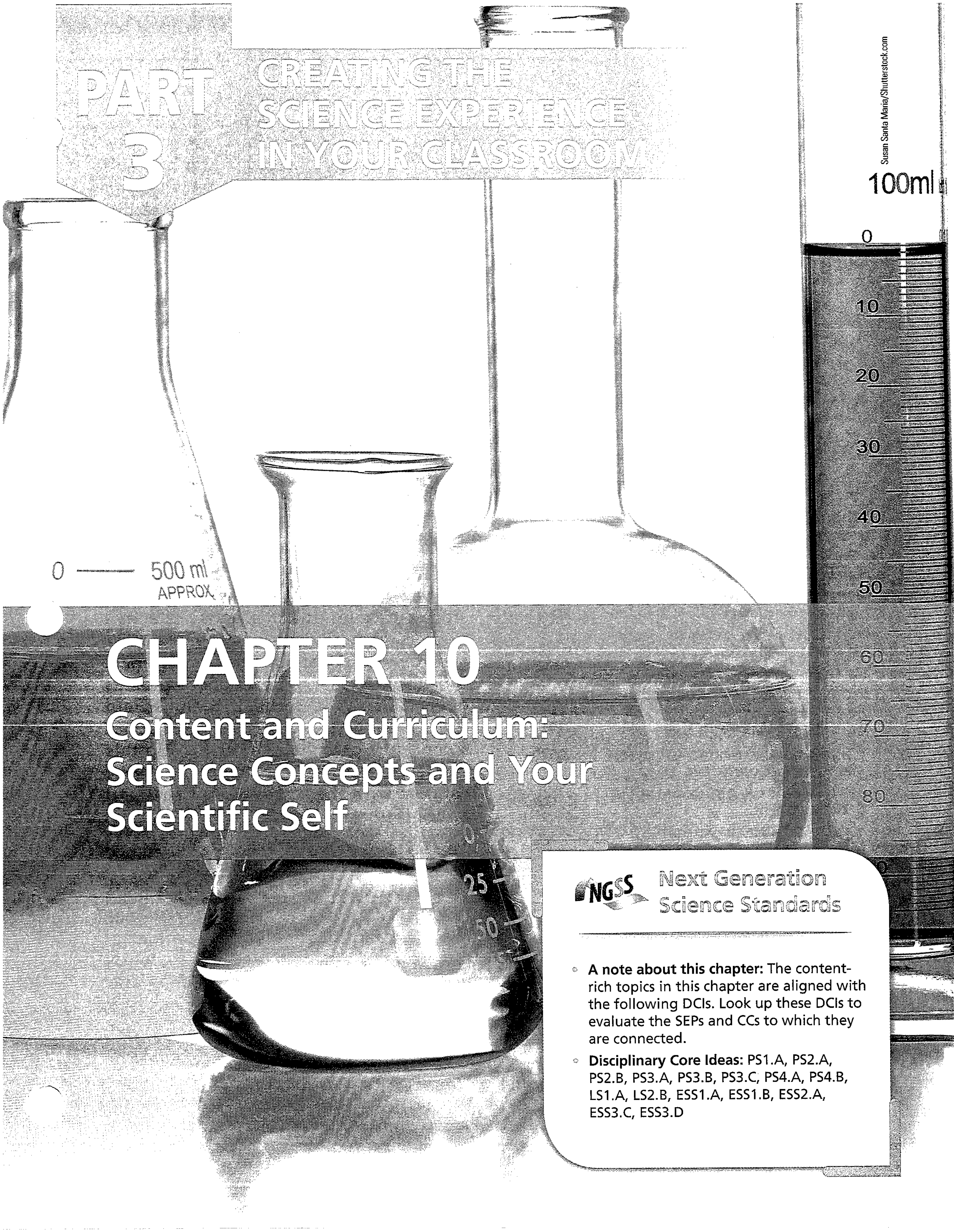


Susan Santa Maria/Shutterstock.com

PART 3

CREATING THE SCIENCE EXPERIENCE IN YOUR CLASSROOM

CHAPTER 10

Content and Curriculum: Science Concepts and Your Scientific Self

NGSS Next Generation Science Standards

- **A note about this chapter:** The content-rich topics in this chapter are aligned with the following DCIs. Look up these DCIs to evaluate the SEPs and CCs to which they are connected.
- **Disciplinary Core Ideas:** PS1.A, PS2.A, PS2.B, PS3.A, PS3.B, PS3.C, PS4.A, PS4.B, LS1.A, LS2.B, ESS1.A, ESS1.B, ESS2.A, ESS3.C, ESS3.D

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- 10-1 Examine how to make the scientific concepts that are new to you "your own."
- 10-2 Describe the range of science topics addressed by life science, physical science, and earth and space science.
- 10-3 Discuss what makes "system thinking" different from just knowing the parts of a system.
- 10-4 Examine the major components of the solar system and the laws of motion that govern it.
- 10-5 Discuss four of the major human body systems that help matter and energy flow through the organism and sustain life.
- 10-6 Examine six types of simple machines and how they work.
- 10-7 Analyze the ways the earth is like a giant system.
- 10-8 Discuss the law of conservation of matter and energy.
- 10-9 Describe the differences among radiation, conduction, and convection of heat energy.
- 10-10 Discuss where electrons come from and how they function in current and static electricity.
- 10-11 Examine the sources of light energy and how light energy travels.
- 10-12 Explain why sound energy requires a medium through which to travel.
- 10-13 Analyze the complex role of magnetism in our world; explain why it is a force.
- 10-14 Discuss the relationship between the NGSS and the science curriculum.
- 10-15 Examine the implications of the STEM movement.
- 10-16 Select a mini-science unit, develop some activities in which to engage the students, and identify the relevant grade level.

Reflection

To Think About:

- What core science concepts are the basics for an understanding of how the natural world works?
- How do you personalize science content and make it your own?
- When you think of a natural system, what comes to mind?

As a child, I was always highly curious about things, especially things related to nature, but there was very little available at my reading level that presented answers to my questions in ways that I could readily understand. Many teachers I meet used to feel the same way. You may have felt this way, too. Today, we are fortunate to have access to websites, blogs, Twitter, and wikis, all of which can be useful in explaining scientific principles. In fact, knowing how to navigate the Web to find just the right explanations is a useful skill lest we be overwhelmed by too much information. The National Science Teachers Association has relevant links for science content for elementary and middle school teachers. Called "Science Objects," these links are two-hour, online, interactive, inquiry-based modules that help teachers better understand the science content they teach.

As you have noticed in the science stories throughout this book, effective teachers guide students as they make sense of new ideas. Teachers listen and reflect back to the students their understandings of the ideas; these conversations help to further the students' thinking about a concept. A teacher's ability to do this is often related to his or her own level of comfort with the scientific material and understanding of the content.

As a teacher, then, you'll want to continue developing your own understanding of science concepts. In this chapter, I hope to give you a guide to some of the science content your students will be exploring. The chapter cannot discuss all of the topics you will delve into, but the ideas and understandings described here will help you frame many of your learning goals for your students.

After discussing some of the major science topics that elementary and middle school students investigate, this chapter will go on to explore how these topics are organized into a curriculum that responds to local, state, or national standards or frameworks. Wherever you teach, you will probably be given a textbook or a set of materials that represents the curriculum you are supposed to "cover." As you've seen throughout this book's *Science Stories*, however, our role as teachers is not just to "cover" a curriculum but to help students *uncover* the ideas and meanings that emerge through their own experiences. This chapter will help you understand how to approach a science curriculum so that this learning can truly take place.

10-1 Making New Concepts Your Own

The major governing science concepts from the Next Generation Science Standards (NGSS) are often called "disciplinary core ideas (DCIs) " or "science ideas" or "big ideas." The ones presented in this chapter have emerged from repeated experimentation and investigation, and they form part of scientists' "taken-for-granted" way of seeing things (Driver et al., 1994). These DCIs are commonly the basis for a lot of elementary and middle school science curriculum. Remember that science ideas are arrived at after analyzing a great deal of **evidence**, and arguing from evidence is one of the eight science and engineering practices described in the NGSS. This is *how* science works, and these science ideas are the result of lots of experimentation. In a similar way, we encourage you and your students to engage in activities that allow them to reach conclusions about the natural world.

evidence
In science, evidence refers to the total amount of information that is used to demonstrate or determine the truth of an assertion, such as a fact or a theory.

Hence, these concepts were arrived at by lots of intellectual struggle among scientists who have engaged with each other and individually in making sense of their observations and experience. These ideas were created through the same sort of knowledge construction and conversation that you have seen in classrooms.

Understanding this, it is important to recognize that just by reading the following science ideas or concepts you will not make them your own. You need to interrogate these ideas in the ways you know your own students will have to do. To construct your own meaning for the science concepts in this chapter, access your own capacity for metacognition and ask yourself the following questions:

- Have I had any experience with this science concept?
- Does it make sense to me?
- How can I find out more about this topic?
- How does this concept fit in with what I already believe about nature?
- How could I express this idea differently?

Having this conversation with yourself will help you to develop your scientific self and make these ideas your own. As you have noticed throughout *Science Stories*, it is even more helpful to discuss science concepts with others who may have different interpretations and prior experiences. Having such conversations helps you to clarify your own understandings.

10-2 Organizing the Science Curriculum

As noted in earlier chapters, students' scientific explorations will address a wide variety of topics, from classroom animals to electric circuits to the solar system. A traditional way of organizing this multitude of topics is to divide them into the three areas of life science, physical science, and earth and space science. Often environmental science, including the types of "green science" we have discussed in this book, falls under the life science or earth science classification, depending on the topic. When we talk about disruptions to ecosystems, for example, it is a topic for life science.

- In *life science*, students and teachers explore characteristics of living things and their interactions with the nonliving environment. They explore ecosystems, heredity, and evolution.
- In *physical science*, students and teachers look at properties of objects and materials, forms of energy, and the motion of objects.
- In *earth and space science*, students and teachers investigate earth's materials and systems, earth's place in the universe and the earth and human activity.

We can also examine science topics across disciplinary boundaries by organizing them into *Systems* and *Interactions and Patterns of Change*. These categories will help you to look at science content differently, furthering your understanding of how the areas of elementary and middle school science relate to one another. This approach to science content is also consistent with the idea of crosscutting concepts described by the NGSS.

Figure 10.1 illustrates the way a number of typical science topics fit into the two conceptual categories. For reference, the figure also identifies the topics according to the three traditional science areas. Whatever way the material may be organized in your own school's curriculum, you can make it come alive by challenging yourself—and your students—to see what apparently different topics have in common.

	Systems	**Interactions and Patterns of Change**
Life science	■ Human body systems ■ Plants and animals ■ Ecosystems	■ Life cycles ■ Tropisms ■ Food chains
Physical science	■ Sinking and floating ■ Simple machines	■ Chemical and physical change ■ Heat energy ■ Electricity and magnetism ■ Light energy and color ■ Sound energy
Earth and space science	■ Solar system; Planetary motions ■ Earth as a super system ■ Moon phases	■ Weather and seasonal change ■ Earth motions ■ Rocks, soil, erosion ■ Earthquakes and volcanoes **Environmental science:** ■ Conservation and recycling ■ Air and water pollution

FIGURE 10.1 Basic science topics

Here some typical topics of elementary and middle school science are organized in two ways: by conceptual category and by the traditional areas of life science, physical science, and earth and space science. There will often be overlap between Systems and Interactions and Patterns of Change.

10-3 Systems

Understanding how systems operate requires that you identify how the parts of a system interrelate and combine to perform specific functions. You also need to recognize the commonalities that exist among all systems.

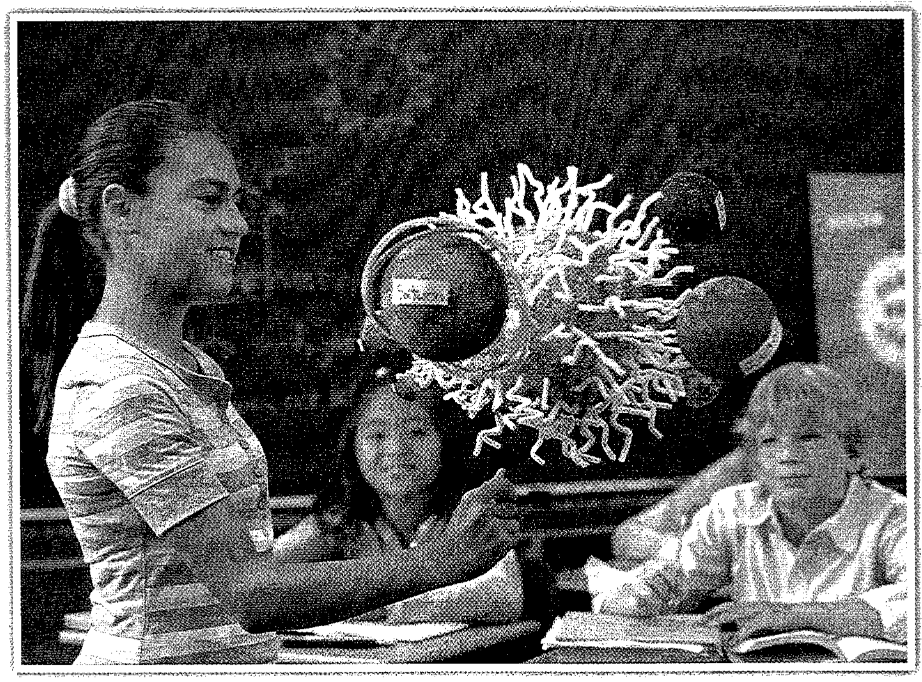
As you read and think about systems, the useful questions you can ask yourself include these:

- Is this system open or closed, or both?
- Is it a naturally occurring system?
- Do human beings impact this system? How?
- How do the parts of the system contribute to the functioning of the whole?

In the school science curriculum, students are often asked to observe and describe interactions among components of simple systems. As examples, I have selected four topics commonly taught in elementary and middle school that relate to systems: the solar system, the systems of the human body, simple machines as systems, and the earth as a system. In the NGSS, the crosscutting concept of Systems and System Models states that specifying a system's boundaries and making explicit a model of that system provides tools for understanding and testing ideas that are applicable throughout science and engineering.

10-4 The Solar System

The solar system is made up of a group of objects, sometimes called heavenly or celestial bodies, that move around the sun (Photo 10.1). These celestial bodies are also called *satellites.* Satellites can move around the sun or around other celestial bodies. Hence, the moon is a satellite of the earth. The earth itself is a satellite of the sun; or we could say that the earth–moon system is a satellite of the sun. When one heavenly body moves around another, we call that movement *revolution.*



Ariel Skelley/Jupiter Images

PHOTO 10.1 Students explore a model of planetary motion as they try to make meaning.

10-4a The Sun and the Planets

The sun is a *star*, one of billions of stars in the universe. Unlike the earth, the sun is not a solid body; rather, it is a huge ball of extremely hot gases. It is much larger than the earth. In fact, the diameter of the sun at its equator is 109 times greater than the diameter of the earth. As we saw in an earlier chapter, if the sun were a hollow ball, we could fit over a million earths inside it. Nevertheless, compared to other stars in the universe, the sun is not a particularly large star. It appears larger to us than other stars because it is so much closer to earth. We often refer to it as *our star.*

There are eight planets that travel around the sun. Along with the sun, these planets are considered the major members of the solar system. Planets are much smaller than the sun and do not make their own light. They shine in the night sky by *reflecting* the light of the sun.

The eight planets travel around the sun in specific paths called *orbits.* Since these orbits are slightly elliptical, all eight planets move closer to and farther from the sun at different points in their orbits. As you saw in the Chapter 8, the average distances of the planets from the sun place them in the following order: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

Most planets *rotate*—that is, spin like a top—as they travel around the sun. Hence, we say that they are rotating as they are revolving. They rotate around an imaginary axis that runs though the north and south poles of each planet. The time needed for each planet to make one complete rotation is called the planets' *day,* and the time needed for the planet to make one complete revolution around the sun is called the planet's *year.* All the planets revolve in a counterclockwise direction around the sun; however, their periods of rotation and revolution differ quite a bit from each other. Obviously, the farthest planets have the longest periods of revolution, while the closest planets revolve in the shortest amount of time. Mercury's eighty-eight days of revolution make its year much shorter than the 365-day earth year.

Most of the planets have satellites of their own. Like earth's satellite, these are called moons. As of this writing, astronomers have discovered more than 160 moons in the solar system.

10-4b Smaller Objects in the Solar System

Other celestial objects in the solar system include *asteroids,* which are also called planetoids. There are many theories about how these chunks of rocklike materials formed, but they travel together in what is referred to as the *belt of asteroids.* This belt contains more than 25,000 asteroids orbiting the sun between Mars and Jupiter.

The asteroids are much smaller than planets. They reflect light like planets do, and they differ in size and brightness. They are really like little planets, which is why they are also called planetoids.

Other rocks, called *meteors,* are found in the space through which the earth travels as it orbits the sun. When meteors encounter the earth's atmosphere, the force of friction between the meteor and the atmosphere causes the meteor to heat up and begin to burn. As they burn up, they look like stars shooting across the sky, and for that reason they are often called "shooting stars," a term that confuses them with real stars. Meteors that fall to earth without burning up are called *meteorites.* Sometimes meteorites form craters when they crash into the ground.

Comets are celestial bodies that revolve around the sun in long, oval-shaped orbits that sometimes cut across the orbits of the planets. Comets are made up of small rocks and dust mixed with frozen gases. As a comet nears the sun in its orbit, it appears to form a "tail," which is really the changing of the frozen gases into vapor. A comet's tail may be millions of miles long; but as its orbit takes it away from the sun's proximity, the comet "loses" its tail. Some comets make regular appearances. For instance, Halley's Comet orbits the sun every 76 years; it was last visible from the earth in 1986. Other comets are seen once and never return, appearing to waste away. No one is quite sure how comets form.

Beyond Neptune, the eighth planet from the sun, are more than one thousand other orbiting bodies, much larger than asteroids but much smaller than planets. This region of the solar system is called the Kuiper belt, and the orbiting objects here are more similar to frozen gases than to the rocklike asteroids. This is where Pluto is found. As we saw in Chapter 8, Pluto is no longer considered a planet but rather a dwarf planet. In 2008, the International Astronomical Union approved a new term to designate Pluto, its counterpart Eris, and other dwarf planets beyond Neptune: plutoids, a name that means Pluto-like bodies.

10-4c Gravity and Inertia: Governing Principles of the Solar System

Think about all these planets, moons, asteroids, plutoids, Kuiper belt objects (KBOs), and other celestial objects moving together in much the same way over billions of years. What makes these components into a system? Here we have a traditional earth science unit, but to understand it we need to call on two important principles of physical science: (1) the law of gravitation and (2) inertia.

1. *The Law of Gravitation.* You may ask yourself: What causes the paths of planets to bend into orbits around the sun?

   The scientist Isaac Newton (1642–1727) helped to explain the underlying reasons why the planets, their moons, and other objects in the solar system move in the way they do. The most important and significant understanding is called Newton's law of **gravitation**, which states that every body in the universe attracts or pulls on every other body with a gravitational force that increases when the masses of the objects increase and decreases as the objects move farther away from each other.

   In the solar system, each of the objects exerts a gravitational pull on each of the other objects. Because the sun is enormous in comparison to the planets and other objects, it has a much greater pull of gravity than any other body in the solar systems system. The continual, mutual gravitational attraction between the sun and the planets keeps the planets revolving in their orbits around the sun. The sun tends to pull the planets toward itself, but the distance of the planets from the sun and their mutual gravitational attraction for each other serve to keep them in defined paths.

gravitation
The attraction of any two objects that have mass. According to the law of gravitation, every body in the universe attracts every other body with a force that increases when the masses of the objects increase and decreases as the objects move farther away from each other.

2. *Inertia.* A body in motion tends to continue in the same motion at the same speed unless it is acted upon by an outside force. Similarly, an object at rest tends to stay at rest unless it is acted upon by an outside force that gets it moving. These ideas were also constructed by Isaac Newton after repeated experiments and investigations. They are known as Newton's first law of motion.

   The tendency of a body to continue with the same motion at the same speed or to remain at rest is called **inertia**. This principle is responsible for the fact that the planets, once they are moving in a certain path, remain in that motion unless some outside force changes it.

inertia
The tendency of a body to continue with the same motion at the same speed or to remain at rest.

Thinking About Systems

The Interconnection of Parts

Frequently, students are immersed in learning about the parts of a system without studying the larger picture: how do the parts connect? In the case of the solar system, each planet and each planetary system (those with one or more moons) affects and is affected by the gravitational attraction between objects in the universe. It is their cumulative *effect on each other* that maintains the entire solar system in its continual pattern of orbital motion.

The human body is another complex system—in fact, it is a system composed of a number of smaller systems. In a typical life science unit in elementary or middle school, students explore in depth the body's digestive, circulatory, respiratory, and nervous systems. Therefore, in the following section, I have chosen to expand on these four body systems. It is important to stress, however, that all these systems function together to maintain the lives of human beings. Hence, as we explore four of the major body systems, we will also be thinking about how interconnected they are.

You can see that the solar system is indeed a working *system,* like an enormous, complex mechanism with many diverse components. The sun is at the helm, so to speak. It drives the orbits of the smaller parts with its enormous gravitational pull, relying on inertia and gravitational attractions to maintain the smaller objects' constant motion in their paths so that nothing comes crashing into the sun.

10-5 Human Body Systems

In the science story "What Makes a Rabbit Real?" (in Chapter 6), you saw young children beginning to understand the most important aspect of living things: their ability to exchange materials with their environment, taking in what they need and getting rid of what they do not need. Our body systems help to perform these functions for us.

A *body system* is a group of organs that work together on a specific bodily activity. There are a number of large systems in the human body. Working all together, they produce this smoothly running machine called the human body.

One typical way of thinking about body systems is to divide them into ten different but connected systems:

1. The *skin system* that covers the body and includes our nails, hair, and skin. The skin is thought of as the largest organ in the body.
2. The *skeletal system* of bones that support us.
3. The *muscular system* that makes it possible for the body and its parts to move; this system includes our muscles, ligaments, and tendons.
4. The *digestive system,* including the mouth, stomach, intestines, and liver, which breaks down foods so that all parts of the body may use the nutrients they need to produce energy and grow.
5. The *circulatory system* that uses our blood vessels and capillaries to transport nutrients and get rid of some wastes.
6. The *respiratory system* that allows us to breathe in and out by using the nose, windpipe, lungs, and diaphragm.
7. The *excretory system,* including the kidneys and bladder, that gets rid of the waste products formed in the body.

8. The *reproductive system* that produces offspring and includes organs that affect sex characteristics.
9. The *endocrine system,* a system of glands that secrete chemical messengers, called hormones, which control and regulate the actions of the body.
10. The *nervous system,* including the brain, neurons (nerves), and the spinal cord.

All living body systems are made up of tissues that develop to perform specific functions, and these tissues are made of specialized cells designed to perform specific functions, not only in humans, but in all animals and plants. The following sections describe four body systems that students frequently examine in their school science units. As you read, think about interconnections among body systems. Notice how often, in describing one system, we make reference to another related system.

10-5a The Digestive System

The body needs food in order to live and grow. The foods we eat contain materials that give the body energy and enable it to build and repair tissues and regulate other activities. The **digestive system** breaks food down into particles so tiny that blood can take nourishment to all parts of the body. The food undergoes a process of physical change as it goes from larger pieces to smaller pieces. It also undergoes a process of chemical change as it is transformed into soluble nutrients that can pass through the membranes of organs and blood vessels and into the body cells. We will explore other aspects of physical and chemical changes later in this chapter.

digestive system
The body system that breaks down food into a form that can be absorbed and used by the body.

The digestive system's main part is a 30-foot (9-meter) tube from mouth to rectum called the *alimentary canal.* Muscles in this food tube force food along. This muscular action, called peristalsis, is strong enough to allow a person standing on his or her head to chew something and have it go "down" (really up) to the stomach.

In the mouth, food is physically changed when it is chewed by our teeth; it is also chemically changed by the chemicals in our saliva. The food then travels from the mouth to the stomach by way of the part of the food tube known as the *esophagus.* For two to three hours, food stays in the stomach, where digestive juices further change it.

After the stomach churns and liquefies the food, it passes through the very convoluted small intestine, which is 23 feet (7 meters) long. In the small intestine, digestive juices from the gallbladder, the small intestine itself, and the pancreas break down food particles. Many of these broken-down particles filter out through tiny, fingerlike structures on the inside of the small intestine called villi. Food that cannot be digested or used by the body passes from the small intestine into the large intestine as waste material. There, this undigested food forms feces and leaves the body through the anus. This process is referred to as elimination.

The parts of the digestive system all work together to ensure that food is broken down and absorbed and unwanted food is eliminated. For the system to be effective, it must complete all three of these main tasks. As we explore the circulatory system, you will see that digesting the food would be useless if our blood could not transport the digested nutrients to the body cells.

10-5b The Circulatory System

The **circulatory system** is made up of the heart and blood vessels, which together maintain a continuous flow of blood around the body. The circulatory system has three main functions:

circulatory system
The system that maintains a continuous flow of blood around the body. The main parts of this system are the heart, arteries, veins, and capillaries.

1. To carry digested nutrients to the cells in the body.

2. To bring oxygen to the cells so it can be combined with the nutrients to release energy.
3. To take away soluble waste materials and carry them to organs that remove them from the body.

The heart pumps oxygen-rich blood from the lungs to all parts of the body through a network of tubes or blood vessels called *arteries* and smaller branches called *arterioles.* Blood returns to the heart through small vessels called *venules,* which lead in turn into larger vessels called *veins.* Notice that arteries carry blood away from the heart, while veins carry blood back to the heart.

A network of tiny blood vessels called *capillaries* links arterioles and venules. Capillaries reach all parts of the body, and they are the sites where the blood deposits oxygen and picks up carbon dioxide. This ongoing exchange between the blood and the body cells is regulated by the circulatory system.

The heart pumps the blood to every part of the body and back again in about thirty seconds. The blood, a liquid organ, has four main parts:

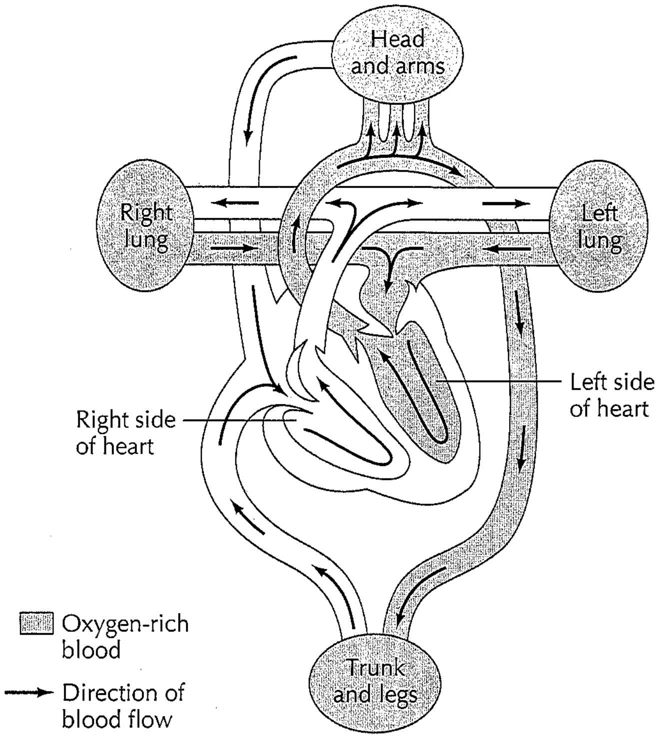
1. *Red blood cells* pick up oxygen from the lungs and carry it to the cells in the body. The cells use the oxygen to burn food, and the waste material is produced as carbon dioxide. Red blood cells pick up the carbon dioxide and carry it to the lungs, where it is given off.
2. *White blood cells* are much less numerous than red blood cells (ratio of 1 to 600) and their purpose is to destroy bacteria and other disease germs.
3. *Platelets* are tiny cells, even smaller than the red blood cells, and their function is to help the blood clot when the body is injured and bleeds. The clot prevents the blood from flowing out of the body.
4. *Plasma* is the liquid portion of the blood.

The heart is a strong muscle, about the size of your fist, located to the left of the middle of the chest. It contracts and relaxes, acting like a pump. When it contracts, it pushes blood into the arteries; when it relaxes, blood flows into it from the veins. The human heart has four chambers: two upper chambers, called the right atrium and left atrium, and two lower chambers, called the right ventricle and left ventricle. The two sides of the heart are completely separated by a wall called a septum; hence, blood in the two sides of the heart does not mix.

The atria receive blood from the veins and pump it down to the ventricles. (Valves on both sides of the heart prevent blood from flowing back into the atria.) The ventricles then pump blood into the arteries. The right ventricle pumps blood to the lungs via the pulmonary artery, and the left ventricle pumps blood to the other organs of the body via the artery named the aorta. The steps look something like this:

1. The blood is pumped out of the right ventricle to the lungs, where it picks up oxygen and deposits carbon dioxide. The reasons for this exchange will become apparent as you read about the respiratory system in the next section.
2. The oxygen-rich blood then leaves the lungs and goes to the left atrium, where it is pumped to the left ventricle and then to the entire rest of the body, depositing oxygen to the body cells.
3. The blood returns to the right atrium of the heart, filled with carbon dioxide from the body cells and needing oxygen. It then is pumped to the right ventricle and starts the cycle all over again.

FIGURE 10.2 The circulatory system
The right side of the heart pumps blood to the lungs, where it picks up oxygen and gives up carbon dioxide. This oxygen-rich blood then goes to the left side of the heart, which pumps it to the rest of the body. The cells of the body use the oxygen and give off carbon dioxide, which the blood then carries back to the right side of the heart, where the cycle begins again.



The *circulation* of the blood from the heart to the lungs and back again, and from the heart to the entire rest of the body and back again, is what gives this system its name. Figure 10.2 shows a simplified, schematic diagram of the circulatory system.

10-5c The Respiratory System

respiratory system
The system that supplies the oxygen needed by body cells and carries off their carbon dioxide waste.

The **respiratory system** supplies the oxygen needed by body cells and carries off their carbon dioxide waste. Inhaled air passes via the trachea (windpipe), through two narrower tubes called bronchi, into the lungs. Each lung is made up of many fine, branching tubes called bronchioles, which end in tiny clustered chambers or air sacs called alveoli.

The alveoli look like tiny clusters of grapes, and each lung is one great mass of these air sacs. Gases in the air pass through the thin walls of the alveoli to and from a network of capillaries. Thus, the oxygen in the air enters the blood through these air sacs. The capillaries send the oxygen-rich blood to the left side of the heart, where it is then pumped to the rest of the body.

The cells in the body use the oxygen to combine with digested food, producing energy and giving off carbon dioxide. The red blood cells then pick up the carbon dioxide, and this blood is pumped back to the right side of the heart, where it travels to the lungs via the pulmonary artery. Now the carbon dioxide leaves the blood, diffusing through the thin walls of the capillaries and of the alveoli. The air containing the carbon dioxide is then forced out of the lungs, and the fresh air containing oxygen is forced into the lungs.

respiration
The metabolic process by which cells take in the oxygen they need and give back carbon dioxide as a waste product.

The term **respiration** refers to this exchange of gases. Think again about the students in Chapter 6 who discussed the exchange of materials in which living things are engaged. Respiration and digestion are two of the body processes that implement this exchange.

Respiration should not be confused with breathing. When we talk about *breathing*, we are referring to the mechanical process of getting oxygen-rich air into the lungs and getting carbon dioxide–rich air out of the body. *Respiration* refers to the metabolic process by which cells take in the oxygen they need and give back carbon dioxide as a waste product.

10-5d The Nervous System

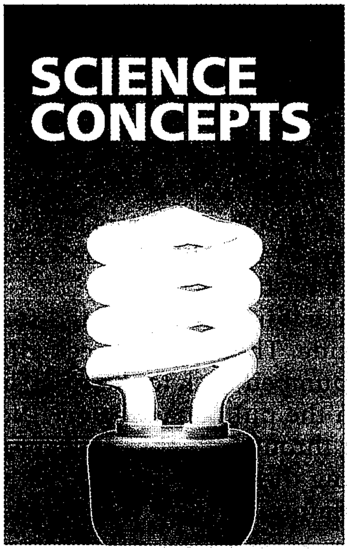
nervous system
The body's internal communications network, including the brain, spinal cord, and nerves.

The **nervous system** is the body's internal, electrochemical communications network. Its main parts are the brain, spinal cord, and nerves. The nervous system has many functions, including controlling the actions of the organs, muscles, and other tissues; controlling sensations such as smell, taste, sight, hearing, touch, pressure, heat, cold, and pain; and controlling thinking, learning, and memory.

The brain and spinal cord form the *central nervous system,* the body's chief controlling and coordinating mechanism. The brain is located in the skull, and the spinal cord lies along almost the entire length of the back. The spinal cord connects with the brain stem through a large hole in the base of the skull. The brain is the major organ of the nervous system and the control center for the body's voluntary and involuntary activities. It is also responsible for the complexities of thought, memory, emotion, and language. In adults, the brain weighs a mere 3 pounds (1.4 kilograms) but contains more than ten thousand million nerve cells.

The brain has three distinct regions: the brain stem, the cerebellum, and the cerebrum, each responsible for controlling different types of bodily functions. The *brain stem* controls vital bodily functions such as breathing and respiration, circulation, and digestion. The *cerebellum*'s main functions are the maintenance of posture and the coordination of body movements. The *cerebrum,* the largest region, consists of the right and left cerebral hemispheres, and it is the site of most conscious and intelligent activities.

How Do We Breathe?



A common alternative conception is that when we inhale, the lungs draw in air and the chest therefore expands. This is not true.

What actually happens is that air outside the body is forced into the lungs when the air pressure inside the body becomes lower than the air pressure outside. How can that occur?

When you begin to take a breath, a sheet of muscle in the bottom of your chest cavity, the *diaphragm*, contracts and moves downward. Simultaneously, your rib muscles contract and move upward and outward. These movements increase the size of your chest cavity, thus reducing the pressure of the air already in your lungs. (When you expand the space that a gas occupies, the pressure drops.) Air then rushes in from outside. When you exhale, the reverse occurs: The muscles in your diaphragm relax and your ribs move downward and inward, forcing air out of your lungs and out of your body.

The nose and nasal passages, the throat (pharynx), the windpipe (trachea), and the voice box (larynx) are all part of this system. They are passages through which the air passes. In the nasal passages, the air is warmed and moistened and tiny dirt particles are trapped. The back of the throat has a flap over the trachea called the epiglottis, which closes when food and water enter the throat, thus preventing the food and water from entering the windpipe.

Thinking About Systems

Noticing Similarities and Differences

Some systems are *open*, meaning that materials enter them and leave them. Other systems tend to be *closed*, so they do not receive external material or discharge material. Still other systems are open and closed at different times.

The digestive and respiratory systems are obviously open systems. What about the circulatory and nervous systems—are they open or closed?

The circulatory system is closed in the sense that the blood vessels and organs are contained within the body. When we bleed, however, the system is open. More important, when we exchange gases through the respiratory system, the circulatory system receives and releases those gases. In that sense, too, it is open.

The nervous system may be thought of as open in that it responds to external as well as internal stimuli. It is also closed in the sense that nothing tangible enters or leaves it.

You can see how complex and interrelated the body systems are. Think about these further questions:

- Is the solar system an open or closed system?
- What do the sun, the alimentary canal, the diaphragm, the heart, and the brain have in common?
- In what ways is the circulatory system like a transportation system?
- What do you think is meant by the often-used term *brain dead*? How could a person be alive if his or her brain were dead?
- How would *you* define a system on the basis of what you have just read and thought about?

We use the word *system* to mean many different things. We talk about political systems, for example, or school systems or transportation systems. The scientific idea of a system implies detailed attention to inputs and outputs as well as to interactions among the system components. In the next section, as you explore simple machines—a traditional physical science unit—think about what connections might be drawn among these devices, the solar system, and the human body. What links and similarities do you see yourself? What ideas might your students explore? In what ways is the functioning of the human body like a system of machines?

Nerves spread out from the brain and spinal cord to every part of the body. There are three main types of nerve cells, or *neurons*:

1. *Sensory neurons* are the nerve cells that allow us to experience sensations. The cell bodies of these neurons are located in the brain and spinal cord, but they have long fibers that spread out to sense organs all over the body.
2. *Motor neurons* have to do with producing motion in the body. Their cell bodies are also located in the brain and spinal cord, and their fibers spread out to muscles, tissues, and organs of the body.
3. *Associative* or *central neurons*, located between the cell bodies of the sensory and motor neurons, transfer nerve impulses from the sensory neurons to the motor neurons. That is, the associative neurons act as go-betweens for receiving and sending messages in the nervous system.

The brain, the spinal cord, and the system of billions of long neurons control the operations of all other systems in the human body.

10-6 Simple Machines

Frequently, students learn about simple machines as discrete topics. Each type of machine discussed is not connected to other simple machines or to more complex machines. In this section, you'll read about several kinds of simple machines. As you read, consider how they relate to each other. Ask yourself questions like these:

- Where do I use this machine?
- How does it make work easier?
- Where does it appear as part of a more complicated device?
- What makes it a system?

Remember, reflecting on the concepts that you read, having conversations about them, and making your own meaning from them will enable you to claim these ideas as your own (Photo 10.2).

A *machine* is any device that helps make people's work easier. But what exactly do we mean by **work**? Work is done when a force is applied to move something. It is the act of applying a force to move an object through a distance. We change an object's position when we do work.

work
The act of applying a force to move an object through a distance.

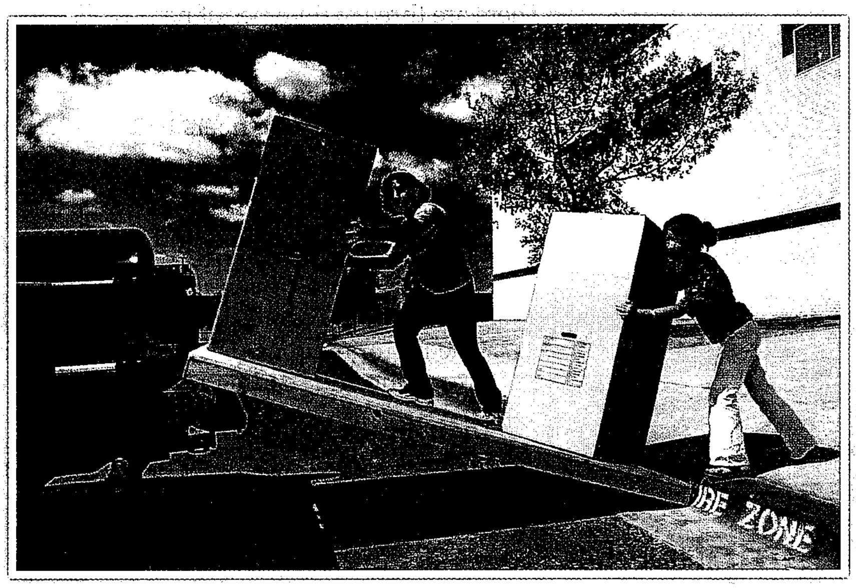
force
A physical agency (such as a push or a pull) that tends to cause a change in the position or motion of an object.

A **force** is a push or a pull. You encountered the term *force* earlier in this chapter in the discussion of gravity and inertia. Gravity is a force—an attraction, a pull of any object in the universe on any other. You can think of the sun as doing work as it exerts its gravitational pull and helps to keep the planets and other objects in orbit around it. Of course, forces are also produced by people when they use their muscles. When you pull this book toward you and change its position, you are doing work.

Machines help us do work in several ways:

1. By transferring force from one place to another.
2. By increasing the amount of force applied.
3. By changing the direction of a force: for instance, when you pull *down* on a rope to raise a flag *up* a flagpole.

According to MS-PS2-2, *the motion of an object is determined by the sum of the forces acting on it. If the total force on an object is not zero, its motion will change.* This disciplinary core idea for middle school physical science reminds us that a larger force causes a larger change in motion.



Bob Daemmrich/The Image Works

PHOTO 10.2 These students are learning a very practical application of a simple machine. What is this machine called in scientific terms? How does it help?

One way to study simple machines is to divide them into different types. Let's look at six types that are commonly explored in school science: the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw. These simple machines receive their force mainly from human muscles, like yours. They are devices that are used to get specific tasks done. Although these simple machines are different, remember to look for commonalities among them.

10-6a Lever

A *lever* is a rigid bar that moves around a fixed point, called a *fulcrum*. The seesaw is an example of a lever. So are a crowbar, scissors, and pliers. These types of levers, called *first-class levers*, change the direction of the force. As you apply force in one direction, the object you are lifting or moving goes in the other direction.

Think about being on a seesaw or teeter-totter (Figure 10.3a). As you move down, your partner moves up. To understand why the seesaw is helping you perform work, think about how difficult it would be to lift your partner the same distance without the seesaw.

The seesaw example also helps show how force and motion are related. Your force on the seesaw depends on your weight. Let's say that your partner weighs more than you do. When you first sit on the seesaw, your weight isn't enough to move your partner up. What will you do? You will move to the very end of the seesaw, increasing your distance from the fulcrum; by so increasing the distance, you decrease the force needed to lift your partner.

A *second-class lever* also reduces the force you need to apply, but the force and the object you are moving go in the same direction. The wheelbarrow, a bottle opener, and an oar for a rowboat are examples of these simple systems.

A *third-class lever* supplies a gain in speed and distance. Examples of such levers are a broom, a shovel, and a fishing pole. To achieve greater speed and distance, the third-class lever actually causes a loss in force: As you sweep with a broom, the broom head moves faster and farther than your hands do but with less force.

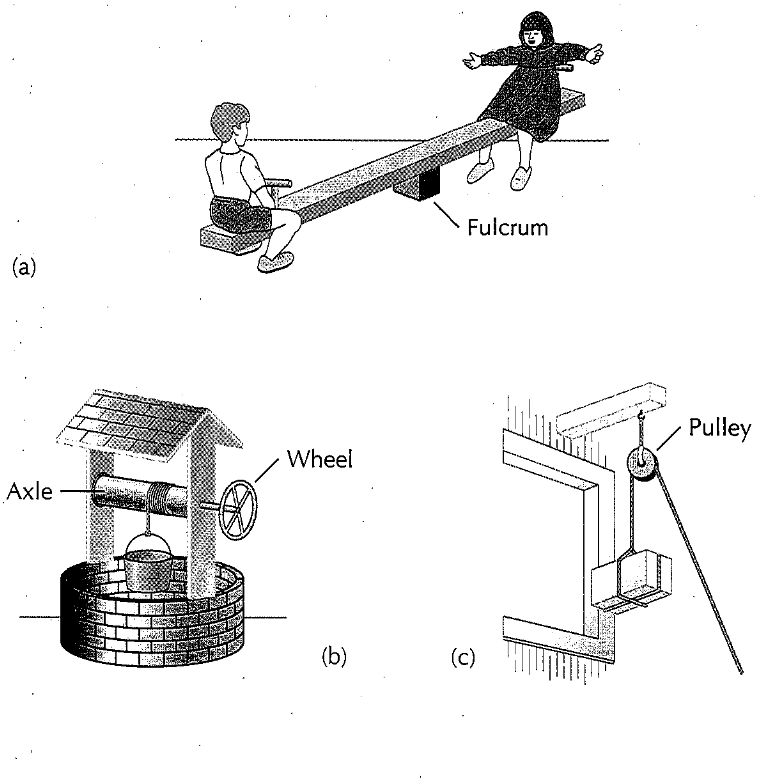


FIGURE 10.3 Simple machines (a) A seesaw as a first-class lever. Notice how the lighter person can lift the heavier person by sitting farther from the fulcrum. (b) A wheel and axle. (c) A pulley.

10-6b Wheel and Axle

A *wheel and axle* is like a spinning lever. A large wheel is connected to a smaller circular device, called the axle or shaft. The fulcrum is in the center of the axle and the wheel. Once the wheel turns, the axle turns (see Figure 10.3b). A wheel and axle can change the direction of a force and also amplify the force.

Examples of wheel-and-axle machines that contain complete wheels include the steering wheel in a car, the gear wheels of a bicycle, a doorknob, and a screwdriver. The steering wheel revolves around an axle called the steering column; the bicycle gears revolve around an axle called a shaft; and a doorknob revolves around an axle called a rod. The handle of a screwdriver does more than enable you to hold it. It amplifies the force you use to turn it to drive the screw home! Its axle is the screwdriver blade.

With a wheel and axle, as the wheel rotates it moves a greater distance than the axle but turns with less force. That is, when you turn the wheel, the axle turns with a greater force than the wheel. In this way, a small rotary motion can open a locked door!

Sometimes a crank instead of a wheel is attached to the axle. Wheel-and-axle machines with a crank include a manual eggbeater and a pencil sharpener.

10-6c Pulley

A *pulley* (see Figure 10.3c) is a wheel that turns around a stationary axle. When the pulley wheel turns, the axle does not turn. Usually there is a groove in the pulley wheel so that a rope around the pulley will stay in place. Sometimes there are two or more pulley wheels side by side on the same axle. If the pulley wheel is attached to a stationary point, it is called a fixed pulley.

You use a pulley to change the direction of a force and make work easier. Fixed pulleys are used when raising flags along flagpoles and when pulling curtains or venetian blinds open or closed. A fixed pulley is like a spinning first-class lever. The fulcrum is at the center of the axle. An elevator is a single-pulley lifting machine. The elevator car is raised or lowered by a cable running over a pulley at the top of the elevator shaft.

10-6d Inclined Plane

An *inclined plane* is a slanting surface that connects one level to another level. A hill, a wheelchair ramp, a sloping floor, an escalator, and a stairway are all examples of inclined planes. Moving an object up an inclined plane requires less force than lifting it straight up to a higher position. The longer the inclined plane, the less steep the slope and the less force required. The tradeoff is that, to reduce the force needed, the inclined plane increases the distance traveled.

10-6e Wedge

A *wedge* is a simple machine used to spread an object apart or to raise an object. The wedge is like a moving inclined plane. It has a sloping side, but it is moved under an object or into an object. A typical doorstop is a single wedge. Examples of double-sided wedges are the blade of an ax, a scissors blade, and a plow blade; each of these is sloped on two sides.

A nail is a type of wedge, and so is a pin. Shovel blades can be examples of wedges. A chisel is a perfect example of a wedge. The longer or thinner a wedge is, the greater the advantage in using it.

10-6f Screw

A *screw* is an inclined plane that winds around and around in a spiral. The spiral ridge of the screw is called the thread. Ordinary wood screws and bolts are examples. Other examples include the caps of jars and bottles, the base of an electric light bulb, and the part of a vise that opens and closes the jaws. Usually another simple machine, such as a lever or a wheel and axle, is used with a screw to reduce the force needed. With a wood screw, for instance, you use a screwdriver; with a vise, you use a handle.

10-6g Compound Machines and Gears

Many of the machines we encounter, like the snow shovel, are *compound machines*. That is, they are made up of two or more simple machines. Consider an ax: its handle is a lever; its blade is a wedge. Here are some other examples:

- A pair of scissors has two levers with wedges for blades.
- The handle of a manual pencil sharpener is a wheel-and-axle system that turns two screws with sharp edges shaped as wedges. The edges act as blades to sharpen a pencil.
- A manual rotary can opener is part wheel and axle and part circular wedge.

As you can see, these are simple systems that combine to form more complex systems, just as our planet–moon system forms part of a larger, more complex solar system and the respiratory system is part of a larger, more complex body system.

A commonly found compound machine is the bicycle. It is a wheel-and-axle machine that uses a system of gears. A *gear* consists of one wheel that is used to turn another wheel. These wheels have saw-like "teeth" on their circumferences that allow the wheels to interact with each other. A chain around both wheels connects them. The chain usually has notches, which fit into the teeth of the wheels.

The bicycle pedal turns a crank that turns a large gear. The chain then turns the smaller gear, and the smaller gear turns the rear wheel, which drives the bicycle forward. Each time the pedals turn the larger gear around once, the smaller gear turns the rear wheel around many times.

Thinking About Systems

Simple Machines as Systems

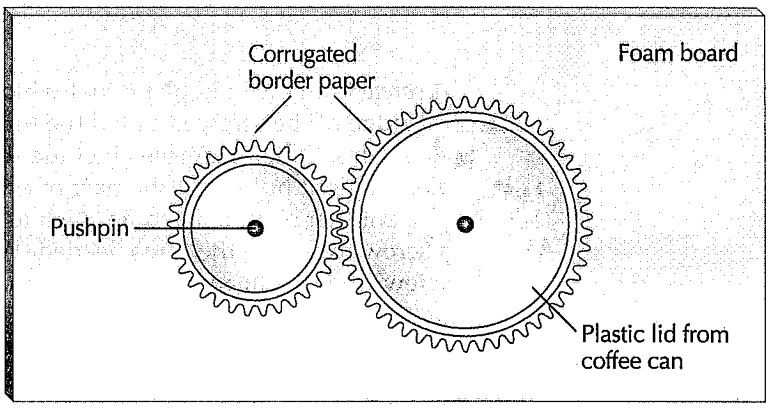
All machines make work easier for people. Each of the machines discussed in this chapter represents a system—parts working together to perform a function.

A single wedge, for example, is a movable inclined plane. Combine it with a simple lever and you have a shovel! Can you see why these are systems? The lever needs a bar and a fulcrum, working together. The wedge needs a flat slope and an inclined slope. Putting them together, you can clear the snow from your front walk or tend to your garden.

To expand your understanding of machines as systems, ponder these questions:

- Are *you* part of the machine systems described here? If so, how?
- Are there parts of your body that can act as simple machines? Which parts?
- Earlier in this chapter, you saw that the solar system and human body systems have forces that make them work, just as simple machines do. What principles from physical science, life science, and earth science can be applied to *all* of these systems?

FIGURE 10.4 Simple gear experiment using two sizes of coffee can lids
Using a setup like this, count the number of times the smaller gear turns for each turn of the large gear. Measure the diameters of both lids. Now can you devise a mathematical way of relating the difference in turns to the difference in diameters?



It is fun to explore the relationship between the diameter of the gear wheels and the number of rotations. If you can obtain plastic lids from one- and two-pound cans of coffee, you can use corrugated border paper, a piece of foam board, and a couple of pushpins to make your own model gear system, as shown in Figure 10.4. Glue the border paper trim around the edges of the plastic lids. Place the lids on the foam board so that the border paper "teeth" interface with each other. Press the pushpins through the center of each lid to secure your "gears" to the foam board. Turn the larger gear once and count the number of times the smaller gear turns. Then repeat the experiment by turning the smaller gear once. Measure the diameters of both lids and create your own gear-ratio theory!

10-7 The Earth as a Super-System

Teachers and students explore the interactions of human activities and natural systems on earth through the study of disrupted ecosystems and local habitats as we saw in Chapter 4. In recent years, more attention has been given to the quality of our air, water, and land as we delve more deeply into the effects of human development on the earth's natural systems. The NGSS DCI, MS-ESS3.C: Human Impacts on Earth Systems, states "Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species" (MS-ESS3-3).

When we think of the earth as a system, we must view the planet from its center to the outer limits of its atmosphere, including everything in and on it. In this sense, the earth can be called a super-system: a complex, mixed living and nonliving system with many interacting components, including the atmosphere, the geosphere, the hydrosphere, and the biosphere (Miller & Miller, 2000).

- The *atmosphere* is the layer of gases surrounding the earth and retained by the earth's gravity. About 78 percent of the atmosphere is nitrogen, about 21 percent oxygen, and 0.93 percent argon. Other gases, including carbon dioxide and water vapor, exist in small, variable amounts.
- The *geosphere* is the solid earth that includes the continental and oceanic crust as well as the various layers of the earth's interior.
- The *hydrosphere* includes all water on earth, in oceans, lakes, rivers, streams, soil, groundwater, ice caps, glaciers, and the atmosphere.
- The *biosphere* is the zone of the earth that includes all living organisms. The biosphere distinguishes earth from all other planets in the solar system.

When we develop an integrated understanding of the earth as a system, then we can understand the role that humans have played in modifying the dynamics of the system.

10-7a The Earth's System and Green Science

The understanding that systems consist of many parts and that the parts usually influence each other underlies the study of environmental science. Something may not work as well (or at all) if a part of it is missing, broken, worn out, mismatched, or misconnected. With these basic concepts, science education can help us to understand the impact of the world's 7.2 billion people and their technologies on the climate, the atmosphere, and other living organisms. Science education may help students learn to live in ways that keep our planet healthy.

The accompanying feature on climate change describes what recent scientific reports tell us about global warming and the connection to greenhouse gas emissions from our cars, our homes, and our industries. When you talk about climate change with students, you should be aware of the way scientists use these key terms:

- As we saw in Chapter 6, **greenhouse gases** are gases in the atmosphere, such as carbon dioxide and methane, that trap the sun's energy and contribute to rising surface temperatures. Greenhouse gases occur naturally and protect the atmosphere from becoming too cold. In excess, however, they trap reflected radiation from the sun and cause unwanted increases in the atmospheric temperature.
- The **fossil fuels** that create greenhouse gases when burned include oil, gas, and coal. These are the remains of plants and animals that lived long ago. Found deep underground, fossil fuels took millions of years to form and thus are not renewable. Once consumed, they cannot be created again.
- **Climate** is the average pattern of weather, taken over a long period of time, often thirty years, for a particular region. Climate depends on the geographic location of the region, its latitude, its terrain, whether it has a persistent ice or snow cover, and its proximity to bodies of water.
- **Weather** describes the short-term conditions of the atmosphere in a particular place.

greenhouse gases
Gases that reduce the amount of heat energy (infrared radiation) that is radiated back toward space when the sun's energy enters the atmosphere and strikes the earth. These gases include carbon dioxide, methane, and nitrous oxide. Many greenhouse gases occur naturally, but they may also be produced by industrial processes. Excess greenhouse gases in the atmosphere can cause average temperatures to climb over time.

fossil fuels
Fuels such as oil, gas, and coal that derive from the remains of plants and animals that lived long ago.

climate
The average pattern of weather for a particular region, measured over a long period of time.

weather
The short-term conditions of the atmosphere in a particular place (compare *climate*).

The same reports that help us understand global warming also offer suggestions for how people may change their impacts on their environment. Clearly, many changes are required at the governmental and institutional level; however, in elementary and middle school science, we can explore areas like conservation, recycling, and the reduction of waste. For example, elementary and middle schools generate a great deal of waste, and students can analyze and monitor that, as you can read about in the *Science Story* about milk waste in Chapter 11. Through a scientific understanding of the effects of fossil fuel burning on the global climate, students can take responsibility for:

- Packing a waste-free lunch.
- Walking or biking to school if possible.
- Using both sides of recycled paper.
- Carpooling when alternative transportation is unavailable.
- Using pencils and rulers made from recycled materials.

Remember that making connections between the scientific concepts and the students' daily lived experience brings classroom science to life.

The Scientific Consensus on Climate Change

Although the changes in earth's climate have been much debated, most environmental scientists now agree on the following:

- The global climate is definitely warming.
- Most of the temperature rise in the past half-century probably stems from the increase in human-produced greenhouse gases. Mathematically speaking, the chance that natural processes account for the warming is less than 5 percent. Carbon dioxide (CO_2) emissions in the United States increased by about 7 percent between 1990 and 2013. CO_2 concentrations in the atmosphere have increased by 40 percent since preindustrial times.
- CO_2 is the primary greenhouse gas emitted through human activities. In 2013, CO_2 accounted for about 82 percent of all U.S. greenhouse gas emissions from human activities. CO_2 is naturally present in the atmosphere as part of the earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle—both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere.
- Although the changes in average temperature seem small in themselves, they have been accompanied by significant increases in floods, droughts, heat waves, and wildfires, particularly since 1970.
- Other recent phenomena apparently related to warming temperatures include increasing intensity of tropical storms, large reductions in summer sea ice in the Arctic Ocean, large increases in summer melting of the Greenland Ice Sheet, and signs of instability on the West Antarctic Ice Sheet.

Sources: IPCC (2013) and EPA (2016).

10-7b Energy and Matter in the Earth's System

Another way to understand earth as a system is to notice the fluxes of energy and matter that become apparent as we explore water, life, air, and rocks on our planet. Some examples include:

- *Cycles:* how things happen or get used over and over again. Examples include the rock cycle, the water cycle, and the carbon cycle.
- *Flows:* how matter and energy move from place to place. For example, energy moves through food chains and from the sun through living systems during photosynthesis.

This idea of regular patterns on earth leads us to our second major conceptual category for organizing science topics: interactions and patterns of change.

10-8 Interactions and Patterns of Change

Many of the phenomena that we observe on earth involve interactions among components of the air, land, and water, and forms of energy such as heat, light, sound, and electricity. We use the term *interaction* to mean a change in matter and energy. Interactions contribute to many patterns of change on the planet, such as the water cycle and weather; earthquakes and volcanoes; and the rock cycle, weathering, and erosion. As you read about interactions between matter and energy, you may want to ask yourself: What is changing? What is remaining the same?

One of the basic beliefs in science stems from the work of the scientist Albert Einstein (1879–1955). In 1905, he proposed a theory relating matter and energy to each other, a theory that many other scientists have tested through their studies of the atom. When such a statement about principles or patterns in nature endures over time and survives consistent tests, we call it a **scientific law**. Earlier, in the section on systems, you read about the law of gravitation. Einstein's explanation of the relationship between matter and energy in ordinary chemical reactions is called the **law of conservation of matter and energy**. According to this law,

1. Neither matter nor energy can be created or destroyed, but either can be changed into other forms of matter or energy.
2. Matter can be changed into energy; energy can be changed into matter.
3. Therefore, the total amount of matter and energy in the universe is always the same.

scientific law
A statement about principles or patterns in nature, indicating relationships between or among facts. Laws have endured over time and have consistently been tested; but, like theories, they are not absolutely "proved."

law of conservation of matter and energy
The scientific law asserting that matter and energy can be changed into each other but cannot be created or destroyed.

This law requires lots of time to think about. Einstein quantified the relationship between matter and energy with his famous *special theory of relativity*, expressed in the equation $E = mc^2$. In this equation, E stands for the amount of energy, m for the amount of matter, and c for the immense speed of light (about 186,000 miles/second, or 300,000 kilometers/second). The equation indicates that the transformation of even a tiny amount of matter will release an enormous amount of energy. I invite you to think about this matter–energy relationship as we explore changes in matter and energy in the following sections.

Different kinds of matter exist and are described by observable properties. **Matter** usually has some mass and takes up space. Air, water, rocks, wood, and metals are examples of matter. People, other animals, plants, the sun, and other stars and planets are also examples of matter. In contrast, **energy** is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another and from place to place (4-PS3-2 and 4-PS3-3). Energy is also thought of as the ability to do work. (Remember, *work* is defined as the process of applying a force to move something through a distance.) Now let's explore the interactions of various forms of energy with various forms of matter.

matter
Anything that has mass and takes up space.

energy
The ability to do work.

10-8a Heat Energy and Matter

Stored-up energy is called *potential energy*, whereas the energy of moving objects is called *kinetic energy*. As we begin the study of heat energy, you will see that it is, in fact, a form of kinetic energy.

Heat energy is really the energy of moving particles. The more heat energy a substance has, the faster its particles move, and the hotter the substance becomes. Remember that there are three main states of matter on earth: solids, liquids, and gases. (Plasma, the fourth state of matter, is the stuff stars are made of.) On earth, the state of matter with the most heat energy is the gaseous state. The particles move fastest in a gas. In liquids, the particles move more slowly, and in solids they move very slowly.

It may be difficult to believe that solids, like your desk, are made of matter that is moving, but indeed that is so. We cannot see the motion, but we know that all matter is made up of atoms and molecules and their own subatomic particles, and that these particles are always in motion.

10-8b Water

When heat energy is added to water, the water becomes hotter and hotter—its particles move faster and faster—until it reaches its boiling point, and then it can change from a liquid into a gas, known as water vapor or steam. This water vapor has a greater amount of heat energy than the liquid. In fact, hot steam can cause a more severe burn than hot water because, to become steam, it had to absorb so much heat energy! Technically, steam itself is not visible. We know that steam is present because as it meets the cooler air, it condenses. It is the condensed particles of water vapor that are visible.

Conversely, if we remove enough heat energy, we can cool water and produce a solid. The more heat energy we remove, the slower the particles move, and eventually the water becomes ice. The point at which this happens is the freezing point of water.

physical change
Change in the physical properties of a substance, that is, in the properties we can readily observe with our senses.

When we change water from a solid into a liquid to a gas, we are creating a **physical change**. That is, we are changing only the water's *physical properties*—the properties that we can readily observe with our senses. The distance between the molecules changes: The molecules are closest together in the solid and farthest apart in the gas. But the basic composition of the water does not change: It is still made up of the same arrangement of atoms of hydrogen and oxygen that chemists designate as H_2O.

Similarly, if we tear a piece of paper in half using the force of our muscles, we are changing the size of the paper but not its composition. This is another example of an interaction of matter and energy that produces a physical change.

10-8c Sugar

Sugar is a compound made up of hydrogen, oxygen, and carbon, but its properties do not resemble the properties of hydrogen, oxygen, or carbon. When these three elements combine to form the compound sugar, the elements lose their original properties. In fact, sugar can be thought of as a system in which the parts and the whole do not have features in common.

When sugar is granulated or formed into cubes, we say it is undergoing a physical change; its composition has not changed. If we add heat energy to sugar so that it slowly caramelizes, we are changing it from a solid into a liquid in a process called melting, and that also is a physical change. The sugar still retains the same chemical composition.

chemical change
A change in the chemical properties of a substance, that is, in the composition of the substance and the way it behaves with other substances; also called a *chemical reaction*.

But when we add enough heat energy to sugar, we will notice steam escaping from it, and a black carbon-like substance forms. This breakdown in the composition of sugar is called a **chemical change** or a *chemical reaction*. This particular type of chemical reaction is called *decomposition*.

The *chemical properties* of a substance are those characteristics that have to do with its composition and the way it behaves with other substances. Chemical changes usually produce new substances that have no resemblance to the original substances.

10-8d Bottles and Balloons

Imagine that you have two empty (except for air, of course) soda bottles, exactly the same size. Pour 100 milliliters of water into one bottle and 100 milliliters of vinegar into the other bottle. Place two tablespoons of baking soda into deflated balloons. Hang a balloon over each bottle like a stocking cap. With the help of a friend, simultaneously raise the balloon over each bottle so that the baking soda drops into the liquid.

Hold on! These two bottle-balloon systems produce different reactions when the baking soda reaches the liquid. In the vinegar bottle, there are lots of bubbles, and the balloon inflates. In the water bottle, the baking soda drops to the bottom, and nothing happens to the balloon. If you wanted to get the baking soda back, you could slowly allow the water to evaporate. In the vinegar bottle, however, a new substance has formed. Baking soda and vinegar combine to produce bubbles of carbon dioxide gas. The balloon inflates when the carbon dioxide is produced in the reaction.

In what ways are these systems the same? Different? Do you think they look the same initially? How could you tell that one bottle had water and one had vinegar?

10-8e Sources of Heat Energy

In order to better understand heat energy, you may want to think about the various sources of heat energy on our planet:

- Solar energy, or energy from the sun, produces heat energy. In fact, the sun–earth system provides us with our main source of heat.
- The mechanical force of friction produces heat energy. For instance, rub your hands or two sticks together, and you produce heat. This is a transformation from mechanical energy of motion into heat energy.
- Heat energy can also be produced by converting chemical energy. The burning of oil, gas, coal, or wood is a chemical process that releases heat energy.
- Electrical energy can produce heat energy when an electric current flows through thin wires, such as the filament of a light bulb or a toaster.
- The energy stored in the nucleus of an atom, or nuclear energy, can produce a vast amount of heat energy.

10-9 Heat Energy on the Move

Heat energy travels in three basic ways, through the processes of radiation, conduction, and convection.

1. *Radiation. Radiation* is the method of heat transfer that occurs when the sun's energy is transferred to the earth. This heat energy travels to us by radiating through space in invisible energy waves. Heat waves, also known as infrared waves, are part of the *electromagnetic spectrum.* This is a family of energy waves that includes radio waves, light rays, ultraviolet rays, x rays, gamma rays, and cosmic rays. They all travel at the speed of light.

   Radiation as a form of heat transfer should not be confused with other types of radiation, such as radioactive emissions, some of which can be very harmful. The type of radiation that is emitted from high-energy nuclear reactors, for example, is harmful.

2. *Conduction.* Every time we use a potholder or wear shoes on a hot beach, we are protecting ourselves from getting burned by the process of *conduction.* As a substance takes in heat energy, its particles (molecules) move faster and faster and bump into each other. They can also collide with particles of another substance, such as the surrounding air or your own skin. The heat energy is passed along or *conducted* from molecule to molecule.

   In order for heat to move by conduction, two things with different temperatures must be touching. A material that passes heat along well is a good conductor. Metals are good heat conductors. Materials that do not allow heat through are insulators. Wool, down jackets, wood, plastic, and rubber are good insulators.

3. *Convection*. The heat transfer that occurs in fluids is known as *convection*. A *fluid* is any substance that flows. Liquids are fluids, and so are gases such as air.

   When a gas or liquid is heated, the molecules move more rapidly and spread farther and farther apart. The greater the space between the particles, the more volume the fluid occupies, and the less dense it becomes (see the discussion of density in Chapter 7). For example, air or water that is warmed expands and becomes less dense.

   Think of a pot of water heated on a stove (Figure 10.5). The water on the bottom of the pot absorbs heat from the burner and becomes less dense. The water near the top of the pot remains colder and denser. The

Thinking About Interactions

Chemical and Physical Changes

We come across chemical and physical changes all the time in our daily lives. For example, when an iron nail rusts, it has changed its composition and undergone a chemical reaction; this is an example of a chemical change. A new substance is formed: iron oxide—the chemical name for rust.

See if you can figure out whether the following are examples of physical change or chemical change, or both. Remember, science is messy, and neat categories often elude us.

1. Sour milk
2. Burnt toast
3. A ripped skirt
4. A mowed lawn
5. A stained shirt
6. A flowing river
7. Eroded rock particles
8. A weathered building
9. Digestion

Some questions you may ask yourself include:

- Was a new substance formed?
- Was there a change in form, not content?
- How did the change occur?

The answers are provided below.

1. Chemical change, because the composition of the milk is changed.
2. Chemical change and physical change: the bread loses some of its water when toasted and changes color.
3. Physical change: there is a tear in the material.
4. Physical change: the grass is shorter.
5. It depends on the stain! If it is an acid stain, then it could change the composition of the materials; otherwise, it is a physical change in the fabric.
6. Physical change: the water moves but it is still water.
7. Physical change: the particles of rock are the same, only smaller.
8. Physical and chemical change: the composition of the surface is changed, and the color appears different as well.
9. Physical and chemical change, because the food changes in both size and composition as it goes through the digestive system.

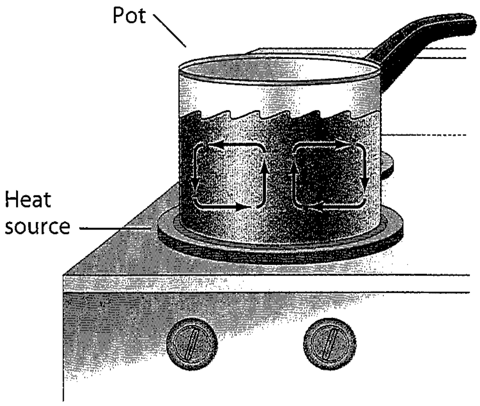


FIGURE 10.5 Convection currents in a pot of water being heated on a burner
Colder, denser water sinks, pushing the warmer, less dense water upward.

denser water sinks, pushing the warmed water upward. Convection, then, is a process by which warmed gases or liquids are pushed upward by cooler, denser gases and liquids. The continuous cycling of these fluids is called a *convection current.*

Lots of people like to say that "heat rises." I remember how surprised I was to learn that heat itself did not magically rise, but that some *thing*—a gas or a liquid—was actually rising. Convection was at work in the story of "The Bottle and the Balloon," in Chapter 2, where we saw a balloon inflated above a bottle that was placed in a pot of hot water. If you have a radiator in your house, you will notice how the warm air rising from the radiator heats up an entire room by setting up a convection current. Some ovens are designed specifically to take advantage of convection currents.

Convection, in fact, is the basis for the earth's system of air and water currents. Uneven heating of the earth's curved surface causes some ocean waters to heat and cool at different rates. The air above these ocean waters heats and cools at different rates as well. The resulting convection currents explain many of our ocean and weather patterns. Even magma, the fluid rock beneath the earth's surface, is heated unevenly. This results in convection currents that contribute to the formation of mountains, earthquakes, volcanoes, and even the spreading of the ocean floor.

Thinking About Interactions

Links between Interactions and Systems

Interactions and systems are linked. When we think of systems, we may ask ourselves, "What are the interactions at work?" When we think of interactions, we may ask, "What system contains these interactions?" For example, you have just read about convection currents, which are interactions between heat energy and liquids or gases. We could also be describing the operation of a system, for example, a convection oven. All systems rely on interactions between matter and energy.

10-10 Electricity

electricity
A form of energy produced by a flow of electrons.

In an earlier chapter, you read two stories about teachers engaging their classes in investigations with electrical circuits. You may recall that **electricity** is a flow of electrons. In this section, we will try to delve more deeply into the following:

- What is an electron?
- How is electrical energy a form of matter–energy interactions?
- How do other forms of energy produce electricity?
- How does a generator work?

10-10a The Structure of Matter and the Electron

Much of the history of science has involved the search for the structure of matter. Matter, as you learned in an earlier chapter, is made up of tiny particles called atoms. An *atom* is the basic structural unit of matter—the smallest part of an element (a pure substance) that still has the properties of that element.

We know a great deal now about the complex structure of the atom itself. There are three basic subatomic particles—protons, neutrons, and electrons—and scientists have broken these down into even smaller particles.

Earlier in the book you also read about *molecules*, the smallest particles of a compound that still have the properties of the compound. The tiniest particle of water that still has the properties of water is a molecule of water. There are literally billions of molecules in a drop of water. Compounds are made up of two or more elements. Hence, molecules are usually made up of two or more atoms. Sometimes substances are made up of only one element, and the atoms of these elements form single-atom or diatomic (two-atom) molecules. Oxygen, nitrogen, and neon are examples of elements that can form molecules by themselves, without any other type of atom.

Atoms, of course, are tinier than molecules, and electrons are much smaller than any given atom. An *electron* is a particle with a negative (−) electrical charge. Although they have very little mass, electrons have a lot of energy, and they move around the nucleus (center) of an atom with great speed, approximately the speed of light.

A *proton* is a particle with a positive (+) electrical charge. It is much heavier than an electron, about 1,840 times the mass of an electron, but it also has a lot of energy. Because of its mass, though, it does not move as fast as an electron. The positive charge of a proton is equal in strength to the negative charge of an electron, and the two charges are considered opposite to each other. When many electrons are near each other, they repel each other—that is, push each other away. When protons are near each other, they also repel each other. Protons and electrons, however, having opposite charges, are attracted to each other. When a proton and an electron are near each other, the effects of their charges are neutralized.

Because atoms have the same number of electrons and protons, the atom is neutral, without electric charge. But if there is a loss or gain of electrons, the charge is out of balance, and the atom is no longer neutral. If there are excess electrons, we say the atom is negatively charged; if there are too few electrons, we say the atom is positively charged. An atom with an electrical charge is called an *ion*. Notice that the atom can gain or lose electrons, but the number of protons and neutrons usually remains stable. This is because the neutrons and protons are closely packed together in the nucleus of the atom.

Neutrons are subatomic particles that have neither a positive nor a negative charge. The mass of a neutron is about the same as the mass of a proton and an electron combined. Scientists believe that a neutron is, in fact, a proton and an electron held together by a small bundle of energy called a neutrino, which has no electrical charge and no mass.

Neutrons and protons are held together in the nucleus of the atom by enormous amounts of energy, sometimes called binding energy. The electrons move around the nucleus of the atom at different distances, called energy levels or orbitals. Thus, an atom's electrons form a sort of hazy electron cloud as they move around the nucleus. Sometimes they are near the nucleus and sometimes they are farther away, depending upon how much energy they have at the moment. (See Chapter 8 for more on electron clouds.)

10-10b Static and Current Electricity

From the structure of the atom, you can see that all matter is electrical in nature. This brings us to the role of the electron in the form of energy called electricity.

Sometimes you can rub certain materials with another material and actually remove electrons from some of the atoms. When the electrons of one material pass to the atoms of another material as they are being rubbed, we may get a "shock." This happens, for instance, when you rub a balloon on a wool sweater. The kind of electricity that has been produced from the force of rubbing is called *static electricity*. Sometimes we say that our clothes feel "static-y."

You've probably also noticed that, after a balloon has been rubbed on a wool sweater, it can adhere to a wall. What is going on? Wool and fur tend to lose electrons when they are rubbed, giving them a net positive charge. The balloon, in contrast, gains electrons and has a net negative charge. When you hold the balloon against the wall, the electrons in the layer of paint on the wall are repelled by the balloon's extra electrons. The paint's electrons move away along the surface, leaving the spot where they originated with a net positive charge. The negatively charged balloon then "sticks" to the wall because opposites attract! For the same reason, little bits of paper are attracted to the charged balloon.

When electricity moves, it is called *current electricity*. Scientists believe that when an electric current is flowing through a material, the electrons flow from atom to atom inside the material. Materials, such as copper wire, that allow an electric current to flow freely through them are called conductors. Most metals are good electrical conductors, just as they are good heat conductors. Carbon, although a nonmetal, can also conduct electricity. Materials that do not allow electrons to flow freely through them are called nonconductors or insulators. Examples of insulators are rubber, many plastics, wood, glass, porcelain, and cloth.

10-10c Energy Transformations and Generators

Electricity is a form of energy and can therefore be produced from other forms of energy. Chemical energy stored in a battery can be changed into electrical energy. Light energy can be transformed into electricity using a photoelectric cell or solar cell. You can even twist two wires together and heat them to produce an electric current; this device is called a thermocouple.

How is the electricity you use in your home produced? In most cases, it comes from a generating plant that takes advantage of the relationship between electricity and magnetism. The basic principle of an electrical *generator* is that electricity is produced by moving magnets around a wire coil—or, alternatively, moving a wire coil between the poles of a U-shaped magnet. A typical generating plant uses a source of heat energy to boil water. The steam from the boiled water turns large wheels called turbines, which then turn the wire coils or the huge magnets of the generator.

Notice that the electrical generator is a system that produces electrical energy as a result of many interactions between matter and other forms of energy. The mechanical energy of the turbines is needed to produce the electricity. The heat energy of the steam is used to produce the mechanical energy. Electrical power plants use different materials to heat the water; many burn fossil fuels like coal and oil, while others use nuclear power. Some power plants use the mechanical energy of running water to turn the turbines. You may want to visit a local electrical power plant to learn more about how it works.

There are environmental concerns about the ways in which utility plants operate. Those that burn fossil fuels often emit significant amounts of harmful greenhouse gases. Nuclear-powered electrical plants may give off harmful radiation in the event of an accident. In 2011, the 9.0 earthquake in Sendai, Japan, and the tsunami it caused did enormous damage to the cooling systems of the nuclear power plants in that part of Japan. The risk of radiation release remains a serious concern for residents of that area. These systems are often not fully understood by the public, but they present issues that may affect the quality of your life and raise the potential for global warming.

10-11 Light

light
A form of energy radiated by the sun and stars. Light is only the visible part of the electromagnetic spectrum, which also includes many types of electromagnetic waves that we cannot see.

Light is a form of energy that is given out, or radiated, from the sun and other light-producing objects in the form of waves. These light waves are sometimes referred to as radiant energy. Light, like heat energy, is part of a group of radiant energy waves called the electromagnetic spectrum. Among these waves, light rays are the only ones that we can see.

All electromagnetic waves, including light waves, travel at the same speed, approximately 186,000 miles/second (300,000 kilometers/second). You may recall that earlier in this chapter we referred to this enormous speed when we explored the conservation of matter and energy. Light travels so quickly that it crosses earthly distances in what appears to be an instant. Light energy makes it possible for us to see the things around us—and to see them without any noticeable delay.

Measured against the vastness of outer space, however, the passage of light is not so instantaneous. Even at its enormous speed, the sun's light takes eight minutes to reach the earth. This is useful for us to reflect on, because it helps us imagine the immensity of space. If the sun were to stop shining, it would not go dark in our sky for eight minutes!

The distance light travels in a year is a called a *light-year,* and it equals about 6 trillion miles, or 9.5 trillion kilometers. The light-year is used as a measure of distance when we are referring to the great expanses of the universe.

Like waves in water, light waves move up and down as they move forward. But light requires no medium to travel in; it can travel in a vacuum, such as the vacuum of outer space. In addition to its wavelike nature, light also acts like a stream of particles. Scientists have dubbed these particles *photons,* and they have learned that photons are a lot like little bundles of energy.

10-11a Sources of Light

The sun is our natural source of light. It produces energy by changing the atomic nuclei of its atoms. This process of *nuclear fusion* produces enormous amounts of solar energy. The energy is released as light and as all the other waves of the electromagnetic spectrum.

One common alternative conception about the sun is that it is "burning." In fact, there is no fire, but there is enormous heat (10,000 degrees Fahrenheit, or 5,538 degrees Celsius) and explosive activity. The sun is made of plasma, like other stars, and it produces its energy in the same way as other stars. The moon and planets do not produce their own light. Rather, they shine by the process of reflection—the sun's light bounces off their surfaces.

Besides the sun's natural light, we have many artificial sources of light. These include candles, kerosene or gasoline lamps, and various forms of electric light.

10-11b Light Energy and Matter

For us to see an object that does not produce its own light, there must be a source of light, the light must strike the object, and the light must bounce off or be *reflected* from the object and then travel to our eyes.

Opaque materials do not allow light to pass through them; instead, they reflect most of the light that strikes them. *Transparent* and *translucent* materials, in contrast, allow most of the light striking them to pass through. Still, some light is reflected and some is absorbed by the material.

Light travels in straight lines; it does not go around corners. When light is reflected, its direction changes, but it still travels in a straight line. A mirror is a good example of a shiny, reflective surface that allows us to experiment with beams of light and watch the direction of reflected beams. Try shining a light at a mirror and studying the way it reflects (Figure 10.6a). Enough experiments of this sort will lead you to believe that the angle at which the incoming light ray hits the mirror is equal to the angle at which it is reflected. This happens only on smooth, polished surfaces, however. Rough surfaces reflect rays of light in an irregular way so the light scatters.

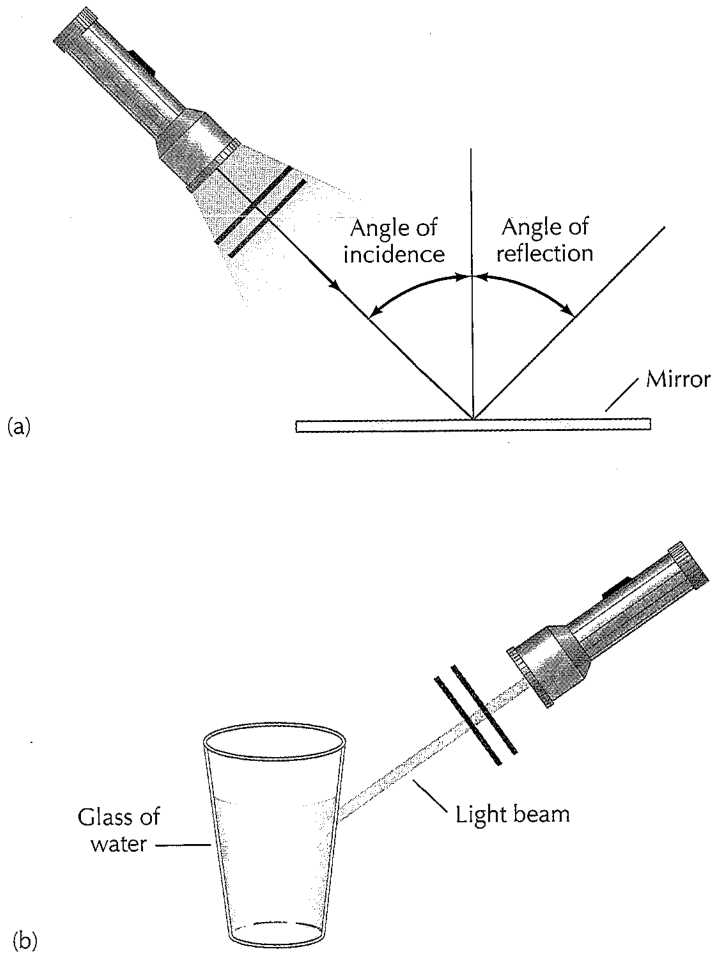


FIGURE 10.6 Reflection and refraction of light
(a) When light strikes a mirror or other smooth surface, the angle at which it bounces off (angle of reflection) equals the angle of the incoming ray (angle of incidence). (b) Passing from one medium to another of different density, light refracts (bends).

Thinking About Interactions

Making Connections: From Electricity to Heat and Light

Many everyday household objects work by converting electricity into heat energy. These include electric hair dryers, toasters, coffeemakers, irons, ranges, and heaters.

You may notice that wires get warm when electric current flows through them. Often, the thinner the wire, the hotter it gets, until it begins to glow. Can you think of how this phenomenon is applied? A common light bulb works on just this principle, converting electricity into heat and light energy.

The filament in a regular light bulb is made of tungsten, which does not melt when it gets very hot. Instead, it glows, in a process called incandescence. Hence, in the system of a light bulb, there are interactions between electrical and heat energy and metal wires to produce light energy.

Oxygen in the air reacts with metals, as in the process of rusting. If this occurred with the tungsten in a light bulb, the bulb would not last long. Therefore, in the space inside the bulb, there is no regular air, just a gas such as argon, which does not react with the tungsten. See Chapter 9 for more about light bulbs.

When light rays travel at a slant or angle from one transparent medium, like air, into another, like water, the rays are bent or *refracted;* that is, they change direction. If you shine a narrow beam of light into a clear glass of water at an angle (see Figure 10.6b), you can see the light beam bending as it passes through the glass and water. If you look closely at the surface of the water, you will notice that the beam bends at the point where the medium through which it is traveling changes.

When light rays are bent, they can magnify an image, making it appear closer. Conversely, if they bend differently, they can make an image seem farther away. This is one of the principles behind the construction of eyeglass lenses as well as microscope, binocular, and telescope lenses. By refracting light in a precise way, lenses can help us see distant objects or bring blurry ones into better focus.

10-11c Color

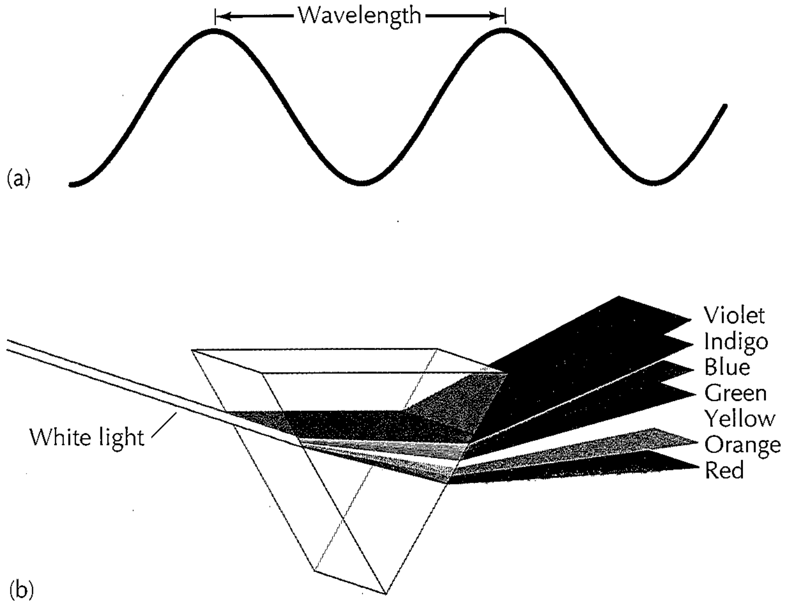
Have you ever held up a glass or plastic prism to a narrow beam of light? If you do so, you will notice a band of colored lights called the **spectrum**. The spectrum of visible light includes red, orange, yellow, green, blue, indigo, and violet. White light is actually a mixture of these colored lights of the spectrum.

spectrum
The band of colors seen when visible light is separated into its component wavelengths, as in a rainbow. The *electromagnetic spectrum* also includes other forms of electromagnetic radiation that we cannot see, such as ultraviolet light, infrared light, radio waves, gamma rays, and cosmic rays.

The colors that make up the spectrum have different wavelengths. *Wavelength* refers to the distance between corresponding parts of two of the light waves (Figure 10.7a). Violet light has the shortest wavelength, and red light the longest. When white light enters a prism, the colors with the shorter waves are refracted (bent) more than are the colors with the longer waves (see Figure 10.7b). The seven colors of white light thus are separated according to how much they are refracted as they go through the prism.

A rainbow is a spectrum that is sometimes produced when the sun shines immediately after a rain shower. The water droplets in the air act as tiny prisms, breaking the sunlight into a spectrum in the form of a beautiful arch. If you create a spray with a garden hose, standing with your back to the sun, you can make an artificial rainbow.

FIGURE 10.7 Color properties of light
(a) The meaning of wavelength.
(b) Refracting different wavelengths by different amounts, a prism separates white light into its component colors.



10-12 Sound

sound
A form of energy that is produced by objects moving back and forth or vibrating.

Sound is a form of energy that is produced by objects moving back and forth or vibrating. The vibrations of material objects cause sound, so when the vibrations stop, the sound stops. Here we see an intricate interaction between matter and energy.

Like light, sound energy travels in waves. Unlike light, however, sound cannot travel in a vacuum. When your alarm clock rings across the room, the vibration of the ringer causes molecules in the air to vibrate. The air molecules pass the energy along, coming closer together and then stretching farther apart in a wave motion until the vibrating air molecules reach your ears. Because sound travels quickly, you hear the alarm clock in a fraction of a second.

10-12a The Speed of Sound

Sound usually reaches us by traveling though the air, but it can also travel though liquids and solids. Sound travels best through materials that have more closely packed particles—in other words, through denser materials. Sound travels through air at a speed of about 1,100 feet per second, or about 1 mile in 5 seconds (1 kilometer in 3 seconds). In ocean water, sound travels more than four times faster than in air (about 4,800 feet/second). In steel, sound travels more than 15 times faster than in air!

You can see why sound cannot travel in a vacuum; there are no molecules in a vacuum to carry the vibrations. You can also notice the huge difference between the speed of sound in air and the speed of light: approximately 1,100 feet per second versus approximately 186,000 *miles* per second. Think about how we notice this difference during a thunderstorm. The sound we know as thunder is caused by lightning passing through the air. The lightning makes the air heat up and expand, and this produces giant vibrations in the air that travel toward us as sound waves. But even though the thunder and lightning happen at virtually the same time, we always see the lightning first and then hear the thunder. This is because light travels so much faster than sound.

10-12b Characteristics of Sound

Experiments with sound reveal that you can vary the properties of materials to produce different types of sounds. For example:

- *Amplitude or intensity.* The loudness or softness of a sound, called its amplitude or intensity, depends on the strength with which the sound-producing object is vibrating.
- *Pitch.* The highness or lowness of a sound, known as the pitch, depends on the rate at which the object is vibrating. The more vibrations per second, the higher the pitch of a sound. The fewer vibrations per second, the lower the pitch. The rate of vibrations is also called the *frequency.* The normal human ear can hear sounds with frequencies ranging between 20 and 20,000 vibrations per second. Dogs can hear higher sounds—that is, sounds with a frequency of more than 20,000 vibrations per second.
- *Quality.* When objects vibrate, they generally send out a mixture of frequencies, and the particular mix determines what is called the quality of the sound. That is why a trumpet sounds different from a violin even when they both are playing the same note. In addition to the main frequency, each instrument is actually producing a set of overtones, or additional frequencies, that combine to give the sound its quality.

10-12c The Human Voice

Humans produce sound by using the larynx or voice box, which is located at the top of the trachea (windpipe). Stretched over the top of the larynx are two thin but strong bands of tissue called the vocal cords. When air from the lungs is blown through the narrow slit between the vocal cords, the cords vibrate and produce sounds.

Thinking About Interactions

Sound Energy and Musical Instruments

Consider a wind instrument—what interactions does it use to create a sound? Basically, the instrument holds a column of air that is made to vibrate, either by blowing into it, as with a saxophone or clarinet, or by blowing across it, as with a flute or piccolo.

In a woodwind instrument like a clarinet, you blow on a thin piece of wood or plastic, called the reed, which is used to make the column of air vibrate. Pressing the keys or covering the holes changes the length of the column of air and therefore changes the vibrations per second and the pitch of the sound produced. A shorter column of air vibrates faster than a longer column of air. Hence, the shorter the column of air, the higher the pitch.

How do you think the amplitude of the clarinet is changed? That's right—by blowing harder into the mouthpiece and causing the reed to vibrate with greater intensity.

In a percussion instrument—drum, xylophone, wood block, triangle, or cymbals—striking the instrument with another object produces sound. For the xylophone, the shorter the bar, the greater the number of vibrations and the higher the pitch. For drums, the thinner and tighter the covering, the greater the number of vibrations and the higher the pitch. Think about this: Can a drummer change the pitch of a drum's sound without altering the drum's covering? (Hint: Is the membrane that covers the drum equally tight all the way across?)

Muscles attached to the vocal cords make them tight or loose, and in this way they control the pitch of your voice. The tighter the cords, the faster they vibrate, and the higher the pitch of the sound you produce. The same is true for a tighter violin string; it, too, will have a higher pitch from vibrating at a greater frequency.

Men's vocal cords are usually longer and thicker than women's, and they do not vibrate as fast. This explains why men tend to have deeper voices than women.

10-13 Magnetism

Earlier in this chapter you saw that a force is essentially a push or a pull. Usually a force causes a change in the position or motion of an object. Gravity, for example, is the force of attraction between objects in the universe. The gravitational attraction between objects is one of the causes of the kinetic energy that keeps the planets in motion around the sun.

magnetism
A force produced when an object exerts an attraction for materials made of certain metals, such as iron, steel, cobalt, and nickel.

Magnetism is another important type of force. It is produced when an object exerts an attraction for materials made of certain metals—iron, steel, cobalt, and nickel. These metals are called magnetic materials. There are two kinds of magnets, human-made and natural:

- Natural magnets, found in the ground, are called lodestones. They contain a mineral called magnetite and look like irregularly shaped rocks.
- Human-made magnets are made from iron, steel, cobalt, and nickel and are named for their shapes: bar magnets, rod magnets, horseshoe magnets, and U-shaped magnets (Photo 10.3).

The force of a magnet is strongest at its ends, which are called the poles of the magnet. When magnets are allowed to swing freely, their poles are attracted to the north or the south of the earth and therefore are called north-seeking or south-seeking poles. When the poles of two magnets are brought near each other, like poles repel each other and opposite poles attract. That is, two north poles tend to push each other away. So do two south poles. But a north pole and a south pole tend to pull each other closer. This is similar to the attraction and repulsion of electrical charges. In fact, magnetism and electricity are closely related.

Tony Freeman/PhotoEdit

PHOTO 10.3 This student observes the effects of magnetism passing through paper.

10-13a Electromagnets

When an electric current passes through a wire, a *magnetic field* is created around the wire. This means that the space around the wire can act like a magnet. This effect is strengthened if the wire that carries the electricity is wrapped into a coil. If you then place a piece of iron inside the coiled wire, you make an even stronger magnet, called an *electromagnet.* The strength of this system can be increased by increasing the number of coils of the wire and by raising the strength of the electric current through the wire.

Like other magnets, an electromagnet has two poles, and it attracts magnetic materials such as iron and steel. But an electromagnet is a temporary magnet—its magnetism can be turned off by breaking the electric circuit.

The ability to create magnetic force with an electromagnet has many practical applications. We use electromagnets in devices ranging from telephones to radios, televisions, computers, motors, cranes, and generators (see the explanation of an electrical generator earlier in this chapter), to name a few.

10-13b What Causes Magnetism?

What, you may wonder, are the causes of magnetism? Where does this mysterious force of attraction come from? Scientists are not sure, but they believe the answer lies with the movement of electrons in the atoms of magnetic materials.

Electrons spin as they revolve around the nucleus of the atom. Each spinning electron acts as a tiny magnet. In nonmagnetic materials, the number of electrons that spin in one direction is equal to the number of electrons that spin in the opposite direction. This cancels out their magnetic effects. In magnetic materials, there are more electrons spinning in one direction than in the opposite direction. It is believed that this imbalance of electrons spinning in opposite directions gives rise to magnetism in the material. This also explains why few naturally occurring materials are magnetic.

10-13c The Earth as a Magnet

The earth behaves as if it were a huge magnet, with a north magnetic pole and a south magnetic pole. This is because the deep interior of the earth, known as the inner core, is made up of iron and nickel. The magnetic field of the earth even extends beyond the planet itself.

When you use a compass to discover which direction you are going, you are relying on the earth's magnetism. Because the compass needle is magnetized, one end points toward the earth's north magnetic pole. Although the earth's north and south magnetic poles do not correspond exactly to the north and south geographic poles, they are close enough for most purposes—especially when you are lost in the woods.

10-14 From Content to Curriculum

From the sampling of science content in this chapter, you can see the richness of the topics that students explore and the importance of the disciplinary core ideas they investigate. But how, you may be wondering, do schools and teachers fit all these topics and ideas into a specific curriculum that meets the needs of students?

curriculum
A plan of studies that includes the ways in which the instructional content is organized and presented at each grade level.

The word *curriculum* derives from a Latin term meaning "running course." In science teaching, we usually think of the **curriculum** as a plan of studies that includes the ways in which the science content is organized and presented at each grade level. It is not merely a list of topics but an organizational scheme that describes the activities used to facilitate the presentation of the content. Often schools use a list of topics as a *summary* of the science curriculum.

In addition to this *formal* science curriculum, good teachers make use of an *informal* curriculum based on the students' daily lives, as you saw in Chapters 2 and 4, and that you will see in Chapter 11. The informal curriculum includes everyday, often unexpected, topics that arise as a result of living in a given geographic environment or of exposure to a newsworthy science topic. An example is Mr. Wilson's use of icicles to teach melting when the ice storm blanketed the area in which his school is located. The ecology projects at the middle school where rain gardens are planted are another example of the informal science curriculum merging with the formal curriculum. Often, formal and informal science curriculum topics merge. For example, if a class in a seaside community is studying the oceans as a formal unit, the teacher and students can find many opportunities to incorporate aspects of their daily lives into the formal study.

A few years ago, I saw a fifth-grade geology curriculum designed by a school in a shore community of Long Island, New York. It had an extensive section on sand, including required reading about the sands of the Sahara Desert. This reading segment was part of the science textbook that had been purchased by this school. Certainly, the Sahara, being the world's largest desert, was of interest, but it was unlikely that students could explore it directly. Unfortunately, the curriculum offered the students no direct access to sand, even though there was a beach full of it—directly accessible and relevant—down the street from the school. The locale and geography of the school should become relevant to the curriculum, as we saw in Part 2's science stories.

This story of the Sahara desert sand illustrates the importance of using many criteria to design a curriculum. Also remember the key question, "Who are my students?" Whatever the formal curriculum dictates, answering this question will help you to make connections to the lived experiences of your students.

10-15 Who Creates the Curriculum? National Influence and Local Control

In American public education, matters of curriculum have traditionally been the prerogative of local school districts. During the past three decades, however, there has been a great deal of national concern about the competencies and academic performance of students. The publication in the 1980s of reports like *A Nation at Risk* (National Commission on Excellence in Education, 1983) and *Educating Americans for the 21st Century* (National Science Board, 1983) alerted the public to the perceived need to address higher standards in American public education. The subsequent "standards movement" has resulted in national standards for several areas of education, including science.

The *National Science Education Standards* (National Research Council, 1996) and the *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993) represented the work of teacher educators, scientists, and classroom science teachers from all over the world. The intent was to provide educators with a way of thinking about the importance of scientific literacy in today's world. **Scientific literacy** refers to an individual's ability to use scientific information to make choices and to "engage intelligently in public discourse and debate about important issues that involve science and technology" (National Research Council, 1996, p. 1). Both documents argued that such literacy should be the major goal of science education.

scientific literacy
The ability to use the processes of science to make important life decisions; in particular, the ability to explore a problem through careful reasoning.

The Next Generation Science Standards (2013) took this goal further by establishing standards for science education at the nexus of three dimensions: science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCs). These current standards invite science teachers to consider not just the what, but the how and the why of their science units in the hopes that students will be able to defend and explain their thinking and establish accurate representations of the natural world. In this way, true scientific literacy can emerge. The NGSS are filled with student performance expectations, but they are not a curriculum. Creating curriculum from the standards requires that all three dimensions be part of all units developed for the elementary and middle school curriculum. The science concepts described by the DCIs in life, physical, and earth and space science build coherently from kindergarten to grade 12. They are useful for planning coherent curriculum in each of the topic areas. Keep in mind, too, that topic selection is only part of curriculum construction. To develop a curriculum, educators also need to explore related activities, such as connections with literature, mathematics, technology, and social studies.

10-15a The STEM Education Movement

Recently, there has been a significant movement to make connections among science, technology, engineering, and mathematics education. The acronym STEM represents that movement and makes a lot of sense. Many of the stories in Part 2 of this book relate to STEM projects. For example, when middle school students design and construct model atoms, the principles of engineering design, science and technology, and mathematics are very connected. STEM stresses the fact that mathematics, science, engineering, and technology are interdependent human enterprises. To promote this integration, the STEM approach often uses computer technology (T) as a tool for brainstorming, doing research, modeling outcomes, creating designs, and presenting information.

10-15b STEM and Group Projects

Students who are engaged in STEM activities also tend to be involved in some form of project-based learning in which they use science ideas or mathematics ideas to solve a problem. Often this problem relates to a *design challenge*, like the one you read about in Chapter 8, where the students in Ms. Murray's class were asked to design and build models of atoms. Engineering design is a special way of engaging students in doing their own thinking and giving them the chance to direct their own learning. Central to STEM is the understanding that students become active learners when they are engaged in experiences related to a meaningful context—a larger purpose that stimulates a need to know and encourages the students to acquire skills to solve a problem.

Working in cooperative learning groups, students engage in brainstorming and do background research in order to plan for the implementation of their design. This group process is very important to STEM learning. It requires that students work together to reach the best solution to their design challenge.

10-15c The Impact of STEM

Movements to create STEM learning encourage problem-solving investigations with respect to the following criteria:

- What is the nature of the problem-solving activities in science?
- Where does mathematics present itself in these activities?

- Are students expected to design a process or a product as part of their investigations?
- What is the nature of students' access to technology during their investigations?
- How are science ideas linked to mathematics and technology ideas?

In this text, you have seen several examples of STEM investigations. In Chapter 7, when Ms. Drescher's students used their understanding of the differing densities of three liquids to design a liquid-display toy, all four components of STEM problem solving—mathematics, science, engineering design, and technology—came into play. In Chapter 8, when students designed a model solar system, they used mathematical analysis of the planets' relative sizes and distances to construct a model that accurately represented the planets in relation to the sun. During this project they employed various kinds of technology, including the WorldWide Telescope. Some of Ms. Travis's students in Chapter 9 designed a blinking lighthouse. They used the science ideas behind series and parallel circuits to light their model, and they used mathematics to determine the scale of the different sections. In Chapter 11, we will examine two projects that use STEM education to guide their development. Ms. O'Connor's second-grade class designs a magnetic car, and Ms. Rhodes's fourth-grade class solves a milk-waste problem.

10-16 Developing Curriculum Units

After reading about standards, frameworks, and the creation of curricula, you may still be puzzled about how schools and teachers get from these broad definitions of expected learning to specific plans for classroom teaching. Usually, this is done by developing curriculum units.

unit of study
A segment of the curriculum that includes several lessons designed around a central theme or topic.

Typically, a **unit of study** includes several lessons that are designed around a central theme or topic. An individual lesson on earthworms, for example, could fit within a unit on classifying vertebrates and invertebrates.

A unit plan usually consists of the following:

- The disciplinary core ideas behind the unit
- The science and engineering practices that activities require
- The specific lesson plans for the unit

Sometimes, unit plans also include a description of the assessment strategy for each unit. We will address several types of assessments later in Chapter 13.

10-16a Aligning a Unit of Study with the NGSS

Teachers are expected to link their units of study to specific science concepts. This process involves the following steps:

1. Identify the topic and its relationship to life, physical, or earth science.
2. Identify the DCIs behind this topic.
3. Explore activity books and other resources relating to the topic.
4. Design lessons that allow students to examine their own ideas and permit the teacher to extend the activities as needed. Make sure the students are engaged with several SEPs.
5. Indicate if there are connections with engineering design, mathematics, technology, literature, and social studies.

10-16b Selecting Activities

If you are selecting activities for a unit, you should follow the same criteria described throughout this book. Ask yourself questions like these:

- Does the activity lend itself to individual thinking and problem solving?
- Does the activity engage students in several SEPs?
- Does the activity match the science idea expressed by the unit?
- Are the materials accessible?
- Do the students have the opportunity to plan and create?

You are looking for science activities that encourage individual explorations of phenomena. Commercial materials and kits can be useful as long as you frame the activity in a way that allows students to make decisions about the plan for their investigations.

10-16c What Is Missing?

When you rely solely on one standard or framework or commercial product to guide your school's or your class's science curriculum, you miss a great deal of the local influence that ought to contribute to the students' science experiences. Who your students are, how they experience nature, where they live, what region of the country your school is located in—all of these considerations should help you frame your units of study.

Remember, also, to learn about what kinds of personal lives your students have. Are they hungry? Poor? Overindulged? Exceptional? Middle class? How will you use science curriculum to help students make meaning in the context of their own lives? That is the major role of your science curriculum: to engage students in their own learning, to relate science experiences to their lives, and to help them explore and draw conclusions. Certainly, national and state documents should help you understand the range of topics and ideas that are appropriate. But what is best for *your* students remains a local decision.

Curriculum—any curriculum—is a lifeless document. You, the teacher, give it life when you use it to guide your students' experiences.

10-16d A Checklist for the Science Curriculum

The following checklist may help you ask the right questions when evaluating a science curriculum:

- What is the role of scientific investigation in the curriculum?
- Are there earth and space science, life science, and physical science topics at each grade level?
- Do your science units have implications for green science, the study of how humans interact with their environment?
- Are technology, mathematics, and engineering design challenges incorporated into some of the science activities?
- Where are the connections to other subjects, such as social studies and literature?

- Do the topics build coherently from lower to higher grades? Are there learning progressions?
- Are there topics that have local geographic connections and personal relevance for the students?
- Are the topics explored in depth?
- Is there room for informal science experiences?

If you are involved in creating the curriculum, you should ensure that these questions are answered as you plan. If you as a teacher are working with a curriculum designed by others, these questions can help you to identify its strong points and weak points and to decide when and how to supplement the formal curriculum with informal experiences.

In the next chapter we will examine what integrating other discipline areas "looks like" when teaching elementary and middle school. Because many middle school grades are often departmentalized, with students moving from one subject to another, integrating science across disciplines is a bit more challenging but, as you will see, very doable!