the balls' motion. In this ideal case, there are no external forces, but the balls exert forces on each other during the collision. According to Newton's third law, the forces are equal in size and opposite in direction. Therefore, the momentum lost by the first ball is gained by the second ball, and the total momentum of the two balls is the same before and after the collision. This is the **law of conservation of momentum**—if no external forces act on a group of objects, their total momentum does not change.

Collisions with multiple objects When a cue ball hits the group of motionless balls, as shown in **Figure 23,** the cue ball slows down and the rest of the balls begin to move. The momentum that the group of balls gained is equal to the momentum that the cue ball lost. Momentum is conserved.

Figure 23 Momentum is conserved in collisions with more than two objects if there are no external forces acting on the objects. The momentums of the cue ball just before the collision is equal to the total of the momentums of the billiard balls (including the cue ball) just after the collision.

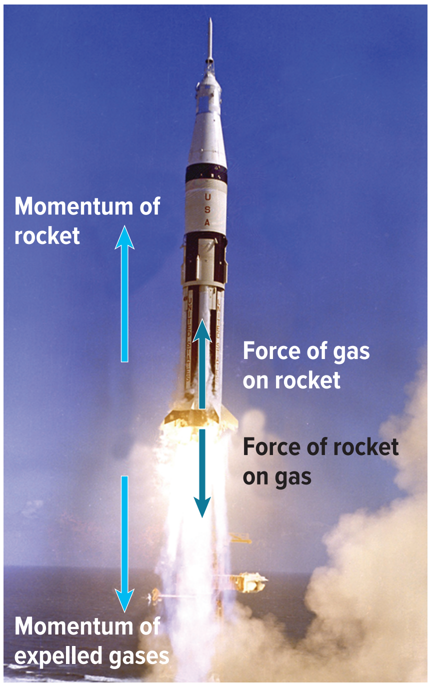


Figure 24 The force on a rocket depends on the amount and velocity of the gas expelled from its engine.

Rocket propulsion

Suppose you are standing on skates holding a softball. You exert a force on the softball when you throw it. According to Newton's third law, the softball exerts a force on you. This force pushes you backward in the direction opposite the softball's motion. Rockets use the same principle to move, even in the vacuum of outer space. In a rocket engine, burning fuel produces hot gases. The rocket engine exerts a force on these gases and causes them to escape out the back of the rocket. By Newton's third law, the gases exert a force on the rocket and push it forward. **Figure 24** shows one of the Apollo rockets that traveled to the Moon. Notice that the force of the rocket on the gases is equal in size to the force of the gases on the rocket.

Momentum is conserved when a rocket ejects the hot gas. If the rocket is initially at rest, then the total momentum of the rocket and the fuel is zero. After the fuel is burned and the hot gas is expelled, the gas travels backward with a momentum of $m_{gas}\, v_{gas}$ and the rocket travels forward with a momentum of $m_{rocket}\, v_{rocket}$. These momenta are equal in size, but opposite in direction. By controlling how much gas is ejected and the gas's velocity, the rocket's motion can be controlled.

Check Your Progress

Summary

- In a car crash, an unrestrained passenger will continue moving at the velocity of the car before the crash.
- Air resistance is a force that opposes an object's motion through the air.
- If gravity is the only force acting on an object, then the object is in free fall.
- Objects appear to be weight-less in free fall.
- A force that causes an object to move in a circular path is called a centripetal force.
- The law of conservation of momentum states that if objects exert forces only on each other, their total momentum is conserved.

Demonstrate Understanding

22. **Describe** Use Newton's laws to describe how inertia, gravity, and air resistance affect skydivers as they fall, open their parachutes, and reach terminal velocity.
23. **Discuss** the advantages of wearing a safety belt when riding in a vehicle.
24. **Explain** why planets orbit the Sun instead of traveling off into space.
25. **Describe** what happens to the momentum of two billiard balls that collide.
26. **Explain** how a rocket can move through outer space, where there is no matter for it to push on.

Explain Your Thinking

27. **Predict** Suppose you are standing on a scale in an elevator that is accelerating upward. Will the scale read your weight as larger or smaller than the weight it reads when you are sta-tionary? Explain.
28. **MATH Connection** A fuel-filled rocket is at rest. It burns its fuel and expels hot gas. The gas has a momentum of 1500 kg·m/s backward. What is the momentum of the rocket?

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Extreme Altitudes

In July of 1969, *Apollo 11* rocketed toward an historic meeting with the Moon. The editors at *The New York Times* were in a distinctly uncomfortable position. Forty-nine years before, the newspaper published an editorial that ridiculed the scientist who suggested that rockets could travel in space. Three days before astronauts first walked on the Moon, editors wrote, "*The Times* regrets the error."

Robert Goddard works on a rocket in 1935.

Rocket man

Robert Goddard, shown in the photo, was passionate about rocketry. In 1919, Goddard wrote a report to the Smithsonian Institution entitled "A Method of Reaching Extreme Altitudes." In this paper, Goddard proposed that a large rocket propelled by powerful fuel could reach the Moon. Goddard was unprepared for the scornful reaction.

Public scorn, private determination

An editorial in *The New York Times* ridiculed Goddard and accused him of lacking "the knowledge ladled out daily in high schools." According to the writer, even students knew that a rocket could not function in space because there was nothing for the fuel exhaust to push against as it exited the rocket to create forward motion.

Goddard continued his experiments, despite the public humiliation. On March 16, 1926, his 3-m rocket, *Nell,* soared into the sky at 28 m/s. *Nell* reached a height of 12.5 m, becoming the first liquid-fueled rocket. This launch began the age of modern rocketry that led to space exploration and landing on the Moon.

Faulty physics

Why was the editorial incorrect? Consider Newton's third law of motion: For every action, there is an equal and opposite reaction. The writer believed that because the exhaust would have nothing to push against in space, there could be no opposing force pushing the rocket forward.

However, he failed to consider what happens inside the rocket. As rocket fuel is burned, a gas is generated. The gas expands rapidly, pushing against everything around it, and escapes through a nozzle at the bottom of the rocket. The escaping exhaust exerts a force on the rocket, causing the rocket to move in the opposite direction.

OBTAIN, EVALUATE, AND COMMUNICATE INFORMATION

Robert Goddard said, "Every vision is a joke until the first man accomplishes it; once realized, it becomes commonplace." Research a modern technology that might have been ridiculed had it been proposed in 1920. Use your findings to write a brief report.

MODULE 3
STUDY GUIDE

GO ONLINE to study with your Science Notebook.

Lesson 1 FORCES

- A force is a push or a pull on an object.
- The net force on an object is the combination of all the forces acting on the object.
- Unbalanced forces cause the motion of objects to change.
- Friction is the force that opposes the sliding motion of two surfaces that are in contact.
- Gravity is an attractive force between all objects that have mass.

- force
- net force
- friction
- gravity
- field
- weight

Lesson 2 NEWTON'S LAWS OF MOTION

- Newton's first law of motion states that the motion of an object at rest or moving with constant velocity will not change unless an unbalanced force acts on the object.
- Inertia is the tendency of an object to resist a change in motion.
- Newton's second law of motion states that the acceleration of an object depends on its mass and the net force exerted on it.
- According to Newton's third law of motion, when an object exerts a force on a second object, the second object exerts a force on the first object that is equal in strength and opposite in direction.

- Newton's first law of motion
- inertia
- Newton's second law of motion
- Newton's third law of motion

Lesson 3 USING NEWTON'S LAWS

- In a car crash, an unrestrained passenger will continue moving at the velocity of the car before the crash.
- Air resistance is a force that opposes an object's motion through the air.
- If gravity is the only force acting on an object, then the object is in free fall.
- Objects appear to be weightless in free fall.
- A force that causes an object to move in a circular path is called a centripetal force.
- The law of conservation of momentum states that if objects exert forces only on each other, their total momentum is conserved.

- air resistance
- terminal velocity
- free fall
- centripetal force
- law of conservation of momentum

THREE-DIMENSIONAL THINKING
Module Wrap-Up

REVISIT THE PHENOMENON

Why can a car stop faster than a train?

CER Claim, Evidence, Reasoning

Explain Your Reasoning Revisit the claim you made when you encountered the phenomenon. Summarize the evidence you gathered from your investigations and research and finalize your Summary Table. Does your evidence support your claim? If not, revise your claim. Explain why your evidence supports your claim.

STEM UNIT PROJECT

Now that you've completed the module, revisit your STEM unit project. You will apply your evidence from this module and complete your project.

GO FURTHER

SEP Data Analysis Lab

Friction and the Curve Ball

The curve ball was invented by a young pitcher named Arthur "Candy" Cummings. Although Cummings first threw the curve ball during a game while pitching for the Brooklyn Excelsiors in 1867, he actually invented his technique many years before. Why does the ball curve? It's all about friction.

The snapping action of the pitcher's wrist puts a spin on the ball. That spin changes the friction between the air and the ball. After it's thrown, parts of the ball experience more air friction and parts of the ball experience less. A curved path results from the ball moving toward the least amount of friction.

Specifically, one movement of the pitcher's wrist when the ball is released causes a top spin, making the top of the ball move forward against the air (more friction) and the bottom move in the same direction as the air (less friction). Like any curve ball, the ball curves toward the least amount of friction—downward.

CER Analyze and Interpret Data

1. **Claim and Reasoning** What effect might the stitches on a baseball have on the baseball's path?
2. **Claim, Evidence, Reasoning** Do you think a baseball curves better at the top of a high mountain or down on a flat plain? Explain.
3. **Claim, Evidence, Reasoning** Describe how the type of spin a pitcher applies will influence the path of a baseball.