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CK-12 Physical Science For Middle School

The Physical Universe SUSD

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Contents

Concept 1 Unit 1: The World of Science

Questions/Observable Phenomena

Chapter 2 The World of Science and Technology

Chapter Outline

Have you ever experienced the thrill of an exciting fireworks display like this one? Fireworks were invented about 2000 years ago in China. But it wasn't until much later that people understood the science behind the technology.

Do you know why fireworks explode? Do you know what causes the brilliant bursts of light and the deep rumbling booms? In this FlexBook® digital resource, you'll find out the "hows" and "whys" of many things in the physical world around you.

Ghengis Fireworks (www.ghengisfireworks.com). www.flickr.com/photos/ghengisfireworks/9710103655/. CC BY 2.0.

2.1 What Is Science?

Lesson Objectives

- Define science.
- Explain how scientists use induction.
- Distinguish between scientific theories and laws.
- Describe milestones in the history of science.
- Identify contributions of women and minorities to science.

Lesson Vocabulary

- induction
- science
- scientific law
- scientific theory

Introduction

Understanding the "hows" and "whys" of the world is the goal of science. The term science comes from a Latin word that means "having knowledge." But science is as much about adding to knowledge as it is about having knowledge. Science is a way of thinking as well as a set of facts. **Science** can be defined as a way of learning about the natural world that is based on evidence and logic.

Thinking Like a Scientist

FIGURE 2.1
Like a scientist, this teen wonders about how and why things happen. What do you wonder about?

Are you like the teen in **Figure** 2.1? Do you ever wonder why things happen? Do you like to find out how things work? If so, then you are already thinking like a scientist. Scientists also wonder how and why things happen. They are curious about the world. To answer their questions, they make many observations. Then they use logic to draw general conclusions.

Induction

Drawing general conclusions from many individual observations is called **induction**. It is a hallmark of scientific thinking. To understand how induction works, think about this simple example. Assume you know nothing about gravity. In fact, pretend you've never even heard of gravity. Perhaps you notice that whenever you let go of an object it falls to the ground. For example, you drop a book, and it crashes to the floor. Your pencil rolls to the edge of the desk and down it goes. You throw a ball into the air, and it falls back down. Based on many such observations (**Figure** 2.2), you conclude that all objects fall to the ground.

FIGURE 2.2
From skydivers in the air to kids on a playground slide, whatever goes up always comes back down. Or does it?

Now assume that someone gives you your first-ever helium balloon. You discover that it rises up into the air if you don't hold on to it. Based on this new observation, do you throw out your first idea about falling objects? No; you decide to observe more helium balloons and try to find other objects that fall up instead of down. Eventually, you come to a better understanding based on all your observations. You conclude that objects heavier than air fall to the ground but objects lighter than air do not. Your new conclusion is better because it applies to a wider range of observations. You can learn more about induction, including its limits, by watching the video at this link: http://www.youtube.com/watch?v=E1TpZ_HbK3M (5:39).

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5002

How Science Advances

The above example shows how science generally advances. New evidence is usually used to improve earlier ideas rather than entirely replace them. In this way, scientists gradually refine their ideas and increase our understanding of the world. On the other hand, sometimes science advances in big leaps. This has happened when a scientist came up with a completely new way of looking at things. For example, Albert Einstein came up with a new view of gravity. He said it was really just a dent in the fabric of space and time.

Different conclusions can be drawn from the same observations, and it's not possible to tell which one is correct. For example, based on observations of the sun moving across the sky, people in the past couldn't tell whether the sun orbits Earth or Earth orbits the sun. Both models of the solar system are pictured in **Figure** 2.3. It wasn't until strong telescopes were invented that people could make observations that let them choose the correct idea. Not sure which idea is correct? You can learn more by watching the student-created video at this link: http://www.youtube.com/watch?v=JcqdUq16S28 .

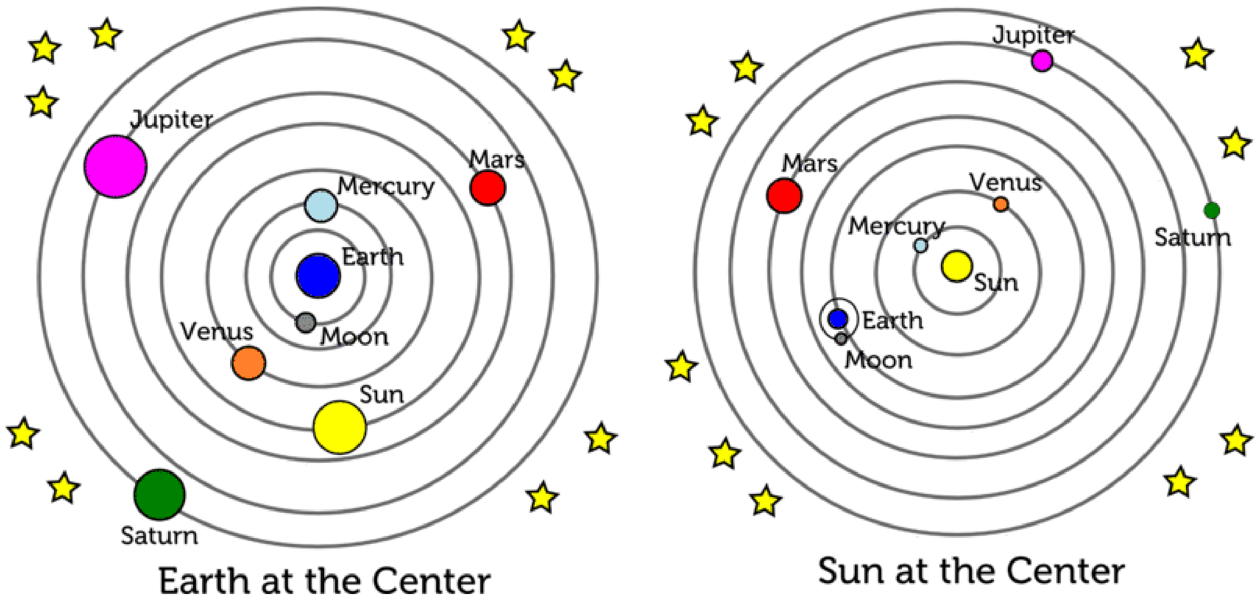


FIGURE 2.3
Both of these models could explain why the sun appears to move across the sky each day. Other observations were needed to decide which model is correct.

Theories and Laws

Some ideas in science gain the status of theories. Scientists use the term "theory" differently than it is used in everyday language. You might say, "I think the dog ate my homework, but it's just a theory." In other words, it's just one of many possible explanations for the missing work. However, in science, a theory is much more than that.

Scientific Theories

A **scientific theory** is a broad explanation that is widely accepted because it is supported by a great deal of evidence. An example is the kinetic theory of matter. According to this theory, all matter consists of tiny particles that are in constant motion. Particles move at different speeds in matter in different states. You can see this in **Figure** 2.4 and at the following URL: http://preparatorychemistry.com/Bishop_KMT_frames.htm . Particles in solids move the least; particles in gases move the most. These differences in particle motion explain why solids, liquids, and gases look and act differently. Think about how ice and water differ, or how water vapor differs from liquid water. The kinetic theory of matter explains the differences. You can learn more about this theory in the chapter *States of Matter*.

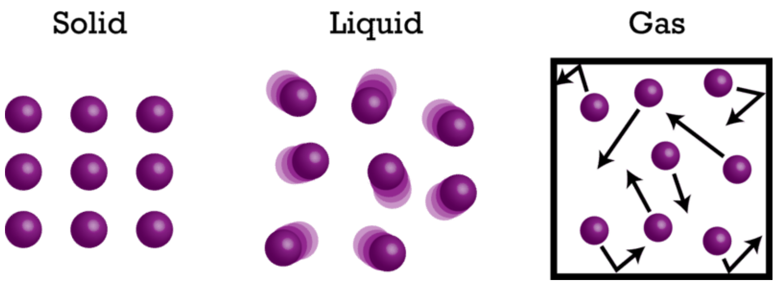


FIGURE 2.4
Why do you think particles move differently in different states of matter? (*Hint*: What causes ice to melt?)

Scientific Laws

Scientific laws are often confused with scientific theories, but they are not the same thing. A **scientific law** is a statement describing what always happens under certain conditions in nature. It answers "how" questions but not "why" questions. An example of a scientific law is Newton's law of gravity. It describes how all objects attract each other. It states that the force of attraction is greater for objects that are closer together or have more mass. However, the law of gravity doesn't explain why objects attract each other in this way. Einstein's theory of general relativity explains why. You can learn more about Newton's law of gravity and Einstein's theory in the chapter *Forces*, and at the following link: http://www.youtube.com/watch?v=O-p8yZYxNGc .

History of Science

People have wondered about the natural world for as long as there have been people. So it's no surprise that modern science has roots that go back thousands of years. The **Table** 2.1 describes just a few milestones in the history of science. A much more detailed timeline is available at the link below. Often, new ideas were not accepted at first because they conflicted with accepted views of the world. A good example is Copernicus' idea that the sun is the center of the solar system. This idea was rejected at first because people firmly believed that Earth was the center of the solar system and the sun moved around it.

http://www.sciencetimeline.net/

TABLE 2.1: Timeline of Scientific Discovery

Date	Scientific Discovery
3500 BC  *Mesopotamian calendar*	Several ancient civilizations studied astronomy. They recorded their observations of the movements of stars, the sun, and the moon. We still use the calendar developed by the Mesopotamians about 5500 years ago. It is based on cycles of the moon.

TABLE 2.1: (continued)

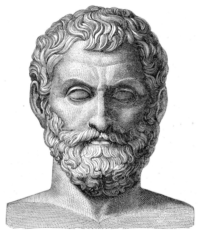
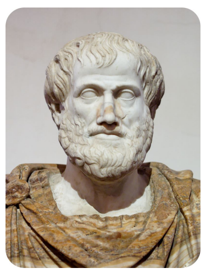
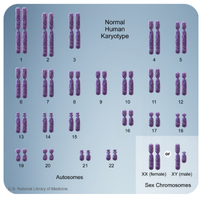
Date	Scientific Discovery
600 BC  *Thales*	The ancient Greek philosopher Thales proposed that natural events, such as lightning and earthquakes, have natural causes. Up until then, people blamed such events on gods or other supernatural causes. Thales has been called the "father of science" for his ideas about the natural world.
350 BC  *Aristotle*	The Greek philosopher Aristotle argued that truth about the natural world can be discovered through observation and induction. This idea is called empiricism. Aristotle's empiricism laid the foundation for the methods of modern science.
400 AD to 1000 AD  *Early Chinese Seismograph*	When Europe went through the Dark Ages, European science withered. However, in other places, science still flourished. For example: • In North Africa, the scientist Alhazen studied light. He used experiments to test competing theories about light. • In China, scientists invented compasses. They also invented seismographs to measure earthquakes. They studied astronomy as well.
Mid-1500s to late 1600s  *Galileo*	The Scientific Revolution occurred in Europe. This was the beginning of modern Western science. Many scientific advances were made during this time. • Copernicus proposed that the sun, not Earth, is the center of the solar system. • Galileo improved the telescope and made important discoveries in astronomy. He discovered evidence that supported Copernicus' theory. • Newton proposed the law of gravity.

TABLE 2.1: (continued)

Date	Scientific Discovery
2001  *Human Chromosomes*	Many scientists around the world worked together to complete the genetic sequence of human chromosomes. This amazing feat will help scientists understand, and perhaps someday cure, genetic diseases.

Women and People of Color in Science

Throughout history, women and people of color have rarely had the same chances as white males for education and careers in science. But they have still made important contributions to science. The **Table** 2.2 gives just a few examples of their contributions to physical science. More contributions are described at these links:

- http://www.inventions.org/culture/science/women/index.html
- http://www1.umn.edu/ships/gender/giese.htm
- https://webfiles.uci.edu/mcbrown/display/faces.html
- http://library.thinkquest.org/20117/

TABLE 2.2: A diversity of people has contributed to physical science.

Contributor	Description
Marie Curie (1867-1934) 	Marie Curie was the first woman to win a Nobel Prize. She won the 1903 Nobel Prize in physics for the discovery of radiation. She won the 1911 Nobel Prize in chemistry for discovering the elements radium and polonium.
Lise Meitner (1878-1968) 	Lise Meitner was one of the scientists who discovered nuclear fission. This is the process that creates enormous amounts of energy in nuclear power plants.

TABLE 2.2: (continued)

Contributor	Description
Irene Joliot-Curie (1897–1956) 	Irene Joliot-Curie, daughter of Marie Curie, won the 1935 Nobel prize in chemistry, along with her husband, for the synthesis of new radioactive elements.
Maria Goeppert-Mayer (1906–1972) 	Maria Goeppert-Mayer was a co-winner of the 1963 Nobel prize in physics for discoveries about the structure of the nucleus of the atom.
Ada E. Yonath (1939–present) 	Ada E. Yonath was a co-winner of the 2009 Nobel prize in chemistry. She made important discoveries about ribosomes, the structures in living cells where proteins are made.
Shirley Ann Jackson (1946-present) 	Shirley Ann Jackson earned a doctoral degree in physics. She became the chair of the US Nuclear Regulatory Commission.
Ellen Ochoa (1958-present) 	Ellen Ochoa is an inventor, research scientist, and NASA astronaut. She has flown several space missions.

TABLE 2.2: (continued)

Contributor	Description

Lesson Summary

- Science is a way of learning about the natural world that is based on evidence and logic. The hallmark of scientific thinking is induction.
- A scientific theory is a broad explanation that is widely accepted because it is supported by a great deal of evidence. A scientific law is a statement describing what always happens under certain conditions in nature.
- Modern science has roots that go back thousands of years. Diverse people from around the world have contributed to the evolution of science.
- Women and minorities have rarely had the same chances in science as white males, but they still have made important contributions.

Lesson Review Questions

Recall

1. Define science.
2. What is induction?
3. State the contributions of Thales and Aristotle to the evolution of science.
4. What was the Scientific Revolution?

Apply Concepts

5. Use induction to draw a logical conclusion based on **Table** 2.3.

TABLE 2.3: Freezing Point of Substances

Substance	Temperature at Freezing (°C)
Pure water (1 cup water)	0
Salt water (1 cup water + 5 grams table salt)	-4
Sugar water (1 cup water + 6 grams sugar)	-5

6. What observation would require you to revise your conclusion in question 5?

Think Critically

7. Compare and contrast scientific theories and scientific laws. Give an example of each.

Points to Consider

Most of the scientists mentioned in this lesson are physical scientists.

- Based on their work, what do you think is the subject matter of physical science?
- What are some questions that physical scientists might investigate?

2.2 Scientific Investigation

Lesson Objectives

- List the steps of a scientific investigation.
- Describe the relationship of ethics to scientific research.

Lesson Vocabulary

- control
- ethics
- experiment
- field study
- hypothesis
- manipulated variable
- observation
- replication
- responding variable

Introduction

Investigation is at the heart of science. It is how scientists do research. Scientific investigations produce evidence that helps answer questions and solve problems. If the evidence cannot provide answers or solutions, it may still be useful. It may lead to new questions or problems for investigation. As more knowledge is discovered, science advances.

Steps of a Scientific Investigation

Scientists investigate the world in many ways. In different fields of science, researchers may use different methods and be guided by different theories and hypotheses. However, most scientists, including physical scientists, usually follow the general approach shown in **Figure** 2.5. This approach typically includes the following steps:

- Identify a research question or problem.
- Form a hypothesis.
- Gather evidence, or data, to test the hypothesis.
- Analyze the evidence.
- Decide whether the evidence supports the hypothesis
- Draw conclusions.
- Communicate the results.

Scientists may follow these steps in a different sequence. Or they may skip or repeat some of the steps. Which steps are repeated in **Figure** 2.5?

Asking Questions

A scientific investigation begins with a question or problem. Often, the question arises because a scientist is curious about something she has observed. An **observation** is any information that is gathered with the senses. People often have questions about things they see, hear, or observe in other ways. For example, a teen named Tara has a bracelet with a magnetic clasp, like the one shown in **Figure** 2.6. Tara has noticed that the two magnets in the clasp feel harder to pull apart on cold days than on warm days. She wonders whether temperature affects the strength of a magnet.

Forming Hypotheses and Making Predictions

Tara is curious. She decides to investigate. She begins by forming a hypothesis. A **hypothesis** is a potential answer to a question that can be tested by gathering information. If it isn't possible to gather evidence to test an answer, then it cannot be used as a scientific hypothesis. In fact, the question it addresses may not even be answerable by science. For example, in the children's television show *Sesame Street*, there was a large Snuffalufagus (kind of like an elephant). But Snuffy would disappear whenever people came around. So if someone said "Is there a Snuffy on Sesame Street?," that question would be unanswerable by science, since there isn't any test that can be performed - because Snuffy would disappear as soon as a scientist showed up. Can you think of other examples of questions outside the realm of science?

This important distinction, that evidence taken in by observation is experimented on by a scientist, is what separates legitimate science from other things which may pretend to be science. Fields which claim to be scientific but don't use the scientific method are called "pseudoscience." If a person can't gather data through some sort of instrument or sense information, they can't form a scientific conclusion. If there is no way to prove the hypothesis false, there is no scientific claim either. For example, if a friend told you that Snuffy visited him every day, but he was invisible whenever anyone walked into the room, this claim is not scientific, *since there is no way to prove him false*.

Developing a hypothesis may require creativity as well as reason. However, in Tara's case, the hypothesis is simple. She hypothesizes that a magnet is stronger at lower temperatures. Based on her hypothesis, Tara makes a prediction. If she cools a magnet, then it will pick up more metal objects, such as paper clips. Predictions are often phrased as "if-then" statements like this one. Is Tara's prediction correct? She decides to do an experiment.

Doing Experiments

An **experiment** is a controlled scientific study of specific variables. A variable is a factor that can take on different values. There must be at least two variables in an experiment. They are called the manipulated variable and the responding variable.

- The **manipulated variable** (also called the "independent variable") is a factor that is changed by the researcher. For example, Tara will change the temperature of a magnet. Temperature is the manipulated variable in her experiment.
- The **responding variable** (also called the "dependent variable") is a factor that the researcher predicts will change if the manipulated variable changes. Tara predicts the number of paper clips attracted by the magnet will be greater at lower temperatures. Number of paper clips is the responding variable in her experiment.

Tara wonders what other variables might affect the strength of a magnet. She thinks that the size and shape of a magnet might affect its strength. These are variables that must be controlled. A **control** is a variable that is held constant so it won't influence the outcome of an experiment. By using the same magnet at different temperatures,

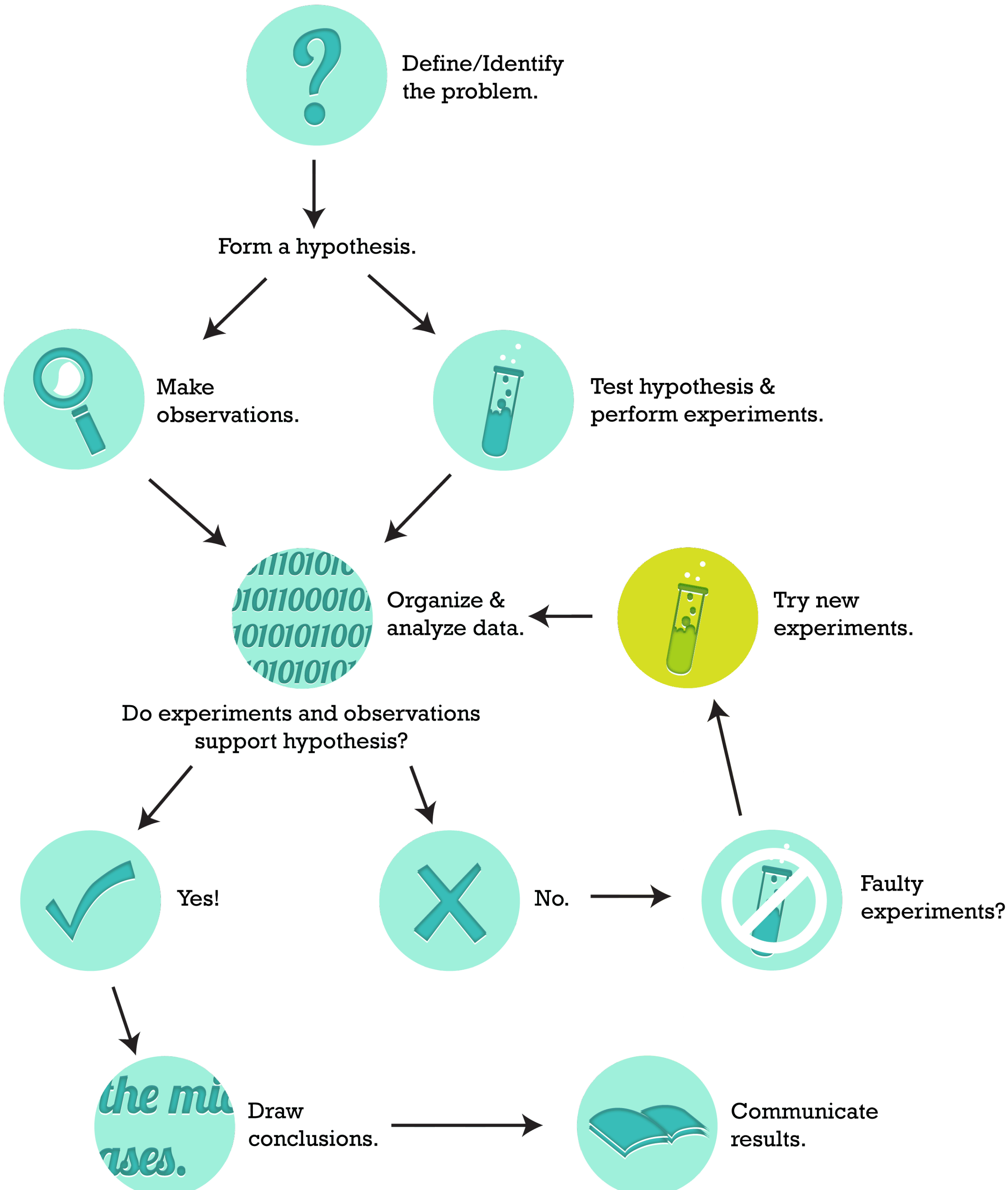


FIGURE 2.5

This diagram shows the steps of a scientific investigation. Other arrows could be added to the diagram. Can you think of one? (*Hint*: Sometimes evidence that does not support one hypothesis may lead to a new hypothesis to investigate.)

FIGURE 2.6
Each end of this bracelet contains a small magnet. The magnets attract each other and hold together the two ends.

Tara is controlling for any magnet variables that might affect the results. What other variables should Tara control? (*Hint*: What about the paper clips?)

Doing Other Types of Studies

Not everything in physical science is as easy to study as magnets and paper clips. Sometimes it's not possible or desirable to do experiments. There are some things with which a person simply cannot experiment. A distant star is a good example. Scientists study stars by making observations with telescopes and other devices. Often, it's important to investigate a problem in the real world instead of in a lab. Scientists do **field studies** to gather real-world evidence. You can see an example of a field study in **Figure** 2.7.

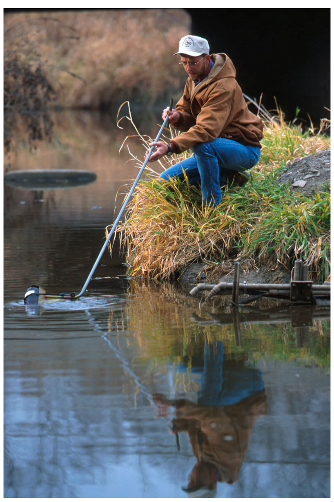


FIGURE 2.7
This scientist is investigating the effects farming practices have on the water quality. He is collecting and analyzing samples of river water. How might the evidence he gathers in the field help him solve the problem?

Communicating Results

Researchers should always communicate their results. By sharing their results, they may be able to get helpful feedback from other scientists. Reporting on research also lets other scientists repeat the investigation to see whether they get the same results. Getting the same results when an experiment is repeated is called **replication**. If results can be replicated, it means they are more likely to be correct. Replication of investigations is one way that a hypothesis may eventually become a theory.

Scientists can share their results in various ways. For example, they can write articles for peer-reviewed science journals. Peer review means that the work is analyzed by peers, in this case other scientists. This is the best way to ensure that the results are accurate and reported honestly. Another way to share results with other scientists is with presentations at scientific meetings (see **Figure** 2.8). Creating websites and writing articles for newspapers and magazines are ways to share research with the public. Why might this be important?

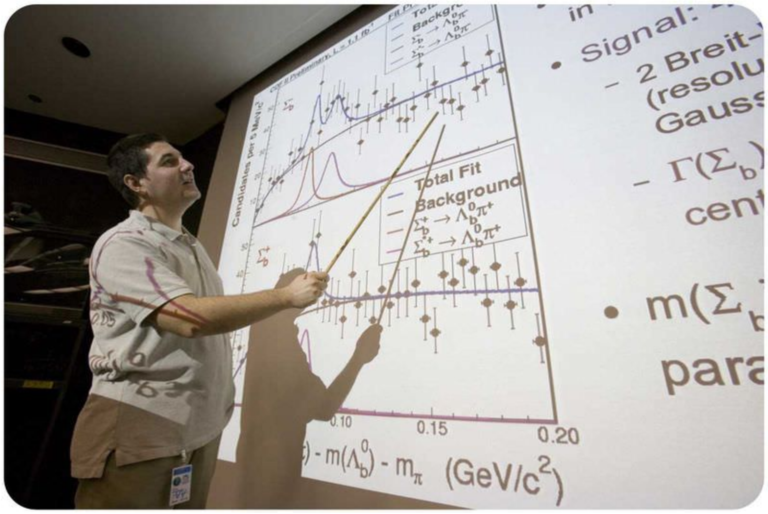


FIGURE 2.8
This researcher is presenting his results to a group of other scientists in his field.

Ethics and Scientific Research

Ethics refers to rules for deciding between right and wrong. Ethics is an important issue in science. Scientific research must be guided by ethical rules, including those listed below. The rules help ensure that the research is done safely and the results are reliable. Following the rules furthers both science and society. You can learn more about the role of ethics in science by following the links at this URL: http://www.files.chem.vt.edu/chem-ed/ethics/index.html#resources .

Ethical Rules for Scientific Research

- Scientific research must be reported honestly. It is wrong and misleading to make up or change research results.
- Scientific researchers must try to see things as they really are. They should avoid being biased by the results they expect or want to get.
- Researchers must be careful. They should take pains to avoid errors in their data.
- Researchers studying human subjects must tell their subjects about any potential risks of the research. Subjects also must be told that they can refuse to participate in the research.
- Researchers must inform coworkers, students, and members of the community about any risks of the research. They should proceed with the research only if they have the consent of these groups.
- Researchers studying living animals must treat them humanely. They should provide for their needs and do what they can to avoid harming them (see **Figure** 2.9).

Sometimes, science can help people make ethical decisions in their own lives, although science is unlikely to be the only factor involved. For example, scientific evidence shows that human actions are affecting Earth's climate. Actions such as driving cars are causing Earth to get warmer. Does this mean that it is unethical to drive a car to work or school? What if driving is the only way to get there? As this example shows, ethical decisions are likely to be influenced by many factors, not just science. Can you think of other factors that might affect ethical decisions such as this one?

FIGURE 2.9
This scientist is studying lab rats. He keeps them in comfortable cages and provides them with plenty of food and water.

Lesson Summary

- Steps of a scientific investigation include identifying a research question or problem, forming a hypothesis, gathering evidence, analyzing evidence, deciding whether the evidence supports the hypothesis, drawing conclusions, and communicating the results.
- Scientific research must be guided by ethical rules. They help ensure that the research is done safely and the results are reliable.

Lesson Review Questions

Recall

1. List the steps of a typical scientific investigation.
2. State why communication is important in scientific research.
3. Identify three ethical rules for scientific research.

Apply Concepts

4. Write a hypothesis based on this question: Do vinegar and water freeze at the same temperature? Make a prediction based on your hypothesis.
5. Describe an experiment you could do to test your prediction in question 4. Identify the variables and controls in your experiment. Include a list of materials. With your teacher's approval, conduct your investigation.

Think Critically

6. In Tara's experiment with the magnet, she measured and recorded the data in the **Table** 2.4.

TABLE 2.4: Tara's Data Table

Magnet Temperature (°C)	Number of Paper Clips Picked up by Magnet
24	8
4	6
3	6

Based on these data, Tara wrote this conclusion:

Magnets get stronger at cooler temperatures, but only down to 4°C. Below 4°C, the strength of magnets does not change.

Do you agree with Tara's conclusion? Why or why not? Suggest an alternative explanation for the data.

7. Describe a better experiment to test Tara's original hypothesis. (*Hint*: You might include more measurements, a wider range of temperatures, and more than one magnet.)

Points to Consider

Scientific investigations often involve measuring. For example, Tara measured the temperature of a magnet with a thermometer. Thermometers may have different scales. You may be most familiar with the Fahrenheit and Celsius scales.

- Do you know how the Fahrenheit and Celsius scales differ? For example, what are the freezing and boiling points of water on each scale?
- Do you know how to convert a temperature from one scale to the other?

2.3 Science Skills

Lesson Objectives

- Explain how measurements are made in scientific research.
- Describe how to keep good records in scientific investigations.
- Demonstrate how to use significant figures and scientific notation.
- Calculate descriptive statistics and use data graphs.
- Identify the role of models in science.
- Describe how to stay safe when doing scientific research.

Lesson Vocabulary

- accuracy
- Kelvin scale
- mean
- model
- precision
- range
- scientific notation
- SI
- significant figures

Introduction

Measuring is an important science skill. Other skills needed to do science include keeping records, doing calculations, organizing data, and making models. Knowing how to stay safe while doing scientific investigations may be the most important skill of all. You will read about all these science skills in this lesson.

Measuring

One of the most important aspects of measuring is the system of units used for measurement. Remember the Mars Climate Orbiter that opened this chapter? It shows clearly why a single system of measurement units is needed in science.

Using SI Units

The measurement system used by most scientists is the International System of Units, or **SI**. **Table** 2.5 lists common units in this system. SI is easy to use because everything is based on the number 10. Basic units are multiplied or divided by powers of ten to arrive at bigger or smaller units. Prefixes are added to the names of the basic units to indicate the powers of ten. For example, the meter is the basic unit of length. The prefix *kilo-* means 1000, so a kilometer is 1000 meters. Can you infer what the other prefixes in the table mean? If not, you can find out at this URL: http://physics.nist.gov/cuu/Units/prefixes.html .

TABLE 2.5: Common SI Units

Variable	Basic SI Unit (English Equivalent)	Related SI Units	Equivalent Units
Length	meter (m) (1 m = 39.37 in)	kilometer (km) decimeter (dm) centimeter (cm) millimeter (mm) micrometer (μm) nanometer (nm)	= 1000 m = 0.1 m = 0.01 m = 0.001 m = 0.000001 m = 0.000000001 m
Volume	cubic meter (m^3) (1 m^3 = 1.3 yd^3)	liter (L) milliliter (mL)	= 1 dm^3 = 1 cm^3
Mass	gram (g) (1 g = 0.04 oz)	kilogram (kg) milligram (mg)	= 1000 g = 0.001 g

The SI system has units for other variables in addition to the three shown here in **Table** 2.5. Some of these other units are introduced in later chapters.

Problem Solving

Problem: Use information in **Table** 2.5 to convert 3 meters to inches.

Solution: 3 m = 3 $\times$ 39.37 in = 118.11 in

You Try It!

Problem: Rod needs to buy 1 m of wire for a science experiment. The wire is sold by the yard, not the meter. If he buys 1 yd of wire, will he have enough? (*Hint*: How many inches are there in 1 yd? In 1 m?)

Measuring Temperature

The SI scale for measuring temperature is the **Kelvin scale**. However, some scientists use the Celsius scale instead. If you live in the U.S., you are probably more familiar with the Fahrenheit scale. **Table** 2.6 compares all three temperature scales. What is the difference between the boiling and freezing points of water on each of these scales?

TABLE 2.6: Temperature Scales

Scale	Freezing Point of Water	Boiling Point of Water
Kelvin	273 K	373 K
Celsius	0°C	100°C
Fahrenheit	32°F	212°F

Each 1-degree change on the Kelvin scale is equal to a 1-degree change on the Celsius scale. This makes it easy to convert measurements between Kelvin and Celsius. For example, to go from Celsius to Kelvin, just add 273. How would you convert a temperature from Kelvin to Celsius?

Converting between Celsius and Fahrenheit is more complicated. The following conversion factors are used:

- Celsius $\rightarrow$ Fahrenheit : $(°C \times 1.8) + 32 = \ °F$
- Fahrenheit $\rightarrow$ Celsius : $(°F - 32) \div 1.8 = \ °C$

Problem Solving

Problem: Convert 10°C to Fahrenheit.

Solution: (10°C $\times$ 1.8) + 32 = 50°F

You Try It!

Problem: The weather forecaster predicts a high temperature today of 86°F. What will the temperature be in Celsius?

Using Measuring Devices

Measuring devices must be used correctly to get accurate measurements. **Figure** 2.10 shows the correct way to use a graduated cylinder to measure the volume of a liquid.

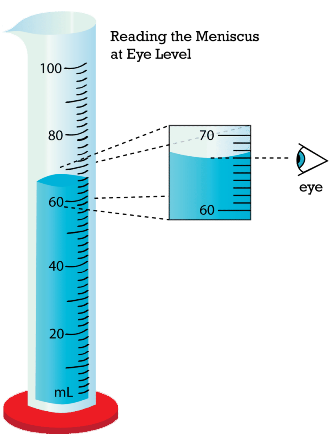


FIGURE 2.10
This cylinder contains about 66 mL of liquid. What would the measurement be if you read the top of the meniscus by mistake?

Follow these steps when using a graduated cylinder to measure liquids:

- Place the cylinder on a level surface before adding liquid.
- Move so your eyes are at the same level as the top of the liquid in the cylinder.
- Read the mark on the glass that is at the lowest point of the curved surface of the liquid. This is called the meniscus.

At the URLs below, you can see the correct way to use a metric ruler to measure length and a beam balance to measure mass.

- http://www.wsd1.org/waec/math/Consumer%20Math%20Advanced/Unit%202%20Design%20and%20Measurement/Ruler%20Meas/measmain.htm (metric ruler)
- http://www.youtube.com/watch?v=C9howXG7LUY (beam balance) (5:14)

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5036

Accuracy and Precision

Measurements should be both accurate and precise.

- **Accuracy** is how close a measurement is to the true value. For example, 66 mL is a fairly accurate measurement of the liquid in **Figure** 2.10.
- **Precision** is how exact a measurement is. A measurement of 65.5 mL is more precise than a measurement of 66 mL. But in **Figure** 2.10, it is not as accurate.

You can think of accuracy and precision in terms of a game like darts. If you are aiming for the bull's-eye and get all of the darts close to it, you are being both accurate and precise. If you get the darts all close to each other somewhere else on the board, you are precise, but not accurate. And finally, if you get the darts spread out all over the board, you are neither accurate nor precise.

Keeping Records

Record keeping is very important in scientific investigations. Follow the tips below to keep good science records.

- Use a bound laboratory notebook so pages will not be lost. Write in ink for a permanent record.
- Record the steps of all procedures.
- Record all measurements and observations.
- Use drawings as needed.
- Date all entries, including drawings.

Calculating

Doing science often requires calculations. Converting units is just one example. Calculations are also needed to find derived quantities.

Calculating Derived Quantities

Derived quantities are quantities that are calculated from two or more different measurements. Examples include area and volume. It's easy to calculate these quantities for a simple shape. For a rectangular solid, like the one in **Figure** 2.11, the formulas are:

$$\text{Area (of each side)} = \text{length} \times \text{ width } (l \times w)$$
$$\text{Volume} = \text{length} \times \text{width} \times \text{height } (l \times w \times h)$$

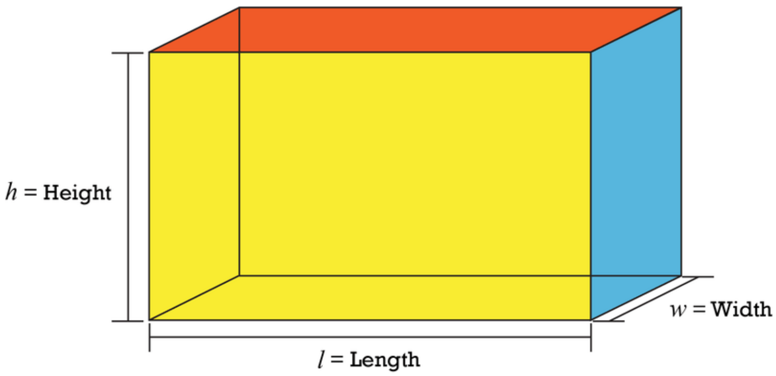


FIGURE 2.11
Dimensions of a rectangular solid include length (l), width (w), and height (h). The solid has six sides. How would you calculate the total surface area of the solid?

Helpful Hints

When calculating area and volume, make sure that:

- all the measurements have the same units.
- answers have the correct units. Area should be in squared units, such as cm^2; volume should be in cubed units, such as cm^3. Can you explain why?

Naturally, not all derived quantities will have the same types of units. In the examples above, the only fundamental unit used was meters for the length of one of the sides of the box. However, if you had a quantity like speed (a derived quantity), it would be equal to distance traveled (which is meters) divided by the amount of time you spent traveling that distance (which is in seconds). Therefore your speed would be measured in meters per second.

Using Significant Figures

Assume you are finding the area of a rectangle with a length of 6.8 m and a width of 6.9 m. When you multiply the length by the width on your calculator, the answer you get is 46.92 m^2. Is this the correct answer? No; the correct answer is 46.9 m^2. The correct answer must be rounded down so there is just one digit to the right of the decimal point. That's because the answer cannot have more digits to the right of the decimal point than any of the original measurements. Using extra digits implies a greater degree of precision than actually exists. The correct number of digits is called the number of **significant figures**. To learn more about significant figures and rounding, you can watch the videos at the URLs below.

- http://www.youtube.com/watch?v=ZbTxK6-1fDg (3:20)
- http://www.youtube.com/watch?v=MuVyoqz5lxM (8:30)

Using Scientific Notation

Quantities in science may be very large or very small. This usually requires many zeroes to the left or right of the decimal point. Such numbers can be hard to read and write accurately. That's where scientific notation comes in. **Scientific notation** is a way of writing very large or small numbers that uses exponents. Numbers are written in this format:

$$a \times 10^b$$

The letter a stands for a decimal number. The letter b stands for an exponent, or power, of 10. For example, the number 300 is written as 3.0×10^2. The number 0.03 is written as 3.0×10^{-2}. **Figure** 2.12 explains how to convert numbers to and from scientific notation. For a review of exponents, watch: http://www.youtube.com/watch?v=8htcZca0JIA .

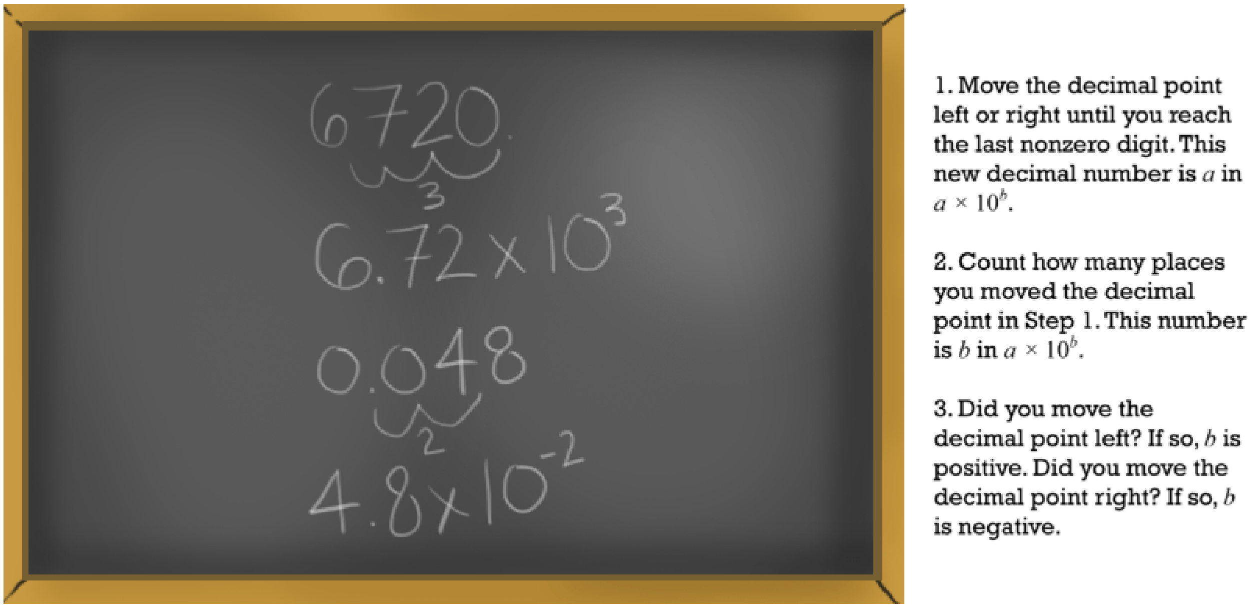


FIGURE 2.12

Follow the steps in reverse to convert numbers from scientific notation.

You Try It!

Problem: Write the number 46,000,000 in scientific notation.

Organizing Data

In a scientific investigation, a researcher may make and record many measurements. These may be compiled in spreadsheets or data tables. In this form, it may be hard to see patterns or trends in the data. Descriptive statistics and graphs can help organize the data so patterns and trends are easier to spot.

Example: A vehicle checkpoint was set up on a busy street. The number of vehicles of each type that passed by the checkpoint in one hour was counted and recorded in **Table** 2.7. These are the only types of vehicles that passed the checkpoint during this period.

TABLE 2.7: Data Table

Type of Vehicle	Number
4-door cars	150
2-door cars	50
SUVs	80

TABLE 2.7: (continued)

Type of Vehicle	Number
vans	50
pick-up trucks	70

Descriptive Statistics

A descriptive statistic sums up a set of data in a single number. Examples include the mean and range.

- The **mean** is the average value. It gives you an idea of the typical measurement. The mean is calculated by summing the individual measurements and dividing the total by the number of measurements. For the data in **Table** 2.7, the mean number of vehicles by type is: (150 + 50 + 80 + 50 + 70) ÷ 5 = 80. (There are two other words people can sometimes use when they use the word "average." They might be referring to a quantity called the "median" or the "mode." You'll see these quantities in later courses, but for now, we'll just say the average is the same thing as the mean.)
- The **range** is the total spread of values. It gives you an idea of the variation in the measurements. The range is calculated by subtracting the smallest value from the largest value. For the data in **Table** 2.7, the range in numbers of vehicles by type is: 150 - 50 = 100.

Graphs

Graphs can help you visualize a set of data. Three commonly used types of graphs are bar graphs, circle graphs, and line graphs. **Figure** 2.13 shows an example of each type of graph. The bar and circle graphs are based on the data in **Table** 2.7, while the line graph is based on unrelated data. You can see more examples at this URL: http://www.beaconlearningcenter.com/weblessons/kindsofgraphs/default.htm .

- Bar graphs are especially useful for comparing values for different types of things. The bar graph in **Figure** 2.13 shows the number of vehicles of each type that passed the checkpoint.
- Circle graphs are especially useful for showing percents of a whole. The circle graph in **Figure** 2.13 shows the percent of all vehicles counted that were of each type.
- Line graphs are especially useful for showing changes over time. The line graph in **Figure** 2.13 shows how distance from school changed over time when some students went on a class trip.

Helpful Hints

Circle graphs show percents of a whole. What are percents?

- Percents are fractions in which the denominator is 100. *Example:* 30% = 30/100
- Percents can also be expressed as decimal numbers. *Example:* 30% = 0.30

You Try It!

Problem: Show how to calculate the percents in the circle graph in **Figure** 2.13.

Need a refresher on percents, fractions, and decimals? Go to this URL: http://www.mathsisfun.com/decimal-fraction-percentage.html .

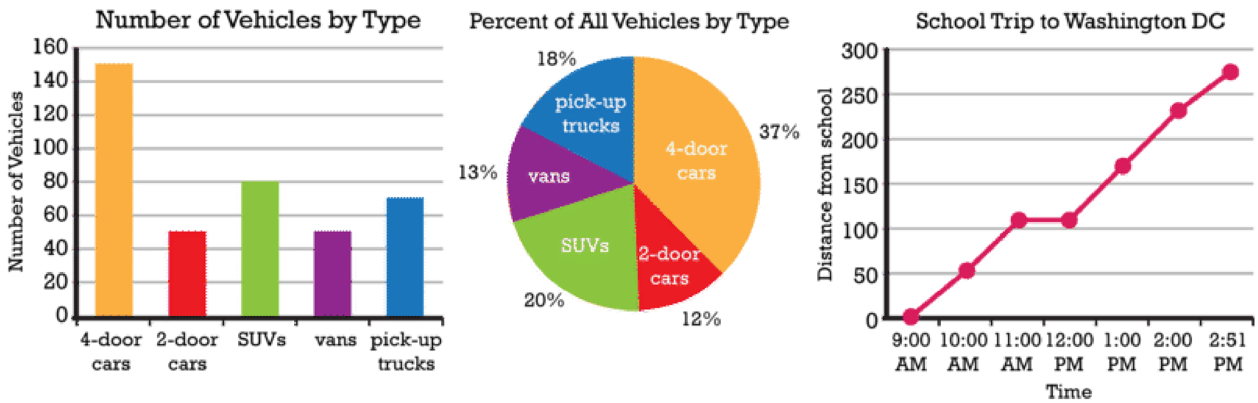


FIGURE 2.13

These are three commonly used types of graphs. When would you want to use a bar graph? What about a line graph?

Using Models

Did you ever read a road map, sketch an object, or play with toy trucks or dolls? No doubt, the answer is yes. What do all these activities have in common? They all involve models. A **model** is a representation of an object, system, or process. For example, a road map is a representation of an actual system of roads on the ground.

Models are very useful in science. They provide a way to investigate things that are too small, large, complex, or distant to investigate directly. **Figure** 2.14 shows an example of a model in chemistry. To be useful, a model must closely represent the real thing in important ways, but it must be simpler and easier to manipulate than the real thing. Do you think the model in **Figure** 2.14 meets these criteria?

Staying Safe in Science

Research in physical science can be exciting, but it also has potential dangers. Whether in the lab or in the field, knowing how to stay safe is important.

Safety Symbols

Lab procedures and equipment may be labeled with safety symbols. These symbols warn of specific hazards, such as flames or broken glass. Learn the symbols so you will recognize the dangers. A list of common safety symbols is shown in **Figure** 2.15. Do you know how to avoid each hazard? You can learn more at this URL: http://www.angelfire.com/va3/chemclass/safety.html .

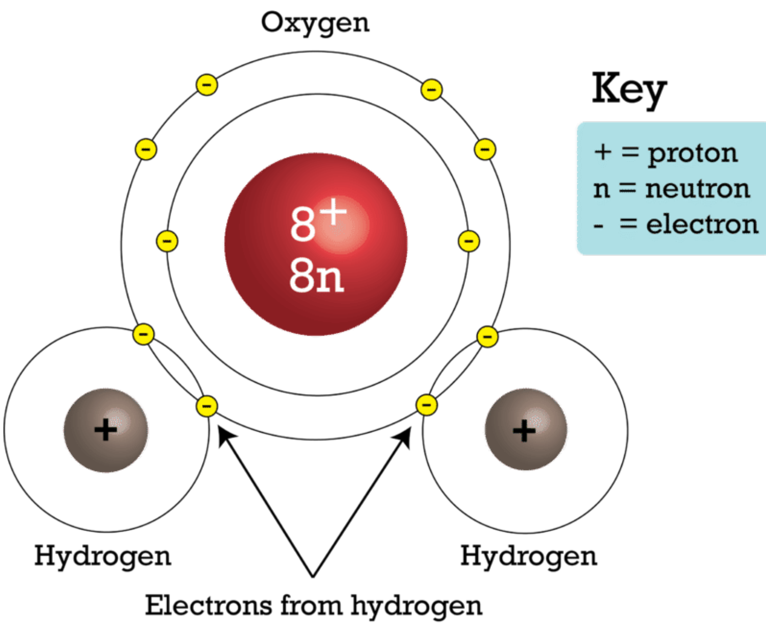


FIGURE 2.14
This model represents a water molecule. It shows that a water molecule consists of an atom of oxygen and two atoms of hydrogen. What else does the model show?

FIGURE 2.15
Why does glassware pose a hazard?

Safety Rules

Following basic safety rules is the best way to stay safe in science. Safe practices help prevent accidents. Several lab safety rules are listed below. Different rules may apply when you work in the field. But in all cases, you should always follow your teacher's instructions.

Lab Safety Rules

- Wear safety gear, including goggles, an apron, and gloves.
- Wear a long-sleeved shirt and shoes that completely cover your feet.
- Tie back your hair if it is long.
- Do not eat or drink in the lab.
- Never work alone.
- Never perform unauthorized experiments.
- Never point the open end of a test tube at yourself or another person.
- Always add acid to water — never water to acid — and add the acid slowly.
- To smell a substance, use your hand to fan vapors toward your nose rather than smell it directly. This is demonstrated in **Figure** 2.16.
- When disposing of liquids in the sink, flush them down the drain with lots of water.
- Wash glassware and counters when you finish your lab work.
- Thoroughly wash your hands with soap and water before leaving the lab.

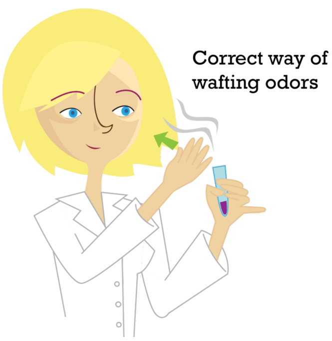


FIGURE 2.16
This is the correct way to smell a chemical in science lab. This helps prevent possible injury from toxic fumes.

Even when you follow the rules, accidents can happen. Immediately alert your teacher if an accident occurs. Report all accidents, even if you don't think they are serious.

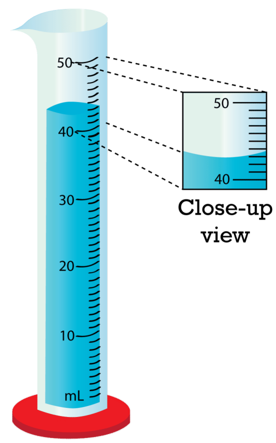
Lesson Summary

- Most scientists use the SI system of units. It includes the Kelvin scale for temperature. Measurements should be both accurate and precise.
- Good record keeping is very important in scientific research.
- Doing science often requires calculations, such as finding derived quantities. Calculations may involve significant figures or scientific notation.
- Descriptive statistics and graphs help organize data so patterns and trends are more apparent. Descriptive statistics include the mean and range. Types of graphs include bar, circle, and line graphs.
- A model is a representation of an object, system, or process. Models help scientists investigate things that are too small, large, complex, or distant to study directly.
- Staying safe while doing scientific research means recognizing safety symbols and following safety rules.

Lesson Review Questions

Recall

1. What are the basic SI units for length, volume, and mass?
2. How much liquid does this graduated cylinder contain?



3. Define the mean and range of a data set. How are they calculated?
4. What is a model? How are models used in science?
5. What hazard does each of these symbols represent?

Apply Concepts

6. Do the following calculations:
    a. Write the number 0.0000087 in scientific notation.
    b. Convert 50°C to °F.
    c. Find the volume of a cube that measures 5 cm on each dimension (length, width, and height).
7. Make a safety poster to convey one of the lab safety rules in this lesson.

Think Critically

8. Compare and contrast accuracy and precision of measurements in science.

Points to Consider

Most of the skills described in this lesson are important in technology as well as science.

- What is technology?
- How do you think technology differs from science?

2.4 Technology

Lesson Objectives

- Define technology.
- Outline the technological design process.
- Explain how science and technology are related.
- Describe how technology and society influence each other.

Lesson Vocabulary

- engineer
- technological design
- technology

Introduction

What do you think of when you hear the word technology? Do devices like computers and solar-powered cars come to mind? Devices such as these are just one meaning of the term "technology." As a field of study, technology is much broader than that.

What is Technology?

Technology is the application of knowledge to real-world problems. It includes methods and processes as well as devices like computers and cars. An example is the Bessemer process. It is a cheap method of making steel that was invented in the 1850s. It is just one of many technological advances that have occurred in manufacturing. Technology is also responsible for most of the major advances in agriculture, transportation, communications, and medicine. Clearly, technology has had a huge impact on people and society. It is hard to imagine what life would be like without it.

Professionals in technology are generally called **engineers**. Most engineers have a strong background in physical science. There are many different careers in engineering. You can learn about some of them at the URL below.

- http://www.sciencebuddies.org/science-fair-projects/science_careers.shtml?gclid=CMbjl5HB4qgCFcW8Kgod7HdmGQ

Technological Design

The development of new technology is called **technological design**. It is similar to scientific investigation. Both processes use evidence and logic to solve problems.

Technological Design Process

Figure 2.17 shows the steps of the technological design process. Consider the problem of developing a solar-powered car. Many questions would have to be researched in the design process. For example, what is the best shape for gathering the sun's rays? How will the energy from the sun be stored? Will a back-up energy source be needed? After researching the answers, possible designs are developed. This takes imagination as well as reason. Then a model is made of the best design, and the model is tested. This allows any problems with the design to be worked out before a final design is selected.

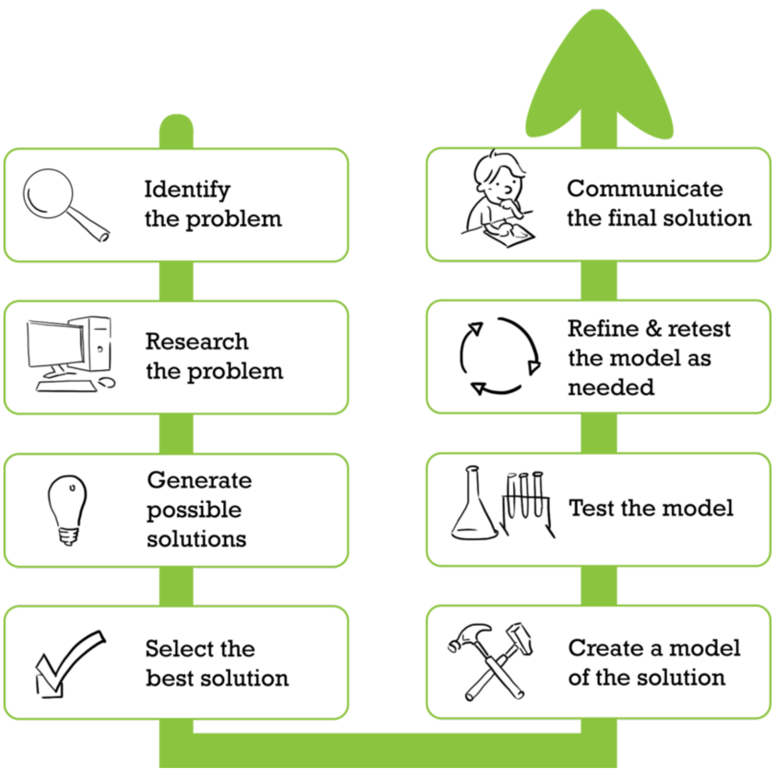


FIGURE 2.17
This flowchart represents the process of technological design. How does the technological design process resemble a scientific investigation?

Constraints on Technological Design

Technological design always has constraints. Constraints are limits on the design. Common constraints include:

- laws of nature, such as the law of gravity.
- properties of the materials used.
- cost of producing a technology.

Ethical concerns are also constraints on many technological designs. Like scientists, engineers must follow ethical rules. For example, the technologies they design must be as safe as possible for people and the environment. Engineers must weigh the benefits and risks of new technologies, and the benefits should outweigh the risks.

Advances in Technology

Technology advances as new materials and processes are invented. Computers are a good example. **Table** 2.8 and the videos below show some of the milestones in their evolution. The evolution of modern computers began in the 1930s. Computers are still evolving today. How have computers changed during your lifetime?

- http://www.youtube.com/watch?v=ETVAlcMXitk (4:11)

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URL: http://www.ck12.org/flx/render/embeddedobject/5039

TABLE 2.8: Evolution of Computers

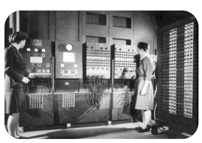
Computer (Year)	Description
ENIAC (1946)  *US Army Photo*	Like other early computers, the huge ENIAC computer used vacuum tubes for electrical signals. This made it very large and expensive. It could do just one task at a time. It had to be rewired to change programs. That's what the women in this photo are doing.
ERMA (1955)	The ERMA computer represented a new computer technology. It used transistors instead of vacuum tubes. This allowed computers to be smaller, cheaper, and more energy efficient.
PDP-8 (1968) 	By the late 1960s, tiny transistors on silicon chips were invented. They increased the speed and efficiency of computers. They also allowed computers to be much smaller. The PDP-8 computer pictured here was the first "mini" computer.

TABLE 2.8: (continued)

Computer (Year)	Description
Macintosh 128K (1984) 	The next major advance in computers was the development of microprocessors. A microprocessor consisted of thousands of integrated circuits placed on a tiny silicon chip. This allowed computers to be more powerful and even smaller. The computer pictured here is the first Macintosh personal computer.
MacBook Air (2010) 	The computers of the 21st century are tiny compared with the lumbering giants of the mid-1900s. Their problem-solving abilities are also immense compared with early computers. The diversity of software programs available today allows users to undertake an immense variety of tasks — and no rewiring is needed!

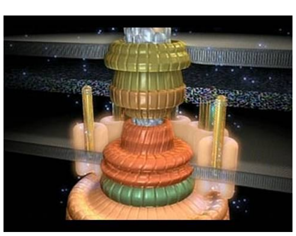
Technology and Science

Technology is sometimes referred to as applied science, but it has a different goal than science. The goal of science is to increase knowledge. The goal of technology is to use knowledge for practical purposes.

Although they have different goals, technology and science work hand in hand. Each helps the other advance. Scientific knowledge is needed to create new technologies. New technologies are used to further science. The microscope is a good example. Scientific knowledge of light allowed 17^{th} century lens makers to make the first microscopes. This new technology let scientists view a world of tiny objects they had never before seen. **Figure** 2.18 describes other examples.

KQED: Nanotechnology Takes Off

What's 100,000 times thinner than a strand of hair? A nanometer. Discover the nanotech boom in Berkeley, where researchers are working to unlock the potential of nanoscience to battle global warming and disease. For more information on nanotechnology, see http://science.kqed.org/quest/video/nanotechnology-takes-off/ .



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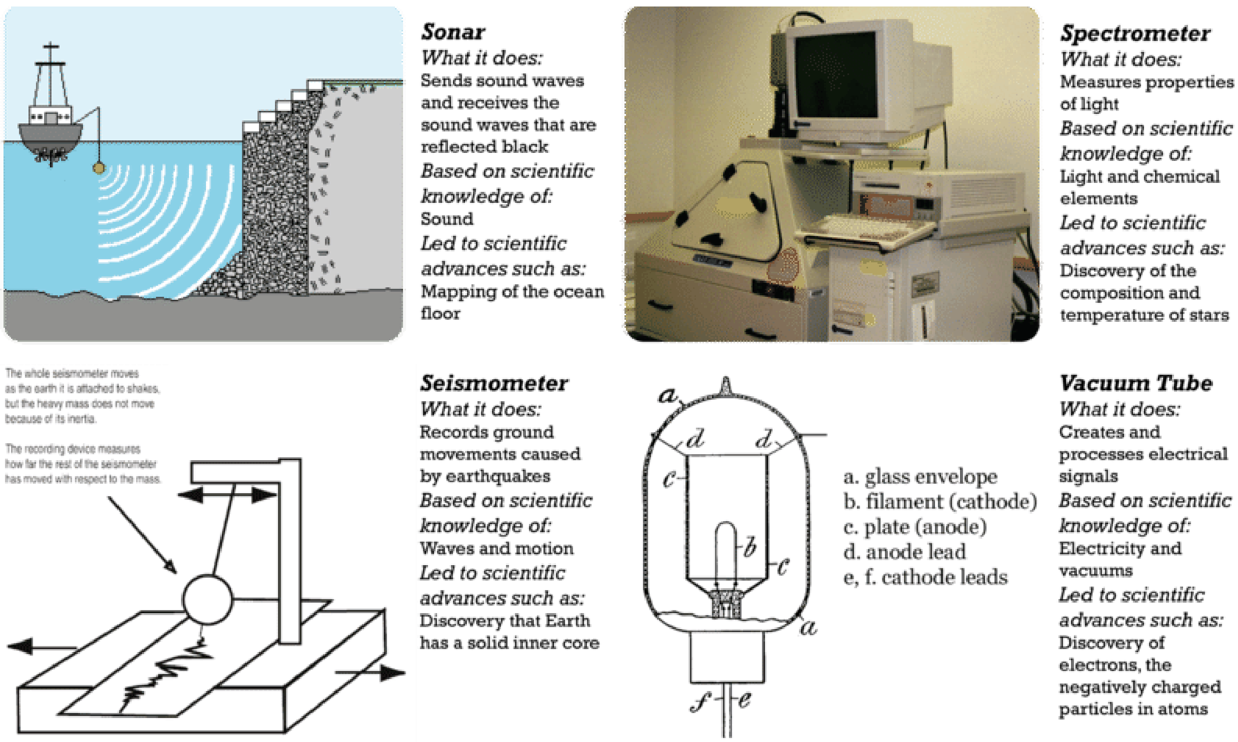

FIGURE 2.18
Each of the technologies pictured here is based on scientific knowledge. Each also led to important scientific advances.

Technology and Society

The goal of technology is to solve people's problems. Therefore, the problems of society generally set the direction that technology takes. Technology, in turn, affects society. It may make people's lives easier or healthier. Two examples are described in **Figure** 2.19.

You can read about other examples at these URLs:

- http://mezocore.wordpress.com/
- http://www.makingthemodernworld.org.uk/everyday_life/

KQED: Darfur Stoves Project

Everyday, women living in the refugee camps of Darfur, Sudan must walk for up to seven hours outside the safety of the camps to collect firewood for cooking, putting them at risk for violent attacks. Now, researchers at Lawrence Berkeley National Laboratory have engineered a more efficient wood-burning stove, which is greatly reducing both the women's need for firewood and the threats against them. For more information on these stoves, see http://science.kqed.org/quest/video/darfur-stoves-project/ .

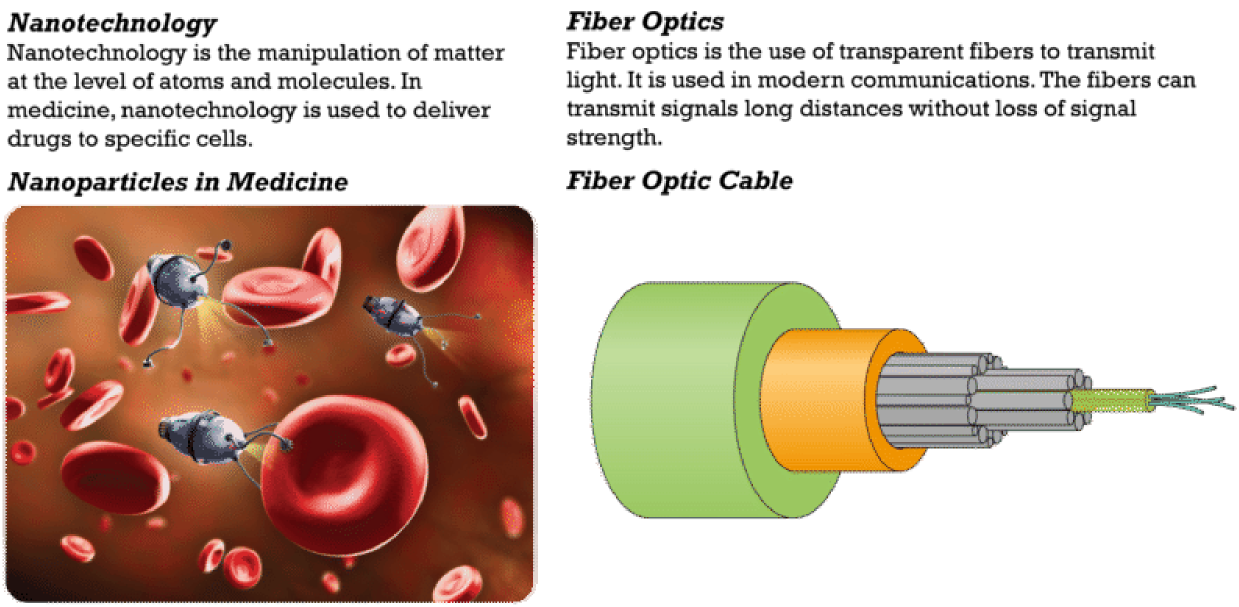

FIGURE 2.19

Technologies that help people may be as simple as forks and knives. Or they may be as complex as the two examples described here. How does technology help you?

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Lesson Summary

- Technology is the application of knowledge to real-world problems. Engineers are professionals in technology.
- Technological design is the development of new technology. The design process is based on evidence and logic.
- Technology and science have different goals, but each helps the other advance.
- The problems of society generally set the direction of technology. New technologies, in turn, may make people's lives easier or healthier.

Lesson Review Questions

Recall

1. Define technology.
2. What do engineers do?
3. List the steps of the technological design process.

Apply Concepts

4. A team of engineers is designing a new type of car. What are likely to be some of the constraints on the design?

Think Critically

5. Compare and contrast science and technology.
6. Relate technology and society.

Points to Consider

Nanotechnology manipulates atoms and molecules of matter.

- What is matter? What are its characteristics?
- Do you think all matter consists of atoms and molecules?

For **Table** 2.8, from top to bottom,

- ENIAC: Courtesy of US Army. http://commons.wikimedia.org/wiki/File:Two_women_operating_ENIAC.gif . Public Domain.
- PDP-8: User:Alkivar/Wikipedia. http://commons.wikimedia.org/wiki/File:PDP-8.jpg . Public Domain.
- Macintosh 128K: Blake Patterson (blakespot). http://www.flickr.com/photos/blakespot/2388811229/ . CC BY 2.0.
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   Slide: http://www.flickr.com/photos/mediatejack/2075620374/">Skydiver: http://www.flickr.com/photos/philleara/704667
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18. Sonar: Courtesy of US Geological Survey; Spectrometer: Courtesy of National Institute for Occupational Safety and Health (NIOSH); Seismometer: Courtesy of US Geological Survey; Vacuum tube: IMeowbot, based on illustration by John Ambrose Fleming. <a href="Sonar: http://marine.usgs.gov/fact-sheets/michigan/michigan.htm
    Spectrometer: http://commons.wikimedia.org/wiki/File:Microscopic_spectrometer.jpg; Seismometer: http://earthquake.us
    Vacuum tube: http://commons.wikimedia.org/wiki/File:Diode-tube.png">Sonar: http://marine.usgs.gov/fact-sheets/michigan/michigan.html; Spectrometer: http://commons.wikimedia.org/wiki/File:Microscopic_spectrometer.jpg; Seismometer: http://earthquake.usgs.gov/learn/kids/coloring/; Vacuum tube: http://commons.wikimedia.org/
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CONCEPT 3 Unit 2: Motion

Questions/Observable Phenomena

CHAPTER 4 Motion

Chapter Outline

A frog flicks out its long tongue to catch insects. In this photo, you can't actually see the frog's tongue moving. But even if you were to witness it in person, you still wouldn't be able to see it. That's because a frog's tongue moves incredibly fast. It travels out and back in about 0.15 seconds, too fast for the human eye to detect. Other organisms can also move at very high speeds. For example, the fastest land animal, the cheetah, can sprint at an amazing 120 kilometers (75 miles) per hour. Speed is one way of measuring motion. What is motion, and what are other ways of measuring it? In this chapter, you'll find out.

4.1 Distance and Displacement

Lesson Objectives

- Define motion, and relate it to frame of reference.
- Describe how to measure distance.
- Explain how to represent displacement.

Lesson Vocabulary

- distance
- displacement
- frame of reference
- motion
- vector

Introduction

You can see several examples of people or things in motion in **Figure** 4.1. You can probably think of many other examples. You know from experience what motion is, so it may seem like a straightforward concept. **Motion** can also be defined simply, as a change in position. But if you think about examples of motion in more depth, you'll find that the idea of motion is not quite as simple and straightforward as it seems.

Frame of Reference

Assume that a school bus, like the one in **Figure** 4.2, passes by as you stand on the sidewalk. It's obvious to you that the bus is moving. It is moving relative to you and the trees across the street. But what about to the children inside the bus? They aren't moving relative to each other. If they look only at the other children sitting near them, they will not appear to be moving. They may only be able to tell that the bus is moving by looking out the window and seeing you and the trees whizzing by.

This example shows that how we perceive motion depends on our frame of reference. **Frame of reference** refers to something that is not moving with respect to an observer that can be used to detect motion. For the children on the bus, if they use other children riding the bus as their frame of reference, they do not appear to be moving. But if they use objects outside the bus as their frame of reference, they can tell they are moving. What is your frame of reference if you are standing on the sidewalk and see the bus go by? How can you tell the bus is moving? The video at the URL below illustrates other examples of how frame of reference is related to motion.

http://www.youtube.com/watch?v=7FYBG5GSklU (6:45)

FIGURE 4.1
These are just a few examples of people or things in motion. If you look around, you're likely to see many more.

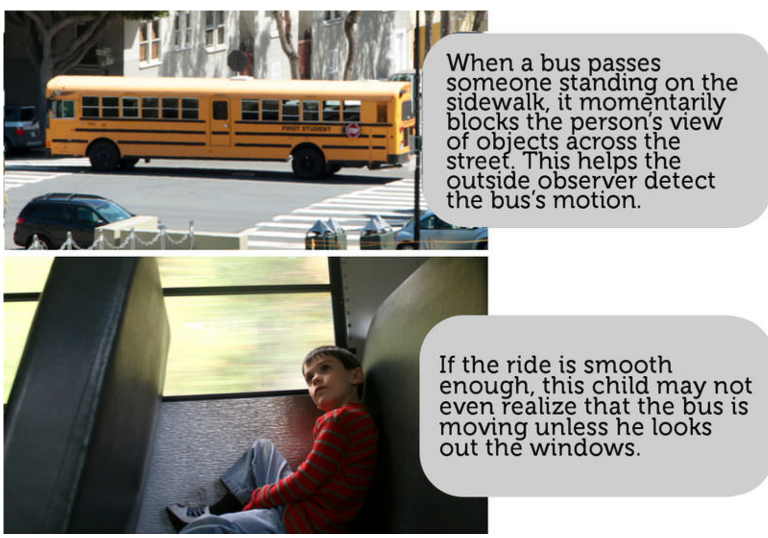

FIGURE 4.2
To a person outside the bus, the bus's motion is obvious. To children riding the bus, its motion may not be as obvious.

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URL: http://www.ck12.org/flx/render/embeddedobject/5019

Distance

Did you ever go to a track meet like the one pictured in **Figure** 4.3? Running events in track include 100-meter sprints and 2000-meter races. Races are named for their distance. **Distance** is the length of the route between two points. The length of the route in a race is the distance between the starting and finishing lines. In a 100-meter sprint, for example, the distance is 100 meters.

FIGURE 4.3
These students are running a 100-meter sprint.

SI Unit for Distance

The SI unit for distance is the meter (1 m = 3.28 ft). Short distances may be measured in centimeters (1 cm = 0.01 m). Long distances may be measured in kilometers (1 km = 1000 m). For example, you might measure the distance a frog's tongue moves in centimeters and the distance a cheetah moves in kilometers.

Using Maps to Measure Distance

Maps can often be used to measure distance. Look at the map in **Figure** 4.4. Find Mia's house and the school. You can use the map key to directly measure the distance between these two points. The distance is 2 kilometers. Measure it yourself to see if you agree.

Di

Things don't always move in straight lines like the route from Mia's house to the school. Sometimes they change direction as they move. For example, the route from Mia's house to the post office changes from west to north at the school (see **Figure** 4.4). To find the total distance of a route that changes direction, you must add up the distances traveled in each direction. From Mia's house to the school, for example, the distance is 2 kilometers. From the school to the post office, the distance is 1 kilometer. Therefore, the total distance from Mia's house to the post office is 3 kilometers.

You Try It!

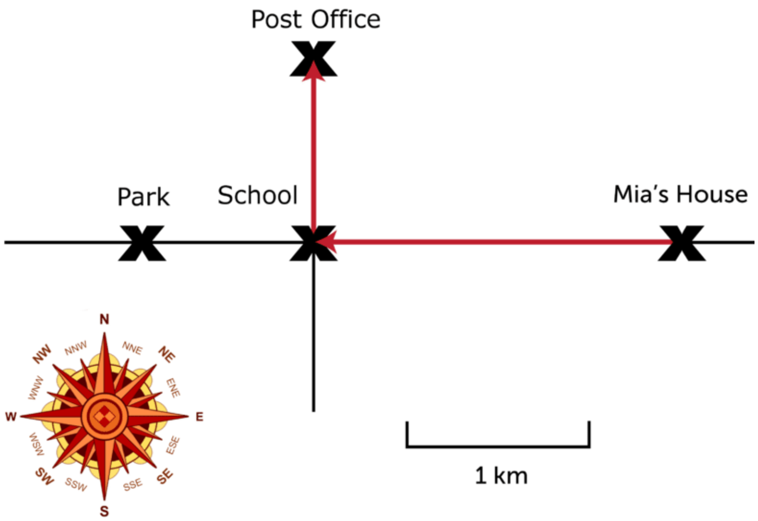


FIGURE 4.4
This map shows the routes from Mia's house to the school, post office, and park.

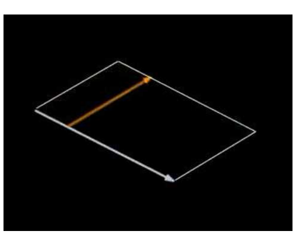
Problem: What is the distance from the post office to the park in **Figure** 4.4?

Displacement is just as important as distance in describing motion. For example, if Mia told a friend how to reach the post office from her house, she couldn't just say, "go 3 kilometers." The friend might end up at the park instead of the post office. Mia would have to be more specific. She could say, "go west for 2 kilometers and then go north for 1 kilometer."

You Try It!

Use the map above. Draw a straight line from Mia's house to the Post Office, and measure it's length. The length of the line should be about 2.24 kilometers. To indicate the direction of motion of Mia, we are going to make that line an arrow, with the tail of the arrow from where she comes from (her house) and the tip of the arrow to where she is going (Post Office). This representation of motion is called **displacement.** Displacement is a vector quantity. A **vector** is a quantity that includes both size and direction. For Mia's displacement, the size is the 2.24 kilometers and the direction is shown by the arrow. When an object moves in one direction, the size of the displacement is equal to the distance traveled. But when the object moves in more than one direction, the size of displacement is always less than distance. Remember, distance is the total length of the route. Displacement it the straight measure from the initial to finish point. If you want to learn more about vectors, watch the videos at these URLs:

- http://www.youtube.com/watch?v=B-iBbcFwFOk (5:27)



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- http://www.youtube.com/watch?v=tSOz3xaHKLs

You Try It!

Problem: Draw vectors to represent the route from the post office to the park in **Figure** 4.4.

Lesson Summary

- Motion is a change of position. The perception of motion depends on a person's frame of reference.
- Distance is the length of the route between two points. The SI unit for distance is the meter (m).
- Direction is just as important as distance in describing motion. A vector is a quantity that has both size and direction. It can be used to represent the distance and direction of motion.

Lesson Review Questions

Recall

1. Define motion.
2. What is distance?
3. Describe how a vector represents distance and direction.

Apply Concepts

4. In **Figure** 4.4, what is the distance from Mia's house to the park?
5. Draw vectors to represent the following route from point A to point B:
   a. Starting at point A, go 2 km east.
   b. Then go 1 km south.
   c. Finally, go 3 km west to point B.

Think Critically

6. Explain how frame of reference is related to motion.

Points to Consider

A snail might travel 2 centimeters in a minute. A cheetah might travel 2 kilometers in the same amount of time. The distance something travels in a given amount of time is its speed.

- How could you calculate the speed of a snail or cheetah?
- Speed just takes distance and time into account. How might direction be considered as well?

4.2 Speed and Velocity

Lesson Objectives

- Outline how to calculate the speed of a moving object.
- Explain how velocity differs from speed.

Lesson Vocabulary

- speed
- velocity

Introduction

Did you ever play fast-pitch softball? If you did, then you probably have some idea of how fast the pitcher throws the ball. For a female athlete, like the one in **Figure** 4.5, the ball may reach a speed of 120 km/h (about 75 mi/h). For a male athlete, the ball may travel even faster. The speed of the ball makes it hard to hit. If the ball changes course, the batter may not have time to adjust the swing to meet the ball.

FIGURE 4.5
In fast-pitch softball, the pitcher uses a "windmill" motion to throw the ball. This is a different technique than other softball pitches. It explains why the ball travels so fast.

Speed

Speed is an important aspect of motion. It is a measure of how fast or slow something moves. It depends on how far something travels and how long it takes to travel that far. Speed can be calculated using this general formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

A familiar example is the speed of a car. In the U.S., this is usually expressed in miles per hour (see **Figure** 4.6). If your family makes a car trip that covers 120 miles and takes 3 hours, then the car's speed is:

$$\text{speed} = \frac{120 \text{ mi}}{3 \text{ h}} = 40 \text{ mi/h}$$

The speed of a car may also be expressed in kilometers per hour (km/h). The SI unit for speed is meters per second (m/s).

FIGURE 4.6
Speed limit signs like this one warn drivers to reduce their speed on dangerous roads.

Instantaneous vs. Average Speed

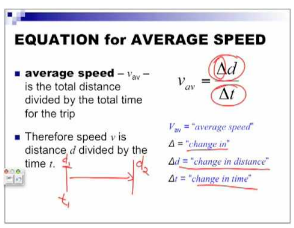
When you travel by car, you usually don't move at a constant speed. Instead you go faster or slower depending on speed limits, traffic, traffic lights, and many other factors. For example, you might travel 65 miles per hour on a highway but only 20 miles per hour on a city street (see **Figure** 4.7). You might come to a complete stop at traffic lights, slow down as you turn corners, and speed up to pass other cars. The speed of a moving car or other object at a given instant is called its instantaneous speed. It may vary from moment to moment, so it is hard to calculate.

It's easier to calculate the average speed of a moving object than the instantaneous speed. The average speed is the total distance traveled divided by the total time it took to travel that distance. To calculate the average speed, you can use the general formula for speed that was given above. Suppose, for example, that you took a 75-mile car trip with your family. Your instantaneous speed would vary throughout the trip. If the trip took a total of 1.5 hours, your average speed for the trip would be:

FIGURE 4.7
Cars race by in a blur of motion on an open highway but crawl at a snail's pace when they hit city traffic.

$$\text{average speed} = \frac{75 \text{ mi}}{1.5 \text{ h}} = 50 \text{ mi/h}$$

You can see a video about instantaneous and average speed and how to calculate them at this URL: http://www.youtube.com/watch?v=a8tIBrj84II (7:18).



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You Try It!

Problem: Terri rode her bike very slowly to the top of a big hill. Then she coasted back down the hill at a much faster speed. The distance from the bottom to the top of the hill is 3 kilometers. It took Terri 15 minutes to make the round trip. What was her average speed for the entire trip?

Distance-Time Graphs

The motion of an object can be represented by a distance-time graph like the one in **Figure** 4.8. A distance-time graph shows how the distance from the starting point changes over time. The graph in **Figure** 4.8 represents a bike trip. The trip began at 7:30 AM (A) and ended at 12:30 PM (F). The rider traveled from the starting point to a destination and then returned to the starting point again.

Slope Equals Speed

In a distance-time graph, the speed of the object is represented by the slope, or steepness, of the graph line. If the line is straight, like the line between A and B in **Figure** 4.8, then the speed is constant. The average speed can be calculated from the graph. The change in distance (represented by Δd) divided by the change in time (represented by Δt):

$$\text{speed} = \frac{\Delta \text{d}}{\Delta \text{t}}$$

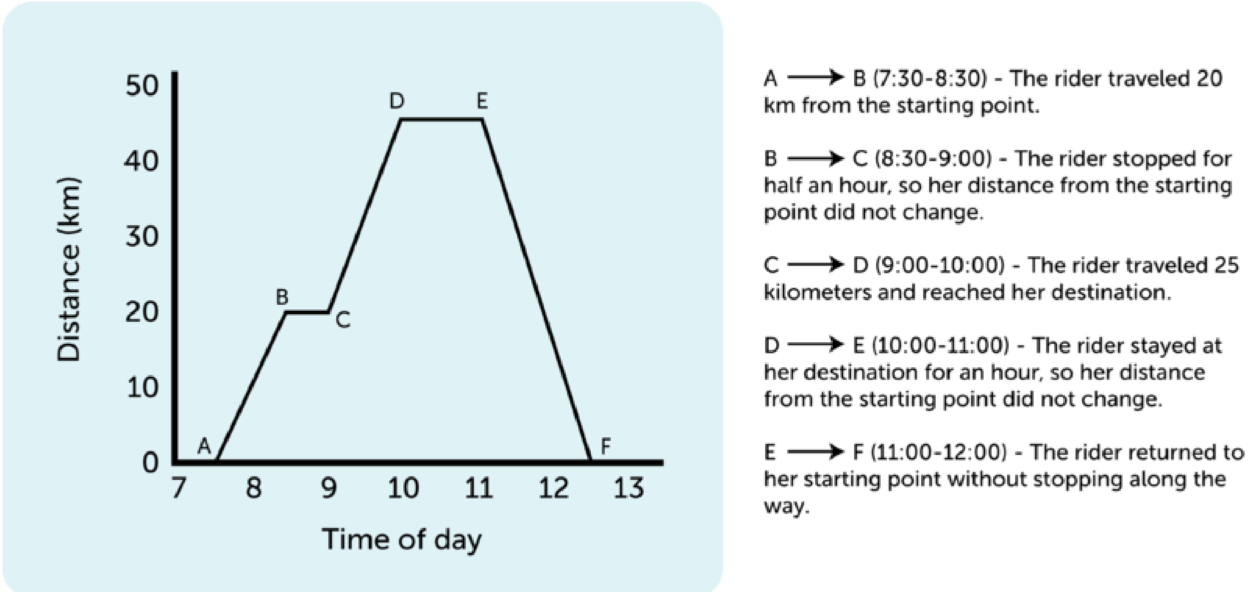

FIGURE 4.8
This graph shows how far a bike rider is from her starting point at 7:30 AM until she returned at 12:30 PM.

For example, the speed between A and B in **Figure** 4.8 is:

$$\text{speed} = \frac{\Delta \text{d}}{\Delta \text{t}} = \frac{20 \text{ km} - 0 \text{ km}}{8{:}30 - 7{:}30 \text{ h}} = \frac{20 \text{ km}}{1 \text{ h}} = 20 \text{ km/h}$$

If the graph line is horizontal, as it is between B and C, then the slope and the speed are zero:

$$\text{speed} = \frac{\Delta \text{d}}{\Delta \text{t}} = \frac{20 \text{ km} - 20 \text{ km}}{9{:}00 - 8{:}30 \text{ h}} = \frac{0 \text{ km}}{0.5 \text{ h}} = 0 \text{ km/h}$$

You Try It!

Problem: In **Figure** 4.8, calculate the speed of the rider between C and D.

Calculating Distance from Speed and Time

If you know the speed of a moving object, you can also calculate the distance it will travel in a given amount of time. To do so, you would use this version of the general speed formula:

$$\text{distance} = \text{speed} \times \text{time}$$

For example, if a car travels at a speed of 60 km/h for 2 hours, then the distance traveled is:

$$\text{distance} = 60 \text{ km/h} \times 2 \text{ h} = 120 \text{ km}$$

You Try It!

Problem: If Maria runs at a speed of 2 m/s, how far will she run in 60 seconds?

Velocity

Speed tells you only how fast an object is moving. It doesn't tell you the direction the object is moving. The measure of both speed and direction is called **velocity**. Velocity is a vector that can be represented by an arrow. The length of the arrow represents speed, and the way the arrow points represents direction. The three arrows in **Figure** 4.9 represent the velocities of three different objects. Vectors A and B are the same length but point in different directions. They represent objects moving at the same speed but in different directions. Vector C is shorter than vector A or B but points in the same direction as vector A. It represents an object moving at a slower speed than A or B but in the same direction as A. If you're still not sure of the difference between speed and velocity, watch the cartoon at this URL: http://www.youtube.com/watch?v=mDcaeO0WxBI (2:10).

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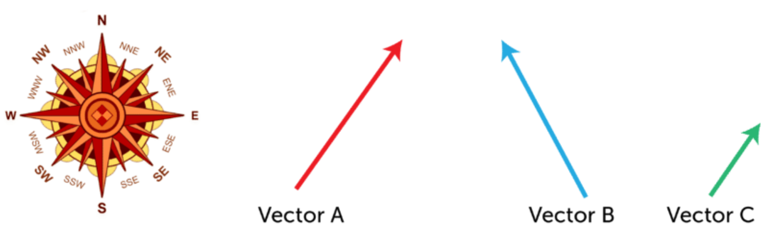

FIGURE 4.9

These vectors show both the speed and direction of motion.

In general, if two objects are moving at the same speed and in the same direction, they have the same velocity. If two objects are moving at the same speed but in different directions (like A and B in **Figure** 4.9), they have different velocities. If two objects are moving in the same direction but at a different speed (like A and C in **Figure** 4.9), they have different velocities. A moving object that changes direction also has a different velocity, even if its speed does not change.

Lesson Summary

- Speed is a measure of how fast or slow something moves. It depends on the distance traveled and how long it takes to travel that distance. The average speed of an object is calculated as the distance traveled divided by the change in time or time of travel.

- Velocity is a measure of both speed and direction. It is a vector that can be represented by an arrow. Velocity changes with a change in speed, a change in direction, or both. It is calculated as the displacement divided by the change in time or travel time.

Lesson Review Questions

Recall

1. What is speed? How is it calculated?
2. Define velocity.

Apply Concepts

3. Sam ran a 2000-meter race. He started at 9:00 AM and finished at 9:05 AM. He started out fast but slowed down toward the end. Calculate Sam's average speed during the race.
4. Create a distance-time graph to represent a typical trip from your home to school or some other route you travel often. You may estimate distances and times.

Think Critically

5. Explain how a distance-time graph represents speed.
6. Compare and contrast speed and velocity.
7. Is speed a vector? Why or why not?

Points to Consider

In this chapter, you read that the speed of a moving object equals the distance traveled divided by the time it takes to travel that distance. Speed may vary from moment to moment as an object speeds up or slows down. In the next lesson, "Acceleration," you will learn how to measure changes in speed over time.

- Do you know what a change in speed or direction is called?
- Why might measuring changes in speed or direction be important?

4.3 Acceleration.

Lesson Objectives

- Define acceleration.
- Explain how to calculate acceleration.
- Describe velocity-time graphs.

Lesson Vocabulary

- acceleration

Introduction

Imagine the thrill of riding on a roller coaster like the one in **Figure** 4.10. The coaster crawls to the top of the track and then flies down the other side. It also zooms around twists and turns at breakneck speeds. These changes in speed and direction are what make a roller coaster ride so exciting. Changes in speed or direction are called **acceleration**.

FIGURE 4.10
Did you ever ride on a roller coaster like this one? It's called the "Blue Streak" for a reason. As it speeds around the track, it looks like a streak of blue.

Defining Acceleration

Acceleration is a measure of the change in velocity of a moving object. It shows how quickly velocity changes. Acceleration may reflect a change in speed, a change in direction, or both. Because acceleration includes both a size (speed) and direction, it is a vector.

People commonly think of acceleration as an increase in speed, but a decrease in speed is also acceleration. In this case, acceleration is negative. Negative acceleration may be called deceleration. A change in direction without a change in speed is acceleration as well. You can see several examples of acceleration in **Figure** 4.11.

FIGURE 4.11
How is velocity changing in each of these pictures?

If you are accelerating, you may be able to feel the change in velocity. This is true whether you change your speed or your direction. Think about what it feels like to ride in a car. As the car speeds up, you feel as though you are being pressed against the seat. The opposite occurs when the car slows down, especially if the change in speed is sudden. You feel yourself thrust forward. If the car turns right, you feel as though you are being pushed to the left. With a left turn, you feel a push to the right. The next time you ride in a car, notice how it feels as the car accelerates in each of these ways. For an interactive simulation about acceleration, go to this URL: http://phet.colorado.edu/en/simulation/moving-man .

Calculating Acceleration

Calculating acceleration is complicated if both speed and direction are changing. It's easier to calculate acceleration when only speed is changing. To calculate acceleration without a change in direction, you just divide the change in velocity (represented by Δv, = v_{final} - $v_{initial}$) by the change in time (represented by Δt). The formula for acceleration in this case is:

$$\text{Acceleration} = \frac{\Delta v}{\Delta t}$$

Consider this example. The cyclist in **Figure** 4.12 speeds up as he goes downhill on this straight trail. His velocity changes from 1 meter per second at the top of the hill to 6 meters per second at the bottom. If it takes 5 seconds for him to reach the bottom, what is his acceleration, on average, as he flies down the hill?

$$\text{Acceleration} = \frac{\Delta v}{\Delta t} = \frac{6 \text{ m/s} - 1 \text{ m/s}}{5 \text{ s}} = \frac{5 \text{ m/s}}{5 \text{ s}} = \frac{1 \text{ m/s}}{1 \text{ m}} = 1 \text{ m/s}^2$$

In words, this means that for each second the cyclist travels downhill, his velocity increases by 1 meter per second (on average). The answer to this problem is expressed in the SI unit for acceleration: m/s^2 ("meters per second squared").

FIGURE 4.12
Gravity helps this cyclist increase his downhill velocity.

You Try It!

Problem: Tranh slowed his skateboard as he approached the street. He went from 8 m/s to 2 m/s in a period of 3 seconds. What was his acceleration?

Velocity-Time Graphs

The acceleration of an object can be represented by a velocity-time graph like the one in **Figure** 4.13. A velocity-time graph shows how velocity changes over time. It is similar to a distance-time graph except the $y-$axis represents velocity instead of distance. The graph in **Figure** 4.13 represents the velocity of a sprinter on a straight track. The runner speeds up for the first 4 seconds of the race, then runs at a constant velocity for the next 3 seconds, and finally slows to a stop during the last 3 seconds of the race.

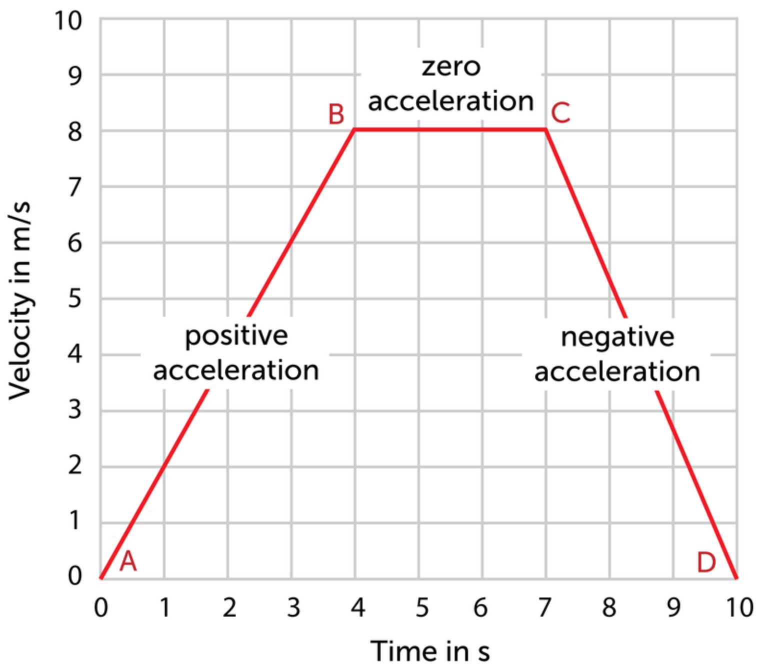

FIGURE 4.13
This graph shows how the velocity of a runner changes during a 10-second sprint.

In a velocity-time graph, acceleration is represented by the slope of the graph line. If the line slopes upward, like the line between A and B in **Figure** 4.13, velocity is increasing, so acceleration is positive. If the line is horizontal, as it is between B and C, velocity is not changing, so acceleration is zero. If the line slopes downward, like the line between C and D, velocity is decreasing, so acceleration is negative. You can review the concept of acceleration as well as other chapter concepts by watching the musical video at this URL: http://www.youtube.com/watch?v=4CWlNoNpXCc .

Lesson Summary

- Acceleration is a measure of the change in velocity of a moving object. It shows how quickly velocity changes and whether the change is positive or negative. It may reflect a change in speed, a change in direction, or both.
- To calculate acceleration without a change in direction, divide the change in velocity by the change in time.
- The slope of a velocity-time graph represents acceleration.

Lesson Review Questions

Recall

1. What is acceleration?
2. How is acceleration calculated?
3. What does the slope of a velocity-time graph represent?

Apply Concepts

4. The velocity of a car on a straight road changes from 0 m/s to 6 m/s in 3 seconds. What is its acceleration?

Think Critically

5. Because of the pull of gravity, a falling object accelerates at 9.8 m/s^2. Create a velocity-time graph to represent this motion.

Points to Consider

Acceleration occurs when a force is applied to a moving object.

- What is force? What are some examples of forces?
- What forces might change the velocity of a moving object? (*Hint*: Read the caption to **Figure** 4.12.)

4.4 References

1. Train: John H. Gray; Cyclist: Flickr:DieselDemon; Inchworm: Clinton Charles Robertson; Hummingbird: Kevin Cole; Cartwheeler: Clemens v. Vogelsang (Flickr:vauvau); Meteor: Ed Sweeney (Flickr:Navicore). <a href="Train: http://www.flickr.com/photos/8391775@N05/3494460809/; Cyclist: http://www.flickr.com/photos/28096801 Inchworm: http://www.flickr.com/photos/dad_and_clint/3571033947/; Hummingbird: http://www.flickr.com/photos/kevco Cartwheeler: http://www.flickr.com/photos/vauvau/8057026163/; Meteor: http://www.flickr.com/photos/edsweeney/41112 http://www.flickr.com/photos/8391775@N05/3494460809/; Cyclist: http://www.flickr.com/photos/28096801@N05/35304 Inchworm: http://www.flickr.com/photos/dad_and_clint/3571033947/; Hummingbird: http://www.flickr.com/photos/kevco Cartwheeler: http://www.flickr.com/photos/vauvau/8057026163/; Meteor: http://www.flickr.com/photos/edsweeney/41112 CC BY 2.0
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10. Flickr:daveynin. <a href="http://www.flickr.com/photos/daveynin/7578666866/">http://www.flickr.com/photos/daveynin/
11. Carousel: Jef Fisher; Skydiver: User:Degrer/Wikimedia Commons; Runner: Mike Spille; Basketball: Maurice Dayao/U.S. Navy; Model rocket: Flickr:kansasphoto; Baseball: Flickr:MyBiggestFan. Carousel: http://www.flickr.com/photos/jeffisher/48397464 Skydiver: http://commons.wikimedia.org/wiki/File:SkydiveroverEslovSweden.jpg; Runner: http://commons.wikimedia.or Marathon_2010_Crossing_Finish_Line.jpg; Basketball: http://commons.wikimedia.org/wiki/File:US_Navy_-080616-N-3581D-208_Ensign_Ian_Hochstein,_assigned_to_the_frigate_USS_Ford_(FFG_54),_teaches_a_young_-girl_to_spin_a_basketball_at_the_Ban_Kao_Chan_Primary_School_in_Sattahip.jpg; Model rocket: http://www.flickr.com Baseball: http://www.flickr.com/photos/msciba/210081711/. Carousel: CC BY 2.0; Skydiver: Public Domain; Runner: CC BY 2.0; Basketball: Public Domain; Model rocket: CC BY 2.0; Baseball: CC BY 2.0

12. Neil Cain. <a href="http://www.flickr.com/photos/pimpmasterjazz/2601898276/">http://www.flickr.com/photos/pimpmas CC BY 2.0
13. Christopher Auyeung. CK-12 Foundation. CC BY-NC 3.0

CONCEPT 5

Unit 3: Forces in the Universe

Questions/Observable Phenomena

CHAPTER 6 Forces

Chapter Outline

Each of these basketball players is trying to push the ball. One player is trying to push it into the basket, and the other player is trying to push it away from the basket. If both players push the ball at the same time, where will it go? It depends on which player pushes the ball with greater force. Forces like this come into play in every sport, whether it's kicking a soccer ball, throwing a baseball, or spiking a volleyball. Forces are involved not only in sports such as these but in every motion in our daily lives. In this chapter, you'll see how forces affect the motion of everything from basketballs to planets.

6.1 What Is Force?

Lesson Objectives

- Define force, and give examples of forces.
- Describe how forces combine and affect motion.

Lesson Vocabulary

- force
- net force
- newton (N)

Introduction

Any time the motion of an object changes, a force has been applied. Force can cause a stationary object to start moving or a moving object to accelerate. The moving object may change its speed, its direction, or both. How much an object's motion changes when a force is applied depends on the strength of the force and the object's mass. You can explore the how force, mass, and acceleration are related by doing the activity at the URL http://www.harcourtschool.com/activity/newton/ . This will provide you with a good hands-on introduction to the concept of force in physics.

Defining Force

Force is defined as a push or a pull acting on an object. Examples of forces include friction and gravity. Both are covered in detail later in this chapter. Another example of force is applied force. It occurs when a person or thing applies force to an object, like the girl pushing the swing in **Figure** 6.1. The force of the push causes the swing to move.

Force as a Vector

Force is a vector because it has both size and direction. For example, the girl in **Figure** 6.1 is pushing the swing away from herself. That's the direction of the force. She can give the swing a strong push or a weak push. That's the size, or strength, of the force. Like other vectors, forces can be represented with arrows. **Figure** 6.2 shows some examples. The length of each arrow represents the strength of the force, and the way the arrow points represents the direction of the force. How could you use an arrow to represent the girl's push on the swing in **Figure** 6.1?

FIGURE 6.1
When this girl pushes the swing away from her, it causes the swing to move in that direction.

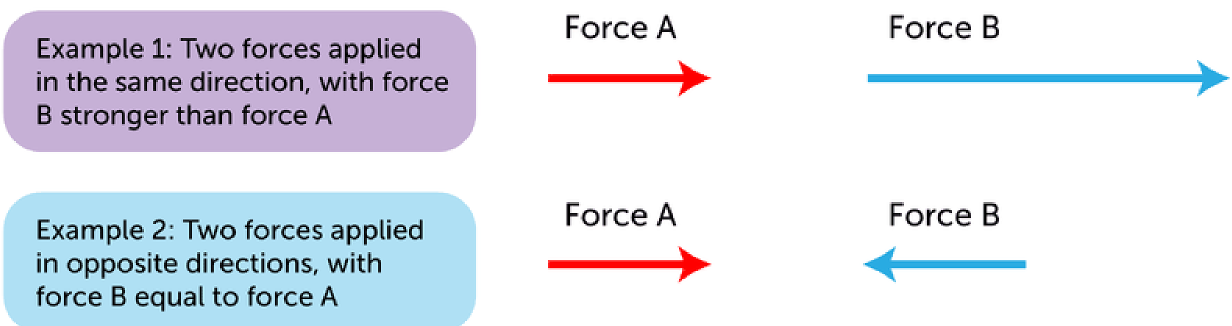


FIGURE 6.2
Forces can vary in both strength and direction.

SI Unit of Force

The SI unit of force is the newton (N). One newton is the amount of force that causes a mass of 1 kilogram to accelerate at 1 m/s^2. Thus, the newton can also be expressed as $kg \cdot m/s^2$. The newton was named for the scientist Sir Isaac Newton, who is famous for his law of gravity. You'll learn more about Sir Isaac Newton later in the chapter.

Combining Forces

More than one force may act on an object at the same time. In fact, just about all objects on Earth have at least two forces acting on them at all times. One force is gravity, which pulls objects down toward the center of Earth. The other force is an upward force that may be provided by the ground or other surface.

Consider the example in **Figure** 6.3. A book is resting on a table. Gravity pulls the book downward with a force of

20 newtons. At the same time, the table pushes the book upward with a force of 20 newtons. The combined forces acting on the book — or any other object — are called the **net force**. This is the overall force acting on an object that takes into account all of the individual forces acting on the object. You can learn more about the concept of net force at this URL: http://www.mansfieldct.org/schools/mms/staff/hand/lawsunbalancedforce.htm .

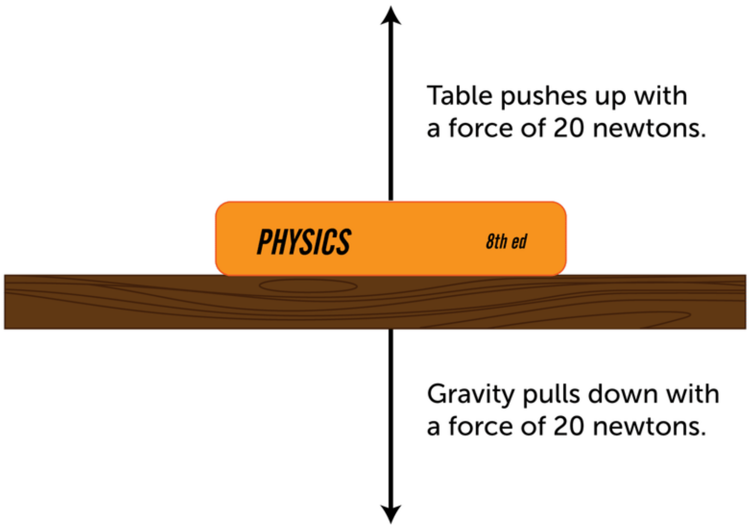


FIGURE 6.3
A book resting on a table is acted on by two opposing forces.

Forces Acting in Opposite Directions

When two forces act on an object in opposite directions, like the book on the table, the net force is equal to the difference between the two forces. In other words, one force is subtracted from the other to calculate the net force. If the opposing forces are equal in strength, the net force is zero. That's what happens with the book on the table. The upward force minus the downward force equals zero (20 N up - 20 N down = 0 N). Because the forces on the book are balanced, the book remains on the table and doesn't move.

In addition to these downward and upward forces, which generally cancel each other out, forces may push or pull an object in other directions. Look at the dogs playing tug-of-war in **Figure** 6.4. One dog is pulling on the rope with a force of 10 newtons to the left. The other dog is pulling on the rope with a force of 12 newtons to the right. These opposing forces are not equal in strength, so they are unbalanced. When opposing forces are unbalanced, the net force is greater than zero. The net force on the rope is 2 newtons to the right, so the rope will move to the right.

Forces Acting in the Same Direction

Two forces may act on an object in the same direction. You can see an example of this in **Figure** 6.5. After the man on the left lifts up the couch, he will push the couch to the right with a force of 25 newtons. At the same time, the man to the right is pulling the couch to the right with a force of 20 newtons. When two forces act in the same direction, the net force is equal to the sum of the forces. This always results in a stronger force than either of the individual forces alone. In this case, the net force on the couch is 45 newtons to the right, so the couch will move to the right.

You Try It!

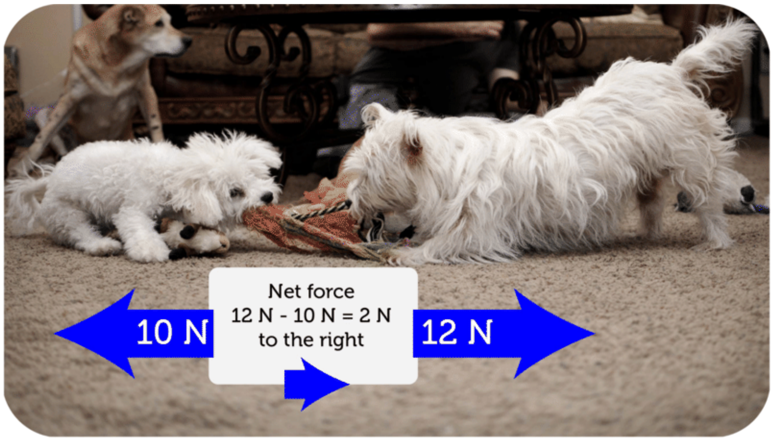


FIGURE 6.4
When unbalanced forces are applied to an object in opposite directions, the smaller force is subtracted from the larger force to yield the net force.

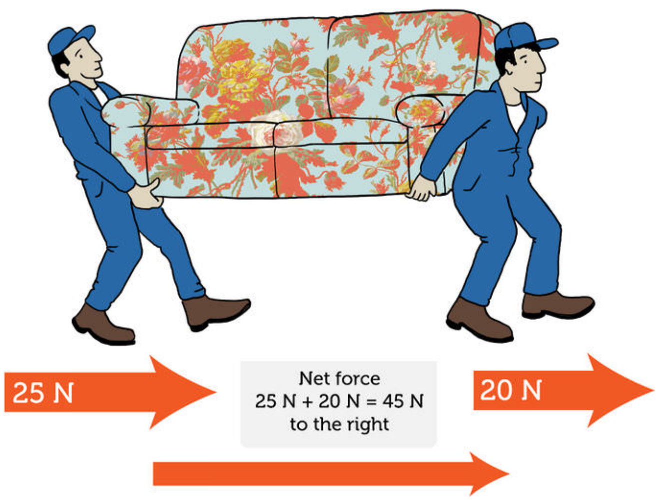
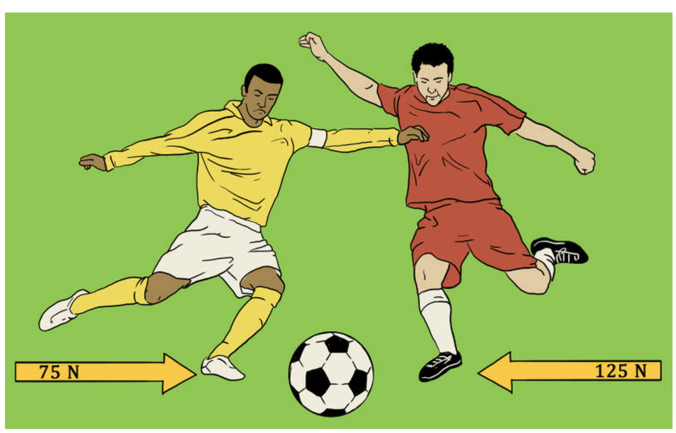


FIGURE 6.5
When two forces are applied to an object in the same direction, the two forces are added to yield the net force.



Problem: The boys in the drawing above are about to kick the soccer ball in opposite directions. What will be the net force on the ball? In which direction will the ball move?

If you need more practice calculating net force, go to this URL: http://www.physicsclassroom.com/class/newtlaws/U2L2d.cfm .

Lesson Summary

- Force is a push or a pull acting on an object. Examples of force include friction and gravity. Force is a vector because it has both size and direction. The SI unit of force is the newton (N).
- The combined forces acting on an object are called the net force. When forces act in opposite directions, they are subtracted to yield the net force. When they act in the same direction, they are added to yield the net force.

Lesson Review Questions

Recall

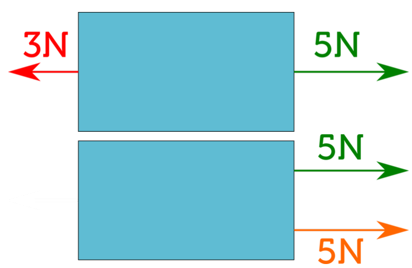
1. Define force. Give an example of a force.
2. What is a newton?
3. What is net force?
4. Describe an example of balanced forces and an example of unbalanced forces.

Apply Concepts

5. What is the net force acting on the block in each diagram below?

a.

b.



Think Critically

6. Explain how forces are related to motion.

Points to Consider

In the next lesson, "Friction," you will read about the force of friction. You experience this force every time you walk. It prevents your feet from slipping out from under you.

- How would you define friction?
- What do you think causes this force?

6.2 Newton's First Law

Lesson Objectives

- State Newton's first law of motion.
- Define inertia, and explain its relationship to mass.

Lesson Vocabulary

- inertia
- Newton's first law of motion

Introduction

The amusement park ride pictured in **Figure** 6.6 keeps changing direction as it zooms back and forth. Each time it abruptly switches direction, the riders are forced to the opposite side of the car. What force causes this to happen? In this lesson, you'll find out.

FIGURE 6.6
Amusement park rides like this one are exciting because of the strong forces the riders feel.

Force and Motion

Newton's first law of motion states that an object's motion will not change unless an unbalanced force acts on the object. If the object is at rest, it will stay at rest. If the object is in motion, it will stay in motion and its velocity will remain the same. In other words, neither the direction nor the speed of the object will change as long as the net force acting on it is zero. You can watch a video about Newton's first law at this URL: http://videos.howstuffworks.com/discovery/29382-assignment-discovery-newtons-first-law-video.htm .

Look at the pool balls in **Figure** 6.7. When a pool player pushes the pool stick against the white ball, the white ball is set into motion. Once the white ball is rolling, it rolls all the way across the table and stops moving only after it crashes into the cluster of colored balls. Then, the force of the collision starts the colored balls moving. Some may roll until they bounce off the raised sides of the table. Some may fall down into the holes at the edges of the table. None of these motions will occur, however, unless that initial push of the pool stick is applied. As long as the net force on the balls is zero, they will remain at rest.

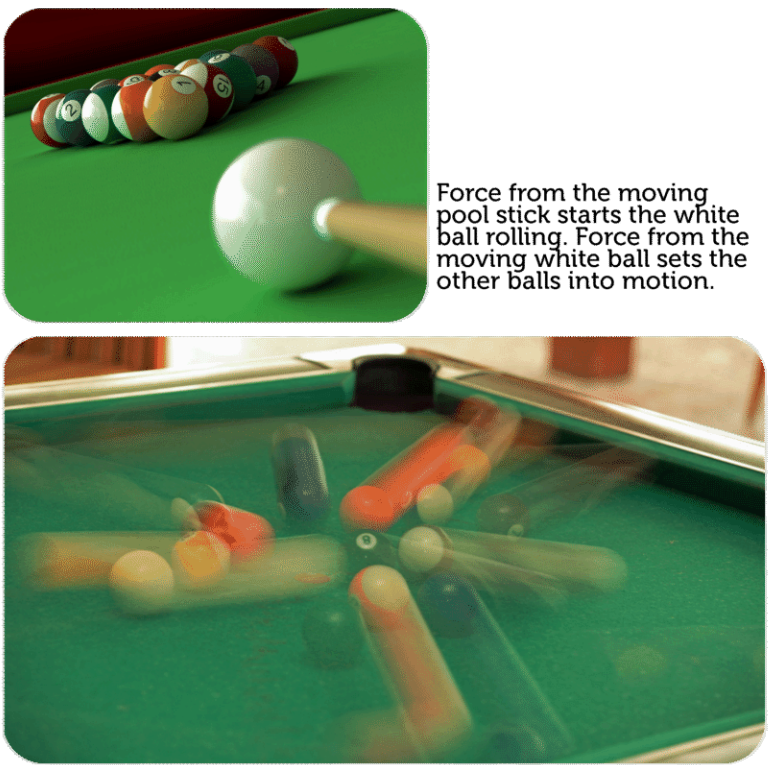


FIGURE 6.7
Pool balls remain at rest until an unbalanced force is applied to them. After they are in motion, they stay in motion until another force opposes their motion.

Inertia

Newton's first law of motion is also called the law of inertia. **Inertia** is the tendency of an object to resist a change in its motion. If an object is already at rest, inertia will keep it at rest. If the object is already moving, inertia will keep it moving.

Think about what happens when you are riding in a car that stops suddenly. Your body moves forward on the seat. Why? The brakes stop the car but not your body, so your body keeps moving forward because of inertia. That's why it's important to always wear a seat belt. Inertia also explains the amusement park ride in **Figure** 6.6. The car keeps changing direction, but the riders keep moving in the same direction as before. They slide to the opposite side of the car as a result. You can see an animation of inertia at this URL: http://www.physicsclassroom.com/mmedia/newtlaws/cci.cfm .

Inertia and Mass

The inertia of an object depends on its mass. Objects with greater mass also have greater inertia. Think how hard it would be to push a big box full of books, like the one in **Figure** 6.8. Then think how easy it would be to push the box if it was empty. The full box is harder to move because it has greater mass and therefore greater inertia.

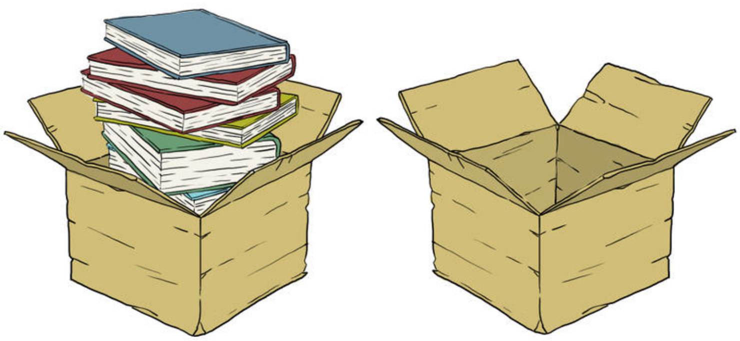


FIGURE 6.8

The tendency of an object to resist a change in its motion depends on its mass. Which box has greater inertia?

Overcoming Inertia

To change the motion of an object, inertia must be overcome by an unbalanced force acting on the object. Until the soccer player kicks the ball in **Figure** 6.9, the ball remains motionless on the ground. However, when the ball is kicked, the force on it is suddenly unbalanced. The ball starts moving across the field because its inertia has been overcome.

FIGURE 6.9

Force must be applied to overcome the inertia of a soccer ball at rest.

Once objects start moving, inertia keeps them moving without any additional force being applied. In fact, they won't stop moving unless another unbalanced force opposes their motion. What if the rolling soccer ball is not kicked by another player or stopped by a fence or other object? Will it just keep rolling forever? It would if another unbalanced force did not oppose its motion. Friction —in this case rolling friction with the ground —will oppose the motion of the rolling soccer ball. As a result, the ball will eventually come to rest. Friction opposes the motion of all moving objects, so, like the soccer ball, all moving objects eventually come to a stop even if no other forces oppose their motion.

Lesson Summary

- Newton's first law of motion states that an object's motion will not change unless an unbalanced force acts on the object. If the object is at rest, it will stay at rest. If the object is in motion, it will stay in motion.
- Inertia is the tendency of an object to resist a change in its motion. The inertia of an object depends on its mass. Objects with greater mass have greater inertia. To overcome inertia, an unbalanced force must be applied to an object.

Lesson Review Questions

Recall

1. State Newton's first law of motion.
2. Define inertia.
3. How does an object's mass affect its inertia?

Apply Concepts

4. Assume you are riding a skateboard and you run into a curb. Your skateboard suddenly stops its forward motion. Apply the concept of inertia to this scenario, and explain what happens next.

Think Critically

5. Why is Newton's first law of motion also called the law of inertia?

Points to Consider

In this lesson, you read that the mass of an object determines its inertia. You also learned that an unbalanced force must be applied to an object to overcome its inertia, whether it is moving or at rest. An unbalanced force causes an object to accelerate.

- Predict how the mass of an object affects its acceleration when an unbalanced force is applied to it.
- How do you think the acceleration of an object is related to the strength of the unbalanced force acting on it?

6.3 Newton's Second Law

Lesson Objectives

- State Newton's second law of motion.
- Identify the relationship between acceleration and weight.

Lesson Vocabulary

- Newton's second law of motion

Introduction

A car's gas pedal, like the one in **Figure** 6.10, is sometimes called the accelerator. That's because it controls the acceleration of the car. Pressing down on the gas pedal gives the car more gas and causes the car to speed up. Letting up on the gas pedal gives the car less gas and causes the car to slow down. Whenever an object speeds up, slows down, or changes direction, it accelerates. Acceleration is a measure of the change in velocity of a moving object. Acceleration occurs whenever an object is acted upon by an unbalanced force.

FIGURE 6.10
The car pedal on the right controls the amount of gas the engine gets. How does this affect the car's acceleration?

Acceleration, Force, and Mass

Newton determined that two factors affect the acceleration of an object: the net force acting on the object and the object's mass. The relationships between these two factors and motion make up **Newton's second law of motion**. This law states that the acceleration of an object equals the net force acting on the object divided by the object's mass. This can be represented by the equation:

$$\text{Acceleration} = \frac{\text{Net force}}{\text{Mass}}, \text{ or}$$
$$a = \frac{F}{m}$$

You can watch a video about how Newton's second law of motion applies to football at this URL: http://science360.gov/obj/video/58e62534-e38d-430b-bfb1-c505e628a2d4 .

Direct and Inverse Relationships

Newton's second law shows that there is a direct relationship between force and acceleration. The greater the force that is applied to an object of a given mass, the more the object will accelerate. For example, doubling the force on the object doubles its acceleration. The relationship between mass and acceleration, on the other hand, is an inverse relationship. The greater the mass of an object, the less it will accelerate when a given force is applied. For example, doubling the mass of an object results in only half as much acceleration for the same amount of force.

Consider the example of a batter, like the boy in **Figure** 6.11. The harder he hits the ball, the greater will be its acceleration. It will travel faster and farther if he hits it with more force. What if the batter hits a baseball and a softball with the same amount of force? The softball will accelerate less than the baseball because the softball has greater mass. As a result, it won't travel as fast or as far as the baseball.

FIGURE 6.11
Hitting a baseball with greater force gives it greater acceleration. Hitting a softball with the same amount of force results in less acceleration. Can you explain why?

Calculating Acceleration

The equation for acceleration given above can be used to calculate the acceleration of an object that is acted on by an unbalanced force. For example, assume you are pushing a large wooden trunk, like the one shown in **Figure** 6.12. The trunk has a mass of 10 kilograms, and you are pushing it with a force of 20 newtons. To calculate the acceleration of the trunk, substitute these values in the equation for acceleration:

$$a = \frac{F}{m} = \frac{20\text{ N}}{10\text{ kg}} = \frac{2\text{ N}}{\text{kg}}$$

Recall that one newton (1 N) is the force needed to cause a 1-kilogram mass to accelerate at 1 m/s^2. Therefore, force can also be expressed in the unit kg·m/s^2. This way of expressing force can be substituted for newtons in the solution to the problem:

$$a = \frac{2\text{ N}}{\text{kg}} = \frac{2\text{ kg}\cdot\text{m/s}^2}{\text{kg}} = 2\text{ m/s}^2$$

Why are there no kilograms in the final answer to this problem? The kilogram units in the numerator and denominator of the fraction cancel out. As a result, the answer is expressed in the correct units for acceleration: m/s^2.

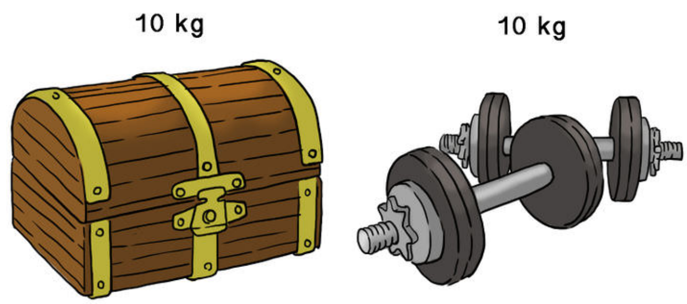


FIGURE 6.12
This empty trunk has a mass of 10 kilograms. The weights also have a mass of 10 kilograms. If the weights are placed in the trunk, what will be its mass? How will this affect its acceleration?

You Try It!

Problem: Assume that you add the weights to the trunk in **Figure** 6.12. If you push the trunk and weights with a force of 20 N, what will be the trunk's acceleration?

Need more practice? You can find additional problems at this URL: http://www.auburnschools.org/ajhs/lmcrowe/Week%2014/WorksheetPracticeProblemsforNewtons2law.pdf .

Acceleration and Weight

Newton's second law of motion explains the weight of objects. Weight is a measure of the force of gravity pulling on an object of a given mass. It's the force (F) in the acceleration equation that was introduced above:

$$a = \frac{F}{m}$$

This equation can also be written as:

$$F = m \times a$$

The acceleration due to gravity of an object equals 9.8 m/s^2, so if you know the mass of an object, you can calculate its weight as:

$$F = m \times 9.8 \text{ m/s}^2$$

As this equation shows, weight is directly related to mass. As an object's mass increases, so does its weight. For example, if mass doubles, weight doubles as well. You can learn more about weight and acceleration at this URL: http://www.nasa.gov/mov/192448main_018_force_equals_mass_time.mov .

Problem Solving

Problem: Daisy has a mass of 35 kilograms. How much does she weigh?

Solution: Use the formula: $F = m \times 9.8 \text{ m/s}^2$.

$F = 35 \text{ kg} \times 9.8 \text{ m/s}^2 = 343.0 \text{ kg} \cdot \text{m/s}^2 = 343.0 \text{ N}$

You Try It!

Problem: Daisy's dad has a mass is 70 kg, which is twice Daisy's mass. Predict how much Daisy's dad weighs. Then calculate his weight to see if your prediction is correct.

Helpful Hints

The equation for calculating weight ($F = m \times a$) works only when the correct units of measurement are used.

- Mass must be in kilograms (kg).
- Acceleration must be in m/s^2.
- Weight (F) is expressed in kg·m/s^2 or in newtons (N).

Lesson Summary

- Newton's second law of motion states that the acceleration of an object equals the net force acting on the object divided by the object's mass.
- Weight is a measure of the force of gravity pulling on an object of a given mass. It equals the mass of the object (in kilograms) times the acceleration due to gravity (9.8 m/s^2).

Lesson Review Questions

Recall

1. State Newton's second law of motion.
2. Describe how the net force acting on an object is related to its acceleration.
3. If the mass of an object increases, how is its acceleration affected, assuming the net force acting on the object remains the same?
4. What is weight?

Apply Concepts

5. Tori applies a force of 20 newtons to move a bookcase with a mass of 40 kg. What is the acceleration of the bookcase?

6. Ollie has a mass of 45 kilograms. What is his weight in newtons?

Think Critically

7. If you know your weight in newtons, how could you calculate your mass in kilograms? What formula would you use?

Points to Consider

Assume that a 5-kilogram skateboard and a 50-kilogram go-cart start rolling down a hill. Both are moving at the same speed. You and a friend want to stop before they plunge into a pond at the bottom of the hill.

- Which will be harder to stop: the skateboard or the go-cart?
- Can you explain why?

6.4 Newton's Third Law

Lesson Objectives

- State Newton's third law of motion.
- Describe momentum and the conservation of momentum.

Lesson Vocabulary

- law of conservation of momentum
- momentum
- Newton's third law of motion

Introduction

Look at the skateboarders in **Figure** 6.13. When they push against each other, it causes them to move apart. The harder they push together, the farther apart they move. This is an example of Newton's third law of motion.

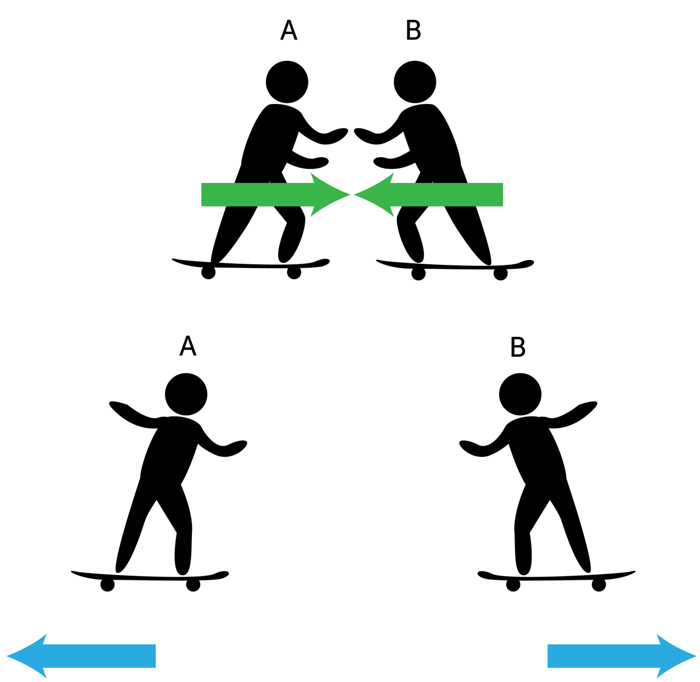


FIGURE 6.13
A and B move apart by first pushing together.

Action and Reaction

Newton's third law of motion states that every action has an equal and opposite reaction. This means that forces always act in pairs. First an action occurs, such as the skateboarders pushing together. Then a reaction occurs that is equal in strength to the action but in the opposite direction. In the case of the skateboarders, they move apart, and the distance they move depends on how hard they first pushed together. You can see other examples of actions and reactions in **Figure** 6.14. You can watch a video about actions and reactions at this URL: http://www.nasa.gov/mov/192449main_019_law_of_action.mov .

FIGURE 6.14
Each example shown here includes an action and reaction.

You might think that actions and reactions would cancel each other out like balanced forces do. Balanced forces, which are also equal and opposite, cancel each other out because they act on the same object. Action and reaction forces, in contrast, act on different objects, so they don't cancel each other out and, in fact, often result in motion. For example, in **Figure** 6.14, the kangaroo's action acts on the ground, but the ground's reaction acts on the kangaroo. As a result, the kangaroo jumps away from the ground. One of the action-reaction examples in the **Figure** 6.14 does not result in motion. Do you know which one it is?

Momentum

What if a friend asked you to play catch with a bowling ball, like the one pictured in **Figure** 6.15? Hopefully, you would refuse to play! A bowling ball would be too heavy to catch without risk of injury —assuming you could even throw it. That's because a bowling ball has a lot of mass. This gives it a great deal of momentum. **Momentum** is a property of a moving object that makes the object hard to stop. It equals the object's mass times its velocity. It can be represented by the equation:

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

This equation shows that momentum is directly related to both mass and velocity. An object has greater momentum if it has greater mass, greater velocity, or both. For example, a bowling ball has greater momentum than a softball when both are moving at the same velocity because the bowling ball has greater mass. However, a softball moving at a very high velocity —say, 100 miles an hour —would have greater momentum than a slow-rolling bowling ball. If an object isn't moving at all, it has no momentum. That's because its velocity is zero, and zero times anything is zero.

FIGURE 6.15

A bowling ball and a softball differ in mass. How does this affect their momentum?

Calculating Momentum

Momentum can be calculated by multiplying an object's mass in kilograms (kg) by its velocity in meters per second (m/s). For example, assume that a golf ball has a mass of 0.05 kg. If the ball is traveling at a velocity of 50 m/s, its momentum is:

$$\text{Momentum} = 0.05 \text{ kg} \times 50 \text{ m/s} = 2.5 \text{ kg} \cdot \text{m/s}$$

Note that the SI unit for momentum is kg·m/s.

Problem Solving

Problem: What is the momentum of a 40-kg child who is running straight ahead with a velocity of 2 m/s?

Solution: The child has momentum of: 40 kg × 2 m/s = 80 kg·m/s.

You Try It!

Problem: Which football player has greater momentum?

Player A: mass = 60 kg; velocity = 2.5 m/s

Player B: mass = 65 kg; velocity = 2.0 m/s

Conservation of Momentum

When an action and reaction occur, momentum is transferred from one object to the other. However, the combined momentum of the objects remains the same. In other words, momentum is conserved. This is the **law of conservation of momentum**.

Consider the example of a truck colliding with a car, which is illustrated in **Figure** 6.16. Both vehicles are moving in the same direction before and after the collision, but the truck is moving faster than the car before the collision occurs. During the collision, the truck transfers some of its momentum to the car. After the collision, the truck is moving slower and the car is moving faster than before the collision occurred. Nonetheless, their combined momentum is the same both before and after the collision. You can see an animation showing how momentum is conserved in a head-on collision at this URL: http://www.physicsclassroom.com/mmedia/momentum/cthoi.cfm .

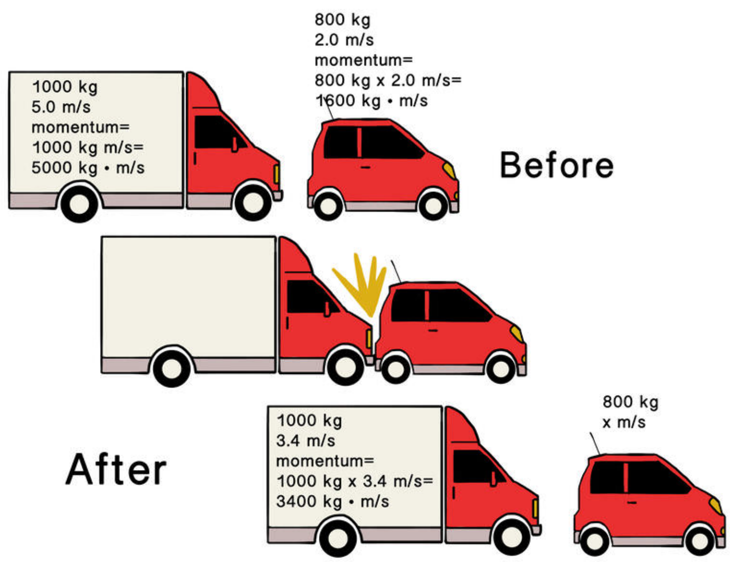


FIGURE 6.16
How can you tell momentum has been conserved in this collision?

KQED: Newton's Laws of Motion

Paul Doherty of the Exploratorium performs a "sit-down" lecture on one of Sir Issac Newton's most famous laws. For more information on Newton's laws of motion, see http://science.kqed.org/quest/video/quest-lab-newtons-laws-of-motion/ .

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/129626

KQED: Out of the Park - The Physics of Baseball

At UC Berkeley, a team of undergrads is experimenting with velocity, force, and aerodynamics. But you won't find them in a lab – they work on a baseball diamond, throwing fast balls, sliders and curve balls. QUEST discovers how the principles of physics can make the difference between a strike and a home run. For more information on the physics of baseball, see http://science.kqed.org/quest/video/out-of-the-park-the-physics-of-baseball/ .

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/129624

Lesson Summary

- Newton's third law of motion states that every action has an equal and opposite reaction.
- Momentum is a property of a moving object that makes it hard to stop. It equals the object's mass times its velocity. When an action and reaction occur, momentum may be transferred from one object to another, but their combined momentum remains the same. This is the law of conservation of momentum.

Lesson Review Questions

Recall

1. State Newton's third law of motion.
2. Define momentum.
3. If you double the velocity of a moving object, how is its momentum affected?

Apply Concepts

4. A large rock has a mass of 50 kg and is rolling downhill at 3 m/s. What is its momentum?
5. Create a diagram to illustrate the transfer and conservation of momentum when a moving object collides with a stationary object.

Think Critically

6. The reaction to an action is an equal and opposite force. Why doesn't this yield a net force of zero?
7. Momentum is a property of an object, but it is different than a physical or chemical property, such as boiling point or flammability. How is momentum different?

Points to Consider

In this chapter, you learned about forces and motions of solid objects, such as balls and cars. In the next chapter, "Fluid Forces," you will learn about forces in fluids, which include liquids and gases.

- How do fluids differ from solids?
- What might be examples of forces in fluids? For example, what force allows some objects to float in water?

6.5 References

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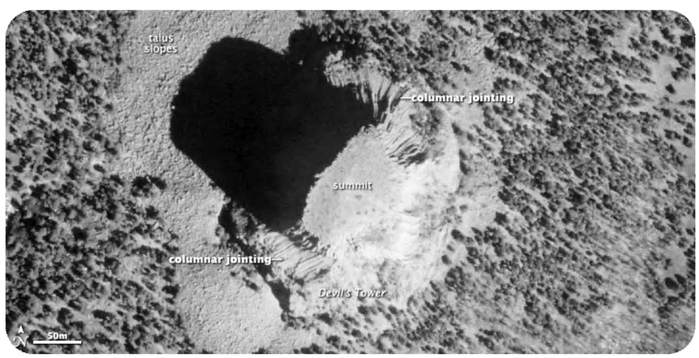
CONCEPT 7

Unit 4: Gravitation and Orbiting Objects

Questions/Observable Phenomena

CHAPTER 8 Gravitation and Orbiting Objects

Chapter Outline



How do planetary geologists learn about the geology of other planets? Since much of the available information is from spacecraft flying high above the planet, these scientists compare images taken of the planet with images taken on Earth. Look at the images above and see if you can find the similarities and differences. Which is from Earth and which from another planet?

It's easy to figure out that the top image is Earth since there are plants. It is Devil's Tower in Wyoming and the bottom image is Marte Vallis on Mars. The features that are common to the images are columnar basalts showing columnar jointing and talus slopes. Columnar basalts form from basalt lavas that flow in a thick layer along a cool surface. The vertical joints speed cooling. Weathering causes the columns to break and form talus slopes.

On Mars the columnar basalts are exposed on the rim of a 160 km diameter crater. Evidence of the lava flows covers more than 200 square km (77 square miles), similar to terrestrial flood basalts. A meteorite impact appears to have created a crater to expose the columnar basalts.

Devil's Tower is a magma that cooled below the surface in sedimentary rock layers and formed columnar joints. The sedimentary rocks have since been eroded, exposing the tower. At the base are slopes of broken columns creating talus slopes.

Mars image courtesy High Resolution Imaging Science Experiment, Arizona State University. Devil's Tower image courtesy Wyoming Geographic Information Adviso

8.1 Circular Motion

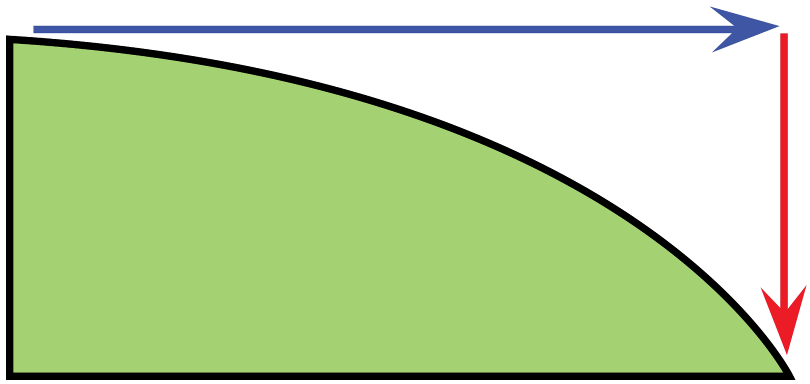
Learning Objectives

- Define centripetal acceleration.
- Understand the theory of the centripetal acceleration equation.
- Use the centripetal acceleration equation.
- Understand the angular relationship between velocity and centripetal acceleration.
- Use the equations for motion in two directions and Newton's Laws to analyze circular motion.

Weather satellites, like the one shown above, are found miles above the earth's surface. Satellites can be polar orbiting, meaning they cover the entire Earth asynchronously, or geostationary, in which they hover over the same spot on the equator.

Circular Motion

The earth is a sphere. If you draw a horizontal straight line from a point on the surface of the earth, the surface of the earth drops away from the line. The distance that the earth drops away from the horizontal line is very small - so small, in fact, that we cannot represent it well in a drawing. In the sketch below, if the blue line is 1600 m, the amount of drop (the red line) would be 0.20 m. If the sketch were drawn to scale, the red line would be too short to see.



When an object is launched exactly horizontally in projectile motion, it travels some distance horizontally before it strikes the ground. In the present discussion, we wish to imagine a projectile fired horizontally on the surface of the earth such that while traveling 1600 m horizontally, the object would fall exactly 0.20 m. If this could occur, then the object would fall exactly the amount necessary during its horizontal motion to remain at the surface of the earth, but not touching it. In such a case, the object would travel all the way around the earth continuously and circle the earth, assuming there were no obstacles, such as mountains.

What initial horizontal velocity would be necessary for this to occur? We first calculate the time to fall the 0.20 m:

$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{(2)(0.20 \text{ m})}{9.80 \text{ m/s}^2}} = 0.20 \text{ s}$

The horizontal velocity necessary to travel 1600 m in 0.20 s is 8000 m/s. Thus, the necessary initial horizontal velocity is 8000 m/s.

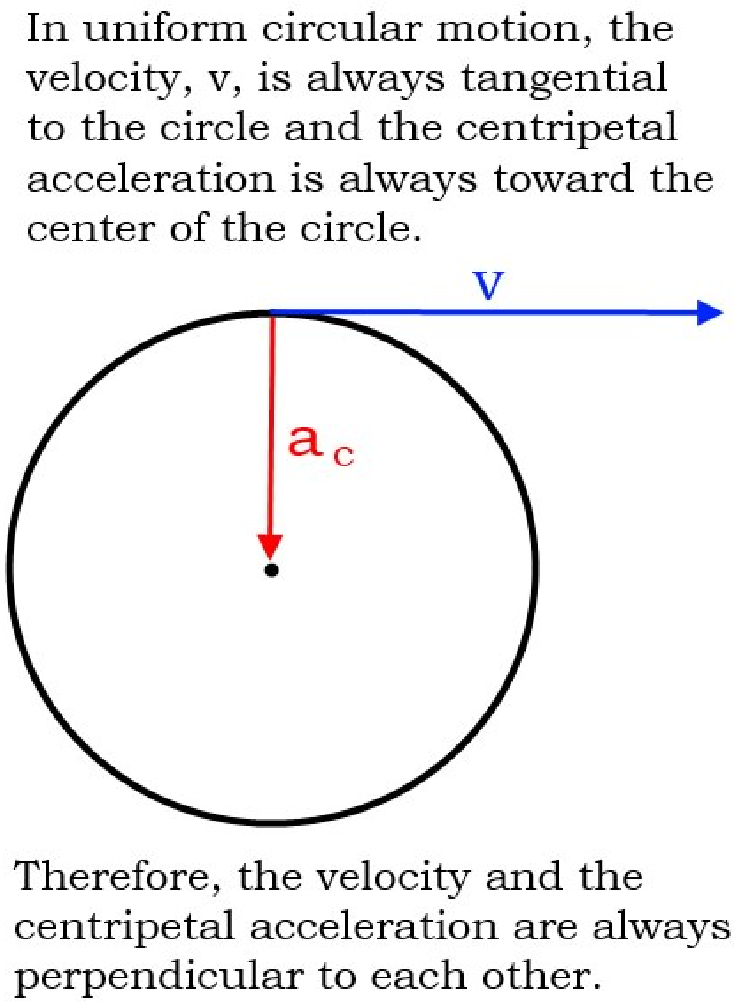
In order to keep an object traveling in a circular path, there must be an acceleration toward the center of the circle. This acceleration is called **centripetal acceleration.** In the case of satellites orbiting the earth, the centripetal acceleration is caused by gravity. If you were swinging an object around your head on a string, the centripetal acceleration would be caused by your hand pulling on the string toward the center of the circle.

It is important to note that the object traveling in a circle has a constant speed but does not have a constant velocity. This is because direction is part of velocity; when an object changes its direction, it is changing its velocity. Hence the object's acceleration. The acceleration in the case of uniform **circular motion** is the change in the direction of the velocity, but not its magnitude.

For an object traveling in a circular path, the centripetal acceleration is directly related to the square of the velocity of the object and inversely related to the radius of the circle.

$$a_c = \frac{v^2}{r}$$

Taking a moment to consider the validity of this equation can help to clarify what it means. Imagine a yo-yo. Instead of using it normally, let it fall to the end of the string, and then spin it around above your head. If we were to increase the speed at which we rotate our hand, we increase the velocity of the yo-yo - it is spinning faster. As it spins faster, it also changes direction faster. The acceleration increases. Now let's think about the bottom of the equation: the radius. If we halve the length of the yo-yo string (bring the yo-yo closer to us), we make the yo-yo's velocity greater. Again, it moves faster, which increases the acceleration. If we make the string longer again, this decreases the acceleration. We now understand why the relationship between the radius and the acceleration is an inverse relationship - as we decrease the radius, the acceleration increases, and visa versa.



Examples

Example 1

A ball at the end of a string is swinging in a horizontal circle of radius 1.15 m. The ball makes exactly 2.00 revolutions per second. What is its centripetal acceleration?

We first determine the velocity of the ball using the facts that the circumference of the circle is $2\pi r$ and the ball goes around exactly twice per second.

$v = \frac{(2)(2\pi r)}{t} = \frac{(2)(2)(3.14)(1.15 \text{ m})}{1.00 \text{ s}} = 14.4 \text{ m/s}$

We then use the velocity and radius in the centripetal acceleration equation.

$a_c = \frac{v^2}{r} = \frac{(14.4 \text{ m/s})^2}{1.15 \text{ m}} = 180. \text{ m/s}^2$

Example 2

The moon's nearly circular orbit around the earth has a radius of about 385,000 km and a period of 27.3 days. Calculate the acceleration of the moon toward the earth.

$v = \frac{2\pi r}{T} = \frac{(2)(3.14)(3.85 \times 10^8 \textbf{ m})}{(27.3 \textbf{ d})(24.0 \textbf{ h/d})(3600 \textbf{ s/h})} = 1020 \textbf{ m/s}$

$a_c = \frac{v^2}{r} = \frac{(1020\ \mathbf{m/s})^2}{3.85 \times 10^8\ \mathbf{m}} = 0.00273\ \mathbf{m/s}^2$

As shown in the previous example, the velocity of an object traveling in a circle can be calculated by

$$v = \frac{2\pi r}{T}$$

Where r is the radius of the circle and T is the period (time required for one revolution).

This equation can be incorporated into the equation for centripetal acceleration as shown below.

$a_c = \frac{v^2}{r} = \frac{\left(\frac{2\pi r}{T}\right)^2}{r} = \frac{4\pi^2 r}{T^2}$

Summary

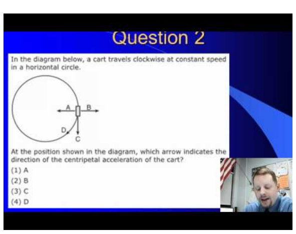
- In order to keep an object traveling in a circular path, there must be an acceleration toward the center of the circle. This acceleration is called centripetal acceleration.
- The acceleration in the case of uniform circular motion changes the direction of the velocity but not its magnitude.
- Formulas for centripetal acceleration are $a_c = \frac{v^2}{r}$ and $a_c = \frac{4\pi^2 r}{T^2}$.

Review

1. An automobile rounds a curve of radius 50.0 m on a flat road at a speed of 14 m/s. What centripetal acceleration is necessary to keep the car on the curve?
2. An object is swung in a horizontal circle on a length of string that is 0.93 m long. If the object goes around once in 1.18 s, what is the centripetal acceleration?

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

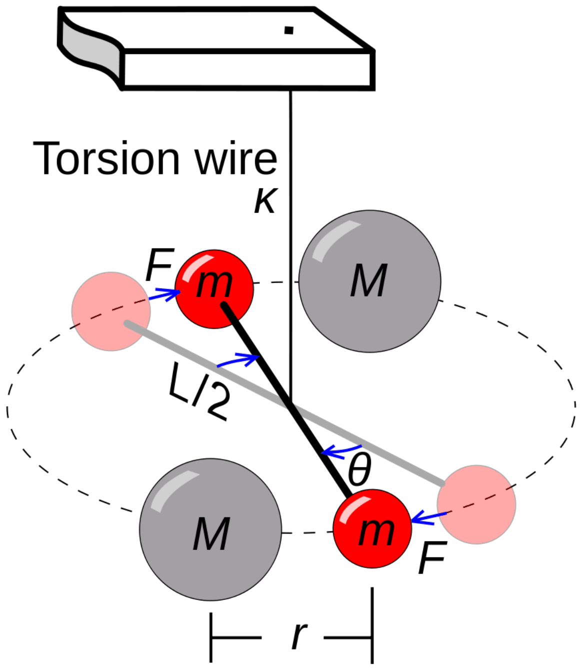
URL: http://www.ck12.org/flx/render/embeddedobject/60134

1. What does centripetal mean?
2. What is uniform circular motion?
3. Why is centripetal acceleration always towards the center?

Vocabulary

- **circular motion:** A movement of an object along the circumference of a circle or rotation along a circular path.
- **centripetal acceleration:** The acceleration toward the center that keeps an object following a circular path.

8.2 Universal Law of Gravity



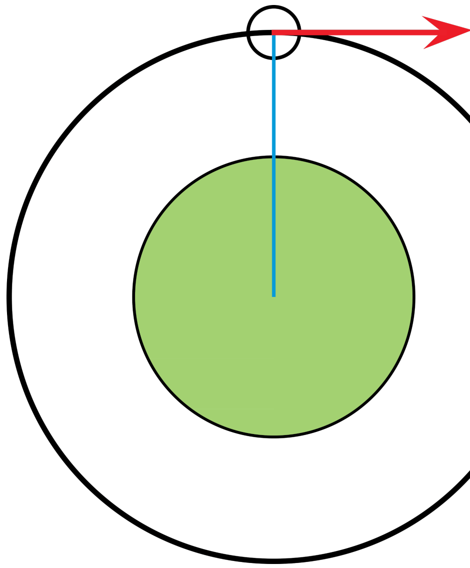
In 1798, Henry Cavendish designed and created an apparatus and experiment to determine the density of the planet and the value of the gravitational constant, G. His apparatus involved a light, rigid rod about 2-feet long with two small lead spheres attached to the ends. The rod was suspended by a thin wire. When the rod rotated, the twisting of the wire pushed *backwards* to restore the rod to the original position.

Force of Gravity

In the mid-1600's, Newton wrote that the sight of a falling apple made him think of the problem of the motion of the planets. He recognized that the apple fell straight down because the earth attracted it and thought this same force of attraction might apply to the moon. It further occured to him that motion of the planets might be controlled by the **gravity** of the sun. He eventually proposed the universal law of gravitational attraction as

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

where m_1 and m_2 are the masses being attracted, d is the distance between the centers of the masses, G is the universal gravitational constant, and F is the force of attraction. The formula for gravitational attraction applies equally to two rocks resting near each other on the earth and to the planets and the sun. The value for the universal gravitational constant, G, was determined by Henry Cavendish (using the apparatus described in the introduction) to be 6.67×10^{-11} N·m^2/kg^2.



The moon is being pulled toward the earth and the earth toward the moon with the same force but in the opposite direction. The force of attraction between the two bodies produces a greater acceleration of the moon than the earth because the moon has smaller mass. Even though the moon is constantly falling toward the earth, it never gets any closer. This is because the velocity of the moon is perpendicular to the radius of the earth (as shown in the image above) and therefore the moon is moving away from the earth. The distance the moon moves away from the orbit line is exactly the same distance that the moon falls in the time period. This is true of all satellites and is the reason objects remain in orbit. In the case of orbiting bodies, the centripetal force is the gravitational force, and they undergo imperfect circular motion.

Examples

Example 1

Since we know the force of gravity on a 1.00 kg ball resting on the surface of the earth is 9.80 N, and we know the radius of the earth is 6380 km, we can use the equation for gravitational force to calculate the mass of the earth.

$$m_e = \frac{Fd^2}{Gm_1} = \frac{(9.80\ \mathbf{m/s^2})(6.38\times10^6\ \mathbf{m})^2}{(6.67\times10^{-11}\ \mathbf{N{\cdot}m^2/kg^2})(1.00\ \mathbf{kg})} = 5.98\times10^{24}\ \mathbf{kg}$$

Example 2

John and Jane step onto the dance floor about 20. m apart at the Junior Prom and they feel an attraction to each other. If John's mass is 70. kg and Jane's mass is 50. kg, assume the attraction is gravity and calculate its magnitude.

$$F_g = \frac{Gm_1m_2}{d^2} = \frac{(6.67\times10^{-11}\ \mathbf{N{\cdot}m^2/kg^2})(70.\ \mathbf{kg})(50.\ \mathbf{kg})}{(20.\ \mathbf{m})^2} = 1.2\times10^{-8}\ \mathbf{N}$$

This is an extremely weak force; it is probably not the force of attraction they truly felt.

Summary

- Newton proposed the universal law of gravitational attraction as $F = G\frac{m_1m_2}{d^2}$.
- The universal gravitational constant, G, was determined by Cavendish to be 6.67×10^{-11} N·m^2/kg^2.

Review

1. The earth is attracted to the sun by the force of gravity. Why doesn't the earth fall into the sun?
2. If the mass of the earth remained the same but the radius of the earth shrank to one-half its present distance, what would happen to the force of gravity on an object that was resting on the surface of the earth?
3. Lifting an object on the moon requires one-sixth the force that would be required to lift the same object on the earth because gravity on the moon is one-sixth that on earth. What about horizontal acceleration? If you threw a rock with enough force to accelerate it at 1.0 m/s^2 horizontally on the moon, how would the required force compare to the force necessary to accelerate the rock in the same way on the earth?
4. The mass of the earth is 5.98×10^{24} kg and the mass of the moon is 7.35×10^{22} kg. If the distance between the earth and the moon is 384,000 km, what is the gravitational force on the moon?

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/112421

1. What is gravity?
2. What caused the sun to form?
3. What is the relationship between the strength of a gravitational force and distance?
4. What is the relationship between the strength of a gravitational force and mass?

Resources

Does gravity effect everything at the same rate? The experiment in this MIT video helps to answer that question.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/145268

8.3 Gravity

Lesson Objectives

- Define gravity.
- State Newton's law of universal gravitation.
- Explain how gravity affects the motion of objects.

Lesson Vocabulary

- gravity
- law of universal gravitation
- orbit
- projectile motion

Introduction

Long, long ago, when the universe was still young, an incredible force caused dust and gas particles to pull together to form the objects in our solar system (see **Figure** 8.1). From the smallest moon to our enormous sun, this force created not only our solar system, but all the solar systems in all the galaxies of the universe. The force is gravity.

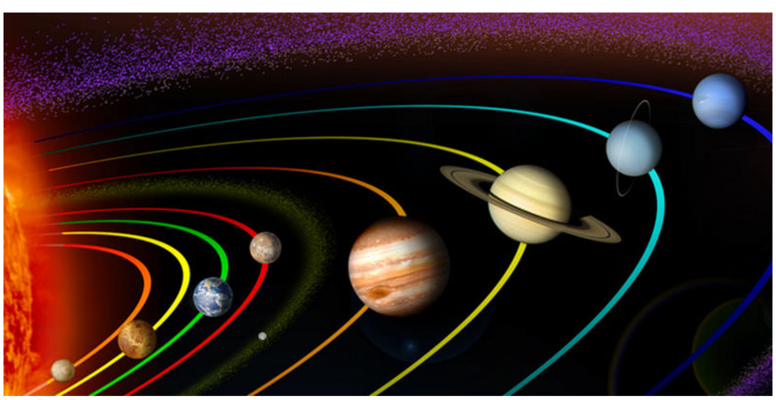


FIGURE 8.1
Gravity helped to form our solar system and all the other solar systems in the universe.

Defining Gravity

Gravity has traditionally been defined as a force of attraction between two masses. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. The effect of gravity is that objects exert a pull on other objects. Unlike friction, which acts only between objects that are touching, gravity also acts between objects that are not touching. In fact, gravity can act over very long distances.

Earth's Gravity

You are already very familiar with Earth's gravity. It constantly pulls you toward the center of the planet. It prevents you and everything else on Earth from being flung out into space as the planet spins on its axis. It also pulls objects above the surface, from meteors to skydivers, down to the ground. Gravity between Earth and the moon and between Earth and artificial satellites keeps all these objects circling around Earth. Gravity also keeps Earth moving around the sun.

Gravity and Weight

Weight measures the force of gravity pulling on an object. Because weight measures force, the SI unit for weight is the **newton (N)**. On Earth, a mass of 1 kilogram has a weight of about 10 newtons because of the pull of Earth's gravity On the moon, which has less gravity, the same mass would weigh less. Weight is measured with a scale, like the spring scale in **Figure** 8.2. The scale measures the force with which gravity pulls an object downward.

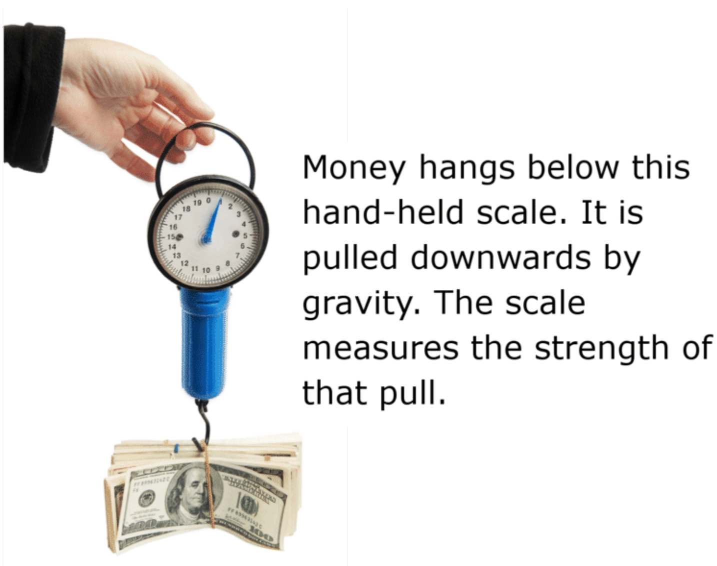


FIGURE 8.2
A scale measures the pull of gravity on an object.

Law of Gravity

People have known about gravity for thousands of years. After all, they constantly experienced gravity in their daily lives. They knew that things always fall toward the ground. However, it wasn't until Sir Isaac Newton developed his law of gravity in the late 1600s that people really began to understand gravity. Newton is pictured in **Figure** 8.3.

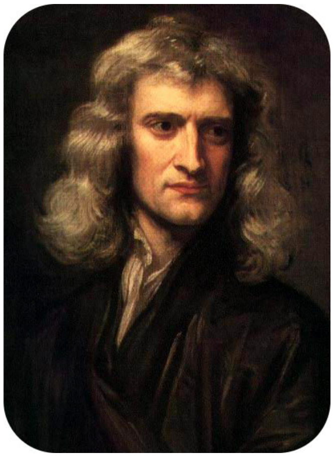


FIGURE 8.3
Sir Isaac Newton discovered that gravity is universal.

Newton's Law of Universal Gravitation

Newton was the first one to suggest that gravity is universal and affects all objects in the universe. That's why his law of gravity is called the **law of universal gravitation**. Universal gravitation means that the force that causes an apple to fall from a tree to the ground is the same force that causes the moon to keep moving around Earth. Universal gravitation also means that while Earth exerts a pull on you, you exert a pull on Earth. In fact, there is gravity between you and every mass around you — your desk, your book, your pen. Even tiny molecules of gas are attracted to one another by the force of gravity.

Newton's law had a huge impact on how people thought about the universe. It explains the motion of objects not only on Earth but in outer space as well. You can learn more about Newton's law of gravity in the video at this URL: http://www.youtube.com/watch?v=O-p8yZYxNGc .

Factors That Influence the Strength of Gravity

Newton's law also states that the strength of gravity between any two objects depends on two factors: the masses of the objects and the distance between them.

- Objects with greater mass have a stronger force of gravity. For example, because Earth is so massive, it attracts you and your desk more strongly than you and your desk attract each other. That's why you and the desk remain in place on the floor rather than moving toward one another.
- Objects that are closer together have a stronger force of gravity. For example, the moon is closer to Earth than it is to the more massive sun, so the force of gravity is greater between the moon and Earth than between the moon and the sun. That's why the moon circles around Earth rather than the sun. This is illustrated in **Figure** 8.4.

You can apply these relationships among mass, distance, and gravity by designing your own roller coaster at this URL: http://www.learner.org/interactives/parkphysics/coaster/ .

Einstein's Theory of Gravity

Newton's idea of gravity can predict the motion of most but not all objects. In the early 1900s, Albert Einstein came up with a theory of gravity that is better at predicting how all objects move. Einstein showed mathematically that gravity is not really a force in the sense that Newton thought. Instead, gravity is a result of the warping, or curving,

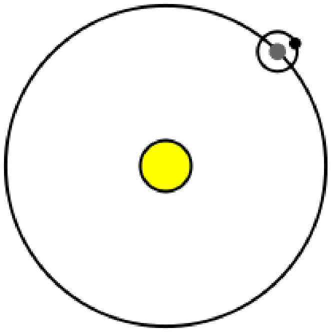


FIGURE 8.4
The moon keeps moving around Earth rather than the sun because it is much closer to Earth.

of space and time. Imagine a bowling ball pressing down on a trampoline. The surface of the trampoline would curve downward instead of being flat. Einstein theorized that Earth and other very massive bodies affect space and time around them in a similar way. This idea is represented in **Figure** 8.5. According to Einstein, objects curve toward one another because of the curves in space and time, not because they are pulling on each other with a force of attraction as Newton thought. You can see an animation of Einstein's theory of gravity at this URL: http://einstein.stanford.edu/Media/Einsteins_Universe_Anima-Flash.html . To learn about recent research that supports Einstein's theory of gravity, go to this URL: http://www.universetoday.com/85401/gravity-probe-b-confirms-two-of-einsteins-space-time-theories/ .

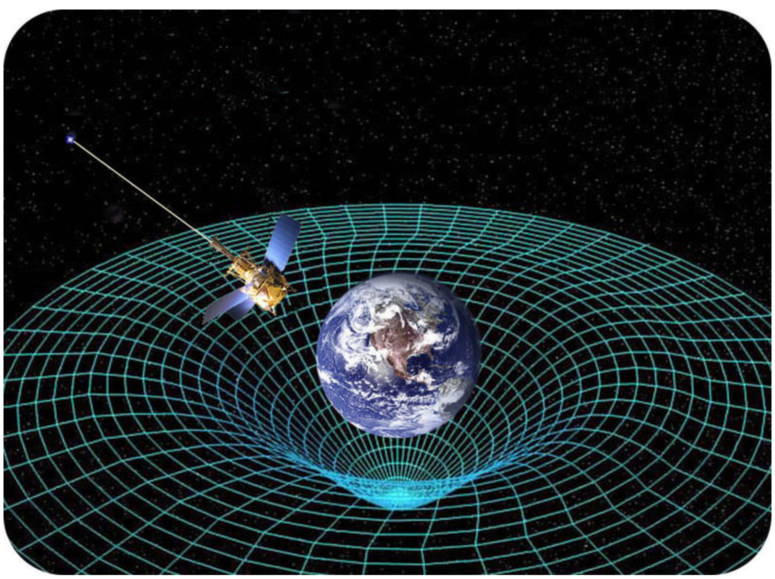


FIGURE 8.5
Einstein thought that gravity is the effect of curves in space and time around massive objects such as Earth. He proposed that the curves in space and time cause nearby objects to follow a curved path. How does this differ from Newton's idea of gravity?

Gravity and Motion

Regardless of what gravity is — a force between masses or the result of curves in space and time — the effects of gravity on motion are well known. You already know that gravity causes objects to fall down to the ground. Gravity affects the motion of objects in other ways as well.

Acceleration Due to Gravity

When gravity pulls objects toward the ground, it causes them to accelerate. Acceleration due to gravity equals 9.8 m/s^2. In other words, the velocity at which an object falls toward Earth increases each second by 9.8 m/s. Therefore, after 1 second, an object is falling at a velocity of 9.8 m/s. After 2 seconds, it is falling at a velocity of 19.6 m/s (9.8 m/s × 2), and so on. This is illustrated in **Figure** 8.6. You can compare the acceleration due to gravity on Earth, the moon, and Mars with the interactive animation called "Freefall" at this URL: http://jersey.uoregon.edu/vlab/ .

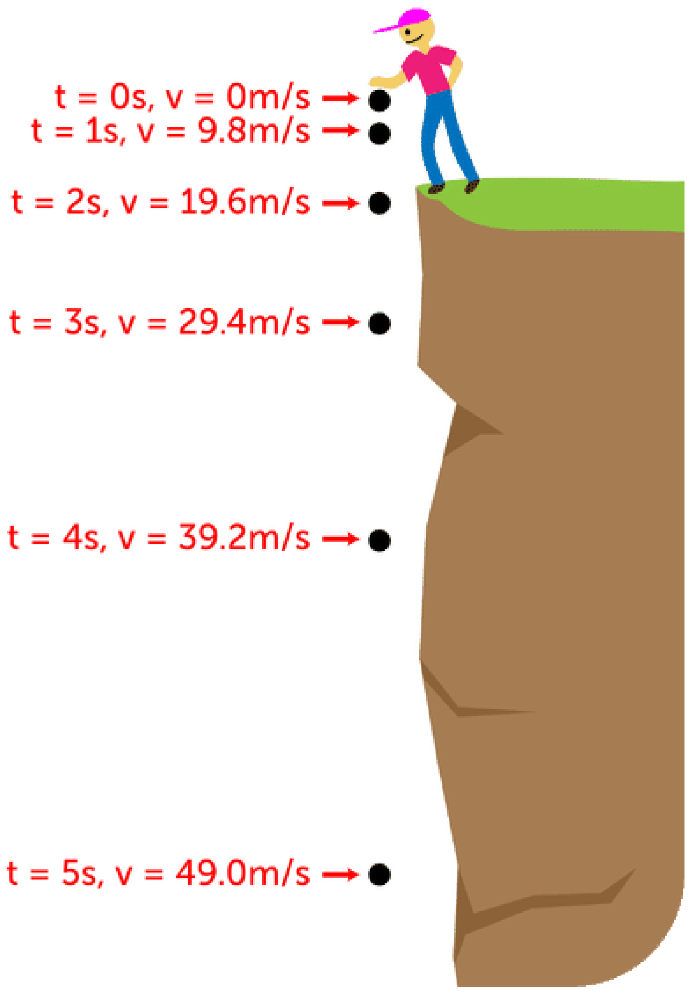


FIGURE 8.6

A boy drops an object at time t = 0 s. At time t = 1 s, the object is falling at a velocity of 9.8 m/s. What is its velocity by time t = 5 ?

You might think that an object with greater mass would accelerate faster than an object with less mass. After all, its greater mass means that it is pulled by a stronger force of gravity. However, a more massive object accelerates at the same rate as a less massive object. The reason? The more massive object is harder to move because of its greater mass. As a result, it ends up moving at the same acceleration as the less massive object.

Consider a bowling ball and a basketball. The bowling ball has greater mass than the basketball. However, if you were to drop both balls at the same time from the same distance above the ground, they would reach the ground together. This is true of all falling objects, unless air resistance affects one object more than another. For example, a falling leaf is slowed down by air resistance more than a falling acorn because of the leaf's greater surface area. However, if the leaf and acorn were to fall in the absence of air (that is, in a vacuum), they would reach the ground at the same time.

Projectile Motion

Earth's gravity also affects the acceleration of objects that start out moving horizontally, or parallel to the ground. Look at **Figure** below. A cannon shoots a cannon ball straight ahead, giving the ball horizontal motion. At the same time, gravity pulls the ball down toward the ground. Both forces acting together cause the ball to move in a curved path. This is called **projectile motion**.

Projectile motion also applies to other moving objects, such as arrows shot from a bow. To hit the bull's eye of a target with an arrow, you actually have to aim for a spot above the bull's eye. That's because by the time the arrow reaches the target, it has started to curve downward toward the ground. **Figure** 8.7 shows what happens if you aim at the bull's eye instead of above it. You can access interactive animations of projectile motion at these URLs:

- http://phet.colorado.edu/en/simulation/projectile-motion
- http://jersey.uoregon.edu/vlab/ *(Select the applet entitled "Cannon.")*

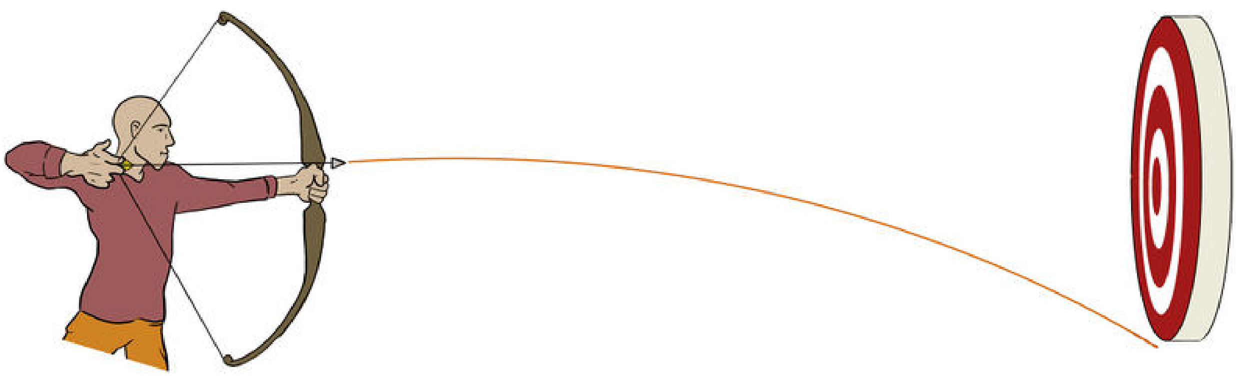


FIGURE 8.7
Aiming at the center of a target is likely to result in a hit below the bull's eye.

Orbital Motion

The moon moves around Earth in a circular path called an **orbit**. Why doesn't Earth's gravity pull the moon down to the ground instead? The moon has enough forward velocity to partly counter the force of Earth's gravity. It constantly falls toward Earth, but it stays far enough away from Earth so that it actually falls around the planet. As a result, the moon keeps orbiting Earth and never crashes into it. The diagram in **Figure** 8.8 shows how this happens. You can explore gravity and orbital motion in depth with the animation at this URL: http://phet.colorado.edu/en/simulation/gravity-and-orbits .

You can see an animated version of this diagram at: http://en.wikipedia.org/wiki/File:Orbital_motion.gif .

Lesson Summary

- Gravity is traditionally defined as a force of attraction between two masses. Weight measures the force of gravity and is expressed in newtons (N).

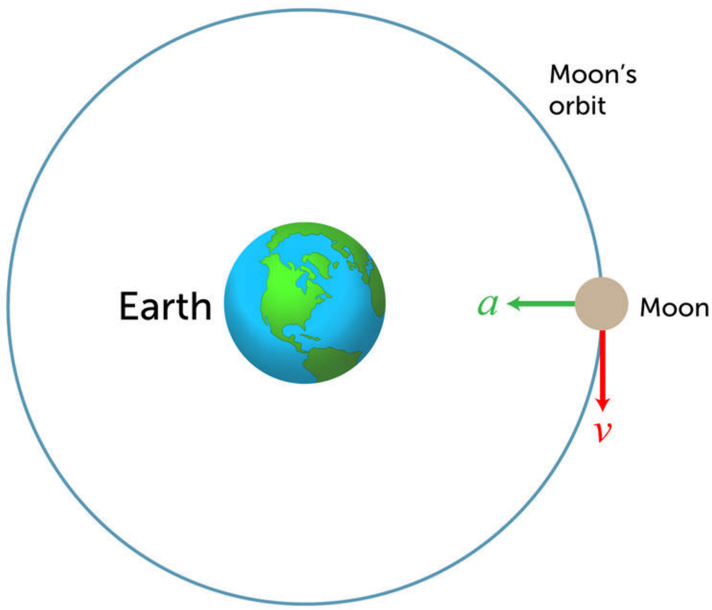


FIGURE 8.8
In this diagram, "v" represents the forward velocity of the moon, and "a" represents the acceleration due to gravity. The line encircling Earth shows the moon's actual orbit, which results from the combination of "v" and "a."

- According to Newton's law of universal gravitation, gravity is a force of attraction between all objects in the universe, and the strength of gravity depends on the masses of the objects and the distance between them. Einstein's theory of gravity states that gravity is an effect of curves in space and time around massive objects such as Earth.
- Gravity causes falling objects to accelerate at 9.8 m/s^2. Gravity also causes projectile motion and orbital motion.

Lesson Review Questions

Recall

1. What is the traditional definition of gravity?
2. How is weight related to gravity?
3. Summarize Newton's law of universal gravitation.
4. Describe Einstein's idea of gravity.

Apply Concepts

5. Create a poster to illustrate the concept of projectile motion.

Think Critically

6. In the absence of air, why does an object with greater mass fall toward Earth at the same acceleration as an object with less mass?
7. Explain why the moon keeps orbiting Earth.

Points to Consider

The scale you saw in **Figure** 8.2 contains a spring. When an object hangs from the scale, the spring exerts an upward force that partly counters the downward force of gravity. The type of force exerted by a spring is called elastic force, which is the topic of the next lesson.

- Besides springs, what other objects do you think might exert elastic force?
- What other ways might you use elastic force?

8.4 Introduction to the Solar System

Lesson Objectives

- Describe historical views of the solar system.
- Name the planets, and describe their motion around the sun.
- Explain how the solar system formed.

Vocabulary

- geocentric model
- heliocentric model
- moon
- nebula
- nebular hypothesis
- solar system

Changing Views of the Solar System

Humans' view of the **solar system** has evolved as technology and scientific knowledge have increased. The ancient Greeks identified five of the planets and for many centuries they were the only planets known. Since then, scientists have discovered two more planets, many other solar-system objects and even planets found outside our solar system.

The Geocentric Universe

The ancient Greeks believed that Earth was at the center of the universe, as shown in **Figure** 8.9. This view is called the **geocentric model** of the universe. Geocentric means "Earth-centered." In the geocentric model, the sky, or heavens, are a set of spheres layered on top of one another. Each object in the sky is attached to a sphere and moves around Earth as that sphere rotates. From Earth outward, these spheres contain the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. An outer sphere holds all the stars. Since the planets appear to move much faster than the stars, the Greeks placed them closer to Earth.

The geocentric model worked well, by explaining why all the stars appear to rotate around Earth once per day. The model also explained why the planets move differently from the stars and from each other.

One problem with the geocentric model is that some planets seem to move backwards (in retrograde) instead of in their usual forward motion around Earth.

A demonstration animation of retrograde motion of Mars as it appears to Earth can be found here:

http://projects.astro.illinois.edu/data/Retrograde/index.html

FIGURE 8.9

Model of a geocentric universe. This diagram of the universe from the Middle Ages shows Earth at the center, with the Moon, the Sun, and the planets orbiting Earth.

Around 150 A.D. the astronomer Ptolemy resolved this problem by using a system of circles to describe the motion of planets (**Figure** 8.10). In Ptolemy's system, a planet moves in a small circle, called an epicycle. This circle moves around Earth in a larger circle, called a deferent. Ptolemy's version of the geocentric model worked so well that it remained the accepted model of the universe for more than a thousand years.

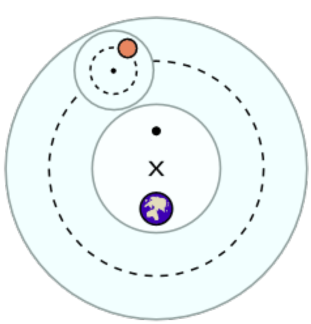


FIGURE 8.10

According to Ptolemy, a planet moves on a small circle (epicycle) that in turn moves on a larger circle (deferent) around Earth.

An animation of Ptolemy's system is seen here:

http://www.youtube.com/watch?v=FHSWVLwbbNw

The Heliocentric Universe

Ptolemy's geocentric model worked but it was not only complicated, it occasionally made errors in predicting the movement of planets. At the beginning of the 16th century A.D., Nicolaus Copernicus proposed that Earth and all the other planets orbit the Sun. With the Sun at the center, this model is called the **heliocentric model** or "sun-centered" model of the universe (**Figure** 8.11). Copernicus' model explained the motion of the planets as well as Ptolemy's model did, but it did not require complicated additions like epicycles and deferents.

Although Copernicus' model worked more simply than Ptolemy's, it still did not perfectly describe the motion of the planets because, like Ptolemy, Copernicus thought planets moved in perfect circles. Not long after Copernicus, Johannes Kepler refined the heliocentric model so that the planets moved around the Sun in ellipses (ovals), not circles (**Figure** 8.11). Kepler's model matched observations perfectly.

Animation of Kepler's Laws of Planetary Motion: http://projects.astro.illinois.edu/data/KeplersLaws/index.html

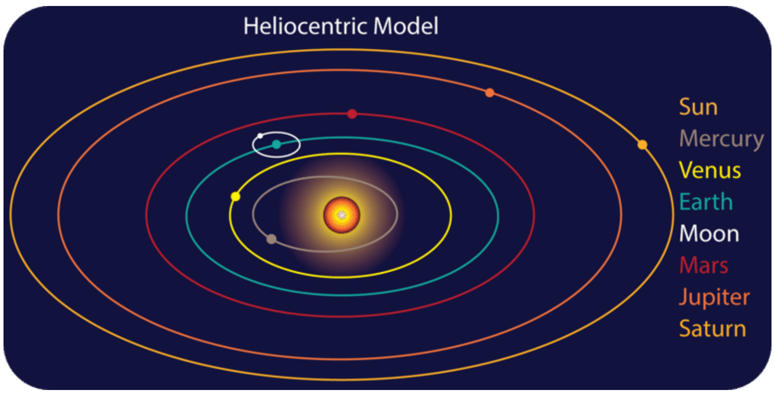


FIGURE 8.11
Kepler's model showed the planets moving around the sun in ellipses. The elliptical orbits are exaggerated in this image.

Because people were so used to thinking of Earth at the center of the universe, the heliocentric model was not widely accepted at first. However, when Galileo Galilei first turned a telescope to the heavens in 1610, he made several striking discoveries. Galileo discovered that the planet Jupiter has **moons** orbiting around it. This provided the first evidence that objects could orbit something besides Earth.

An animation of three of Jupiter's moons orbiting the planet is seen here: http://upload.wikimedia.org/wikipedia/commons/e/e7/Galilean_moon_Laplace_resonance_animation_de.gif .

Galileo also discovered that Venus has phases like the Moon (**Figure** 8.12), which provides direct evidence that Venus orbits the Sun.

Galileo's discoveries caused many more people to accept the heliocentric model of the universe, although Galileo himself was found guilty of heresy for his ideas. The shift from an Earth-centered view to a Sun-centered view of the universe is referred to as the Copernican Revolution.

Watch this animation of the Ptolemaic and Copernican models of the solar system. Ptolemy made the best model he could with the assumption that Earth was the center of the universe, but by letting that assumption go, Copernicus came up with a much simpler model. Before people would accept that Copernicus was right, they needed to accept that the Sun was the center of the solar system **(1n - IE Stand.)**: http://www.youtube.com/watch?v=VyQ8Tb85HrU (0:47).

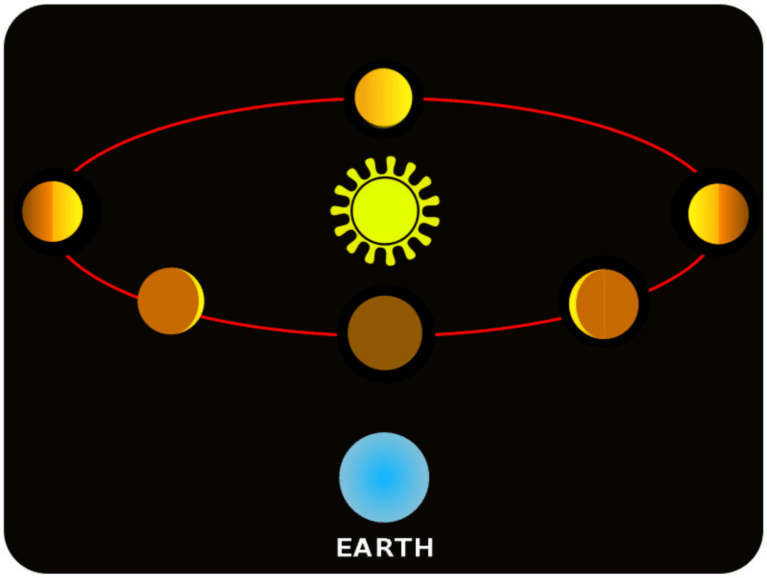
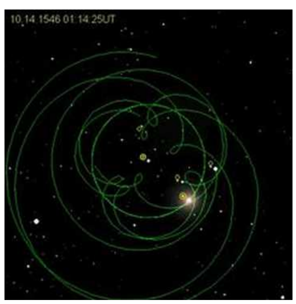


FIGURE 8.12
The phases of Venus.



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The Modern Solar System

Today, we know that our solar system is just one tiny part of the universe as a whole. Neither Earth nor the Sun are at the center of the universe. However, the heliocentric model accurately describes the solar system. In our modern view of the solar system, the Sun is at the center, with the planets moving in elliptical orbits around the Sun. The planets do not emit their own light, but instead reflect light from the Sun.

Extrasolar Planets or Exoplanets

Since the early 1990s, astronomers have discovered other solar systems, with planets orbiting stars other than our own Sun (called "extrasolar planets" or simply "exoplanets") (**Figure** 8.13).

Some extrasolar planets have been directly imaged, but most have been discovered by indirect methods. One technique involves detecting the very slight motion of a star periodically moving toward and away from us along our line-of-sight (also known as a star's "radial velocity"). This periodic motion can be attributed to the gravitational pull of a planet or, sometimes, another star orbiting the star.

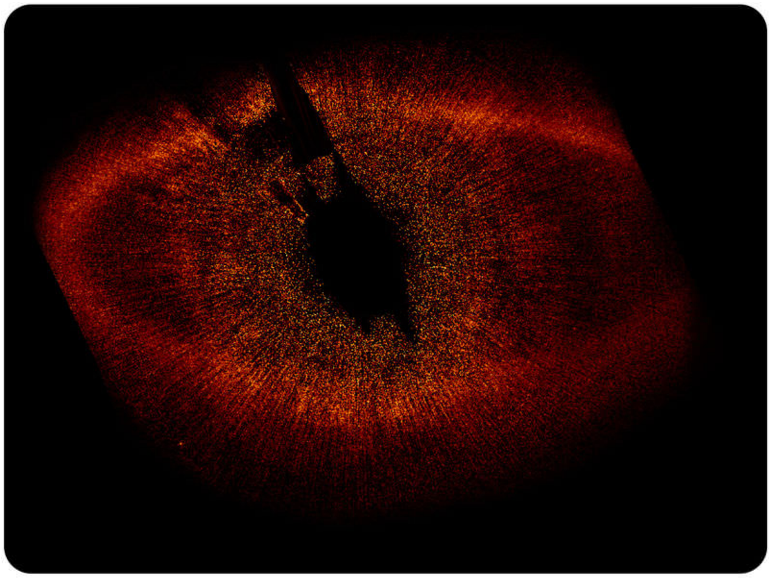


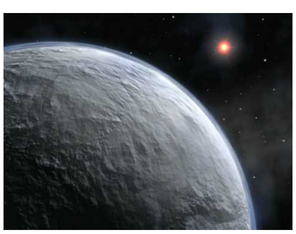
FIGURE 8.13
The extrasolar planet Fomalhaut is surrounded by a large disk of gas. The disk is not centered on the planet, suggesting that another planet may be pulling on the gas as well.

This is in line with the plane of the system: http://en.wikipedia.org/wiki/File:Dopspec-inline.gif .

A planet may also be identified by measuring a star's brightness over time. A temporary, periodic decrease in light emitted from a star can occur when a planet crosses in front of (or "transits") the star it is orbiting, momentarily blocking out some of the starlight.

More than 3,600 extrasolar planets have been identified and the rate of discovery is increasing rapidly.

Extrasolar Planet from the ESA discusses extrasolar planets and particularly a planetary system very similar to our solar system **(1g)**: http://www.youtube.com/watch?v=ouJahDONTWc (3:29).



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An introduction to extrasolar planets from NASA is available at **(1g)**: http://www.youtube.com/watch?v=oeeZCHDNTvQ (3:14).

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KQED: The Planet Hunters

Hundreds of exoplanets have now been discovered. To learn something about how planet hunters find these balls of rock they usually can't even see, watch this QUEST video. Learn more at: http://science.kqed.org/quest/video/the-planet-hunters/ and http://science.kqed.org/quest/audio/exoplanets/ .

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URL: http://www.ck12.org/flx/render/embeddedobject/60944

Planets and Their Motions

Since the time of Copernicus, Kepler, and Galileo, we have learned a lot more about our solar system. Astronomers have discovered two more planets (Uranus and Neptune), four dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects.

(**Figure** 8.14) shows the Sun and the major objects that orbit the Sun. There are eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune) and the five known dwarf planets and the five known dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris).

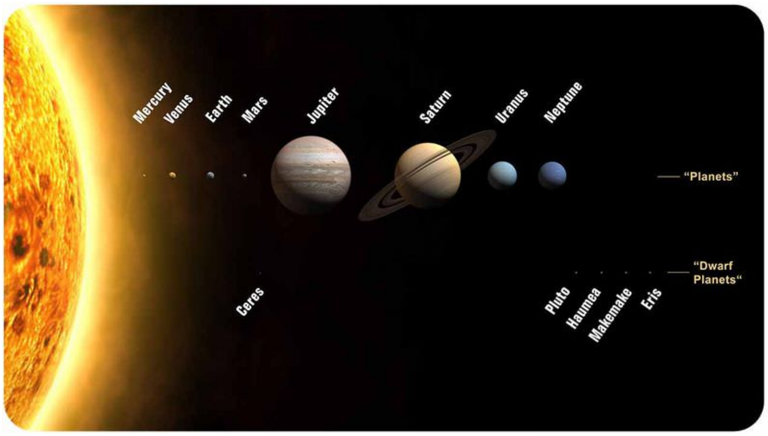

FIGURE 8.14
Relative sizes of the Sun, planets and dwarf planets. The relative sizes are correct and their position relative to each other is correct, but the relative distances are not correct.

Although the Sun is just an average star compared to other stars, it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! Table 8.1 gives data on the sizes of the Sun and planets relative to Earth.

TABLE 8.1: Sizes of Solar System Objects Relative to Earth

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter
Neptune	17.2 Earth's mass	3.81 Earth's diameter

The Size and Shape of Orbits

Figure 8.15 shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical with the Sun located at one of the foci (**Figure** 8.16).

While studying the solar system, Johannes Kepler discovered the relationship between the time it takes a planet to

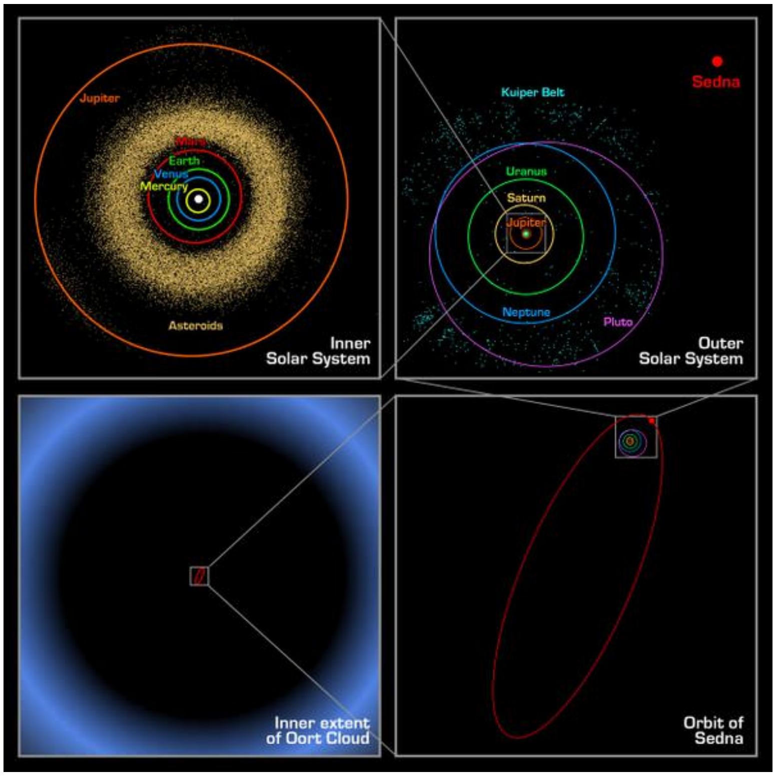

FIGURE 8.15
The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

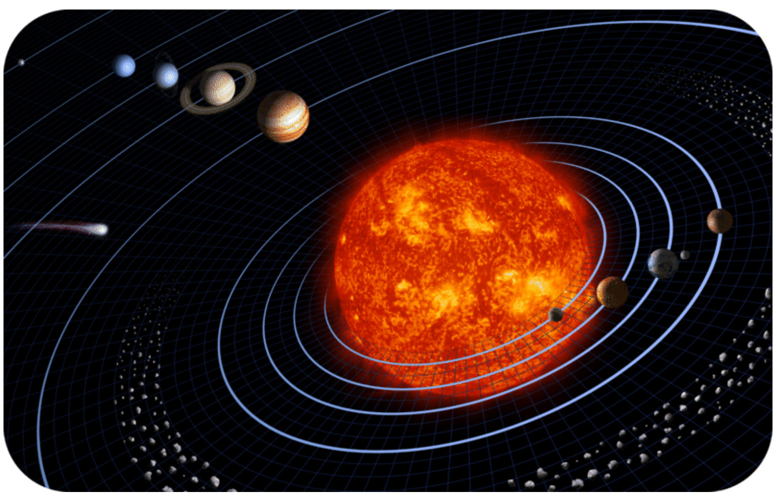

FIGURE 8.16
The planets orbit the Sun in regular paths.

make one complete orbit around the Sun, its "orbital period," and the distance from the Sun to the planet. If the orbital period of a planet is known, then it is possible to determine the planet's distance from the Sun. This is how astronomers without modern telescopes could determine the distances to other planets within the solar system.

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km, or 93 million mi. **Table** 8.2 shows the distances to the planets (the average radius of orbits) in AU. The table also shows how long it takes each planet to spin on its axis (the length of a day) and how long it takes each planet to complete an orbit (the length of a year); in particular, notice how slowly Venus rotates relative to Earth.

TABLE 8.2: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

How old are you on Earth? How old would you be if you lived on Jupiter? How many days is it until your birthday on Earth? How many days until your birthday if you lived on Saturn?

Scaling the solar system creates a scale to measure all objects in solar system **(1i - IE Stand.)**: http://www.youtube.com/watch?v=-6szEDHMxP4 (4:44).

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The Role of Gravity

Isaac Newton was one of the first scientists to explore gravity. He understood that the Moon circles the Earth because a force is pulling the Moon toward Earth's center. Without that force, the Moon would continue moving in a straight line off into space. Newton also came to understand that the same force that keeps the Moon in its orbit is the same force that causes objects on Earth to fall to the ground.

Newton defined the Universal Law of Gravitation, which states that a force of attraction, called gravity, exists between all objects in the universe (**Figure** 8.17). The strength of the gravitational force depends on how much mass the objects have and how far apart they are from each other. The greater the objects' mass, the greater the force of attraction; in addition, the greater the distance between the objects, the smaller the force of attraction.

The distance between the Sun and each of its planets is very large, but the Sun and each of the planets are also very large. Gravity keeps each planet orbiting the Sun because the star and its planets are very large objects. The force of gravity also holds moons in orbit around planets.

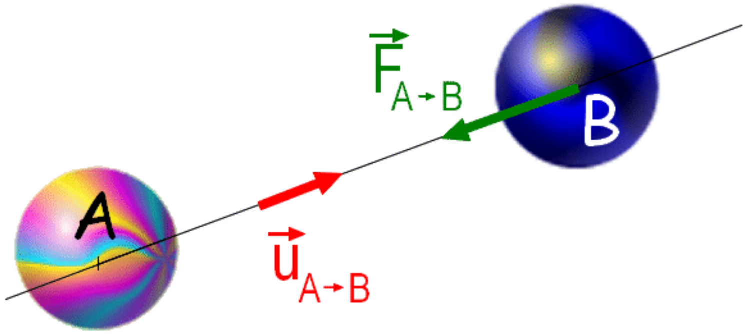


FIGURE 8.17
The force of gravity exists between all objects in the universe; the strength of the force depends on the mass of the objects and the distance between them.

Formation of the Solar System

There are two additional key features of the solar system:

1. All the planets lie in nearly the same plane, or flat disk like region.
2. All the planets orbit in the same direction around the Sun.

These two features are clues to how the solar system formed.

A Giant Nebula

The most widely accepted explanation of how the solar system formed is called the **nebular hypothesis**. According to this hypothesis, the Sun and the planets of our solar system formed about 4.6 billion years ago from the collapse of a giant cloud of gas and dust, called a **nebula**.

The nebula was drawn together by gravity, which released gravitational potential energy. As small particles of dust and gas smashed together to create larger ones, they released kinetic energy. As the nebula collapsed, the gravity at the center increased and the cloud started to spin because of its angular momentum. As it collapsed further, the spinning got faster, much as an ice skater spins faster when he pulls his arms to his sides during a spin.

Much of the cloud's mass migrated to its center but the rest of the material flattened out in an enormous disk, as shown in **Figure** 8.18. The disk contained hydrogen and helium, along with heavier elements and even simple organic molecules.

Formation of the Sun and Planets

As gravity pulled matter into the center of the disk, the density and pressure at the center became intense. When the pressure in the center of the disk was high enough, nuclear fusion began. A star was born—the Sun. The burning star stopped the disk from collapsing further.

Meanwhile, the outer parts of the disk were cooling off. Matter condensed from the cloud and small pieces of dust started clumping together. These clumps collided and combined with other clumps. Larger clumps, called planetesimals, attracted smaller clumps with their gravity. Gravity at the center of the disk attracted heavier particles, such as rock and metal and lighter particles remained further out in the disk. Eventually, the planetesimals formed protoplanets, which grew to become the planets and moons that we find in our solar system today.

Because of the gravitational sorting of material, the inner planets — Mercury, Venus, Earth, and Mars — formed

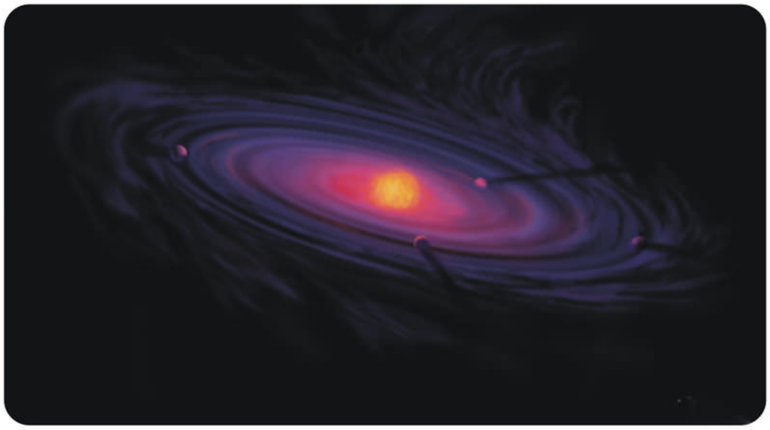


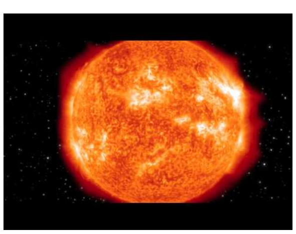
FIGURE 8.18
An artist's painting of a protoplanetary disk.

from dense rock and metal. The outer planets — Jupiter, Saturn, Uranus and Neptune — condensed farther from the Sun from lighter materials such as hydrogen, helium, water, ammonia, and methane. Out by Jupiter and beyond, where it's very cold, these materials form solid particles.

The nebular hypothesis was designed to explain some of the basic features of the solar system:

- The orbits of the planets lie in nearly the same plane with the Sun at the center
- The planets revolve in the same direction
- The planets mostly rotate in the same direction
- The axes of rotation of the planets are mostly nearly perpendicular to the orbital plane
- The oldest moon rocks are 4.5 billion years

This video, from the ESA, discusses the Sun, planets, and other bodies in the Solar System and how they formed **(1a, 1d)**. The first part of the video explores the evolution of our view of the solar system starting with the early Greeks who reasoned that since some points of light - which they called planets - moved faster than the stars, they must be closer: http://www.youtube.com/watch?v=-NxfBOhQ1CY (8:34).



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Lesson Summary

- The solar system is the Sun and all the objects that are bound to the Sun by gravity.
- The solar system has eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Ceres, Makemake, Pluto and Eris are dwarf planets.
- The ancient Greeks and people for centuries afterwards believed in a geocentric model of the universe, with Earth at the center and everything else orbiting our planet.
- Copernicus, Kepler, and Galileo promoted a heliocentric model of the universe, with the Sun at the center and Earth and the other planets orbiting the Sun.
- Gravity holds planets in elliptical orbits around the Sun.
- The nebular hypothesis describes how the solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.

Review Questions

1. What does geocentric mean?
2. Describe the geocentric model and heliocentric model of the universe.
3. How was Kepler's version of the heliocentric model different from Copernicus'?
4. Name the eight planets in order from the Sun outward. Which are the inner planets and which are the outer planets?
5. Compare and contrast the inner planets and the outer planets.
6. What object used to be considered a planet, but is now considered a dwarf planet? What are the other dwarf planets?
7. What keeps planets and moons in their orbits?
8. How old is the solar system? How old is Earth?
9. Use the nebular hypothesis to explain why the planets all orbit the Sun in the same direction.

Further Reading / Supplemental Links

- More information about the solar system from NASA: http://sse.jpl.nasa.gov/planets/index.cfm
- Lots of information about the solar system from the BBC: BBC Explore the solar system http://www.bbc.co.uk/solarsystem/
- Information about solar system objects: http://www.solarviews.com/eng/homepage.htm
- A multimedia tour of the solar system: http://www.nineplanets.org/
- Windows to the Universe: http://www.windows.ucar.edu/tour/link=/our_solar_system/formation.html
- Space news: http://www.space.com/

Points to Consider

- Would you expect all the planets in the solar system to be made of similar materials? Why or why not?

- The planets are often divided into two groups: the inner planets and the outer planets. Which planets do you think are in each of these two groups? What do members of each group have in common?

8.5 Planet Earth

Lesson Objectives

- Recognize that Earth is a modified sphere (oblate spheroid), and describe the evidence for this conclusion.
- Explain what causes Earth's magnetism and the effects that magnetism has on the Earth.
- Describe Earth's rotation on its axis.
- Describe Earth's revolution around the Sun.

Vocabulary

- axis
- ellipse
- hemisphere
- revolution
- rotation

Introduction

This book so far has been almost entirely about Earth. This chapter is concerned with Earth as a planetary body, a member of the Earth-Moon pair that orbit each other and the Sun.

Earth as a Planetary Body

Earth is an inner planet in the solar system and it is very much like the other inner planets, at least in its size, shape, and composition. But many features make Earth very different from the planets and any other planet that we know of so far.

Earth's Shape

Earth is a sphere or, more correctly, an oblate spheroid, which is a sphere that is a bit squished down at the poles and bulges a bit at the equator. Or to be more technical, the minor axis (the diameter through the poles) is smaller than the major axis (the diameter through the equator). Half of the sphere is a **hemisphere**. North of the equator is the northern hemisphere and south of the equator is the southern hemisphere. Eastern and western hemispheres are also designated.

What evidence is there that Earth is spherical? What evidence was there before spaceships and satellites?

Try to design an experiment involving a ship and the ocean to show Earth is round. If you are standing on the shore and a ship is going out to sea, the ship gets smaller as it moves further away from you but the ship's bottom also starts to disappear as the vessel goes around the arc of the planet (**Figure** 8.19). There are many other ways that early scientists and mariners knew that Earth was not flat.

FIGURE 8.19
Earth's curvature is noticeable when objects at a distance are below the arc.

Even the ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. NASA has an animation of a lunar eclipse here: http://science.nasa.gov/media/medialibrary/2003/10/29/04nov_lunareclipse2_resources/reddy1_big.gif .

The Sun and the other planets of the solar system are also spherical. Larger satellites, those that have enough mass for their gravitational attraction to have made them round, are as well.

Earth's Magnetism

Earth has a **magnetic field** (**Figure** 8.20) that behaves as if the planet had a gigantic bar magnet inside of it. Earth's magnetic field also has a north and south pole and a magnetic field that surrounds it. The magnetic field arises from the convection of molten iron and nickel metal in Earth's outer liquid iron core.

Earth's magnetic field extends several thousand kilometers into space. The magnetic field shields the planet from harmful radiation from the Sun (**Figure** 8.21).

Earth's Motions

Imagine a line passing through the center of Earth that goes through both the North Pole and the South Pole. This imaginary line is called an **axis**. Earth spins around its axis, just as a top spins around its spindle. This spinning movement is called Earth's **rotation**. At the same time that the Earth spins on its axis, it also orbits, or revolves around the Sun. This movement is called **revolution.**

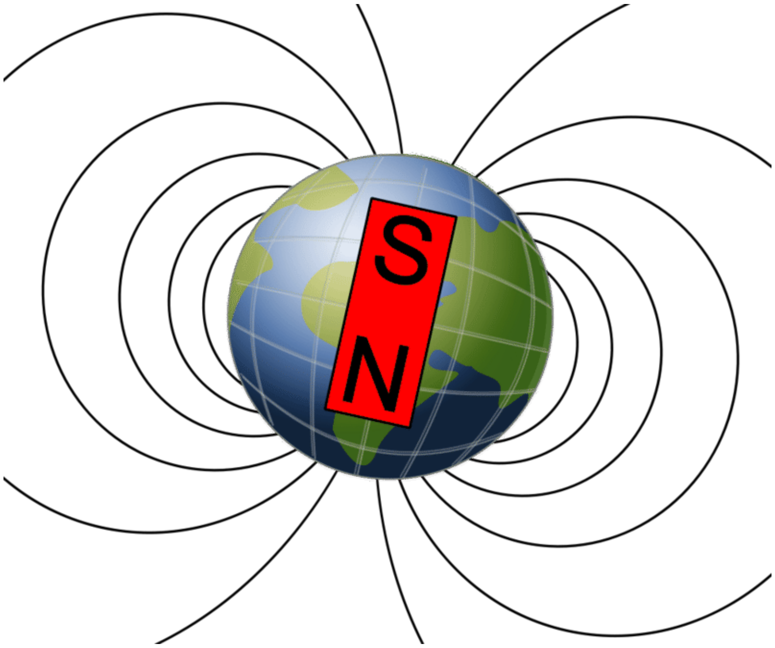

FIGURE 8.20
Earth's magnetic field.

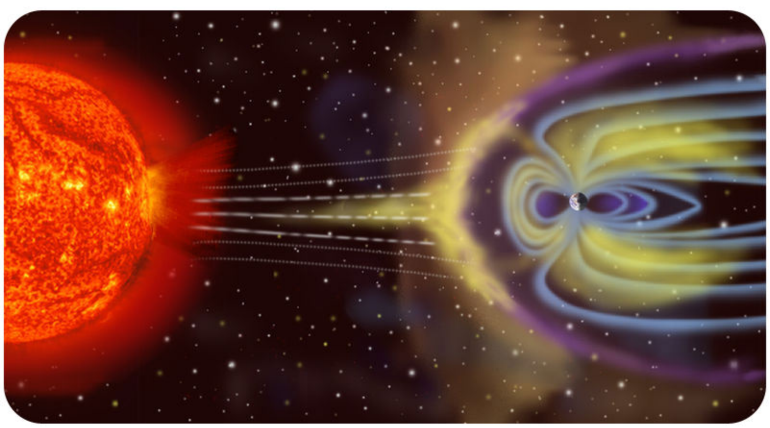

FIGURE 8.21
Earth, on the right, is tiny in comparison to the Sun, but its magnetic field extends far outward.

Earth's Rotation

In 1851, a French scientist named Léon Foucault took an iron sphere and swung it from a wire. He pulled the sphere to one side and then released it, letting it swing back and forth in a straight line (**Figure** 8.22). A ball swinging back and forth on a string is called a pendulum.

A pendulum set in motion will not change its motion, and so the direction of its swinging should not change. However, Foucault observed that his pendulum did seem to change direction. Since he knew that the pendulum could not change its motion, he concluded that the Earth, underneath the pendulum was moving. **Figure** 8.23 shows how this might look.

An observer in space will see that Earth requires 23 hours, 56 minutes, and 4 seconds to make one complete rotation on its axis. But because Earth moves around the Sun at the same time that it is rotating, the planet must turn just a little bit more to reach the same place relative to the Sun. Hence the length of a day on Earth is actually 24 hours. At the equator, the Earth rotates at a speed of about 1,700 km per hour, but at the poles the movement speed is nearly

FIGURE 8.22
Foucault's pendulum is now on display in the Pantheon in Paris.

FIGURE 8.23
Imagine a pendulum at the North Pole. The pendulum always swings in the same direction, but because of Earth's rotation, its direction appears to change to observers on Earth.

nothing.

A Turn of the Earth

In this video, MIT students demonstrate how a Foucault Pendulum is used to prove that the Earth is rotating. See the video at https://www.youtube.com/watch?v=_pECtfYa2Us .

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Earth's Revolution

For Earth to make one complete revolution around the Sun takes 365.24 days. This amount of time is the definition of one year. The gravitational pull of the Sun keeps Earth and the other planets in orbit around the star. Like the other planets, Earth's orbital path is an **ellipse** (**Figure** 8.24) so the planet is sometimes farther away from the Sun than at other times. The closest Earth gets to the Sun each year is at perihelion (147 million km) on about January 3rd and the furthest is at aphelion (152 million km) on July 4th. Earth's elliptical orbit has nothing to do with Earth's seasons.

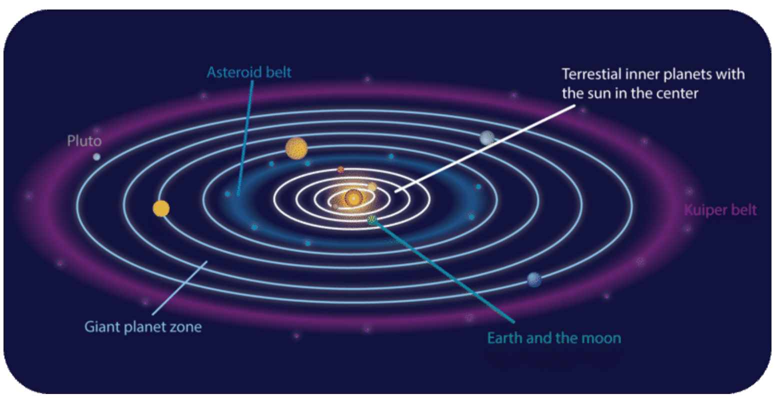

FIGURE 8.24

Earth and the other planets in the solar system orbit around the Sun. Although the orbits are slightly elliptical, in this image the ellipses are exaggerated.

During one revolution around the Sun, Earth travels at an average distance of about 150 million km. Earth revolves around the Sun at an average speed of about 27 km (17 mi) per second, but the speed is not constant. The planet moves slower when it is at aphelion and faster when it is at perihelion.

The reason the Earth (or any planet) has seasons is that Earth is tilted 23 $1/2^o$ on its axis. During the Northern Hemisphere summer the North Pole points toward the Sun, and in the Northern Hemisphere winter the North Pole is tilted away from the Sun (**Figure** 8.25).

Lesson Summary

- Earth rotates or spins on its axis approximately once each day and revolves around the Sun approximately once a year.

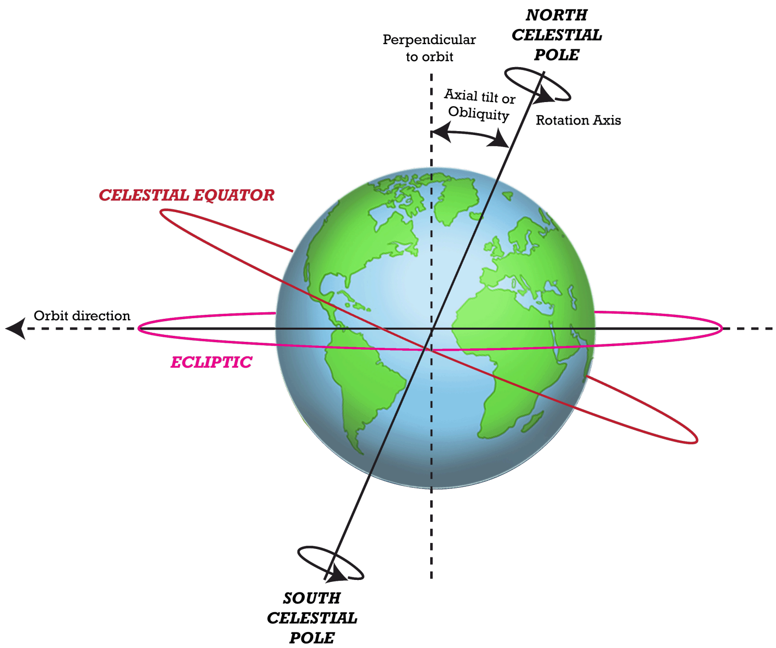

FIGURE 8.25
The Earth tilts on its axis.

- Earth's orbit around the Sun is elliptical; the planet is closer at perihelion and farther at aphelion.
- The tilt of Earth's axis produces seasons.
- The Earth and other planets in our solar system are rotating spheres.
- Earth has a magnetic field created by the convection of molten liquid in the outer core.
- The magnetic field shields Earth from harmful solar radiation.

Review Questions

1. When you watch a tall ship sail over the horizon of the Earth, you see the bottom part of it disappear faster than the top part. Why does this happen?

2. Why are we able to use magnets to determine north-south directions on Earth?

3. Describe the difference between Earth's rotation and its revolution.

4. What is the force that keeps the Earth and other planets in their orbital paths?

5. In its elliptical orbit around the Sun, the Earth is closest to the Sun in January. If Earth is closes to the Sun in January, why is January winter in the Northern Hemisphere?

6. Where on Earth would Foucault's pendulum appear to not be moving? Where would it appear to be moving the most?

7. The planet Jupiter is about 778,570,000 kilometers from the Sun; Earth is about 150,000,000 kilometers from the Sun. Does Jupiter take more or less time to make one revolution around the sun? Explain your answer.

Points to Consider

- What type of experiment could you create to prove that the Earth is rotating on its axis?

- If you lived at the equator, would you experience any effects because of Earth's tilted axis?
- If Earth suddenly increased in mass, what might happen to its orbit around the Sun?
- Would life on Earth be impacted if Earth lost its magnetic field?
- Why are the inner planets spherical?

8.6 Inner Planets

Lesson Objectives

- Describe key features of each of the inner planets.
- Compare each of the inner planets to Earth and to one another.

Vocabulary

- day
- inner planets
- terrestrial planets
- year

Introduction

What evidence do planetary geologists have to go on to determine the geology of the inner planets? On Earth, scientists can collect and analyze the chemistry of samples, do radiometric dating to determine their ages, and look at satellite images to see large-scale features. Rovers have landed on Mars and sent back enormous amounts of information but much of the rest of what is known about the inner planets is from satellite images.

The Inner Planets

The **inner planets**, or **terrestrial planets**, are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. **Figure** 8.26 shows the relative sizes of these four inner planets.

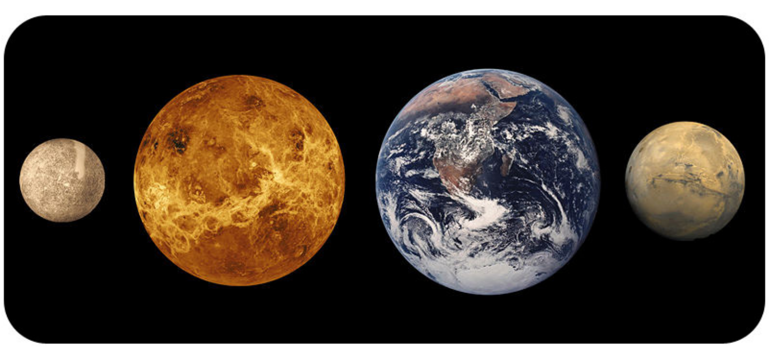

FIGURE 8.26
This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

Unlike the outer planets, which have many of satellites, Mercury and Venus do not have moons, Earth has one, and Mars has two. Of course, the inner planets have shorter orbits around the Sun, and they all spin more slowly. Geologically, the inner planets are all made of cooled igneous rock with iron cores, and all have been geologically active, at least early in their history. None of the inner planets has rings.

Earth

Although Earth is the third planet out from the Sun this lesson will start here. We know a lot more about Earth, so what we know can be used for comparison with the other planets.

FIGURE 8.27
What are Earth's most distinctive features? This famous image of Earth was taken during the Apollo 17 mission to the moon. Can you find a hurricane? A storm spinning in the opposite direction from the hurricane?

Earth's Surface and Life

As you can see in (**Figure** 8.27), Earth has vast oceans of liquid water, large masses of exposed land, and a dynamic atmosphere with clouds of water vapor. Earth also has ice covering its polar regions. Earth's average surface temperature is 14°C (57°F). Water is a liquid at this temperature, but the planet also has water in its other two states, solid and gas. The oceans and the atmosphere help keep Earth's surface temperatures fairly steady.

As yet Earth is the only planet known to have life. The presence of liquid water, the ability of the atmosphere to filter out harmful radiation, and many other features make the planet uniquely suited to harbor life. Life and Earth now affect each other; for example, the evolution of plants allowed oxygen to enter the atmosphere in large enough quantities for animals to evolve. Although life has not been found elsewhere in the solar system, other planets or satellites may harbor primitive life forms. Life may also be found elsewhere in the universe.

Structure and Plate Tectonics

The heat that remained from the planet's accretion, gravitational compression, and radioactive decay allowed the Earth to melt, probably more than once. As it subsequently cooled, gravity pulled metal into the center to create the core. Heavier rocks formed the mantle and lighter rocks formed the crust.

Earth's crust is divided into tectonic plates, which move around on the surface because of the convecting mantle below. Movement of the plates causes other geological activity, such as earthquakes, volcanoes, and the formation of mountains. The locations of these features are mostly related to current or former plate boundaries. Earth is the only planet known to have plate tectonics.

Earth's Motions and Satellites

Earth rotates on its axis once per **day**, by definition. Earth orbits the Sun once every 365.24 days, which is defined as a **year**. Earth has one large moon, which orbits Earth once every 29.5 days, a period known as a month.

Earth's moon is the only large moon orbiting a terrestrial planet in the solar system. The Moon is covered with craters; it also has large plains of lava. The huge number of craters suggests that Moon's surface is ancient. There is evidence that the Moon formed when a large object —perhaps as large as the planet Mars —struck Earth in the distant past (**Figure** 8.28).

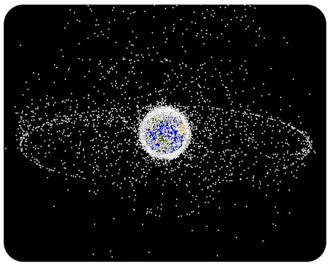

FIGURE 8.28
Besides its Moon, Earth is orbited by a great deal of space debris, the remains of satellites, and rocket stages.

Mercury

The smallest planet, Mercury, is the planet closest to the Sun. Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. However, the Mariner 10 spacecraft, shown in **Figure** 8.29, visited Mercury from 1974 to 1975. The MESSENGER spacecraft has been studying Mercury in detail since 2005. The craft is currently in orbit around the planet, where it is creating detailed maps. MESSENGER stands for Mercury Surface, Space Environment, Geochemistry and Ranging.

As **Figure** 8.30 shows, the surface of Mercury is covered with craters, like Earth's moon. Ancient impact craters means that for billions of years Mercury hasn't changed much geologically. Also, with very little atmosphere, the processes of weathering and erosion do not wear down structures on the planet.

There are many images, movies and activities on the MESSENGER site: http://messenger.jhuapl.edu/index.php .

Short Year, Long Days

Mercury is named for the Roman messenger god, who could run extremely quickly, just as the planet moves very quickly in its orbit around the Sun. A year on Mercury —the length of time it takes to orbit the Sun —is just 88 Earth days.

Despite its very short years, Mercury has very long days. A day is defined as the time it takes a planet to turn on its axis. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. Therefore, each day on Mercury is 57 Earth days long. In other words, on Mercury, a year is only a Mercury day and a half long!

Extreme Temperatures

Mercury is close to the Sun, so it can get very hot. However, Mercury has virtually no atmosphere, no water to insulate the surface, and it rotates very slowly. For these reasons, temperatures on the surface of Mercury vary

FIGURE 8.29

(a) Mariner 10 made three flybys of Mercury in 1974 and 1975. (b) A 2008 image of compiled from a flyby by MESSENGER.

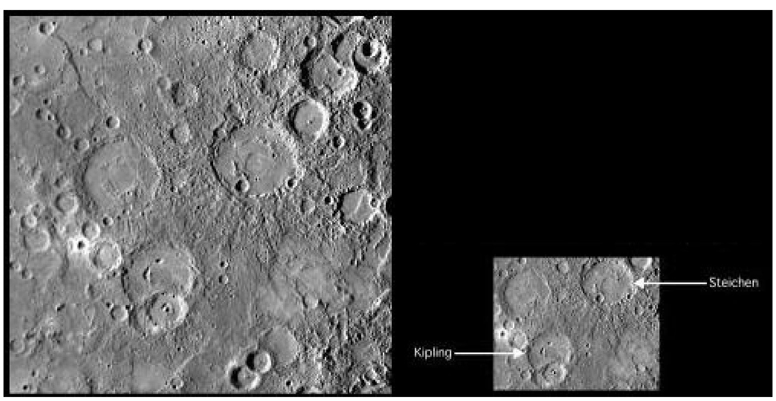

FIGURE 8.30

Mercury is covered with craters, like Earth's moon. MESSENGER has taken extremely detailed pictures of the planet's surface.

widely. In direct sunlight, the surface can be as hot as 427°C (801°F). On the dark side, or in the shadows inside craters, the surface can be as cold as -183°C (-297°F)! Although most of Mercury is extremely dry, scientists think there may be a small amount of water in the form of ice at the poles of Mercury, in areas that never receive direct sunlight.

A Liquid Metal Core

Figure 8.31 shows a diagram of Mercury's interior. Mercury is one of the densest planets. It's relatively large, liquid core, made mostly of melted iron, takes up about 42% of the planet's volume.

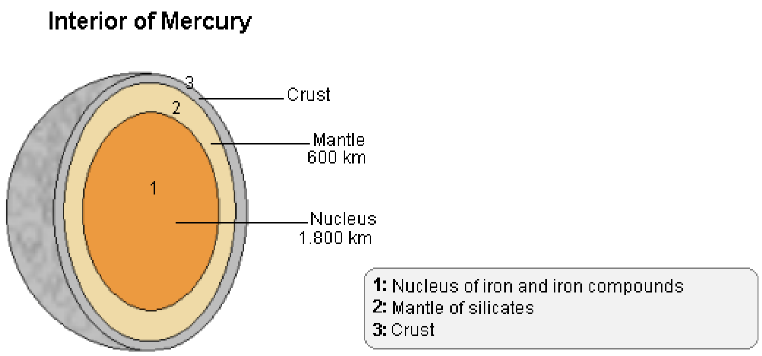

FIGURE 8.31
Mercury contains a thin crust, a mantle, and a large, liquid core that is rich in iron.

Venus

Named after the Roman goddess of love, Venus is the only planet named after a female. Venus' thick clouds reflect sunlight well so Venus is very bright. When it is visible, Venus is the brightest object in the sky besides the Sun and the Moon. Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. When Venus rises just before the Sun rises, the bright object is called the morning star. When it sets just after the Sun sets, it is the evening star.

Of the planets, Venus is most similar to Earth in size and density. Venus is also our nearest neighbor. The planet's interior structure is similar to Earth's with a large iron core and a silicate mantle (**Figure** 8.32). But the resemblance between the two inner planets ends there.

Find out more about Venus at the following link: http://www.nasa.gov/worldbook/venus_worldbook.html .

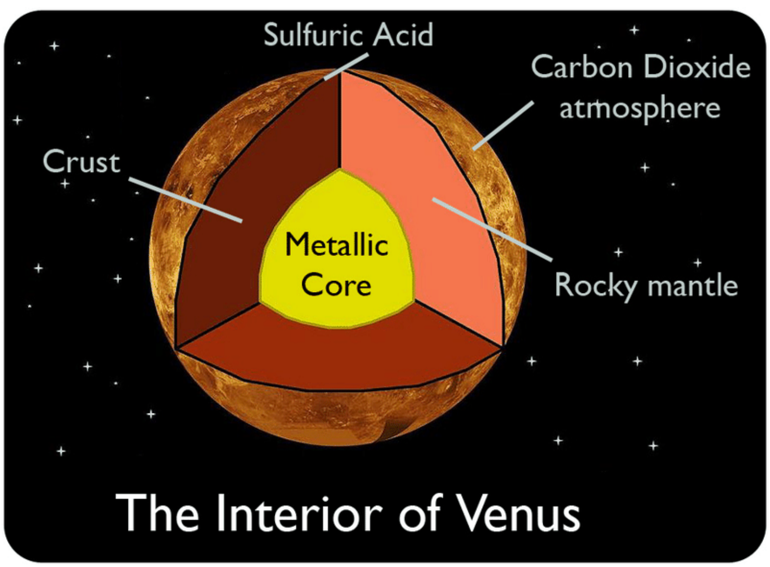

FIGURE 8.32
Venus's interior is similar to Earth's.

Motion

Venus rotates in a direction opposite the other planets and opposite to the direction it orbits the Sun. This rotation is extremely slow, only one turn every 243 days. This is longer than a year on Venus—it takes Venus only 224 days to orbit the Sun.

Extreme Atmosphere

Venus is covered by a thick layer of clouds, as shown in pictures of Venus taken at ultraviolet wavelengths (**Figure** 8.33).

FIGURE 8.33
This ultraviolet image from the Pioneer Venus Orbiter shows thick layers of clouds in the atmosphere of Venus.

Venus' clouds are not made of water vapor like Earth's clouds. Clouds on Venus are made mostly of carbon dioxide with a bit of sulfur dioxide —and they also contain corrosive sulfuric acid. Because carbon dioxide is greenhouse gas, the atmosphere traps heat from the Sun and creates a powerful greenhouse effect. Even though Venus is further from the Sun than Mercury, the greenhouse effect makes Venus the hottest planet. Temperatures at the surface reach 465°C (860°F). That's hot enough to melt lead.

The atmosphere of Venus is full of acid, its pressure is crushing, and the enormous amount of carbon dioxide causes runaway greenhouse effect **(4d)**: http://www.youtube.com/watch?v=HqFVxWfVtoo (2:05).

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/1464

The atmosphere of Venus is so thick that the atmospheric pressure on the planet's surface is 90 times greater than the atmospheric pressure on Earth's surface. The dense atmosphere totally obscures the surface of Venus, even from spacecraft orbiting the planet.

Venus's Surface

Since spacecraft cannot see through the thick atmosphere, radar is used to map Venus' surface. Many features found on the surface are similar to Earth and yet are very different. **Figure** 8.34 shows a topographical map of Venus produced by the Magellan probe using radar.

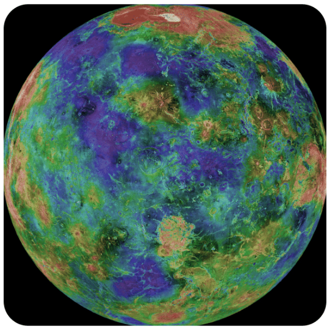

FIGURE 8.34
This false color image of Venus was made from radar data collected by the Magellan probe between 1990 and 1994. What features can you identify?

Orbiting spacecraft have used radar to reveal mountains, valleys, and canyons. Most of the surface has large areas of volcanoes surrounded by plains of lava. In fact, Venus has many more volcanoes than any other planet in the solar system and some of those volcanoes are very large.

Most of the volcanoes are no longer active, but scientists have found evidence that there is some active volcanism (**Figure** 8.35). Think about what you know about the geology of Earth and what produces volcanoes. What does the presence of volcanoes suggest about the geology of Venus? What evidence would you look for to find the causes of volcanism on Venus?

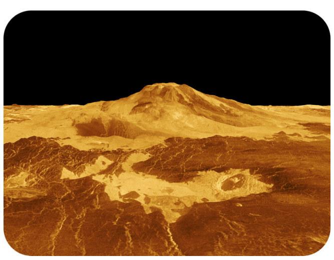

FIGURE 8.35
This image of the Maat Mons volcano with lava beds in the foreground was generated by a computer from radar data. The reddish-orange color is close to what scientists think the color of sunlight would look like on the surface of Venus.

Venus also has very few impact craters compared with Mercury and the Moon. What is the significance of this? Earth has fewer impact craters than Mercury and the Moon too. Is this for the same reason that Venus has fewer impact craters?

It's difficult for scientists to figure out the geological history of Venus. The environment is too harsh for a rover to go there. It is even more difficult for students to figure out the geological history of a distant planet based on the information given here. Still we can piece together a few things.

On Earth, volcanism is generated because the planet's interior is hot. Much of the volcanic activity is caused by plate tectonic activity. But on Venus, there is no evidence of plate boundaries and volcanic features do not line up the way they do at plate boundaries.

Because the density of impact craters can be used to determine how old a planet's surface is, the small number of impact craters means that Venus' surface is young. Scientists think that there is frequent, planet-wide resurfacing of Venus with volcanism taking place in many locations. The cause is heat that builds up below the surface that has no escape until finally it destroys the crust and results in volcanoes.

Mars

Mars is the fourth planet from the Sun, and the first planet beyond Earth's orbit (**Figure** 8.36). Mars is a quite different from Earth and yet more similar than any other planet. Mars is smaller, colder, drier, and appears to have no life, but volcanoes are common to both planets and Mars has many.

Mars is easy to observe so Mars has been studied more thoroughly than any other extraterrestrial planet. Space probes, rovers, and orbiting satellites have all yielded information to planetary geologists. Although no humans have ever set foot on Mars, both NASA and the European Space Agency have set goals of sending people to Mars sometime between 2030 and 2040.

Find out all you want to know about Mars at http://mars.jpl.nasa.gov/extreme/ .

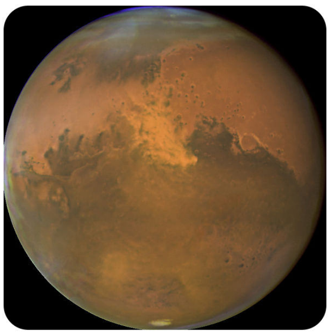

FIGURE 8.36
This image of Mars, taken by the Hubble Space Telescope in October, 2005, shows the planet's red color, a small ice cap on the south pole, and a dust storm.

A Red Planet

Viewed from Earth, Mars is reddish in color. The ancient Greeks and Romans named the planet after the god of war. But the surface is not red from blood but from large amounts of iron oxide in the soil.

The Martian atmosphere is very thin relative to Earth's and has much lower atmospheric pressure. Although the atmosphere is made up mostly of carbon dioxide, the planet has only a weak greenhouse effect so temperatures are only slightly higher than if the planet had no atmosphere.

Surface Features

Mars has mountains, canyons, and other features similar to Earth. Some of these surface features are amazing for their size! Olympus Mons is a shield volcano, similar to the volcanoes that make up the Hawaiian Islands. But Olympus Mons is also the largest mountain in the solar system (**Figure** 8.37).

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** 8.38).

Mars has more impact craters than Earth, though fewer than the Moon. A video comparing geologic features on Mars and Earth is seen here: Mars tectonics video http://news.discovery.com/videos/space-3-questions-mars-tectonics.html

Is There Water on Mars?

Water cannot stay in liquid form on Mars because the atmospheric pressure is too low. However, there is a lot of water in the form of ice and even prominent ice caps (**Figure** 8.39). Scientists also think that there is a lot of water

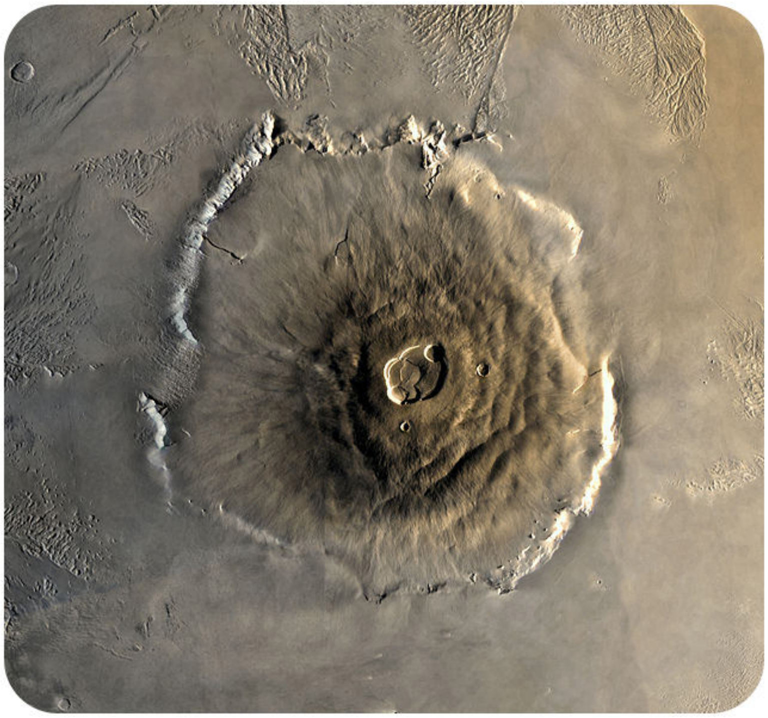

FIGURE 8.37
Olympus Mons is about 27 km (16.7 miles/88,580 ft) above the Martian surface, more than three times taller than Mount Everest. The volcano's base is about the size of the state of Arizona.

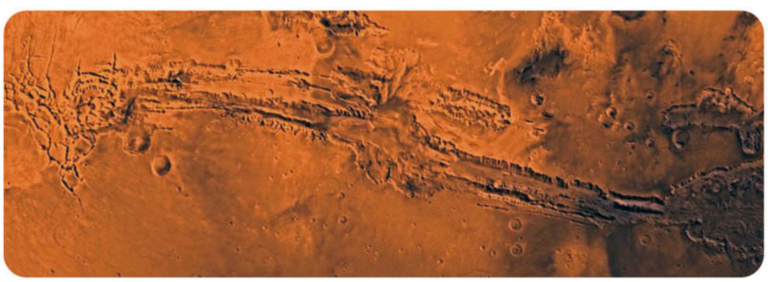

FIGURE 8.38
Valles Marineris is 4,000 km (2,500 mi) long, as long as Europe is wide, and one-fifth the circumference of Mars. The canyon is 7 km (4.3 mi) deep. By comparison, the Grand Canyon on Earth is only 446 km (277 mi) long and about 2 km (1.2 mi) deep.

ice present just under the Martian surface. This ice can melt when volcanoes erupt, and water can flow across the surface temporarily.

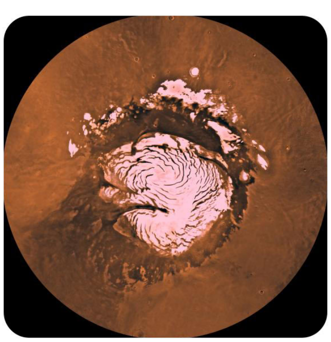

FIGURE 8.39
The north polar ice cap on Mars.

Scientists think that water once flowed over the Martian surface because there are surface features that look like water-eroded canyons (**Figure** 8.40). The presence of water on Mars, even though it is now frozen as ice, suggests that it might have been possible for life to exist on Mars in the past.

FIGURE 8.40
The Mars rover collected rounded clumps of crystals that, on Earth, are known to form in water.

A video of the top five Phoenix Lander sites on Mars is seen here: http://news.discovery.com/videos/space-top-5-mars-phoenix-lander-images.html .

Two Martian Moons

Mars has two very small moons that are irregular rocky bodies (**Figure** 8.41). Phobos and Deimos are named after characters in Greek mythology —the two sons of Ares, who followed their father into war. Ares is equivalent to the Roman god Mars.

An animation of the moons orbiting Mars is seen here: http://commons.wikimedia.org/wiki/File:Orbits_of_Phobos_and_Deimos.gif .

KQED: Searching for Life on Mars

The Mars Science Laboratory was launched on November 26, 2011 and will search for any evidence that the Red Planet was once capable of supporting life. Curiosity is a car-sized rover that is scouring the red planet for clues; it landed in August 2012. Learn more at: http://science.kqed.org/quest/video/searching-for-life-on-mars/ .

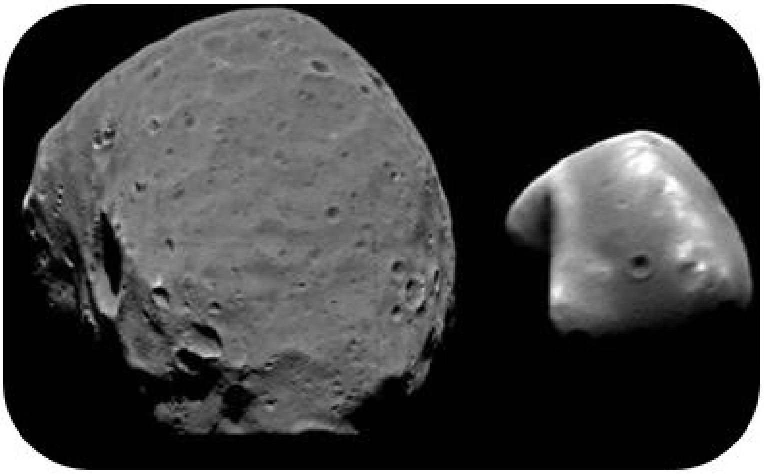

FIGURE 8.41
Mars has two small moons, Phobos (left) and Deimos (right). Both were discovered in 1877 and are thought to be captured asteroids.

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Lesson Summary

- The four inner planets, or terrestrial planets, have solid, rocky surfaces.
- Earth, the third planet from the Sun, is the only planet with large amounts of liquid water, and the only planet known to support life. Earth has a large round moon.
- Mercury is the smallest planet and is the closest to the Sun. With its extremely thin atmosphere, Mercury has a large temperature range. Like the Moon, it is covered with craters.
- Venus is the second planet from the Sun and the closest planet to Earth, in distance and in size. With its thick, corrosive atmosphere, the surface temperature is extremely high.
- Venus has mountainous areas, as well as volcanoes surrounded by plains of lava.
- Mars is the fourth planet from the Sun. Mars is reddish in color and has the largest mountain and the largest canyon in the solar system. It has two small moons.
- Water ice is found in the polar ice caps and under the surface of Mars.

Review Questions

1. Name the inner planets from the Sun outward. Then name them from smallest to largest.
2. Why do the temperatures on some planets vary widely? Why are some temperatures much less variable?
3. Why does Venus have higher temperatures than Mercury?
4. How are maps of Venus made?
5. Name two major ways in which Earth is unlike any other planet.

6. Why is Mars red?

7. Suppose you are planning a mission to Mars. Identify two places where you might be able to get water on the planet. Why is this important?

Further Reading / Supplemental Links

- The Jet Propulsion Lab home page has all the current and past missions with media and activities and great images: http://www.jpl.nasa.gov/ .
- NASA Solar System Explorer, Mercury: http://solarsystem.nasa.gov/planetselector.cfm?Object=Mercury ; http://solarsystem.jpl.nasa.gov/planets/profile.cfm?Object=Mercury&Display=Kids
- Google maps has Mars! http://www.google.com/mars/
- Home page of the Mars Exploration Rover Mission: http://marsrovers.jpl.nasa.gov/home/index.html
- A short video about Mercury: http://www.youtube.com/watch?v=U8-DTJpygyk
- A short video about Venus: http://www.youtube.com/watch?v=HqFVxWfVtoo
- A short video about Mars: http://www.youtube.com/watch?v=M-KfYEQUg2s

Points to Consider

- The first humans may reach Mars sometime in the next few decades. What conditions will they face? Why do you think we are going to Mars instead of Mercury or Venus?
- Why are the four inner planets called terrestrial planets? What might a planet be like if it weren't a terrestrial planet?

8.7 Outer Planets

Lesson Objectives

- Describe key features of the outer planets and their moons.
- Compare the outer planets to each other and to Earth.

Vocabulary

- Galilean moons
- gas giants
- Great Red Spot
- outer planets
- planetary rings

Introduction

The four outer planets are farther from the Sun as well as farther from Earth. They are much more difficult to learn about since they are very different from our home planet.

The Outer Planets

The four planets farthest from the Sun are the **outer planets**. **Figure** 8.42 shows the relative sizes of the outer planets and the Sun. These planets are much larger than the inner planets and are made primarily of gases and liquids, so they are also called **gas giants**.

The gas giants are made up primarily of hydrogen and helium, the same elements that make up most of the Sun. Astronomers think that hydrogen and helium gases comprised much of the solar system when it first formed. Since the inner planets didn't have enough mass to hold on to these light gases, their hydrogen and helium floated away into space. The Sun and the massive outer planets had enough gravity to keep hydrogen and helium from drifting away.

All of the outer planets have numerous moons. They all also have **planetary rings**, composed of dust and other small particles that encircle the planet in a thin plane.

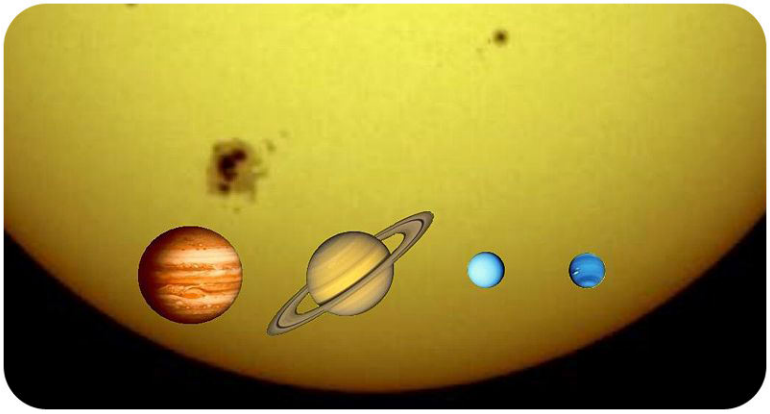


FIGURE 8.42
This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune.

Jupiter

Because Jupiter is so large, it reflects a lot of sunlight. Jupiter is extremely bright in the night sky; only the Moon and Venus are brighter (**Figure** 8.43). This brightness is all the more impressive because Jupiter is quite far from the Earth —5.20 AUs away. It takes Jupiter about 12 Earth years to orbit once around the Sun.

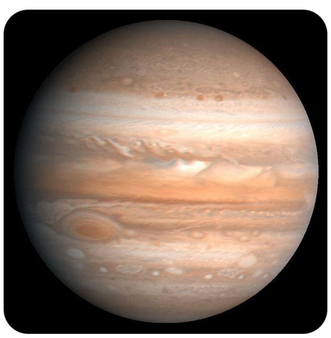


FIGURE 8.43
This image of Jupiter was taken by Voyager 2 in 1979. The colors were later enhanced to bring out more details.

Jupiter is named for the king of the gods in Roman mythology. The planet is enormous, the largest object in the solar system besides the Sun. Although Jupiter is over 1,300 times Earth's volume, it has only 318 times the mass of Earth. Like the other gas giants, it is much less dense than Earth.

Check out NASA's world book to learn more about Jupiter: http://www.nasa.gov/worldbook/jupiter_worldbook.html .

A Ball of Gas and Liquid

Astronauts trying to land a spaceship on the surface of Jupiter would find that there is no solid surface at all! Jupiter is made mostly of hydrogen, with some helium, and small amounts of other elements (**Figure** 8.44).

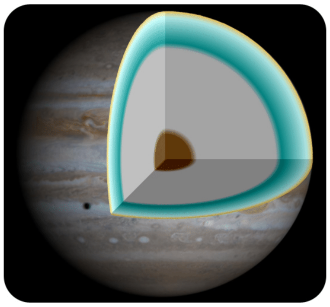


FIGURE 8.44

Jupiter's atmosphere is composed of hydrogen and helium. Deeper within the planet, pressure compresses the gases into a liquid. Some evidence suggests that Jupiter may have a small rocky core of heavier elements at its center.

A Stormy Atmosphere

The upper layer of Jupiter's atmosphere contains clouds of ammonia (NH_3) in bands of different colors. These bands rotate around the planet, but also swirl around in turbulent storms. The **Great Red Spot** (**Figure** 8.45) is an enormous, oval-shaped storm found south of Jupiter's equator. This storm is more than three times as wide as the entire Earth. Clouds in the storm rotate in a counterclockwise direction, making one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years, since astronomers could first see the storm through telescopes. Do you think the Great Red Spot is a permanent feature on Jupiter? How could you know?

FIGURE 8.45

This image of Jupiter's Great Red Spot (upper right of image) was taken by the Voyager 1 spacecraft. The white storm just below the Great Red Spot is about the same diameter as Earth.

Jupiter's Moons and Rings

Jupiter has a very large number of moons – 63 have been discovered so far. Four are big enough and bright enough to be seen from Earth, using no more than a pair of binoculars. These moons —Io, Europa, Ganymede, and Callisto —were first discovered by Galileo in 1610, so they are sometimes referred to as the **Galilean moons** (**Figure** 8.46). The Galilean moons are larger than the dwarf planets Pluto, Ceres, and Eris. Ganymede is not only the biggest moon in the solar system it is even larger than the planet Mercury!

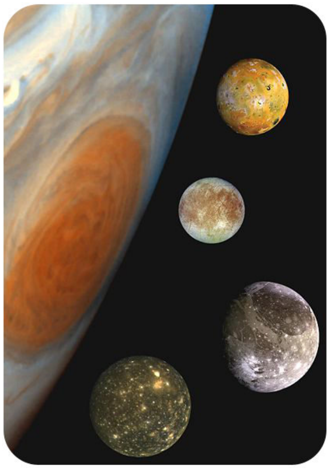


FIGURE 8.46
This composite image shows the four Galilean moons and their sizes relative to the Great Red Spot. From top to bottom, the moons are Io, Europa, Ganymede, and Callisto. Jupiter's Great Red Spot is in the background. Sizes are to scale.

Scientists are particularly interested in Europa because it may be a place to find extraterrestrial life. What features might make a satellite so far from the Sun a candidate for life? Although the surface of Europa is a smooth layer of ice, there is evidence that there is an ocean of liquid water underneath (**Figure** 8.47). Europa also has a continual source of energy —it is heated as it is stretched and squashed by tidal forces from Jupiter. Numerous missions have been planned to explore Europa, including plans to drill through the ice and send a probe into the ocean. However, no such mission has yet been attempted.

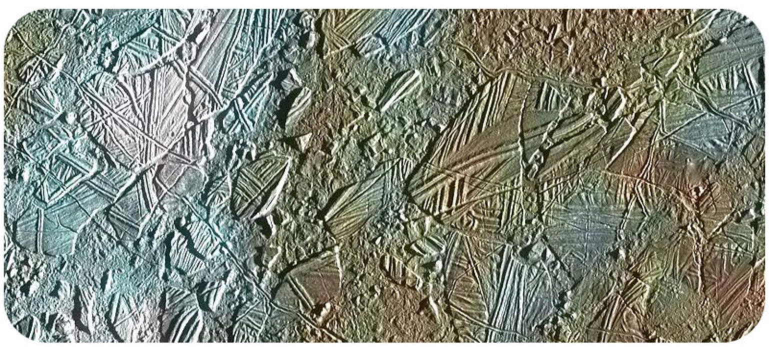


FIGURE 8.47
An enhanced color image of a portion of Europa's icy surface. The surface ice may have motions similar to plate tectonics on Earth.

In 1979, two spacecrafts —Voyager 1 and Voyager 2 —visited Jupiter and its moons. Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is difficult to observe from Earth.

Saturn

Saturn, shown in **Figure** 8.48, is famous for its beautiful rings. Although all the gas giants have rings, only Saturn's can be easily seen from Earth. In Roman mythology, Saturn was the father of Jupiter.

Saturn's mass is about 95 times the mass of Earth, and its volume is 755 times Earth's volume, making it the second largest planet in the solar system. Saturn is also the least dense planet in the solar system. It is less dense than water. What would happen if you had a large enough bathtub to put Saturn in? Saturn would float! Saturn orbits the Sun once about every 30 Earth years.

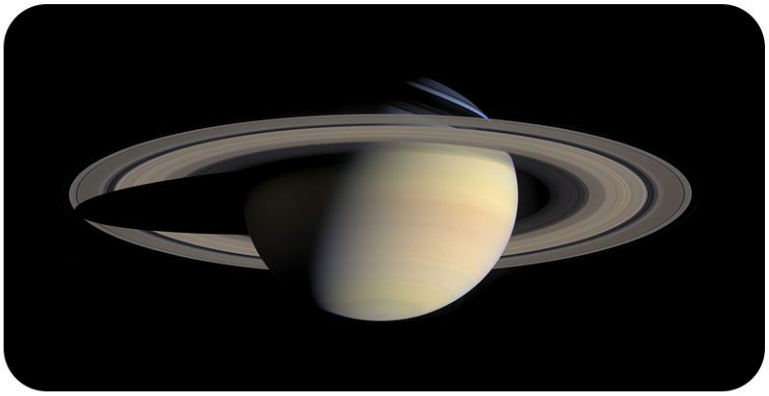


FIGURE 8.48
This image of Saturn and its rings is a composite of pictures taken by the Cassini orbiter in 2008

Like Jupiter, Saturn is made mostly of hydrogen and helium gases in the outer layers and liquids at greater depths. The upper atmosphere has clouds in bands of different colors. These rotate rapidly around the planet, but there seems to be less turbulence and fewer storms on Saturn than on Jupiter. One interesting phenomena that has been observed in the storms on Saturn is the presence of thunder and lightning (see video, below). The planet likely has a small rocky and metallic core.

Cassini scientists waited years for the right conditions to produce the first movie that shows lightning on another planet – Saturn. http://saturn.jpl.nasa.gov/video/videodetails/?videoID=210 Lots more videos from the Cassini mission are indexed here: http://saturn.jpl.nasa.gov/video/

Saturn's Rings

In 1610 Galileo first observed Saturn's rings with his telescope, but he thought they might be two large moons, one on either side of the planet. In 1659, the Dutch astronomer Christian Huygens realized that the features were rings (**Figure** 8.49).

Saturn's rings circle the planet's equator and appear tilted because Saturn itself is tilted about 27 degrees. The rings do not touch the planet.

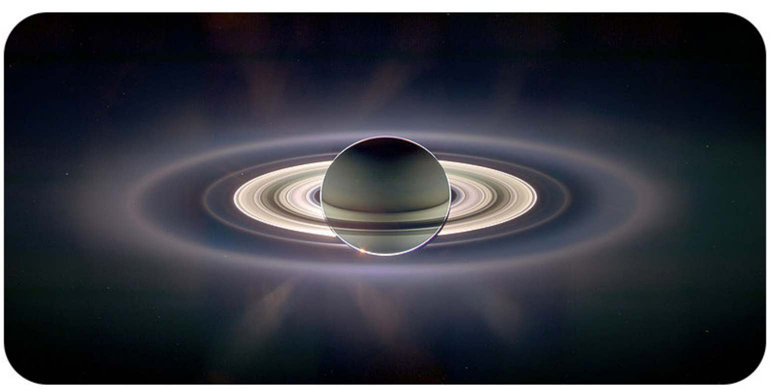


FIGURE 8.49
A color-exaggerated mosaic of Saturn and its rings taken by Cassini as Saturn eclipses the Sun.

The Voyager 1 and 2 spacecraft in 1980 and 1981 sent back detailed pictures of Saturn, its rings, and some of its moons. Saturn's rings are made of particles of water and ice, with some dust and rocks (**Figure** 8.50). There are several gaps in the rings that scientists think have originated because (1) the material was cleared out by the gravitational pull within the rings or (2) by the gravitational forces of Saturn and of moons outside the rings.

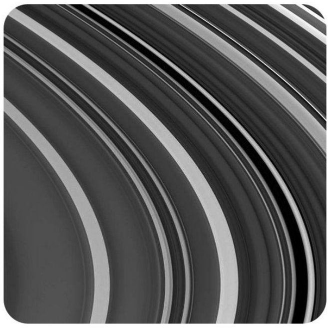


FIGURE 8.50
A close-up of Saturn's outer C ring showing areas with higher particle concentration and gaps.

The rings were likely formed by the breakup of one of Saturn's moons or from material that never accreted into the planet when Saturn originally formed.

An animation of dark spokes in Saturn's rings is seen here: http://en.wikipedia.org/wiki/File:Saturn_ring_spokes_PIA11144_300px_secs15.5to23_20080926.ogv . The spokes appear seasonally and their origin is as yet unknown.

Saturn's Moons

Most of Saturn's moons are very small and only seven are large enough for gravity to have made them spherical. Only Titan is larger than Earth's Moon at about 1.5 times its size. Titan is even larger than the planet Mercury.

Scientists are interested in Titan because its atmosphere is similar to what Earth's was like before life developed. Nitrogen is dominant and methane is the second most abundant gas. Titan may have a layer of liquid water and ammonia under a layer of surface ice. Lakes of liquid methane (CH_4) and ethane (C_2H_6) are found on Titan's surface. Although conditions are similar enough to those of early Earth for scientists to speculate that extremely primitive life may exist on Titan, the extreme cold and lack of carbon dioxide make it unlikely (**Figure** 8.51).

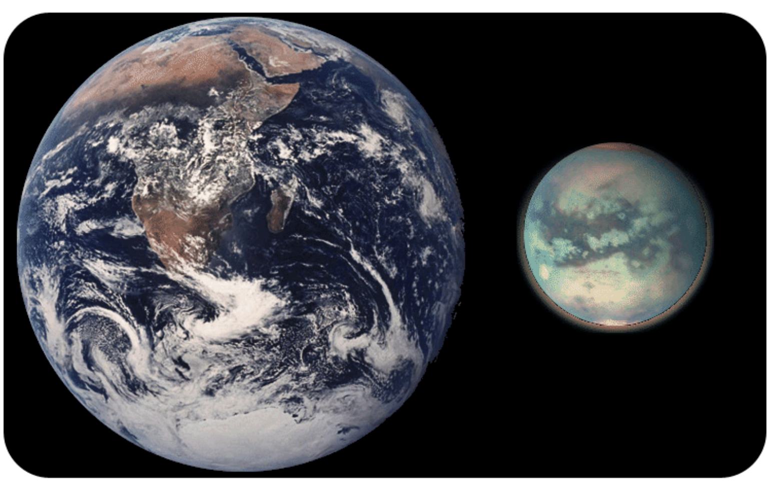


FIGURE 8.51
This composite image compares Saturn's largest moon, Titan (right) to Earth (left).

Uranus

Uranus (YOOR-uh-nuhs) is named for the Greek god of the sky (**Figure** 8.52). From Earth, Uranus is so faint that it was unnoticed by ancient observers. William Herschel first discovered the planet in 1781.

FIGURE 8.52
Uranus is an icy blue-green ball.

Although Uranus is very large, it is extremely far away, about 2.8 billion km (1.8 billion mi) from the Sun. Light from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

Uranus has a mass about 14 times the mass of Earth, but it is much less dense than Earth. Gravity at the surface of Uranus is weaker than on Earth's surface so if you were at the top of the clouds on Uranus, you would weigh about 10% less than what you weigh on Earth.

An Icy Blue-Green Ball

Like Jupiter and Saturn, Uranus is composed mainly of hydrogen and helium, with an outer gas layer that gives way to liquid on the inside. Uranus has a higher percentage of icy materials, such as water, ammonia (NH_3), and methane (CH_4), than Jupiter and Saturn.

When sunlight reflects off Uranus, clouds of methane filter out red light, giving the planet a blue-green color. There are bands of clouds in the atmosphere of Uranus, but they are hard to see in normal light, so the planet looks like a plain blue ball.

The Sideways Planet

Most of the planets in the solar system rotate on their axes in the same direction that they move around the Sun. Uranus, though, is tilted on its side so its axis is almost parallel to its orbit. In other words, it rotates like a top that was turned so that it was spinning parallel to the floor. Scientists think that Uranus was probably knocked over by a collision with another planet-sized object billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings (**Figure** 8.53). The rings circle the planet's equator, but because Uranus is tilted on its side, the rings are almost perpendicular to the planet's orbit.

Uranus has 27 known moons and all but a few of them are named for characters from the plays of William Shakespeare. The five biggest moons of Uranus —Miranda, Ariel, Umbriel, Titania, and Oberon —are shown in **Figure** 8.54.

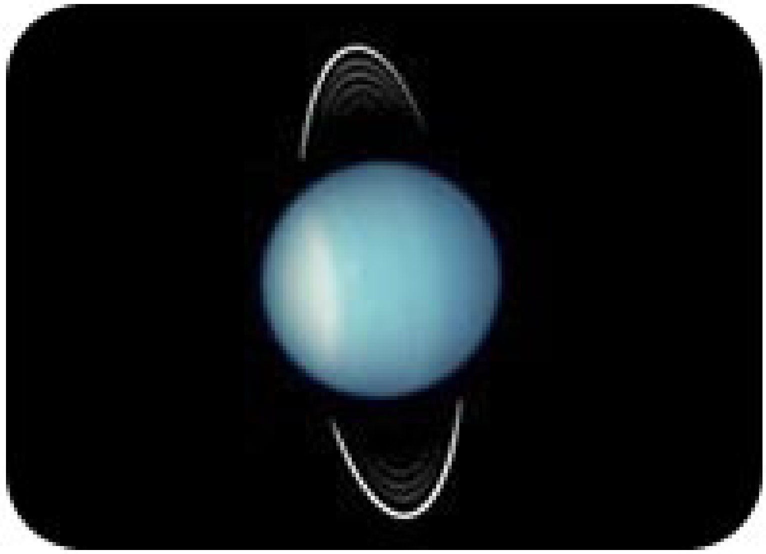


FIGURE 8.53
This image from the Hubble Space Telescope shows the faint rings of Uranus. The planet is tilted on its side, so the rings are nearly vertical.

FIGURE 8.54
These Voyager 2 photos have been resized to show the relative sizes of the five main moons of Uranus.

Neptune

Neptune, shown in **Figure** 8.55, is the only major planet that can't be seen from Earth without a telescope. Scientists predicted the existence of Neptune before it was discovered because Uranus did not always appear exactly where it should appear. They knew that the gravitational pull of another planet beyond Uranus must be affecting Uranus' orbit.

Neptune was discovered in 1846, in the position that had been predicted, and it was named Neptune for the Roman god of the sea because of its bluish color.

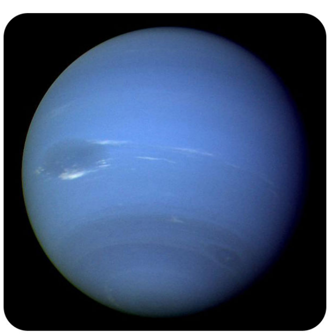


FIGURE 8.55
This image of Neptune was taken by Voyager 2 in 1989. The Great Dark Spot seen on the left center in the picture has since disappeared, but a similar dark spot has appeared on another part of the planet.

In many respects, Neptune is similar to Uranus (**Figure** 8.56). Neptune has slightly more mass than Uranus, but it is slightly smaller in size. Neptune is much farther from the Sun at nearly 4.5 billion km (2.8 billion mi). The planet's slow orbit means that it takes 165 Earth years to go once around the Sun.

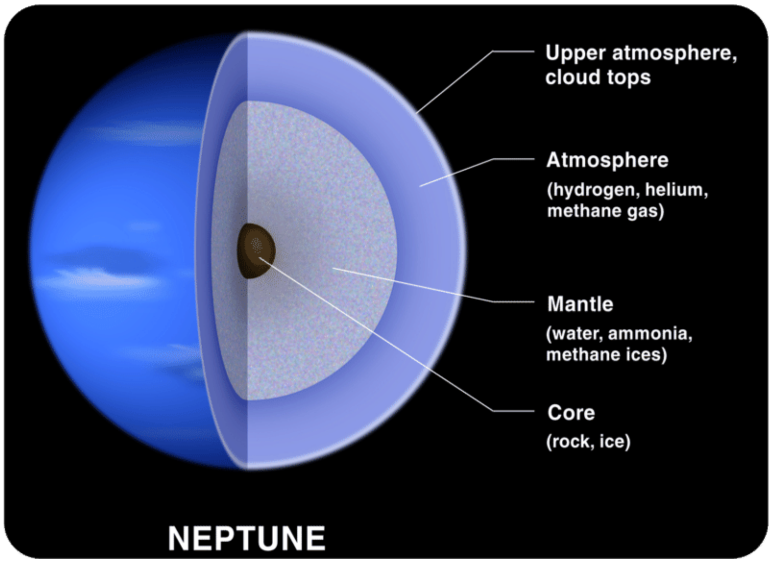


FIGURE 8.56
Neptune's composition is that of a gas giant: (1) upper atmosphere, (2) atmosphere composed of hydrogen, helium and methane gas, (3) mantle of water, ammonia and methane ice, (4) core of rock and ice.

Extremes of Cold and Wind

Neptune's blue color is mostly because of frozen methane (CH_4). When Voyager 2 visited Neptune in 1986, there was a large dark-blue spot that scientists named the Great Dark Spot, south of the equator. When the Hubble Space Telescope took pictures of Neptune in 1994, the Great Dark Spot had disappeared but another dark spot had appeared north of the equator. Astronomers think that both of these spots represent gaps in the methane clouds on Neptune.

The changing appearance of Neptune is caused by its turbulent atmosphere. The winds on Neptune are stronger than on any other planet in the solar system, reaching speeds of 1,100 km/h (700 mi/h), close to the speed of sound. This extreme weather surprised astronomers, since the planet receives little energy from the Sun to power weather systems. Neptune is also one of the coldest places in the solar system. Temperatures at the top of the clouds are about -218^{o}C (-360^{o}F).

Neptune's Rings and Moons

Neptune has faint rings of ice and dust that may change or disappear in fairly short time frames.

Neptune has 13 known moons. Triton, shown in **Figure** 8.57, is the only one of them that has enough mass to be spherical in shape. Triton orbits in the direction opposite to the orbit of Neptune. Scientists think Triton did not form around Neptune, but instead was captured by Neptune's gravity as it passed by.

Fly by Neptune's moon Triton by watching this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath#playerTop

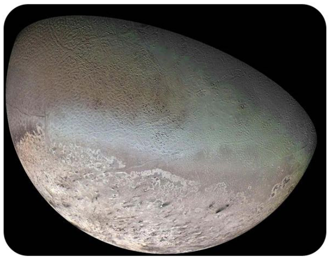


FIGURE 8.57
This image Triton, Neptune's largest moon, was taken by Voyager 2 in 1989.

Lesson Summary

- The four outer planets are all gas giants made primarily of hydrogen and helium. They have thick gaseous outer layers and liquid interiors.
- The outer planets have numerous moons, as well as planetary rings.
- Jupiter, by far the largest planet in the solar system, has bands of different colored clouds, and a long-lasting storm called the Great Red Spot.
- Jupiter has more than 60 moons including the four largest, the Galilean moons.
- Europa has an ocean of liquid water under a layer of ice where life may have formed.
- Saturn is smaller than Jupiter but has a large system of beautiful rings.
- Titan's atmosphere is similar to early Earth's and the moon could harbor primitive life.
- Uranus and Neptune were discovered relatively recently since they are so far away.
- Uranus is tilted on its side, probably because of a past collision with a large object.
- Neptune is very cold and has strong winds. Its dark spots are storms in Neptune's atmosphere.

Review Questions

1. Name the outer planets a) in order from the Sun outward, b) from largest to smallest by mass, and c) from largest to smallest by size.
2. Why are the outer planets called gas giants?
3. How do the Great Red Spot and Great Dark Spot differ?
4. Name the Galilean moons, and explain why they have that name.
5. Why might Europa be a likely place to find extraterrestrial life?
6. What causes gaps in Saturn's rings?
7. Why are scientists interested in the atmosphere of Saturn's moon Titan?
8. What liquid is found on the surface of Titan?
9. Why is Uranus blue-green in color?
10. What is the name of Neptune's largest moon?

Further Reading / Supplemental Links

- Cool jobs! Planetary meteorologist: http://news.discovery.com/videos/discovery-news-2009-planetary-meteorologist.html
- About the Cassini Mission to Saturn: http://saturn.jpl.nasa.gov/
- NASA's world book, Jupiter: http://www.nasa.gov/worldbook/jupiter_worldbook.html
- NASA's planet selector: http://solarsystem.nasa.gov/planetselector.cfm
- Short videos of the planet Jupiter: http://www.youtube.com/watch?v=5iVw72sX3Bg;
- Video of Saturn: http://www.youtube.com/watch?v=iLXeUVCNoX8
- From the BBC Documentary, The Planets, Neptune: http://www.youtube.com/watch?v=29wfzotaBIg

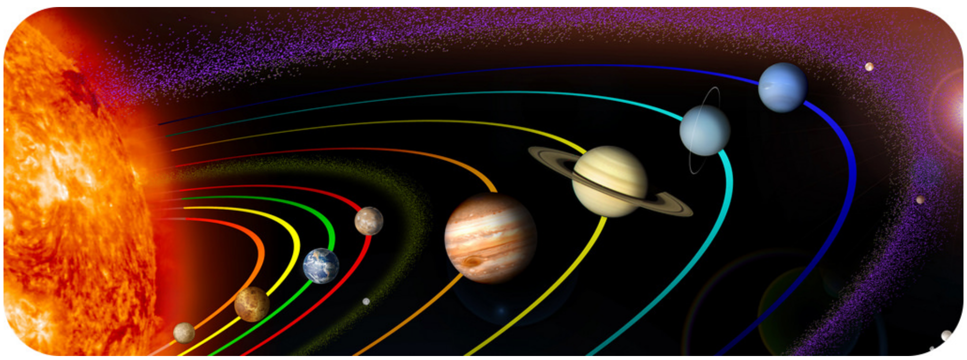
Points to Consider

- The inner planets are small and rocky, while the outer planets are large and gaseous. Why might the planets have formed into these two groups?
- We have discussed the Sun, the planets, and the moons of the planets. What other objects can you think of that can be found in our solar system?

8.8 Kepler's Laws of Planetary Motion

Learning Objectives

- Describe Kepler's three laws.
- Calculate satellite periods given average radius and vice versa.



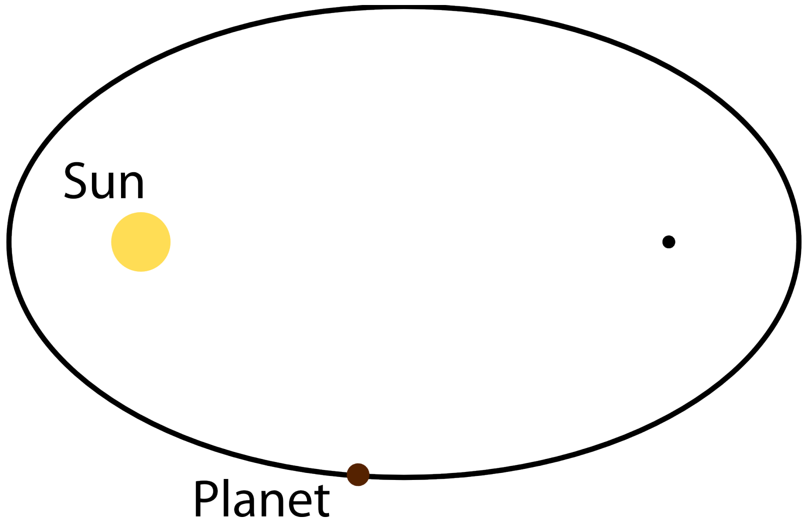
Though a drawing, not an accurate portrayal of the solar system, the elliptical appearance of the orbits is correct. The elliptical orbits around the sun are not limited to the planets; comets, asteroids, and other orbiting objects also follow elliptical paths.

Kepler's Laws

Fifty years before Newton proposed his three laws of motion and his law of universal gravitation, Johannes Kepler (1571 - 1630) published a number of astronomical papers with detailed descriptions of the motions of the planets. Included in those papers were the findings that we now refer to as *Kepler's Laws of Planetary Motion.* These are summarized below.

Kepler's First Law

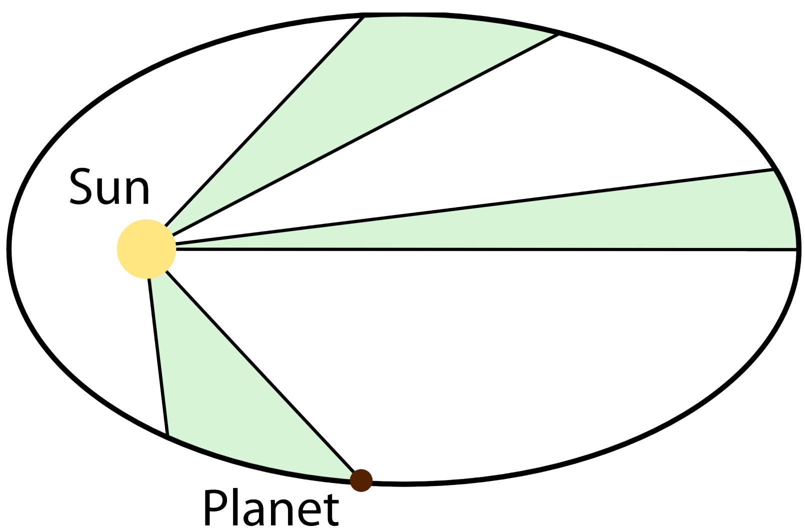
The path of each planet around the sun is an ellipse with the sun at one focus.



Though it seems at first glance that this law is incorrect (the sun appears to be in the center of our orbit), remember that a perfect circle is an ellipse with the foci in the same place. Since the Earth's orbit is nearly circular, the sun appears to stay in the center.

Kepler's Second Law

As a planet moves in its orbit, a line from the sun to the planet sweeps out equal areas in equal times.



The image above illustrates this relationship. Though the green wedges may appear significantly different in area, Kepler's Second Law states that the areas are equal if the planet travels along the perimeter of the segments in equal periods of time. From this, we can clearly see that the planet moves with greater speed when it is near the sun and slower when it is far away.

Kepler's Third Law

The ratio of the squares of the periods of any two planets revolving around the sun is equal to the ratio of the cubes of their average distance from the sun.

$$\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{r_1}{r_2}\right)^3$$

This is the only one of Kepler's three laws that deals with more than one planet at a time.

This equation can be reworked to reveal that the ratio between the period and the radius of the planet's orbit is always the same:

$$\frac{(T_1)^2}{(r_1)^3} = \frac{(T_2)^2}{(r_2)^3}$$

In truth, it has been calculated that this ratio holds for all the planets in our solar system, in addition to moons and other satellites.

Example

The planet Venus has a mean distance from the sun of 108.2 $\times 10^6$ km and a period of 0.615 years. The planet Mars has an average mean distance from the sun of 227.9 $\times 10^6$ km and a period of 1.88 years. Do these planets follow Kepler's third law?

The average mean distance of Venus divided by the average mean distance of Mars = 0.475. The period of Venus divided by the period of Mars = 0.327.

The square of the period ratio is 0.107 and the cube of the mean distance ratio is 0.107. It is clear that these two planets follow Kepler's third law.

Summary

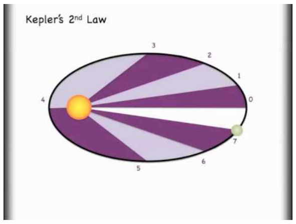
- Kepler's First Law: The path of each planet around the sun is an ellipse with the sun at one focus.
- Kepler's Second Law: Each planet moves such that an imaginary line drawn from the sun to the planet sweeps out equal areas in equal periods of time.
- Kepler's Third Law: The ratio of the squares of the periods of any two planets revolving around the sun is equal to the ratio of the cubes of their average distance from the sun.

Review

1. The average mean distance of the earth from the sun is 149.6 $\times 10^6$ km and the period of the earth is 1.0 year. The average mean distance of Saturn from the sun is 1427 $\times 10^6$ km. Using Kepler's third law, calculate the period of Saturn.
2. Which of the following is one of Kepler's Laws of Planetary Motion?
    1. Planets move in elliptical orbits with the Sun at one focus.
    2. Gravitational force between two objects decreases as the distance squared.
    3. An object in motion remains in motion.
    4. Inner planets orbit in a different direction that outer ones.
3. If a planet's orbital speed is 20 km/s when it's at its average distance from the sun, which is most likely orbital speed when it is nearest the sun?
    1. 10 km/s
    2. 15 km/s
    3. 20 km/s
    4. 25 km/s

Explore More

Use this resource to answer the questions that follow.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/62072

1. What is the shape of a planetary orbit?
2. How are the areas swept out by the line able to be equal, when the line is much longer at some times than others?
3. What is the T in Kepler's Third Law? What is the r?

Vocabulary

- **Kepler's First Law:** The path of each planet around the sun is an ellipse with the sun at one focus.
- **Kepler's Second Law:** Each planet moves such that an imaginary line drawn from the sun to the planet sweeps out equal areas in equal periods of time.
- **Kepler's Third Law:** The ratio of the squares of the periods of any two planets revolving around the sun is equal to the ratio of the cubes of their average distance from the sun.

8.9 Other Objects in the Solar System

Lesson Objectives

- Locate and describe the asteroid belt.
- Explain where comets come from and what causes their tails.
- Differentiate between meteors, meteoroids, and meteorites.

Vocabulary

- asteroid
- asteroid belt
- comet
- dwarf planet
- Kuiper belt
- meteor
- meteor shower
- meteoroid

Introduction

When the solar system formed, most of the matter ended up in the Sun. Material spinning in a disk around the Sun clumped together into larger and larger pieces to form the eight planets. But some of the smaller pieces of matter never joined one of these larger bodies and are still out there in space.

Asteroids

Asteroids are very small, rocky bodies that orbit the Sun. "Asteroid" means "star-like," and in a telescope, asteroids look like points of light, just like stars. Asteroids are irregularly shaped because they do not have enough gravity to become round. They are also too small to maintain an atmosphere and without internal heat they are not geologically active (**Figure** 8.58). Collisions with other bodies may break up the asteroid or create craters on its surface.

Asteroid impacts have had dramatic impacts on the shaping of the planets, including Earth. Early impacts caused the planets to grow as they cleared their portions of space. An impact with an asteroid about the size of Mars caused fragments of Earth to fly into space and ultimately create the Moon. Asteroid impacts are linked to mass extinctions throughout Earth history.

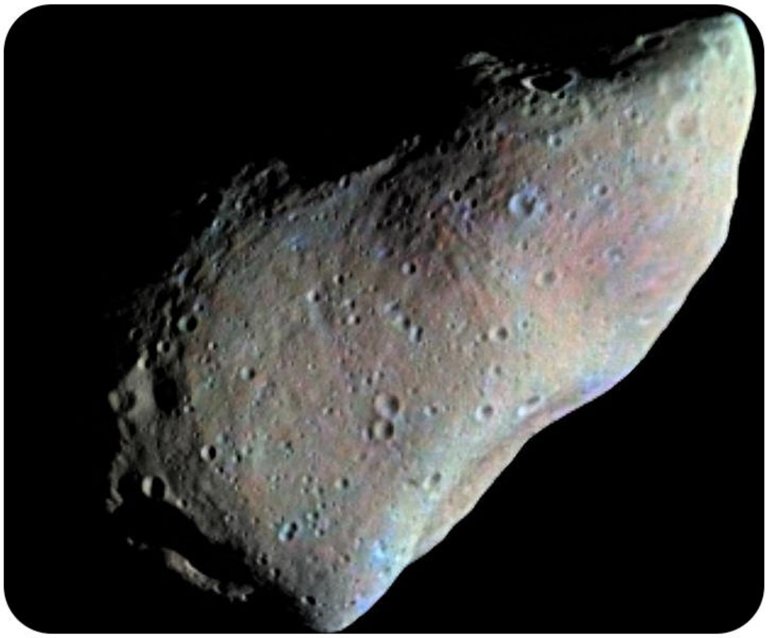


FIGURE 8.58
In 1991, Asteroid 951 Gaspra was the first asteroid photographed at close range. Gaspra is a medium-sized asteroid, measuring about 19 by 12 by 11 km (12 by 7.5 by 7 mi).

The Asteroid Belt

Hundreds of thousands of asteroids have been discovered in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month. The majority of the asteroids are found in between the orbits of Mars and Jupiter, in a region called the **asteroid belt**, as shown in **Figure** 8.59. Although there are many thousands of asteroids in the asteroid belt, their total mass adds up to only about 4% of Earth's moon.

Scientists think that the bodies in the asteroid belt formed during the formation of the solar system. The asteroids might have come together to make a single planet, but they were pulled apart by the intense gravity of Jupiter.

Near-Earth Asteroids

More than 4,500 asteroids cross Earth's orbit; they are near-Earth asteroids. Between 500 and 1,000 of these are over 1 km in diameter.

Any object whose orbit crosses Earth's can collide with Earth and many asteroids do. On average, each year a rock about 5–10 m in diameter hits Earth (**Figure** 8.60). Since past asteroid impacts have been implicated in mass extinctions, astronomers are always on the lookout for new asteroids, and follow the known near-Earth asteroids closely, so they can predict a possible collision as early as possible.

Asteroid Missions

Scientists are interested in asteroids because they are representatives of the earliest solar system (**Figure** 8.61). Eventually asteroids could be mined for rare minerals or for construction projects in space. A few missions have studied asteroids directly. NASA's DAWN mission orbited asteroid Vesta from July 2011 to September 2012 and is on its way to meet dwarf planet Ceres in 2015.

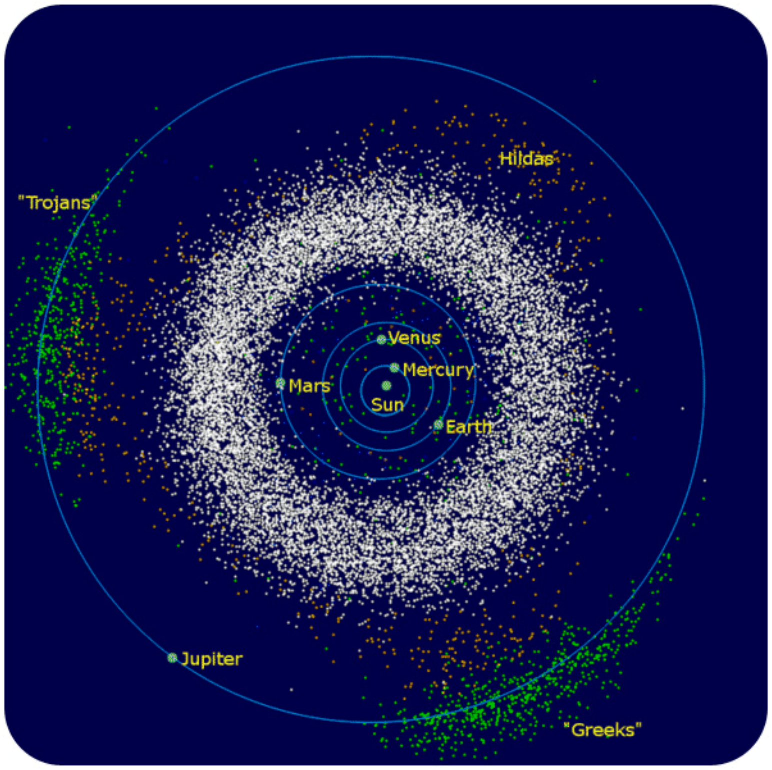


FIGURE 8.59
The white dots in the figure are asteroids in the main asteroid belt. Other groups of asteroids closer to Jupiter are called the Hildas (orange), the Trojans (green), and the Greeks (also green).

FIGURE 8.60
A painting of what an asteroid a few kilometers across might look like as it strikes Earth.

KQED: Asteroid Hunters

Thousands of objects, including comets and asteroids, are zooming around our solar system; some could be on a collision course with Earth. QUEST explores how these Near Earth Objects are being tracked and what scientists are saying should be done to prevent a deadly impact. Learn more at: http://science.kqed.org/quest/video/asteroid-hunters/ .

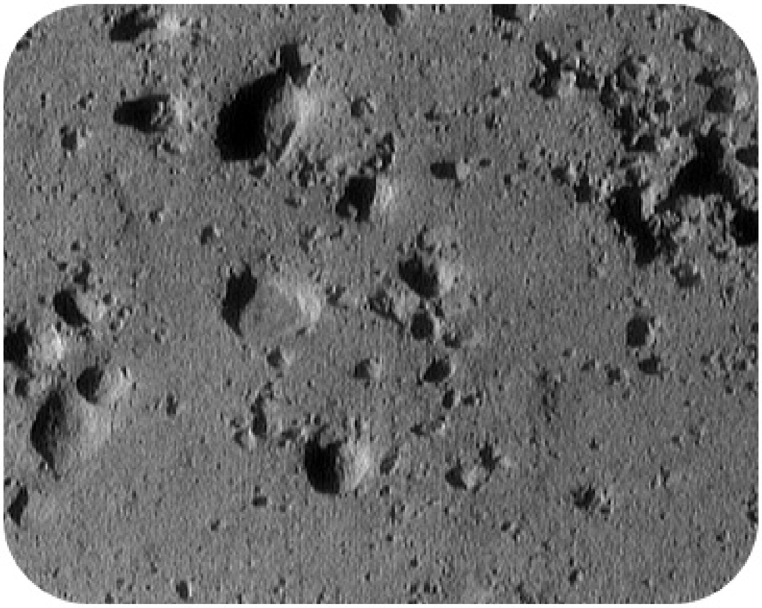


FIGURE 8.61
The NEAR Shoemaker probe took this photo as it was about to land on 433 Eros in 2001.

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/114950

Meteors

A **meteor**, such as in **Figure** 8.62, is a streak of light across the sky. People call them shooting stars but they are actually small pieces of matter burning up as they enter Earth's atmosphere from space.

Meteors are called **meteoroids** before they reach Earth's atmosphere. Meteoroids are smaller than asteroids and range from the size of boulders down to the size of tiny sand grains. Still smaller objects are called interplanetary dust. When Earth passes through a cluster of meteoroids, there is a **meteor shower**. These clusters are often remnants left behind by comet tails.

Meteorites

Although most meteors burn up in the atmosphere, larger meteoroids may strike the Earth's surface to create a meteorite. Meteorites are valuable to scientists because they provide clues about our solar system. Many meteorites are from asteroids that formed when the solar system formed (**Figure** 8.63). A few meteorites are made of rocky material that is thought to have come from Mars when an asteroid impact shot material off the Martian surface and into space.

FIGURE 8.62
A meteor streaks across the sky.

FIGURE 8.63
A lunar meteorite originates on the Moon and strikes Earth.

Comets

Comets are small, icy objects that have very elliptical orbits around the Sun. Their orbits carry them from the outer solar system to the inner solar system, close to the Sun (**Figure** 8.64). Early in Earth's history, comets may have brought water and other substances to Earth during collisions.

Comet tails form the outer layers of ice melt and evaporate as the comet flies close to the Sun. The ice from the comet vaporizes and forms a glowing coma, which reflects light from the Sun. Radiation and particles streaming from the Sun push this gas and dust into a long tail that always points away from the Sun (**Figure** 8.65). Comets

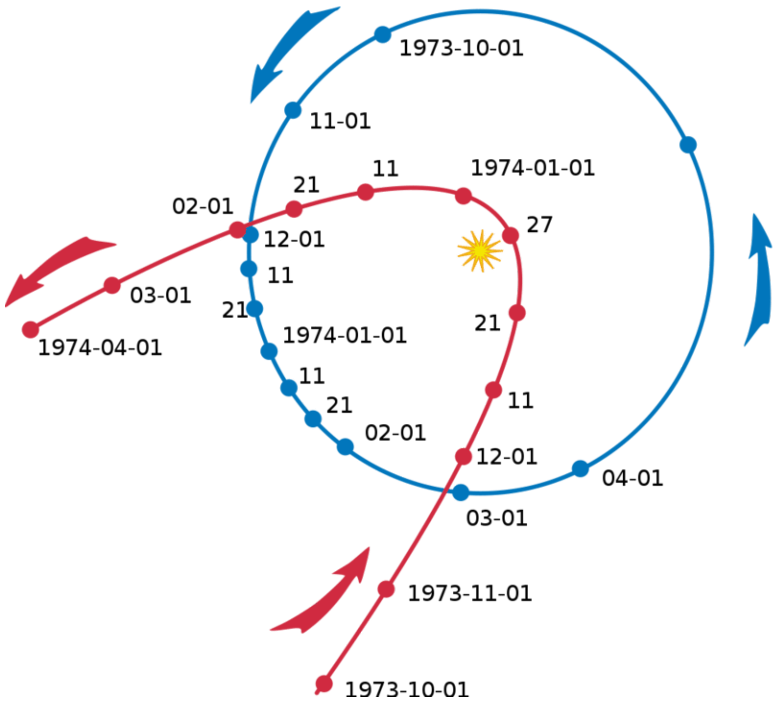

FIGURE 8.64
The highly elliptical orbit of Kohoutek (red) relative to Earth's more circular orbit (blue) and the position of the Sun.

appear for only a short time when they are near the Sun, then seem to disappear again as they move back to the outer solar system.

FIGURE 8.65
Comet Hale-Bopp, also called the Great Comet of 1997, shone brightly for several months in 1997. The comet has two visible tails: a bright, curved dust tail and a fainter, straight tail of ions (charged atoms) pointing directly away from the Sun.

The time between one appearance of a comet and the next is called the comet's period. Halley's comet, with a period of 75 years, will next be seen in 2061. The first mention of the comet in historical records may go back as much as two millennia.

Where Comets Come From

Short-period comets, with periods of about 200 years or less, come from a region beyond the orbit of Neptune. The **Kuiper belt** (pronounced "KI-per") contains not only comets, but asteroids, and at least two dwarf planets.

Comets with periods as long as thousands or even millions of years come from a very distant region of the solar system called the Oort cloud, about 50,000–100,000 AU from the Sun (50,000–100,000 times the distance from the

Sun to Earth).

Dwarf Planets

The **dwarf planets** of our solar system are exciting proof of how much we are learning about our solar system. With the discovery of many new objects in our solar system, in 2006, astronomers refined the definition of a planet. Their subsequent reclassification of Pluto to the new category dwarf planet stirred up a great deal of controversy. How the classification of Pluto has evolved is an interesting story in science. The question is: What is and is not a planet?

Pluto

From the time it was discovered in 1930 until the early 2000s Pluto was considered the ninth planet. When astronomers first located Pluto, the telescopes were not as good so Pluto and its moon, Charon, were seen as one much larger object (**Figure** 8.66). With better telescopes, astronomers realized that Pluto was much smaller than they had thought.

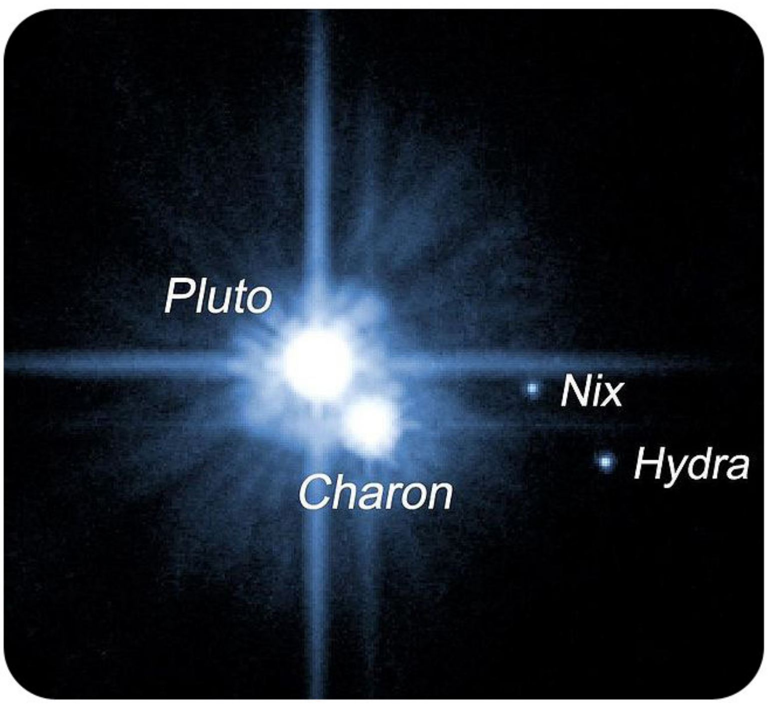

FIGURE 8.66
Pluto and its moon Charon are actually two objects.

Better technology also allowed astronomers to discover many smaller objects like Pluto that orbit the Sun. One of them, Eris, discovered in 2005, is even larger than Pluto (**Figure** 8.67).

Even when it was considered a planet, Pluto was an oddball. Unlike the other outer planets in the solar system, which are all gas giants, it is small, icy, and rocky. With a diameter of about 2,400 km, it is only about one-fifth the mass of Earth's Moon. Pluto's orbit is tilted relative to the other planets and is shaped like a long, narrow ellipse. Pluto's orbit sometimes even passes inside Neptune's orbit.

In 1992 Pluto's orbit was recognized to be part of the Kuiper belt. With more than 200 million Kuiper belt objects, Pluto has failed the test of clearing other bodies out its orbit.

FIGURE 8.67
Eris and its moon Dysnomia.

From what you've read above, do you think Pluto should be called a planet? Why are people hesitant to take away Pluto's planetary status?

In 2006, the International Astronomical Union decided that there were too many questions surrounding what could be called a planet and so refined the definition of a planet.

According to the new definition, a planet must:

- Orbit a star.
- Be big enough that its own gravity causes it to be shaped as a sphere.
- Be small enough that it isn't a star itself.
- Have cleared the area of its orbit of smaller objects.

A dwarf planet is an object that meets items the first three items in the list above, but not but not the fourth. Pluto is now called a dwarf planet, along with the objects Ceres, Makemake, and Eris.

According to the IAU, a dwarf planet must:

- Orbit a star.
- Have enough mass to be nearly spherical.
- Not have cleared the area around its orbit of smaller objects.
- Not be a moon.

A video showing why Pluto isn't a planet any more: http://www.youtube.com/watch?v=FqX2YdnwtRc .

Pluto has three moons of its own. The largest, Charon, is big enough that the Pluto-Charon system is sometimes considered to be a double dwarf planet (**Figure** 8.69). Two smaller moons, Nix and Hydra, were discovered in 2005. But having moons is not enough to make an object a planet.

Ceres

Ceres is the largest object in the asteroid belt (**Figure** 8.68). Before 2006, Ceres was considered the largest of the asteroids, with only about 1.3% of the mass of the Earth's Moon. But unlike the asteroids, Ceres has enough mass that its gravity causes it to be shaped like a sphere. Like Pluto, Ceres is rocky.

Is Ceres a planet? How does it match the criteria above? Ceres orbits the Sun, is round, and is not a moon. As part of the asteroid belt, its orbit is full of other smaller bodies, so Ceres fails the fourth criterion for being a planet.

FIGURE 8.68
This composite image compares the size of the dwarf planet Ceres to Earth and the Moon.

Makemake

Makemake is the third largest and second brightest dwarf planet we have discovered so far (**Figure** 8.69). With a diameter estimated to be between 1,300 and 1,900 km, it is about three-quarters the size of Pluto. Makemake orbits the Sun in 310 years at a distance between 38.5 to 53 AU. It is thought to be made of methane, ethane, and nitrogen ices.

Eris

Eris is the largest known dwarf planet in the solar system —about 27% more massive than Pluto. The object was not discovered until 2003 because it is about three times farther from the Sun than Pluto, and almost 100 times farther from the Sun than Earth is. For a short time Eris was considered the "tenth planet" in the solar system, but its discovery helped to prompt astronomers to better define planets and dwarf planets in 2006. Eris also has a small moon, Dysnomia that orbits it once about every 16 days.

Astronomers know there may be other dwarf planets in the outer reaches of the solar system. Haumea was made a dwarf planet in 2008 and so now the total is five. Quaoar, Varuna and Orcus may be added to the list of dwarf planets in the future. We still have a lot to discover and explore.

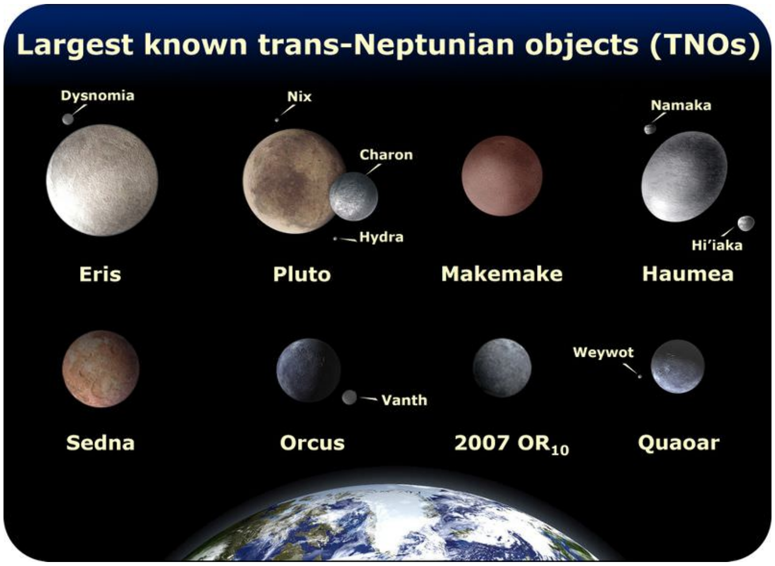

FIGURE 8.69

Largest Known Trans-Neptunian Objects. Makemake is named after the deity that created humanity in the mythology of the people of Easter Island.

Lesson Summary

- Asteroids are irregularly shaped, rocky bodies that orbit the Sun. Most are found in the asteroid belt, between the orbits of Mars and Jupiter.
- Meteoroids are smaller than asteroids, ranging from the size of boulders to the size of sand grains. When meteoroids enter Earth's atmosphere, they vaporize, creating a trail of glowing gas called a meteor. If any of the meteoroid reaches Earth, it is a meteorite.
- Comets are small, icy objects that have very elliptical orbits. When they are close to the Sun, they form comas and tails, which glow and make the comet more visible.
- Short-period comets come from the Kuiper belt, beyond Neptune. Long-period comets come from the very distant Oort cloud.
- Dwarf planets are spherical bodies that orbit the Sun, but that have not cleared their orbit of smaller bodies. Ceres is a dwarf planet in the asteroid belt. Pluto, Makemake and Eris are dwarf planets in the Kuiper belt.

Review Questions

1. Arrange the following from smallest to largest: asteroid, star, meteoroid, planet, dwarf planet.
2. Where are most asteroids found?
3. What is the difference between a meteor, a meteoroid, and a meteorite?
4. Why are meteorites extremely valuable to scientists?
5. What objects would scientists study to learn about the composition of the Oort cloud?
6. Why is Pluto no longer considered a planet?
7. Name the four known dwarf planets in our solar system.

Further Reading / Supplemental Links

- NASA worldbook on asteroids: http://www.nasa.gov/worldbook/asteroid_worldbook.html

Points to Consider

- In 2006, astronomers changed the definition of a planet and created a new category of dwarf planets. Do you think planets, dwarf planets, moons, asteroids, and meteoroids are clearly separate groups?
- What defines each of these groups, and what do objects in these different groups have in common? Could an object change from being in one group to another? How?
- We have learned about many different kinds of objects that are found within our solar system. What objects or systems of objects can you think of that are found outside our solar system?

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CONCEPT 9

Unit 5: Momentum and Collision

Questions/Observable Phenomena

Concept 10 Momentum and Impulse

Learning Objectives

- Define momentum.
- Define impulse.
- Given mass and velocity of an object, calculate momentum.
- Calculate the change in momentum of an object.
- State the relationship that exists between the change in momentum and impulse.
- Using the momentum-impulse theorem and given three of the four variables, calculate the fourth.

Rachel Flatt performs a layback spin at the 2011 Rostelecom Cup in Moscow, Russia.

When an ice skater spins, angular momentum must be conserved. When her arms or feet are far away from her body, her spin slows; when she brings her arms and feet close in to her body, she spins faster.

Momentum and Impulse

If a bowling ball and a ping-pong ball are each moving with a velocity of 5 mph, you intuitively understand that it will require more effort to stop the bowling ball than the ping pong ball because of the greater mass of the bowling ball. Similarly, if you have two bowling balls, one moving at 5 mph and the other moving at 10 mph, you know it will take more effort to stop the ball with the greater speed. It is clear that both the mass and the velocity of a moving object contribute to what is necessary to change the motion of the moving object. The product of the mass and velocity of an object is called its **momentum.** Momentum is a vector quantity that has the same direction as the velocity of the object and is represented by a lowercase letter p.

$p = mv$

The momentum of a 0.500 kg ball moving with a velocity of 15.0 m/s will be

$$p = mv = (0.500 \text{ kg})(15.0 \text{ m/s}) = 7.50 \text{ kg} \cdot \text{m/s}$$

You should note that the units for momentum are kg·m/s.

According to Newton's first law, the velocity of an object cannot change unless a force is applied. If we wish to change the momentum of a body, we must apply a force. The longer the force is applied, the greater the change in momentum. The **impulse** is the quantity defined as the force multiplied by the time it is applied. It is a vector quantity that has the same direction as the force. The units for impulse are N·s but we know that Newtons are also kg·m/s^2 and so N·s = (kg·m/s^2)(s) = kg·m/s. Impulse and momentum have the same units; when an impulse is applied to an object, the momentum of the object changes and the change of momentum is equal to the impulse.

$Ft = \Delta mv$

Example 1

A 0.15 kg ball is moving with a velocity of 35 m/s. Find the momentum of the ball.

$p = mv = (0.15 \text{ kg})(35 \text{ m/s}) = 5.25 \text{ kg} \cdot \text{m/s}$

Example 2

If a ball with mass 5.00 kg has a momentum of 5.25 kg · m/s, what is its velocity?

$v = \frac{p}{m} = \frac{5.25 \textbf{ kg·m/s}}{5.00 \textbf{ kg}} = 1.05 \textbf{ m/s}$

It should be clear from the equation relating impulse to change in momentum, $Ft = \Delta mv$, that any amount of force would (eventually) bring a moving object to rest. If the force is very small, it must be applied for a long time, but a greater force can bring the object to rest in a shorter period of time.

If you jump off a porch and land on your feet with your knees locked in the straight position, your motion would be brought to rest in a very short period of time and thus the force would need to be very large - large enough, perhaps, to damage your joints or bones.

Suppose that when you hit the ground, your velocity was 7.0 m/s and that velocity was brought to rest in 0.05 seconds. If your mass is 100. kg, what force was required to bring you to rest?

$F = \frac{\Delta mv}{t} = \frac{(100. \text{ kg})(7.0 \text{ m/s})}{0.050 \text{ s}} = 14,000 \text{ N}$

If, on the other hand, when your feet first touched the ground, you allowed your knees to flex so that the period of time over which your body was brought to rest is increased, then the force on your body would be smaller and it would be less likely that you would damage your legs.

Suppose that when you first touch the ground, you allow your knees to bend and extend the stopping time to 0.50 seconds. What force would be required to bring you to rest this time?

$F = \frac{\Delta mv}{t} = \frac{(100. \text{ kg})(7.0 \text{ m/s})}{0.50 \text{ s}} = 1400 \text{ N}$

With the longer period of time for the force to act, the necessary force is reduced to one-tenth of what was needed before.

Extending the period of time over which a force acts in order to lessen the force is a common practice in design. Padding in shoes and seats allows the time to increase. The front of automobiles are designed to crumple in an accident; this increases the time the car takes to stop. Similarly, barrels of water or sand in front of abutments on the highway and airbags serve to slow down the stoppage time. These changes all serve to decrease the amount of force it takes to stop the momentum in a car crash, which consequently saves lives.

Example 3

An 0.15 kg baseball is thrown horizontally at 40. m/s and after it is struck by a bat, it is traveling at -40. m/s.

(a) What impulse did the bat deliver to the ball?

(b) If the contact time of the bat and bat was 0.00080 seconds, what was the average force the bat exerted on the ball?

(c) Calculate the average acceleration of the ball during the time it was in contact with the bat.

We can calculate the change in momentum and give the answer as impulse because we know that the impulse is equal to the change in momentum.

(a)

$$\begin{aligned} p = m\Delta v &= (0.15 \text{ kg})(-40. \text{ m/s} - 40. \text{ m/s}) \\ &= (0.15 \text{ kg})(-80. \text{ m/s}) = -12 \text{ kg}\cdot\text{m/s} \end{aligned}$$

The minus sign indicates that the impulse was in the opposite direction of the original throw.

(b) $F = \frac{\Delta mv}{t} = \frac{-12 \text{ kg}\cdot\text{m/s}}{0.00080 \text{ s}} = -15000 \text{ N}$

Again, the negative sign indicates the force was in the opposite direction of the original throw.

(c) $a = \frac{F}{m} = \frac{-15000 \text{ N}}{0.15 \text{ kg}} = -100,000 \text{ m/s}^2$

Summary

- The product of the mass and velocity of an object is called momentum, given by the equation $\rho = mv$.
- Momentum is a vector quantity that has the same direction as the velocity of the object.
- The quantity of force multiplied by the time it is applied is called impulse.
- Impulse is a vector quantity that has the same direction as the force.
- Momentum and impulse have the same units: kg·m/s.
- The change of momentum of an object is equal to the impulse. $Ft = \Delta mv$

Review

1. A small car with a mass of 800. kg is moving with a velocity of 27.8 m/s.
    1. What is the momentum of the car?
    2. What velocity is needed for a 2400. kg car in order to have the same momentum?
2. A scooter has a mass of 250. kg. A constant force is exerted on it for 60.0 s. During the time the force is exerted, the scooter increases its speed from 6.00 m/s to 28.0 m/s.
    1. What is the change in momentum?
    2. What is the magnitude of the force exerted on the scooter?

3. The brakes on a 15,680 N car exert a stopping force of 640. N. The car's velocity changes from 20.0 m/s to 0 m/s.
    1. What is the car's mass?
    2. What was its initial momentum?
    3. What was the change in momentum for the car?
    4. How long does it take the braking force to bring the car to rest?

Explore More

Use this resource to answer the question that follows.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/112422

1. Why don't the glasses of water spill when the tablecloth is pulled out from under them?
2. How does the video get from momentum to impulse?

Vocabulary

- **momentum:** A measure of the motion of a body equal to the product of its mass and velocity. Also called linear momentum**.**
- **impulse:** The product obtained by multiplying the average value of a force by the time during which it acts. The impulse equals the change in momentum produced by the force in this time interval.

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CONCEPT 11 Conservation of Momentum in One Dimension

Learning Objectives

- State the law of conservation of momentum.
- Use the conservation of momentum to solve one-dimensional collision problems.

For this whale to leap out of the water, something underwater must be moving in the opposite direction, and intuition tells us it must be moving with relatively high velocity. The water that moves downward is pushed downward by the whale's tail, and that allows the whale to rise up.

Conservation of Momentum in One Dimension

When impulse and momentum were introduced, we used an example of a batted ball to discuss the impulse and momentum change that occurred with the ball. At the time, we did not consider what had happened to the bat. According to Newton's third law, however, when the bat exerted a force on the ball, the ball also exerted an equal and opposite force on the bat. Since the time of the collision between bat and ball is the same for the bat and for the ball, then we have equal forces (in opposite directions) exerted for equal times on the ball AND the bat. That means that the impulse exerted on the bat is equal and opposite (-Ft) to the impulse on the ball (Ft) and that also means that there was a change in momentum of the bat $[-\Delta(mv)_{\text{BAT}}]$ that was equal and opposite to the change in momentum of the ball $[\Delta(mv)_{\text{BALL}}]$.

The change in momentum of the ball is quite obvious because it changes direction and flies off at greater speed. However, the change in momentum of the bat is not obvious at all. This occurs primarily because the bat is more massive than the ball. Additionally, the bat is held firmly by the batter, so the batter's mass can be combined with the mass of the bat. Since the bat's mass is so much greater than that of the ball, but they have equal and opposite forces, the bat's final velocity is significantly smaller than that of the ball.

Consider another system: that of two ice skaters. If we have one of the ice skaters exert a force on the other skater, the force is called an **internal force** because both the object exerting the force and the object receiving the force are inside the system. In a closed system such as this, momentum is always conserved. The total final momentum always equals the total initial momentum in a closed system. Conversely, if we defined a system to contain just one ice skater, putting the other skater outside the system, this is not a closed system. If one skater pushes the other, the force is an external force because the receiver of the force is outside the system. Momentum is not guaranteed to be conserved unless the system is closed.

In a closed system, momentum is always conserved. Take another example: if we consider two billiard balls colliding on a billiard table and ignore friction, we are dealing with a closed system. The momentum of ball *A* before the collision plus the momentum of ball *B* before collision will equal the momentum of ball *A* after collision plus the momentum of ball *B* after collision. This is called the law of **conservation of momentum** and is given by the equation

$$p_{A\text{before}} + p_{B\text{before}} = p_{A\text{after}} + p_{B\text{after}}$$

Example 1

Ball *A* has a mass of 2.0 kg and is moving due west with a velocity of 2.0 m/s while ball *B* has a mass of 4.0 kg and is moving west with a velocity of 1.0 m/s. Ball *A* overtakes ball *B* and collides with it from behind. After the collision, ball *A* is moving westward with a velocity of 1.0 m/s. What is the velocity of ball *B* after the collision?

Because of the law of conservation of momentum, we know that

$$p_{A\text{before}} + p_{B\text{before}} = p_{A\text{after}} + p_{B\text{after}}$$

.

$m_A v_A + m_B v_B = m_A v'_A + m_B v'_B$

$(2.0 \text{ kg})(2.0 \text{ m/s}) + (4.0 \text{ kg})(1.0 \text{ m/s}) = (2.0 \text{ kg})(1.0 \text{ m/s}) + (4.0 \text{ kg})(v_B' \text{ m/s})$

$4.0 \text{ kg} \cdot \text{m/s} + 4.0 \text{ kg} \cdot \text{m/s} = 2.0 \text{ kg} \cdot \text{m/s} + 4v_B' \text{ kg} \cdot \text{m/s}$

$4v_B' = 8.0 - 2.0 = 6.0$

$v_B' = 1.5 \text{ m/s}$

After the collision, ball *B* is moving westward at 1.5 m/s.

Example 2

A railroad car whose mass is 30,000. kg is traveling with a velocity of 2.2 m/s due east and collides with a second railroad car whose mass is also 30,000. kg and is at rest. If the two cars stick together after the collision, what is the velocity of the two cars?

Note that since the two trains stick together, the final mass is m_A+m_B, and the final velocity for each object is the same. Thus the conservation of momentum equation, $m_A v_A + m_B v_B = m_A v'_A + m_B v'_B$, can be rewritten $m_A v_A + m_B v_B = (m_A + m_B)v'$

$(30,000. \text{ kg})(2.2 \text{ m/s}) + (30,000. \text{ kg})(0 \text{ m/s}) = (60,000. \text{ kg})(v' \text{ m/s})$

$66000 + 0 = 60000v'$

$v' = \frac{66000}{60000} = 1.1 \text{ m/s}$

After the collision, the two cars move off together toward the east with a velocity of 1.1 m/s.

Summary

- A closed system is one in which both the object exerting a force and the object receiving the force are inside the system.
- In a closed system, momentum is always conserved.

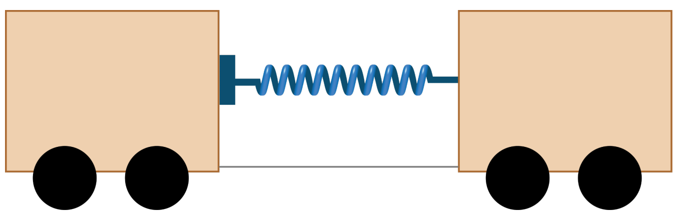
Review

1. A 0.111 kg hockey puck moving at 55 m/s is caught by a 80. kg goalie at rest. With what speed does the goalie slide on the (frictionless) ice?

2. A 0.050 kg bullet strikes a 5.0 kg stationary wooden block and embeds itself in the block. The block and the bullet fly off together at 9.0 m/s. What was the original velocity of the bullet?

3. A 0.50 kg ball traveling at 6.0 m/s due east collides head on with a 1.00 kg ball traveling in the opposite direction at -12.0 m/s. After the collision, the 0.50 kg ball moves away at -14 m/s. Find the velocity of the second ball after the collision.

4. Two carts are stationary with a compressed spring between them and held together by a thread. When the thread is cut, the two carts move apart. After the spring is released, one cart $m = 3.00$ kg has a velocity of 0.82 m/s east. What is the magnitude of the velocity of the second cart $(m = 1.70 \text{ kg})$after the spring is released?



5. Compared to falling on a tile floor, a glass may not break if it falls onto a carpeted floor. This is because

a. less impulse in stopping.
b. longer time to stop.
c. both of these
d. neither of these.

6. A butterfly is hit by a garbage truck on the highway. The force of the impact is greater on the

a. garbage truck.
b. butterfly.
c. it is the same for both.

7. A rifle recoils from firing a bullet. The speed of the rifle's recoil is small compared to the speed of the bullet because

a. the force on the rifle is small.
b. the rifle has a great deal more mass than the bullet.
c. the momentum of the rifle is unchanged.
d. the impulse on the rifle is less than the impulse on the bullet.
e. none of these.

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/112424

1. What is Newton's Cradle?
2. How does Newton's Cradle work?
3. How does a Newton's Cradle show conservation of momentum?

Vocabulary

- **Law of Conservation of Momentum:** The total linear momentum of an isolated system remains constant regardless of changes within the system.

References

1. Courtesy of NOAA. http://commons.wik whale_noaa.jpg.
2. Samantha Bacic. CK-12 Foundation.

Concept 12 Unit 6: Energy and Energy Transfer

Questions/Observable Phenomena

CHAPTER 13 Introduction to Energy

Chapter Outline

The whirring blades of these wind turbines look stark against the darkening sky at sunset. The energy of the wind causes the blades to spin, and the energy of the spinning blades is used to generate electricity. People have been using wind for energy for centuries. Until about 200 years ago, for example, ships depended on wind to sail the oceans. And windmills have long been used to gather wind energy to pump water and do other useful work. Today, wind energy is making a comeback. Do you know why? What might be advantages of using the wind for energy? This chapter has the answers.

Lee Bailey. www.flickr.com/photos/leebailey/6066524282/. CC BY 2.0.

13.1 Types of Energy

Lesson Objectives

- Relate energy to work.
- Describe kinetic energy.
- Identify two types of potential energy.
- Give examples of energy conversions between potential and kinetic energy.

Lesson Vocabulary

- energy conversion
- potential energy

Introduction

Did you ever babysit younger children, like the children in **Figure** 13.1? If you did, then you probably noticed that young children are often very active. They seem to be in constant motion. It may be hard to keep up with their boundless energy. What is energy, and where does it come from? Read on to find out.

FIGURE 13.1
Young children seem to be full of energy.

Defining Energy

The concept of energy was first introduced in the chapter "States of Matter," where it is defined as the ability to cause change in matter. Energy can also be defined as the ability to do work. Work is done whenever a force is used to move matter. When work is done, energy is transferred from one object to another. For example, when the batter in **Figure** 13.2 uses energy to swing the bat, she transfers energy to the bat. The moving bat, in turn, transfers energy to the ball. Like work, energy is measured in the joule (J), or newton·meter (N·m).

FIGURE 13.2
It takes energy to swing a bat. Where does the batter get her energy?

Energy exists in different forms, which you can read about in the lesson "Forms of Energy" later in the chapter. Some forms of energy are mechanical, electrical, and chemical energy. Most forms of energy can also be classified as kinetic or potential energy. Kinetic and potential forms of mechanical energy are the focus of this lesson. Mechanical energy is the energy of objects that are moving or have the potential to move.

Kinetic Energy

What do all the photos in **Figure** 13.3 have in common? All of them show things that are moving. Kinetic energy is the energy of moving matter. Anything that is moving has kinetic energy —from the atoms in matter to the planets in solar systems. Things with kinetic energy can do work. For example, the hammer in the photo is doing the work of pounding the nail into the board. You can see a cartoon introduction to kinetic energy and its relation to work at this URL: http://www.youtube.com/watch?v=zhX01toLjZs .

The amount of kinetic energy in a moving object depends on its mass and velocity. An object with greater mass or

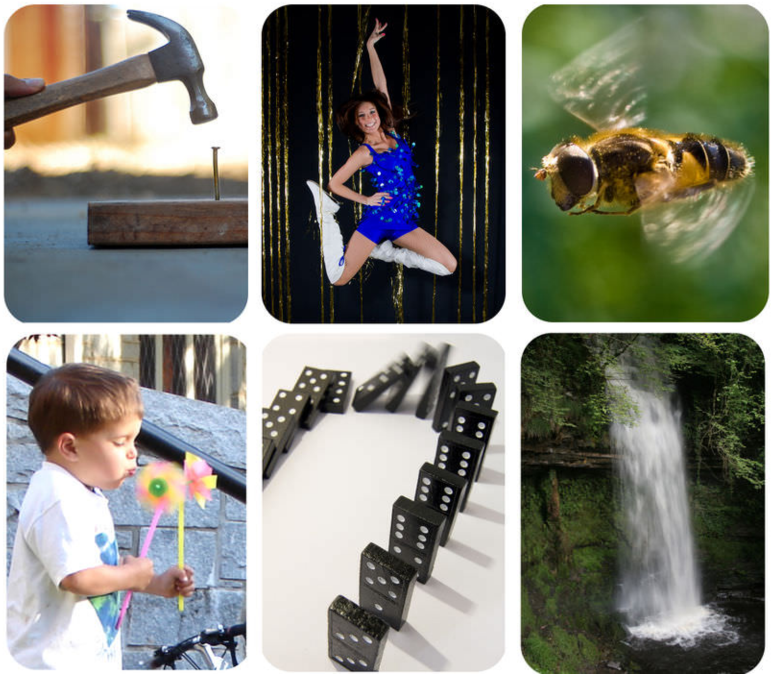


FIGURE 13.3
All of these photos show things that have kinetic energy because they are moving.

greater velocity has more kinetic energy. The kinetic energy of a moving object can be calculated with the equation:

$$\text{Kinetic Energy (KE)} = \frac{1}{2}\text{mass} \times \text{velocity}^2$$

This equation for kinetic energy shows that velocity affects kinetic energy more than mass does. For example, if mass doubles, kinetic energy also doubles. But if velocity doubles, kinetic energy increases by a factor of four. That's because velocity is squared in the equation. You can see for yourself how mass and velocity affect kinetic energy by working through the problems below.

Problem Solving

Problem: Juan has a mass of 50 kg. If he is running at a velocity of 2 m/s, how much kinetic energy does he have?

Solution: Use the formula: $\text{KE} = \frac{1}{2}\text{mass} \times \text{velocity}^2$

$$\begin{aligned}\text{KE} &= \frac{1}{2} \times 50 \text{ kg} \times (2 \text{ m/s}^2)\\ &= 100 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 100 \text{ N} \cdot \text{ m, or } 100 \text{ J}\end{aligned}$$

You Try It!

Problem: What is Juan's kinetic energy if he runs at a velocity of 4 m/s?

Problem: Juan's dad has a mass of 100 kg. How much kinetic energy does he have if he runs at a velocity of 2 m/s?

Potential Energy

Did you ever see a scene like the one in **Figure** 13.4? In many parts of the world, trees lose their leaves in autumn. The leaves turn color and then fall from the trees to the ground. As the leaves are falling, they have kinetic energy. While they are still attached to the trees they also have energy, but it's not because of motion. Instead, they have stored energy, called **potential energy**. An object has potential energy because of its position or shape. For example leaves on trees have potential energy because they could fall due to the pull of gravity.

FIGURE 13.4
Before leaves fall from trees in autumn, they have potential energy. Why do they have the potential to fall?

Gravitational Potential Energy

Potential energy due to the position of an object above Earth is called gravitational potential energy. Like the leaves on trees, anything that is raised up above Earth's surface has the potential to fall because of gravity. You can see examples of people with gravitational potential energy in **Figure** 13.5.

FIGURE 13.5
All three of these people have gravitational potential energy. Can you think of other examples?

Gravitational potential energy depends on an object's weight and its height above the ground. It can be calculated with the equation:

$$\text{Gravitational potential energy (GPE)} = \text{weight} \times \text{height}$$

Consider the diver in **Figure** 13.5. If he weighs 70 newtons and the diving board is 5 meters above Earth's surface, then his potential energy is:

$$\text{GPE} = 70 \text{ N} \times 5 \text{ m} = 350 \text{ N} \cdot \text{ m, or } 350 \text{ J}$$

You Try It!

Problem: Kris is holding a 2-kg book 1.5 m above the floor. What is the gravitational potential energy of the book?

Elastic Potential Energy

Potential energy due to an object's shape is called elastic potential energy. This energy results when elastic objects are stretched or compressed. Their elasticity gives them the potential to return to their original shape. For example, the rubber band in **Figure** 13.6 has been stretched, but it will spring back to its original shape when released. Springs like the handspring in the figure have elastic potential energy when they are compressed. What will happen when the handspring is released?

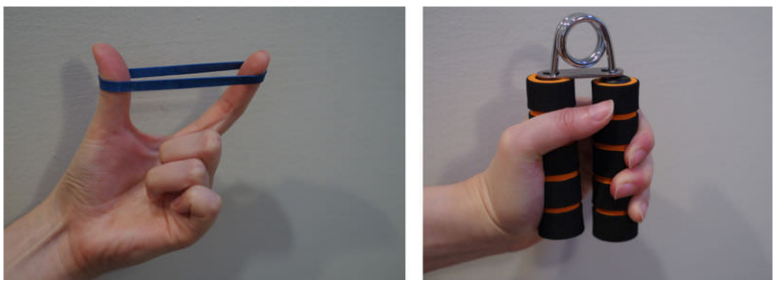


FIGURE 13.6
Changing the shape of an elastic material gives it potential energy.

Energy Conversion

Remember the diver in **Figure** 13.5? What happens when he jumps off the diving board? His gravitational potential energy changes to kinetic energy as he falls toward the water. However, he can regain his potential energy by getting out of the water and climbing back up to the diving board. This requires an input of kinetic energy. These changes in energy are examples of **energy conversion**, the process in which energy changes from one type or form to another.

Conservation of Energy

The law of conservation of energy applies to energy conversions. Energy is not used up when it changes form, although some energy may be used to overcome friction, and this energy is usually given off as heat. For example, the diver's kinetic energy at the bottom of his fall is the same as his potential energy when he was on the diving board, except for a small amount of heat resulting from friction with the air as he falls.

Examples of Energy Conversions

There are many other examples of energy conversions between potential and kinetic energy. **Figure** 13.7 describes how potential energy changes to kinetic energy and back again on swings and trampolines. You can see an animation of changes between potential and kinetic energy on a ramp at the URL below. Can you think of other examples?

http://www.physicsclassroom.com/mmedia/energy/ie.cfm

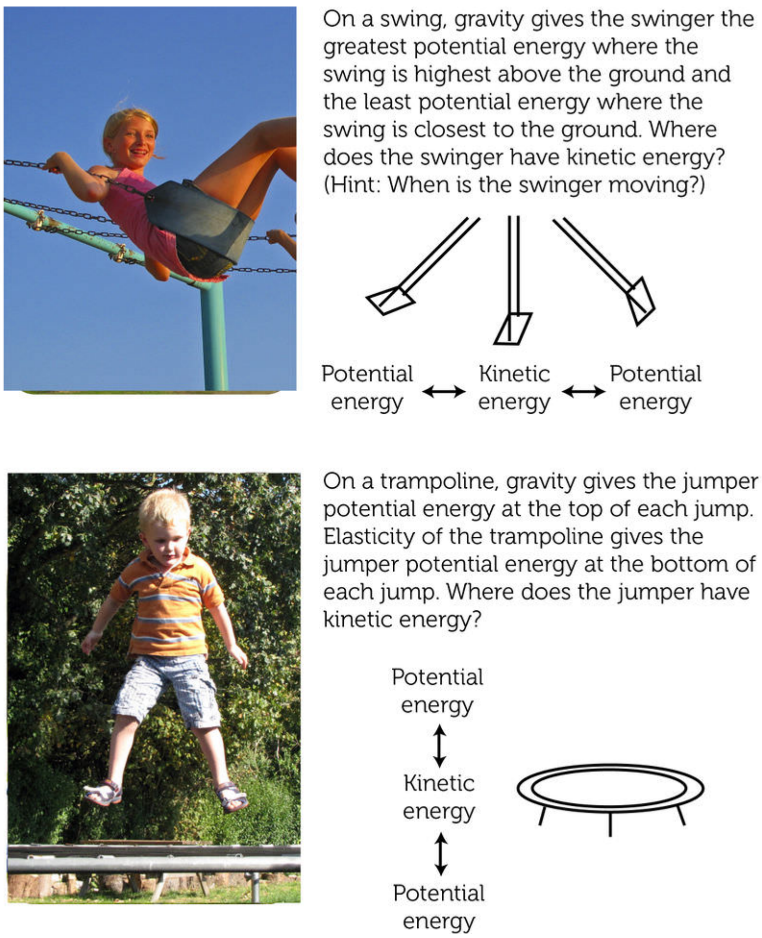


FIGURE 13.7

Energy continuously changes back and forth between potential and kinetic energy on a swing or trampoline.

KQED: Make it at Home: Table-Top Linear Accelerator

QUEST teams up with Make Magazine to construct the latest must have, do-it-yourself device hacks and science projects. This week we'll show you how to make a tabletop linear accelerator that demonstrates the finer points of kinetic energy by shooting a steel ball. For more information on the tabletop linear accelerator, see http://science.kqed.org/quest/video/make-it-at-home-table-top-linear-accelerator/ .

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/129629

Lesson Summary

- Energy is the ability to do work. When work is done, energy is transferred from one object to another. Energy can exist in different forms, such as electrical and chemical energy. Most forms of energy can also be classified as kinetic or potential energy.

- Kinetic energy is the energy of moving matter. Things with kinetic energy can do work. Kinetic energy depends on an object's mass and velocity.
- Potential energy is the energy stored in an object because of its position or shape. It includes gravitational potential energy and elastic potential energy. Gravitational potential energy depends on an object's weight and height above the ground.
- Energy conversion occurs when energy changes from one type or form of energy to another. Energy often changes between potential and kinetic energy. Energy is always conserved during energy conversions.

Lesson Review Questions

Recall

1. Define kinetic energy and give an example.
2. What is potential energy?
3. Describe how energy changes on a swing.

Apply Concepts

4. Explain how energy changes in the spring toy below when it goes down stairs.

5. 

Think Critically

5. How is energy related to work?
6. Compare and contrast gravitational potential energy and elastic potential energy.

Points to Consider

The examples of kinetic and potential energy you read about in this lesson are types of mechanical energy. Mechanical energy is one of several forms of energy you can read about in the next lesson, "Forms of Energy."

- Based on the examples in this lesson, how would you define mechanical energy?
- What might be other examples of mechanical energy?

13.2 Forms of Energy

Lesson Objectives

- Identify different forms of energy.
- Describe how energy changes form.

Lesson Vocabulary

- chemical energy
- electrical energy
- electromagnetic energy
- mechanical energy
- sound energy
- thermal energy

Introduction

The young man in **Figure** 13.8 is playing an electric guitar in a rock concert. He plucks the strings of the guitar with skill, and the sounds of the music thrill the crowd. The bright stage lights in the otherwise dark concert hall add to the excitement, although they make it hot on stage. This scene represents energy in several different forms. Do you know what they are? You'll find out in this lesson.

FIGURE 13.8
How many different forms of energy can you identify in this picture?

Comparing Forms of Energy

Energy, or the ability to do work, can exist in many different forms. The photo in **Figure** 13.8 represents six of the eight different forms of energy that are described in this lesson. The guitarist gets the energy he needs to perform from chemical energy in food. He uses mechanical energy to pluck the strings of the guitar. The stage lights use electrical energy and give off both light energy and thermal energy, commonly called heat. The guitar also uses electrical energy, and it produces sound energy when the guitarist plucks the strings. For an introduction to all these forms of energy, go to this URL: http://www.need.org/needpdf/FormsofEnergy.pdf .

For an interactive animation about the different forms of energy, visit this URL: http://www.explorelearning.com/index.cfm?method=cResource.dspView&ResourceID=651 .

After you read below about different forms of energy, you can check your knowledge by doing the drag and drop quiz at this URL: http://www.think-energy.co.uk/ThinkEnergy/11-14/activities/TypesEnergy.aspx .

Mechanical Energy

Mechanical energy is the energy of an object that is moving or has the potential to move. It is the sum of an object's kinetic and potential energy. In **Figure** 13.9, the basketball has mechanical energy because it is moving. The arrow in the same figure has mechanical energy because it has the potential to move due to the elasticity of the bow. What are some other examples of mechanical energy?

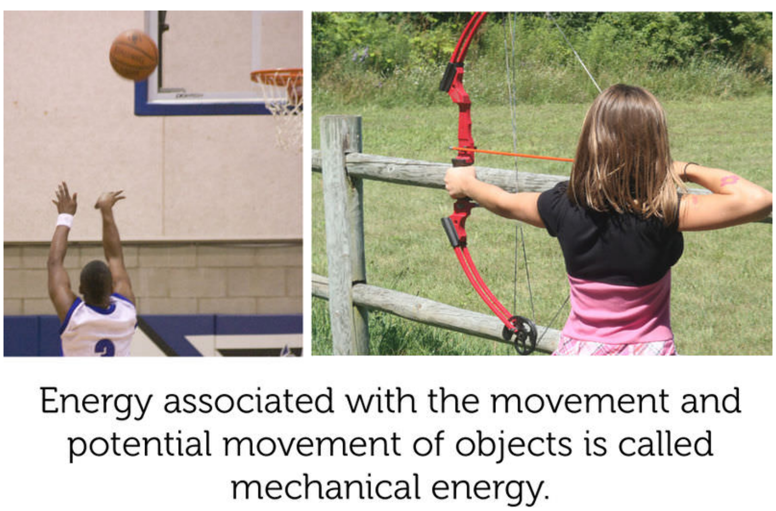


FIGURE 13.9
Kinetic and potential energy add up to mechanical energy.

Chemical Energy

Energy is stored in the bonds between atoms that make up compounds. This energy is called **chemical energy**, and it is a form of potential energy. If the bonds between atoms are broken, the energy is released and can do work. The wood in the fireplace in **Figure** 13.10 has chemical energy. The energy is released as thermal energy when the wood burns. People and many other living things meet their energy needs with chemical energy stored in food. When food molecules are broken down, the energy is released and may be used to do work.

FIGURE 13.10
Chemical energy is stored in wood and released when the wood burns.

Electrical Energy

Electrons are negatively charged particles in atoms. Moving electrons have a form of kinetic energy called **electrical energy**. If you've ever experienced an electric outage, then you know how hard it is to get by without electrical energy. Most of the electrical energy we use is produced by power plants and arrives in our homes through wires. Two other sources of electrical energy are pictured in **Figure** 13.11.

FIGURE 13.11
A lightning bolt is a powerful discharge of electrical energy. A battery contains stored chemical energy and converts it to electrical energy.

Nuclear Energy

The nuclei of atoms are held together by powerful forces. This gives them a tremendous amount of stored energy, called nuclear energy. The energy can be released and used to do work. This happens in nuclear power plants when nuclei fission, or split apart. It also happens in the sun and other stars when nuclei fuse, or join together. Some of the sun's energy travels to Earth, where it warms the planet and provides the energy for photosynthesis (see **Figure** 13.12).

Thermal Energy

The atoms that make up matter are in constant motion, so they have kinetic energy. All that motion gives matter thermal energy. **Thermal energy** is defined as the total kinetic energy of all the atoms that make up an object. It

FIGURE 13.12
In the sun, hydrogen nuclei fuse to form helium nuclei. This releases a huge amount of energy, some of which reaches Earth.

depends on how fast the atoms are moving and how many atoms the object has. Therefore, an object with more mass has greater thermal energy than an object with less mass, even if their individual atoms are moving at the same speed. You can see an example of this in **Figure** 13.13.

FIGURE 13.13
Atoms are moving at the same speed in the soup on the spoon as they are in the soup in the pot. However, there are more atoms of soup in the pot, so it has more thermal energy.

Electromagnetic Energy

Energy that the sun and other stars release into space is called **electromagnetic energy**. This form of energy travels through space as electrical and magnetic waves. Electromagnetic energy is commonly called light. It includes visible light, as well as radio waves, microwaves, and X rays (**Figure** 13.14).

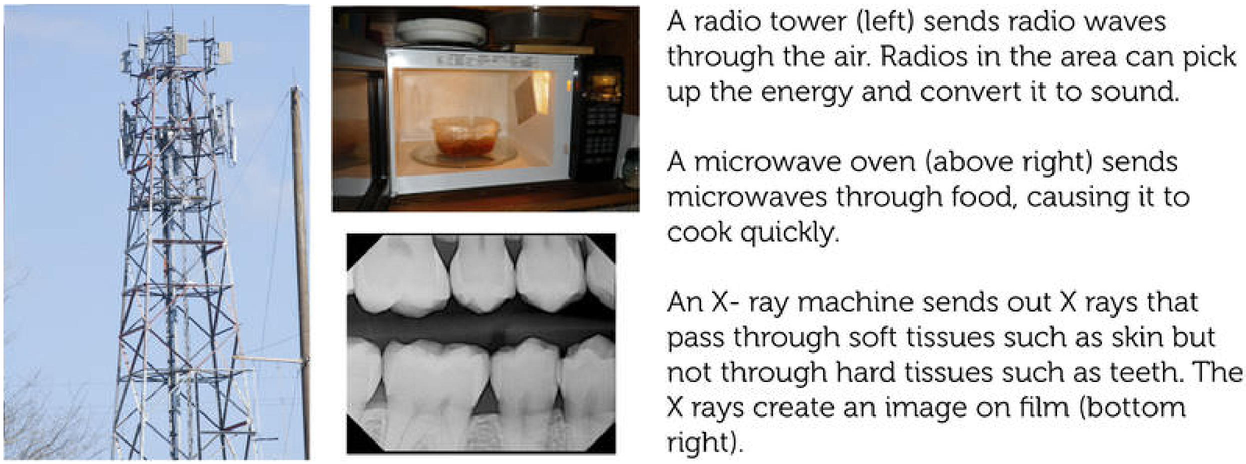


FIGURE 13.14
Radio waves, microwaves, and X rays are examples of electromagnetic energy.

Sound Energy

The drummer in **Figure** 13.15 is hitting the drumheads with drumsticks. This causes the drumheads to vibrate. The vibrations pass to surrounding air particles and then from one air particle to another in a wave of energy called **sound energy**. We hear sound when the sound waves reach our ears. Sound energy can travel through air, water, and other substances, but not through empty space. That's because the energy needs particles of matter to pass it on.

FIGURE 13.15
Vibrating objects such as drumheads produce sound energy.

How Energy Changes Form

Energy often changes from one form to another. For example, the mechanical energy of a moving drumstick changes to sound energy when it strikes the drumhead and causes it to vibrate. Any form of energy can change into any other form. Frequently, one form of energy changes into two or more different forms. For example, when wood burns, the wood's chemical energy changes to both thermal energy and light energy. Other examples of energy conversions are described in **Figure** 13.16. You can see still others at this URL: http://fi.edu/guide/hughes/energychangeex.html .

You can check your understanding of how energy changes form by doing the quizzes at these URLs:

- http://www.think-energy.co.uk/ThinkEnergy/11-14/activities/EnergyTrans2.aspx
- http://www.poweringourfuture.com/students/energy/2.html

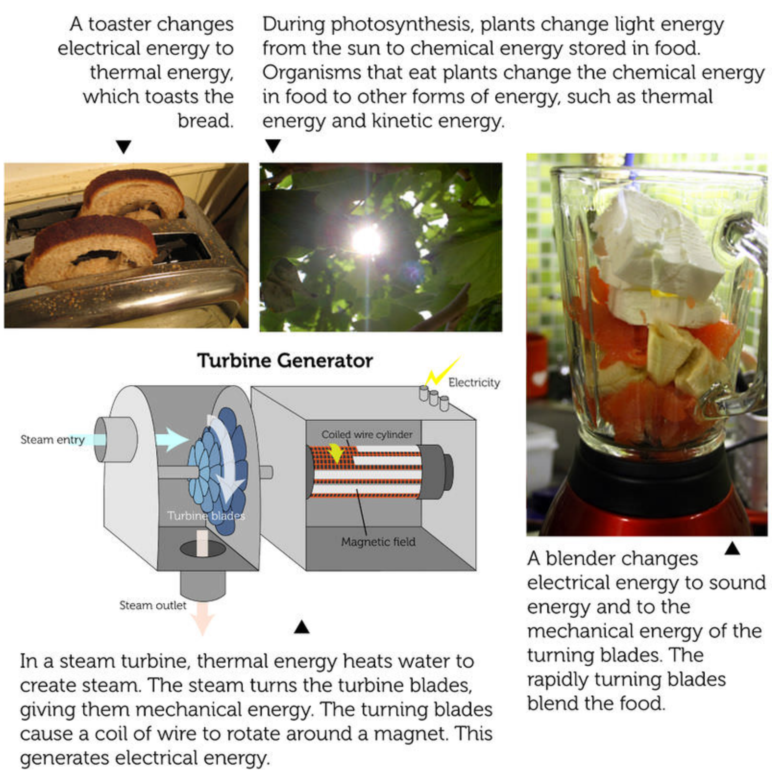


FIGURE 13.16
Energy is constantly changing form. Can you think of other examples of energy conversions?

Energy is conserved in energy conversions. No energy is lost when energy changes form, although some may be released as thermal energy due to friction. For example, not all of the energy put into a steam turbine in **Figure** 13.16 changes to electrical energy. Some changes to thermal energy because of friction of the turning blades and other moving parts. The more efficient a device is, the greater the percentage of usable energy it produces. Appliances with an "Energy Star" label like the one in **Figure** 13.17 use energy efficiently and thereby reduce energy use.

Lesson Summary

- Forms of energy include mechanical, chemical, electrical, nuclear, thermal, electromagnetic, and sound energy. These forms of energy can occur as either kinetic or potential energy.

FIGURE 13.17
The U.S. government's Energy Star program certifies the energy efficiency of appliances. Look for this label to identify those that are energy efficient.

- Energy often changes from one form to another. Any form of energy can change into any other, and one form may change into two or more different forms. Energy is always conserved when it changes form.

Lesson Review Questions

Recall

1. Define mechanical energy.
2. Give an example of chemical energy.
3. What is electrical energy?
4. Name two processes that release nuclear energy.
5. List three types of electromagnetic energy.

Apply Concepts

6. If you were on the moon, no sound energy would be able to reach your ears. Explain why. (*Hint:* The moon has no atmosphere.)
7. State how energy is converted by the following electrical devices: light bulb, alarm clock, hair dryer.

Think Critically

8. Relate the thermal energy of an object to the object's atoms.

Points to Consider

In this lesson, you read about electrical appliances that convert electrical energy to other forms of energy, such as thermal energy or sound energy.

- What form of energy is converted to electrical energy when electric current is generated?
- What natural resources might provide the energy needed to generate electricity?

13.3 Energy Resources

Lesson Objectives

- Describe nonrenewable energy resources.
- Identify several renewable energy resources.
- Outline world energy use and ways to conserve energy.

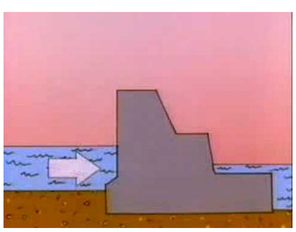
Lesson Vocabulary

- conservation
- fossil fuel
- natural resource
- nonrenewable resource
- renewable resource

Introduction

Did you ever go whitewater rafting, like the people in **Figure** 13.18? What an exciting ride! The churning water tosses the raft and drenches its riders with spray and foam. Water is a great place to have fun, whether you are rafting, swimming, snorkeling, jet skiing, or fishing. In fact, water is one of our most precious natural resources. A **natural resource** is anything people can use that comes from nature. In this lesson, you'll learn how we use water —and many other natural resources —for energy. For a brief overview of the energy resources you'll learn about in this lesson, go to this URL: http://www.think-energy.co.uk/ThinkEnergy/11-14/activities/EnergyTrans.aspx .

For a cartoon introduction to energy resources, go to this URL: http://www.youtube.com/watch?v=RD_54Cq_UMM (1:39).



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5031

Nonrenewable Energy Resources

Nonrenewable resources are natural resources that are limited in supply and cannot be replaced except over millions

FIGURE 13.18
Whitewater rafting is an exciting sport.

of years. Nonrenewable energy resources include fossil fuels and radioactive elements such as uranium.

Fossil Fuels

Fossil fuels are mixtures of hydrocarbons that formed over millions of years from the remains of dead organisms. They include petroleum (commonly called oil), natural gas, and coal. Fossil fuels provide most of the energy used in the world today. They are burned in power plants to produce electrical energy, and they also fuel cars, heat homes, and supply energy for many other purposes. You can see examples of their use in **Figure** 13.19.

Natural gas burns with a blue flame in this gas stove. Many homes also have natural gas water heaters and furnaces. Some motor vehicles burn natural gas as well.

Petroleum is used to make gasoline, which fuels most motor vehicles. It is also used to make heating oil for furnaces and kerosene for camp stoves.

The majority of electric power in the U.S. is generated by burning coal in power plants like this one.

FIGURE 13.19
Do you use any of these fossil fuels? How do you use them?

Fossil fuels contain stored chemical energy that came originally from the sun. Ancient plants changed energy in sunlight to stored chemical energy in food, which was eaten by other organisms. After the plants and other organisms died, their remains gradually changed to fossil fuels as they were pressed beneath layers of sediments. Petroleum and natural gas formed from marine organisms and are often found together. Coal formed from giant tree ferns and other swamp plants.

When fossil fuels burn, they release thermal energy, water vapor, and carbon dioxide. Carbon dioxide produced by fossil fuel use is a major cause of global warming. The burning of fossil fuels also releases many pollutants into the air. Pollutants such as sulfur dioxide form acid rain, which kills living things and damages metals, stonework, and other materials. Pollutants such as nitrogen oxides cause smog, which is harmful to human health. Tiny particles, or particulates, released when fossil fuels burn also harm human health. Natural gas releases the least pollution; coal releases the most (see **Figure** 13.20). Petroleum has the additional risk of oil spills, which may seriously damage ecosystems.

Fossil Fuel Pollution Levels

Pounds per Billion Units of Energy

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0	0.007	0.016

FIGURE 13.20
This table compares the levels of several air pollutants released by the burning of natural gas, oil, and coal.

Nuclear Energy

Like fossil fuels, the radioactive element uranium can be used to generate electrical energy in power plants. In a nuclear power plant, the nuclei of uranium atoms are split in the process of nuclear fission. This process releases a tremendous amount of energy from just a small amount of uranium. The total supply of uranium in the world is quite limited, however, and cannot be replaced once it is used up. This makes nuclear energy a nonrenewable resource. Although using nuclear energy does not release carbon dioxide or cause air pollution, it does produce dangerous radioactive wastes. Accidents at nuclear power plants also have the potential to release large amounts of radioactive material into the environment. **Figure** 13.21 describes the nuclear disaster caused by a Japanese tsunami in 2011. You can learn more about the disaster and its aftermath at the URLs below.

- http://www.bbc.co.uk/news/world-asia-pacific-12711226
- http://www.bbc.co.uk/news/world-asia-pacific-12731781
- http://www.bbc.co.uk/news/world-asia-pacific-12726591

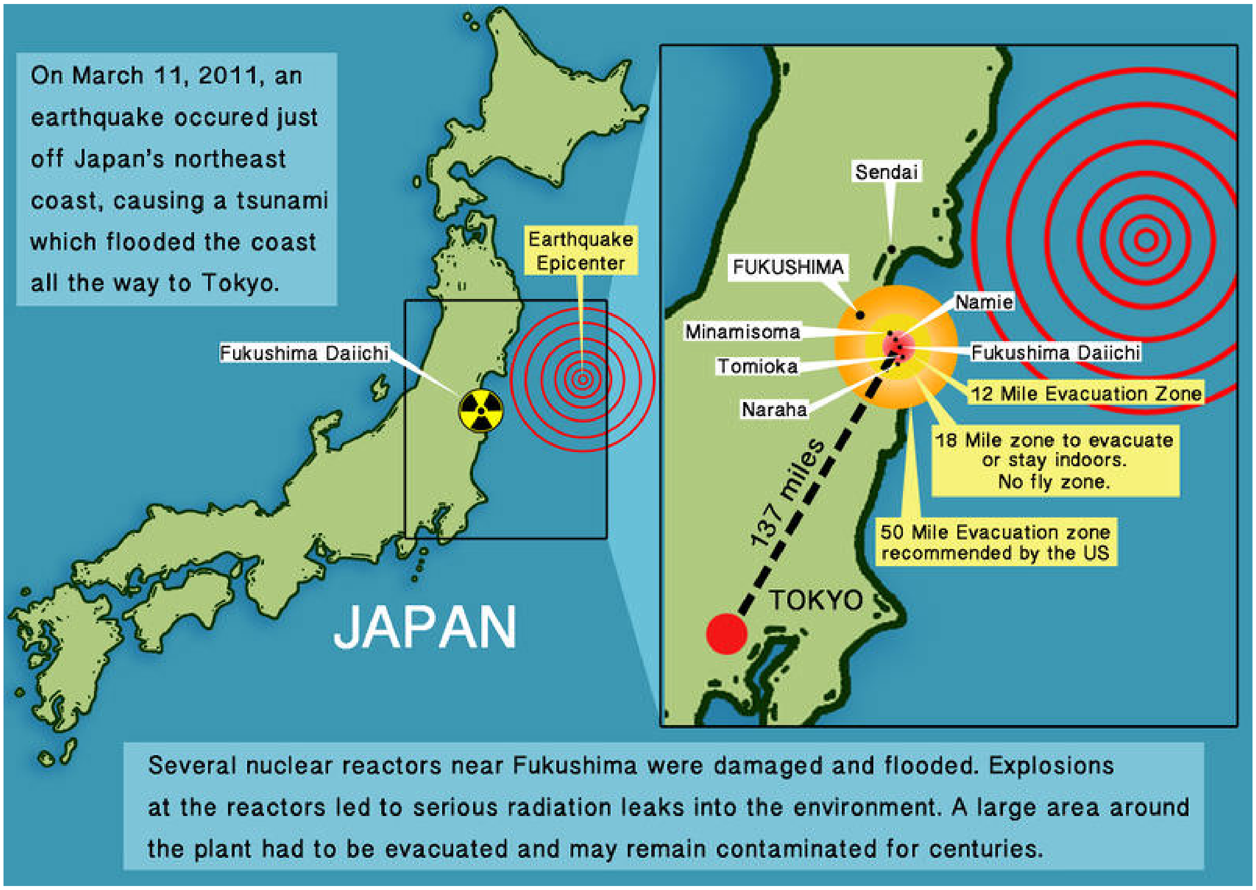


FIGURE 13.21
Do you remember Japan's 2011 nuclear disaster? (Note: the map on the right is not to scale.)

KQED: What's Next for Nuclear?

President Obama says the United States needs new nuclear reactors, to meet the country's energy demands and counter climate change. But can nuclear power be produced more safely and affordably? A scientist at the University of California, Berkeley, is working to do just that. For more information about nuclear energy, see http://science.kqed.org/quest/video/whats-next-for-nuclear/ .

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/131609

http://science.kqed.org/quest/video/whats-next-for-nuclear/

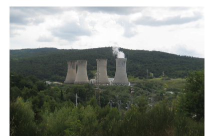
Renewable Energy Resources

Renewable resources are natural resources that can be replaced in a relatively short period of time or are virtually limitless in supply. Renewable energy resources include sunlight, moving water, wind, biomass, and geothermal energy. Each of these energy resources is described in **Table** 13.1. Resources such as sunlight and wind are limitless in supply, so they will never run out. Besides their availability, renewable energy resources also have the advantage of producing little if any pollution and not contributing to global warming. The technology needed to gather energy from renewable resources is currently expensive to install, but most of the resources themselves are free for the taking.

TABLE 13.1: What are the pros and cons of using each of the renewable energy resources described here?

Renewable Energy Resource	Example
Sunlight The energy in sunlight, or solar energy, can be used to heat homes. It can also be used to produce electricity in solar cells. However, solar energy may not be practical in areas that are often cloudy.	 Solar panels on the roof of this house generate enough electricity to supply a family's needs.
Moving Water When water falls downhill, its potential energy is converted to kinetic energy that can turn a turbine and generate electricity. The water may fall naturally over a waterfall or flow through a dam. A drawback of dams is that they flood land upstream and reduce water flow downstream. Either effect may harm ecosystems.	 Water flowing through Hoover dam between Arizona and Nevada generates electricity for both of these states and also by southern California. The dam spans the Colorado River.
Wind Wind is moving air, so it has kinetic energy that can do work. Remember the wind turbines that opened this chapter? Wind turbines change the kinetic energy of the wind to electrical energy. Only certain areas of the world get enough steady wind to produce much electricity. Many people also think that wind turbines are noisy and unattractive in the landscape.	 This old-fashioned windmill captures wind energy that is used for pumping water out of a well. Windmills like this one have been used for centuries.

TABLE 13.1: (continued)

Renewable Energy Resource	Example
Biomass The stored chemical energy of trees and other plants is called biomass energy. When plant materials are burned, they produce thermal energy that can be used for heating, cooking, or generating electricity. Biomass—especially wood—is an important energy source in countries where most people can't afford fossil fuels. Some plants can also be used to make ethanol, a fuel that is added to gasoline. Ethanol produces less pollution than gasoline, but large areas of land are needed to grow the plants needed to make it.	 This large machine is harvesting and grinding plants to be used for biomass energy.
Geothermal Heat below Earth's surface—called geothermal energy—can be used to produce electricity. A power plant pumps water underground where it is heated. Then it pumps the water back to the plant and uses its thermal energy to generate electricity. On a small scale, geothermal energy can be used to heat homes. Installing a geothermal system can be very costly, however, because of the need to drill through underground rocks.	 This geothermal power plant is located in Italy where hot magma is close to the surface.

KQED: Big Solar Comes of Age

The largest solar thermal plant in the world opens in California's Mojave Desert, after a debate that pitted renewable energy against a threatened tortoise. The Ivanpah solar plant is one of seven big solar farms scheduled to open in California in the coming months, as a result of the state's push to produce one third of its electricity from renewable energy. Some 30 states have similar mandates. For more information on this solar plant, see http://science.kqed.org/quest/video/largest-solar-plant-in-the-world-goes-through-last-test-before-opening/ .

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/131610

KQED: Airborne Wind Energy

On the windswept tarmac of the former Alameda Naval Air Station, an inventive group of scientists and engineers are test-flying a kite-like tethered wing that may someday help revolutionize clean energy. QUEST explores the potential of wind energy and new airborne wind turbines designed to harness the stronger and more consistent winds found at higher altitudes. For more information on wind energy, see http://science.kqed.org/quest/video/airborne-wind-energy/ .

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/131611

KQED: Geothermal Heats Up

Solar and wind power may get the headlines when it comes to renewable energy. But another type of clean power is heating up in the hills just north of Sonoma wine country. Geothermal power uses heat from deep inside the Earth to generate electricity. The Geysers, the world's largest power-producing geothermal field, has been providing electricity for roughly 850,000 Northern California households, and is set to expand even further. For more information on geothermal energy, see http://science.kqed.org/quest/video/geothermal-heats-up/ .

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/116511

Energy Use and Conservation

Figure 13.22 shows the mix of energy resources used worldwide in 2006. Fossil fuels still provide most of the world's energy, with oil being the single most commonly used energy resource. Natural gas is used less than the other two fossil fuels, but even natural gas is used more than all renewable energy resources combined. Wind, solar, and geothermal energy contribute the least to global energy use, despite the fact that they are virtually limitless in supply and nonpolluting.

Energy Use by Nation

People in the richer nations of the world use far more energy, especially energy from fossil fuels, than people in the poorer nations do. **Figure** 13.23 compares the amounts of oil used by the top ten oil-consuming nations. The U.S. uses more oil than several other top-ten countries combined. If you also consider the population size in these countries, the differences are even more stunning. The average person in the U.S. uses a whopping 23 barrels of oil a year! In comparison, the average person in India or China uses just 1 or 2 barrels a year. Because richer nations use more fossil fuels, they also cause more air pollution and global warming than poorer nations do.

Conserving Energy

We can reduce our use of energy resources and the pollution they cause by conserving energy. **Conservation** means saving resources by using them more efficiently or not using them at all. **Figure** 13.24 shows several ways that people can conserve energy in their daily lives. You can find more energy-saving tips at the URL below. What do you do to save energy? What else could you do?

http://www.partselect.ca/resources/Home-Energy-Saving-Tips.aspx

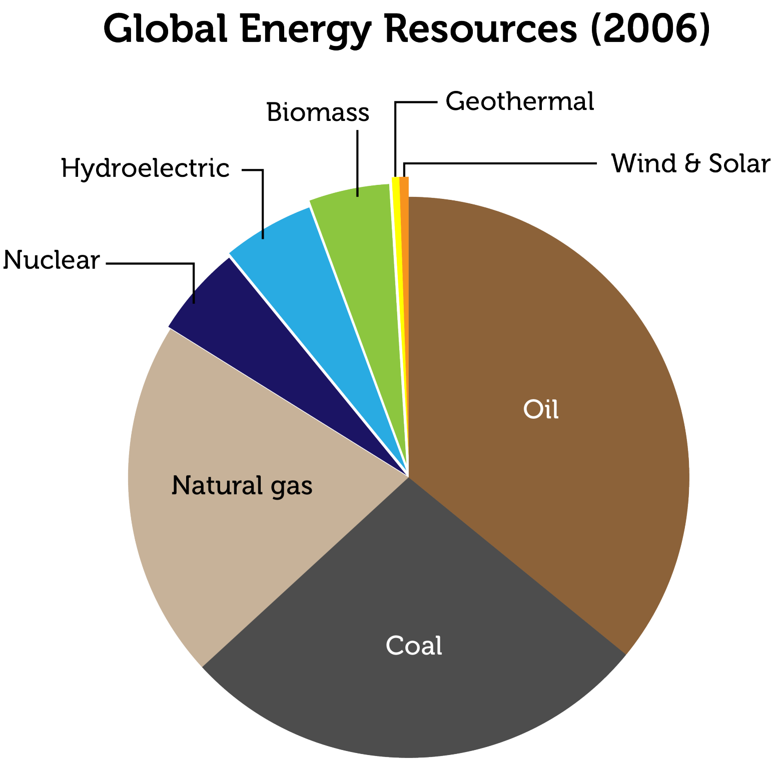


FIGURE 13.22
Which of the energy resources in this circle graph are renewable?

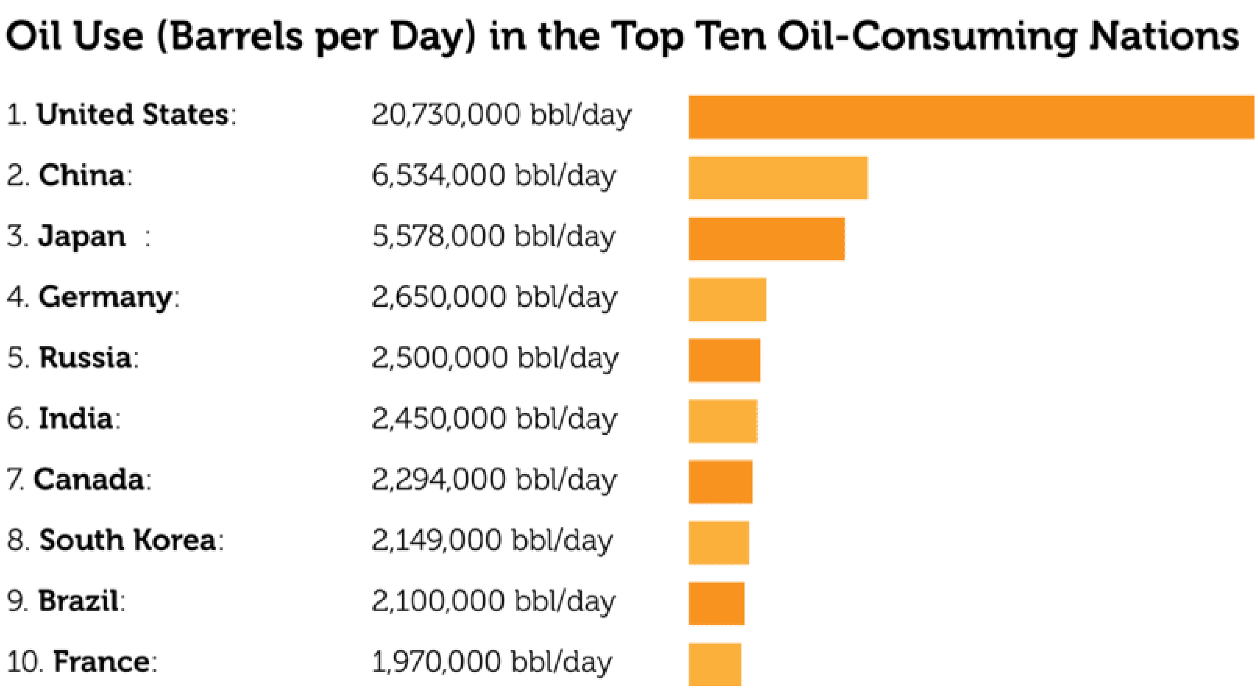


FIGURE 13.23
The U.S. uses far more oil than any other country in the world. It is even far ahead of the next largest oil user, which is China. The differences in use per person in these countries are even greater.

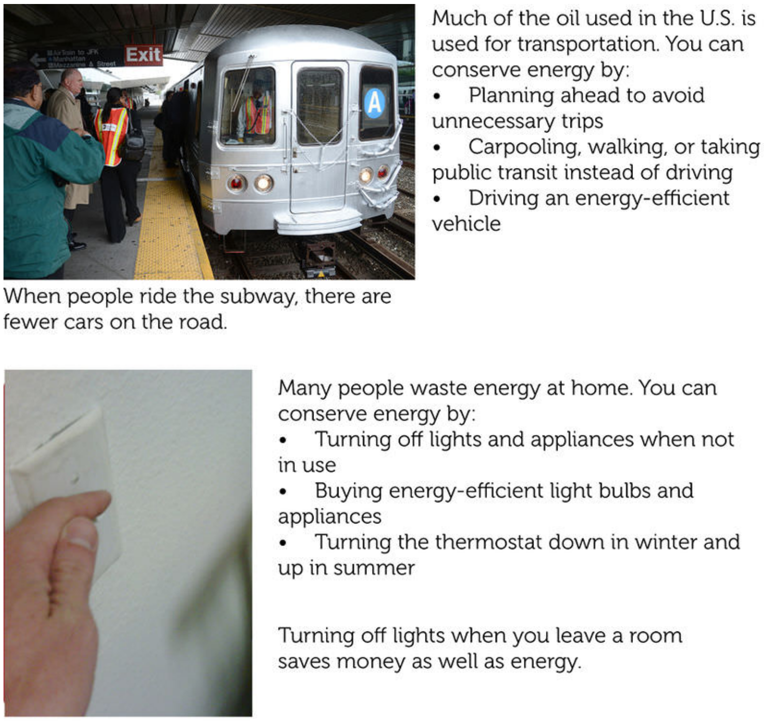
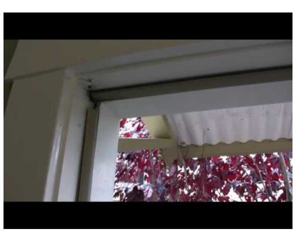


FIGURE 13.24

Small savings in energy really add up when everybody conserves energy.

KQED: Web Extra: Home Energy Audit

QUEST teams up with Climate Watch to give you an inside look at home energy efficiency. Tag along with Sustainable Spaces on a home efficiency "green-up" and learn tips on how to make your home more energy efficient. For more information on home energy audits, see http://science.kqed.org/quest/video/web-extra-home-energy-audit/ .



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URL: http://www.ck12.org/flx/render/embeddedobject/129630

KQED: Climate Watch: Unlocking the Grid

With the race on to reduce global warming and fossil fuel dependency, experts in alternative energy see a bright future for renewable resources like wind, solar, hydro-power and geothermal energy. QUEST and Climate Watch team up to look at the "Smart Grid" of the future and how it might be improved to more cleanly and efficiently keep the lights on in California. For more information on the "Smart Grid", see http://science.kqed.org/quest/video/climate-watch-unlocking-the-grid/ .

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/116510

Lesson Summary

- Nonrenewable resources are natural resources that are limited in supply and cannot be replaced except over millions of years. They also release pollutants and contribute to global climate change. Nonrenewable energy resources include fossil fuels, which are burned, and uranium, which is used for nuclear fission.
- Renewable resources are natural resources that can be replaced in a relatively short period of time or are virtually limitless in supply. They cause little if any pollution or global climate change. Renewable energy resources include sunlight, moving water, wind, biomass, and geothermal energy.
- Fossil fuels provide most of the energy used worldwide. Richer nations use far more energy resources, especially fossil fuels, than poorer nations do. There are several ways that people can conserve energy in their daily lives.

Lesson Review Questions

Recall

1. What is a natural resource?
2. Identify three fossil fuels.
3. Describe how fossil fuels form.
4. What are drawbacks of using fossil fuels?
5. State why nuclear energy is a nonrenewable resource.

Apply Concepts

6. Create a Web page or poster that encourages people to conserve energy and gives tips for how to do it.

Think Critically

7. Compare and contrast nonrenewable and renewable energy resources.
8. Argue for the use of any two renewable energy resources.

Points to Consider

In this chapter, you read that energy is transferred when work is done. You also read about thermal energy.

- You can use the thermal energy of a stove to cook food. How is thermal energy transferred from the hot stovetop to a pot on the stove?

- You can feel the thermal energy of a campfire, even when you are sitting a few feet away. How does thermal energy travel through the air from the fire to you?

For **Table** 13.1,

- Solar panel: Jon Callas. http://www.flickr.com/photos/joncallas/5586087273/ . CC BY 2.0.
- Dam: Flickr:NatureClip. http://www.flickr.com/photos/natureclip/9764092224/ . CC BY 2.0.
- Windmill: Fuzzy Gerdes. http://www.flickr.com/photos/fuzzy/3772169287/ . CC BY 2.0.
- Biomass: Image courtesy of Idaho National Laboratory (INL) Bioenergy Program (www.inl.gov/bioenergy). http://www.flickr.com/photos/inl/7896779532/ . CC BY 2.0.
- Geothermal plant: Birgit Juel Martinsen. http://www.flickr.com/photos/martinsen-jordenrundt/5437266214/ . CC BY 2.0.

13.4 Energy Resources 1

Lesson Objectives

- Compare ways in which energy changes from one form to another.
- Discuss what happens when a fuel burns.
- Describe the difference between renewable and non-renewable resources.
- Classify different energy resources as renewable or non-renewable.

Vocabulary

- chemical energy
- energy
- fuel
- heat
- kinetic energy
- law of conservation of energy
- non-renewable resources
- potential energy
- renewable resources

Introduction

Everything requires energy. Even when you are sitting as still as you possibly can, your body is using energy to breathe, circulate blood, digest food, and perform many other functions. Producing light or heat requires energy. Making something requires energy. Plants and animals all require energy to function. To repeat, everything requires energy!

The Need for Energy

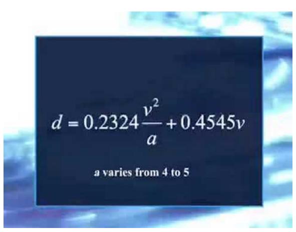
Energy is the ability to do work or produce change. Every living thing needs energy to perform its daily functions and even more energy to grow. Plants get energy from the "food" they make by photosynthesis, and animals get energy directly or indirectly from that food. People also use energy for many things, such as cooking food, keeping ice cream cold in the freezer, heating a house, constructing a skyscraper, or lighting their homes. Because billions of people all around the world use energy, there is a huge need for energy resources (**Figure** 13.25). Energy conservation is something everyone can do now to help reduce the strain on energy resources.

The **law of conservation of energy** says that energy cannot be created or destroyed. This means that even though energy changes form, the total amount of energy always stays the same. How does energy get converted from one

FIGURE 13.25
Electrical transmission towers like the one shown in this picture help deliver the electricity people use for energy every day.

type to another when you kick a soccer ball? When your body breaks down the food you eat, it stores the energy from the food as **chemical energy**. Chemical energy is stored within chemical bonds. But some of this stored energy has to be released to make your leg muscles move. The chemical energy is converted to another form of energy called **kinetic energy**. Kinetic energy is the energy of anything in motion. Your muscles move your leg, your foot kicks the ball, and the ball gains kinetic energy from the kick. So you can think of the action of kicking the ball as a story of energy changing forms.

To learn the quadratic equations related to getting a rapidly moving car to overcome its kinetic energy and come to a stop, watch this video (**IE 1e**): http://www.youtube.com/watch?v=v-Z2-jxCqVw (6:01).



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URL: http://www.ck12.org/flx/render/embeddedobject/11

Potential energy is energy that is stored. Potential energy has the potential to do work or the potential to be converted into other forms of energy. If a ball is sitting on the very edge at the top of the hill, it is not moving, but it has a lot of potential energy.

Animations showing the conversion of potential energy to kinetic energy can be seen at the following sites:

- http://www.physicsclassroom.com/mmedia/energy/se.cfm
- http://www.physicsclassroom.com/mmedia/energy/ce.cfm
- http://www.physicsclassroom.com/mmedia/energy/dg.cfm

Energy, Fuel, and Heat

If you read a book beneath a lit lamp, that lamp has energy from electricity. The energy to make the electricity comes from **fuel.** Fuel has energy that it releases. A fuel is any material that can release energy in a chemical change.

What are some examples of fuel, and what are they used for?

1. Food is fuel for your body.
2. Sunlight is the energy plants need to make food by photosynthesis.
3. Gasoline is fuel for cars.
4. Hydrogen is fuel for the Sun.

For a fuel to be useful, its energy must be released in a way that can be controlled. Controlling the release of energy makes it possible for the energy to be used to do work. When fuel is used for its energy, it is usually burned, and most of the energy is released as **heat** (**Figure** 13.26). The heat may then be used to do work. Think of a person striking a match to set some small twigs on fire. After the twigs burn for a while, they get hot enough to make some larger sticks burn. The fire keeps getting hotter, and soon it is hot enough to burn whole logs. Pretty soon the fire is roaring, and a pot of water placed on the fire starts to boil. Some of the liquid water evaporates.

FIGURE 13.26
A controlled fire.

What is the source of energy for boiling and evaporating the water? Although some chemical energy from the match was put into starting the fire, the heat to boil and evaporate the water comes from the energy that was stored in the wood. The wood is the fuel for the fire.

Types of Energy Resources

Energy resources are either renewable or non-renewable. **Non-renewable resources** are used faster than they can be replaced,so the supply available to society is limited (see example in **Figure** 13.27). **Renewable resources** will not run out because they are replaced as quickly as they are used. Can you think of some renewable and non-renewable energy sources?

FIGURE 13.27
Anthracite coal is a non-renewable energy resource.

Non-renewable Resources

Fossil fuels - coal, oil, and natural gas - are the most common example of non-renewable energy resources. Fossil fuels are formed from fossils, the partially decomposed remains of once living plants and animals. These fossils took millions of years to form. When fossil fuels are burned for energy, they release pollutants into the atmosphere. Fossil fuels also release carbon dioxide and other greenhouse gases, which are causing global temperatures to rise. The environmental effects of fossil fuel use are discussed in the "Climate" and "Human Actions and the Atmosphere" chapters.

Renewable Resources

Renewable energy resources include solar, water, wind, biomass, and geothermal. These resources are either virtually limitless like the Sun, which will continue to shine for billions of years, or will be replaced faster than we can use them. Amounts of falling water or wind will change over the course of time, but they are quite abundant. Biomass energy, like wood for fire, can be replaced quickly.

The use of renewable resources may also cause problems. Some are expensive, while some, such as trees, have other uses. Some cause environmental problems. As the technology improves and more people use renewable energy, the prices may come down. At the same time, as we use up fossil fuels, coal, oil, and natural gas, these non-renewable resources will become more expensive. At some point, even if renewable energy costs are high, non-renewable energy will be even more expensive. Ultimately, we will have to use renewable sources.

Important Things to Consider about Energy Resources

With both renewable and non-renewable resources, there are at least two important things to consider. One is that we have to have a practical way to turn the resource into a useful form of energy. The other is that we have to consider what happens when we turn the resource into energy.

For example, if we get much less energy from burning a fuel than we put into making it, then that fuel is probably not a practical energy resource. On the other hand, if another fuel gives us large amounts of energy but creates large amounts of pollution, that fuel also may not be the best choice for an energy resource.

KQED: Climate Watch: Unlocking the Grid

Today we rely on electricity more than ever, but the resources that currently supply our power are finite. The race is on to harness more renewable resources, but getting all that clean energy from production sites to homes and businesses is proving to be a major challenge. Learn more by watching the resource below: http://www.kqed.org/

quest/television/climate-watch-unlocking-the-grid .

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/116510

Lesson Summary

- According to the law of conservation of energy, energy is neither created nor destroyed.
- Renewable resources can be replaced at the rate they are being used.
- Non-renewable resources are available in limited amounts or are being used faster than they can be replaced.

Review Questions

1. What is needed by anything that moves or changes in any way?
2. What is the original source of most energy used on Earth?
3. In what form does a living creature store energy from food?
4. When we burn a fuel, what is released that allows work to be done?
5. For biomass, solar, coal, natural gas, oil, and geothermal energy, identify each energy resource as renewable or non-renewable and explain why.
6. What factors are important in judging how helpful an energy resource is to us?
7. Is the energy from a rechargeable battery renewable? (A rechargeable battery can be recharged by being put into a device that is plugged into the wall.) Explain.

Further Reading / Supplemental Links

- Kydes, Andy, "Primary Energy." Encyclopedia of Earth, 2006. Available on the Web at: http://www.eoearth.org/article/Primary_energy .
- Some of the Earth science news on this website is related to energy: http://www.earthportal.org/ .

Points to Consider

- How long do fossil fuels take to form?
- Are all fossil fuels non-renewable resources?
- Do all fossil fuels affect the environment equally?
- How is food energy measured?
- Is a rechargeable battery a renewable source of energy?

13.5 Renewable Energy Resources

Lesson Objectives

- Describe different renewable resources and understand why they are renewable.
- Discuss how the Sun is the source of most of Earth's energy.
- Describe how energy is carried from one place to another as heat and by moving objects.
- Discuss why some renewable energy sources cost less than others do and why some cause less pollution than others.
- Explain how renewable energy resources are turned into useful forms of energy.
- Describe how the use of different renewable energy resources affects the environment.

Vocabulary

- biofuel
- conduction
- radiation

Introduction

Fossil fuels have the advantage of being cheap and transportable, but they cause environmental damage and will eventually run out. Renewable energy sources, by definition, will not run out, and most do not cause much pollution. But renewable energy sources do have a downside, too. Both the advantages and disadvantages of solar, water, wind, biomass, and geothermal energy will be described in this lesson.

Solar Power

The Sun is Earth's main source of energy, making the development of solar power a natural choice for an alternative energy source.

Solar Energy

Energy from the Sun comes from the lightest element, hydrogen, fusing together to create the second lightest element, helium. Nuclear fusion releases tremendous amounts of solar energy. The energy travels to the Earth, mostly as visible light. The light carries the energy through the empty space between the Sun and the Earth as **radiation**.

Solar Power Use

Solar energy has been used for power on a small scale for hundreds of years, and plants have used it for billions of year. Unlike energy from fossil fuels, which almost always come from a central power plant or refinery, solar power can be harnessed locally (**Figure** 13.28). A set of solar panels on a home's rooftop can be used to heat water for a swimming pool or can provide electricity to the house.

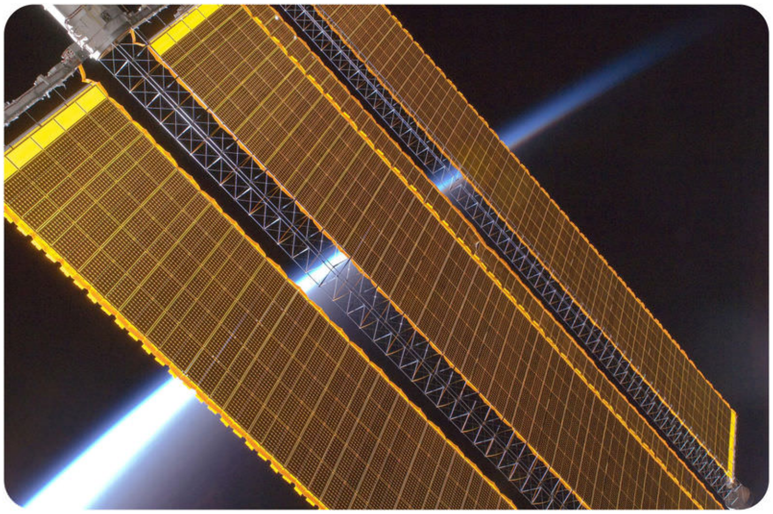

FIGURE 13.28
Solar panels supply power to the International Space Station.

Society's use of solar power on a larger scale is just starting to increase. Scientists and engineers have very active, ongoing research into new ways to harness energy from the Sun more efficiently. Because of the tremendous amount of incoming sunlight, solar power is being developed in the United States in southeastern California, Nevada, and Arizona.

Solar power plants turn sunlight into electricity using a large group of mirrors to focus sunlight on one place, called a receiver (**Figure** 13.29). A liquid, such as oil or water, flows through this receiver and is heated to a high temperature by the focused sunlight. The heated liquid transfers its heat to a nearby object that is at a lower temperature through a process called **conduction**. The energy conducted by the heated liquid is used to make electricity.

A video of how solar energy can be concentrated so that it can be used for power: http://www1.eere.energy.gov/multimedia/video_csp.html .

Consequences of Solar Power Use

Solar energy has many benefits. It is extremely abundant, widespread, and will never run out. But there are problems with the widespread use of solar power.

- Sunlight must be present. Solar power is not useful in locations that are often cloudy or at night. However, storage technology is being developed.
- The technology needed for solar power is still expensive. An increase in interested customers will provide incentive for companies to research and develop new technologies and to figure out how to mass-produce existing technologies (**Figure** 13.30).
- Solar panels require a lot of space. Fortunately, solar panels can be placed on any rooftop to supply at least some of the power required for a home or business.

FIGURE 13.29
This solar power plant uses mirrors to focus sunlight on the tower in the center. The sunlight heats a liquid inside the tower to a very high temperature, producing energy to make electricity.

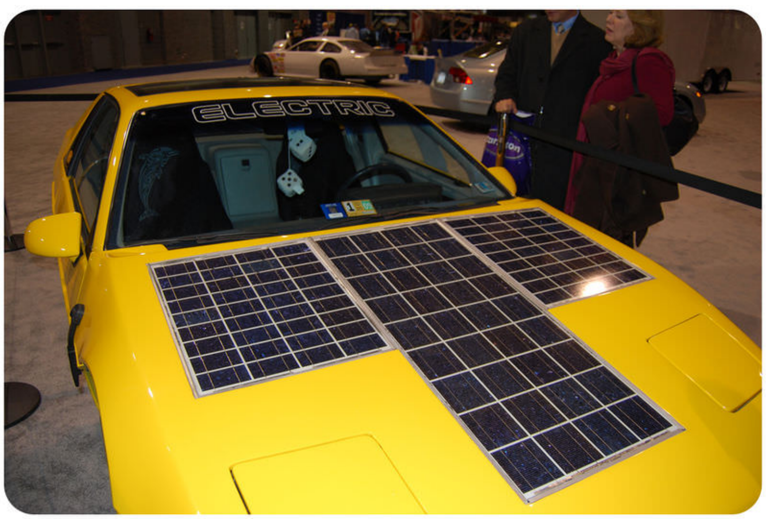

FIGURE 13.30
This experimental car is one example of the many uses that engineers have found for solar energy.

Water Power

Water covers 70% of the planet's surface, and water power (hydroelectric power) is the most widely used form of renewable energy in the world. Hydroelectric power from streams provides almost one fifth of the world's electricity.

Hydroelectric Power

Remember that potential energy is the energy of an object waiting to fall. Water held behind a dam has a lot of potential energy. In a hydroelectric plant, a dam across a riverbed holds a stream to create a reservoir. Instead of flowing down its normal channel, the water is allowed to flow into a large turbine. As the water moves, it has kinetic energy, which makes the turbine spin. The turbine is connected to a generator, which makes electricity (**Figure** 13.31).

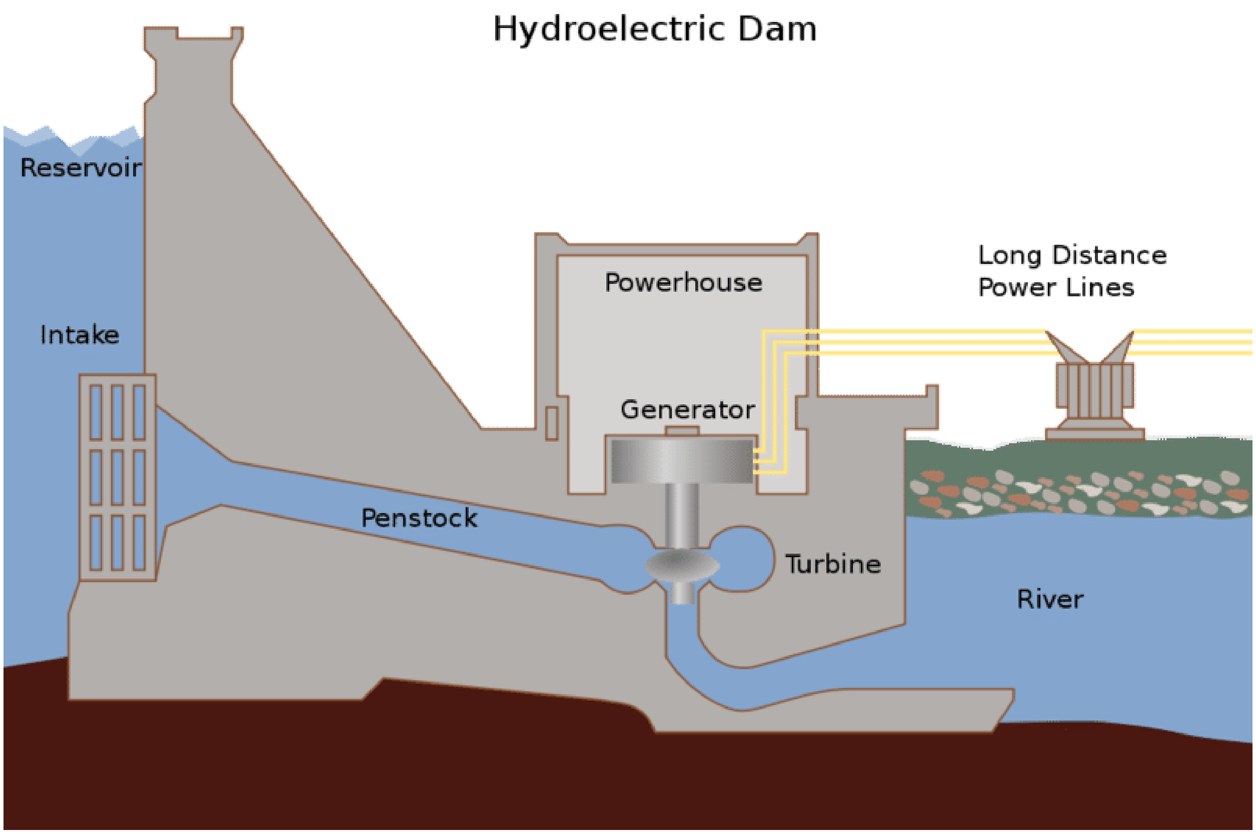

FIGURE 13.31
A cross-section of a hydroelectric plant.

Most of the streams in the United States and elsewhere in the developed world that are suitable for hydroelectric power have already been dammed (**Figure** 13.32). In California, about 14.5% of the total electricity comes from hydropower. The state's nearly 400 hydropower plants are mostly located in the eastern mountain ranges where large streams descend down a steep grade.

Consequences of Water Power Use

The major benefit of hydropower is that it generates power without releasing any pollution. Hydropower is also a renewable resource since the stream will keep on flowing. However, there are a limited number of suitable dam sites. Hydropower also has environmental problems. When a large dam disrupts a river's flow, it changes the ecosystem upstream. As the land is flooded by rising water, plants and animals are displaced or killed. Many beautiful landscapes, villages, and archeological sites have been drowned by the water in a reservoir (**Figure** 13.33).

The dam and turbines also change the downstream environment for fish and other living things. Dams slow the release of silt so that downstream deltas retreat and seaside cities become dangerously exposed to storms and rising sea levels.

FIGURE 13.32
Hydroelectric dams like this one use the power of moving water to create electricity.

FIGURE 13.33
Glen Canyon Dam in Arizona created Lake Powell. The dam was controversial because it flooded Glen Canyon, a beautiful desert canyon.

Ocean Water Power

The energy of waves and tides can be used to produce water power. Tidal power stations may need to close off a narrow bay or estuary. Wave power applications have to be able to withstand coastal storms and the corrosion of seawater. Because of the many problems with them, tide and wave power plants are not very common.

KQED: Harnessing Power from the Sea

Although not yet widely used, many believe tidal power has more potential than wind or solar power for meeting alternative energy needs. Quest radio looks at plans for harnessing power from the sea by San Francisco and along the northern California coast.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/60951

Wind Power

Wind power is the fastest growing renewable energy source in the world. Windmills are now seen in many locations, either individually or, more commonly, in large fields.

Wind Powering America follows the development of wind power in the United States over the past several years: http://www.windpoweringamerica.gov/wind_installed_capacity.asp .

Wind Energy

Energy from the Sun also creates wind, which can be used as wind power. The Sun heats different locations on Earth by different amounts. Air that becomes warm rises and then sucks cooler air into that spot. The movement of air from one spot to another along the ground creates wind. Since wind is moving, it has kinetic energy.

Wind Power Use

Wind is the source of energy for wind power. Wind has been used for power for centuries. For example, windmills were used to grind grain and pump water. Sailing ships traveled by wind power long before ships were powered by fossil fuels. Wind can be used to generate electricity, as the moving air spins a turbine to create electricity (**Figure** 13.34).

FIGURE 13.34
Wind turbines like the ones shown here turn wind into electricity without creating pollution.

This animation shows how wind power works: http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10501 .

Consequences of Wind Power

Wind power has many advantages. It does not burn, so it does not release pollution or carbon dioxide. Also, wind is plentiful in many places. Wind, however, does not blow all of the time, even though power is needed all of the time. Just as with solar power, engineers are working on technologies that can store wind power for later use.

Windmills are expensive and wear out quickly. A lot of windmills are needed to power a region, so nearby residents may complain about the loss of a nice view if a wind farm is built. Coastlines typically receive a lot of wind, but wind farms built near beaches may cause unhappiness for local residents and tourists.

The Cape Wind Project off of Cape Cod has been approved but is generating much controversy. Opponents are in favor of green power but not at that location. Proponents say that clean energy is needed and the project would supply 75% of the electricity needed for Cape Cod and nearby islands (**Figure** 13.35).

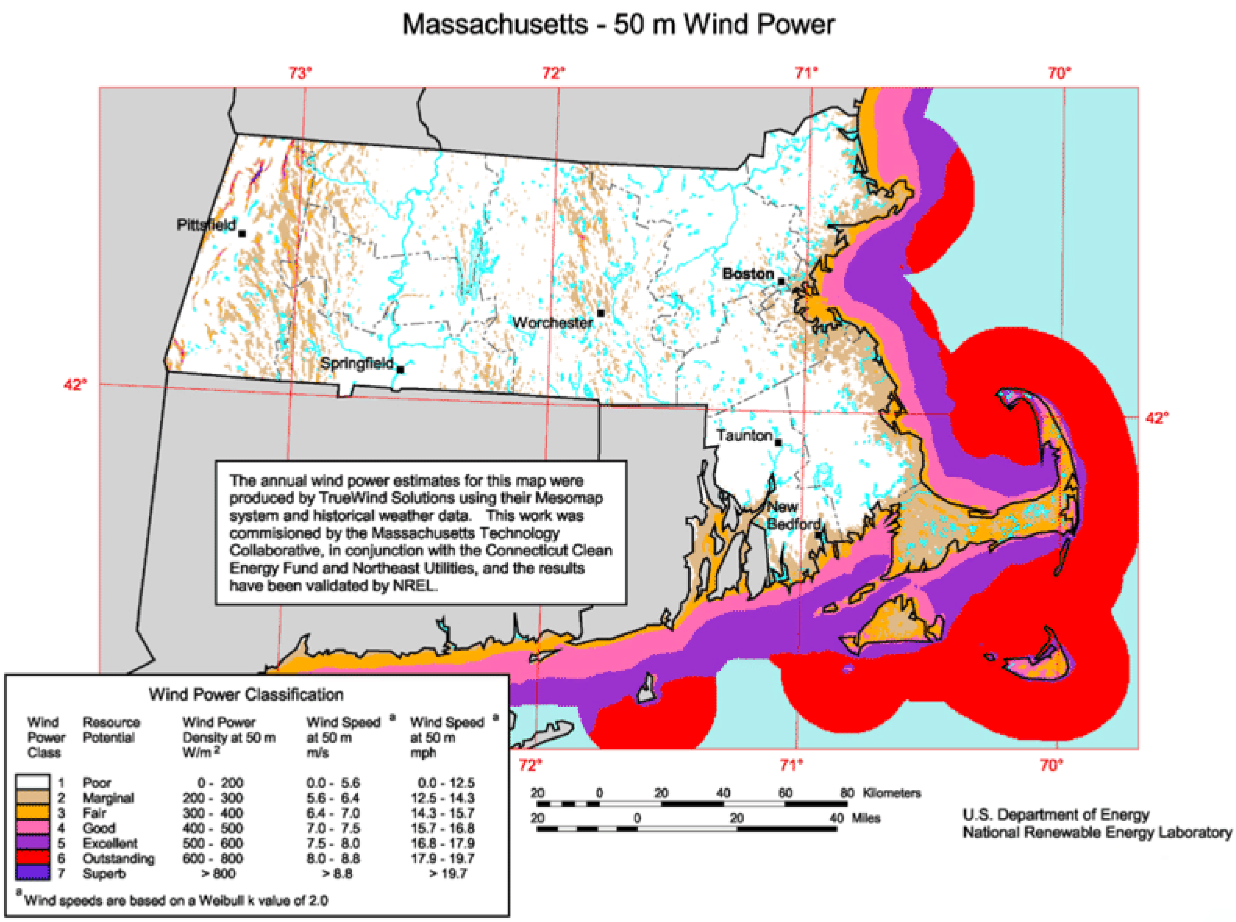

FIGURE 13.35

Cape Wind off of Cape Cod in Massachusetts receives a great deal of wind (red color) but is also popular with tourists for its beauty.

California was an early adopter of wind power. Windmills are found in mountain passes where the cooler Pacific Ocean air is sucked through on its way to warmer inland valleys. Large fields of windmills can be seen at Altamont pass in the eastern San Francisco Bay Area, San Gorgonio Pass east of Los Angeles, and Tehachapi Pass at the southern end of the San Joaquin Valley.

Geothermal Power

Geothermal energy comes from heat deep below the surface of the Earth. Nothing must be done to the geothermal energy. It is a resource that can be used without processing.

Geothermal Energy

The heat that is used for geothermal power may come to the surface naturally as hot springs or geysers, like The Geysers in northern California. Where water does not naturally come to the surface, engineers may pump cool water into the ground. The water is heated by the hot rock and then pumped back to the surface for use. The hot water or steam from a geothermal well spins a turbine to make electricity.

Geothermal energy is clean and safe. The energy source is renewable since hot rock is found everywhere in the Earth, although in many parts of the world the hot rock is not close enough to the surface for building geothermal power plants. In some areas, geothermal power is common (**Figure** 13.36).

FIGURE 13.36
A geothermal energy plant in Iceland. Iceland gets about one fourth of its electricity from geothermal sources.

In the United States, California is a leader in producing geothermal energy. The largest geothermal power plant in the state is in the Geysers Geothermal Resource Area in Napa and Sonoma Counties, north of San Francisco. The source of heat is thought to be a large magma chamber lying beneath the area.

KQED: Geothermal Heats Up

Where Earth's internal heat gets close to the surface, geothermal power is a clean source of energy. In California, The Geysers supplies energy for many nearby homes and businesses.

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/116511

Biomass

Biomass is the material that comes from plants and animals that were recently living. Biomass can be burned directly, such as setting fire to wood. For as long as humans have had fire, people have used biomass for heating and cooking. People can also process biomass to make fuel, called **biofuel.** Biofuel can be created from crops, such as corn or algae, and processed for use in a car (**Figure** 13.37). The advantage to biofuels is that they burn more cleanly than fossil fuels. As a result, they create less pollution and less carbon dioxide. Critics say, however, that the amount of energy, fertilizer, and land needed to produce the crops used make biofuels only a slightly better alternative than fossil fuels.

FIGURE 13.37
Biofuels, such as ethanol, are added to gasoline to cut down the amount of fossil fuels that are used.

KQED: How Green is Biomass Energy?

Organic material, like almond shells, can be made into electricity. Biomass power is a great use of wastes and is more reliable than other renewable energy sources, but harvesting biomass energy uses energy and biomass plants produce pollutants including greenhouse gases.

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KQED: From Waste to Watts: Biofuel Bonanza

Cow manure can have a second life as a source of methane gas, which can be converted to electricity. Not only that food scraps can also be converted into green energy.

MEDIA
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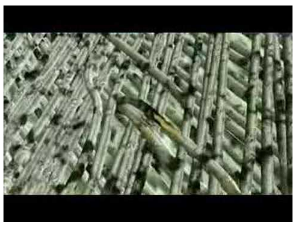
KQED: Biofuels: Beyond Ethanol

To generate biomass energy, break down the cell walls of plants to release the sugars and then ferment those sugars to create fuel. Corn is a very inefficient source; scientists are looking for much better sources of biomass energy.



MEDIA
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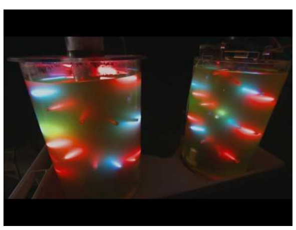
Algae Power

Many people think that the best source of biomass energy for the future is algae. Compared to corn, algae is not a food crop, it can grow in many places, its much easier to convert to a usable fuel and its carbon neutral.



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Power Up with Leftovers

Food that is tossed out produces methane, a potent greenhouse gas. But that methane from leftovers can be harnessed and used as fuel. Sounds like a win-win situation.

MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/60957

Lesson Summary

- Solar energy, water power, wind power, geothermal energy, and biomass energy are renewable energy sources.

- Solar energy can be used either by passively storing and holding the Sun's heat, converting it to electricity, or concentrating it.
- There are many ways to use the energy of moving water, including hydroelectric dams and tidal and wave plants.
- Wind power uses the energy of moving air to turn turbines.
- Geothermal energy uses heat from deep within the earth to heat homes or produce steam that turns turbines.
- Biomass energy uses renewable materials such as wood or grains to produce energy.

Review Questions

1. If you turn on the burner on a gas stove under a pan of cold water, energy moves from the burner to the pan of water. What is this type of energy transfer called? How does this energy move?
2. If solar power needs sunshine, how can solar power be a viable option for power?
3. If you burn wood in a fireplace, which type of energy resource are you using?
4. Which form of energy is an important factor in making electricity from water power?
5. Most of the energy that travels from the Sun to the Earth arrives in the form of visible light. What is this movement of energy called?
6. Explain how mirrors are used in some solar energy plants.
7. Explain how wind power uses kinetic energy.
8. NIMBY means "Not in My Backyard." How do various green energy projects, like Cape Wind, qualify as NIMBY projects?

Further Reading / Supplemental Links

- Cleveland, Cutler, "Energy Transitions Past and Future." Encyclopedia of Earth, 2007. Available on the Web at: http://www.eoearth.org/article/Energy_transitions_past_and_future .

Points to Consider

- What areas do you think would be best for using solar energy?
- What causes the high temperatures deep inside the Earth that make geothermal energy possible?
- Do you think your town or city could use wind or water power?

13.6 Non-renewable Energy Resources

Lesson Objectives

- Describe the natural processes that form the different fossil fuels.
- Describe different fossil fuels, and understand why they are non-renewable resources.
- Explain how fossil fuels are turned into useful forms of energy.
- Understand that when we burn a fossil fuel, its energy is released as heat.
- Describe how a nuclear power plant produces energy.

Vocabulary

- coal
- crude oil
- fossil
- fossil fuel
- hydrocarbon
- natural gas
- nuclear energy
- oil

Introduction

Millions of years ago, plants used energy from the Sun to form sugars, carbohydrates, and other energy-rich carbon compounds that were later transformed into coal, oil, or natural gas. The solar energy stored in these fuels is a rich source of energy. Although fossil fuels provide very high quality energy, they are non-renewable.

In large part, non-renewable energy sources are responsible for the world's lights seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/LIGHTS_3.MPG .

Formation of Fossil Fuels

Can you name some fossils? How about dinosaur bones or dinosaur footprints? Animal skeletons, teeth, shells, coprolites (otherwise known as feces), or any other remains or trace from a living creature that becomes a rock is a **fossil**.

The same processes that formed these fossils also created some of our most important energy resources, **fossil fuels**. Coal, oil, and natural gas are fossil fuels. Fossil fuels come from living matter starting about 500 million years ago. As plants and animals died, their remains settled on the ground on land and in swamps, lakes, and seas (**Figure** 13.38).

FIGURE 13.38
This wetland may look something like an ancient coal-forming swamp.

Over time, layer upon layer of these remains accumulated. Eventually, the layers were buried so deeply that they were crushed by an enormous mass of earth. The weight of this earth pressing down on these plant and animal remains created intense heat and pressure. After millions of years of heat and pressure, the material in these layers turned into chemicals called **hydrocarbons** (**Figure** 13.39). An animated view of a hydrocarbon is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CH4_3.MPG .

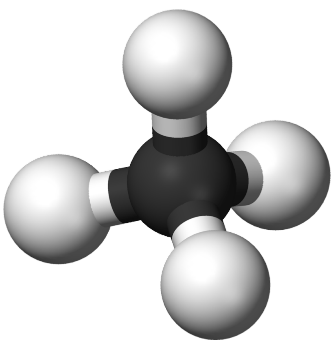

FIGURE 13.39
Hydrocarbons are made of carbon and hydrogen atoms. This molecule with one carbon and four hydrogen atoms is methane.

Hydrocarbons can be solid, liquid, or gaseous. The solid form is what we know as coal. The liquid form is petroleum, or crude oil. Natural gas is the gaseous form.

Coal

Coal, a solid fossil fuel formed from the partially decomposed remains of ancient forests, is burned primarily to produce electricity. Coal use is undergoing enormous growth as the availability of oil and natural gas decreases and cost increases. This increase in coal use is happening particularly in developing nations, such as China, where coal is cheap and plentiful.

Coal Formation

Coal forms from dead plants that settled at the bottom of ancient swamps. Lush coal swamps were common in the tropics during the Carboniferous period, which took place more than 300 million years ago (**Figure** 13.40). The climate was warmer then.

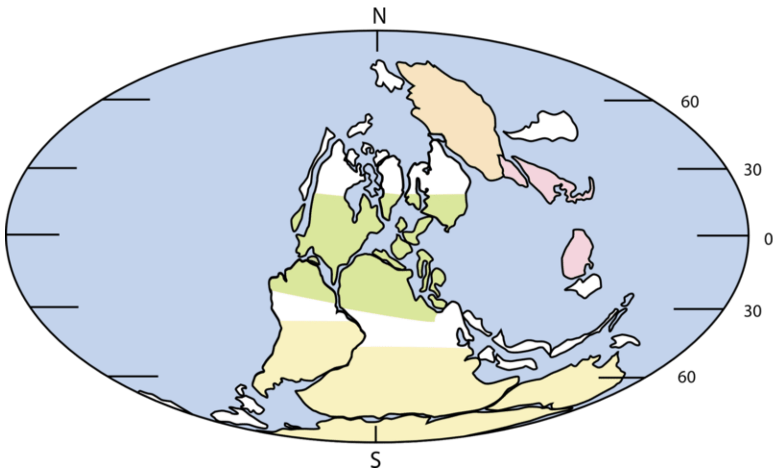

FIGURE 13.40
The location of the continents during the Carboniferous period. Notice that quite a lot of land area is in the region of the tropics.

Mud and other dead plants buried the organic material in the swamp, and burial kept oxygen away. When plants are buried without oxygen, the organic material can be preserved or fossilized. Sand and clay settling on top of the decaying plants squeezed out the water and other substances. Millions of years later, what remains is a carbon-containing rock that we know as coal.

Coal is black or brownish-black. The most common form of coal is bituminous, a sedimentary rock that contains impurities such as sulfur (**Figure** 13.41). Anthracite coal, seen in **Figure** 13.27, has been metamorphosed and is nearly all carbon. For this reason, anthracite coal burns more cleanly than bituminous coal.

FIGURE 13.41
Bituminous coal is a sedimentary rock.

Coal Use

Around the world, coal is the largest source of energy for electricity. The United States is rich in coal (**Figure** 13.42). California once had a number of small coal mines, but the state no longer produces coal. To turn coal into electricity, the rock is crushed into powder, which is then burned in a furnace that has a boiler. Like other fuels, coal releases its energy as heat when it burns. Heat from the burning coal boils the water in the boiler to make steam. The steam spins turbines, which turn generators to create electricity. In this way, the energy stored in the coal is converted to useful energy like electricity.

Coal that has been located but is not being used is part of our reserves. Reserves are important because if the price of the resource goes up or the cost of extracting it goes down, they may be useful.

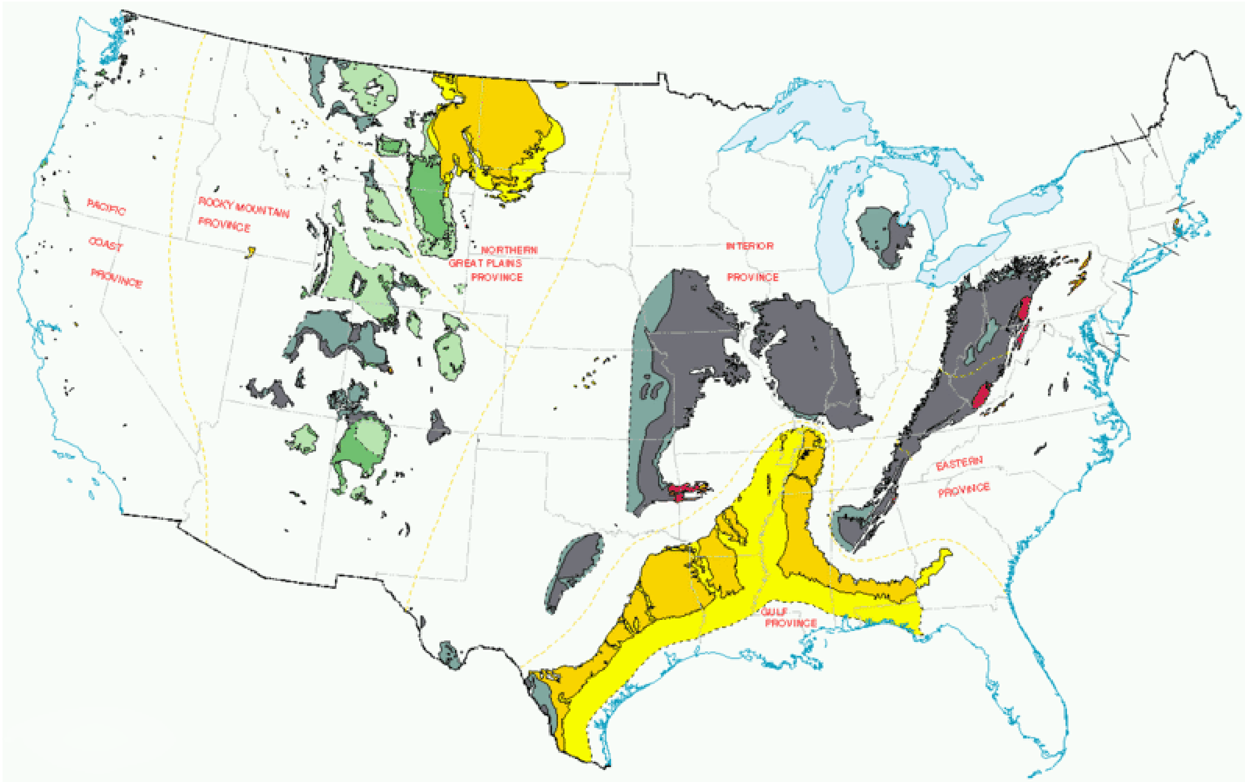

FIGURE 13.42

United States coal-producing regions in 1996. Orange is highest grade anthracite; red is low volatile bituminous; gray and gray-green is medium to high-volatile bituminous; green is subbituminous; and yellow is the lowest grade lignite.

Consequences of Coal Use

For coal to be used as an energy source, it must first be mined. Coal mining occurs at the surface or underground by methods that are described in the "Earth's Minerals" chapter (**Figure** 13.43). Mining, especially underground mining, can be dangerous. In April 2010, 29 miners were killed at a West Virginia coal mine when gas that had accumulated in the mine tunnels exploded and started a fire.

Some possible types of environmental damage from mining are discussed in the "Earth's Minerals" chapter. Coal mining exposes minerals and rocks from underground to air and water at the surface. Many of these minerals contain the element sulfur, which mixes with air and water to make sulfuric acid, a highly corrosive chemical. If the sulfuric acid gets into streams, it can kill fish, plants, and animals that live in or near the water.

Oil

Oil is a liquid fossil fuel that is extremely useful because it can be transported easily and can be used in cars and other vehicles. Oil is currently the single largest source of energy in the world.

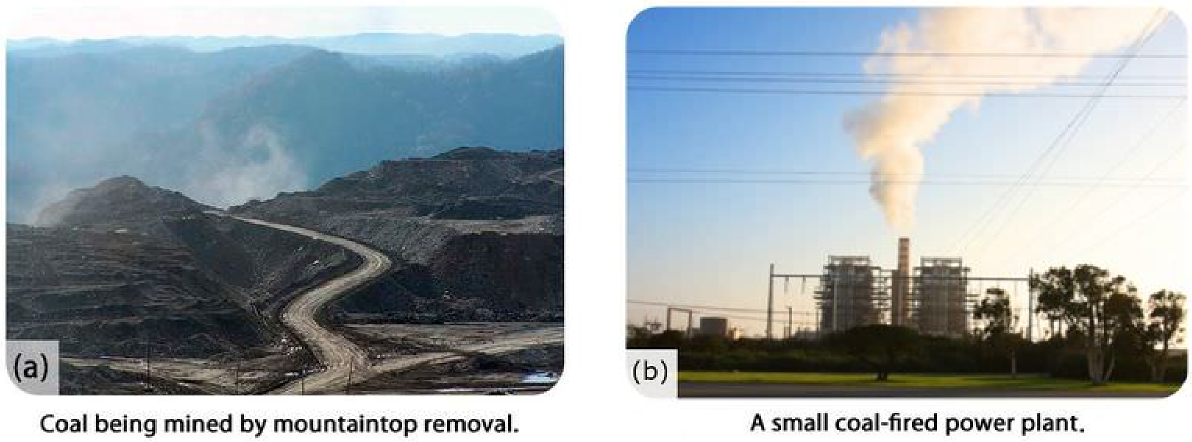

FIGURE 13.43
The coal used in power plants must be mined. One method to mine coal is by mountaintop removal.

Oil Formation

Oil from the ground is called **crude oil**, which is a mixture of many different hydrocarbons. Crude oil is a thick dark brown or black liquid hydrocarbon. Oil also forms from buried dead organisms, but these are tiny organisms that live on the sea surface and then sink to the seafloor when they die. The dead organisms are kept away from oxygen by layers of other dead creatures and sediments. As the layers pile up, heat and pressure increase. Over millions of years, the dead organisms turn into liquid oil.

Oil Production

In order to be collected, the oil must be located between a porous rock layer and an impermeable layer (**Figure** 13.44). Trapped above the porous rock layer and beneath the impermeable layer, the oil will remain between these layers until it is extracted from the rock.

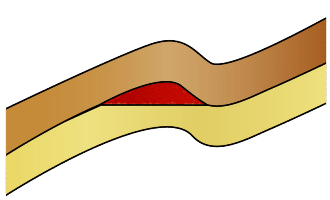

FIGURE 13.44
Oil (red) is found in the porous rock layer (yellow) and trapped by the impermeable layer (brown). The folded structure has allowed the oil to pool so a well can be drilled into the reservoir.

- An animation of an oil deposit forming is shown here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/ENTRAP_3.MPG .
- The oil pocket is then drilled into from the surface. An animation of an oil deposit being drilled is shown here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/DRILL_3.MPG .

- Sideways drilling allows a deposit that lies beneath land that cannot be drilled to be mined for oil: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/HORDRI_3.MPG .

To separate the different types of hydrocarbons in crude oil for different uses, the crude oil must be refined in refineries like the one shown in **Figure** 13.45. Refining is possible because each hydrocarbon in crude oil boils at a different temperature. When the oil is boiled in the refinery, separate equipment collects the different compounds.

FIGURE 13.45
Refineries like this one separate crude oil into many useful fuels and other chemicals.

Oil Use

Most of the compounds that come out of the refining process are fuels, such as gasoline, diesel, and heating oil. Because these fuels are rich sources of energy and can be easily transported, oil provides about 90% of the energy used for transportation around the world. The rest of the compounds from crude oil are used for waxes, plastics, fertilizers, and other products.

Gasoline is in a convenient form for use in cars and other transportation vehicles. In a car engine, the burned gasoline mostly turns into carbon dioxide and water vapor. The fuel releases most of its energy as heat, which causes the gases to expand. This creates enough force to move the pistons inside the engine and to power the car.

Consequences of Oil Use

The United States does produce oil, but the amount produced is only about one-quarter as much as the nation uses. The United States has only about 1.5% of the world's proven oil reserves, and so most of the oil used by Americans must be imported from other nations.

The main oil-producing regions in the United States are the Gulf of Mexico, Texas, Alaska, and California. Most offshore drilling occurs in the Gulf of Mexico, but there are offshore platforms in California as well (**Figure** 13.46). An animation of the location of petroleum basins in the contiguous United States can be seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/BASINS_3.MPG .

As in every type of mining, mining for oil has environmental consequences. Oil rigs are unsightly (**Figure** 13.47), and spills are too common (**Figure** 13.48).

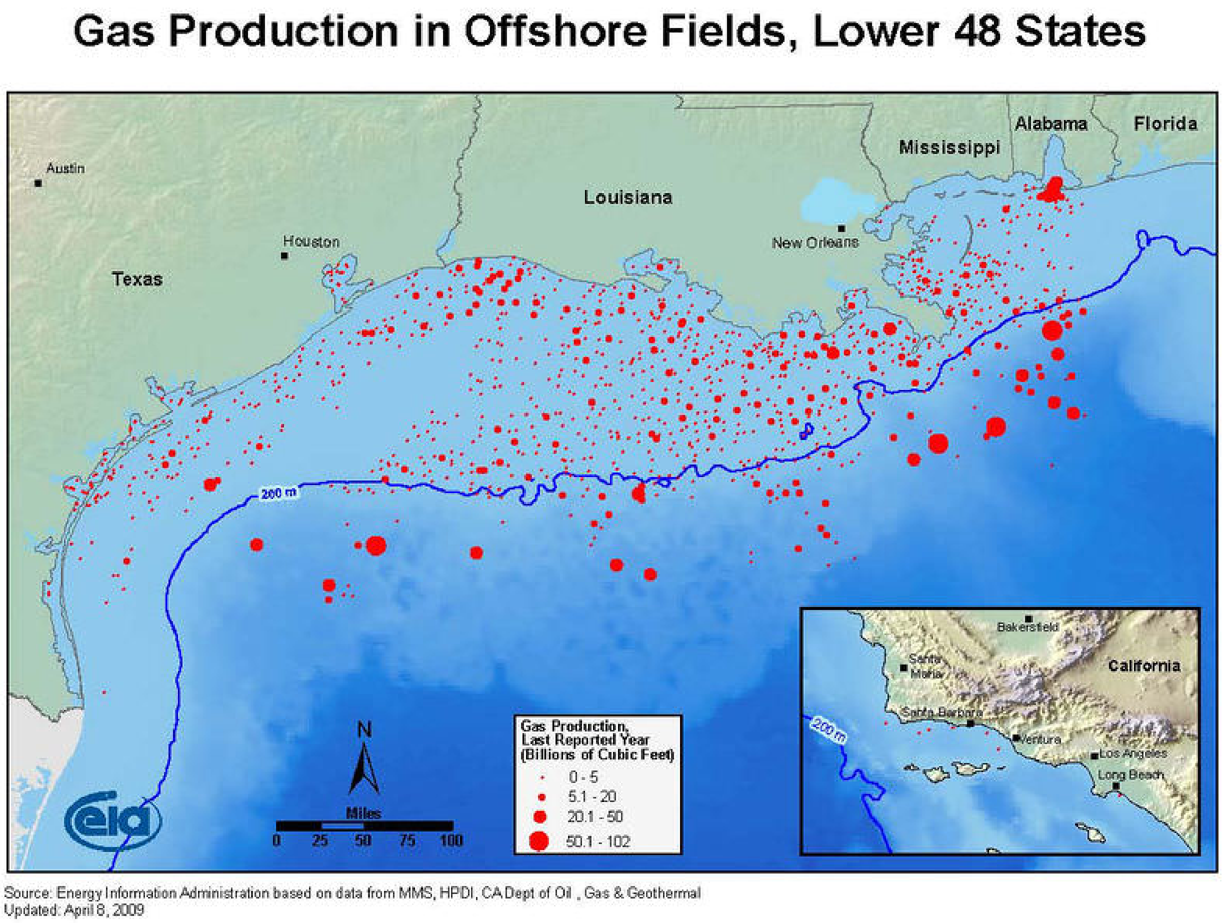

FIGURE 13.46
Offshore well locations in the Gulf of Mexico. Note that some wells are located in very deep water.

FIGURE 13.47
Drill rigs at the San Ardo Oil Field in Monterey, California.

Natural Gas

Natural gas, often known simply as gas, is composed mostly of the hydrocarbon methane (refer to **Figure** 13.39 for the structure).

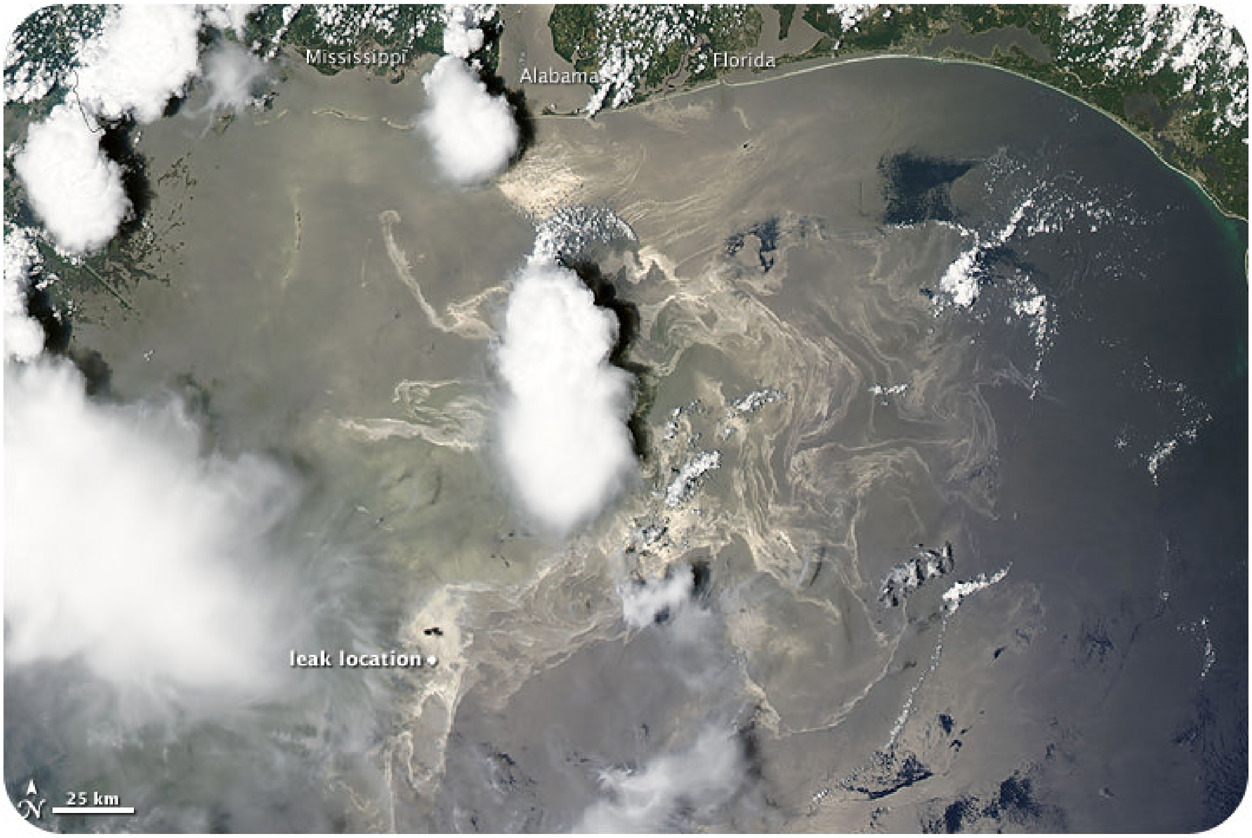

FIGURE 13.48
A deadly explosion on an oil rig in the Gulf of Mexico in April 2010 led to a massive oil spill. When this picture was taken in July 2010, oil was still spewing into the Gulf. The long-term consequences of the spill are being studied and are as yet unknown.

Natural Gas Formation

Natural gas forms under the same conditions that create oil. Organic material buried in the sediments harden to become a shale formation that is the source of the gas. Although natural gas forms at higher temperatures than crude oil, the two are often found together.

The formation of a minable oil and gas deposit is seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/PETSYS_3.MPG .

The largest natural gas reserves in the United States are in the Appalachian Basin, Texas, and the Gulf of Mexico region (**Figure** 13.49). California also has natural gas, found mostly in the Central Valley. In the northern Sacramento Valley and the Sacramento Delta, a sediment-filled trough formed along a location where crust was pushed together (an ancient convergent margin).

- An animation of global natural gas reserves is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/GLOBE_3.MPG .

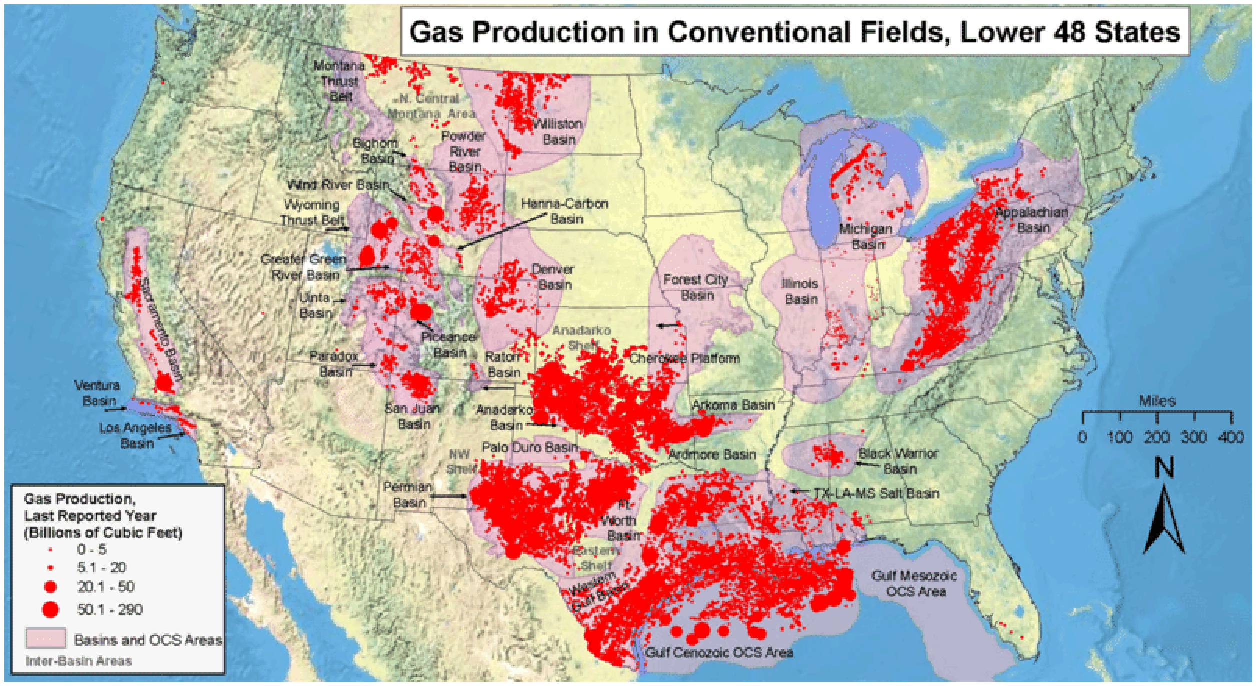

FIGURE 13.49

Gas production in the Lower l8 United States.

Natural Gas Use

Like crude oil, natural gas must be processed before it can be used as a fuel. Some of the chemicals in unprocessed natural gas are poisonous to humans. Other chemicals, such as water, make the gas less useful as a fuel. Processing natural gas removes almost everything except the methane. Once the gas is processed, it is ready to be delivered and used. Natural gas is delivered to homes for uses such as cooking and heating. Like coal and oil, natural gas is also burned to generate heat for powering turbines. The spinning turbines turn generators, and the generators create electricity.

Consequences of Natural Gas Use

Natural gas burns much cleaner than other fossil fuels, meaning that it causes less air pollution. Natural gas also produces less carbon dioxide than other fossil fuels do for the same amount of energy, so its global warming effects are less (**Figure** 13.50).

- See the pollution created by a car burning gasoline and a car burning natural gas in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/GASPOL_3.MPG .

Unfortunately, drilling for natural gas can be environmentally destructive. One technique used is hydraulic fracturing, also called fracking, which increases the rate of recovery of natural gas. Fluids are pumped through a borehole to create fractures in the reservoir rock that contains the natural gas. Material is added to the fluid to prevent the fractures from closing. The damage comes primarily from chemicals in the fracturing fluids. Chemicals that have been found in the fluids may be carcinogens (cancer-causing), radioactive materials, or endocrine disruptors, which

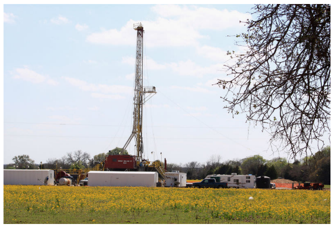

FIGURE 13.50
A natural gas drill rig.

interrupt hormones in the bodies of humans and animals. The fluids may get into groundwater or may runoff into streams and other surface waters.

Fossil Fuel Reserves

Fossil fuels provide about 85% of the world's energy at this time. Worldwide fossil fuel usage has increased many times over in the past half century (coal - 2.6x, oil - 8x, natural gas - 14x) because of population increases, because of increases in the number of cars, televisions, and other fuel-consuming uses in the developed world, and because of lifestyle improvements in the developing world.

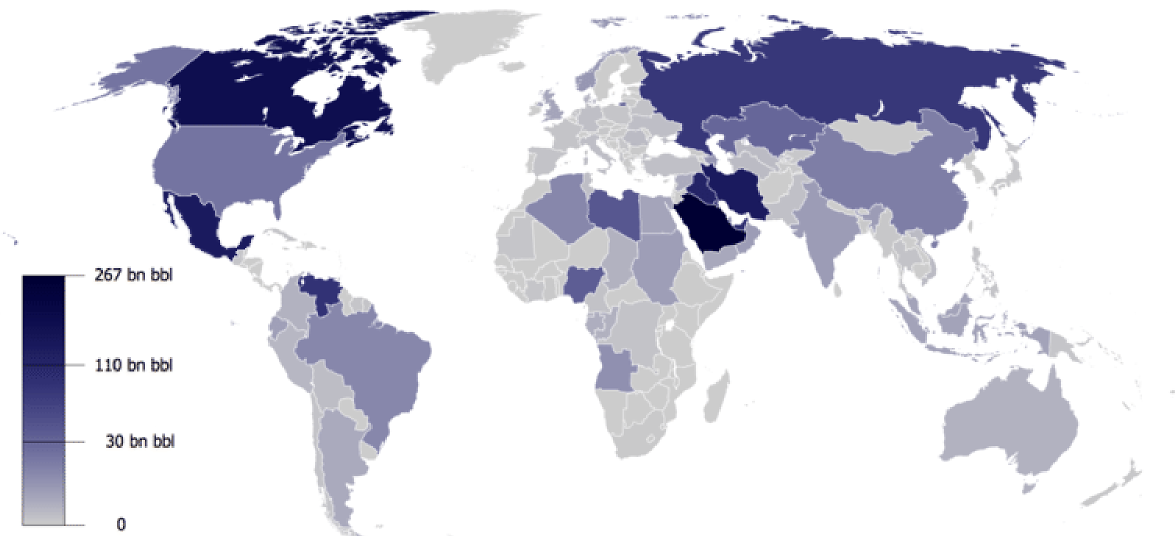

FIGURE 13.51
Worldwide oil reserves.

- Past and predicted use of different types of energy in the United States can be seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/MAXGAS_3.MPG .

The amount of fossil fuels that remain untapped is unknown but can likely be measured in decades for oil and natural gas and in a few centuries for coal (**Figure** 13.51). Alternative sources of fossil fuels, such as oil shales and tar sands, are increasingly being exploited (**Figure** 13.52).

FIGURE 13.52
A satellite image of an oil-sands mine in Canada.

The environmental consequences of mining these fuels, and of fossil fuel use in general, along with the fact that these fuels do not have a limitless supply, are prompting the development of alternative energy sources.

Nuclear Energy

When the nucleus of an atom is split, it releases a huge amount of energy called **nuclear energy.** For nuclear energy to be used as a power source, scientists and engineers have learned to split nuclei and to control the release of energy (**Figure** 13.53).

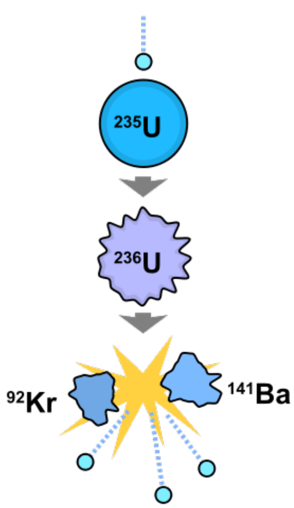

FIGURE 13.53
When struck by a tiny particle, Uranium-235 breaks apart and releases energy.

Nuclear Energy Use

Nuclear power plants, such as the one seen in **Figure** 13.54, use uranium, which is mined, processed, and then concentrated into fuel rods. When the uranium atoms in the fuel rods are hit by other extremely tiny particles, they split apart. The number of tiny particles allowed to hit the fuel rods needs to be controlled or they would cause a dangerous explosion. The energy from a nuclear power plant heats water, which creates steam and causes a turbine to spin. The spinning turbine turns a generator, which in turn produces electricity.

FIGURE 13.54
Nuclear power plants like this one provide France with almost 80% of its electricity.

Many countries around the world use nuclear energy as a source of electricity. In the United States, a little less than 20% of electricity comes from nuclear energy.

Consequences of Nuclear Power

Nuclear power is clean. It does not pollute the air or release carbon dioxide. However, the use of nuclear energy does create other environmental problems. Uranium must be mined (**Figure** 13.55). The process of splitting atoms creates radioactive waste, which remains dangerous for thousands or hundreds of thousands of years. As yet, there is no long-term solution for storing this waste.

The development of nuclear power plants has been on hold for three decades. Accidents at Three Mile Island and Chernobyl, Ukraine verified people's worst fears about the dangers of harnessing nuclear power (**Figure** 13.56).

Recently, nuclear power appeared to be making a comeback as society looked for alternatives to fossil fuels. But the 2011 disaster at the Fukushima Daiichi Nuclear Power Plant in Japan may have resulted in a new fear of nuclear power. The cause of the disaster was a 9.0 magnitude earthquake and subsequent tsunami, which compromised the plant. Although a total meltdown was averted, the plant experienced multiple partial meltdowns, core breaches, radiation releases, and cooling failures. The plant is scheduled for a complete cold shutdown before the end of 2011.

KQED: Nuclear Energy Use

Nuclear power is a controversial subject in California and most other places. Nuclear power has no pollutants including carbon emissions, but power plants are not always safe and the long-term disposal of wastes is a problem that has not yet been solved. The future of nuclear power is murky.

FIGURE 13.55
Uranium mine in Kakadu National Park, Australia.

FIGURE 13.56
Damaged building near the site of the Chernobyl disaster.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/179008

Lesson Summary

- Fossil fuels are non-renewable sources of energy that produce environmental damage.
- Coal, oil, and natural gas are fossil fuels formed from the remains of living organisms.
- Coal is the largest source of energy for producing electricity.
- Oil and natural gas are important energy sources for vehicles and electricity generation.
- Nuclear energy is produced by splitting atoms. It also produces radioactive wastes that are very dangerous for many years.

Review Questions

1. What is a hydrocarbon?
2. How do fossil fuels form?
3. Why is anthracite harder and cleaner than other kinds of coal?
4. What byproduct of nuclear energy has caused concerns about the use of this resource and why?
5. What are two important fuels that comes out of the oil refining process?
6. Which chemical element exposed in surface coal mining can cause environmental problems in nearby bodies of water?
7. Why does natural gas need to be processed before it can be used as a fuel?
8. What characteristic of gasoline is most important in making it a useful fuel for transportation? Explain.
9. Since nuclear power is clean, why is it not used more extensively in the United States?

Further Reading / Supplemental Links

- Perry, Mildred, "Coal." Encyclopedia of Earth, 2007. Available on the Web at: http://www.eoearth.org/article/Coal .

Points to Consider

- What are the main categories of non-renewable energy discussed in this chapter?
- Why is nuclear energy considered non-renewable?
- Are non-renewable energy sources equally harmful? What are the advantages of using them?
- Are renewable energy sources harmful or beneficial for the environment?

13.7 References

1. Angus Chan (Flickr:gusmaru). http://www.flickr.c
CC BY 2.0
2. Flickr:MyBiggestFan. http://www.flickr.com/photos/msciba
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3. Hammer and nail: Robert Lopez; Jumping girl: Johan Viirok; Bees: William Warby; Boy and pinwheel: Flickr:popofatticus; Dominoes: Barry Skeates; Waterfall: Tony Hisgett. <a href="Hammer and nail: CK-12 Foundation; Jumping girl: http://www.flickr.com/photos/viirok/5287805940/; Bees: http://www.flickr.com/photos/wwarby
Boy and pinwheel: http://www.flickr.com/photos/barretthall/3470428667/; Dominoes: http://www.flickr.com/photos/barry
Waterfall: http://www.flickr.com/photos/hisgett/422399097/">Hammer and nail: CK-12 Foundation; Jumping girl: http://www.flickr.com/photos/viirok/5287805940/; Bees: http://www.flickr.com/photos/wwarby/2990091410/;
Boy and pinwheel: http://www.flickr.com/photos/barretthall/3470428667/; Dominoes: http://www.flickr.com/photos/barry
Waterfall: http://www.flickr.com/photos/hisgett/422399097/. Hammer and nail: CC BY-NC 3.0; Rest: CC BY 2.0
4. Flickr:unukorno. http://www.flickr.com/photos/unukorno
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Skateboarder: http://www.flickr.com/photos/fixersphotos/3379770368/">Diving: http://www.flickr.com/photos/rattler97/5
Upside down girl: http://www.flickr.com/photos/28096801@N05/3647910820/; Skateboarder: http://www.flickr.com/phot
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thmc/7219683088/. CC BY 2.0
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CHAPTER 14 Thermal Energy

Chapter Outline

Death Valley, California, pictured here, is one of the hottest places on Earth. The temperature of the air near the ground can be as high as 57°C (134°F) —and that's in the shade! The temperature of the sand in the baking sun can be much higher. If you were to walk barefoot on the hot sand, it would burn your feet. How does energy from the sun heat the sand? What causes the sand's temperature to rise? And what exactly does temperature measure? Think about these questions as you read about thermal energy in this chapter.

William Warby. www.flickr.com/photos/wwarby/9641689318/. CC BY 2.0.

14.1 Temperature and Heat

Lesson Objectives

- Explain the relationship between temperature and thermal energy.
- Define heat and specific heat.

Lesson Vocabulary

- heat
- specific heat

Introduction

The hot air and sand in Death Valley have a lot of thermal energy, or the kinetic energy of moving particles. But even cold objects have some thermal energy. That's because the particles of all matter are in constant random motion. If cold as well as hot objects have moving particles, what, if anything, does temperature have to do with thermal energy?

Temperature

No doubt you already have a good idea of what temperature is. You might define it as how hot or cold something feels. In physics, temperature is defined as the average kinetic energy of the particles in an object. When particles move more quickly, temperature is higher and an object feels warmer. When particles move more slowly, temperature is lower and an object feels cooler.

Temperature and Thermal Energy

If two objects have the same mass, the object with the higher temperature has greater thermal energy. Temperature affects thermal energy, but temperature isn't the same thing as thermal energy. That's because an object's mass also affects its thermal energy. The examples in **Figure** 14.1 make this clear. In the figure, the particles of cocoa are moving faster than the particles of bathwater. Therefore, the cocoa has a higher temperature. However, the bath water has more thermal energy because there is so much more of it. It has many more moving particles. Bill Nye the Science Guy cleverly discusses these concepts at this URL: http://www.youtube.com/watch?v=f1eAOygDP5s&feature=related (2:06).

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/5032

If you're still not clear about the relationship between temperature and thermal energy, watch the animation "Temperature" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

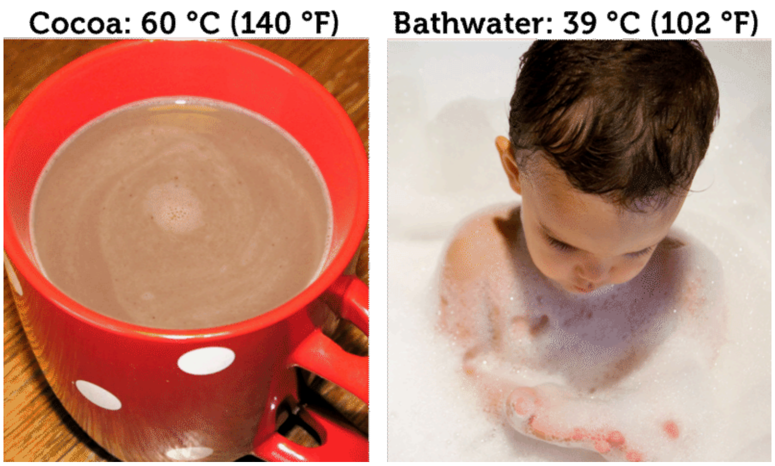


FIGURE 14.1

The cocoa is scalding hot. The bath water is comfortably warm. Why does the bath water have more thermal energy than the cocoa?

Measuring Temperature

Temperature is measured with a thermometer. A thermometer shows how hot or cold something is relative to two reference temperatures, usually the freezing and boiling points of water. Scientists often use the Celsius scale for temperature. On this scale, the freezing point of water is 0°C and the boiling point is 100°C. To learn more about measuring temperature, watch the animation "Measuring Temperature" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

Did you ever wonder how a thermometer works? Look at the thermometer in **Figure** 14.2. Particles of the red liquid have greater energy when they are warmer, so they move more and spread apart. This causes the liquid to expand and rise higher in the glass tube. Like the liquid in a thermometer, most types of matter expand to some degree when they get warmer. Gases usually expand the most when heated, followed by liquids. Solids generally expand the least. (Water is an exception; it takes up more space as a solid than as a liquid.)

Heat

Something that has a high temperature is said to be hot. Does temperature measure heat? Is heat just another word for thermal energy? The answer to both questions is no. **Heat** is the transfer of thermal energy between objects that have different temperatures. Thermal energy always moves from an object with a higher temperature to an object with a lower temperature. When thermal energy is transferred in this way, the warm object becomes cooler and the cool object becomes warmer. Sooner or later, both objects will have the same temperature. Only then does the

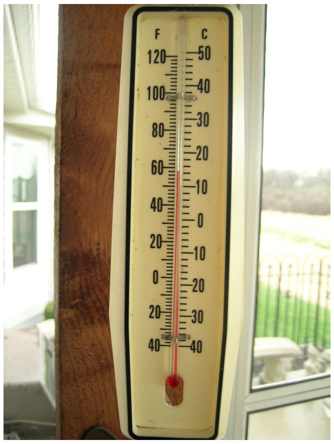


FIGURE 14.2
The red liquid in this thermometer is alcohol. Alcohol expands uniformly over a wide range of temperatures. This makes it ideal for use in thermometers.

transfer of thermal energy end. For a visual explanation of these concepts, watch the animation "Temperature vs. Heat" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

Example of Thermal Energy Transfer

Figure 14.3 illustrates an example of thermal energy transfer. Before the spoon was put into the steaming hot coffee, it was cool to the touch. Once in the coffee, the spoon heated up quickly. The fast-moving particles of the coffee transferred some of their energy to the slower-moving particles of the spoon. The spoon particles started moving faster and became warmer, causing the temperature of the spoon to rise. Because the coffee particles lost some of their kinetic energy to the spoon particles, the coffee particles started to move more slowly. This caused the temperature of the coffee to fall. Before long, the coffee and spoon had the same temperature.

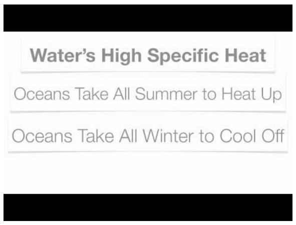
FIGURE 14.3
A cool spoon gets warmer when it is placed in a hot liquid. Can you explain why?

Specific Heat

The girls in **Figure** below are having fun at the beach. It's a warm, sunny day, and the sand feels hot under their bare hands and feet. The water, in contrast, feels much cooler. Why does the sand get so hot while the water does not?

The answer has to do with specific heat.

Specific heat is the amount of energy (in joules) needed to raise the temperature of 1 gram of a substance by 1°C. Specific heat is a property that is specific to a given type of matter. **Table** 14.1 lists the specific heat of four different substances. Metals such as iron have relatively low specific heat. It doesn't take much energy to raise their temperature. That's why a metal spoon heats up quickly when placed in hot coffee. Sand also has a relatively low specific heat, whereas water has a very high specific heat. It takes a lot more energy to increase the temperature of water than sand. This explains why the sand on a beach gets hot while the water stays cool. Differences in the specific heat of water and land also affect climate. To learn how, watch the video at this URL: http://www.youtube.com/watch?v=dkBStF2Rnu4 (7:07).



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In **Table** 14.1, how much greater is the specific heat of water than sand?

TABLE 14.1: Specific Heat of Some Common Substances

Substances	Specific Heat (joules)
iron	0.45
sand	0.67
wood	1.76
water	4.18

KQED: Bridge Thermometer

The roadway across the Golden Gate Bridge rises and falls as much as 16 feet depending on the temperature. When the sun hits the bridge, the metal expands and the bridge cables stretch. As the fog rolls in, the cables contract and the bridge goes up. Curators from the Outdoor Exploratorium in San Francisco have set up a scope two miles away so you can see how the bridge is moving up or down depending on the weather. For more information on how the bridge moves due to temperature, see http://science.kqed.org/quest/video/quest-lab-bridge-thermometer/ .

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Lesson Summary

- Temperature is the average kinetic energy of particles of an object. Warmer objects have faster particles and higher temperatures. If two objects have the same mass, the object with the higher temperature has greater thermal energy. Temperature is measured with a thermometer.
- Heat is the transfer of thermal energy between objects that have different temperatures. Thermal energy always moves from an object with a higher temperature to an object with a lower temperature. Specific heat is the amount of energy (in joules) needed to raise the temperature of 1 gram of a substance by 1°C. Substances differ in their specific heat.

Lesson Review Questions

Recall

1. What is temperature?
2. How is temperature measured?
3. Define heat.

Apply Concepts

4. Give an example of heat that you didn't read about in this lesson.
5. Glass has a specific heat of 0.84 J/g·°C. Copper has a specific heat of 0.39 J/kg·°C. Which material takes more energy to warm up?

Think Critically

6. Explain how a cooler object can have more thermal energy than a warmer object.
7. Relate heat to temperature.

Points to Consider

In this lesson, you read that heat is the transfer of thermal energy from one object to another.

- How do you think the transfer of thermal energy occurs? For example, how does thermal energy move from hot sand to bare feet when someone walks on a beach?
- Do you think there might be more than one way that thermal energy can be transferred? For example, how does thermal energy move from a bonfire to a nearby person who isn't touching the flames?

14.2 Transfer of Thermal Energy

Lesson Objectives

- Describe the conduction of thermal energy.
- Explain how convection transfers thermal energy.
- Give an example of the radiation of thermal energy.

Lesson Vocabulary

- conduction
- convection
- convection current
- thermal conductor
- thermal insulator

Introduction

Did you ever cook over a campfire? The man in the **Figure** 14.4 is waiting for his lunch to finish cooking over the campfire. Thermal energy from the fire heats the water. Eventually, all the water in the pot will be boiling hot. The man also feels warm from the flames, even though he isn't touching them. Thermal energy is transferred from the fire in three ways: conduction, convection, and radiation. You'll read about each way in this lesson. For an animated preview of the three ways, go to this URL: http://www.nd.edu/~ysun/Yang/PhysicsAnimation/collection/transportP.swf .

FIGURE 14.4
Thermal energy from the fire is transferred to the pot and water and to the man sitting by the fire.

Conduction

Conduction is the transfer of thermal energy between particles of matter that are touching. When energetic particles collide with nearby particles, they transfer some of their thermal energy. From particle to particle, like dominoes falling, thermal energy moves throughout a substance. In **Figure** 14.4, conduction occurs between particles of the metal in the pot and between particles of the pot and the water. **Figure** 14.5 shows additional examples of conduction. For a deeper understanding of this method of heat transfer, watch the animation "Conduction" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

Hands feel cold when they're holding ice because they lose thermal energy to the ice.

Hair feels warm after a hot curling iron passes over it because it gains thermal energy from the curling iron.

FIGURE 14.5

How is thermal energy transferred in each of these examples?

Thermal Conductors

Conduction is usually faster in liquids and certain solids than in gases. Materials that are good conductors of thermal energy are called **thermal conductors**. Metals are excellent thermal conductors. They have freely moving electrons that can transfer energy quickly and easily. That's why the metal pot in **Figure** 14.4 soon gets hot all over, even though it gains thermal energy from the fire only at the bottom of the pot. In **Figure** 14.5, the metal heating element of the curling iron heats up almost instantly and quickly transfers energy to the strands of hair that it touches.

Thermal Insulators

Particles of gases are farther apart and have fewer collisions, so they are not good at transferring thermal energy. Materials that are poor thermal conductors are called **thermal insulators**. **Figure** 14.6 shows several examples. Fluffy yellow insulation inside the roof of a home is full of air. The air prevents the transfer of thermal energy into the house on hot days and out of the house on cold days. A puffy down jacket keeps you warm in the winter for the same reason. Its feather filling holds trapped air that prevents energy transfer from your warm body to the cold air outside. Solids like plastic and wood are also good thermal insulators. That's why pot handles and cooking utensils are often made of these materials.

KQED: Darfur Stoves Project

Everyday, women living in the refugee camps of Darfur, Sudan must walk for up to seven hours outside the safety of the camps to collect firewood for cooking, putting them at risk for violent attacks. Now, researchers at Lawrence Berkeley National Laboratory have engineered a more efficient wood-burning stove, which is greatly reducing both the women's need for firewood and the threats against them. For more information on these stoves, see http://science.kqed.org/quest/video/darfur-stoves-project/ .

FIGURE 14.6
Thermal insulators have many practical uses. Can you think of others?

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Convection

Convection is the transfer of thermal energy by particles moving through a fluid. Particles transfer energy by moving from warmer to cooler areas. That's how energy is transferred in the soup in **Figure** 14.6. Particles of soup near the bottom of the pot get hot first. They have more energy so they spread out and become less dense. With lower density, these particles rise to the top of the pot (see **Figure** 14.7). By the time they reach the top of the pot they have cooled off. They have less energy to move apart, so they become denser. With greater density, the particles sink to the bottom of the pot, and the cycle repeats. This loop of moving particles is called a **convection current**.

Convection currents move thermal energy through many fluids, including molten rock inside Earth, water in the oceans, and air in the atmosphere. In the atmosphere, convection currents create wind. You can see one way this happens in **Figure** 14.8. Land heats up and cools off faster than water because it has lower specific heat. Therefore, land is warmer during the day and cooler at night than water. Air close to the surface gains or loses heat as well. Warm air rises because it is less dense, and when it does, cool air moves in to take its place. This creates a convection current that carries air from the warmer to the cooler area. You can learn more about convection currents by watching "Convection" at this URL: http://www.sciencehelpdesk.com/unit/science2/3 .

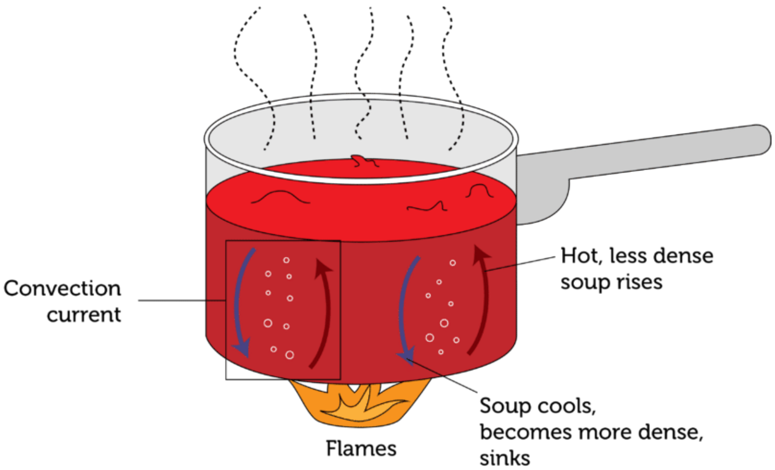


FIGURE 14.7
Convection currents carry thermal energy throughout the soup in the pot.

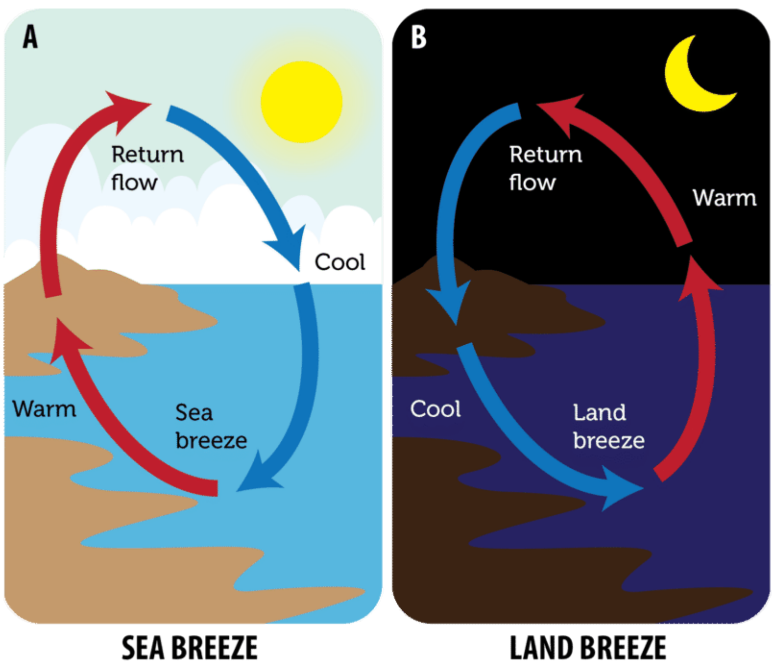


FIGURE 14.8
A sea breeze blows toward land during the day, and a land breeze blows toward water at night. Why does the wind change direction after the sun goes down?

Radiation

Both conduction and convection transfer energy through matter. Radiation is the only way of transferring energy that doesn't require matter. Radiation is the transfer of energy by waves that can travel through empty space. When the waves reach objects, they transfer energy to the objects, causing them to warm up. This is how the sun's energy reaches Earth and heats its surface (see **Figure** 14.9). Radiation is also how thermal energy from a campfire warms people nearby. You might be surprised to learn that all objects radiate thermal energy, including people. In fact, when a room is full of people, it may feel noticeably warmer because of all the thermal energy the people radiate! To learn more about thermal radiation, watch "Radiation" at the URL below.

http://www.sciencehelpdesk.com/unit/science2/3

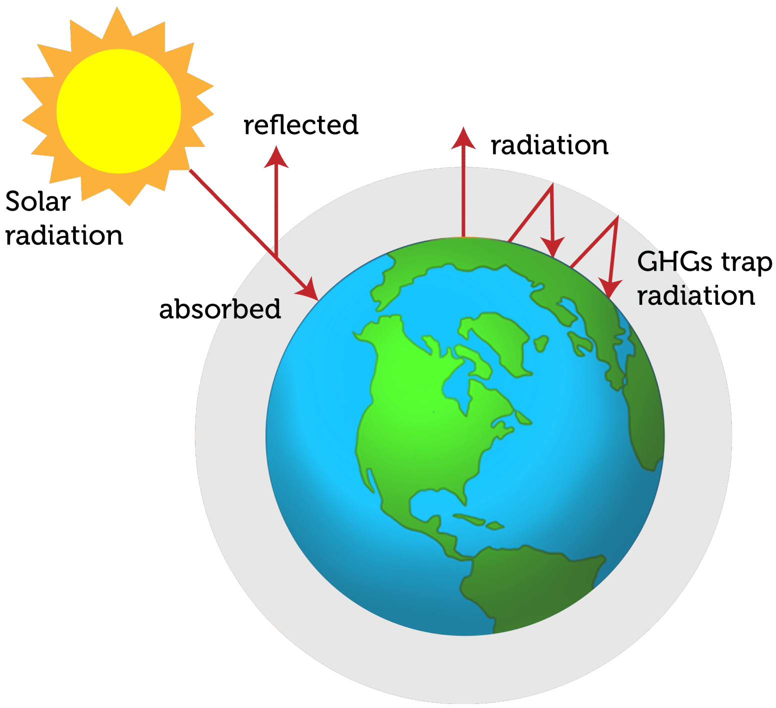


FIGURE 14.9
Earth is warmed by energy that radiates from the sun. Earth radiates some of the energy back into space. Greenhouse gases (GHGs) trap much of the re-radiated energy, causing an increase in the temperature of the atmosphere close to the surface.

Lesson Summary

- Conduction is the transfer of thermal energy between particles of matter that are touching. Thermal conductors are materials that are good conductors of thermal energy. Thermal insulators are materials that are poor conductors of thermal energy. Both conductors and insulators have important uses.
- Convection is the transfer of thermal energy by particles moving through a fluid. The particles transfer energy by moving from warmer to cooler areas. They move in loops called convection currents.
- Radiation is the transfer of thermal energy by waves that can travel through empty space. When the waves reach objects, they transfer thermal energy to the objects. This is how the sun's energy reaches and warms Earth.

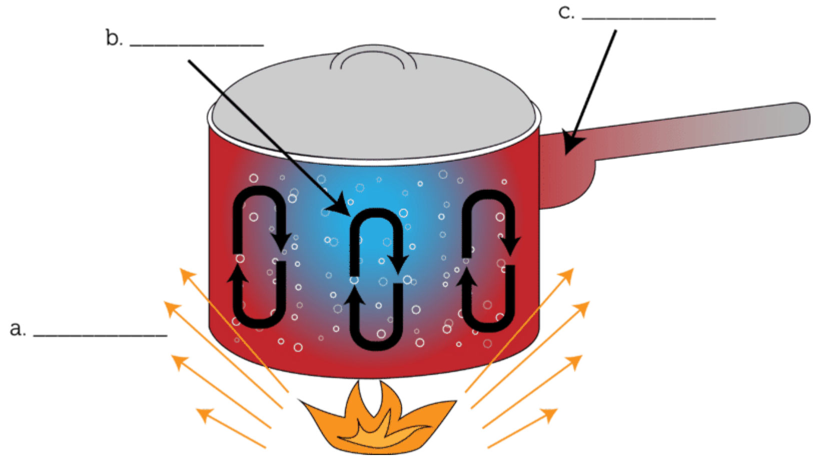
Lesson Review Questions

Recall

1. Define conduction.
2. What is convection?
3. Define the radiation of thermal energy.

Apply Concepts

4. Fill in each blank in the diagram below with the correct method of heat transfer.



5. How could you insulate an ice cube to keep it from melting? What material(s) would you use?

Think Critically

6. Why does convection occur only in fluids?
7. George says that insulation keeps out the cold. Explain why this statement is incorrect. What should George have said?

Points to Consider

Thermal energy is very useful. For example, we use thermal energy to keep our homes warm and our motor vehicles moving.

- How does thermal energy heat a house? What devices and systems are involved?
- How does thermal energy run a car? How does burning gas in the engine cause the wheels to turn?

14.3 Heat, Temperature, and Thermal Energy Transfer

Learning Objectives

- Define heat.
- Define temperature.
- Describe thermal energy transfer.
- Define Celsius and Kelvin temperature scales.
- Convert Celsius temperatures to Kelvin and vice versa.

The temperature of basalt lava at Kilauea (Hawaii) reaches 1,160 degrees Celsius (2,120 degrees Fahrenheit). A crude estimation of temperature can be determined by looking at the color of the rock: orange-to-yellow colors are emitted when rocks (or metals) are hotter than about 900 degrees Celsius; dark-to-bright cherry red is characteristic as material cools to 630 degrees Celsius; faint red glow persists down to about 480 degrees Celsius. For comparison, a pizza oven is commonly operated at temperatures ranging from 260 to 315 degrees Celsius.

Heat, Temperature, and Thermal Energy Transfer

The first theory about how a hot object differs from a cold object was formed in the 18th century. The suggested explanation was that when an object was heated, an invisible fluid called "caloric" was added to the object. Hot objects contained more caloric than cold objects. The caloric theory could explain some observations about heated objects (such as that the fact that objects expanded as they were heated) but could not explain others (such as why your hands got warm when you rub them together).

In the mid-19th century, scientists devised a new theory to explain heat. The new theory was based on the assumption that matter is made up of tiny particles that are always in motion. In a hot object, the particles move faster and therefore have greater kinetic energy. The theory is called the kinetic-molecular theory and is the accepted theory of heat. Just as a baseball has a certain amount of kinetic energy due to its mass and velocity, each molecule has a certain amount of kinetic energy due to its mass and velocity. Adding up the kinetic energy of all the molecules in an object yields the **thermal energy** of the object.

When a hot object and a cold object touch each other, the molecules of the objects collide along the surface where they touch. When higher kinetic energy molecules collide with lower kinetic energy molecules, kinetic energy is passed from the molecules with more kinetic energy to those with less kinetic energy. In this way, heat always flows from hot to cold and heat will continue to flow until the two objects have the same temperature. The movement of heat from one object to another by molecular collision is called **conduction**.

Heat is the energy that flows as a result of a difference in temperature. We use the symbol Q for heat. Heat, like all forms of energy, is measured in joules.

The **temperature** of an object is a measurement of the average kinetic energy of all the molecules of the object. You should note the difference between heat and temperature. Heat is the *sum* of all the kinetic energies of all the molecules of an object, while temperature is the *average* kinetic energy of the molecules of an object. If an object was composed of exactly three molecules and the kinetic energies of the three molecules are 50 J, 70 J, and 90 J, the heat would be 210 J and the temperature would be 70 J.

The terms *hot* and *cold* refer to temperature. A hot object has greater average kinetic energy but may not have greater total kinetic energy. Suppose you were to compare a milliliter of water near the boiling point with a bathtub full of water at room temperature. The bathtub contains a billion times as many water molecules, and therefore has a higher total kinetic energy and more heat. Nonetheless, we would consider the bathtub colder because its average kinetic energy, or temperature, is lower.

Temperature Scales: Celsius and Kelvin

A **thermometer** is a device used to measure temperature. It is placed in contact with an object and allowed to reach thermal equilibrium with the object (they will have the same temperature). The operation of a thermometer is based on some property, such as volume, that varies with temperature. The most common thermometers contain liquid mercury, or some other liquid, inside a sealed glass tube. The liquid expands and contracts faster than the glass tube. Therefore, when the temperature of the thermometer increases, the liquid volume expands faster than the glass volume, allowing the liquid to rise in the tube. The positions of the liquid in the tube can then be calibrated for accurate temperature readings. Other properties that change with temperature can also be used to make thermometers; liquid crystal colors and electrical conductivity change with temperature, and are also relatively common thermometers.

The most commonly used temperature scale in the United States is the Fahrenheit scale. However, this scale is rarely used throughout the world; the metric temperature scale is Celsius. This scale, based on the properties of water, was devised by the Swedish physicist, Anders Celsius (1704 - 1744). The freezing point of water is 0°C and the boiling point of water was assigned to be 100°C. The kinetic energies between these two points was divided evenly into 100 "degrees Celsius".

The Kelvin or "Absolute" temperature scale is the scale often used by chemists and physicists. It is based on the temperature at which all molecular motion ceases; this temperature is called absolute zero and is 0 K. This temperature corresponds to -273.15°C. Since absolute zero is the coldest possible temperature, there are no negative values on the Kelvin temperature scale. Conveniently, the Kelvin and Celsius scales have the same definition of a degree, which makes it very easy to convert from one scale to the other. The relationship between Celsius and Kelvin temperature scales is given by:

$$K = {}^\circ C + 273.15$$

On the Kelvin scale, water freezes at 273 K and boils at 373 K.

Example

Convert 25°C to Kelvin.

K = °C + 273 = 25°C + 273 = 298 K

Summary

- The thermal energy, or heat, of an object is obtained by adding up the kinetic energy of all the molecules within it.
- Temperature is the average kinetic energy of the molecules.
- Absolute zero is the temperature where molecular motion stops and is the lowest possible temperature.
- Zero on the Celsius scale is the freezing point of water and 100°C is the boiling point of water.
- The relationship between Celsius and Kelvin temperature scales is given by K = °C + 273.15.

Review

1. Convert 4.22 K to °C.
2. Convert 37°C to K.
3. If you had beeswax attached to one end of a metal skewer and you placed the other end of the skewer in a flame, what would happen after a few minutes?
4. Which contains more heat, a coffee cup of boiling water or a bathtub of room temperature water?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/82540

1. Which material was a better conductor of heat?
2. Explain why metals feel cold even when thay are at room temperature.

Resources

By clicking this link, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

This MIT video examines the phenomenon of Joule heating through the perspective of a blender, reproducing the experiment of the English physicist James Prescott Joule. See the video at http://techtv.mit.edu/videos/14887-blender-the-next-stove-the-joule-experiment .

Vocabulary

- **thermal energy:** The total energy of a substance particles due to their translational movement or vibrations.
- **heat:** energy transferred from one body to another by thermal interactions.
- **temperature:** A measurement of the average kinetic energy of the molecules in an object or system and can be measured with a thermometer or a calorimeter.
- **conduction:** The transfer of thermal energy by the movement of particles that are in contact with each other.
- **absolute zero:** The lowest possible temperature, at which point the atoms of a substance transmit no thermal energy - they are completely at rest. It is 0 degrees on the Kelvin scale, which translates to -273.15 degrees Celsius (or -459.67 degrees Fahrenheit).

14.4 References

1. Cocoa: F_A (Flickr:seelensturm); Boy in bath: Brandon Doan (Flickr:bdogggut34). <a href="Cocoa: http://www.flickr.con
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   Soup: www.flickr.com/photos/90037546@N00/3156066767/">Insulation: http://www.flickr.com/photos/epicfireworks/46
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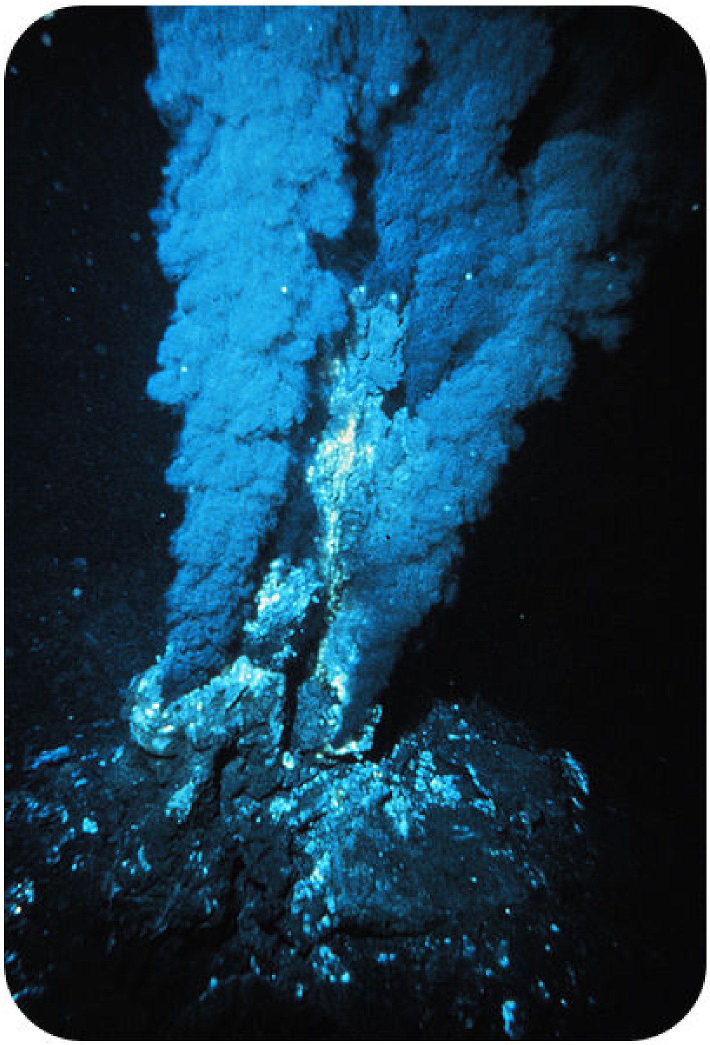
    q.jpg.

CONCEPT 15 Unit 7: Energy and Geological Processes

Questions/Observable Phenomena

CHAPTER 16 Plate Tectonics

Chapter Outline



Like just about everything in Earth Science, this strange feature is related to plate tectonics. It's really just a hot geyser like the ones found at Yellowstone National Park, except this geyser is found under 10,000 feet of seawater. These features, called hydrothermal vents, are found where lava eruptions hit seawater in regions where new ocean crust is being created. The hot water coming from the vent explodes from the release of pressure. Once in the cold seawater, sulfide minerals precipitate out, creating the "smoke" in the photo. As the sulfide minerals fall, they create the chimney-like structure in the photo.

Many hydrothermal vents are home to unusual life forms.

Courtesy of P. Rona/NOAA. commons.wikimedia.org/wiki/File:Blacksmoker_in_Atlantic_Ocean.jpg. Public Domain.

16.1 Inside Earth

Lesson Objectives

- Compare and describe each of these Earth layers: lithosphere, oceanic crust, and continental crust.
- Compare some of the ways geologists learn about Earth's interior.
- Describe how convection takes place in the mantle.
- Compare the two parts of the core and describe why they are different from each other.

Vocabulary

- conduction
- continental crust
- convection
- convection cell
- core
- crust
- lithosphere
- mantle
- meteorite
- oceanic crust
- P-waves
- S-waves
- seismic waves

Introduction

Before you can learn about plate tectonics, you need to know something about the layers that are found inside Earth. These layers are divided by composition into core, mantle, and crust or by mechanical properties into lithosphere and asthenosphere. Scientists use information from earthquakes and computer modeling to learn about Earth's interior.

Exploring Earth's Interior

How do scientists know what is inside the Earth? We don't have direct evidence! Rocks yield some clues, but they only reveal information about the outer crust. In rare instances, a mineral, such as a diamond, comes to the surface from deeper down in the crust or the mantle. To learn about Earth's interior, scientists use energy to "see" the different layers of the Earth, just like doctors can use an MRI, CT scan, or x-ray to see inside our bodies.

Seismic Waves

One ingenious way scientists learn about Earth's interior is by looking at how energy travels from the point of an earthquake. These are **seismic waves** (**Figure** 16.1). Seismic waves travel outward in all directions from where the ground breaks at an earthquake. These waves are picked up by seismographs around the world. Two types of seismic waves are most useful for learning about Earth's interior.

- **P-waves** (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a compression/expansion type motion, squeezing and unsqueezing earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave shadow zone. No P-waves are picked up at seismographs 104° to 140° from the earthquakes focus.

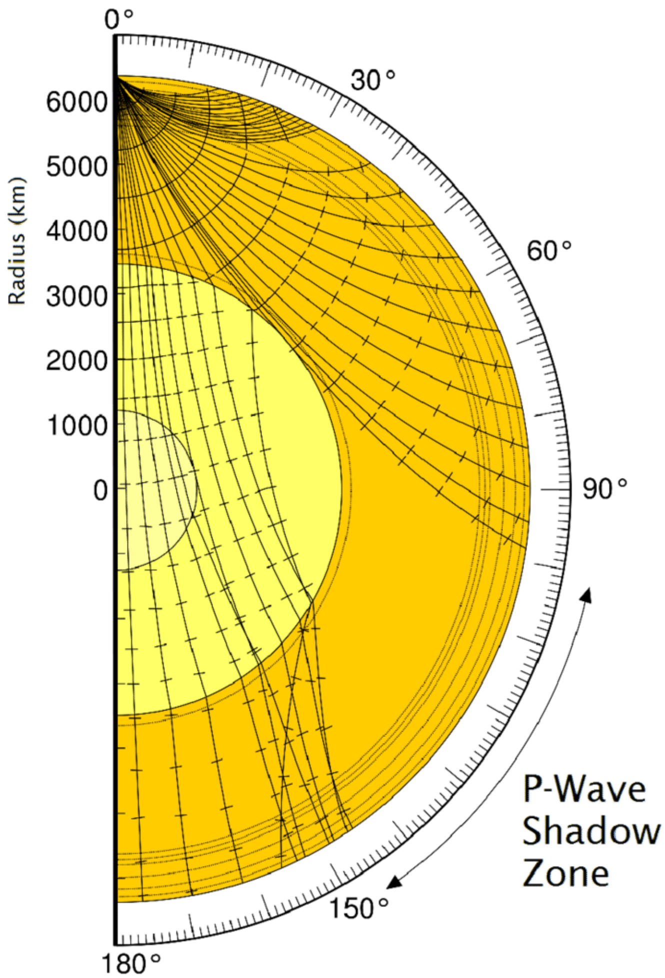


FIGURE 16.1
How P-waves travel through Earth's interior.

- **S-waves** (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of wave travel. This produces a change in shape for the earth materials they move through. Only solids resist a change in shape, so S-waves are only able to propagate through solids. S-waves cannot travel through liquid.

By tracking seismic waves, scientists have learned what makes up the planet's interior (**Figure** 16.2).

- P-waves slow down at the mantle core boundary, so we know the outer core is less rigid than the mantle.
- S-waves disappear at the mantle core boundary, so the outer core is liquid.

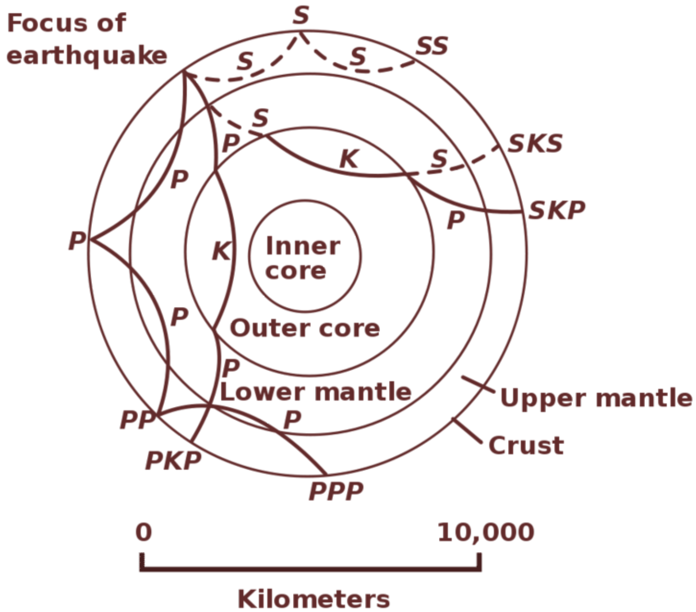


FIGURE 16.2
Letters describe the path of an individual P-wave or S-wave. Waves traveling through the core take on the letter K.

This animation shows a seismic wave shadow zone: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Shadow+Zone&flash_file=shadowzone&flash_width=220&flash_height=320 .

Other Clues about Earth's Interior

1. Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.
2. Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.
3. **Meteorites** are the remains of the material that formed the early solar system and are thought to be similar to material in Earth's interior (**Figure** 16.3).

FIGURE 16.3
This meteorite contains silica minerals and iron-nickel. The material is like the boundary between Earth's core and mantle. The meteorite is 4.2 billion years old.

The Earth's Layers

The layers scientists recognize are pictured in the **Figure** 16.4.

Core, mantle, and crust are divisions based on composition:

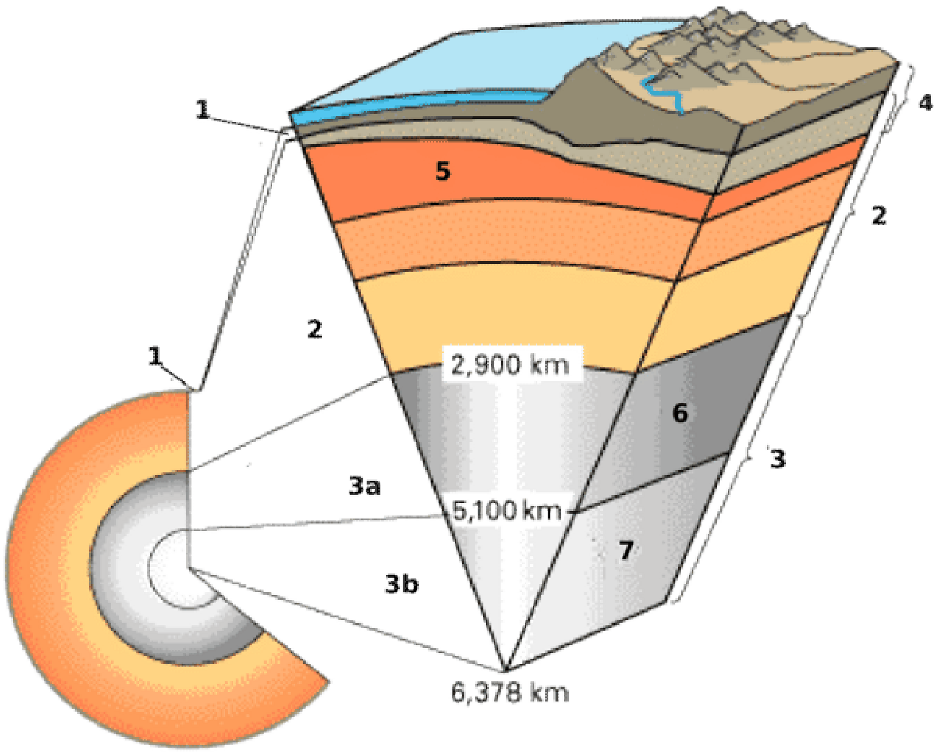


FIGURE 16.4
A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

1. The **crust** is less than 1% of Earth by mass. The **oceanic crust** is mafic, while **continental crust** is often more felsic rock.
2. The **mantle** is hot, ultramafic rock. It represents about 68% of Earth's mass.
3. The **core** is mostly iron metal. The core makes up about 31% of the Earth.

Lithosphere and asthenosphere are divisions based on mechanical properties:

1. The lithosphere is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid.
2. The asthenosphere is partially molten upper mantle material that behaves plastically and can flow.

This animation shows the layers by composition and by mechanical properties: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html .

Crust and Lithosphere

Earth's outer surface is its crust; a cold, thin, brittle outer shell made of rock. The crust is very thin, relative to the radius of the planet. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in **Table** 16.1.

TABLE 16.1: Oceanic and Continental Crust

Crust	Thickness	Density	Composition	Rock types
Oceanic	5-12 km (3-8 mi)	3.0 g/cm^3	Mafic	Basalt and gabbro
Continental	Avg. 35 km (22 mi)	2.7 g/cm^3	Felsic	All types

Oceanic crust is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro (**Figure** 16.5).

FIGURE 16.5
Gabbro from ocean crust. The gabbro is deformed because of intense faulting at the eruption site.

Sediments, primarily muds and the shells of tiny sea creatures, coat the seafloor. Sediment is thickest near the shore where it comes off the continents in rivers and on wind currents.

Continental crust is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust (**Figure** 16.6). Because it is thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet's oceans.

FIGURE 16.6
This granite from Missouri is more than 1 billion years old.

The **lithosphere** is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. Look at **Figure** 16.4. Can you find where the crust and the lithosphere are located? How are they different from each other?

The definition of the lithosphere is based on how earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

Mantle

The two most important things about the mantle are: (1) it is made of solid rock, and (2) it is hot. Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties fit the ultramafic rock peridotite, which is made of the iron- and magnesium-rich silicate minerals (**Figure** 16.7). Peridotite is rarely found at Earth's surface.

FIGURE 16.7
Peridotite is formed of crystals of olivine (green) and pyroxene (black).

Scientists know that the mantle is extremely hot because of the heat flowing outward from it and because of its physical properties.

Heat flows in two different ways within the Earth:

1. Conduction: Heat is transferred through rapid collisions of atoms, which can only happen if the material is solid. Heat flows from warmer to cooler places until all are the same temperature. The mantle is hot mostly because of heat conducted from the core.
2. **Convection:** If a material is able to move, even if it moves very slowly, convection currents can form.

Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing its density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle **convection cell** is complete (**Figure** 16.8).

Core

At the planet's center lies a dense metallic core. Scientists know that the core is metal because:

1. The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
2. Metallic meteorites are thought to be representative of the core. The 85% iron/15% nickel calculation above is also seen in metallic meteorites (**Figure** 16.9).

If Earth's core were not metal, the planet would not have a magnetic field. Metals such as iron are magnetic, but rock, which makes up the mantle and crust, is not.

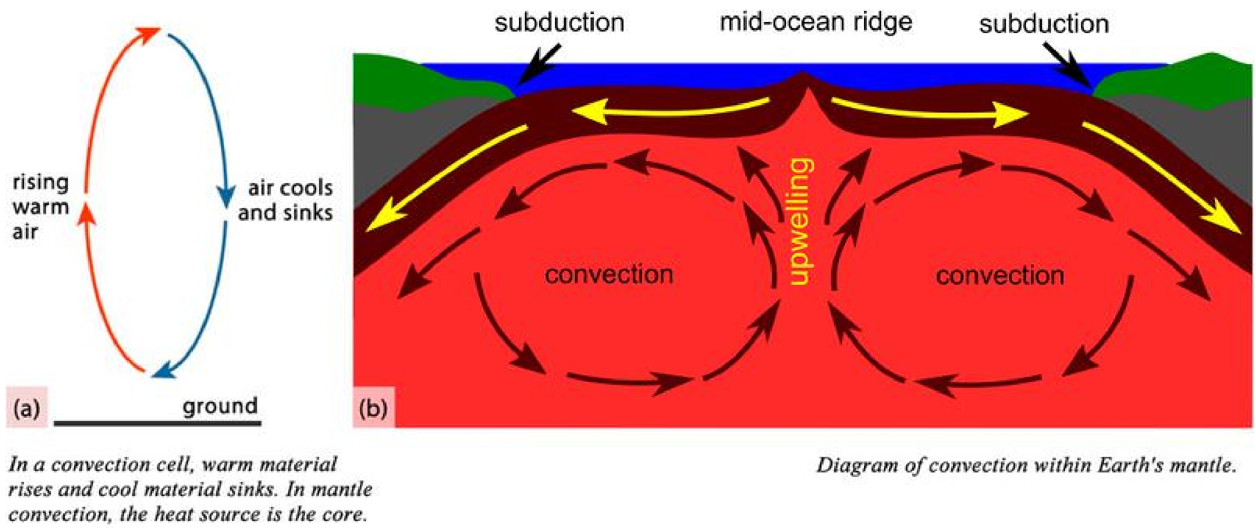


FIGURE 16.8
Convections

FIGURE 16.9
An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

Scientists know that the outer core is liquid and the inner core is solid because:

1. S-waves stop at the inner core.
2. The strong magnetic field is caused by convection in the liquid outer core. Convection currents in the outer core are due to heat from the even hotter inner core.

The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

Lesson Summary

- Earth is made of three layers: the crust, mantle, and core.
- The brittle crust and uppermost mantle are together called the lithosphere.
- Beneath the lithosphere, the mantle is solid rock that can flow, or behave plastically.
- The hot core warms the base of the mantle, which causes mantle convection.

Review Questions

1. What are the two main ways that scientists learn about Earth's interior and what do these two things indicate?
2. What is the difference between crust and lithosphere? Include in your answer both where they are located and what their properties are.
3. How do the differences between oceanic and continental crust lead to the presence of ocean basins and continents?
4. What types of rock make up the oceanic crust and how do they form?
5. What types of rock make up the continental crust?
6. How do scientists know about the liquid outer core? How do scientists know that the outer core is liquid?
7. Describe the properties of each of these parts of the Earth's interior: lithosphere, mantle, and core. What are they made of? How hot are they? What are their physical properties?
8. When you put your hand above a pan filled with boiling water, does your hand warm up because of convection or conduction? If you touch the pan, does your hand warm up because of convection or conduction? Based on your answers, which type of heat transfer moves heat more easily and efficiently?

Points to Consider

- Oceanic crust is thinner and denser than continental crust. All crust sits atop the mantle. What might Earth be like if this were not true?
- If sediments fall onto the seafloor over time, what can sediment thickness tell scientists about the age of the seafloor in different regions?
- How might convection cells in the mantle affect the movement of solid crust on the planet's surface?

16.2 Continental Drift

Lesson Objectives

- Explain the continental drift hypothesis.
- Describe the evidence Wegener used to support his continental drift idea.
- Describe later evidence for continental drift.

Vocabulary

- apparent polar wander
- continental drift
- magnetic field
- magnetic polarity
- magnetite
- magnetometer

Introduction

The continental drift hypothesis was developed in the early part of the 20^{th} century, mostly by Alfred Wegener. Wegener said that continents move around on Earth's surface and that they were once joined together as a single supercontinent. While Wegener was alive, scientists did not believe that the continents could move.

The Continental Drift Idea

Find a map of the continents and cut each one out. Better yet, use a map where the edges of the continents show the continental shelf. That's the true size and shape of a continent. Can you fit the pieces together? The easiest link is between the eastern Americas and western Africa and Europe, but the rest can fit together too (**Figure** 16.10).

Alfred Wegener proposed that the continents were once united into a single supercontinent named Pangaea, meaning *all earth* in ancient Greek. He suggested that Pangaea broke up long ago and that the continents then moved to their current positions. He called his hypothesis **continental drift.**

Evidence for Continental Drift

Besides the way the continents fit together, Wegener and his supporters collected a great deal of evidence for the continental drift hypothesis.

FIGURE 16.10
The continents fit together like pieces of a puzzle. This is how they looked 250 million years ago.

- Identical rocks, of the same type and age, are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side-by-side and that the land had since moved apart.
- Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean. The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway (**Figure** 16.11). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.

- Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated (**Figure** 16.12). Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. He suggested that the organisms would not have been able to travel across the oceans.
  - Fossils of the seed fern *Glossopteris* were too heavy to be carried so far by wind.
  - *Mesosaurus* was a swimming reptile but could only swim in fresh water.
  - *Cynognathus* and *Lystrosaurus* were land reptiles and were unable to swim.

- Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most of the Earth. Today glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.
- Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later had drifted to new locations on the continents.

FIGURE 16.11
The similarities between the Appalachian and the eastern Greenland mountain ranges are evidences for the continental drift hypothesis.

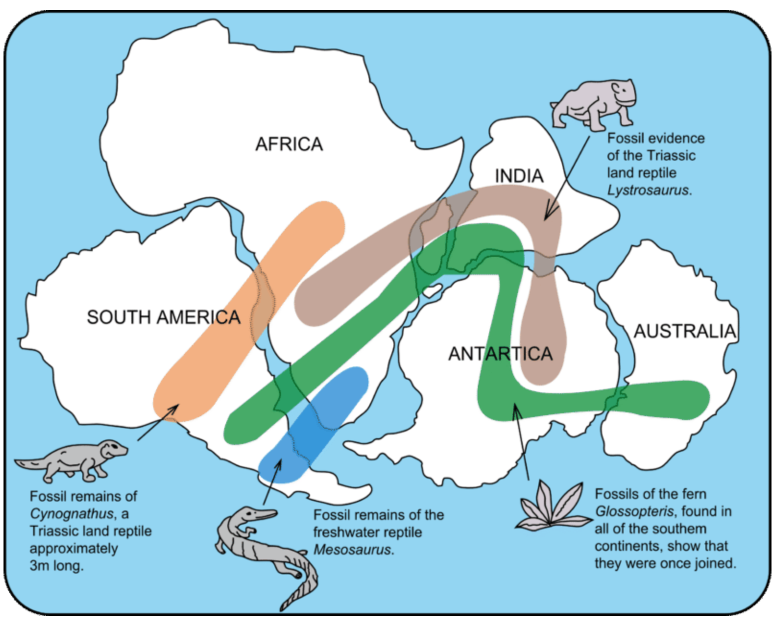


FIGURE 16.12
Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart.

An animation showing that Earth's climate belts remain in roughly the same position while the continents move is seen here: http://www.scotese.com/paleocli.htm .

An animation showing how the continents split up can be found here: http://www.exploratorium.edu/origins/antarctica/ideas/gondwana2.html .

Although Wegener's evidence was sound, most geologists at the time rejected his hypothesis of continental drift. Why do you think they did not accept continental drift?

Scientists argued that there was no way to explain how solid continents could plow through solid oceanic crust. Wegener's idea was nearly forgotten until technological advances presented even more evidence that the continents moved and gave scientists the tools to develop a mechanism for Wegener's drifting continents.

Magnetic Polarity Evidence

Puzzling new evidence came in the 1950s from studies on the Earth's magnetic history (**Figure** 16.13). Scientists used **magnetometers**, devices capable of measuring the magnetic field intensity, to look at the magnetic properties of rocks in many locations.

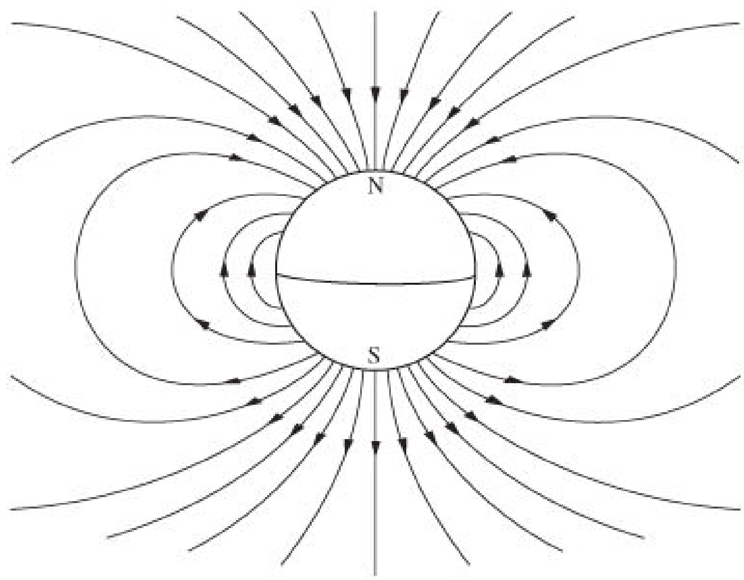


FIGURE 16.13
Earth's magnetic field is like a magnet with its north pole near the geographic North Pole and the south pole near the geographic South Pole.

Magnetite crystals are like tiny magnets that point to the north magnetic pole as they crystallize from magma. The crystals record both the direction and strength of the **magnetic field** at the time. The direction is known as the field's **magnetic polarity.**

Magnetic Polarity on the Same Continent with Rocks of Different Ages

Geologists noted important things about the magnetic polarity of different aged rocks on the same continent:

- Magnetite crystals in fresh volcanic rocks point to the current magnetic north pole (**Figure** 16.14) no matter what continent or where on the continent the rocks are located.
- Older rocks that are the same age and are located on the same continent point to the same location, but that location is not the current north magnetic pole.
- Older rock that are of different ages do not point to the same locations or to the current magnetic north pole.

In other words, although the magnetite crystals were pointing to the magnetic north pole, the location of the pole seemed to wander. Scientists were amazed to find that the north magnetic pole changed location through time (**Figure** 16.15).

There are three possible explanations for this:

1. The continents remained fixed and the north magnetic pole moved.
2. The north magnetic pole stood still and the continents moved.
3. Both the continents and the north pole moved.

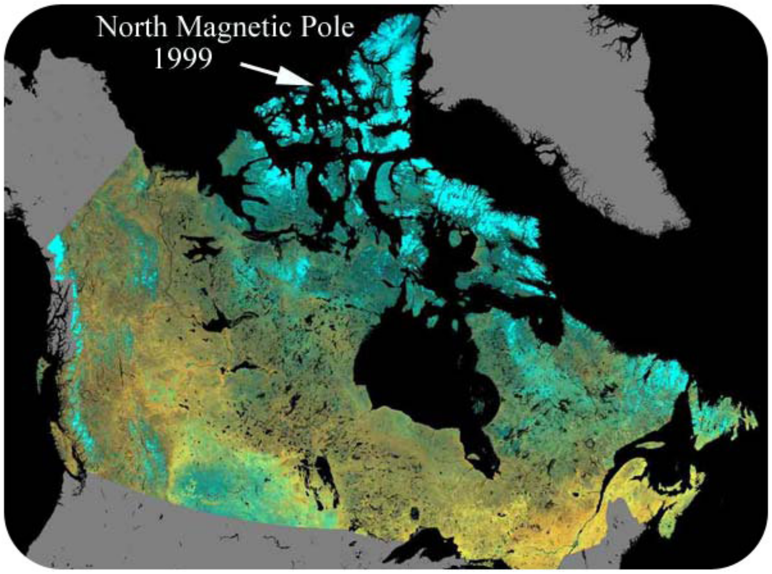


FIGURE 16.14
Earth's current north magnetic pole is in northern Canada.

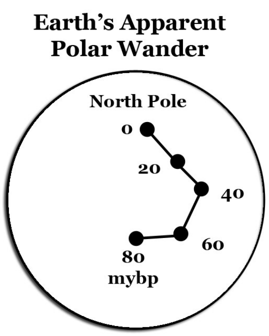


FIGURE 16.15
The location of the north magnetic north pole 80 million years before present (mybp), then 60, 40, 20, and now.

Magnetic Polarity on Different Continents with Rocks of the Same Age

Geologists noted that for rocks of the same age but on different continents, the little magnets pointed to different magnetic north poles.

- 400-million-year-old magnetite in Europe pointed to a different north magnetic pole than the same-aged magnetite in North America.
- 250 million years ago, the north poles were also different for the two continents.

The scientists looked again at the three possible explanations. Only one can be correct. If the continents had remained fixed while the north magnetic pole moved, there must have been two separate north poles. Since there is only one north pole today, the only reasonable explanation is that the north magnetic pole has remained fixed but that the continents have moved.

To test this, geologists fitted the continents together as Wegener had done. It worked! There has only been one magnetic north pole and the continents have drifted (**Figure** 16.16). They named the phenomenon of the magnetic pole that seemed to move but actually did not **apparent polar wander.**

This evidence for continental drift gave geologists renewed interest in understanding how continents could move about on the planet's surface.

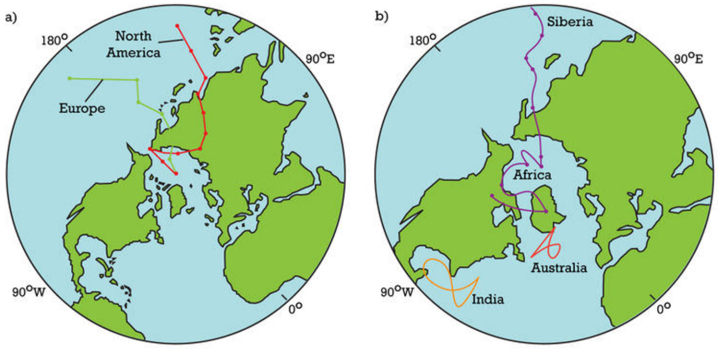


FIGURE 16.16
On the left: The apparent north pole for Europe and North America if the continents were always in their current locations. The two paths merge into one if the continents are allowed to drift.

Lesson Summary

- In the early part of the 20th century, scientists began to put together evidence that the continents could move around on Earth's surface.
- The evidence for continental drift included the fit of the continents; the distribution of ancient fossils, rocks, and mountain ranges; and the locations of ancient climatic zones.
- Although the evidence for continental drift was extremely strong, scientists rejected the idea because no mechanism for how solid continents could move around on the solid earth was developed.
- The discovery of apparent polar wander renewed scientists interest in continental drift.

Review Questions

1. Why can paper cutouts of the continents including the continental margins be pieced together to form a single whole?
2. How can the locations where ancient fossils are found be used as evidence for continental drift?
3. To show that mountain ranges on opposite sides of the Atlantic formed as two parts of the same range and were once joined, what would you look for?
4. What are the three possible explanations for apparent polar wander? Considering all the evidence, which explanation is the only one likely to be true and why?
5. With so much evidence to support continental drift, how could scientists reject the idea?
6. Look at a world map. Besides the coast of west Africa and eastern South America, what are some other regions of the world that look as they could be closely fit together?

Points to Consider

- Why is continental drift referred to as a hypothesis (or idea) and not a theory?
- What did Wegener's idea need for it to be accepted?
- What other explanations did scientists come up with to explain the evidence Wegener had for continental drift?

16.3 Seafloor Spreading

Lesson Objectives

- Describe the main features of the seafloor.
- Explain what seafloor magnetism tells scientists about the seafloor.
- Describe the process of seafloor spreading.

Vocabulary

- abyssal plains
- echo sounder
- seafloor spreading
- trench

Introduction

World War II gave scientists the tools to find the mechanism for continental drift that had eluded Wegener. Maps and other data gathered during the war allowed scientists to develop the seafloor spreading hypothesis. This hypothesis traces oceanic crust from its origin at a mid-ocean ridge to its destruction at a deep sea trench and is the mechanism for continental drift.

Seafloor Bathymetry

During World War II, battleships and submarines carried **echo sounders** to locate enemy submarines (**Figure** 16.17). Echo sounders produce sound waves that travel outward in all directions, bounce off the nearest object, and then return to the ship. By knowing the speed of sound in seawater, scientists calculate the distance to the object based on the time it takes for the wave to make a round-trip. During the war, most of the sound waves ricocheted off the ocean bottom.

This animation shows how sound waves are used to create pictures of the sea floor and ocean crust: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sonar.html .

After the war, scientists pieced together the ocean depths to produce bathymetric maps, which reveal the features of the ocean floor as if the water were taken away. Even scientist were amazed that the seafloor was not completely flat (**Figure** 16.18).

The major features of the ocean basins and their colors on the map in **Figure** 16.18 include:

- mid-ocean ridges: rise up high above the deep seafloor as a long chain of mountains; e.g. the light blue gash in middle of Atlantic Ocean.

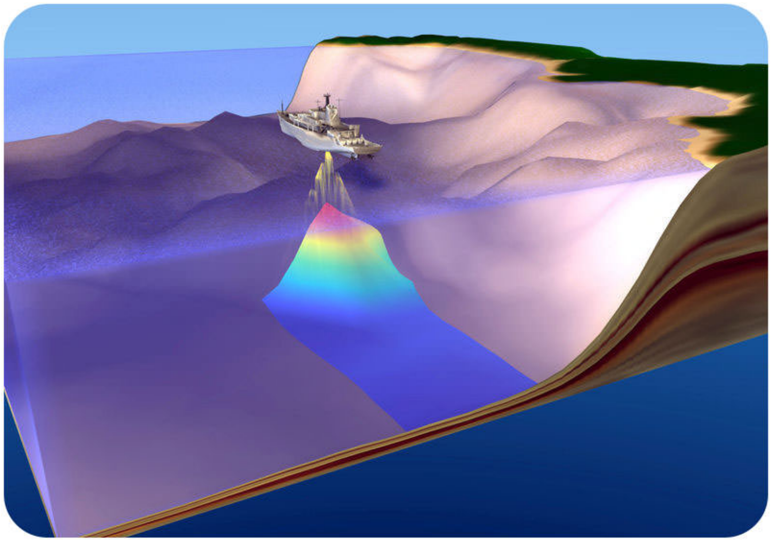


FIGURE 16.17
This echo sounder has many beams and creates a three dimensional map of the seafloor. Early echo sounders had a single beam and created a line of depth measurements.

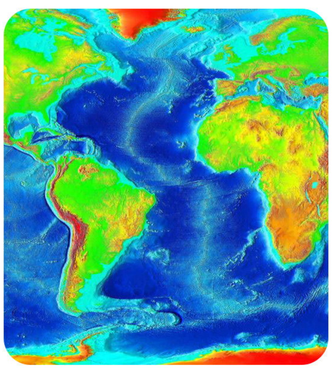


FIGURE 16.18
A modern map of the southeastern Pacific and Atlantic Oceans.

- deep sea **trenches:** found at the edges of continents or in the sea near chains of active volcanoes; e.g. the very deepest blue, off of western South America.
- **abyssal plains:** flat areas, although many are dotted with volcanic mountains; e.g. consistent blue off of southeastern South America.

When they first observed these bathymetric maps, scientists wondered what had formed these features.

Seafloor Magnetism

Sometimes – no one really knows why – the magnetic poles switch positions. North becomes south and south becomes north.

- Normal polarity: north and south poles are aligned as they are now.
- Reversed polarity: north and south poles are in the opposite position.

During WWII, magnetometers attached to ships to search for submarines located an astonishing feature: the normal and reversed magnetic polarity of seafloor basalts creates a pattern.

- Stripes of normal polarity and reversed polarity alternate across the ocean bottom.
- Stripes form mirror images on either side of the mid-ocean ridges (**Figure** 16.19).
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench (**Figure** 16.20).

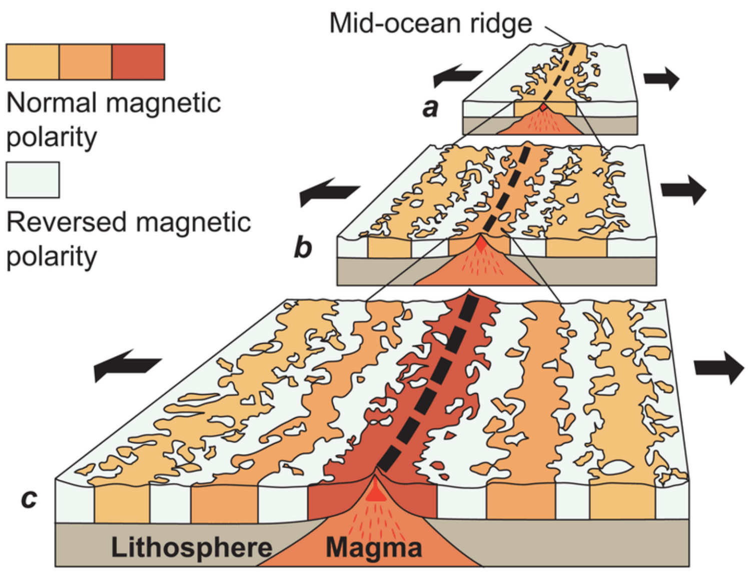


FIGURE 16.19
Magnetic polarity is normal at the ridge crest but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

The characteristics of the rocks and sediments change with distance from the ridge axis as seen in the **Table** 16.2.

TABLE 16.2: Characteristics of crustal rocks with distance from ridge axis

	Rock ages	**Sediment thickness**	**Crust thickness**	**Heat flow**
At ridge axis	youngest	none	thinnest	hottest
With distance from axis	becomes older	becomes thicker	becomes thicker	becomes cooler

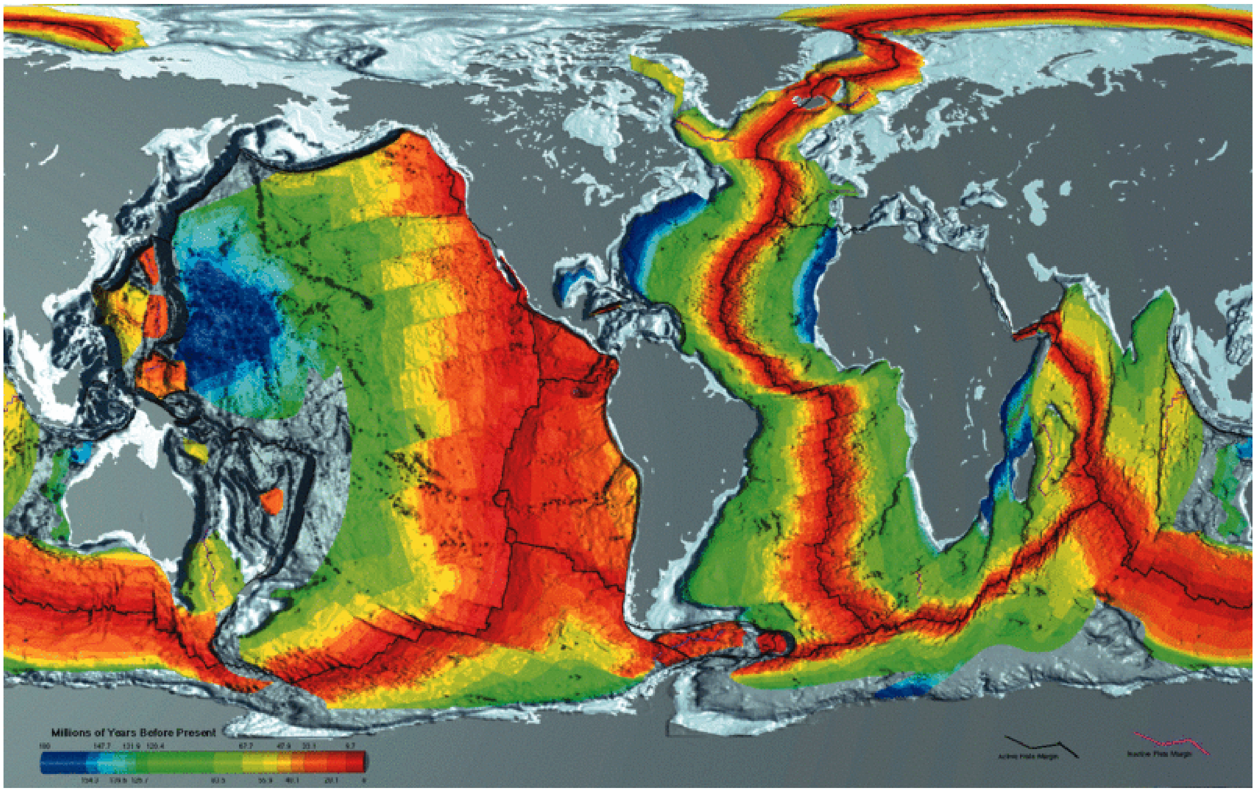


FIGURE 16.20

Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

A map of sediment thickness is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sedimentthickness.html .

The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old (**Figure** 16.20). Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that seafloor was being destroyed in a relatively short time.

This 65 minute video explains "The Role of Paleomagnetism in the Evolution of Plate Tectonic Theory": http://online.wr.usgs.gov/calendar/2004/jul04.html .

The Seafloor Spreading Hypothesis

Scientists brought these observations together in the early 1960s to create the **seafloor spreading** hypothesis. In this hypothesis, hot buoyant mantle rises up a mid-ocean ridge, causing the ridge to rise upward (**Figure** 16.21).

The hot magma at the ridge erupts as lava that forms new seafloor. When the lava cools, the magnetite crystals take on the current magnetic polarity. As more lava erupts, it pushes the seafloor horizontally away from ridge axis.

These animations show the creation of magnetic stripes of normal and reversed polarity at a mid-ocean ridge: http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A49.gif ; http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A55.gif .

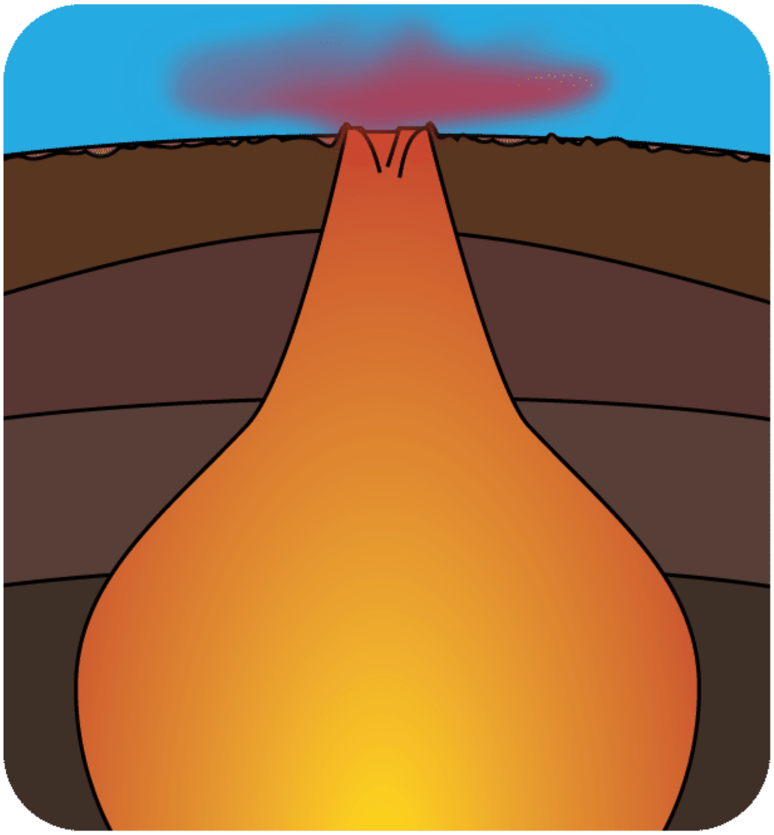


FIGURE 16.21
Magma at the mid-ocean ridge creates new seafloor.

The magnetic stripes continue across the seafloor.

- As oceanic crust forms and spreads, moving away from the ridge crest, it pushes the continent away from the ridge axis.
- If the oceanic crust reaches a deep sea trench, it sinks into the trench and is lost into the mantle.
- The oldest crust is coldest and lies deepest in the ocean because it is less buoyant than the hot new crust.

Seafloor spreading is the mechanism for Wegener's drifting continents. Convection currents within the mantle take the continents on a conveyor-belt ride of oceanic crust that over millions of years takes them around the planet's surface.

The breakup of Pangaea by seafloor spreading is seen in this animation: http://www.scotese.com/sfsanim.htm .

The breakup of Pangaea with a focus on the North Atlantic: http://www.scotese.com/natlanim.htm .

An animation of the breakup of Pangaea focused on the Pacific Ocean: http://www.scotese.com/pacifanim.htm .

Seafloor spreading is the topic of this Discovery Education video: http://video.yahoo.com/watch/1595570/5390151 .

The history of the seafloor spreading hypothesis and the evidence that was collected to develop it are the subject of this video **(3a)**: http://www.youtube.com/watch?v=6CsTTmvX6mc (8:05).

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/1445

Lesson Summary

- Using technologies developed to fight World War II, scientists were able to gather data that allowed them to recognize seafloor spreading as the mechanism for Wegener's drifting continents.
- Bathymetric maps revealed high mountain ranges and deep trenches in the seafloor.
- Magnetic polarity stripes give clues to seafloor ages and the importance of mid-ocean ridges in the creation of oceanic crust.
- Seafloor spreading processes create new oceanic crust at mid-ocean ridges and destroy older crust at deep sea trenches.

Review Questions

1. Describe how sound waves are used to develop a map of the features of the seafloor.
2. Why is the oldest seafloor less than 180 million years when the oldest continental crust is about 4 billion years old?
3. Describe the major features and the relative ages of mid-ocean ridges, deep sea trenches, and abyssal plains.
4. Describe how continents move across the ocean basins as if they are on a conveyor belt.
5. If you were a paleontologist who studies fossils of very ancient life forms, where would be the best place to look for very old fossils: on land or in the oceans?
6. Imagine that Earth's magnetic field was fixed in place and the polarity didn't reverse. What effect would this have on our observations of seafloor basalts?
7. Look at a map of the Atlantic seafloor with magnetic polarity stripes and recreate the history of the Atlantic Ocean basin.

Further Reading / Supplemental Links

- A basic description of sea floor spreading with animations: http://www.pbs.org/wnet/savageearth/hellscrust/index.html .

Points to Consider

- How were the technologies that were developed to fight World War II used by scientists for the development of the seafloor spreading hypothesis?
- In what two ways did magnetic data lead scientists to understand more about continental drift and plate tectonics?

- How does seafloor spreading provide a mechanism for continental drift?
- Look at the features of the North Pacific Ocean basin and explain them in seafloor spreading terms.
- What would have to happen if oceanic crust was not destroyed at oceanic trenches, but new crust was still created at mid-ocean ridges?

16.4 Theory of Plate Tectonics

Lesson Objectives

- Describe what a plate is and how scientists can recognize its edges.
- Explain how mantle convection moves lithospheric plates.
- List the three types of boundaries. Are they prone to earthquakes or volcanoes?
- Describe how plate tectonics processes lead to changes in Earth's surface features.

Vocabulary

- batholith
- continental arc
- continental rifting
- convergent plate boundary
- divergent plate boundary
- epicenter
- hotspot
- intraplate activity
- island arc
- plate
- plate boundary
- plate tectonics
- subduction
- subduction zone
- supercontinent cycle
- transform fault
- transform plate boundary

Introduction

When the concept of seafloor spreading came along, scientists recognized that it was the mechanism to explain how continents could move around Earth's surface. Like the scientists before us, we will now merge the ideas of continental drift and seafloor spreading into the theory of plate tectonics.

Continental drift and the mechanism of seafloor spreading create plate tectonics: http://video.yahoo.com/watch/1595682/5390276 .

Earth's Tectonic Plates

Seafloor and continents move around on Earth's surface, but what is actually moving? What portion of the Earth makes up the "plates" in plate tectonics? This question was also answered because of technology developed during war times - in this case, the Cold War. The **plates** are made up of the lithosphere.

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the earthquakes around the planet. The seismic records could be used to locate an earthquake's **epicenter**, the point on Earth's surface directly above the place where the earthquake occurs.

Earthquake epicenters outline the plates. Mid-ocean ridges, trenches, and large faults mark the edges of the plates, and this is where earthquakes occur (**Figure** 16.22).

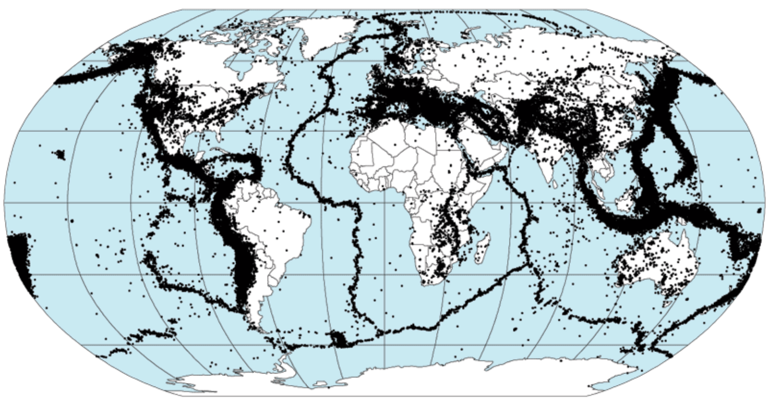


FIGURE 16.22
Earthquakes outline the plates.

The lithosphere is divided into a dozen major and several minor plates (**Figure** 16.23). The plates' edges can be drawn by connecting the dots that mark earthquakes' epicenters. A single plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both.

Movement of the plates over Earth's surface is termed **plate tectonics**. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

How Plates Move

If seafloor spreading drives the plates, what drives seafloor spreading? Picture two convection cells side-by-side in the mantle, similar to the illustration in **Figure** 16.24.

1. Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust.
2. The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor.
3. The outer limbs of the convection cells plunge down into the deeper mantle, dragging oceanic crust as well. This takes place at the deep sea trenches.
4. The material sinks to the core and moves horizontally.
5. The material heats up and reaches the zone where it rises again.

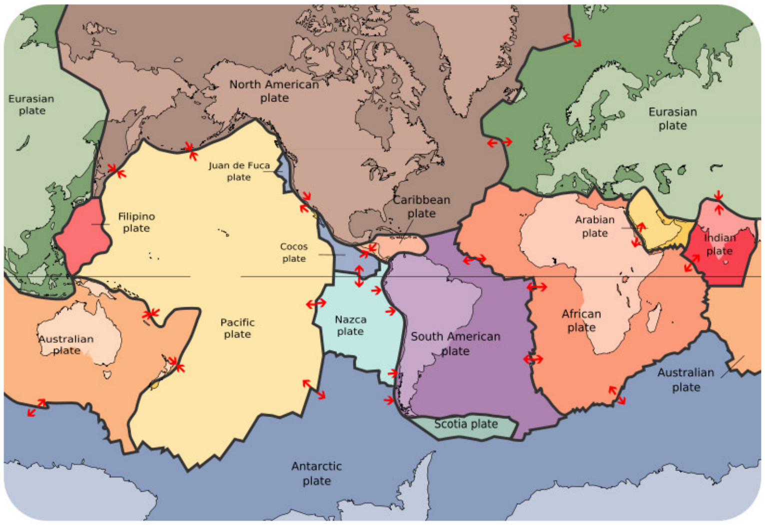


FIGURE 16.23

The lithospheric plates and their names. The arrows show whether the plates are moving apart, moving together, or sliding past each other.

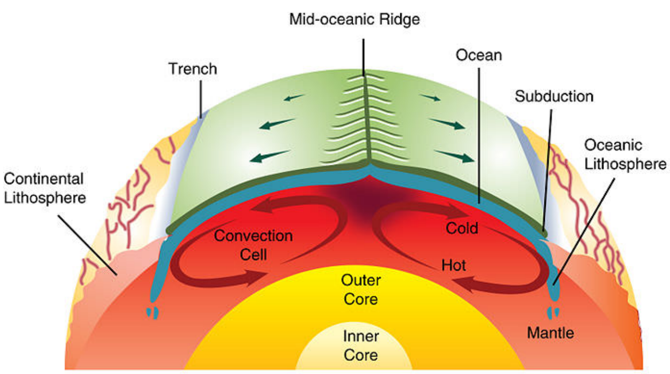


FIGURE 16.24

Mantle convection drives plate tectonics. Hot material rises at mid-ocean ridges and sinks at deep sea trenches, which keeps the plates moving along the Earth's surface.

Mantle convection is shown in these animations:

- http://www.youtube.com/watch?v=p0dWF_3PYh4
- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html

Plate Boundaries

Plate boundaries are the edges where two plates meet. Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. How can two plates move relative to each other?

- **Divergent plate boundaries**: the two plates move away from each other.
- **Convergent plate boundaries**: the two plates move towards each other.
- **Transform plate boundaries**: the two plates slip past each other.

The type of plate boundary and the type of crust found on each side of the boundary determines what sort of geologic activity will be found there.

Divergent Plate Boundaries

Plates move apart at mid-ocean ridges where new seafloor forms. Between the two plates is a rift valley. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. So the entire ridge system is made up of igneous rock that is either extrusive or intrusive. Earthquakes are common at mid-ocean ridges since the movement of magma and oceanic crust results in crustal shaking. The vast majority of mid-ocean ridges are located deep below the sea (**Figure** 16.25).

FIGURE 16.25
(a) Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates; (b) The rift valley in the Mid-Atlantic Ridge on Iceland.

USGS animation of divergent plate boundary at mid-ocean ridge: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary&flash_file=divergent&flash_width=500&flash_height=200 .

Divergent plate boundary animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Divergent_480.mov .

Can divergent plate boundaries occur within a continent? What is the result? In **continental rifting** (**Figure** 16.26), magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, creating an ocean between continents.

Convergent Plate Boundaries

When two plates converge, the result depends on the type of lithosphere the plates are made of. No matter what, smashing two enormous slabs of lithosphere together results in magma generation and earthquakes.

Ocean-continent: When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called **subduction**, occurs at the oceanic trenches (**Figure** 16.27). The entire

FIGURE 16.26
The Arabian, Indian, and African plates are rifting apart, forming the Great Rift Valley in Africa. The Dead Sea fills the rift with seawater.

region is known as a **subduction zone**. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (**Figure** 16.28). The volcanoes are known as a **continental arc**.

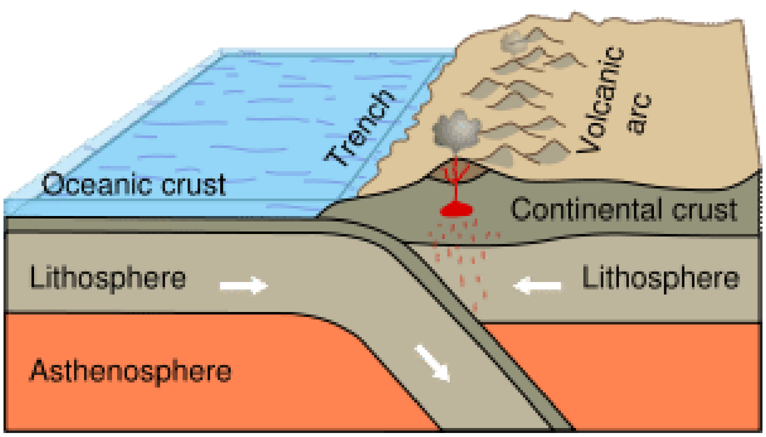


FIGURE 16.27
Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc.

The movement of crust and magma causes earthquakes. A map of earthquake epicenters at subduction zones is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_earthquakessubduction.html .

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html .

The volcanoes of northeastern California—Lassen Peak, Mount Shasta, and Medicine Lake volcano—along with the rest of the Cascade Mountains of the Pacific Northwest are the result of subduction of the Juan de Fuca plate beneath the North American plate (**Figure** 16.29). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

If the magma at a continental arc is felsic, it may be too viscous (thick) to rise through the crust. The magma will cool slowly to form granite or granodiorite. These large bodies of intrusive igneous rocks are called **batholiths**, which may someday be uplifted to form a mountain range (**Figure** 16.30).

Ocean-ocean: When two oceanic plates converge, the older, denser plate will subduct into the mantle. An ocean trench marks the location where the plate is pushed down into the mantle. The line of volcanoes that grows on the upper oceanic plate is an **island arc**. Do you think earthquakes are common in these regions (**Figure** 16.31)?

An animation of an ocean continent plate boundary is seen here: http://www.iris.edu/hq/files/programs/education_

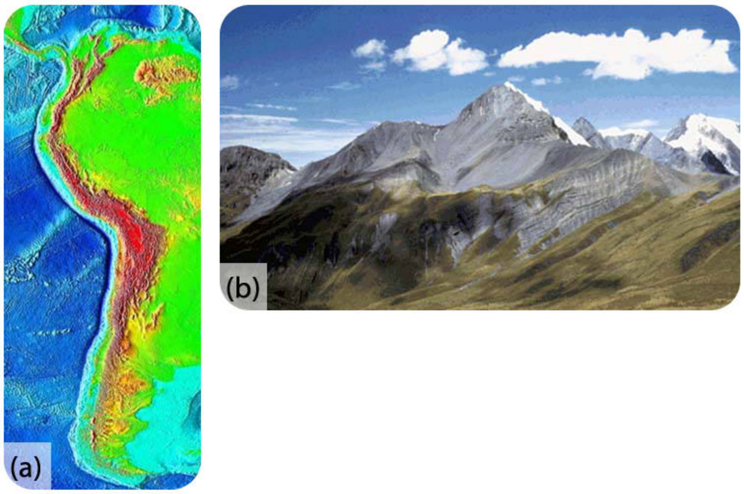


FIGURE 16.28
(a) At the trench lining the western margin of South America, the Nazca plate is subducting beneath the South American plate, resulting in the Andes Mountains (brown and red uplands); (b) Convergence has pushed up limestone in the Andes Mountains where volcanoes are common.

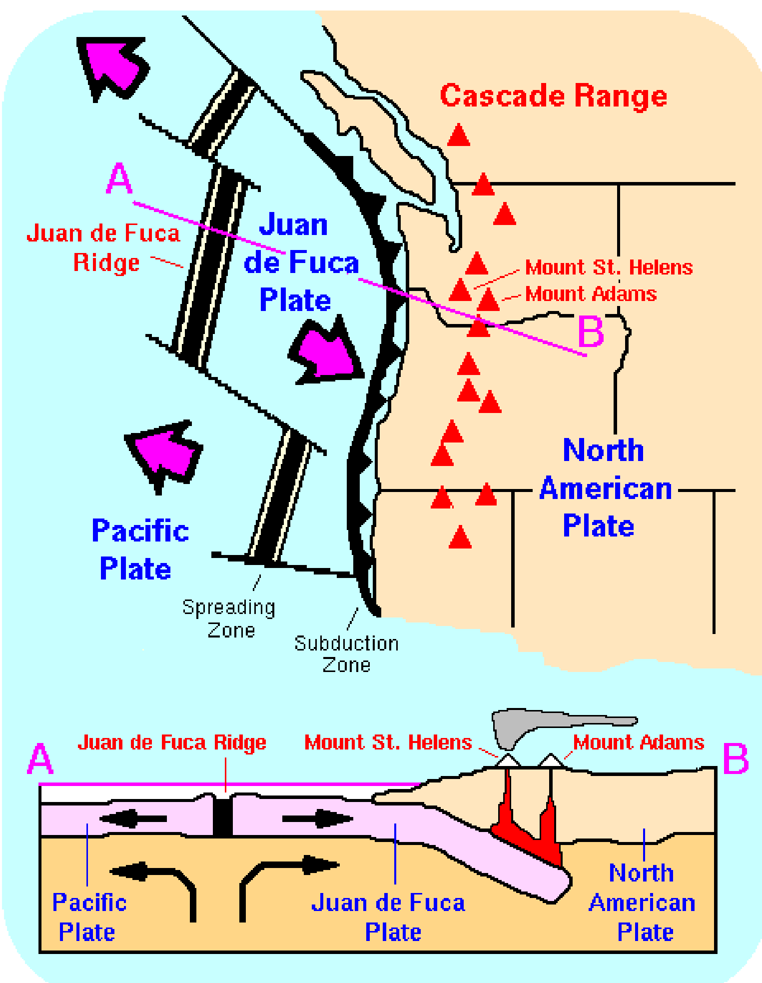


FIGURE 16.29
The Cascade Mountains of the Pacific Northwest are a continental arc.

FIGURE 16.30
The Sierra Nevada batholith cooled beneath a volcanic arc roughly 200 million years ago. The rock is well exposed here at Mount Whitney. Similar batholiths are likely forming beneath the Andes and Cascades today.

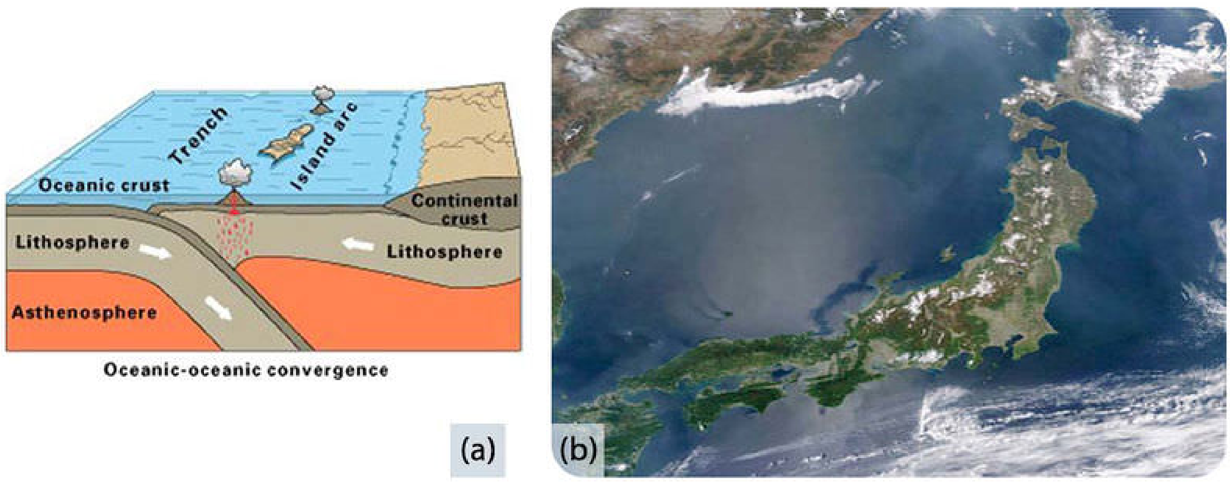


FIGURE 16.31
(a) Subduction of an ocean plate beneath an ocean plate results in a volcanic island arc, an ocean trench and many earthquakes. (b) Japan is an arc-shaped island arc composed of volcanoes off the Asian mainland, as seen in this satellite image.

and_outreach/aotm/11/AOTM_09_01_Convergent_480.mov .

Continent-continent: Continental plates are too buoyant to subduct. What happens to continental material when it collides? Since it has nowhere to go but up, this creates some of the world's largest mountains ranges (**Figure** 16.32). Magma cannot penetrate this thick crust so there are no volcanoes, although the magma stays in the crust. Metamorphic rocks are common because of the stress the continental crust experiences. With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and large earthquakes.

A short animation of the Indian Plate colliding with the Eurasian Plate: http://www.scotese.com/indianim.htm .

An animation of the Himalaya rising: http://www.youtube.com/watch?v=ep2_axAA9Mw .

The Appalachian Mountains are the remnants of a large mountain range that was created when North America

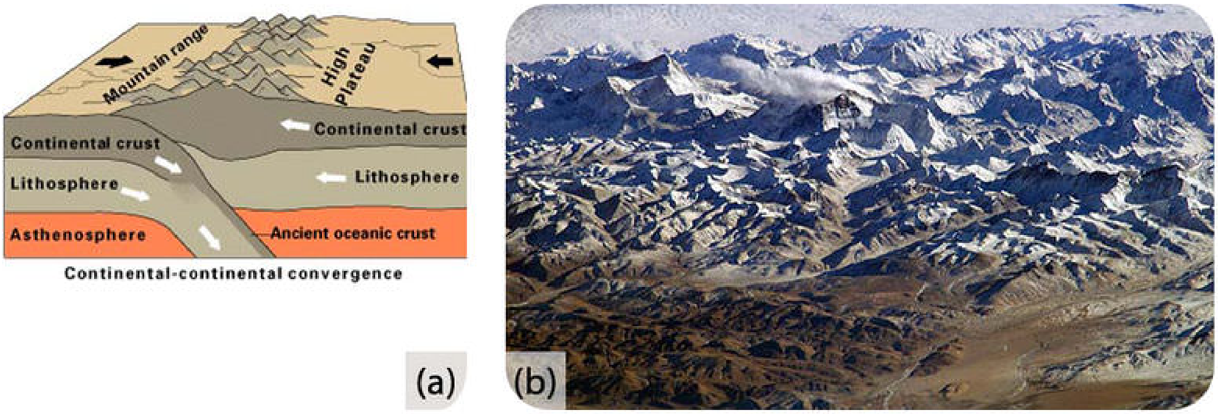


FIGURE 16.32
(a) In continent-continent convergence, the plates push upward to create a high mountain range. (b) The world's highest mountains, the Himalayas, are the result of the collision of the Indian Plate with the Eurasian Plate, seen in this photo from the International Space Station.

rammed into Eurasia about 250 million years ago.

Transform Plate Boundaries

Transform plate boundaries are seen as **transform faults**, where two plates move past each other in opposite directions. Transform faults on continents bring massive earthquakes (**Figure** 16.33).

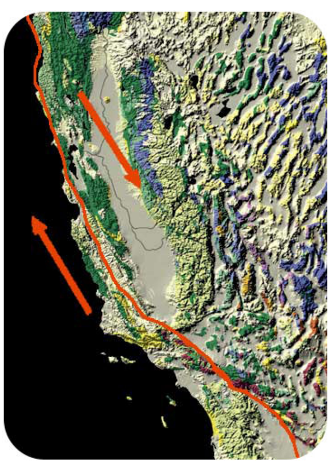


FIGURE 16.33
At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest. At the northern end of the picture, the transform boundary turns into a subduction zone.

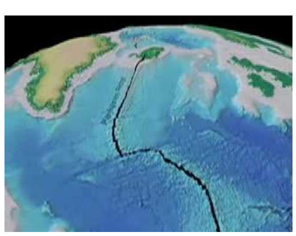
California is very geologically active. What are the three major plate boundaries in or near California (**Figure** 16.34)?

1. A transform plate boundary between the Pacific and North American plates creates the San Andreas Fault, the world's most notorious transform fault.

2. Just offshore, a divergent plate boundary, Juan de Fuca ridge, creates the Juan de Fuca plate.
3. A convergent plate boundary between the Juan de Fuca oceanic plate and the North American continental plate creates the Cascades volcanoes.

FIGURE 16.34
This map shows the three major plate boundaries in or near California.

A brief review of the three types of plate boundaries and the structures that are found there is the subject of this wordless video **(3b)**: http://www.youtube.com/watch?v=ifke1GsjNN0 (4:50).



MEDIA
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URL: http://www.ck12.org/flx/render/embeddedobject/8524

Earth's Changing Surface

Geologists know that Wegener was right because the movements of continents explain so much about the geology we see. Most of the geologic activity that we see on the planet today is because of the interactions of the moving plates.

In the map of North America (**Figure** 16.35), where are the mountain ranges located? Using what you have learned about plate tectonics, try to answer the following questions:

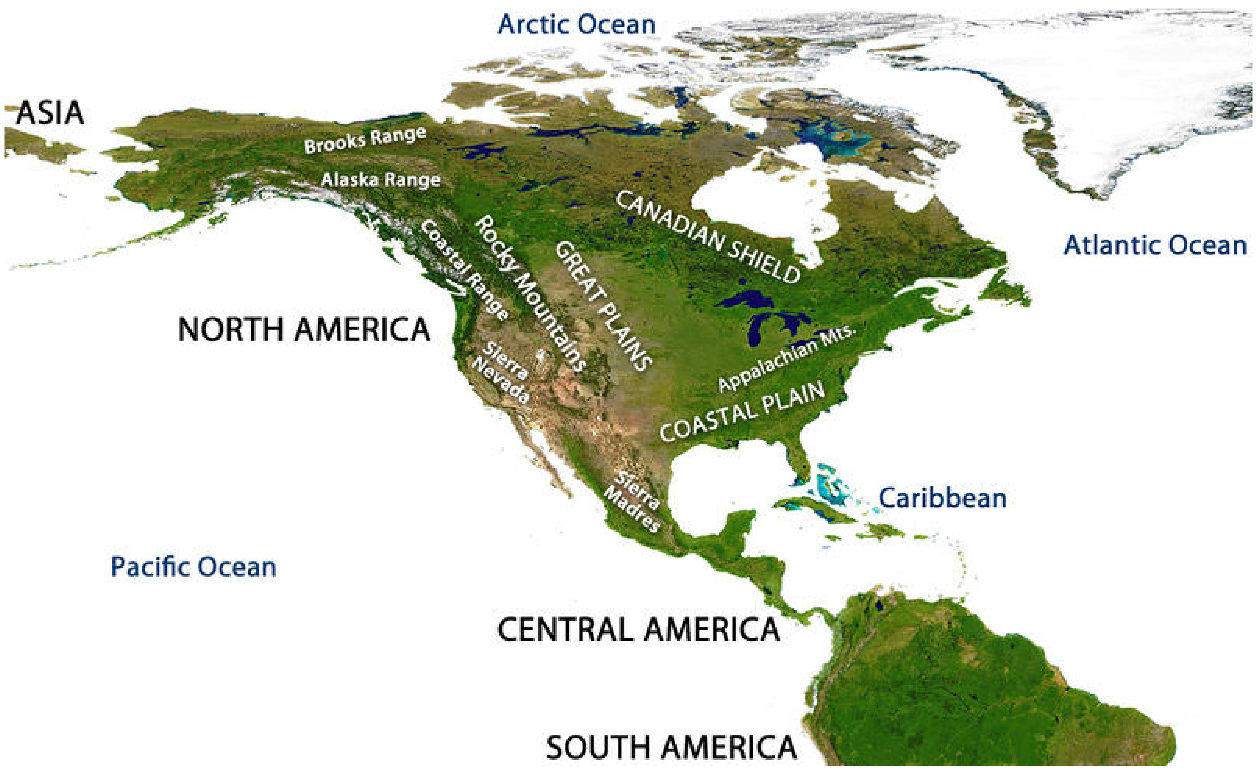

FIGURE 16.35
Mountain ranges of North America.

1. What is the geologic origin of the Cascades Range? The Cascades are a chain of volcanoes in the Pacific Northwest. They are not labelled on the diagram but they lie between the Sierra Nevada and the Coastal Range.
2. What is the geologic origin of the Sierra Nevada? (Hint: These mountains are made of granitic intrusions.)
3. What is the geologic origin of the Appalachian Mountains along the Eastern US?

Remember that Wegener used the similarity of the mountains on the west and east sides of the Atlantic as evidence for his continental drift hypothesis. The Appalachian mountains formed at a convergent plate boundary as Pangaea came together (**Figure** 16.36).

Before Pangaea came together, the continents were separated by an ocean where the Atlantic is now. The proto-Atlantic ocean shrank as the Pacific ocean grew. Currently, the Pacific is shrinking as the Atlantic is growing. This

FIGURE 16.36
About 200 million years ago, the Appalachian Mountains of eastern North America were probably once as high as the Himalaya, but they have been weathered and eroded significantly since the breakup of Pangaea.

supercontinent cycle is responsible for most of the geologic features that we see and many more that are long gone (**Figure** 16.37).

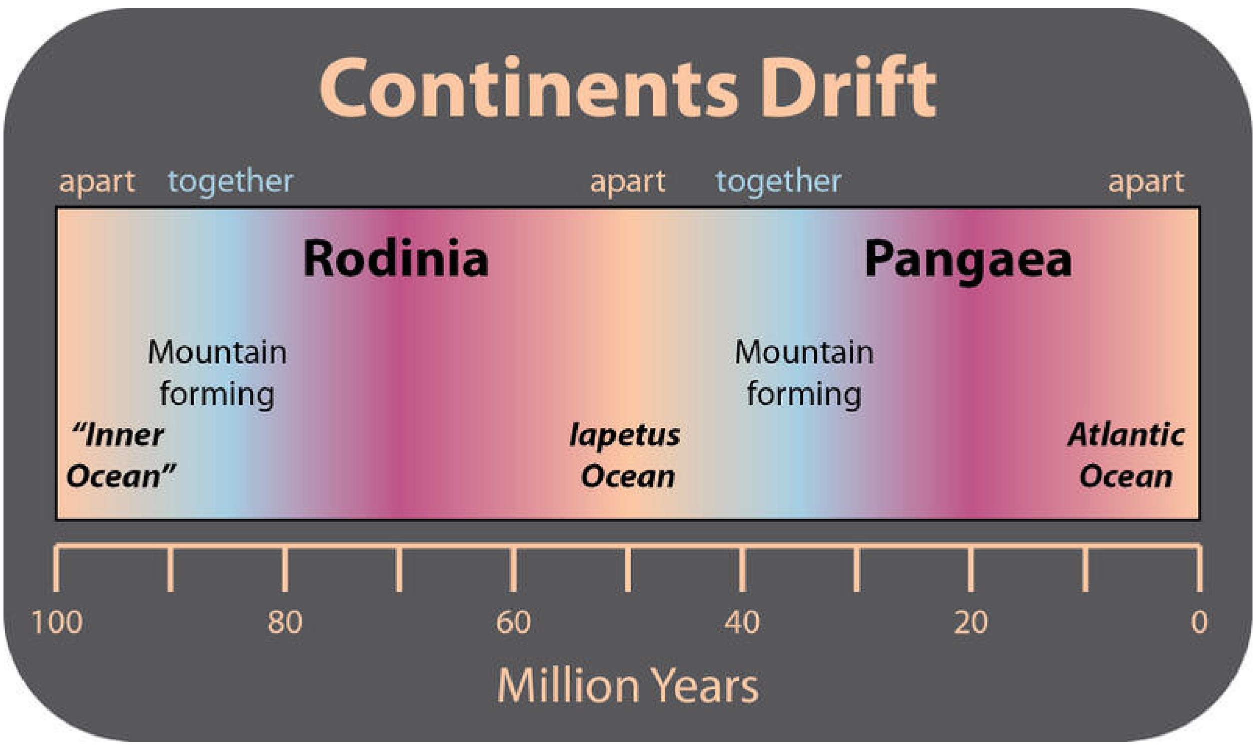

FIGURE 16.37
Scientists think that the creation and breakup of a supercontinent takes place about every 500 million years. The supercontinent before Pangaea was Rodinia. A new continent will form as the Pacific ocean disappears.

This animation shows the movement of continents over the past 600 million years beginning with the breakup of Rodinia: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_plate_reconstruction_blakey.html .

Intraplate Activity

A small amount of geologic activity, known as **intraplate activity**, does not take place at plate boundaries but within a plate instead. Mantle plumes are pipes of hot rock that rise through the mantle. The release of pressure causes melting near the surface to form a **hotspot**. Eruptions at the hotspot create a volcano. Hotspot volcanoes are found in a line (**Figure** 16.38). Can you figure out why? Hint: The youngest volcano sits above the hotspot and volcanoes become older with distance from the hotspot.

An animation of the creation of a hotspot chain is seen here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_hawaii.html .

Geologists use some hotspot chains to tell the direction and the speed a plate is moving (**Figure** 16.39).

Hotspot magmas rarely penetrate through thick continental crust. One exception is the Yellowstone hotspot (**Figure** 16.40).

Plate Tectonics Theory

Plate tectonics is the unifying theory of geology. Plate tectonics theory explains why:

- Earth's geography has changed through time and continues to change today.
- some places are prone to earthquakes while others are not.
- certain regions may have deadly, mild, or no volcanic eruptions.
- mountain ranges are located where they are.

Plate tectonic motions affect Earth's rock cycle, climate, and the evolution of life.

Lesson Summary

- Plates of lithosphere move because of convection currents in the mantle. One type of motion is produced by seafloor spreading.
- Plate boundaries can be located by outlining earthquake epicenters.
- Plates interact at three types of plate boundaries: divergent, convergent and transform.
- Most of the Earth's geologic activity takes place at plate boundaries.
- At a divergent boundary, volcanic activity produces a mid ocean ridge and small earthquakes.
- At a convergent boundary with at least one oceanic plate, an ocean trench, a chain of volcanoes develops and many earthquakes occur.
- At a convergent boundary where both plates are continental, mountain ranges grow and earthquakes are common.
- At a transform boundary, there is a transform fault and massive earthquakes occur but there are no volcanoes.
- Processes acting over long periods of time create Earth's geographic features.

Review Questions

Use this diagram to review this chapter (**Figure** 16.41).

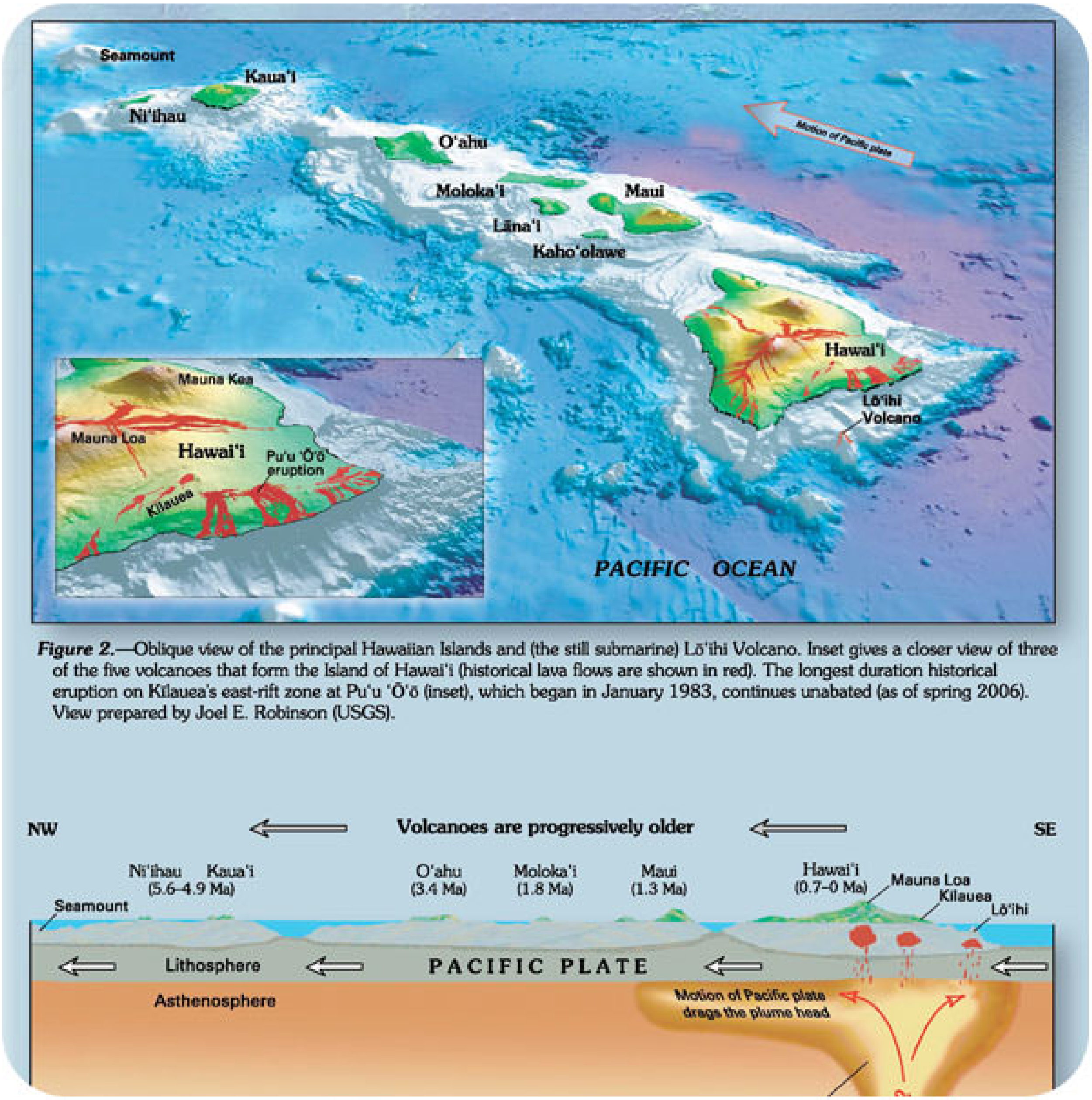

FIGURE 16.38

The Hawaiian Islands are a beautiful example of a hotspot chain. Kilauea volcano lies above the Hawaiian hotspot. Mauna Loa volcano is older than Kilauea and is still erupting, but at a lower rate. The islands get progressively older to the northwest because they are further from the hotspot. Loihi, the youngest volcano, is still below the sea surface.

1. What are the three types of plate boundaries and what type of geologic activity is found at each?
2. As a geologist, you come across a landscape with a massive fault zone that produces a lot of large earthquakes but has no volcanoes. What type of plate boundary is this? What are the movements of plates there? Where is this type of boundary found in California?

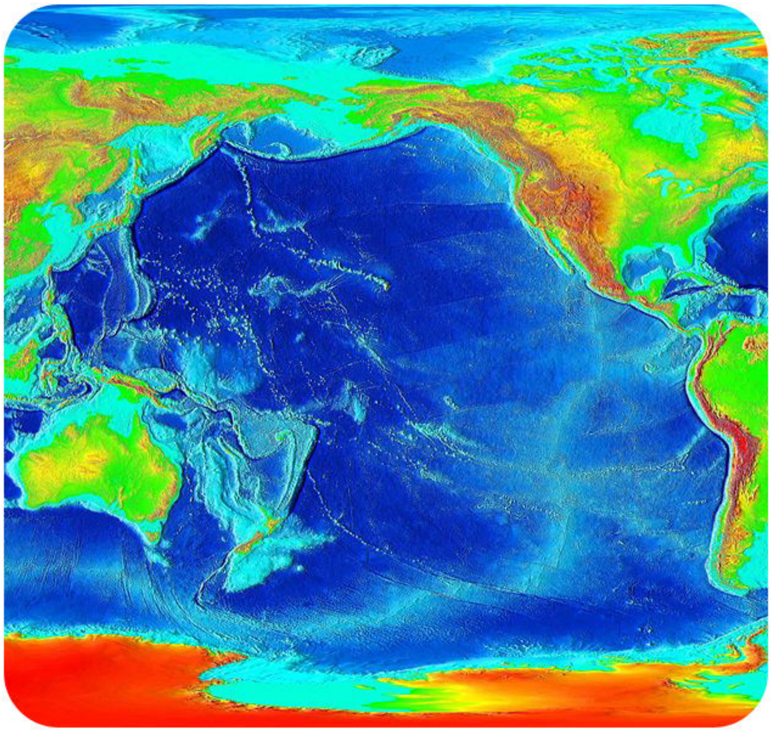

FIGURE 16.39
The Hawaiian chain continues into the Emperor Seamounts. The bend in the chain was caused by a change in the direction of the Pacific plate 43 million years ago. Using the age and distance of the bend, geologists can figure out the speed of the Pacific plate over the hotspot.

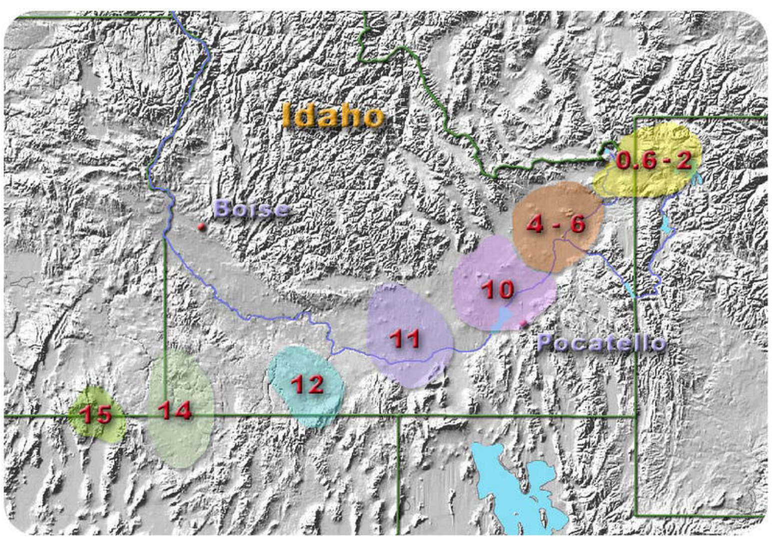

FIGURE 16.40
Volcanic activity above the Yellowstone hotspot on the North American Plate can be traced from 15 million years ago to its present location.

3. Next you find a chain of volcanoes along a coast on land, not too far inland from the ocean. The region experiences frequent large earthquakes. What type of plate boundary is this? What types of plates are involved? Where is this type of boundary found in California?
4. What is the driving force behind the movement of lithospheric plates on the Earth's surface? About how fast do the plates move?
5. How does the theory of plate tectonics explain the locations of volcanoes, earthquakes, and mountain belts on Earth?
6. What causes earthquakes and at what types of plate boundaries are earthquakes common? Explain.
7. Thinking about the different types of plate boundaries, where do mountain ranges that do not include volcanoes

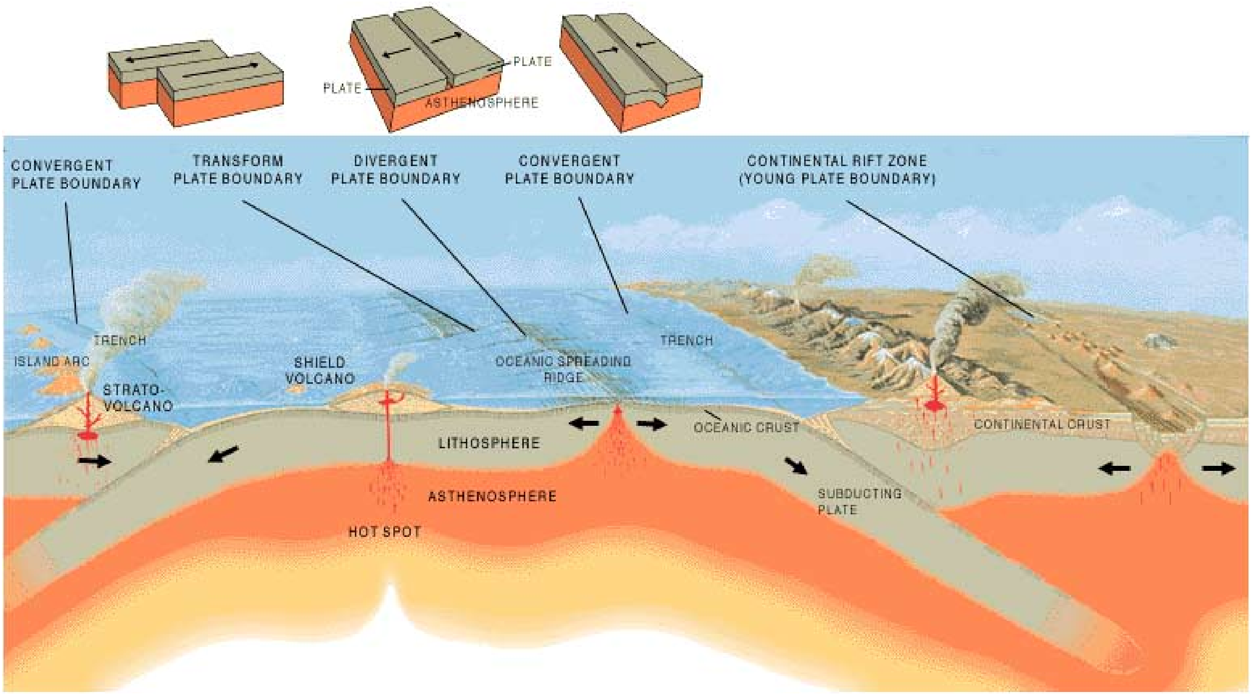

FIGURE 16.41
Plate boundaries

occur and why?

8. Why are there no volcanoes along transform plate boundaries? At continent-continent convergent plate boundaries?

Points to Consider

- On the map in **Figure** 16.23, the arrows show the directions that the plates are going. The Atlantic has a mid-ocean ridge, where seafloor spreading is taking place. The Pacific Ocean has many deep sea trenches, where subduction is taking place. What is the future of the Atlantic plate? What is the future of the Pacific plate?
- Using your hands and words, explain to someone how plate tectonics works. Be sure you describe how continents drift and how seafloor spreading provides a mechanism for continental movement.
- Now that you know about plate tectonics, where do you think would be a safe place to live if you wanted to avoid volcanic eruptions and earthquakes?

16.5 References

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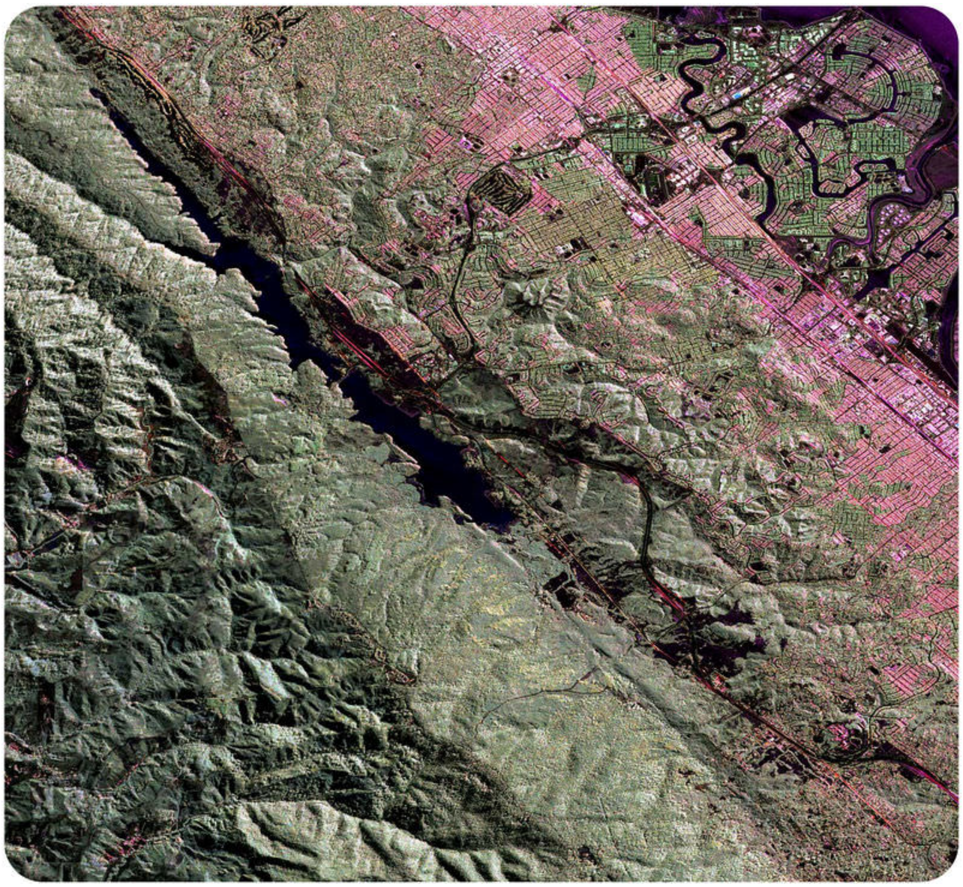
Chapter 17 Earthquakes

Chapter Outline



A portion of the 800-mile-long San Andreas Fault as it runs through the San Francisco Bay Area is seen from the upper left to the lower right of this image. The development in pink and green is San Mateo and Burlingame. Foster City, which is built on fill, has curved streets extending into the bay. The fault forms a trough that is filled with water at Crystal Springs Reservoir. Scientists will use space-based radar along this same flight path over the next years to look for changes in the ground surface along the fault.

Courtesy of NASA. www.nasa.gov/multimedia/imagegallery/image_feature_1395.html. Public Domain.

17.1 Stress in Earth's Crust

Lesson Objectives

- List the different types of stresses that cause different types of deformation.
- Compare the different types of folds and the conditions under which they form.
- Compare fractures and faults and define how they are related to earthquakes.
- Compare how mountains form and at what types of plate boundaries they form.

Vocabulary

- anticline
- basin
- compression
- confining stress
- deformation
- dip
- dip-slip fault
- dome
- elastic deformation
- fault
- fold
- fracture
- joint
- monocline
- normal fault
- plastic deformation
- reverse fault
- shear
- slip
- strain
- stress
- strike-slip fault
- syncline
- tension
- thrust fault
- uplift

Introduction

Enormous slabs of lithosphere move unevenly over the planet's spherical surface, resulting in earthquakes. This chapter deals with two types of geological activity that occur because of plate tectonics: mountain building and earthquakes. First, we will consider what can happen to rocks when they are exposed to stress.

Causes and Types of Stress

Stress is the force applied to an object. In geology, stress is the force per unit area that is placed on a rock. Four types of stresses act on materials.

- A deeply buried rock is pushed down by the weight of all the material above it. Since the rock cannot move, it cannot deform. This is called **confining stress.**
- **Compression** squeezes rocks together, causing rocks to fold or fracture (break) (**Figure** 17.1). Compression is the most common stress at convergent plate boundaries.

FIGURE 17.1
Stress caused these rocks to fracture.

- Rocks that are pulled apart are under **tension**. Rocks under tension lengthen or break apart. Tension is the major type of stress at divergent plate boundaries.
- When forces are parallel but moving in opposite directions, the stress is called **shear** (**Figure** 17.2). Shear stress is the most common stress at transform plate boundaries.

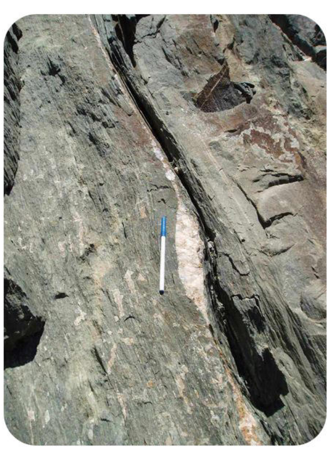


FIGURE 17.2
Shearing in rocks. The white quartz vein has been elongated by shear.

When stress causes a material to change shape, it has undergone **strain** or **deformation.** Deformed rocks are common in geologically active areas.

A rock's response to stress depends on the rock type, the surrounding temperature, and pressure conditions the rock is under, the length of time the rock is under stress, and the type of stress.

Rocks have three possible responses to increasing stress (illustrated in **Figure** 17.3):

- **elastic deformation**: the rock returns to its original shape when the stress is removed.
- **plastic deformation**: the rock does not return to its original shape when the stress is removed.
- **fracture**: the rock breaks.

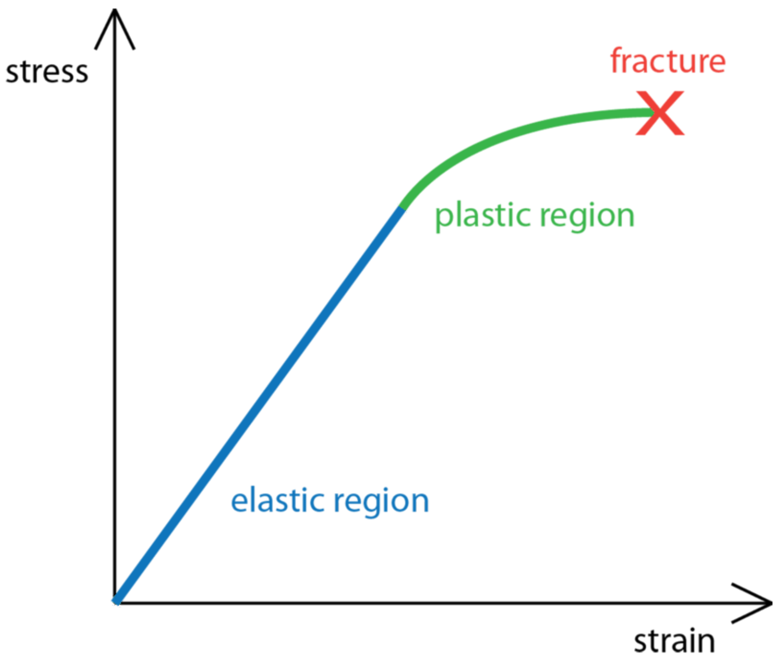


FIGURE 17.3
With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.

Under what conditions do you think a rock is more likely to fracture? Is it more likely to break deep within Earth's crust or at the surface? What if the stress applied is sharp rather than gradual?

- At the Earth's surface, rocks usually break quite quickly, but deeper in the crust, where temperatures and pressures are higher, rocks are more likely to deform plastically.
- Sudden stress, such as a hit with a hammer, is more likely to make a rock break. Stress applied over time often leads to plastic deformation.

Geologic Structures

Sedimentary rocks are important for deciphering the geologic history of a region because they follow certain rules.

1. Sedimentary rocks are formed with the oldest layers on the bottom and the youngest on top.
2. Sediments are deposited horizontally, so sedimentary rock layers are originally horizontal, as are some volcanic rocks, such as ash falls.
3. Sedimentary rock layers that are not horizontal are deformed.

You can trace the deformation a rock has experienced by seeing how it differs from its original horizontal, oldest-on-bottom position (**Figure** 17.4). This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses (**Figure** 17.4). Using the rules listed above, try to figure out the geologic history of the geologic column below.

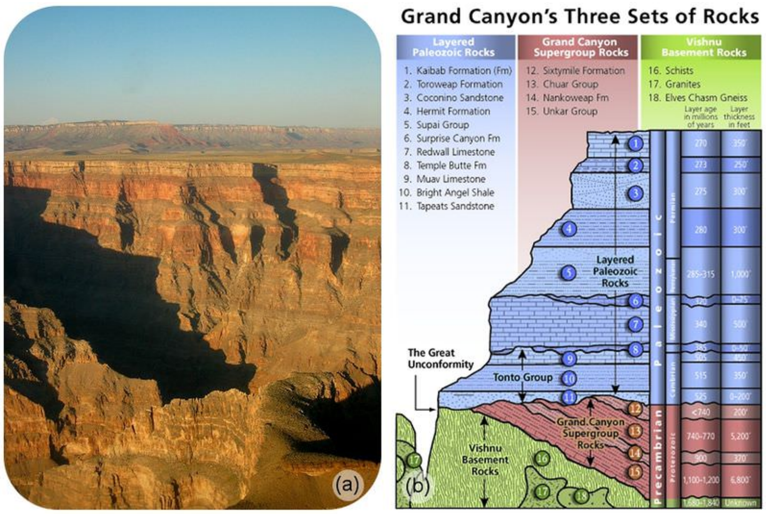


FIGURE 17.4

(a) In the Grand Canyon, the rock layers are exposed like a layer cake. Each layer is made of sediments that were deposited in a particular environment - perhaps a lake bed, shallow offshore region, or a sand dune. (b) In this geologic column of the Grand Canyon, the sedimentary rocks of the "Layered Paleozoic Rocks" column (layers 1 through 11) are still horizontal. Grand Canyon Supergroup rocks (layers 12 through 15) have been tilted. Vishnu Basement Rocks are not sedimentary (rocks 16 through 18). The oldest layers are on the bottom and youngest are on the top.

Folds

Rocks deforming plastically under compressive stresses crumple into **folds** (**Figure** 17.5). They do not return to their original shape. If the rocks experience more stress, they may undergo more folding or even fracture.

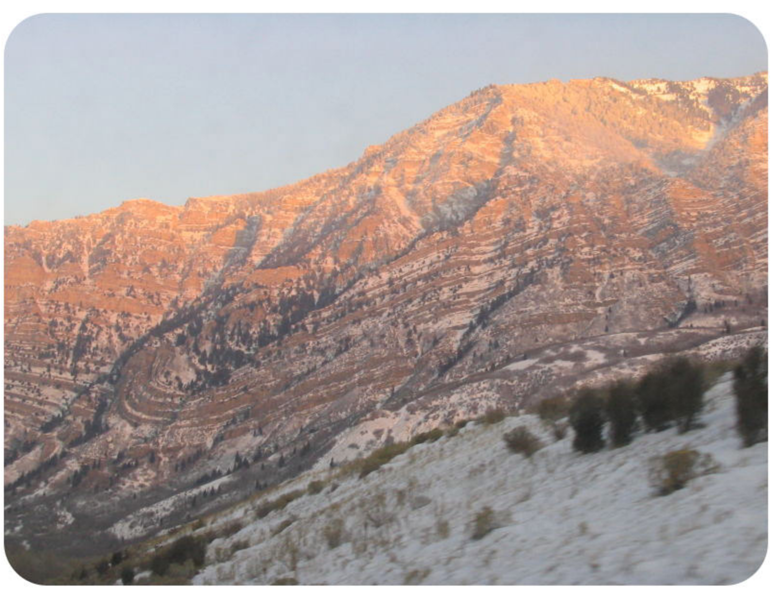


FIGURE 17.5

Snow accentuates the fold exposed in these rocks in Provo Canyon, Utah.

Three types of folds are seen.

- Mononcline: A **monocline** is a simple bend in the rock layers so that they are no longer horizontal (see **Figure** 17.6 for an example).

FIGURE 17.6
At Colorado National Monument, the rocks in a monocline plunge toward the ground.

- Anticline: An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (**Figure** 17.7). The oldest rocks are at the center of an anticline and the youngest are draped over them.

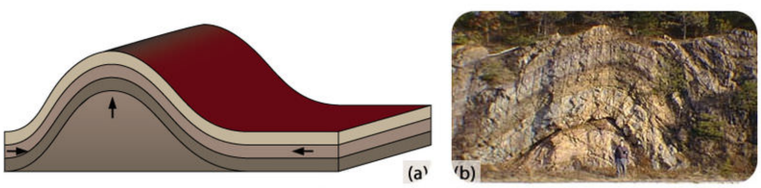


FIGURE 17.7
(a) Schematic of an anticline. (b) An anticline exposed in a road cut in New Jersey.

When rocks arch upward to form a circular structure, that structure is called a **dome.** If the top of the dome is sliced off, where are the oldest rocks located?

- Syncline: A **syncline** is a fold that bends downward. The youngest rocks are at the center and the oldest are at the outside (**Figure** 17.8).

When rocks bend downward in a circular structure, that structure is called a **basin** (**Figure** 17.9). If the rocks are exposed at the surface, where are the oldest rocks located?

Faults

A rock under enough stress will fracture. If there is no movement on either side of a fracture, the fracture is called a **joint**, as shown in (**Figure** 17.10).

If the blocks of rock on one or both sides of a fracture move, the fracture is called a **fault** (**Figure** 17.11). Sudden motions along faults cause rocks to break and move suddenly. The energy released is an earthquake.

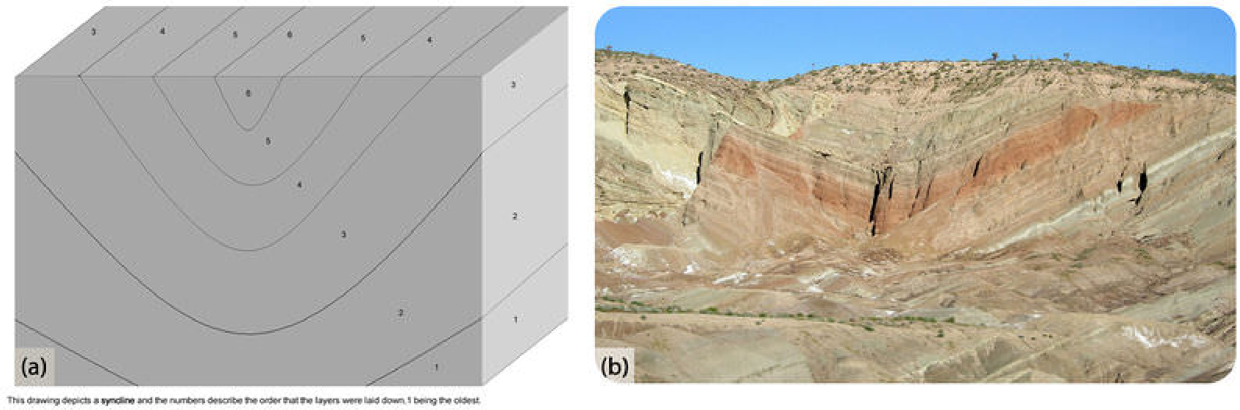


FIGURE 17.8
(a) Schematic of a syncline. (b) This syncline is in Rainbow Basin, California.

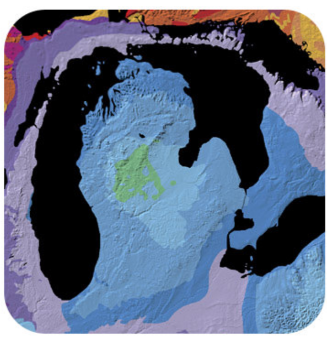


FIGURE 17.9
Basins can be enormous. This is a geologic map of the Michigan Basin, which is centered in the state of Michigan but extends into four other states and a Canadian province.

FIGURE 17.10
Granite rocks in Joshua Tree National Park showing horizontal and vertical jointing. These joints formed when the confining stress was removed from the granite.

FIGURE 17.11
Faults are easy to recognize as they cut across bedded rocks.

Slip is the distance rocks move along a fault. Slip can be up or down the fault plane. Slip is relative, because there is usually no way to know whether both sides moved or only one. Faults lie at an angle to the horizontal surface of the Earth. That angle is called the fault's **dip.** The dip defines which of two basic types a fault is. If the fault's dip is inclined relative to the horizontal, the fault is a **dip-slip fault** (**Figure** 17.12). There are two types of dip-slip faults. In **normal faults**, the hanging wall drops down relative to the footwall. In **reverse faults**, the footwall drops down relative to the hanging wall.

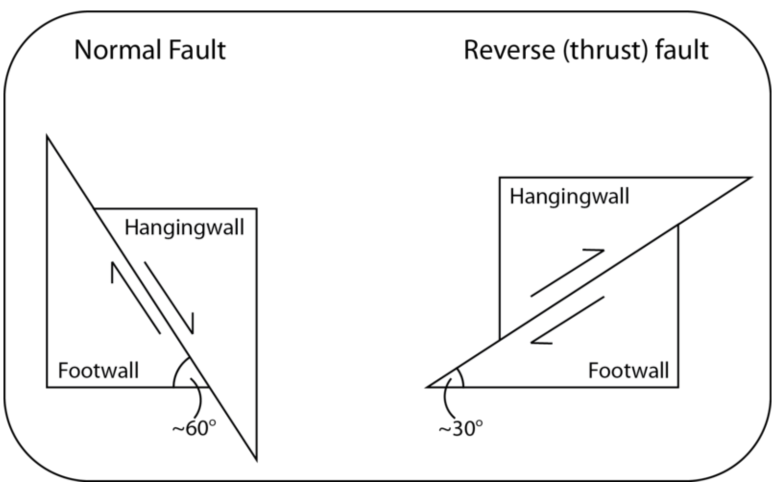


FIGURE 17.12
This diagram illustrates the two types of dip-slip faults: normal faults and reverse faults. Imagine miners extracting a resource along a fault. The hanging wall is where miners would have hung their lanterns. The footwall is where they would have walked.

An animation of a normal fault is seen here: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Normal+Fault&flash_file=normalfault&flash_width=220&flash_height=320 .

A **thrust fault** is a type of reverse fault in which the fault plane angle is nearly horizontal. Rocks can slip many miles along thrust faults (**Figure** 17.13).

An animation of a thrust fault is seen here: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Thrust+Fault&flash_file=thrustfault&flash_width=220&flash_height=320 .

Normal faults can be huge. They are responsible for uplifting mountain ranges in regions experiencing tensional stress (**Figure** 17.14).

FIGURE 17.13
At Chief Mountain in Montana, the upper rocks at the Lewis Overthrust are more than 1 billion years older than the lower rocks. How could this happen?

FIGURE 17.14
The Teton Range in Wyoming rose up along a normal fault.

A **strike-slip fault** is a dip-slip fault in which the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. (**Figure** 17.15).

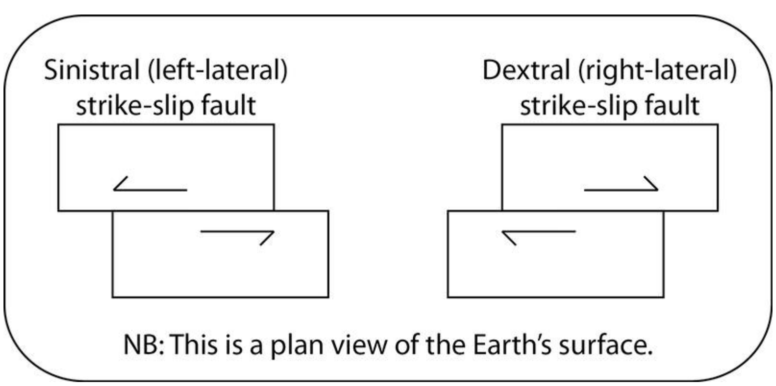


FIGURE 17.15
Imagine placing one foot on either side of a strike-slip fault. One block moves toward you. If that block moves toward your right foot, the fault is a right-lateral strike-slip fault; if that block moves toward your left foot, the fault is a left-lateral strike-slip fault.

California's San Andreas Fault is the world's most famous strike-slip fault. It is a right-lateral strike slip fault (**Figure** 17.16).

A strike-slip fault animation: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Strike-Slip+Fault&flash_file=strikeslip&flash_width=240&flash_height=310 .

FIGURE 17.16
The San Andreas is a massive transform fault.

People sometimes say that California will fall into the ocean someday, which is not true. This animation shows movement on the San Andreas into the future: http://visearth.ucsd.edu/VisE_Int/aralsea/bigone.html .

Stress and Mountain Building

Two converging continental plates smash upwards to create mountain ranges (**Figure** 17.17). Stresses from this **uplift** cause folds, reverse faults, and thrust faults, which allow the crust to rise upwards.

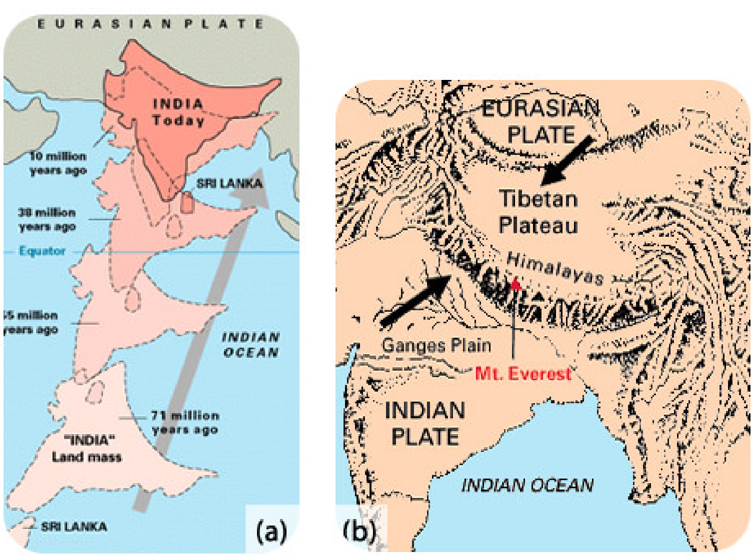


FIGURE 17.17
(a) The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. (b) The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

Subduction of oceanic lithosphere at convergent plate boundaries also builds mountain ranges (**Figure** 17.18).

FIGURE 17.18
The Andes Mountains are a chain of continental arc volcanoes that build up as the Nazca Plate subducts beneath the South American Plate.

When tensional stresses pull crust apart, it breaks into blocks that slide up and drop down along normal faults. The result is alternating mountains and valleys, known as a basin-and-range (**Figure** 17.19).

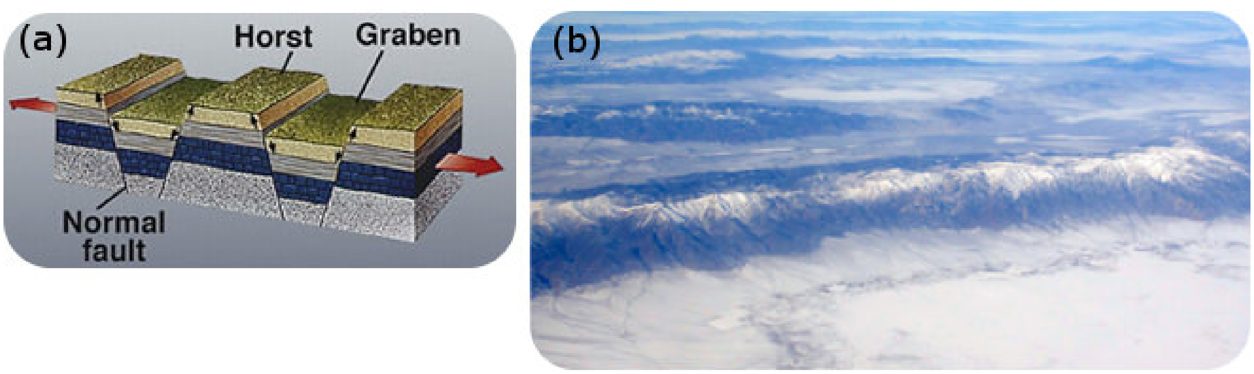


FIGURE 17.19
(a) In basin-and-range, some blocks are uplifted to form ranges, known as horsts, and some are down-dropped to form basins, known as grabens. (b) Mountains in Nevada are of classic basin-and-range form.

This is a very quick animation of movement of blocks in a basin-and-range setting: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Horst+%26amp%3B+Graben&flash_file=horstandgraben&flash_width=380&flash_height=210 .

Lesson Summary

- Stress is the force applied to a rock and may cause deformation. The three main types of stress are typical of the three types of plate boundaries: compression at convergent boundaries, tension at divergent boundaries, and shear at transform boundaries.
- Where rocks deform plastically, they tend to fold. Brittle deformation brings about fractures and faults.
- The two main types of faults are dip-slip (the fault plane is inclined to the horizontal) and strike-slip (the fault plane is perpendicular to the horizontal).
- The world's largest mountains grow at convergent plate boundaries, primarily by thrust faulting and folding.

Review Questions

1. Why don't rocks deform under confining stress?
2. What type of stress is compression and at what type of plate boundary is this found?
3. What type of stress is tension and at what type of plate boundary is it found?
4. What type of stress is shear and at what type of plate boundary is it found?
5. What is the difference between plastic and elastic strain?
6. Under what conditions is a rock more likely to deform plastically than to break?
7. In the picture of the Grand Canyon geologic column (**Figure** 17.4), what type of fold do you see?
8. While walking around in the field you spot a section of rocks in which the oldest are on top and the youngest are on the bottom. How do you explain this?
9. Describe an anticline and name the age order of rocks.
10. Describe a syncline and name the age order of rocks.
11. What are domes and basins and what is the age order of rocks in each?
12. Name one similarity and one difference between a fracture and a fault.
13. What are the two types of dip-slip faults and how are they different from each other?
14. Why are so many severe earthquakes located along the San Andreas Fault?
15. Describe the plate tectonics processes and associated stresses that have led to the formation of the Himalayas, the world's largest mountain range.

Points to Consider

- Where in an ocean basin would you find features that indicate tensional stresses? Where would you find the features that indicate compressional stresses?
- Earthquakes are primarily the result of plate tectonic motions. List the three types of plate boundaries and what you think the stresses are that would cause earthquakes there.
- Which type of plate boundary do you think has the most dangerous earthquakes? How do earthquakes cause the greatest damage?

17.2 The Nature of Earthquakes

Lesson Objectives

- Be able to identify an earthquake focus and its epicenter.
- Identify earthquake zones and what makes some regions prone to earthquakes.
- Compare the characteristics of the different types of seismic waves.
- Describe how tsunamis are caused by earthquakes, particularly using the 2004 Boxing Day Tsunami as an example.

Vocabulary

- amplitude
- body waves
- crest
- earthquake
- elastic rebound theory
- focus
- seismology
- surface waves
- trough
- tsunami
- wavelength

Introduction

An **earthquake** is sudden ground movement caused by the sudden release of energy stored in rocks. Earthquakes happen when so much stress builds up in the rocks that the rocks rupture. The energy is transmitted by seismic waves. Each year there are more than 150,000 earthquakes strong enough to be felt by people and 900,000 recorded by seismometers!

Causes of Earthquakes

The description of how earthquakes occur is called **elastic rebound theory** (**Figure** 17.20).

Elastic rebound theory in an animation: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Elastic+Rebound&flash_file=elasticrebound&flash_width=300&flash_height=350 .

In an earthquake, the initial point where the rocks rupture in the crust is called the **focus**. The epicenter is the point on the land surface that is directly above the focus. In about 75% of earthquakes, the focus is in the top 10 to 15

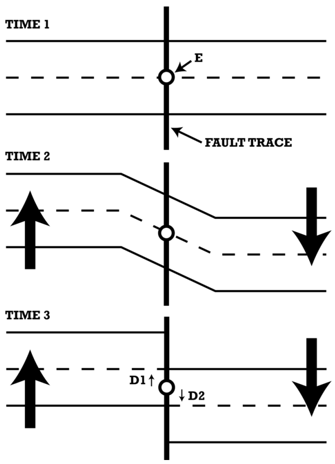


FIGURE 17.20
Elastic rebound theory. Stresses build on both sides of a fault, causing the rocks to deform plastically (Time 2). When the stresses become too great, the rocks break and end up in a different location (Time 3). This releases the built up energy and creates an earthquake.

kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage because the focus is near where people live. However, it is the epicenter of an earthquake that is reported by scientists and the media (**Figure** 17.21).

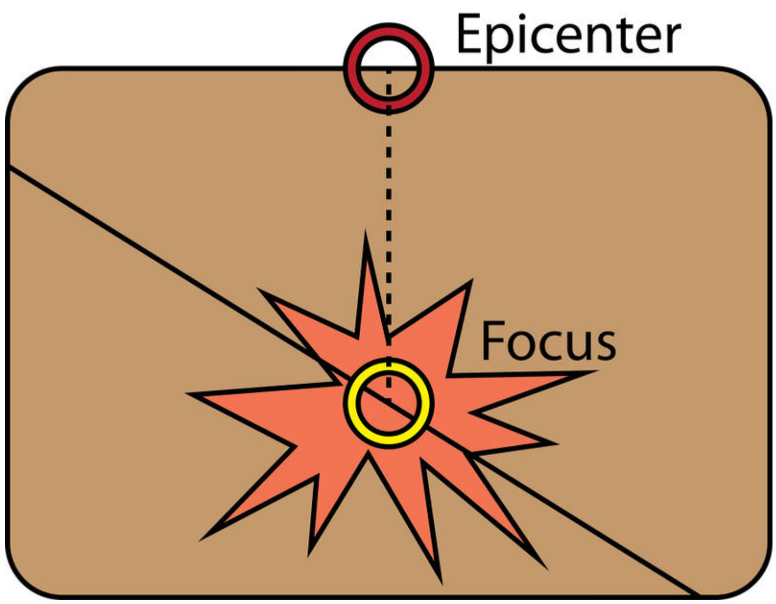


FIGURE 17.21
In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

This animation shows the relationship between focus and epicenter of an earthquake: http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::640::480::/sites/dl/free/0072402466/30425/16_04.swf::Fig.%20%2016.4%20-%20Focus%20of%20an%20Earthquake .

Earthquake Zones

Nearly 95% of all earthquakes take place along one of the three types of plate boundaries, but earthquakes do occur along all three types of plate boundaries.

- About 80% of all earthquakes strike around the Pacific Ocean basin because it is lined with convergent and transform boundaries (**Figure** 17.22).
- About 15% take place in the Mediterranean-Asiatic Belt, where convergence is causing the Indian Plate to run into the Eurasian Plate.
- The remaining 5% are scattered around other plate boundaries or are intraplate earthquakes.

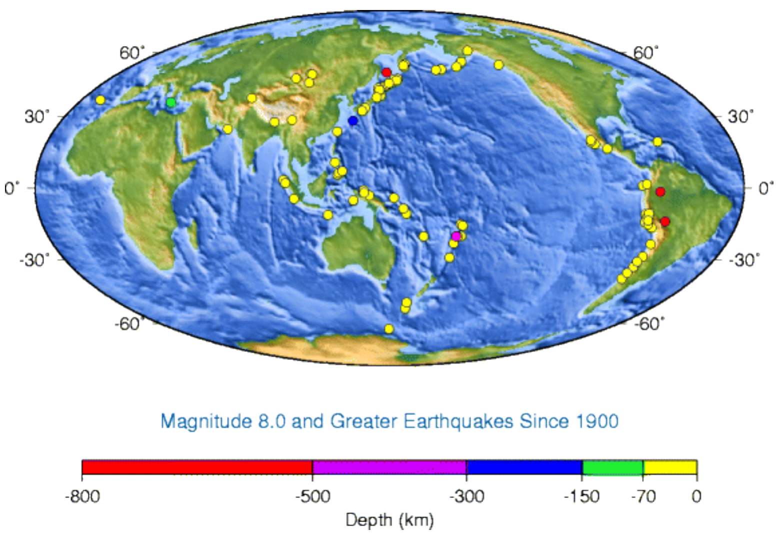


FIGURE 17.22
Earthquake epicenters for magnitude 8.0 and greater events since 1900. The earthquake depth shows that most large quakes are shallow focus, but some subducted plates cause deep focus quakes.

Transform plate boundaries

Deadly earthquakes occur at transform plate boundaries. Transform faults have shallow focus earthquakes. Why do you think this is so? The faults along the San Andreas Fault zone produce around 10,000 earthquakes a year. Most are tiny, but occasionally one is massive. In the San Francisco Bay Area, the Hayward Fault was the site of a magnitude 7.0 earthquake in 1868. The 1906 quake on the San Andreas Fault had a magnitude estimated at about 7.9 (**Figure** 17.23).

Recent California earthquakes:

- 1989: Loma Prieta earthquake near Santa Cruz, California. Magnitude 7.1 quake, 63 deaths, 3,756 injuries, 12,000+ people homeless, property damage about $6 billion.
- 1994: Northridge earthquake on a blind thrust fault near Los Angeles. Magnitude 6.7, 72 deaths, 12,000 injuries, damage estimated at $12.5 billion.

Although California is prone to many natural hazards, including volcanic eruptions at Mt. Shasta or Mt. Lassen, and landslides on coastal cliffs, the natural hazard the state is linked with is earthquakes. In this video, the boundaries between three different tectonic plates and the earthquakes that result from their interactions are explored **(9b)**: http://www.youtube.com/watch?v=upEh-1DpLMg (1:59).

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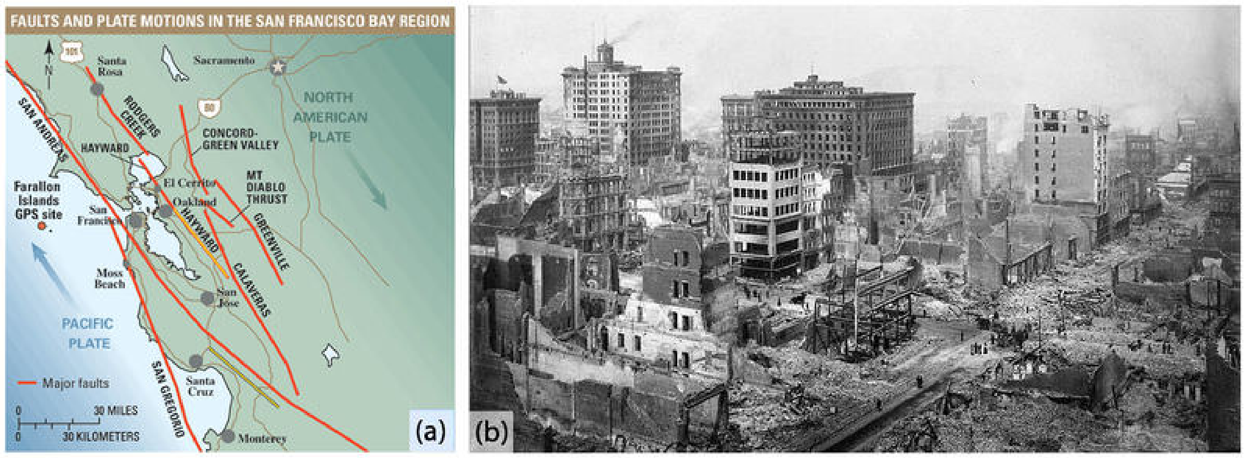

FIGURE 17.23

(a) The San Andreas Fault zone in the San Francisco Bay Area. (b) The 1906 San Francisco earthquake is still the most costly natural disaster in California history. About 3,000 people died and 28,000 buildings were lost, mostly in the fire.

New Zealand also has strike-slip earthquakes, about 20,000 a year! Only a small percentage of those are large enough to be felt. A 6.3 quake in Christchurch in February 2011 killed about 180 people.

Convergent plate boundaries

Earthquakes at convergent plate boundaries mark the motions of subducting lithosphere as it plunges through the mantle (**Figure** 17.24). Eventually the plate heats up enough deform plastically and earthquakes stop.

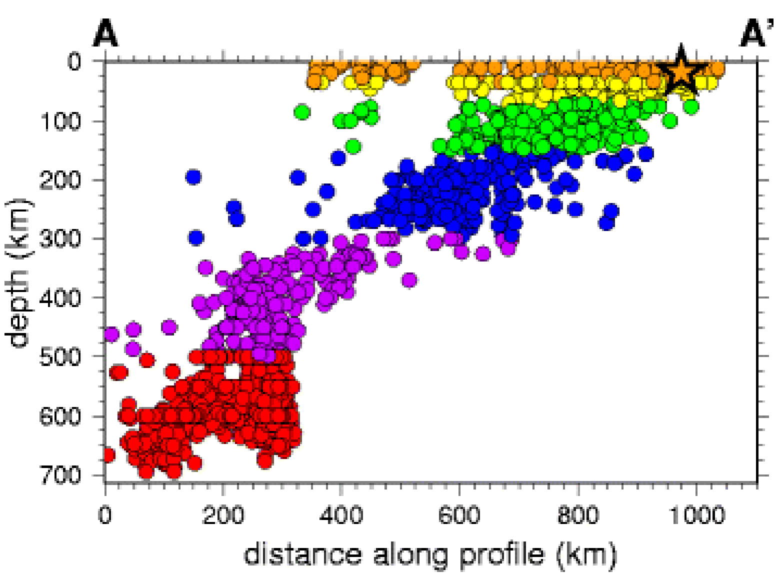

FIGURE 17.24

This cross section of earthquake epicenters with depth outlines the subducting plate with shallow, intermediate, and deep earthquakes.

Convergent plate boundaries produce earthquakes all around the Pacific Ocean basin. The Philippine Plate and the Pacific Plate subduct beneath Japan, creating a chain of volcanoes and as many as 1,500 earthquakes annually.

In March 2011 an enormous 9.0 earthquake struck off of Sendai in northeastern Japan. This quake, called the 2011 Tōhoku earthquake, was the most powerful ever to strike Japan and one of the top five known in the world. Damage from the earthquake was nearly overshadowed by the tsunami it generated, which wiped out coastal cities and towns (**Figure** 17.25). Two months after the earthquake, about 25,000 people were dead or missing, and 125,000 buildings had been damaged or destroyed. Aftershocks, some as large as major earthquakes, have continued to rock the region.

A map of aftershocks is seen here: http://earthquake.usgs.gov/earthquakes/seqs/events/usc0001xgp/ .

Here is an interactive feature article about the earthquake: http://www.nytimes.com/interactive/2011/03/11/world/asia/maps-of-earthquake-and-tsunami-damage-in-japan.html .

FIGURE 17.25
Destruction in Ofunato, Japan, from the 2011 Tōhoku Earthquake.

The Pacific Northwest of the United States is at risk from a potentially massive earthquake that could strike any time. Subduction of the Juan de Fuca plate beneath North America produces active volcanoes, but large earthquakes only hit every 300 to 600 years. The last was in 1700, with an estimated magnitude of around 9.

An image of earthquakes beneath the Pacific Northwest and the depth to the epicenter is shown here: http://pubs.usgs.gov/ds/91/ .

Elastic rebound at a subduction zone generates an earthquake in this animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/5/AOTF5_Subduction_ElasticRebound480.mov .

Massive earthquakes are the hallmark of the thrust faulting and folding when two continental plates converge (**Figure** 17.26). The 2001 Gujarat earthquake in India was responsible for about 20,000 deaths, and many more people became injured or homeless.

In Understanding Earthquakes: From Research to Resilience, scientists try to understand the mechanisms that cause earthquakes and tsunamis and the ways that society can deal with them **(3d)**: http://www.youtube.com/watch?v=W5Qz-aZ2nUM (8:06).

FIGURE 17.26
Damage from the 2005 Kashmir earthquake.

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URL: http://www.ck12.org/flx/render/embeddedobject/1417

Divergent Plate Boundaries

Earthquakes at mid-ocean ridges are small and shallow because the plates are young, thin, and hot. On land where continents split apart, earthquakes are larger and stronger.

Intraplate Earthquakes

Intraplate earthquakes are the result of stresses caused by plate motions acting in solid slabs of lithosphere. In 1812, a magnitude 7.5 earthquake struck near New Madrid, Missouri. The earthquake was strongly felt over approximately 50,000 square miles and altered the course of the Mississippi River. Because very few people lived there at the time, only 20 people died. Many more people live there today (**Figure** 17.27). A similar earthquake today would undoubtedly kill many people and cause a great deal of property damage.

Seismic Waves

Energy is transmitted in waves. Every wave has a high point called a **crest** and a low point called a **trough**. The height of a wave from the center line to its crest is its **amplitude**. The distance between waves from crest to crest (or trough to trough) is its **wavelength**. The parts of a wave are illustrated in **Figure** 17.28.

The energy from earthquakes travels in seismic waves, which were discussed in the chapter "Plate Tectonics." The study of seismic waves is known as **seismology.** Seismologists use seismic waves to learn about earthquakes and

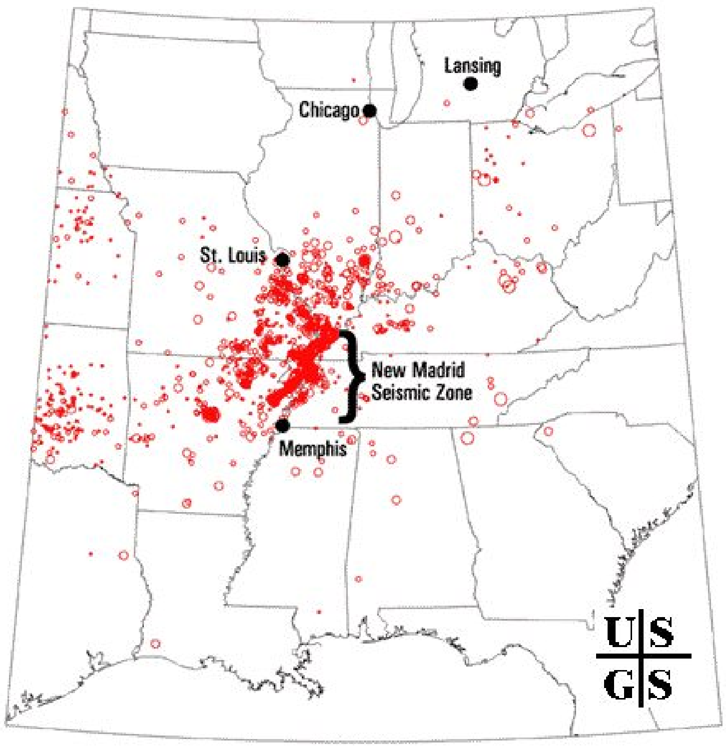

FIGURE 17.27
The New Madrid Seismic Zone is within the North American plate. Around 4,000 earthquakes have occurred in the region since 1974.

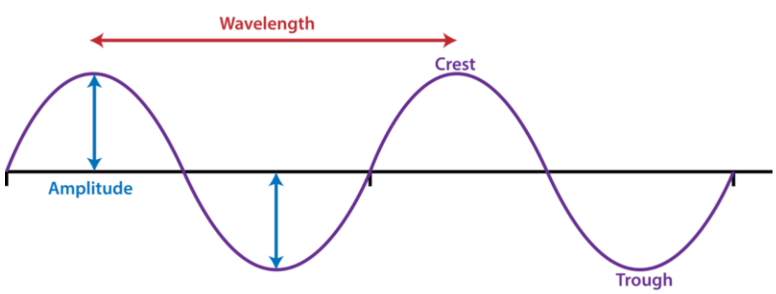

FIGURE 17.28
The crest, trough, and amplitude are illustrated in this diagram.

also to learn about the Earth's interior. The two types of seismic waves described in "Plate Tectonics," P-waves and S-waves, are known as **body waves** because they move through the solid body of the Earth. P-waves travel through solids, liquids, and gases. S-waves only move through solids. **Surface waves** travel along the ground, outward from an earthquake's epicenter. Surface waves are the slowest of all seismic waves, traveling at 2.5 km (1.5 miles) per second. There are two types of surface waves (**Figure** 17.29).

In an earthquake, body waves produce sharp jolts. The rolling motions of surface waves do most of the damage in an earthquake.

Interesting earthquake videos are seen at National Geographic Videos, Environment Video, Natural Disasters, Earthquakes: http://video.nationalgeographic.com/video/player/environment/ . Titles include:

- Earthquake 101
- "Inside Earthquakes" looks at this sudden natural disaster.

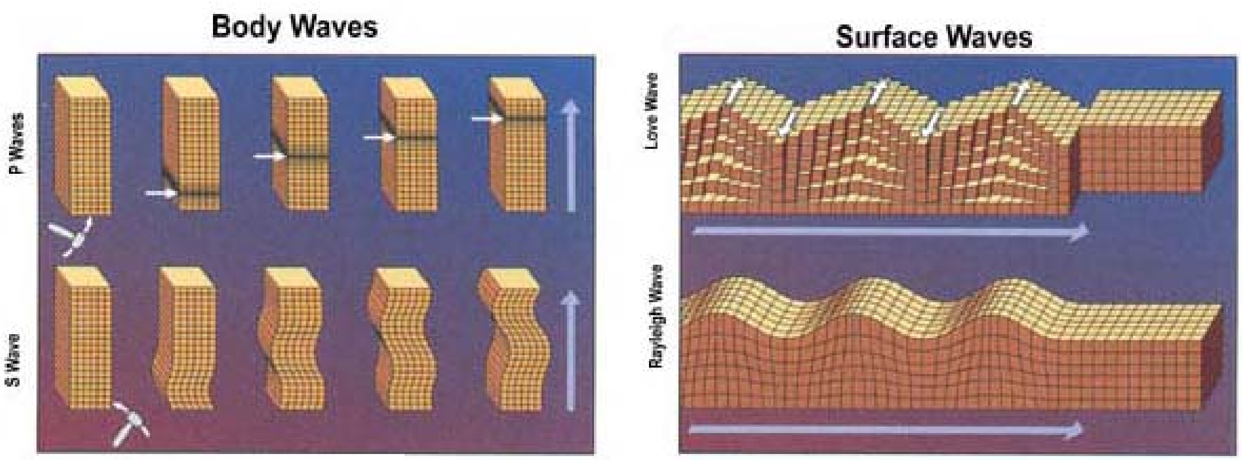

FIGURE 17.29
P-waves move material forward and backward in the direction they are traveling. The material returns to its original size and shape after the P-wave goes by. S-waves move up and down, perpendicular to the direction the wave is traveling. This motion produces shear stresses.

Tsunami

Tsunami are deadly ocean waves from an earthquake. The sharp jolt of an undersea quake forms a set of waves that travel through the sea entirely unnoticed. When they come onto shore, they can grow to enormous heights. Fortunately, few undersea earthquakes generate tsunami.

How a tsunami forms is shown in this animation: http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::640::480::/sites/dl/free/0072402466/30425/16_19.swf::Fig.%2016.19%20-%20Formation%20of%20a%20Tsunami .

The Boxing Day Tsunami of December 26, 2004 was by far the deadliest of all time (**Figure** 17.30). The tsunami was caused by the 2004 Indian Ocean Earthquake. With a magnitude of 9.2, it was the second largest earthquake ever recorded. The extreme movement of the crust displaced trillions of tons of water along the entire length of the rupture. Several tsunami waves were created with about 30 minutes between the peaks of each one. The waves that struck nearby Sumatra 15 minutes after the quake reached more than 10 meters (33 feet) in height. The size of the waves decreased with distance from the earthquake and were about 4 meters (13 feet) high in Somalia.

About 230,000 people died in eight countries (**Figure** 17.31) with fatalities even as far away as South Africa, nearly 8,000 kilometers (5,000 miles) from the earthquake epicenter. More than 1.2 million people lost their homes and many more lost their ways of making a living.

The 2011 Tōhoku earthquake in Japan created massive tsunami waves that hit the island nation. As seen in **Figure** 17.32, waves in some regions topped 9 meters (27 feet). The tsunami did much more damage than the massive earthquake (**Figure** 17.33). Worst was the damage done to nuclear power plants along the northeastern coast.

As a result of the 2004 tsunami, an Indian Ocean warning system was put into operation in June 2006. Prior to 2004, no one had thought a large tsunami was possible in the Indian Ocean. In comparison, a warning system has been in effect around the Pacific Ocean for more than 50 years (**Figure** 17.34). Why do you think a Pacific warning system has been in place for so long? The system was used to warn of possible tsunami waves after the Tōhoku earthquake.

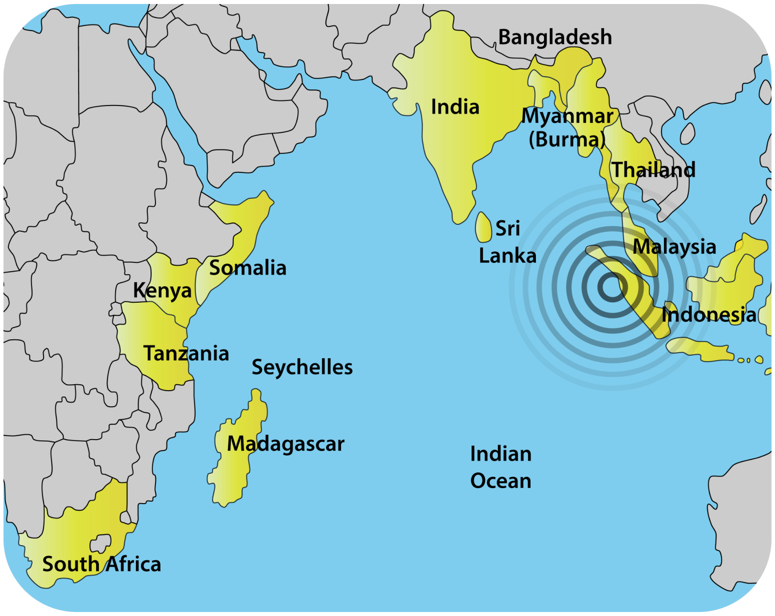

FIGURE 17.30
The countries that were most affected by the 2004 Boxing Day tsunami.

FIGURE 17.31
The Boxing Day tsunami strikes a beach in Thailand.

People were evacuated along many pacific coastlines although the waves were not nearly as large as those that struck Japan shortly after the quake.

Lesson Summary

- During an earthquake, the ground shakes as stored up energy is released from rocks.
- Elastic rebound theory states that rock will deform plastically as stresses build up until the stresses become too great and the rock breaks.
- Earthquakes occur at all types of plate boundaries.
- The Pacific Ocean basin and the Mediterranean-Asiatic Belt are the two geographic regions most likely to

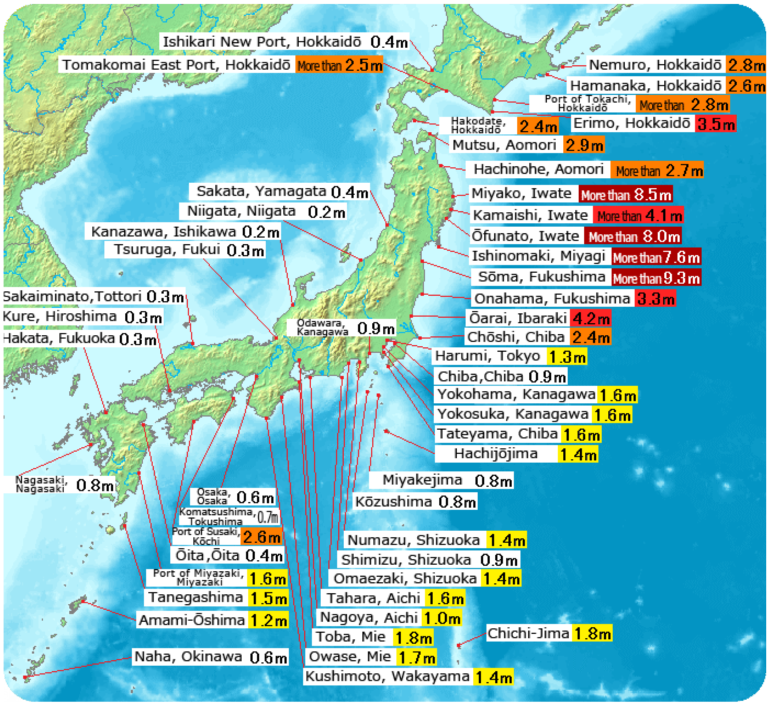

FIGURE 17.32

This map shows the peak tsunami wave heights.

FIGURE 17.33

An aerial view shows the damage to Sendai, Japan caused by the earthquake and tsunami. The black smoke is coming from an oil refinery, which was set on fire by the earthquake. The tsunami prevented efforts to extinguish the fire until several days after the earthquake.

experience quakes.

- Surface waves do the most damage in an earthquake.
- Body waves travel through the planet and travel faster than surface waves.
- Tsunami are deadly ocean waves that are caused by undersea earthquakes.

Review Questions

1. What is an earthquake's focus? What is its epicenter?

FIGURE 17.34
This sign indicates a tsunami hazard zone in California.

2. Why do most earthquakes take place along plate boundaries?
3. Using elastic rebound theory, describe what triggers an earthquake.
4. Why are there far more earthquakes around the Pacific Ocean than anywhere else?
5. What causes intraplate earthquakes?
6. Besides the San Andreas Fault zone, what other type of plate boundary in or near California can produce earthquakes?
7. Using plate tectonics and elastic rebound theory, describe why Juan de Fuca plate subduction produces so few earthquakes. What will happen in the future?
8. What type of faulting is found where two slabs of continental lithosphere are converging?
9. What are the characteristics of body waves? What are the two types?
10. What types of materials can P-waves travel through and how fast are they? Describe a P-wave's motion.
11. What material can S-waves travel through and how fast are they? Describe an S-wave's motion.
12. How are surface waves different from body waves? Which are more damaging?

Further Reading / Supplemental Links

- The U.S. Geological survey earthquake site is found here: http://earthquake.usgs.gov/ .
- Fault line discusses seismic science: http://www.exploratorium.edu/faultline/index.html .
- How the geography of the Pacific Northwest reflects the plate tectonic features is found here: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/2.NWplateRollover.swf .

Points to Consider

- Do the largest earthquakes cause the most deaths and the most damage to property?
- The last time there was a large earthquake on the Hayward Fault in the San Francisco Bay area of California was in 1868. Use elastic rebound theory to describe what may be happening along the Hayward Fault today and what will likely happen in the future.

- Why is California so prone to earthquakes?
- How could coastal California be damaged by a tsunami? Where would the earthquake occur? How could such a tsunami be predicted?

17.3 Measuring and Predicting Earthquakes

Lesson Objectives

- Describe how to find an earthquake epicenter.
- Describe the different earthquake magnitude scales and what the numbers for moment magnitude mean.
- Describe how earthquakes are predicted and why the field of earthquake prediction has had little success.

Vocabulary

- seismogram
- seismograph
- seismometer

Introduction

Seismograms record seismic waves. Over the past century, scientists have developed several ways of measuring earthquake intensity. The currently accepted method is the moment magnitude scale, which measures the total amount of energy released by the earthquake. At this time, seismologists have not found a reliable method for predicting earthquakes.

Measuring Magnitude

A **seismograph** produces a graph-like representation of the seismic waves it receives and records them onto a **seismogram** (**Figure** 17.35). Seismograms contain information that can be used to determine how strong an earthquake was, how long it lasted, and how far away it was. Modern **seismometers** record ground motions using electronic motion detectors. The data are then kept digitally on a computer.

If a seismogram records P-waves and surface waves but not S-waves, the seismograph was on the other side of the Earth from the earthquake. The amplitude of the waves can be used to determine the magnitude of the earthquake, which will be discussed in a later section.

- A seismograph records an earthquake 50 miles away: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/17/Seismogram_RegionalEarthquake.mov .
- This animation shows three different stations picking up seismic waves: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/10/4StationSeismoNetwork480.mov .

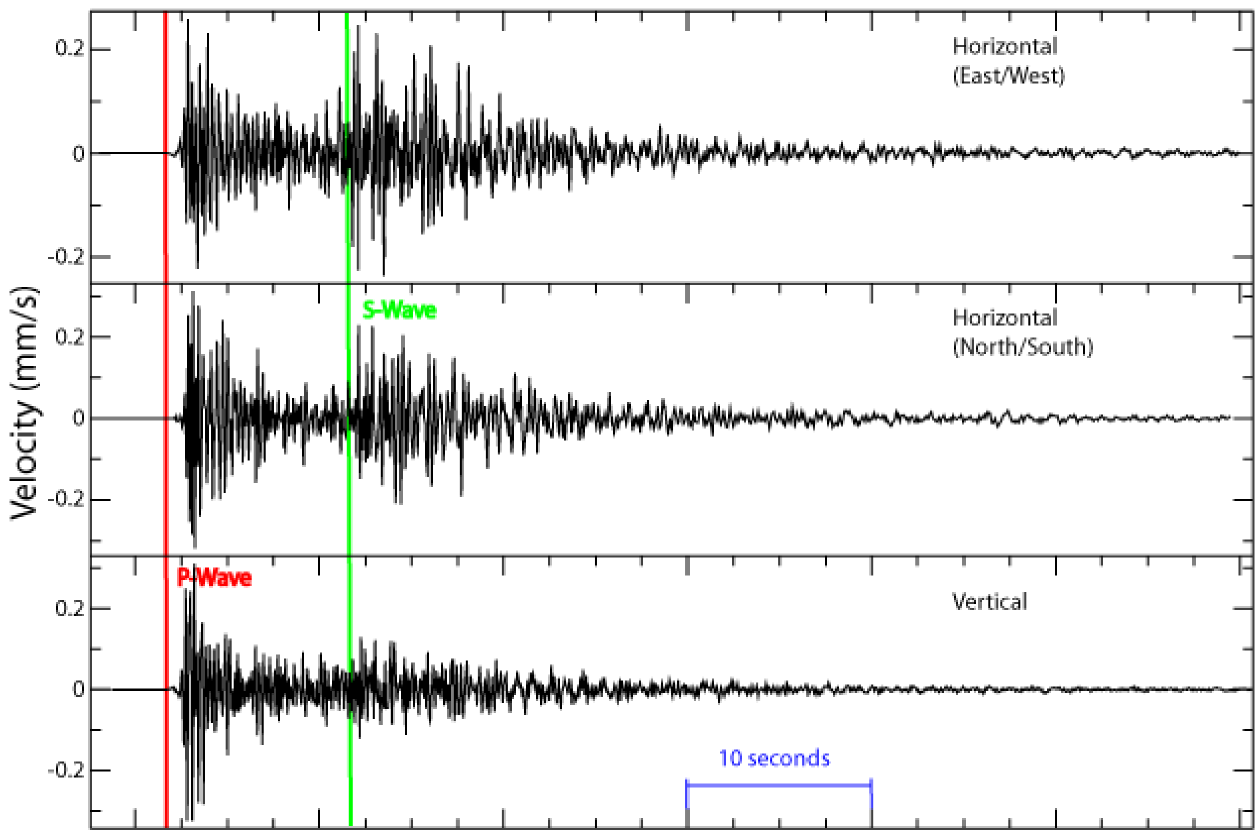

FIGURE 17.35
These seismograms show the arrival of P-waves and S-waves. The surface waves arrive just after the S-waves and are difficult to distinguish. Time is indicated on the horizontal portion (or x-axis) of the graph.

Finding the Epicenter

To locate an earthquake epicenter:

1. Scientists first determine the epicenter distance from three different seismographs. The longer the time between the arrival of the P-wave and S-wave, the farther away is the epicenter. So the difference in the P and S wave arrival times determines the distance between the epicenter and a seismometer. This animation shows how distance is determined using P, S, and surface waves: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/12/IRIStravelTime_Bounce_480.mov .

2. The scientist then draws a circle with a radius equal to the distance from the epicenter for that seismograph. The epicenter is somewhere along that circle. This is done for three locations. Using data from two seismographs, the two circles will intercept at two points. A third circle will intercept the other two circles at a single point. This point is the earthquake epicenter (**Figure** 17.36). Although useful for decades, this technique has been replaced by digital calculations.

Seismic stations record ten earthquakes in this animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/12/TravelTime_Sphere_10Stn_480.mov .

FIGURE 17.36
Circles are drawn with radii representing the distance from each seismic station to the earthquake's epicenter. The intersection of these three circles is the earthquake's epicenter.

Earthquake Intensity

Measuring Earthquakes

People have always tried to quantify the size of and damage done by earthquakes. Since early in the 20^{th} century, there have been three methods. What are the strengths and weaknesses of each?

- Mercalli Intensity Scale. Earthquakes are described in terms of what nearby residents felt and the damage that was done to nearby structures.
- Richter magnitude scale. Developed in 1935 by Charles Richter, this scale uses a seismometer to measure the magnitude of the largest jolt of energy released by an earthquake.
- Moment magnitude scale. Measures the total energy released by an earthquake. Moment magnitude is calculated from the area of the fault that is ruptured and the distance the ground moved along the fault.

The Richter scale and the moment magnitude scale are logarithmic.

- The amplitude of the largest wave increases ten times from one integer to the next.
- An increase in one integer means that thirty times more energy was released.
- These two scales often give very similar measurements.

How does the amplitude of the largest seismic wave of a magnitude 5 earthquake compare with the largest wave of a magnitude 4 earthquake? How does it compare with a magnitude 3 quake? The amplitude of the largest seismic wave of a magnitude 5 quake is 10 times that of a magnitude 4 quake and 100 times that of a magnitude 3 quake.

How does an increase in two integers on the moment magnitude scale compare in terms of the amount of energy released? Two integers equals a 900-fold increase in released energy.

Which scale do you think is best? With the Richter scale, a single sharp jolt measures higher than a very long intense earthquake that releases more energy. The moment magnitude scale more accurately reflects the energy released and the damage caused. Most seismologists now use the moment magnitude scale.

The way scientists measure earthquake intensity and the two most common scales, Richter and moment magnitude, are described along with a discussion of the 1906 San Francisco earthquake in *Measuring Earthquakes* video **(3d)**:

http://www.youtube.com/watch?v=wtlu_aDteCA (2:54).

MEDIA

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Annual Earthquakes

In a single year, on average, more than 900,000 earthquakes are recorded and 150,000 of them are strong enough to be felt. Each year about 18 earthquakes are major with a Richter magnitude of 7.0 to 7.9, and on average one earthquake has a magnitude of 8 to 8.9.

Magnitude 9 earthquakes are rare. The United States Geological Survey lists five since 1900 (see **Figure** 17.37) and (**Table** 17.1). All but the Great Indian Ocean Earthquake of 2004 occurred somewhere around the Pacific Ocean basin.

FIGURE 17.37

The 1964 Good Friday Earthquake centered in Prince William Sound, Alaska released the second most amount of energy of any earthquake in recorded history.

TABLE 17.1: Earthquakes of magnitude 9 or greater

Location	**Year**	**Magnitude**
Valdivia, Chile	1960	9.5
Prince William Sound, Alaska	1964	9.2
Great Indian Ocean Earthquake	2004	9.1
Kamchatka, Alaska	1952	9.0
Tōhoku, Japan	2011	9.0

Earthquake Prediction

Scientists are a long way from being able to predict earthquakes. A good prediction must be accurate as to where an earthquake will occur, when it will occur, and at what magnitude it will be so that people can evacuate. An unnecessary evacuation is expensive and causes people not to believe authorities the next time an evacuation is ordered.

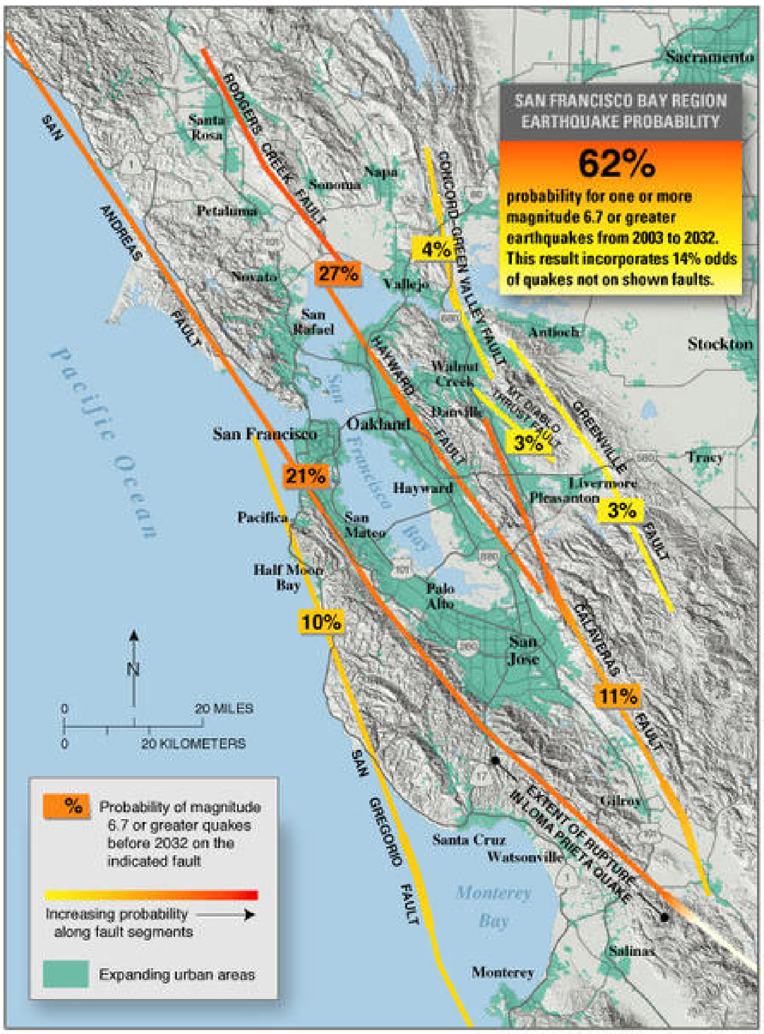


FIGURE 17.38
The probabilities of earthquakes striking along various faults in the San Francisco area between 2003 (when the work was done) and 2032.

Where an earthquake will occur is the easiest feature to predict. Scientists know that earthquakes take place at plate boundaries and tend to happen where they've occurred before (**Figure** 17.38). Earthquake-prone communities should always be prepared for an earthquake. These communities can implement building codes to make structures earthquake safe.

When an earthquake will occur is much more difficult to predict. Since stress on a fault builds up at the same rate over time, earthquakes should occur at regular intervals (**Figure** 17.39). But so far scientists cannot predict when quakes will occur even to within a few years.

Signs sometimes come before a large earthquake. Small quakes, called foreshocks, sometimes occur a few seconds to a few weeks before a major quake. However, many earthquakes do not have foreshocks and small earthquakes are not necessarily followed by a large earthquake. Often, the rocks around a fault will dilate as microfractures

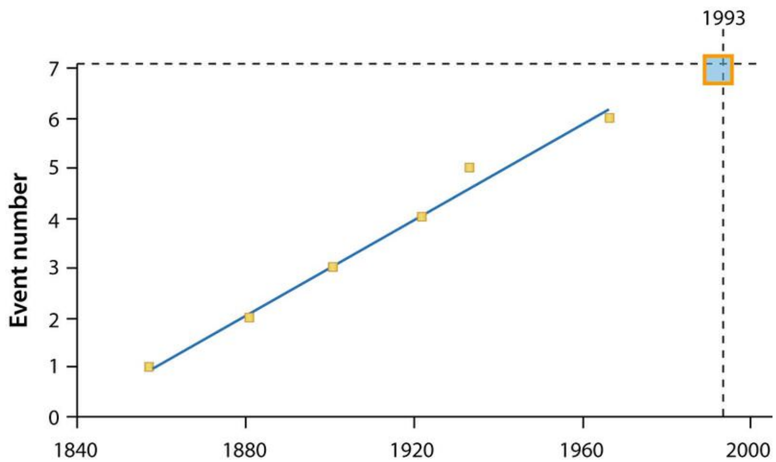
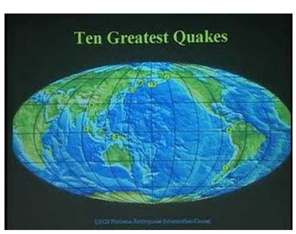


FIGURE 17.39
Around Parkfield, California, an earthquake of magnitude 6.0 or higher occurs about every 22 years. So seismologists predicted that one would strike in 1993, but that quake came in 2004 - 11 years late.

form. Ground tilting, caused by the buildup of stress in the rocks, may precede a large earthquake, but not always. Water levels in wells fluctuate as water moves into or out of fractures before an earthquake. This is also an uncertain predictor of large earthquakes. The relative arrival times of P-waves and S-waves also decreases just before an earthquake occurs.

Folklore tells of animals behaving erratically just before an earthquake. Mostly these anecdotes are told after the earthquake. If indeed animals sense danger from earthquakes or tsunami, scientists do not know what it is they could be sensing, but they would like to find out.

The geology of California underlies the state's wealth of natural resources as well as its natural hazards. This video explores the enormous diversity of California's geology **(9a)**: http://www.youtube.com/watch?v=QzdBx9zL0ZY (57:50).



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KQED: Earthquakes: Breaking New Ground

Earthquake prediction is very difficult and not very successful, but scientists are looking for a variety of clues in a variety of locations and to try to advance the field. Learn more at: http://science.kqed.org/quest/video/earthquakes-breaking-new-ground/ .

Adobe Flash

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KQED: Predicting the Next Big One

It's been twenty years since the Loma Prieta Earthquake ravaged downtown Santa Cruz and damaged San Francisco's Marina District and the Bay Bridge. QUEST looks at the dramatic improvements in earthquake prediction technology since 1989. But what can be done with ten seconds of warning? Learn more at: http://science.kqed.org/quest/audio/predicting-the-next-big-one/

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Lesson Summary

- Seismograms indicate an earthquake's strength, how far away it is, and how long it lasts.
- Epicenters can be calculated using the difference in the arrival times of P- and S-waves from three seismograms.
- Three different methods can be used to determine an earthquake's strength. The Mercalli Scale identifies the damage done and what people felt after an earthquake has occurred, the Richter scale measures the greatest single shock, and the moment magnitude scale measures the total energy released.
- Seismologists have not come too far in their ability to predict earthquakes.

Review Questions

1. How can a seismograph measure ground shaking if all parts of it must be attached to the ground?
2. On a seismogram, which waves arrive first, second, third, and last?
3. What information is needed to calculate the distance from a seismic station to an earthquake's epicenter?
4. If a seismogram records P-waves and surface waves but not S-waves, where was the earthquake epicenter located relative to the seismograph and why?
5. On the Richter or magnitude moment scale, what is the difference in energy released by an earthquake that is a 7.2 versus an 8.2 in magnitude? A 7.2 versus a 9.2?
6. Why do you need at least three seismographs to locate an earthquake epicenter?
7. What were the problems with the Mercalli scale of measuring earthquake magnitudes? Why did Richter and moment magnitude scales need to be developed?
8. Why is the moment magnitude scale thought to be more accurate than the Richter scale for measuring earthquake magnitudes?
9. What is the difference in energy released between a 6 and a 7 on the Richter scale? How about a 6 and a 7 on the moment magnitude scale?
10. How do seismologists use earthquake foreshocks to predict earthquakes? Why are foreshocks not always an effective prediction tool?
11. For earthquake prediction to be really useful, what would need to be predicted?

Further Reading / Supplemental Links

- How to triangulate for an earthquake epicenter: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/swf_earthquake_triangulation/p_activity_eqtriangulation.html .

Points to Consider

- If you live in an earthquake prone area, how do you feel about your home now? What can you do to minimize the risk to you and your family? If you do not live in an earthquake prone area, what would it take to get you to move to one? What risks from natural disasters do you face where you live?
- What do you think are the most promising clues that scientists might someday be able to use to predict earthquakes?
- What good does information about possible earthquake locations do for communities in those earthquake-prone regions?

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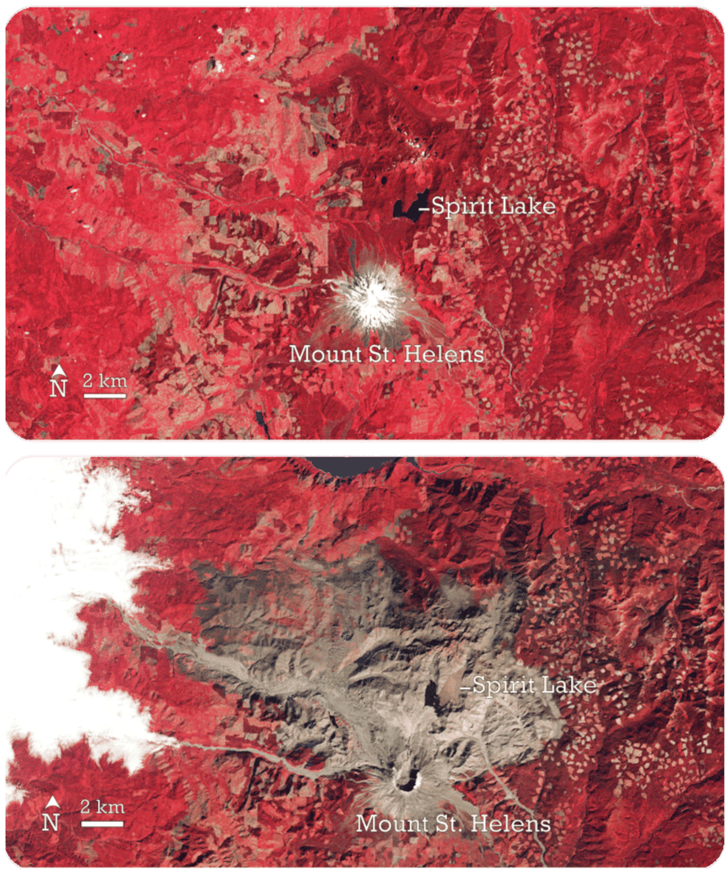
CHAPTER 18 Volcanoes

Chapter Outline



Above are two false-color Landsat satellite images of Mount St. Helens and vicinity. The first image is from August 29, 1979. Just months later, in March 1980, the ground began to shake. Red indicates vegetation; patches of lighter color are where the region was logged.

The second image is from September 24, 1980, four months after the large eruption on May 18. The relics of the eruption are everywhere. The mountain's northern flank has collapsed, leaving a horseshoe shaped crater. Rock and ash have blown over 230 square miles. Dead trees are floating in Spirit Lake and volcanic mudflows clog the rivers. A more recent image shows that vegetation has begun to colonize at the farther reaches of the area affected by the eruption.

Courtesy of Robert Simmon and NASA's Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=43999. Public Domain.

18.1 Where Volcanoes Are Located

Lesson Objectives

- Describe how the locations of volcanoes are related to plate tectonics.
- Suggest why volcanoes are found at convergent and divergent plate boundaries.
- Describe how intraplate volcanoes can form.

Vocabulary

- fissure

Introduction

Volcanoes are a vibrant manifestation of plate tectonics processes. Volcanoes are common along convergent and divergent plate boundaries. Volcanoes are also found within lithospheric plates away from plate boundaries. Wherever mantle is able to melt, volcanoes may be the result.

See if you can give a geological explanation for the locations of all the volcanoes in **Figure** 18.1. What is the Pacific Ring of Fire? Why are the Hawaiian volcanoes located away from any plate boundaries? What is the cause of the volcanoes along the mid-Atlantic ridge?

Volcanoes erupt because mantle rock melts. This is the first stage in creating a volcano. Remember from the chapter "Rocks" that mantle may melt if temperature rises, pressure lowers, or water is added. Be sure to think about how melting occurs in each of the following volcanic settings.

Convergent Plate Boundaries

Why does melting occur at convergent plate boundaries? The subducting plate heats up as it sinks into the mantle. Also, water is mixed in with the sediments lying on top of the subducting plate. This water lowers the melting point of the mantle material, which increases melting. Volcanoes at convergent plate boundaries are found all along the Pacific Ocean basin, primarily at the edges of the Pacific, Cocos, and Nazca plates. Trenches mark subduction zones, although only the Aleutian Trench and the Java Trench appear on the map in **Figure** 18.1.

Remember your plate tectonics knowledge. Large earthquakes are extremely common along convergent plate boundaries. Since the Pacific Ocean is rimmed by convergent and transform boundaries, about 80% of all earthquakes strike around the Pacific Ocean basin (**Figure** 18.2). Why are 75% of the world's volcanoes found around the Pacific basin? Of course, these volcanoes are caused by the abundance of convergent plate boundaries around the Pacific.

A description of the Pacific Ring of Fire along western North America is a description of the plate boundaries.

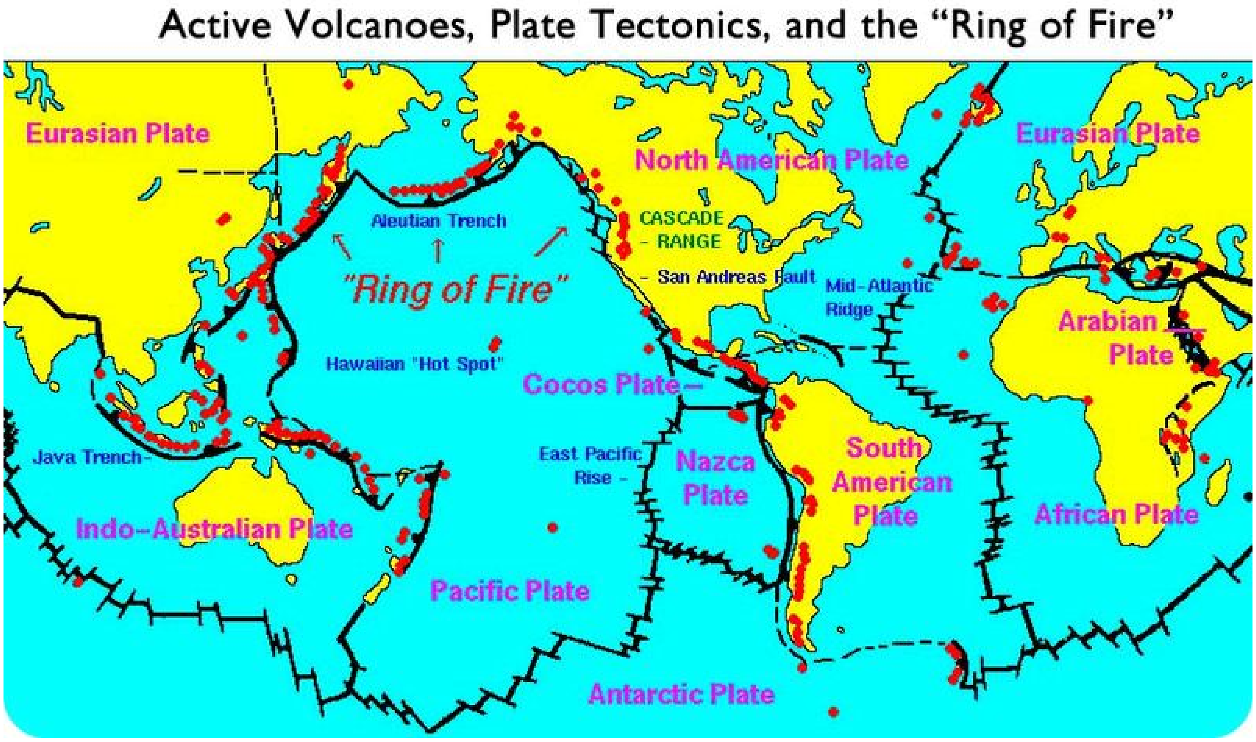


FIGURE 18.1
World map of active volcanoes.

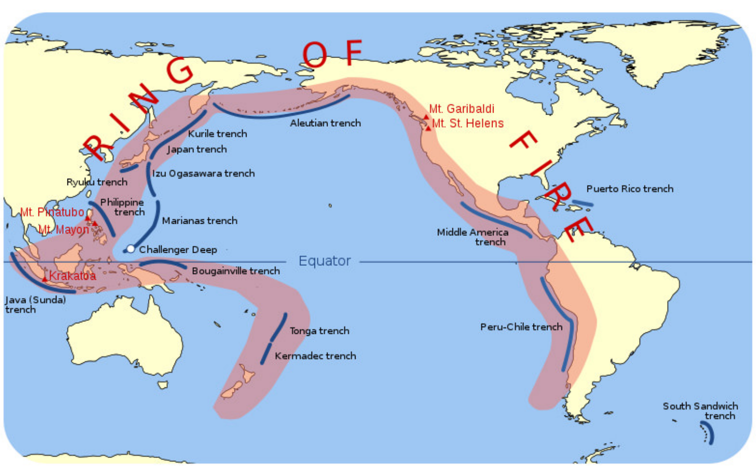


FIGURE 18.2
The Pacific Ring of Fire is where the majority of the volcanic activity on the Earth occurs.

- Subduction at the Middle American Trench creates volcanoes in Central America.
- The San Andreas Fault is a transform boundary.
- Subduction of the Juan de Fuca plate beneath the North American plate creates the Cascade volcanoes.
- Subduction of the Pacific plate beneath the North American plate in the north creates the Aleutian Islands volcanoes.

The Cascades are shown on this interactive map with photos and descriptions of each of the volcanoes: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/6.Volcanoes4Rollover.swf .

This incredible explosive eruption of Mount Vesuvius in Italy in A.D. 79 is an example of a composite volcano that forms as the result of a convergent plate boundary **(3f)**: http://www.youtube.com/watch?v=1u1Ys4m5zY4 (1:53).

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/8526

Divergent plate boundaries

Why does melting occur at divergent plate boundaries? Hot mantle rock rises where the plates are moving apart. This releases pressure on the mantle, which lowers its melting temperature. Lava erupts through long cracks in the ground, or **fissures.**

Footage of Undersea Volcanic Eruptions is seen in National Geographic Videos, Environment Video, Habitat, Ocean section: http://video.nationalgeographic.com/video/player/environment/ .

- Fantastic footage of undersea volcanic eruption is in the "Deepest Ocean Eruption Ever Filmed."
- "Giant Undersea Volcano Revealed" explores a volcano and its life off of Indonesia.

Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge, where seafloor spreading creates new seafloor in the rift valleys. Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands (**Figure** 18.3).

FIGURE 18.3

A volcanic eruption at Surtsey, a small island near Iceland.

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in **Figure** 18.4 are in the East African Rift between the African and Arabian plates.

FIGURE 18.4
Mount Gahinga, a mountain in Uganda, located in the East African Rift valley.

Volcanic Hotspots

Although most volcanoes are found at convergent or divergent plate boundaries, intraplate volcanoes are found in the middle of a tectonic plate. Why is there melting at these locations? The Hawaiian Islands are the exposed peaks of a great chain of volcanoes that lie on the Pacific plate. These islands are in the middle of the Pacific plate. The youngest island sits directly above a column of hot rock called a mantle plume. As the plume rises through the mantle, pressure is released and mantle melts to create a hotspot (**Figure** 18.5).

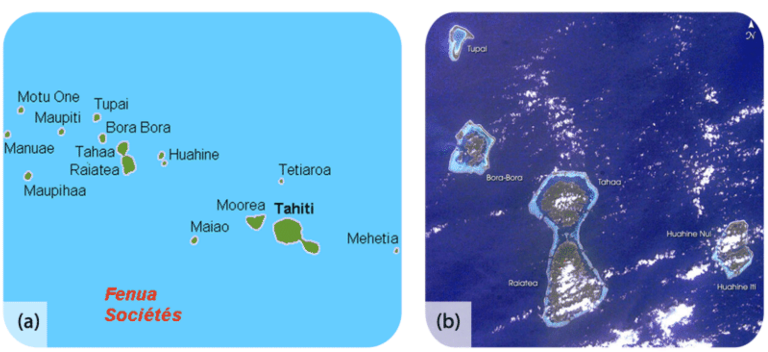


FIGURE 18.5
(a) The Society Islands formed above a hotspot that is now beneath Mehetia and two submarine volcanoes. (b) The satellite image shows how the islands become smaller and coral reefs became more developed as the volcanoes move off the hotspot and grow older.

Earth is home to about 50 known hot spots. Most of these are in the oceans because they are better able to penetrate oceanic lithosphere to create volcanoes. The hotspots that are known beneath continents are extremely large, such as Yellowstone (**Figure** 18.6).

A hot spot beneath Hawaii, the origin of the voluminous lava produced by the shield volcano Kilauea can be viewed here(**3f**): http://www.youtube.com/watch?v=byJp5o49IF4 (2:06).

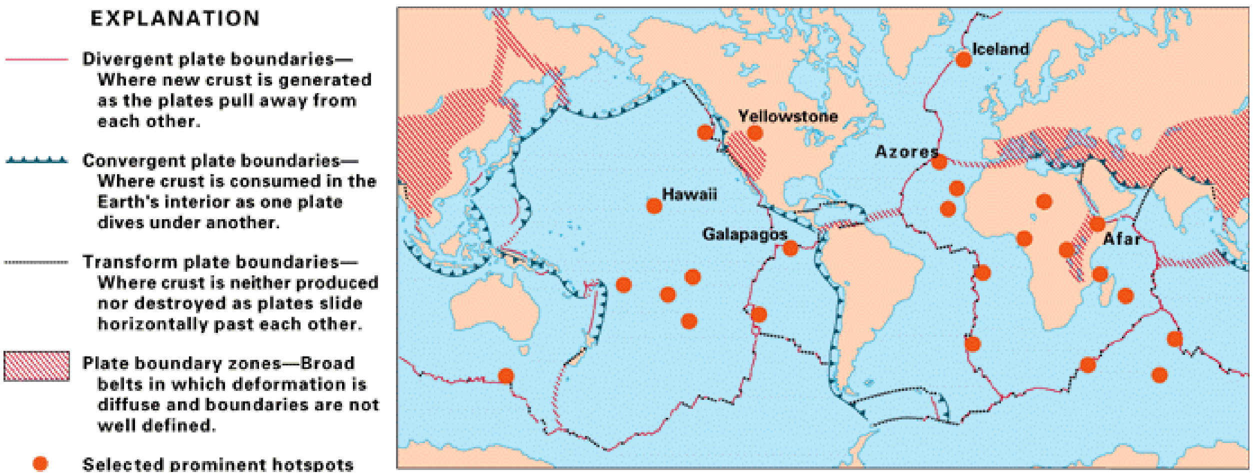


FIGURE 18.6
Prominent hotspots of the world.

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Click image to the left or use the URL below.
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How would you be able to tell hotspot volcanoes from island arc volcanoes? At island arcs, the volcanoes are all about the same age. By contrast, at hotspots the volcanoes are youngest at one end of the chain and oldest at the other.

Lesson Summary

- Most volcanoes are found along convergent or divergent plate boundaries.
- The Pacific Ring of Fire is the most geologically active region in the world.
- Volcanoes such as those that form the islands of Hawaii form over hotspots, which are melting zones above mantle plumes.

Review Questions

1. Why are there volcanoes along the west coast of the United States?
2. Why does melting occur at divergent plate boundaries?
3. In **Figure** 18.1, explain the geologic reason for every group of volcanoes in the diagram.
4. How did the Pacific Ring of Fire get its name? Does it deserve it?
5. What is a mantle plume?

6. Suppose a new volcano suddenly formed in the middle of the United States. How might you explain what caused this volcano?

Points to Consider

- Some volcanoes are no longer active. What could cause a volcano to become extinct?
- Hot spots are still poorly understood by Earth scientists. Why do you think it's hard to understand hotspots? What clues are there regarding these geological phenomena?
- Volcanoes have been found on Venus, Mars, and even Jupiter's moon Io. What do you think this indicates to planetary geologists?

18.2 Volcanic Eruptions

Lesson Objectives

- Explain how magma composition affects the type of eruption.
- Compare the types of volcanic eruptions.
- Distinguish between different types of lava and the rocks they form.
- Describe a method for predicting volcanic eruptions.

Vocabulary

- active volcano
- dormant volcano
- effusive eruption
- eruption
- explosive eruption
- extinct volcano
- lahar
- magma chamber
- pyroclastic flow
- tephra
- viscosity

Introduction

In 1980, Mount St. Helens blew up in the costliest and deadliest volcanic eruption in United States history. The eruption killed 57 people, destroyed 250 homes and swept away 47 bridges (**Figure** 18.7).

Mt. St. Helens still has minor earthquakes and eruptions. The volcano now has a horseshoe-shaped crater with a lava dome inside. The dome is formed of viscous lava that oozes into place.

Magma Composition

Volcanoes do not always erupt in the same way. Each volcanic **eruption** is unique, differing in size, style, and composition of erupted material. One key to what makes the eruption unique is the chemical composition of the magma that feeds a volcano, which determines (1) the eruption style, (2) the type of volcanic cone that forms, and (3) the composition of rocks that are found at the volcano.

Remember from the Rocks chapter that different minerals within a rock melt at different temperatures. The amount of partial melting and the composition of the original rock determine the composition of the magma. Magma collects

FIGURE 18.7
Mount St. Helens on May 18, 1980.

in **magma chambers** in the crust at 160 kilometers (100 miles) beneath the surface.

The words that describe composition of igneous rocks also describe magma composition.

- Mafic magmas are low in silica and contain more dark, magnesium and iron rich mafic minerals, such as olivine and pyroxene.
- Felsic magmas are higher in silica and contain lighter colored minerals such as quartz and orthoclase feldspar. The higher the amount of silica in the magma, the higher is its **viscosity.** Viscosity is a liquid's resistance to flow (**Figure** 18.8).

FIGURE 18.8
Honey flows slowly. It is more viscous than water.

Viscosity determines what the magma will do. Mafic magma is not viscous and will flow easily to the surface. Felsic magma is viscous and does not flow easily. Most felsic magma will stay deeper in the crust and will cool to form igneous intrusive rocks such as granite and granodiorite. If felsic magma rises into a magma chamber, it may be too viscous to move and so it gets stuck. Dissolved gases become trapped by thick magma. The magma churns in the chamber and the pressure builds.

Eruptions

The type of magma in the chamber determines the type of volcanic eruption. Although the two major kinds of eruptions –explosive and effusive - are described in this section, there is an entire continuum of eruption types. Which magma composition do you think leads to each type?

Explosive Eruptions

A large **explosive eruption** creates even more devastation than the force of the atom bomb dropped on Nagasaki at the end of World War II in which more than 40,000 people died. A large explosive volcanic eruption is 10,000 times as powerful. Felsic magmas erupt explosively. Hot, gas-rich magma churns within the chamber. The pressure becomes so great that the magma eventually breaks the seal and explodes, just like when a cork is released from a bottle of champagne. Magma, rock, and ash burst upward in an enormous explosion. The erupted material is called **tephra** (**Figure** 18.9).

FIGURE 18.9
Ash and gases create a mushroom cloud above Mt. Redoubt in Alaska, 1989. The cloud reached 45,000 feet and caught a Boeing 747 in its plume.

Scorching hot tephra, ash, and gas may speed down the volcano's slopes at 700 km/h (450 mph) as a **pyroclastic flow.** Pyroclastic flows knock down everything in their path. The temperature inside a pyroclastic flow may be as high as 1,000°C (1,800°F) (**Figure** 18.10).

A pyroclastic flow at Montserrat volcano is seen in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/PyroclasticFlow.MOV .

Prior to the Mount St. Helens eruption in 1980, the Lassen Peak eruption on May 22, 1915, was the most recent Cascades eruption. A column of ash and gas shot 30,000 feet into the air. This triggered a high-speed pyroclastic flow, which melted snow and created a volcanic mudflow known as a **lahar**. Lassen Peak currently has geothermal activity and could erupt explosively again. Mt. Shasta, the other active volcano in California, erupts every 600 to 800 years. An eruption would most likely create a large pyroclastic flow, and probably a lahar. Of course, Mt. Shasta could explode and collapse like Mt. Mazama in Oregon (**Figure** 18.11).

Volcanic gases can form poisonous and invisible clouds in the atmosphere. These gases may contribute to environmental problems such as acid rain and ozone destruction. Particles of dust and ash may stay in the atmosphere for years, disrupting weather patterns and blocking sunlight (**Figure** 18.12).

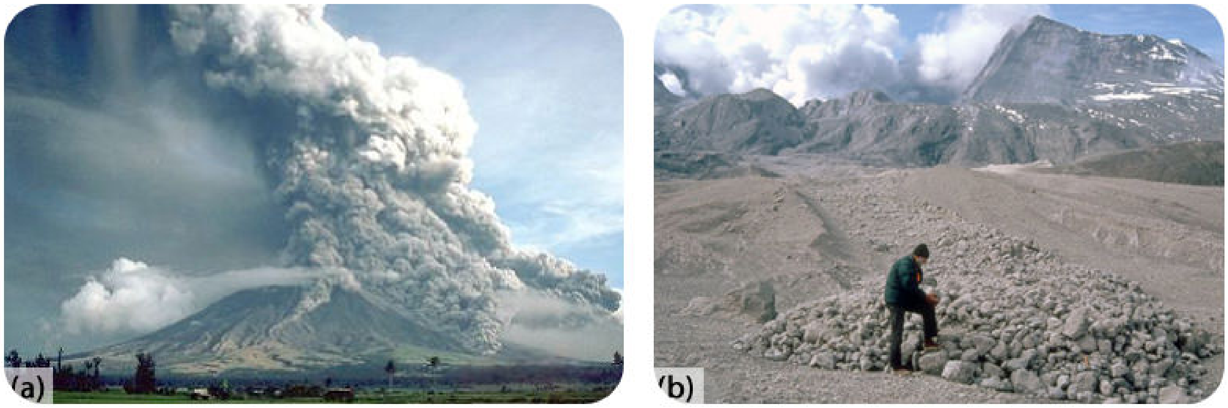

FIGURE 18.10
(a) An explosive eruption from the Mayon Volcano in the Philippines in 1984. Ash flies upward into the sky and pyroclastic flows pour down the mountainside. (b) The end of a pyroclastic flow at Mount St. Helens.

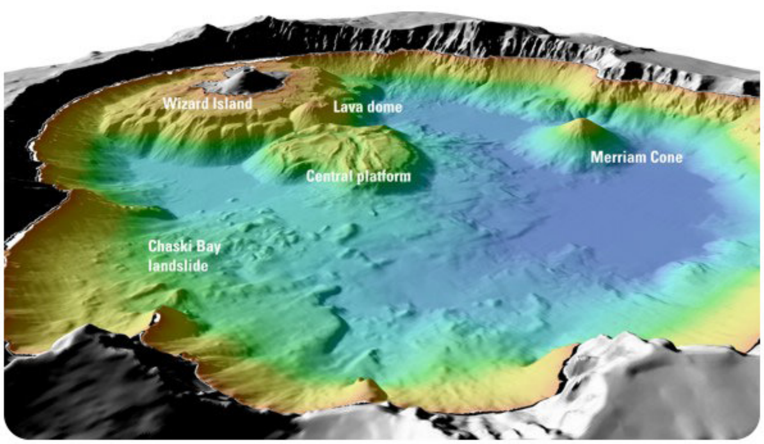

FIGURE 18.11
Crater Lake fills the caldera of the collapsed Mt. Mazama, which erupted with 42 times more power than Mount St. Helens in 1980. The bathymetry of the lake shows volcanic features such as cinder cones.

FIGURE 18.12
The ash plume from Eyjafjallajökull volcano in Iceland disrupted air travel across Europe for six days in April 2010.

Effusive Eruptions

Mafic magma creates gentler **effusive eruptions**. Although the pressure builds enough for the magma to erupt, it does not erupt with the same explosive force as felsic magma. People can usually be evacuated before an effusive eruption, so they are much less deadly. Magma pushes toward the surface through fissures. Eventually, the magma reaches the surface and erupts through a vent (**Figure** 18.13).

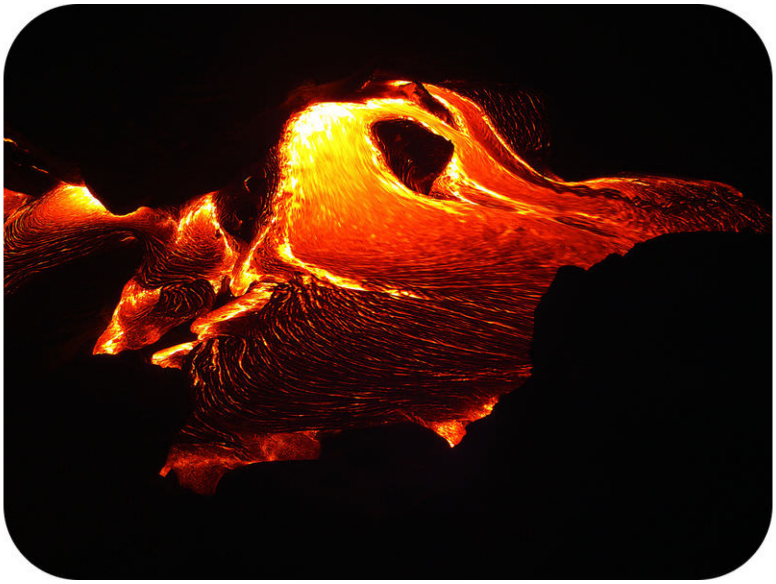

FIGURE 18.13
In effusive eruptions, lava flows readily, producing rivers of molten rock.

- The Kilauea volcanic eruption in 2008 is seen in this short video: http://www.youtube.com/watch?v=BtH79yxBIJI .
- A Quicktime movie with thermal camera of a lava stream within the vent of a Hawaiian volcano is seen here: http://hvo.wr.usgs.gov/kilauea/update/archive/2009/Nov/OverflightFLIR_13Jan2010.mov .

Low-viscosity lava flows down mountainsides. Differences in composition and where the lavas erupt result in three types of lava flow coming from effusive eruptions (**Figure** 18.14).

- Undersea eruption videos are seen here http://news.discovery.com/videos/earth-undersea-eruption-now-in-stereo.html and here http://news.discovery.com/videos/earth-underwater-volcano-caught-on-video.html .

Although effusive eruptions rarely kill anyone, they can be destructive. Even when people know that a lava flow is approaching, there is not much anyone can do to stop it from destroying a building or road (**Figure** 18.15).

Predicting Volcanic Eruptions

Volcanologists attempt to forecast volcanic eruptions, but this has proven to be nearly as difficult as predicting an earthquake. Many pieces of evidence can mean that a volcano is about to erupt, but the time and magnitude of the eruption are difficult to pin down. This evidence includes the history of previous volcanic activity, earthquakes, slope deformation, and gas emissions.

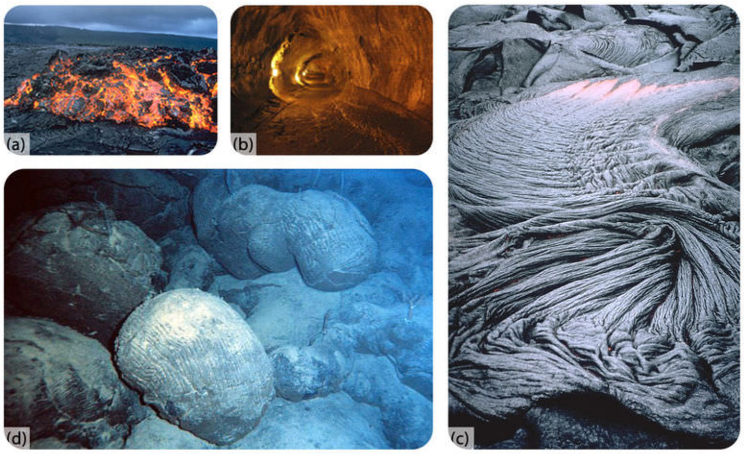

FIGURE 18.14

(a) A'a lava forms a thick and brittle crust that is torn into rough and jagged pieces. A'a lava can spread over large areas as the lava continues to flow underneath the crust's surface. (b) Pāhoehoe lava forms lava tubes where fluid lava flows through the outer cooled rock crust, as can be seen at the Thurston Lava Tube in Hawai'i Volcanoes National Park. (c) Pāhoehoe lava is less viscous than a'a lava so its surface looks is smooth and ropy. (d) Mafic lava that erupts underwater creates pillow lava. The lava cools very quickly to roughly spherical rocks. Pillow lava is common at mid-ocean ridges.

FIGURE 18.15

A road is overrun by an eruption at Kilauea volcano in Hawaii.

History of Volcanic Activity

A volcano's history – how long since its last eruption and the time span between its previous eruptions – is a good first step to predicting eruptions. Which of these categories does the volcano fit into?

- **Active:** currently erupting or showing signs of erupting soon.
- **Dormant:** no current activity, but has erupted recently (**Figure** 18.16).
- **Extinct:** no activity for some time; will probably not erupt again.

Active and dormant volcanoes are heavily monitored, especially in populated areas.

FIGURE 18.16
Mount Vesuvius destroyed Pompeii in 79 AD. Fortunately this volcano is dormant because the region is now much more heavily populated.

Earthquakes

Moving magma shakes the ground, so the number and size of earthquakes increases before an eruption. A volcano that is about to erupt may produce a sequence of earthquakes. Scientists use seismographs that record the length and strength of each earthquake to try to determine if an eruption is imminent.

Slope Deformation

Magma and gas can push the volcano's slope upward. Most ground deformation is subtle and can only be detected by tiltmeters, which are instruments that measure the angle of the slope of a volcano. But ground swelling may sometimes create huge changes in the shape of a volcano. Mount St. Helens grew a bulge on its north side before its 1980 eruption. Ground swelling may also increase rock falls and landslides.

Gas Emissions

Gases may be able to escape a volcano before magma reaches the surface. Scientists measure gas emissions in vents on or around the volcano. Gases, such as sulfur dioxide (SO_2), carbon dioxide (CO_2), hydrochloric acid (HCl), and even water vapor can be measured at the site (**Figure** 18.17) or, in some cases, from a distance using satellites. The amounts of gases and their ratios are calculated to help predict eruptions.

Remote Monitoring

Some gases can be monitored using satellite technology (**Figure** 18.18). Satellites also monitor temperature readings and deformation. As technology improves, scientists are better able to detect changes in a volcano accurately and safely.

Since volcanologists are usually uncertain about an eruption, officials may not know whether to require an evacuation. If people are evacuated and the eruption doesn't happen, the people will be displeased and less likely to evacuate the next time there is a threat of an eruption. The costs of disrupting business are great. However, scientists continue to work to improve the accuracy of their predictions.

FIGURE 18.17
Scientists monitoring gas emissions at Mount St. Helens.

FIGURE 18.18
A satellite above Earth.

Lesson Summary

- The style of a volcanic eruption depends on magma viscosity.
- Felsic magmas produce explosive eruptions. Mafic magmas produce effusive eruptions.
- Explosive eruptions happen along the edges of continents and produce tremendous amounts of material ejected into the air.
- Non-explosive eruptions produce lavas, such as a'a, pahoehoe, and pillow lavas.
- Volcanoes are classified as active, dormant, or extinct.
- Signs that a volcano may soon erupt include earthquakes, surface bulging, and gases emitted, as well as other changes that can be monitored by scientists.

Review Questions

1. What are the two basic types of volcanic eruptions?

2. Several hundred years ago, a volcano erupted near the city of Pompeii, Italy. Archaeologists have found the remains of people embracing each other, suffocated by ash and rock that covered everything. What type of eruption must have this been?

3. What is pyroclastic material?

4. Name three substances that have low viscosity and three that have high viscosity.

5. Why might the addition of water make an eruption more explosive?

6. What are three names for non-explosive lava?

7. What factors are considered in predicting volcanic eruptions?

8. Why is predicting a volcanic eruption so important?

9. Given that astronomers are far away from the planets they study, what evidence might they look for to determine the composition of a planet on which a volcano is found?

Further Reading / Supplemental Links

- The top five volcano web cams and video: http://news.discovery.com/videos/earth-top-5-volcano-webcams-and-videos.html

Points to Consider

- What would you look for to determine if an old eruption was explosive or non-explosive?
- Given the different styles of eruptions discussed above, what do you think the shapes of volcanoes are?
- Where do you think the names a'a and pāhoehoe came from?
- Do earthquakes always indicate an imminent eruption? What factors about an earthquake might indicate a relationship to a volcanic eruption?

18.3 Types of Volcanoes

Lesson Objectives

- Describe the basic shapes of volcanoes.
- Compare the features of volcanoes.
- Describe the stages in the formation of volcanoes.

Vocabulary

- caldera
- cinder cone
- composite volcano
- shield volcano
- supervolcano

Introduction

A volcano is a vent through which molten rock and gas escape from a magma chamber. Volcanoes differ in many features such as height, shape, and slope steepness. Some volcanoes are tall cones and others are just cracks in the ground (**Figure** 18.19). As you might expect, the shape of a volcano is related to the composition of its magma.

FIGURE 18.19
Mount St. Helens was a beautiful, classic, cone-shaped volcano. The volcano's 1980 eruption blew more than 400 meters (1,300 feet) off the top of the mountain.

Composite Volcanoes

Composite volcanoes are made of felsic to intermediate rock. The viscosity of the lava means that eruptions at these volcanoes are often explosive (**Figure** 18.20).

FIGURE 18.20
Mt. Fuji, the highest mountain in Japan, is a dormant composite volcano.

The viscous lava cannot travel far down the sides of the volcano before it solidifies, which creates the steep slopes of a composite volcano. Viscosity also causes some eruptions to explode as ash and small rocks. The volcano is constructed layer by layer, as ash and lava solidify, one upon the other (**Figure** 18.21). The result is the classic cone shape of composite volcanoes.

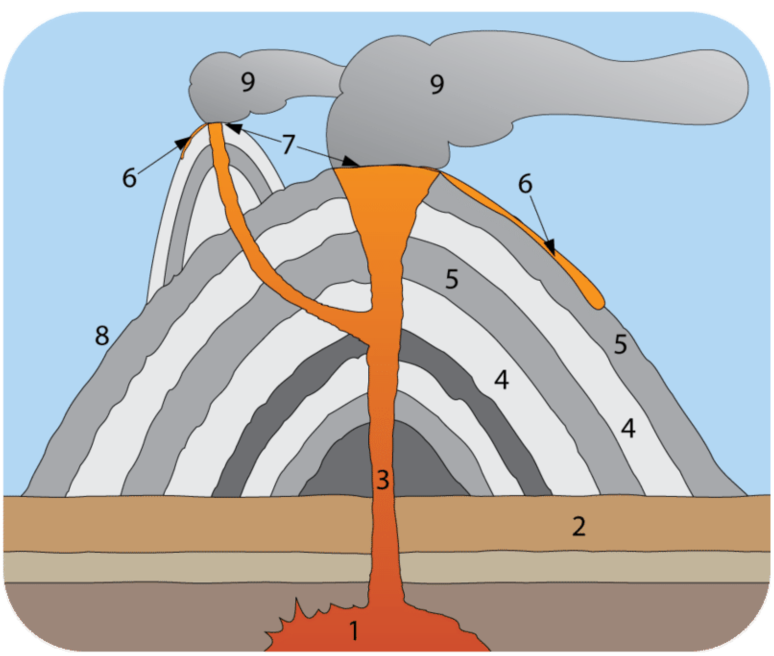

FIGURE 18.21
A cross section of a composite volcano reveals alternating layers of rock and ash: (1) magma chamber, (2) bedrock, (3) pipe, (4) ash layers, (5) lava layers, (6) lava flow, (7) vent, (8) lava, (9) ash cloud. Frequently there is a large crater at the top from the last eruption.

Shield Volcanoes

Shield volcanoes get their name from their shape. Although shield volcanoes are not steep, they may be very large. Shield volcanoes are common at spreading centers or intraplate hot spots (**Figure** 18.22).

FIGURE 18.22
Mauna Loa Volcano in Hawaii (in the background) is the largest shield volcano on Earth with a diameter of more than 112 kilometers (70 miles). The volcano forms a significant part of the island of Hawaii.

The lava that creates shield volcanoes is fluid and flows easily. The spreading lava creates the shield shape. Shield volcanoes are built by many layers over time and the layers are usually of very similar composition. The low viscosity also means that shield eruptions are non-explosive.

This *Volcanoes 101* video from National Geographic discusses where volcanoes are found and what their properties come from **(3e)**: http://www.youtube.com/watch?v=uZp1dNybgfc (3:05).

MEDIA
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Cinder Cones

Cinder cones are the most common type of volcano. A cinder cone has a cone shape, but is much smaller than a composite volcano. Cinder cones rarely reach 300 meters in height but they have steep sides. Cinder cones grow rapidly, usually from a single eruption cycle (**Figure** 18.23). Cinder cones are composed of small fragments of rock, such as pumice, piled on top of one another. The rock shoots up in the air and doesn't fall far from the vent. The exact composition of a cinder cone depends on the composition of the lava ejected from the volcano. Cinder cones usually have a crater at the summit.

Cinder cones are often found near larger volcanoes (**Figure** 18.24).

Supervolcanoes

Supervolcano eruptions are extremely rare in Earth history. It's a good thing because they are unimaginably large.

FIGURE 18.23
In 1943, a Mexican farmer first witnessed a cinder cone erupting in his field. In a year, Paricutín was 336 meters high. By 1952, it reached 424 meters and then stopped erupting.

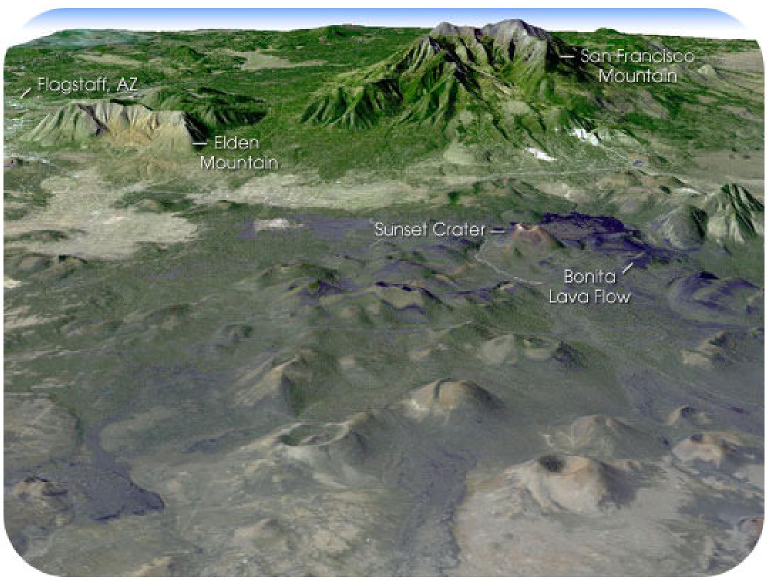

FIGURE 18.24
This Landsat image shows the topography of San Francisco Mountain, an extinct volcano, with many cinder cones near it in northern Arizona. Sunset crater is a cinder cone that erupted about 1,000 years ago.

A supervolcano must erupt more than 1,000 cubic km (240 cubic miles) of material, compared with 1.2 km^3 for Mount St. Helens or 25 km^3 for Mount Pinatubo, a large eruption in the Philippines in 1991. Not surprisingly, supervolcanoes are the most dangerous type of volcano.

Supervolcanoes are a fairly new idea in volcanology. The exact cause of supervolcano eruptions is still debated. However, scientists think that a very large magma chamber erupts entirely in one catastrophic explosion. This creates a huge hole or **caldera** into which the surface collapses (**Figure** 18.25).

The largest supervolcano in North America is beneath Yellowstone National Park in Wyoming. Yellowstone sits above a hotspot that has erupted catastrophically three times: 2.1 million, 1.3 million, and 640,000 years ago. Yellowstone has produced many smaller (but still enormous) eruptions more recently (**Figure** 18.26). Fortunately, current activity at Yellowstone is limited to the region's famous geysers.

Long Valley Caldera, south of Mono Lake in California, is the second largest supervolcano in North America (**Figure** 18.27). Long Valley had an extremely hot and explosive rhyolite about 700,000 years ago. An earthquake swarm in 1980 alerted geologists to the possibility of a future eruption, but the quakes have since calmed down.

FIGURE 18.25
The caldera at Santorini in Greece is so large that it can only be seen by satellite.

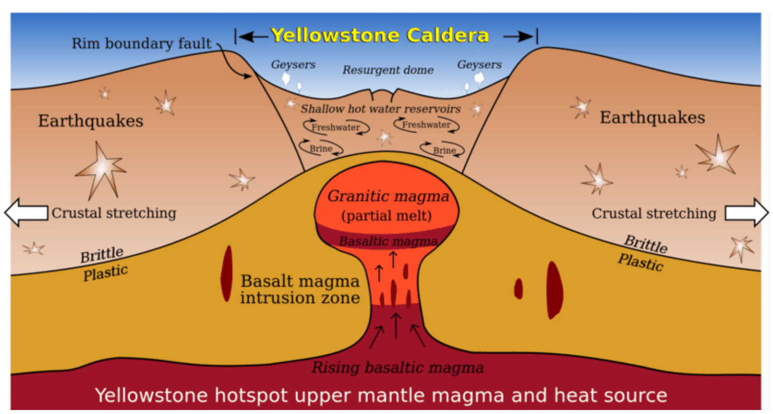

FIGURE 18.26
The Yellowstone hotspot has produced enormous felsic eruptions. The Yellowstone caldera collapsed in the most recent super eruption.

- An interactive image of the geological features of Long Valley Caldera is available here:

http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/B&R_LongValleyCaldera.swf

A supervolcano could change life on Earth as we know it. Ash could block sunlight so much that photosynthesis would be reduced and global temperatures would plummet. Volcanic eruptions could have contributed to some of the mass extinctions in our planet's history. No one knows when the next super eruption will be.

Interesting volcano videos are seen on National Geographic Videos, Environment Video, Natural Disasters, Earthquakes: http://video.nationalgeographic.com/video/player/environment/ . One interesting one is "Mammoth Mountain," which explores Hot Creek and the volcanic area it is a part of in California.

FIGURE 18.27
The hot water that gives Hot Creek, California, its name is heated by hot rock below Long Valley Caldera.

Lesson Summary

- Composite, shield, cinder cones, and supervolcanoes are the main types of volcanoes.
- Composite volcanoes are tall, steep cones that produce explosive eruptions.
- Shield volcanoes form very large, gently sloped mounds from effusive eruptions.
- Cinder cones are the smallest volcanoes and result from accumulation of many small fragments of ejected material.
- An explosive eruption may create a caldera, a large hole into which the mountain collapses.
- Supervolcano eruptions are devastating but extremely rare in Earth history.

Review Questions

1. Rank, in order, the four types of volcanoes from smallest to largest in diameter.
2. What factor best determines what type of volcano will form in a given area?
3. Which type of volcano is most common?
4. Why do pahoehoe and a'a lava erupt from shield volcanoes? Why don't they erupt from composite volcanoes?
5. Why are cinder cones short-lived?
6. If supervolcanoes are so big, why did it take so long for scientists to discover them?

Points to Consider

- Composite volcanoes and volcanic cones usually have craters on the top. Why are the craters sometimes U- or horseshoe-shaped?
- Think about plate boundaries again. What type of volcanoes do you think are found at convergent, divergent, and transform boundaries? How about at intraplate sites?
- Some people have theorized that if a huge asteroid hits the Earth, the results would be catastrophic. How might an asteroid impact and a supervolcano eruption be similar?

18.4 References

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CONCEPT 19 Unit 8: Energy and Earth's Atmosphere

Questions/Observable Phenomena

CHAPTER 20 Earth's Atmosphere

Chapter Outline

Astronauts took this photo of the Moon barely visible above Earth's atmosphere. Earth's blue halo appears because the atmosphere scatters blue light more than other wavelengths. At the top of the atmosphere, gases become so thin that they just cease to exist and then there is nothing but empty space. Since there is no easy way to define the top of the atmosphere, scientists say that it is 100 km above Earth's surface. At that location, solar energy enters the Earth system mostly as visible light. Energy as reflected light and heat leave the Earth system there. If average global temperature remains the same, the incoming and outgoing energy are equal. If more energy is coming in than going out, global temperatures increase. If more energy is going out than coming in, global temperatures decrease. Increases or decreases in greenhouse gases can change this energy balance. Clouds appear in Earth's atmosphere where there is water vapor. Clouds, along with snow and ice, reflect sunlight and play an important role in global climate. Where clouds reflect light back into space, they reduce the energy in the atmosphere. But water vapor is a greenhouse gas, so clouds can also trap heat. Scientists are interested in the effects of clouds on Earth's heat balance.

Courtesy of NASA's Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=7373. Public Domain.

20.1 The Atmosphere

Lesson Objectives

- Describe the importance of the atmosphere to our planet and its life.
- Outline the role of the atmosphere in the water cycle.
- List the major components of the atmosphere and know their functions.
- Describe how atmospheric pressure changes with altitude.

Vocabulary

- air pressure
- altitude
- atmosphere
- greenhouse gas
- humidity
- ozone
- respiration
- ultraviolet (UV) radiation
- water vapor
- weather

Introduction

Earth's atmosphere is a thin blanket of gases and tiny particles —together called air. We are most aware of air when it moves and creates wind. All living things need some of the gases in air for life support. Without an atmosphere, Earth would likely be just another lifeless rock.

Significance of the Atmosphere

Earth's atmosphere, along with the abundant liquid water at Earth's surface, are the keys to our planet's unique place in the solar system. Much of what makes Earth exceptional depends on the atmosphere. Let's consider some of the reasons we are lucky to have an atmosphere.

Atmospheric Gases Are Indispensable for Life on Earth

Without the atmosphere, Earth would look a lot more like the Moon. Atmospheric gases, especially carbon dioxide (CO_2) and oxygen (O_2), are extremely important for living organisms. How does the atmosphere make life possible?

How does life alter the atmosphere?

In photosynthesis plants use CO_2 and create O_2. Photosynthesis is responsible for nearly all of the oxygen currently found in the atmosphere. The chemical reaction for photosynthesis is:

$6CO_2 + 6H_2O$ + solar energy $\rightarrow C_6H_{12}O_6$ (sugar) + $6O_2$

By creating oxygen and food, plants have made an environment that is favorable for animals. In **respiration**, animals use oxygen to convert sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + useable energy

How is respiration similar to and different from photosynthesis? They are approximately the reverse of each other. In photosynthesis, CO_2 is converted to O_2 and in respiration, O_2 is converted to CO_2 (**Figure** 20.1).

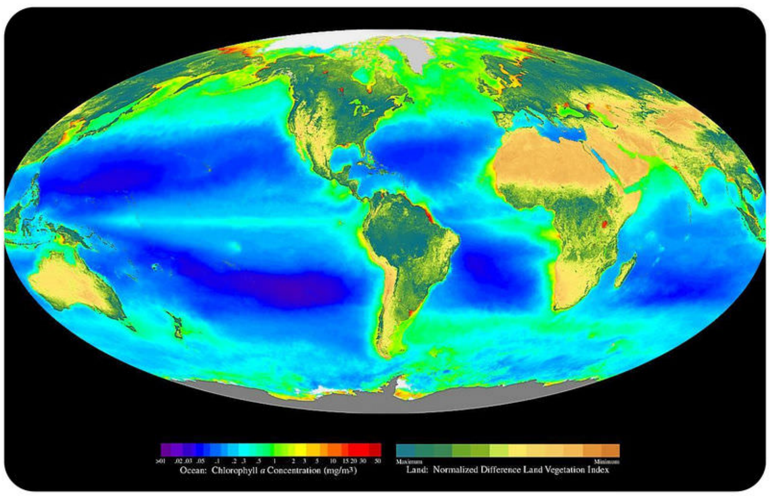


FIGURE 20.1
Chlorophyll indicates the presence of photosynthesizing plants as does the vegetation index.

The Atmosphere is a Crucial Part of the Water Cycle

As part of the hydrologic cycle, which was detailed in the Earth's Fresh Water chapter, water spends a lot of time in the atmosphere, mostly as water vapor.

All **weather** takes place in the atmosphere, virtually all of it in the lower atmosphere. Weather describes what the atmosphere is like at a specific time and place, and may include temperature, wind, and precipitation. Weather is the change we experience from day to day. Climate is the long-term average of weather in a particular spot. Although the weather for a particular winter day in Tucson, Arizona, may include snow, the climate of Tucson is generally warm and dry.

Ozone in the Upper Atmosphere Makes Life on Earth Possible

Ozone is a molecule composed of three oxygen atoms, (O_3). Ozone in the upper atmosphere absorbs high-energy **ultraviolet (UV) radiation** coming from the Sun. This protects living things on Earth's surface from the Sun's most harmful rays. Without ozone for protection, only the simplest life forms would be able to live on Earth.

The Atmosphere Keeps Earth's Temperature Moderate

Along with the oceans, the **atmosphere** keeps Earth's temperatures within an acceptable range. **Greenhouse gases** trap heat in the atmosphere so they help to moderate global temperatures (**Figure** 20.2). Without an atmosphere with greenhouse gases, Earth's temperatures would be frigid at night and scorching during the day. Important greenhouse gases include carbon dioxide, methane, water vapor, and ozone.

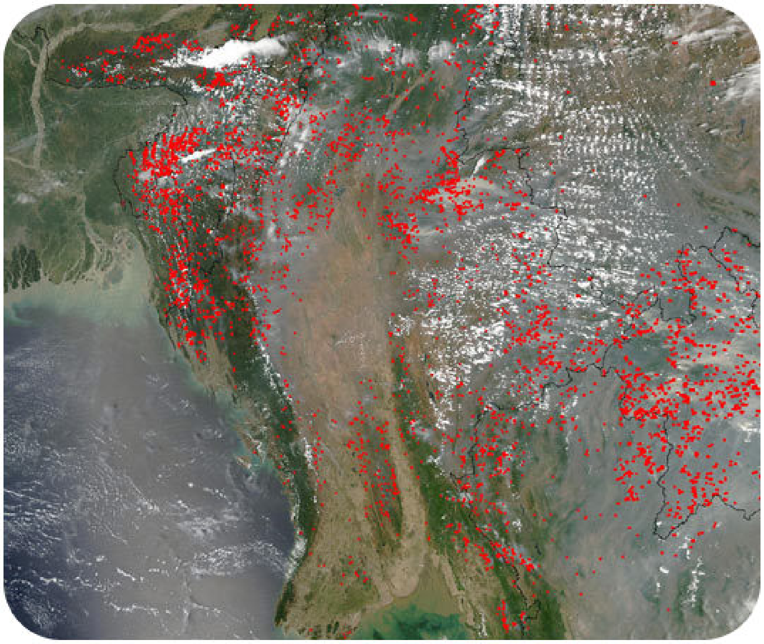


FIGURE 20.2
Fires, such as these set to burn forests across southeast Asia, contribute greenhouse gases to the atmosphere.

Atmospheric Gases Provide the Substance for Waves to Travel Through

The atmosphere is made of gases that take up space and transmit energy. Sound waves are among the types of energy that travel though the atmosphere. Without an atmosphere, we could not hear a single sound. Earth would be as silent as outer space. Of course, no insect, bird, or airplane would be able to fly because there would be no atmosphere to hold it up. Explosions in movies about space should be silent.

Composition of Air

Nitrogen and oxygen together make up 99% of the planet's atmosphere. The rest of the gases are minor components but sometimes are very important (**Figure** 20.3).

Humidity is the amount of water vapor in the air. Humidity varies from place to place and season to season. This fact is obvious if you compare a summer day in Atlanta, Georgia, where humidity is high, with a winter day in Phoenix, Arizona, where humidity is low. When the air is very humid, it feels heavy or sticky. Dry air usually feels more comfortable.

Where around the globe is mean atmospheric water vapor higher and where is it lower and why (**Figure** 20.4)? Higher humidity is found around the equatorial regions because air temperatures are higher and warm air can hold more moisture than cooler air. Of course, humidity is lower near the polar regions because air temperature is lower.

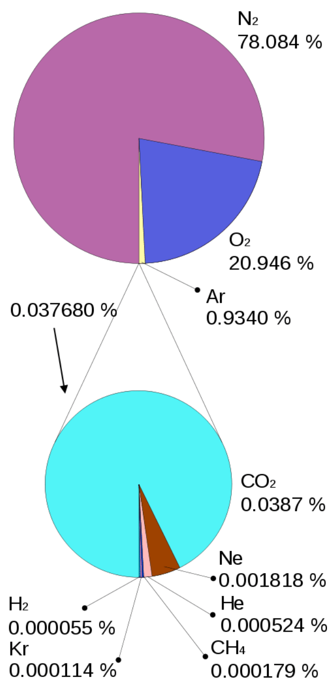


FIGURE 20.3
Nitrogen and oxygen make up 99% of the atmosphere; carbon dioxide is a very important minor component.

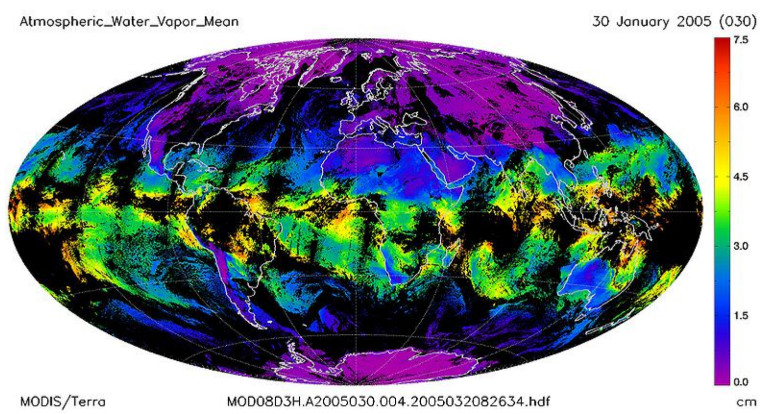


FIGURE 20.4
Mean winter atmospheric water vapor in the Northern Hemisphere when temperature and humidity are lower than they would be in summer.

Some of what is in the atmosphere is not gas. Particles of dust, soil, fecal matter, metals, salt, smoke, ash, and other solids make up a small percentage of the atmosphere. Particles provide starting points (or nuclei) for water vapor to condense on and form raindrops. Some particles are pollutants, which are discussed in the Human Actions and the Atmosphere chapter.

Pressure and Density

The atmosphere has different properties at different elevations above sea level, or **altitudes**. The air density (the number of molecules in a given volume) decreases with increasing altitude. This is why people who climb tall mountains, such as Mt. Everest, have to set up camp at different elevations to let their bodies get used to the decreased air (**Figure** 20.5).

Why does air density decrease with altitude? Gravity pulls the gas molecules towards Earth's center. The pull of gravity is stronger closer to the center at sea level. Air is denser at sea level where the gravitational pull is greater.

Gases at sea level are also compressed by the weight of the atmosphere above them. The force of the air weighing down over a unit of area is known as its atmospheric pressure, or **air pressure**. Why are we not crushed? The molecules inside our bodies are pushing outward to compensate. Air pressure is felt from all directions, not just from above.

FIGURE 20.5

This bottle was closed at an altitude of 3,000 meters where air pressure is lower. When it was brought down to sea level, the higher air pressure caused the bottle to collapse.

At higher altitudes the atmospheric pressure is lower and the air is less dense than at higher altitudes. If your ears have ever "popped", you have experienced a change in air pressure. Gas molecules are found inside and outside your ears. When you change altitude quickly, like when an airplane is descending, your inner ear keeps the density of molecules at the original altitude. Eventually the air molecules inside your ear suddenly move through a small tube in your ear to equalize the pressure. This sudden rush of air is felt as a popping sensation.

Although the density of the atmosphere changes with altitude, the composition stays the same with altitude, with one exception. In the ozone layer, at about 20 km to 40 km above the surface, there is a greater concentration of ozone molecules than in other portions of the atmosphere

Lesson Summary

- Without its atmosphere, Earth would be a very different planet. Gases in the atmosphere allow plants to photosynthesize and animals and plants to engage in respiration.
- Water vapor, which is an atmospheric gas, is an essential part of the water cycle.
- Although the amount of gases do not vary relative to each other in the atmosphere, there is one exception: the ozone layer. Ozone in the upper atmosphere protects life from the Sun's high energy ultraviolet radiation.
- Air pressure varies with altitude and temperature.

Review Questions

1. What gas is used and what gas is created during photosynthesis? What gas is used and what gas is created during respiration?

2. Describe two reasons why photosynthesis is important.

3. On an unusual February day in Portland, Oregon, the temperature is 18°C (65°F) and it is dry and sunny. The winter climate in Portland is usually chilly and rainy. How could you explain a warm, dry day in Portland in winter?

4. What important role do greenhouse gases play in the atmosphere?

5. Why do your ears pop when you are in an airplane and the plane descends for a landing?

Points to Consider

- How would Earth be different if it did not have an atmosphere?
- What are the most important components of the atmosphere?
- How does the atmosphere vary with altitude?

20.2 Atmospheric Layers

Lesson Objectives

- List the major layers of the atmosphere and their temperatures.
- Discuss why all weather takes place in the troposphere.
- Discuss how the ozone layer protects the surface from harmful radiation.

Vocabulary

- aurora
- exosphere
- inversion
- ionosphere
- magnetosphere
- mesosphere
- ozone layer
- solar wind
- stratosphere
- temperature gradient
- thermosphere
- troposphere

Introduction

The atmosphere is layered, corresponding with how the atmosphere's temperature changes with altitude. By understanding the way temperature changes with altitude, we can learn a lot about how the atmosphere works. While weather takes place in the lower atmosphere, interesting things, such as the beautiful aurora, happen higher in the atmosphere.

Air Temperature

Why does warm air rise (**Figure** 20.6)? Gas molecules are able to move freely and if they are uncontained, as they are in the atmosphere, they can take up more or less space.

- When gas molecules are cool, they are sluggish and do not take up as much space. With the same number of molecules in less space, both air density and air pressure are higher.
- When gas molecules are warm, they move vigorously and take up more space. Air density and air pressure are lower.

FIGURE 20.6
Papers held up by rising air currents above a radiator demonstrate the important principle that warm air rises.

Warmer, lighter air is more buoyant than the cooler air above it, so it rises. The cooler air then sinks down, because it is denser than the air beneath it. This is convection, which was described in the Plate Tectonics chapter.

The property that changes most strikingly with altitude is air temperature. Unlike the change in pressure and density, which decrease with altitude, changes in air temperature are not regular. A change in temperature with distance is called a **temperature gradient**.

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** 20.7). The temperature gradient of each layer is different. In some layers, temperature increases with altitude and in others it decreases. The temperature gradient in each layer is determined by the heat source of the layer (**Figure** 20.8).

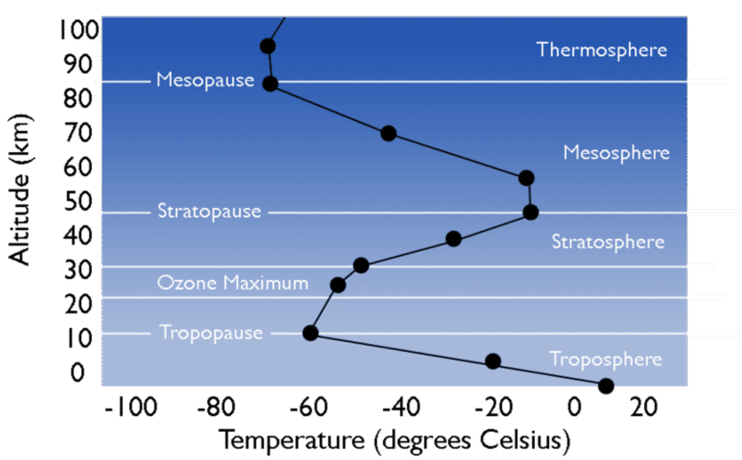


FIGURE 20.7
The four main layers of the atmosphere have different temperature gradients, creating the thermal structure of the atmosphere.

Most of the important processes of the atmosphere take place in the lowest two layers: the troposphere and the stratosphere.

FIGURE 20.8
The layers of the atmosphere appear as different colors in this image from the International Space Station.

Troposphere

The temperature of the **troposphere** is highest near the surface of the Earth and decreases with altitude. On average, the temperature gradient of the troposphere is 6.5°C per 1,000 m (3.6°F per 1,000 ft.) of altitude. What is the source of heat for the troposphere?

Earth's surface is a major source of heat for the troposphere, although nearly all of that heat comes from the Sun. Rock, soil, and water on Earth absorb the Sun's light and radiate it back into the atmosphere as heat. The temperature is also higher near the surface because of the greater density of gases. The higher gravity causes the temperature to rise.

Notice that in the troposphere warmer air is beneath cooler air. What do you think the consequence of this is? This condition is unstable. The warm air near the surface rises and cool air higher in the troposphere sinks. So air in the troposphere does a lot of mixing. This mixing causes the temperature gradient to vary with time and place. The rising and sinking of air in the troposphere means that all of the planet's weather takes place in the troposphere.

Sometimes there is a temperature **inversion**, air temperature in the troposphere increases with altitude and warm air sits over cold air. Inversions are very stable and may last for several days or even weeks. Inversions form:

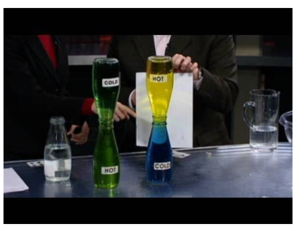
- Over land at night or in winter when the ground is cold. The cold ground cools the air that sits above it, making this low layer of air denser than the air above it.
- Near the coast where cold seawater cools the air above it. When that denser air moves inland, it slides beneath the warmer air over the land.

Since temperature inversions are stable, they often trap pollutants and produce unhealthy air conditions in cities (**Figure** 20.9).

At the top of the troposphere is a thin layer in which the temperature does not change with height. This means that the cooler, denser air of the troposphere is trapped beneath the warmer, less dense air of the stratosphere. Air from the troposphere and stratosphere rarely mix.

A science experiment that clearly shows how a temperature inversion traps air, along with whatever pollutants are in it, near the ground is seen in this video (**5c**): http://www.youtube.com/watch?v=LPvn9qhVFbM (2:50).

FIGURE 20.9
Smoke makes a temperature inversion visible. The smoke is trapped in cold dense air that lies beneath a cap of warmer air.



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Stratosphere

Ash and gas from a large volcanic eruption may burst into the **stratosphere**, the layer above the troposphere. Once in the stratosphere, it remains suspended there for many years because there is so little mixing between the two layers. Pilots like to fly in the lower portions of the stratosphere because there is little air turbulence.

In the stratosphere, temperature increases with altitude. What is the heat source for the stratosphere? The direct heat source for the stratosphere is the Sun. Air in the stratosphere is stable because warmer, less dense air sits over cooler, denser air. As a result, there is little mixing of air within the layer.

The **ozone layer** is found within the stratosphere between 15 to 30 km (9 to 19 miles) altitude. The thickness of the ozone layer varies by the season and also by latitude.

The ozone layer is extremely important because ozone gas in the stratosphere absorbs most of the Sun's harmful ultraviolet (UV) radiation. Because of this, the ozone layer protects life on Earth. High-energy UV light penetrates cells and damages DNA, leading to cell death (which we know as a bad sunburn). Organisms on Earth are not adapted to heavy UV exposure, which kills or damages them. Without the ozone layer to reflect UVC and UVB radiation, most complex life on Earth would not survive long (**Figure** 20.10).

Mesosphere

Temperatures in the **mesosphere** decrease with altitude. Because there are few gas molecules in the mesosphere to absorb the Sun's radiation, the heat source is the stratosphere below. The mesosphere is extremely cold, especially

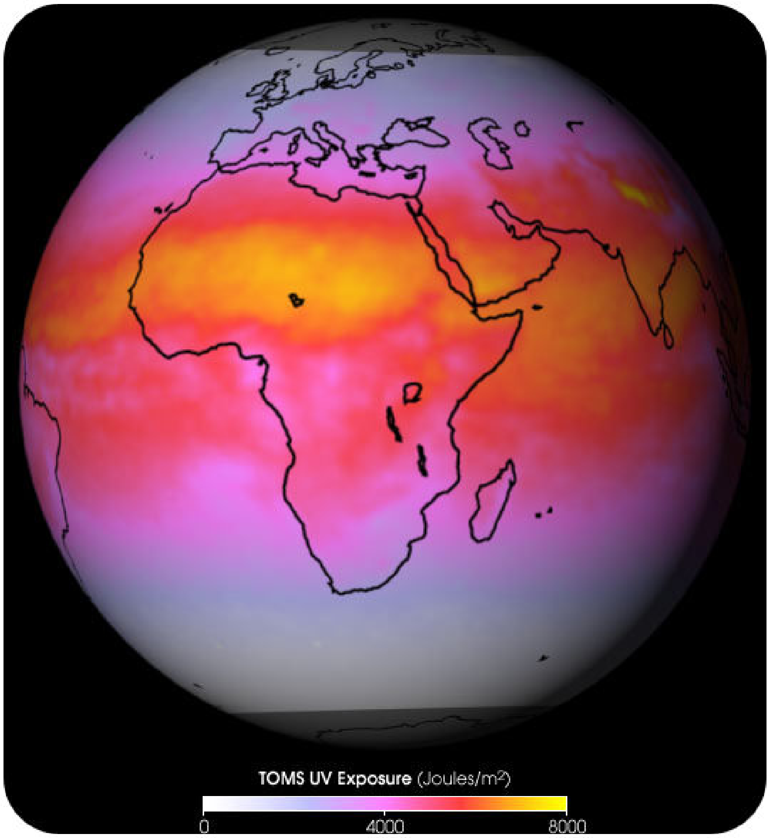


FIGURE 20.10
Even with the ozone layer, UVB radiation still manages to reach Earth's surface, especially where solar radiation is high.

at its top, about -90°C (-130°F).

The air in the mesosphere has extremely low density: 99.9% of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low (**Figure** 20.11). A person traveling through the mesosphere would experience severe burns from ultraviolet light since the ozone layer which provides UV protection is in the stratosphere below. There would be almost no oxygen for breathing. Stranger yet, an unprotected traveler's blood would boil at normal body temperature because the pressure is so low.

Thermosphere and Beyond

The density of molecules is so low in the **thermosphere** that one gas molecule can go about 1 km before it collides with another molecule. Since so little energy is transferred, the air feels very cold (**Figure** 20.12).

Within the thermosphere is the **ionosphere**. The ionosphere gets its name from the solar radiation that ionizes gas molecules to create a positively charged ion and one or more negatively charged electrons. The freed electrons travel within the ionosphere as electric currents. Because of the free ions, the ionosphere has many interesting characteristics.

At night, radio waves bounce off the ionosphere and back to Earth. This is why you can often pick up an AM radio station far from its source at night.

The Van Allen radiation belts are two doughnut-shaped zones of highly charged particles that are located beyond the atmosphere in the **magnetosphere**. The particles originate in solar flares and fly to Earth on the solar wind. Once trapped by Earth's magnetic field, they follow along the field's magnetic lines of force. These lines extend from

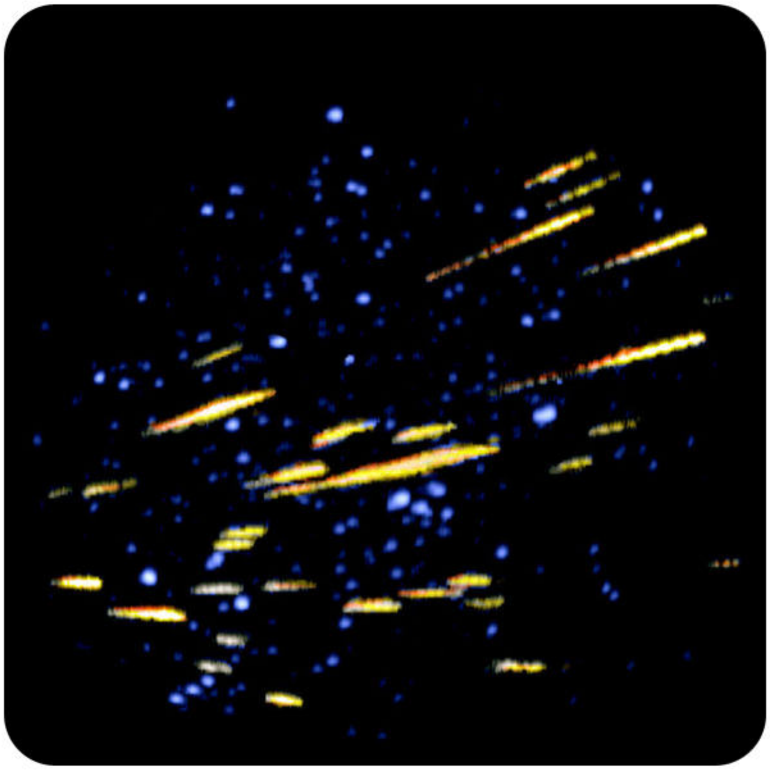


FIGURE 20.11
Meteors burn in the mesosphere even though the gas is very thin; these burning meteors are shooting stars.

FIGURE 20.12
The International Space Station (ISS) orbits within the upper part of the thermosphere, at about 320 to 380 km above the Earth.

above the equator to the North Pole and also to the South Pole then return to the equator.

When massive solar storms cause the Van Allen belts to become overloaded with particles, the result is the most spectacular feature of the ionosphere – the nighttime **aurora** (**Figure** 20.13). The particles spiral along magnetic field lines toward the poles. The charged particles energize oxygen and nitrogen gas molecules, causing them to light up. Each gas emits a particular color of light.

There is no real outer limit to the **exosphere**, the outermost layer of the atmosphere; the gas molecules finally become so scarce that at some point there are no more. Beyond the atmosphere is the solar wind. The **solar wind** is made of

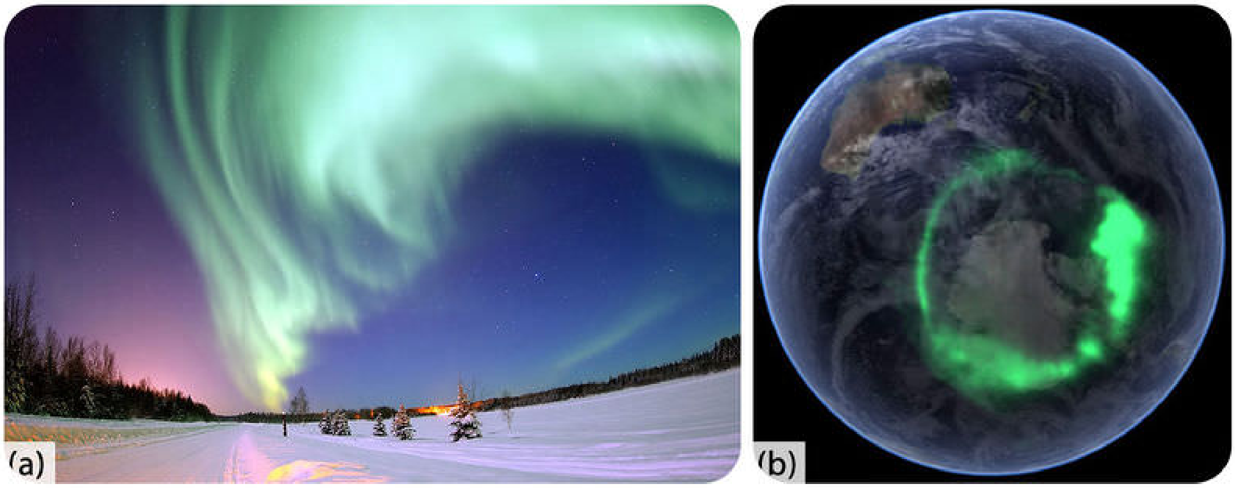
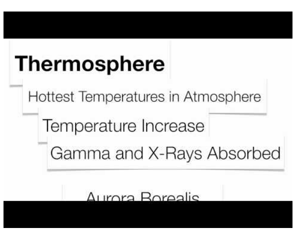


FIGURE 20.13

(a) Spectacular light displays are visible as the aurora borealis or northern lights in the Northern Hemisphere. (b) The aurora australis or southern lights encircles Antarctica.

high-speed particles, mostly protons and electrons, traveling rapidly outward from the Sun.

This video is very thorough in its discussion of the layers of the atmosphere. Remember that the chemical composition of each layer is nearly the same except for the ozone layer that is found in the stratosphere **(8a)**: http://www.youtube.com/watch?v=S-YAKZoy1A0 (6:44).



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KQED: Illuminating the Northern Lights

What would Earth's magnetic field look like if it were painted in colors? It would look like the aurora! This QUEST video looks at the aurora, which provides clues about the solar wind, Earth's magnetic field and Earth's atmosphere. Learn more in the video below:

MEDIA

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Lesson Summary

- Features of the atmosphere change with altitude: density decreases, air pressure decreases, temperature changes vary.
- Different temperature gradients create different layers within the atmosphere.
- The lowest layer is the troposphere where most of the atmospheric gases and all of the planet's weather are located. The troposphere is heated from the ground, so temperature decreases with altitude. Because warm air rises and cool air sinks, the troposphere is unstable.
- In the stratosphere, temperature increases with altitude. The stratosphere contains the ozone layer, which protects the planet from the Sun's harmful UV radiation.

Review Questions

1. Give a detailed explanation of why warm air rises.

2. Why doesn't air temperature change uniformly with altitude? Give examples.

3. Describe how the ground acts as the heat source for the troposphere. What is the source of energy and what happens to that energy?

4. How stable is an inversion and why? How does an inversion form?

5. Phoenix, Arizona, is a city in the Southwestern desert. Summers are extremely hot. Winter days are often fairly warm but winter nights can be quite chilly. In December, inversions are quite common. How does an inversion form under these conditions and what are the consequences of an inversion to this sprawling, car-dependent city?

6. Why can't air from the troposphere and the stratosphere mix freely?

7. What is the heat source for the stratosphere? How is that heat absorbed?

8. Describe ozone creation and loss in the ozone layer. Does one occur more than the other?

9. How and where are "shooting stars" created?

10. Why would an unprotected traveler's blood boil in the mesosphere?

Further Reading / Supplemental Links

NASA, The Mystery of the Aurora: http://www.youtube.com/watch?v=PaSFAbATPvk .

Points to Consider

- How does solar energy create the atmosphere's layers?
- How does solar energy create the weather?
- What would happen to life on Earth if there was less ozone in the ozone layer?

20.3 Energy in the Atmosphere

Lesson Objectives

- Describe how energy is transmitted.
- Describe the Earth's heat budget and what happens to the Sun's energy.
- Discuss the importance of convection in the atmosphere.
- Describe how a planet's heat budget can be balanced.
- Describe the greenhouse effect and why it is so important for life on Earth.

Vocabulary

- albedo
- electromagnetic waves
- greenhouse effect
- insolation
- insulation
- latent heat
- reflection
- specific heat
- temperature

Introduction

Wind, precipitation, warming, and cooling depend on how much energy is in the atmosphere and where that energy is located. Much more energy from the Sun reaches low latitudes (nearer the equator) than high latitudes (nearer the poles). These differences in **insolation** — the amount of solar radiation that reaches a given area in a given time – cause the winds, affect climate, and drive ocean currents. Heat is held in the atmosphere by greenhouse gases.

Energy, Temperature, and Heat

Energy

Energy travels through space or material. This is obvious when you stand near a fire and feel its warmth or when you pick up the handle of a metal pot even though the handle is not sitting directly on the hot stove. Invisible energy waves can travel through air, glass, and even the vacuum of outer space. These waves have electrical and magnetic properties, so they are called **electromagnetic waves**. The transfer of energy from one object to another through electromagnetic waves is known as radiation.

Different wavelengths of energy create different types of electromagnetic waves (**Figure** 20.14).

- The wavelengths humans can see are known as "visible light." These wavelengths appear to us as the colors of the rainbow. What objects can you think of that radiate visible light? Two include the Sun and a light bulb.
- The longest wavelengths of visible light appear red. Infrared wavelengths are longer than visible red. Snakes can see infrared energy. We feel infrared energy as heat.
- Wavelengths that are shorter than violet are called ultraviolet.

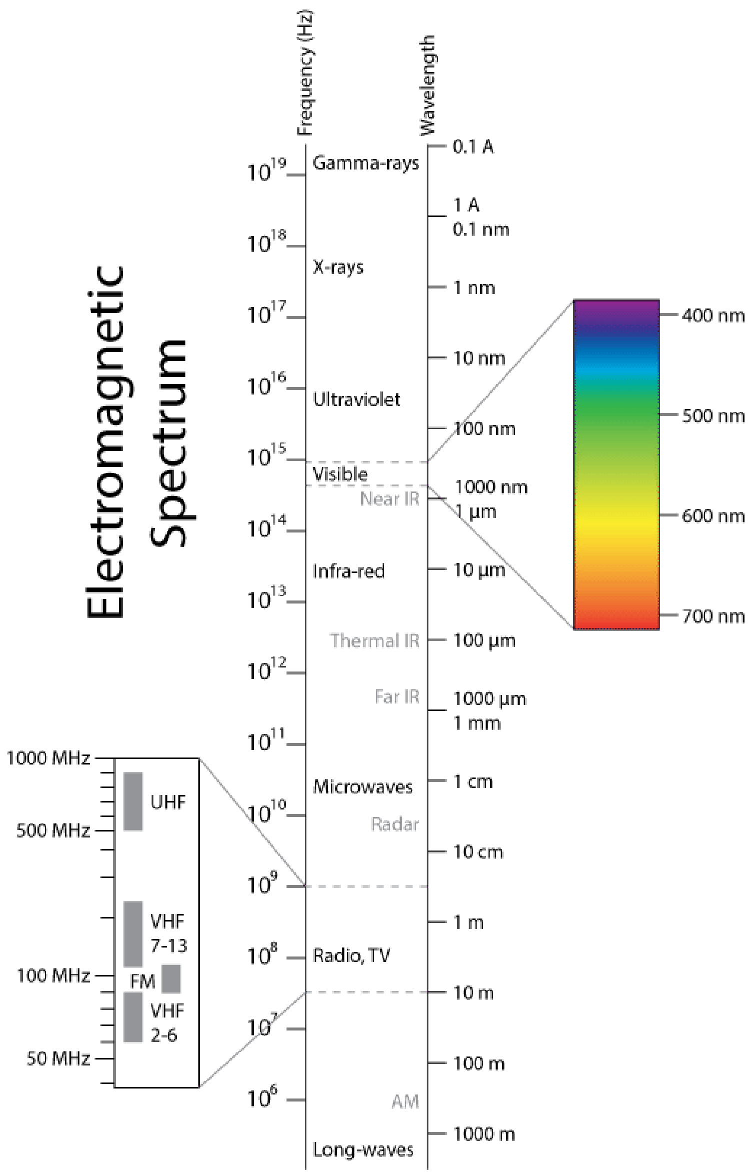


FIGURE 20.14
The electromagnetic spectrum; short wavelengths are the fastest with the highest energy.

Can you think of some objects that appear to radiate visible light, but actually do not? The moon and the planets do not emit light of their own; they reflect the light of the Sun. **Reflection** is when light (or another wave) bounces back from a surface. **Albedo** is a measure of how well a surface reflects light. A surface with high albedo reflects a large percentage of light. A snow field has high albedo.

One important fact to remember is that energy cannot be created or destroyed – it can only be changed from one form to another. This is such a fundamental fact of nature that it is a law: the law of conservation of energy.

In photosynthesis, for example, plants convert solar energy into chemical energy that they can use. They do not create new energy. When energy is transformed, some nearly always becomes heat. Heat transfers between materials easily, from warmer objects to cooler ones. If no more heat is added, eventually all of a material will reach the same temperature.

Temperature

Temperature is a measure of how fast the atoms in a material are vibrating. High temperature particles vibrate faster than low temperature particles. Rapidly vibrating atoms smash together, which generates heat. As a material cools down, the atoms vibrate more slowly and collide less frequently. As a result, they emit less heat. What is the difference between heat and temperature?

- Temperature measures how fast a material's atoms are vibrating.
- Heat measures the material's total energy.

Which has higher heat and which has higher temperature: a candle flame or a bathtub full of hot water?

- The flame has higher temperature, but less heat, because the hot region is very small.
- The bathtub has lower temperature but contains much more heat because it has many more vibrating atoms. The bathtub has greater total energy.

Heat

Heat is taken in or released when an object changes state, or changes from a gas to a liquid, or a liquid to a solid. This heat is called **latent heat**. When a substance changes state, latent heat is released or absorbed. A substance that is changing its state of matter does not change temperature. All of the energy that is released or absorbed goes toward changing the material's state.

For example, imagine a pot of boiling water on a stove burner: that water is at 100°C (212°F). If you increase the temperature of the burner, more heat enters the water. The water remains at its boiling temperature, but the additional energy goes into changing the water from liquid to gas. With more heat the water evaporates more rapidly. When water changes from a liquid to a gas it takes in heat. Since evaporation takes in heat, this is called evaporative cooling. Evaporative cooling is an inexpensive way to cool homes in hot, dry areas.

Substances also differ in their **specific heat**, the amount of energy needed to raise the temperature of one gram of the material by 1.0°C (1.8°F). Water has a very high specific heat, which means it takes a lot of energy to change the temperature of water. Let's compare a puddle and asphalt, for example. If you are walking barefoot on a sunny day, which would you rather walk across, the shallow puddle or an asphalt parking lot? Because of its high specific heat, the water stays cooler than the asphalt, even though it receives the same amount of solar radiation.

Energy From the Sun

Most of the energy that reaches the Earth's surface comes from the Sun (**Figure** 20.15). About 44% of solar radiation is in the visible light wavelengths, but the Sun also emits infrared, ultraviolet, and other wavelengths.

When viewed together, all of the wavelengths of visible light appear white. But a prism or water droplets can break the white light into different wavelengths so that separate colors appear (**Figure** 20.16).

Of the solar energy that reaches the outer atmosphere, UV wavelengths have the greatest energy. Only about 7% of solar radiation is in the UV wavelengths. The three types are:

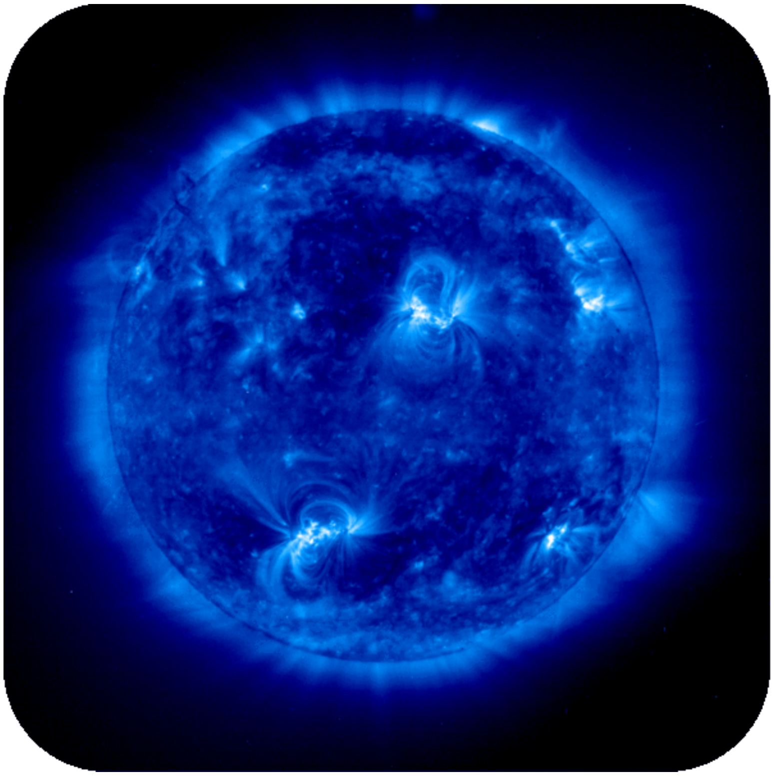


FIGURE 20.15
An image of the sun taken by the SOHO spacecraft. The sensor is picking up only the 17.1 nm wavelength, in the ultraviolet wavelengths.

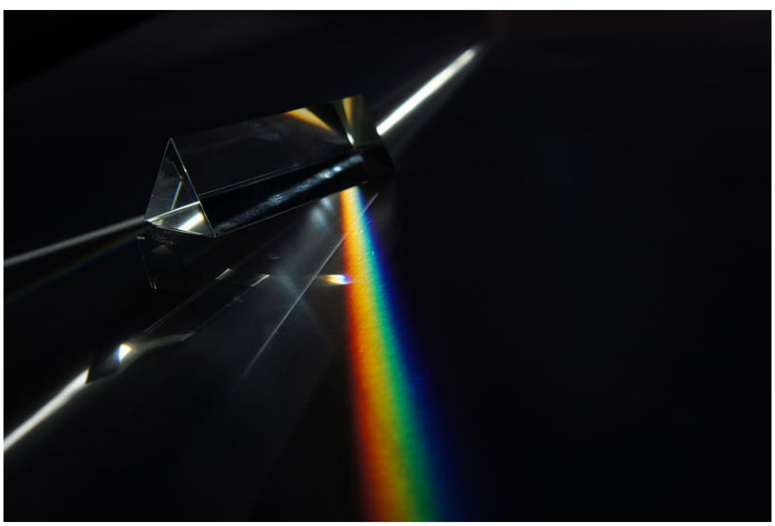


FIGURE 20.16
A prism breaks apart white light.

- UVC: the highest energy ultraviolet, does not reach the planet's surface at all.
- UVB: the second highest energy, is also mostly stopped in the atmosphere.
- UVA: the lowest energy, travels through the atmosphere to the ground.

The remaining solar radiation is the longest wavelength, infrared. Most objects radiate infrared energy, which we feel as heat (**Figure** 20.17).

Some of the wavelengths of solar radiation traveling through the atmosphere may be lost because they are absorbed by various gases (**Figure** 20.18). Ozone completely removes UVC, most UVB, and some UVA from incoming

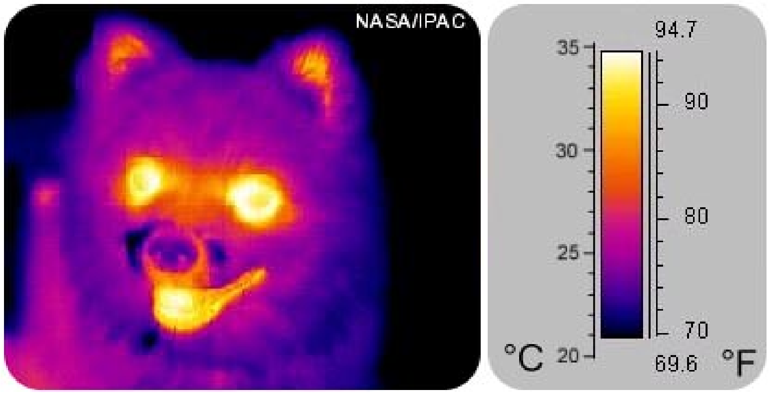


FIGURE 20.17
An infrared sensor detects different amounts of heat radiating from a dog.

sunlight. O_2, CO_2 and H_2O also filter out some wavelengths.

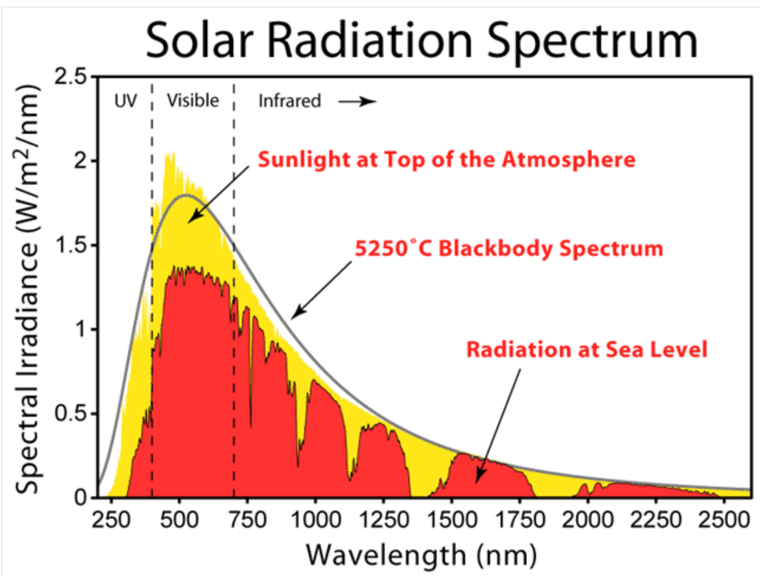


FIGURE 20.18
Atmospheric gases filter some wavelengths of incoming solar energy. Yellow shows the energy that reaches the top of the atmosphere. Red shows the wavelengths that reach sea level. Ozone filters out the shortest wavelength UV and oxygen filters out most infrared.

Solar Radiation on Earth

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most insolation? The Sun's rays strike the surface most directly at the equator.

Different areas also receive different amounts of sunlight in different seasons. What causes the seasons? The seasons are caused by the direction Earth's axis is pointing relative to the Sun.

The Earth revolves around the Sun once each year and spins on its axis of rotation once each day. This axis of rotation is tilted 23.5° relative to its plane of orbit around the Sun. The axis of rotation is pointed toward Polaris, the North Star. As the Earth orbits the Sun, the tilt of Earth's axis stays lined up with the North Star.

Northern Hemisphere Summer

The North Pole is tilted towards the Sun and the Sun's rays strike the Northern Hemisphere more directly in summer (**Figure** 20.19). At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5°N); that is, the angle of incidence of the sun's rays there is zero (the angle of incidence is the deviation in the angle of an incoming ray from straight on). When it is summer solstice in the Northern Hemisphere, it is winter solstice in the Southern Hemisphere.

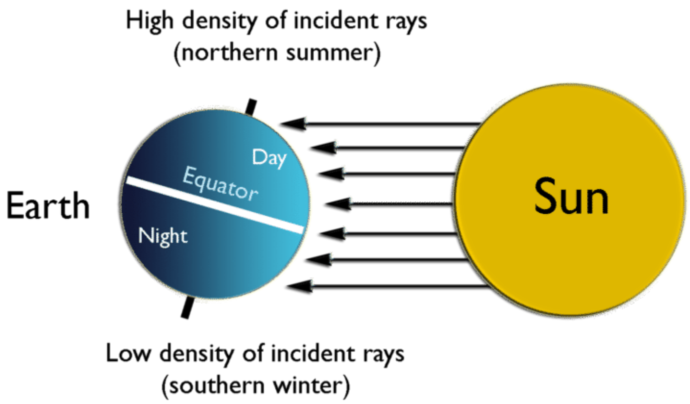


FIGURE 20.19
Summer solstice in the Northern Hemisphere.

Northern Hemisphere Winter

Winter solstice for the Northern Hemisphere happens on December 21 or 22. The tilt of Earth's axis points away from the Sun (**Figure** 20.20). Light from the Sun is spread out over a larger area, so that area isn't heated as much. With fewer daylight hours in winter, there is also less time for the Sun to warm the area. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.

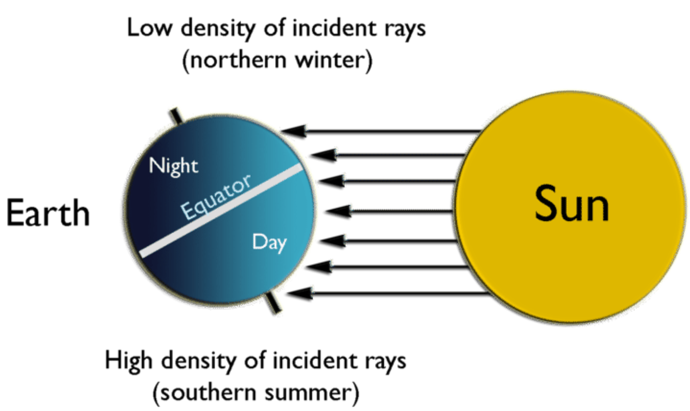


FIGURE 20.20
In Southern Hemisphere summer, the Sun's rays directly strike the Tropic of Capricorn (23.5°S). Sunlight is spread across a large area near the South Pole. No sunlight reaches the North Pole.

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the equator, called an "equinox" (**Figure** 20.21). The daylight and nighttime hours are exactly equal on an equinox. The autumnal equinox happens on September 22 or 23 and the vernal or spring equinox happens March 21 or 22 in the Northern Hemisphere.

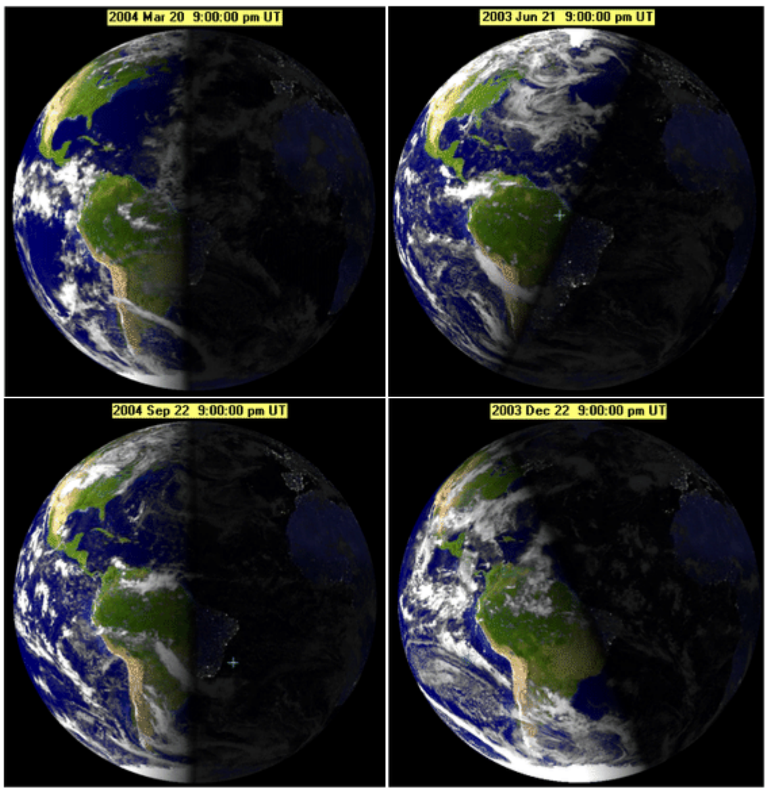


FIGURE 20.21
Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 p.m. Universal Time, at Greenwich, England.

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth (Plate Tectonics chapter) or another medium. What follows is a review of the way heat flows, but applied to the atmosphere.

Radiation is the transfer of energy between two objects by electromagnetic waves. Heat radiates from the ground into the lower atmosphere.

In conduction, heat moves from areas of more heat to areas of less heat by direct contact. Warmer molecules vibrate rapidly and collide with other nearby molecules, transferring their energy. In the atmosphere, conduction is more effective at lower altitudes where air density is higher; transfers heat upward to where the molecules are spread further apart or transfers heat laterally from a warmer to a cooler spot, where the molecules are moving less vigorously.

Heat transfer by movement of heated materials is called convection. Heat that radiates from the ground initiates convection cells in the atmosphere (**Figure** 20.22).

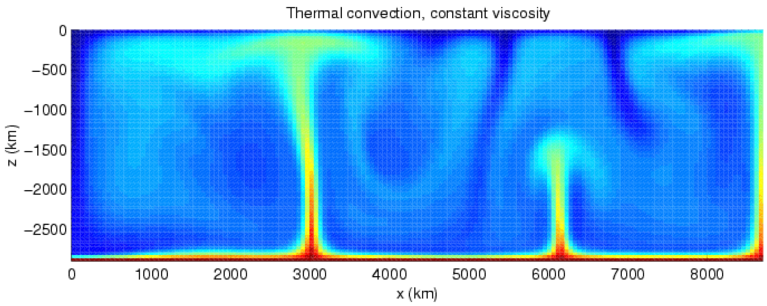


FIGURE 20.22

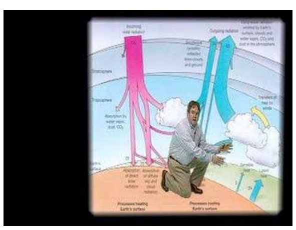
Thermal convection where the heat source is at the bottom and there is a ceiling at the top.

Heat at Earth's Surface

About half of the solar radiation that strikes the top of the atmosphere is filtered out before it reaches the ground. This energy can be absorbed by atmospheric gases, reflected by clouds, or scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction.

About 3% of the energy that strikes the ground is reflected back into the atmosphere. The rest is absorbed by rocks, soil, and water and then radiated back into the air as heat. These infrared wavelengths can only be seen by infrared sensors.

The basics of Earth's annual heat budget are described in this video **(4b)**: http://www.youtube.com/watch?v=mjj2i3hNQF0 (5:40).



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Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no (although the next section contains an exception) because energy from Earth escapes into space through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then average global temperature stays the same. This means that the planet's heat budget is in balance. What happens if more energy comes in than goes out? If more energy goes out than comes in?

To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes (**Figure** 20.23). Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why? See **Table** 20.1

TABLE 20.1: The Amount of Incoming Solar Energy

	Day Length	Sun Angle	Solar Radiation	Albedo
Equatorial Region	Nearly the same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

Note: Colder temperatures mean more ice and snow cover the ground, making albedo relatively high.

The difference in solar energy received at different latitudes drives atmospheric circulation.

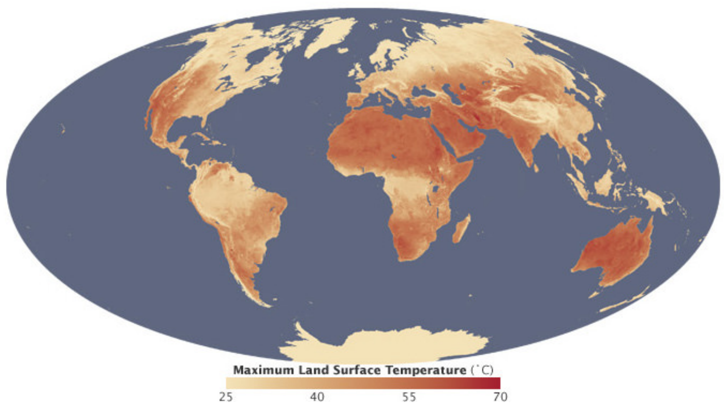


FIGURE 20.23
The maximum land surface temperature of the Earth, showing a roughly gradual temperature gradient from the low to the high latitudes.

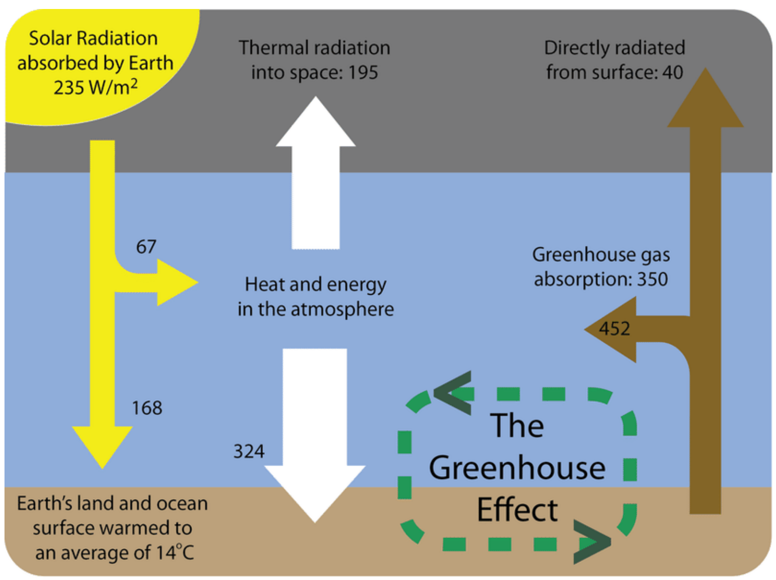


FIGURE 20.24
The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location.

Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. **Table** 20.2 shows how each greenhouse gas naturally enters the atmosphere.

TABLE 20.2: Greenhouse Gas Entering the Atmosphere

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

Different greenhouse gases have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere.

Human activity has significantly raised the levels of many of greenhouse gases in the atmosphere. Methane levels are about 2 1/2 times higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have

Review Questions

1. What is the difference between temperature and heat?

2. Give a complete description of these three categories of energy relative to each other in terms of their wavelengths and energy: infrared, visible light, and ultraviolet.

3. Why do the polar regions have high albedo?

4. Give an example of the saying "energy can't be created or destroyed."

5. Describe what happens to the temperature of a pot of water and to the state of the water as the dial on the stove is changed from no heat to the highest heat.

6. Describe where the Sun is relative to the Earth on summer solstice, autumnal equinox, winter solstice and spring equinox. How much sunlight does the North Pole get on June 21? How much does the South Pole get on that same day?

7. What is the difference between conduction and convection?

8. What is a planet's heat budget? Is Earth's heat budget balanced or not?

9. On a map of average annual temperature, why are the lower latitudes so much warmer than the higher latitudes?

10. Why is carbon dioxide the most important greenhouse gas?

11. How does the amount of greenhouse gases in the atmosphere affect the atmosphere's temperature?

Points to Consider

- How does the difference in solar radiation that reaches the lower and upper latitudes explain the way the atmosphere circulates?
- How does the atmosphere protect life on Earth from harmful radiation and from extreme temperatures?
- What would the consequences be if the Earth's overall heat budget were not balanced?

20.4 Air Movement

Lesson Objectives

- List the properties of the air currents within a convection cell.
- Describe how high and low pressure cells create local winds and explain how several types of local winds form.
- Discuss how global convection cells lead to the global wind belts.

Vocabulary

- advection
- Chinook winds (Foehn winds)
- haboob
- high pressure zone
- jet stream
- katabatic winds
- land breeze
- low pressure zone
- monsoon
- mountain breeze
- polar front
- rainshadow effect
- Santa Ana winds
- sea breeze
- valley breeze

Introduction

A few basic principles go a long way toward explaining how and why air moves: Warm air rising creates a **low pressure zone** at the ground. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at top of the troposphere; horizontal flow is called **advection**. The air cools until it descends. Where it reaches the ground, it creates a **high pressure zone**. Air flowing from areas of high pressure to low pressure creates winds. Warm air can hold more moisture than cold air. Air moving at the bases of the three major convection cells in each hemisphere north and south of the equator creates the global wind belts.

Air Pressure and Winds

Within the troposphere are convection cells (**Figure** 20.25).

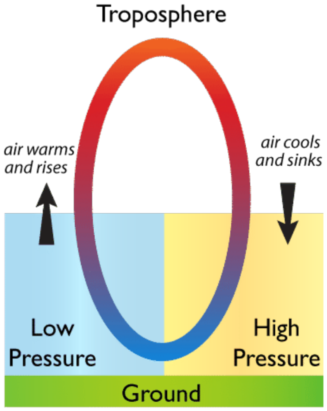


FIGURE 20.25
Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

Air that moves horizontally between high and low pressure zones makes wind. The greater the pressure difference between the pressure zones the faster the wind moves.

Convection in the atmosphere creates the planet's weather. When warm air rises and cools in a low pressure zone, it may not be able to hold all the water it contains as vapor. Some water vapor may condense to form clouds or precipitation. When cool air descends, it warms. Since it can then hold more moisture, the descending air will evaporate water on the ground.

Air moving between large high and low pressure systems creates the global wind belts that profoundly affect regional climate. Smaller pressure systems create localized winds that affect the weather and climate of a local area.

An online guide to air pressure and winds from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fw/home.rxml .

Local Winds

Local winds result from air moving between small low and high pressure systems. High and low pressure cells are created by a variety of conditions. Some local winds have very important effects on the weather and climate of some regions.

Land and Sea Breezes

Since water has a very high specific heat, it maintains its temperature well. So water heats and cools more slowly than land. If there is a large temperature difference between the surface of the sea (or a large lake) and the land next to it, high and low pressure regions form. This creates local winds.

- **Sea breezes** blow from the cooler ocean over the warmer land in summer (**Figure** 20.26). Where is the high pressure zone and where is the low pressure zone? Sea breezes blow at about 10 to 20 km (6 to 12 miles) per hour and lower air temperature much as 5 to 10°C (9 to 18°F).
- **Land breezes** blow from the land to the sea in winter. Where is the high pressure zone and where is the low pressure zone? Some warmer air from the ocean rises and then sinks on land, causing the temperature over the land to become warmer.

Land and sea breezes create the pleasant climate for which Southern California is known. The effect of land and sea breezes are felt only about 50 to 100 km (30 to 60 miles) inland. This same cooling and warming effect occurs to a smaller degree during day and night, because land warms and cools faster than the ocean.

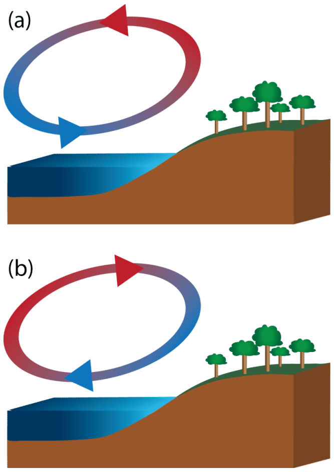


FIGURE 20.26
How do sea and land breezes moderate coastal climates?

Monsoon Winds

Monsoon winds are larger scale versions of land and sea breezes; they blow from the sea onto the land in summer and from the land onto the sea in winter. Monsoon winds are occur where very hot summer lands are next to the sea. Thunderstorms are common during monsoons (**Figure** 20.27).

FIGURE 20.27
In the southwestern United States relatively cool moist air sucked in from the Gulf of Mexico and the Gulf of California meets air that has been heated by scorching desert temperatures.

The most important monsoon in the world occurs each year over the Indian subcontinent. More than two billion residents of India and southeastern Asia depend on monsoon rains for their drinking and irrigation water. Back in the days of sailing ships, seasonal shifts in the monsoon winds carried goods back and forth between India and Africa.

Mountain and Valley Breezes

Temperature differences between mountains and valleys create mountain and valley breezes. During the day, air on mountain slopes is heated more than air at the same elevation over an adjacent valley. As the day progresses, warm air rises and draws the cool air up from the valley, creating a **valley breeze**. At night the mountain slopes cool more quickly than the nearby valley, which causes a **mountain breeze** to flow downhill.

Katabatic Winds

Katabatic winds move up and down slopes, but they are stronger mountain and valley breezes. Katabatic winds form over a high land area, like a high plateau. The plateau is usually surrounded on almost all sides by mountains. In winter, the plateau grows cold. The air above the plateau grows cold and sinks down from the plateau through gaps in the mountains. Wind speeds depend on the difference in air pressure over the plateau and over the surroundings. Katabatic winds form over many continental areas. Extremely cold katabatic winds blow over Antarctica and Greenland.

Chinook Winds (Foehn Winds)

Chinook winds (or **Foehn winds**) develop when air is forced up over a mountain range. This takes place, for example, when the westerly winds bring air from the Pacific Ocean over the Sierra Nevada Mountains in California. As the relatively warm, moist air rises over the windward side of the mountains, it cools and contracts. If the air is humid, it may form clouds and drop rain or snow. When the air sinks on the leeward side of the mountains, it forms a high pressure zone. The windward side of a mountain range is the side that receives the wind; the leeward side is the side where air sinks.

The descending air warms and creates strong, dry winds. Chinook winds can raise temperatures more than 20°C (36°F) in an hour and they rapidly decrease humidity. Snow on the leeward side of the mountain disappears melts quickly. If precipitation falls as the air rises over the mountains, the air will be dry as it sinks on the leeward size. This dry, sinking air causes a **rainshadow effect** (**Figure** 20.28), which creates many of the world's deserts.

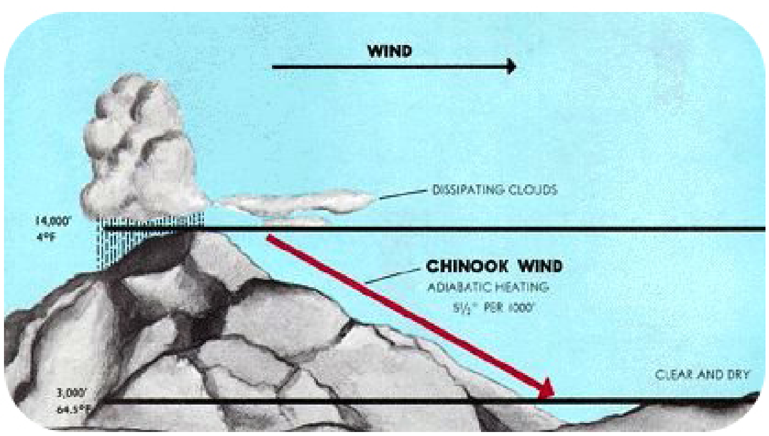


FIGURE 20.28
As air rises over a mountain it cools and loses moisture, then warms by compression on the leeward side. The resulting warm and dry winds are Chinook winds. The leeward side of the mountain experiences rainshadow effect.

Santa Ana Winds

Santa Ana winds are created in the late fall and winter when the Great Basin east of the Sierra Nevada cools, creating a high pressure zone. The high pressure forces winds downhill and in a clockwise direction (because of

Coriolis). The air pressure rises, so temperature rises and humidity falls. The winds blow across the Southwestern deserts and then race downhill and westward toward the ocean. Air is forced through canyons cutting the San Gabriel and San Bernardino mountains (**Figure** 20.29).

FIGURE 20.29
The winds are especially fast through Santa Ana Canyon, for which they are named. Santa Ana winds blow dust and smoke westward over the Pacific from Southern California.

The Santa Ana winds often arrive at the end of California's long summer drought season. The hot, dry winds dry out the landscape even more. If a fire starts, it can spread quickly, causing large-scale devastation (**Figure** 20.30).

FIGURE 20.30
In October 2007, Santa Ana winds fueled many fires that together burned 426,000 acres of wild land and more than 1,500 homes in Southern California.

Desert Winds

High summer temperatures on the desert create high winds, which are often associated with monsoon storms. Desert winds pick up dust because there is not as much vegetation to hold down the dirt and sand. (**Figure** 20.31). A **haboob** forms in the downdrafts on the front of a thunderstorm.

Dust devils, also called whirlwinds, form as the ground becomes so hot that the air above it heats and rises. Air flows into the low pressure and begins to spin. Dust devils are small and short-lived but they may cause damage.

FIGURE 20.31
A haboob in the Phoenix metropolitan area, Arizona.

Atmospheric Circulation

Because more solar energy hits the equator, the air warms and forms a low pressure zone. At the top of the troposphere, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense and when it reaches a high pressure zone it sinks to the ground. The air is sucked back toward the low pressure at the equator. This describes the convection cells north and south of the equator.

If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the Coriolis Effect must be taken into account. Coriolis Effect was described in the Earth's Oceans chapter.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis Effect (**Figure** 20.32). Air rises at the equator, but as it moves toward the pole at the top of the troposphere, it deflects to the right. (Remember that it just appears to deflect to the right because the ground beneath it moves.) At about 30°N latitude, the air from the equator meets air flowing toward the equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend, creating a high pressure zone. Once on the ground, the air returns to the equator. This convection cell is called the Hadley Cell and is found between 0° and 30°N.

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30°N and 50° to 60°N. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50°N to 60°N and the North Pole, where cold air descends.

There are three mirror image circulation cells in the Southern Hemisphere. In that hemisphere, the Coriolis Effect makes objects appear to deflect to the left.

Global Wind Belts

Global winds blow in belts encircling the planet. The global wind belts are enormous and the winds are relatively steady (**Figure** 20.33). These winds are the result of air movement at the bottom of the major atmospheric circulation cells, where the air moves horizontally from high to low pressure.

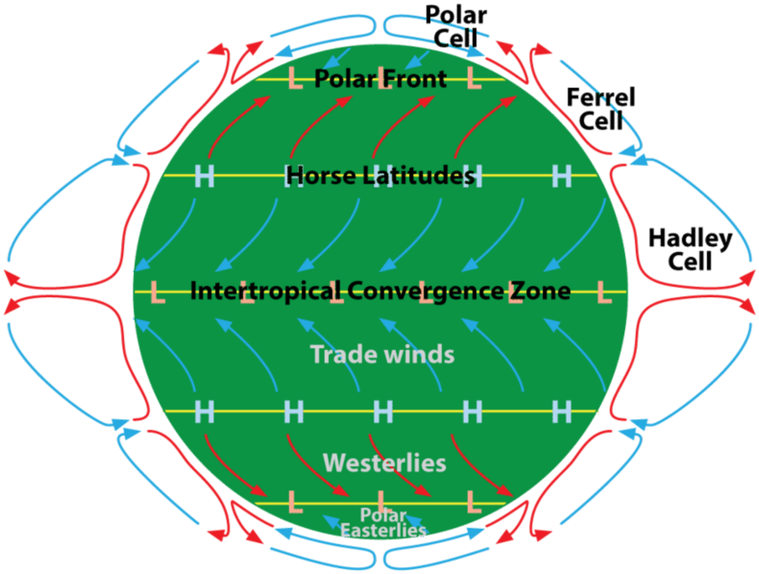


FIGURE 20.32
The atmospheric circulation cells, showing direction of winds at Earth's surface.

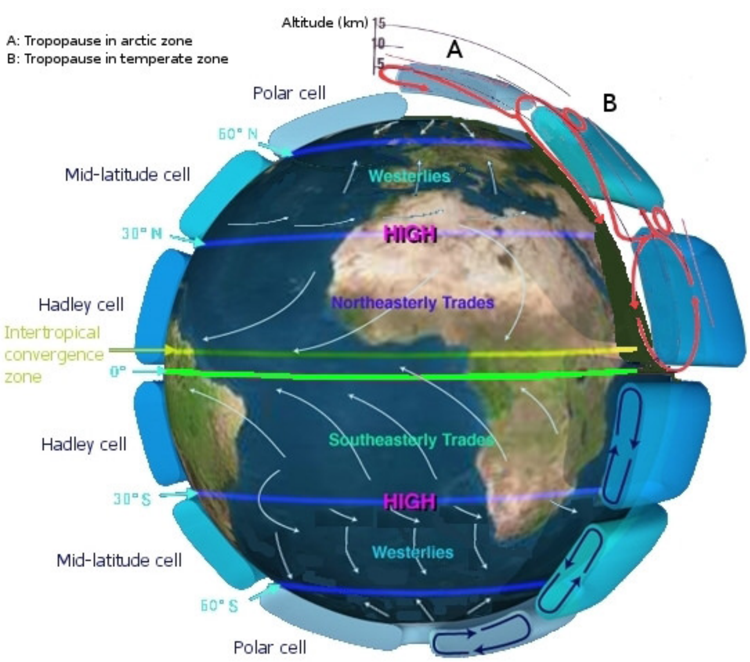


FIGURE 20.33
The major wind belts and the directions that they blow.

Global Wind Belts

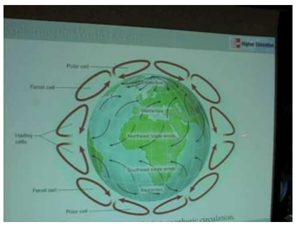
Let's look at the global wind belts in the Northern Hemisphere.

- In the Hadley cell air should move north to south, but it is deflected to the right by Coriolis. So the air blows from northeast to the southwest. This belt is the trade winds, so called because at the time of sailing ships they were good for trade.
- In the Ferrel cell air should move south to north, but the winds actually blow from the southwest. This belt is the westerly winds or westerlies. Why do you think a flight across the United States from San Francisco to

New York City takes less time than the reverse trip?
- In the Polar cell, the winds travel from the northeast and are called the polar easterlies

The wind belts are named for the directions from which the winds come. The westerly winds, for example, blow from west to east. These names hold for the winds in the wind belts of the Southern Hemisphere as well.

This video lecture discusses the 3-cell model of atmospheric circulation and the resulting global wind belts and surface wind currents **(5a)**: http://www.youtube.com/watch?v=HWFDKdxK75E (8:45).



MEDIA

Click image to the left or use the URL below.

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Global Winds and Precipitation

Besides their effect on the global wind belts, the high and low pressure areas created by the six atmospheric circulation cells determine in a general way the amount of precipitation a region receives. In low pressure regions, where air is rising, rain is common. In high pressure areas, the sinking air causes evaporation and the region is usually dry. More specific climate effects will be described in the chapter about climate.

Polar Fronts and Jet Streams

The **polar front** is the junction between the Ferrell and Polar cells. At this low pressure zone, relatively warm, moist air of the Ferrell Cell runs into relatively cold, dry air of the Polar cell. The weather where these two meet is extremely variable, typical of much of North America and Europe.

The polar **jet stream** is found high up in the atmosphere where the two cells come together. A jet stream is a fast-flowing river of air at the boundary between the troposphere and the stratosphere. Jet streams form where there is a large temperature difference between two air masses. This explains why the polar jet stream is the world's most powerful (**Figure** 20.34).

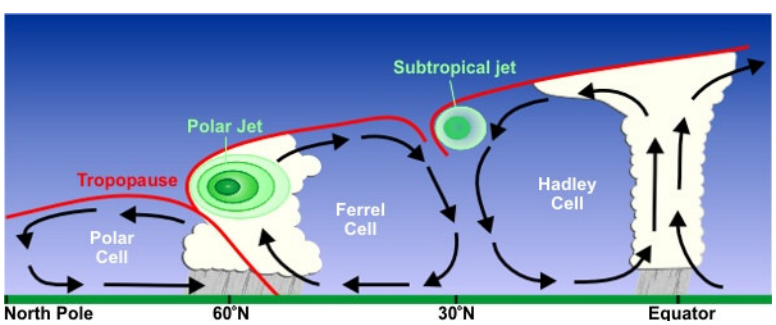

FIGURE 20.34

A cross section of the atmosphere with major circulation cells and jet streams. The polar jet stream is the site of extremely turbulent weather.

Jet streams move seasonally just as the angle of the Sun in the sky moves north and south. The polar jet stream, known as "the jet stream," moves south in the winter and north in the summer between about 30°N and 50° to 75°N.

Lesson Summary

- Winds blow from high pressure zones to low pressure zones. The pressure zones are created when air near the ground becomes warmer or colder than the air nearby.
- Local winds may be found in a mountain valley or near a coast.
- The global wind patterns are long-term, steady winds that prevail around a large portion of the planet.
- The location of the global wind belts has a great deal of influence on the weather and climate of an area.

Review Questions

1. Draw a picture of a convection cell in the atmosphere. Label the low and high pressure zones and where the wind is.

2. Under what circumstances will winds be very strong?

3. Given what you know about global-scale convection cells, where would you travel if you were interested in experiencing warm, plentiful rain?

4. Describe the atmospheric circulation for two places where you are likely to find deserts, and explain why these regions are relatively warm and dry.

5. How could the Indian monsoons be reduced in magnitude? What effect would a reduction in these important monsoons have on that part of the world?

6. Why is the name "snow eater" an apt description of Chinook winds?

7. Why does the Coriolis Effect cause air to appear to move clockwise in the Northern Hemisphere? When does Coriolis Effect cause air to appear to move counterclockwise?

8. Sailors once referred to a portion of the ocean as the doldrums. This is a region where there is frequently no wind, so ships would become becalmed for days or even weeks. Where do you think the doldrums might be relative to the atmospheric circulation cells?

9. Imagine that the jet stream is located further south than usual for the summer. What is the weather like in regions just north of the jet stream, as compared to a normal summer?

10. Give a general description of how winds form.

Further Reading / Supplemental Links

High and Low Pressure Systems animations, Bureau of Meteorology, Australian Government http://www.bom.gov.au/lam/Students_Teachers/pressure.shtml

Points to Consider

- How do local winds affect the weather in an area?
- How do the global wind belts affect the climate in an area?
- What are the main principles that control how the atmosphere circulates?

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Navy_071023-N-3927C-001_The_Harris_fire,_named_after_the_road_it_started_near,_burns_a_hillside_as_-it_moves_west_toward_San_Diego.jpg">https://commons.wikimedia.org/wiki/File:US_Navy_071023-N-3927C-001_The_Harris_fire,_named_after_the_road_it_started_near,_burns_a_hillside_as_it_moves_west_toward_-San_Diego.jpg. Public Domain
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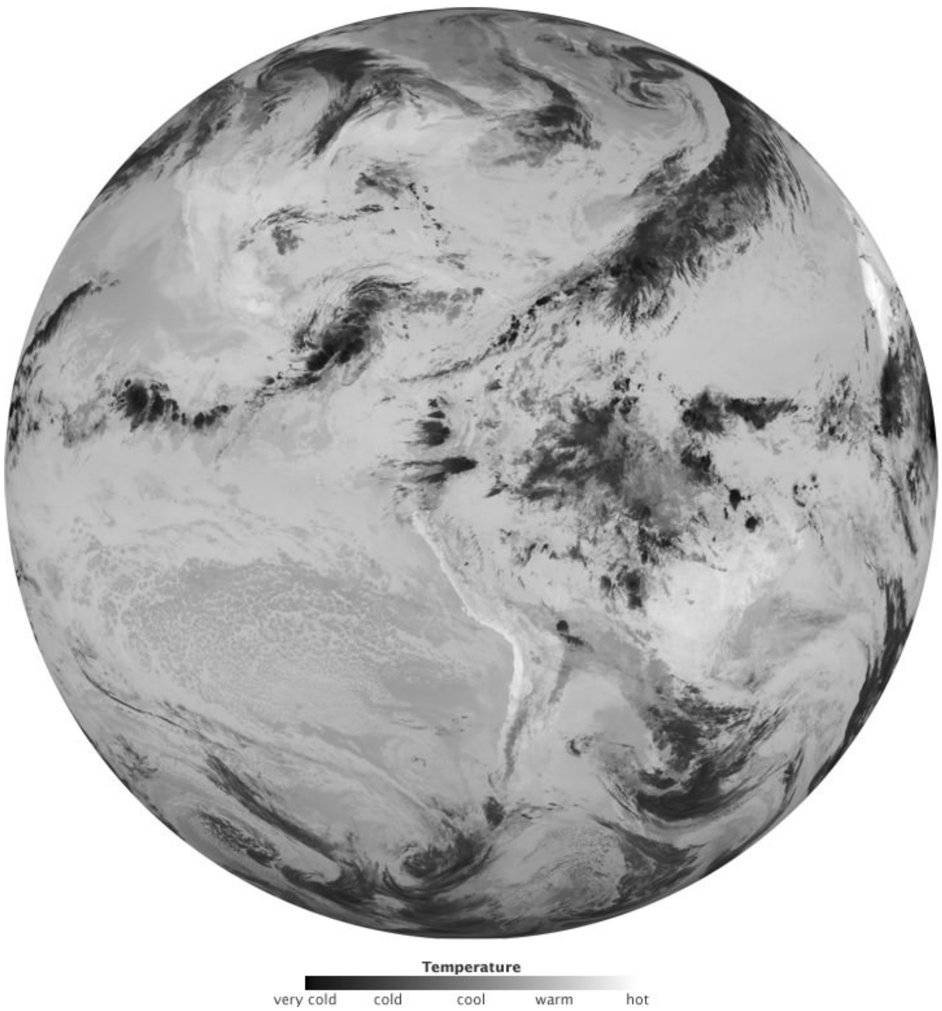
CHAPTER 21 Climate

Chapter Outline



Clouds trap solar energy, which helps to warm the atmosphere. A warmer atmosphere can hold more moisture and could build up even more clouds. These clouds would then trap more heat and. . . well, you get the idea. This is called a positive feedback mechanism. There are many positive feedback mechanisms in climate change. Another is albedo. As temperatures warm, snow and ice melt. This reduces albedo, which causes temperatures to warm and more snow and ice to melt.

Clouds also reflect energy and shade the land. This would help to reduce global temperatures. So scientists are not sure what the net effect of clouds on global temperatures is. Clouds are the second biggest uncertainty in climate models. The biggest is in how people's behavior will change, to change human impacts on the atmosphere.

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21.1 Climate and Its Causes

Lesson Objectives

- Describe the effect of latitude on climate.
- Diagram the Hadley, Ferrell, and Polar atmospheric circulation cells and show how they influence the climate of various locations.
- Discuss the other important location factors that influence a location's climate: position in the global wind belts, proximity to a large water body, position relative to a mountain range, and others.

Vocabulary

- continental climate
- Intertropical Convergence Zone (ITCZ)
- maritime climate

Introduction

Although almost anything can happen with the weather, climate is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's (**Figure** 21.1). Climate then is the long-term average of weather. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good!

FIGURE 21.1
Lake Tahoe's climate makes it easy to predict that there will be snow in the winter.

What is Climate?

Climate is the average of weather in that location over a long period of time, usually for at least 30 years. A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation. Climate can change, but only over long periods of time.

The climate of a region depends on its position relative to many things. These factors are described in the next sections.

Latitude

The main factor influencing the climate of a region is latitude because different latitudes receive different amounts of solar radiation. To review from the Earth's Atmosphere chapter:

- The equator receives the most solar radiation. Days are equally long year-round and the sun is just about directly overhead at midday.
- The polar regions receive the least solar radiation. The night lasts six months during the winter. Even in summer, the sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. The high albedo, because of ice and snow, reflects a good portion of the sun's light.

Atmospheric Circulation Cells

Recall from the Earth's Atmosphere chapter the circulation cells and global wind belts (**Figure** 21.2):

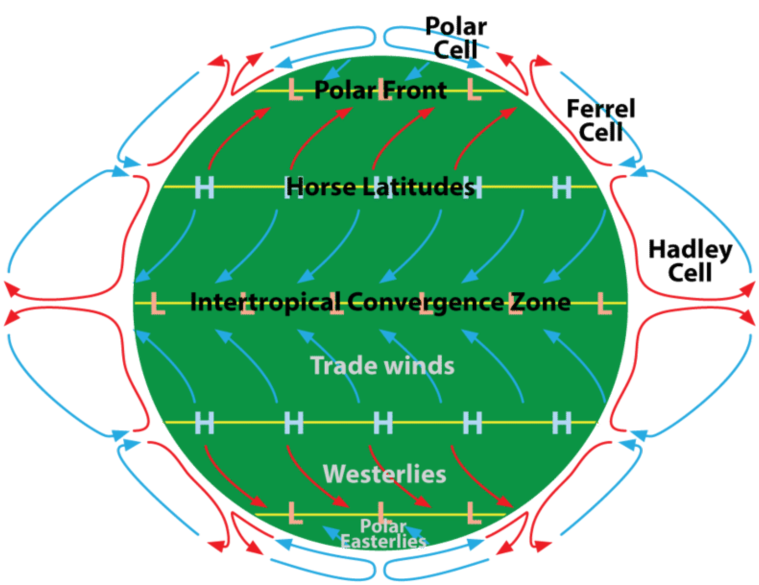

FIGURE 21.2
The atmospheric circulation cells and their relationships to air movement on the ground.

The position of a region relative to the circulation cells and wind belts has a great effect on its climate. In an area where the air is mostly rising or sinking, there is not much wind.

The ITCZ

The **Intertropical Convergence Zone (ITCZ)** is the low pressure area near the equator in the boundary between the two Hadley Cells. The air rises so that it cools and condenses to create clouds and rain (**Figure** 21.3). Climate along the ITCZ is therefore warm and wet. Early mariners called this region the doldrums because their ships were often unable to sail because there were no steady winds.

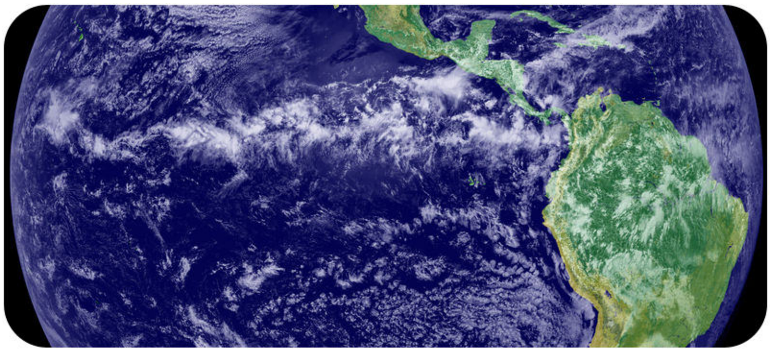

FIGURE 21.3
The ITCZ can easily be seen where thunderstorms are lined up north of the equator.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Because there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5° north of the equator while in the winter it shifts back and is approximately at the equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area (**Figure** 21.4).

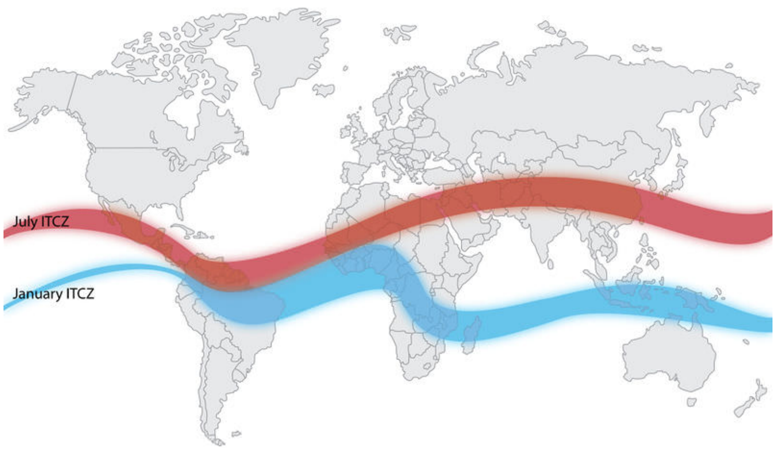

FIGURE 21.4
Seasonal differences in the location of the ITCZ are shown on this map.

Hadley Cell and Ferrell Cell Boundary

At about 30°N and 30°S, the air is fairly warm and dry because much of it came from the equator where it lost most of its moisture at the ITCZ. At this location the air is descending, and sinking air warms and causes evaporation

Mariners named this region the horse latitudes. Sailing ships were sometimes delayed for so long by the lack of wind that they would run out of water and food for their livestock. Sailors tossed horses and other animals over the side after they died. Sailors sometimes didn't make it either.

Ferrell Cell and Polar Cell Boundary

The polar front is around 50° to 60°, where cold air from the poles meets warmer air from the tropics. The meeting of the two different air masses causes the polar jet stream, which is known for its stormy weather. As the Earth orbits the Sun, the shift in the angle of incoming sunlight causes the polar jet stream to move. Cities to the south of the polar jet stream will be under warmer, moister air than cities to its north. Directly beneath the jet stream, the weather is often stormy and there may be thunderstorms and tornadoes.

Prevailing Winds

The prevailing winds are the bases of the Hadley, Ferrell, and Polar Cells. These winds greatly influence the climate of a region because they bring the weather from the locations they come from. For example, in California, the predominant winds are the westerlies blowing in from the Pacific Ocean, which bring in relatively cool air in summer and relatively warm air in winter. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

Continental Position

When a particular location is near an ocean or large lake, the body of water plays an extremely important role in affecting the region's climate.

- A **maritime climate** is strongly influenced by the nearby sea. Temperatures vary a relatively small amount seasonally and daily. For a location to have a true maritime climate, the winds must most frequently come off the sea.
- A **continental climate** is more extreme, with greater temperature differences between day and night and between summer and winter.

The ocean's influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37°N latitude, within the westerly winds (**Figure** 21.5).

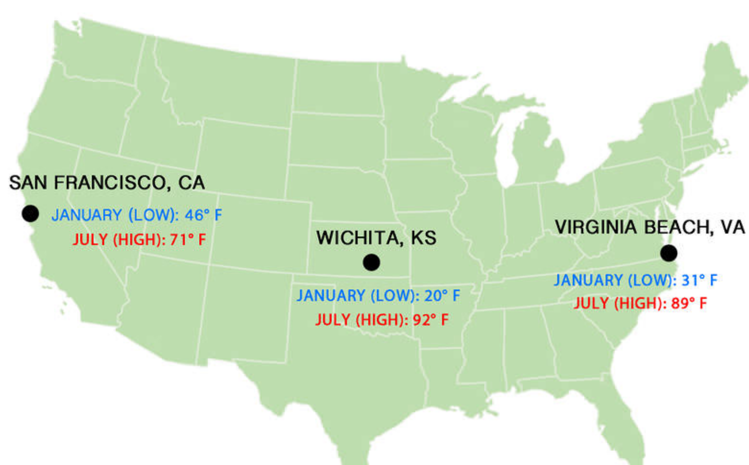

FIGURE 21.5
How does the ocean influence the climate of these three cities?

Ocean Currents

The temperature of the water offshore influences the temperature of a coastal location, particularly if the winds come off the sea. The cool waters of the California Current bring cooler temperatures to the California coastal region. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures. Further north, in southern Alaska, the upwelling actually raises the temperature of the surrounding land because the ocean water is much warmer than the land. The important effect of the Gulf Stream on the climate of northern Europe is described in the chapter, Earth's Oceans.

Altitude and Mountain Ranges

Air pressure – and air temperature – decrease with altitude. The closer molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher altitudes, the air is less dense and air molecules are more spread out and less likely to collide. A location in the mountains has lower average temperatures than one at the base of the mountains. In Colorado, for example, Lakewood (5,640 feet) average annual temperature is 62°F (17°C), while Climax Lake (11,300 feet) is 42°F (5.4°C).

Mountain ranges have two effects on the climate of the surrounding region:

- rainshadow effect, which brings warm dry climate to the leeward size of a mountain range, was described in the Earth's Atmosphere chapter (**Figure** 21.6).
- separation in the coastal region from the rest of the continent. Since a maritime air mass may have trouble rising over a mountain range, the coastal area will have a maritime climate but the inland area on the leeward side will have a continental climate.

FIGURE 21.6

The Bonneville Salt Flats are part of the very dry Great Basin of the Sierra Nevada of California. The region receives little rainfall.

Lesson Summary

- A region's position on the globe and on a continent determines its fundamental climate.
- Latitude determines a location's solar radiation and location within the wind belts.
- If a region is near a large water body, its climate will be influenced by that water body.
- Mountain ranges separate land areas from the oceans and create rainshadow effect, which influences climate.

Review Questions

1. Describe the weather of the location where you are right now. How is the weather today typical or atypical of your usual climate for today's date?

2. In what two ways could a desert be found at 30°N?

3. Could a desert form at 45°N latitude? Explain how.

4. Why is there so little wind in the locations where the atmospheric circulation cells meet?

5. If it is windy at 30°N where there is normally little wind, does that mean the model of the atmospheric circulation cells is wrong?

6. What is the ITCZ? What winds do you expect to find there?

7. How does the polar jet stream move from summer to winter? How does this affect the climate of the locations where it moves?

8. Imagine two cities in North America. How does the climate of a city at 45°N near the Pacific Ocean differ from one at the same latitude near the Atlantic Coast?

9. Why does the ocean water off California cool the western portion of the state, while the water off the southeastern United States warms that region?

10. Think about what you know about surface ocean currents. How would you expect the climate of western South America to be influenced by the Pacific Ocean? Could this same effect happen in the Northern Hemisphere?

11. The Andes Mountains line western South America. How do you think they influence the climate of that region and the lands to the east of them?

Points to Consider

- Describe how two cities at the same latitude can have very different climates. For example, Tucson, Arizona, has a hot, dry desert climate and New Orleans, Louisiana, has a warm, muggy climate even though both cities are at approximately the same latitude.
- How does climate influence the plants and animals that live in a particular place?
- Would you expect climate at similar latitudes to be the same or different on the opposite side of the equator. For example, how would the climate of a city at 45°N be similar or different to one at 45°S latitude?

21.2 Climate Change

Lesson Objectives

- Describe some ways that climate change has been an important part of Earth history.
- Discuss what factors can cause climate to change and which of these can be exacerbated by human activities.
- Discuss the consequences of rising greenhouse gas levels in the atmosphere, the impacts that are already being measured, and the impacts that are likely to occur in the future.

Vocabulary

- El Niño
- global warming
- La Niña
- Milankovitch cycles
- slash-and-burn agriculture
- sunspot

Introduction

For the past two centuries, climate has been relatively stable. People placed their farms and cities in locations that were in a favorable climate without thinking that the climate could change. But climate has changed throughout Earth history, and a stable climate is not the norm. In recent years, Earth's climate has begun to change again. Most of this change is warming because of human activities that release greenhouse gases into the atmosphere. The effects of warming are already being seen and will become more extreme as temperature rise.

Climate Change in Earth History

Climate has changed throughout Earth history. Much of the time Earth's climate was hotter and more humid than it is today, but climate has also been colder, as when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago (**Figure** 21.7). Glaciers advanced and retreated in cycles, known as glacial and interglacial periods. With so much of the world's water bound into the ice, sea level was about 125 meters (395 feet) lower than it is today. Many scientists think that we are now in a warm, interglacial period that has lasted about 10,000 years.

For the past 1500 years, climate has been relatively mild and stable when compared with much of Earth's history. Why has climate stability been beneficial for human civilization? Stability has allowed the expansion of agriculture and the development of towns and cities.

FIGURE 21.7
The maximum extent of Northern Hemisphere glaciers during the Pleistocene epoch.

Fairly small temperature changes can have major effects on global climate. The average global temperature during glacial periods was only about 5.5°C (10°F) less than Earth's current average temperature. Temperatures during the interglacial periods were about 1.1°C (2.0°F) higher than today (**Figure** 21.8).

Since the end of the Pleistocene, the global average temperature has risen about 4°C (7°F). Glaciers are retreating and sea level is rising. While climate is getting steadily warmer, there have been a few more extreme warm and cool times in the last 10,000 years. Changes in climate have had effects on human civilization.

- The Medieval Warm Period from 900 to 1300 A.D. allowed Vikings to colonize Greenland and Great Britain to grow wine grapes.
- The Little Ice Age, from the 14th to 19th centuries, the Vikings were forced out of Greenland and humans had to plant crops further south.

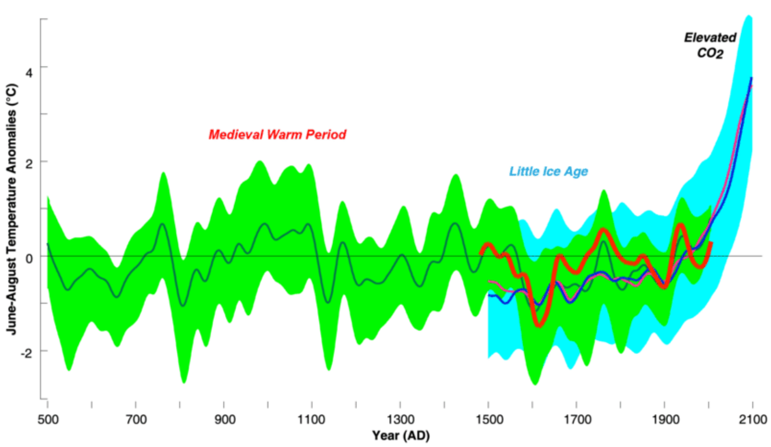

FIGURE 21.8
The graph is a compilation of 5 reconstructions (the green line is the mean of the five records) of mean temperature changes. This illustrates the high temperatures of the Medieval Warm Period, the lows of the Little Ice Age, and the very high (and climbing) temperature of this decade.

Short-Term Climate Changes

Short-term changes in climate are common (**Figure** 21.9). The largest and most important of these is the oscillation between El Niño and La Niña conditions. This cycle is called the ENSO (El Niño southern oscillation). The ENSO drives changes in climate that are felt around the world about every two to seven years.

In a normal year, the trade winds blow across the Pacific Ocean near the equator from east to west (toward Asia). A low pressure cell rises above the western equatorial Pacific. Warm water in the western Pacific Ocean and raises sea levels by one-half meter. Along the western coast of South America, the Peru Current carries cold water northward, and then westward along the equator with the trade winds. Upwelling brings cold, nutrient-rich waters from the deep sea.

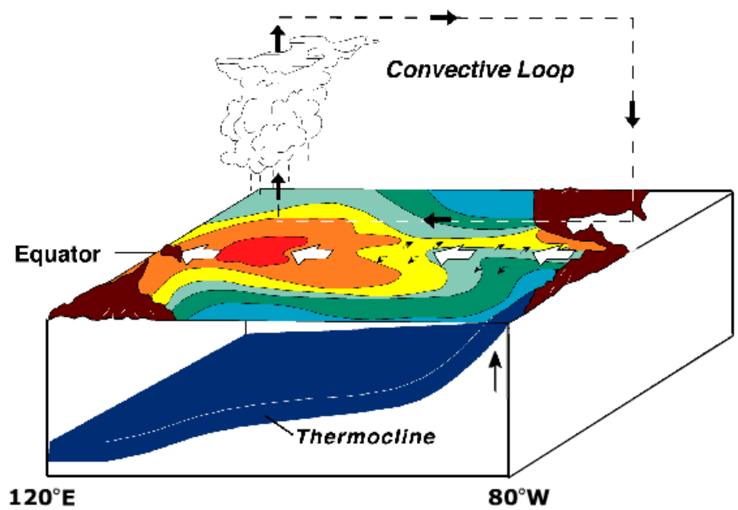

FIGURE 21.9
Under normal conditions, low pressure and warm water (shown in red) build up in the western Pacific Ocean. Notice that continents are shown in brown in the image. North and South America are on the right in this image.

In an **El Niño** year, when water temperature reaches around 28°C (82°F), the trade winds weaken or reverse direction and blow east (toward South America) (**Figure** 21.10). Warm water is dragged back across the Pacific Ocean and piles up off the west coast of South America. With warm, low-density water at the surface, upwelling stops. Without upwelling, nutrients are scarce and plankton populations decline. Since plankton form the base of the food web, fish cannot find food, and fish numbers decrease as well. All the animals that eat fish, including birds and humans, are affected by the decline in fish.

By altering atmospheric and oceanic circulation, El Niño events change global climate patterns.

- Some regions receive more than average rainfall, including the west coast of North and South America, the southern United States, and Western Europe.
- Drought occurs in other parts of South America, the western Pacific, southern and northern Africa, and southern Europe.

An El Niño cycle lasts one to two years. Often normal circulation patterns resume. Sometimes circulation patterns bounce back quickly and extremely (**Figure** 21.11). This is a **La Niña**.

In a La Niña year, as in a normal year, trade winds moves from east to west and warm water piles up in the western Pacific Ocean. Ocean temperatures along coastal South America are colder than normal (instead of warmer, as in El Niño). Cold water reaches farther into the western Pacific than normal.

An online guide to El Niño and La Niña events from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/eln/home.rxml .

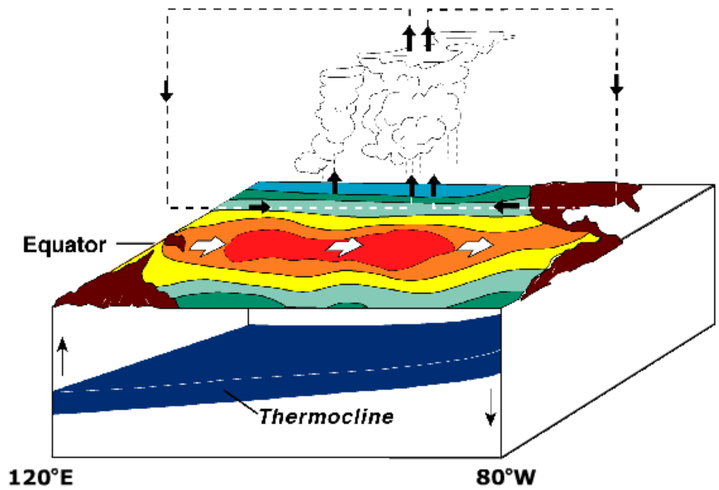

FIGURE 21.10
In El Niño conditions, the trade winds weaken or reverse directions. Warm water moves eastward across the Pacific Ocean and piles up against South America.

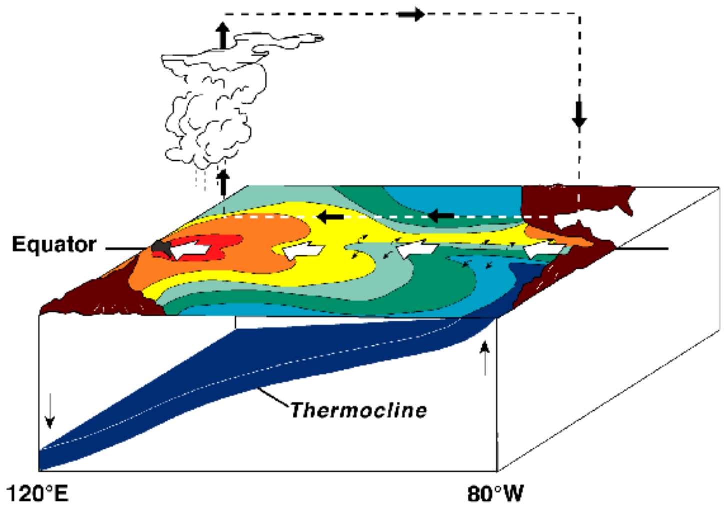

FIGURE 21.11
A La Niña year is like a normal year but the circulation patters are more extreme.

Other important oscillations are smaller and have a local, rather than global, effect. The North Atlantic Oscillation mostly alters climate in Europe. The Mediterranean also goes through cycles, varying between being dry at some times, and warm and wet at others.

The ABC News video explores the relationship of El Niño to global warming. El Niño is named as the cause of strange weather across the United States in the winter of 2007 in this video **(5g)**: http://www.youtube.com/watch?v=5uk9nwtAOio (3:33).

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Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes:

- in the amount of energy the Sun produces over years.
- in the positions of the continents over millions of years.
- in the tilt of Earth's axis and orbit over thousands of years.
- that are sudden and dramatic because of random catastrophic events, such as a large asteroid impact.
- in greenhouse gases in the atmosphere, caused naturally or by human activities.

Solar Variation

The amount of energy the Sun radiates is variable. **Sunspots** are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (**Figure** 21.12). When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is and there is no known 11-year cycle in climate variability. The Little Ice Age corresponded to a time when there were no sunspots on the Sun.

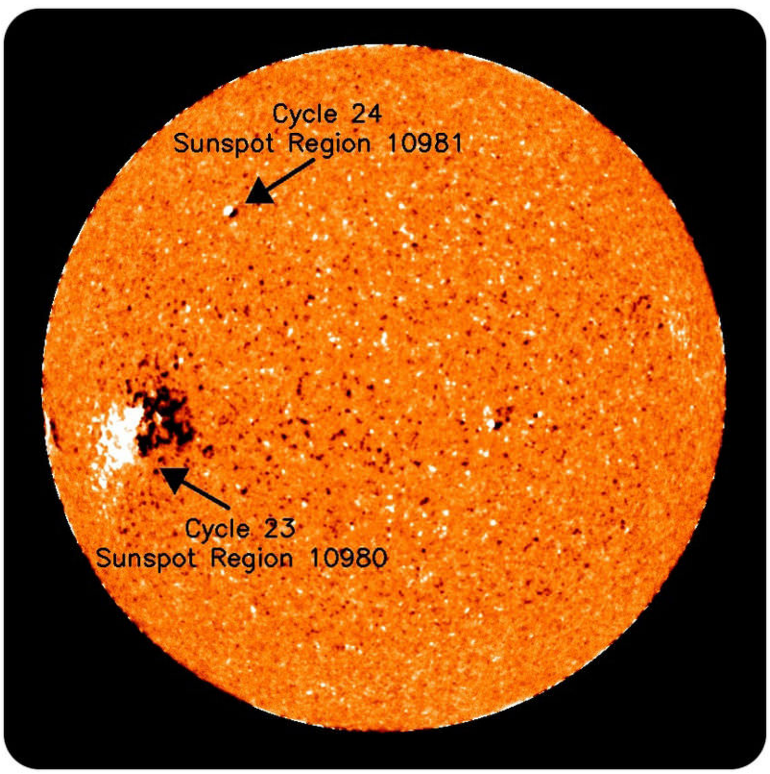

FIGURE 21.12
Sunspots on the face of the Sun.

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (such as Pangaea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed.

Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather (**Figure** 21.13). Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

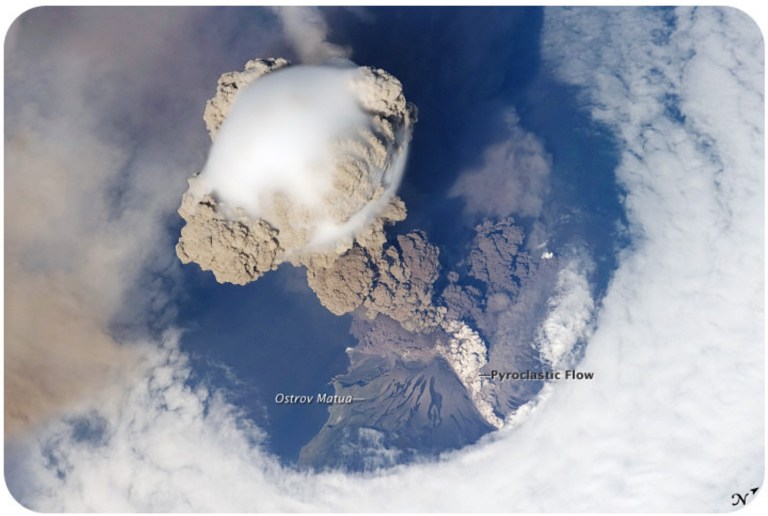

FIGURE 21.13
An eruption like Sarychev Volcano (Kuril Islands, northeast of Japan) in 2009 would have very little impact on weather.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as **Milankovitch cycles**.

The Earth goes through regular variations in its position relative to the Sun:

1. The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.

2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. This results in chilly summers and warmer winters.

3. The planet's tilt on its axis varies between 22.1° and 24.5°. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5° angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Changes in Atmospheric Greenhouse Gas Levels

Since greenhouse gases trap the heat that radiates off the planet's surfaces what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises air temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods (**Figure** 21.14).

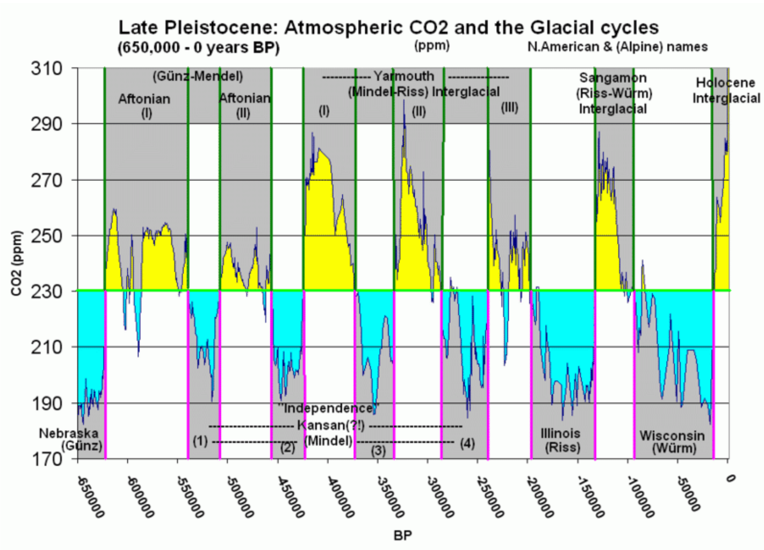

FIGURE 21.14

CO_2 levels during glacial (blue) and interglacial (yellow) periods. Are CO_2 levels relatively high or relatively low during interglacial periods? Current carbon dioxide levels are at 392 ppm, the highest level for the last 650,000 years. BP means years before present.

Natural processes add and remove CO_2 from the atmosphere

- Processes that add CO_2
  - volcanic eruptions
  - decay or burning of organic matter.
- Processes that remove CO_2
  - absorption by plant and animal tissue.

When plants are turned into fossil fuels the CO_2 in their tissue is stored with them. So CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

What happens to atmospheric CO_2 when the fossil fuels are burned? What happens to global temperatures?

Fossil fuel use has skyrocketed in the past few decades more people want more cars and industrial products. This has released CO_2 into the atmosphere.

Burning tropical rainforests, to clear land for agriculture, a practice called **slash-and-burn agriculture**, also increases atmospheric CO_2. By cutting down trees, they can no longer remove CO_2 from the atmosphere. Burning the trees releases all the CO_2 stored in the trees into the atmosphere.

There is now nearly 40% more CO_2 in the atmosphere than there was 200 years ago, before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958 (**Figure** 21.15).

CO_2 is the most important greenhouse gas that human activities affect because it is so abundant. But other greenhouse gases are increasing as well. A few are:

- Methane: released from raising livestock, rice production, and the incomplete burning of rainforest plants.
- Chlorofluorocarbons (CFCs): human-made chemicals that were invented and used widely in the 20th century.
- Tropospheric ozone: from vehicle exhaust, it has more than doubled since 1976.

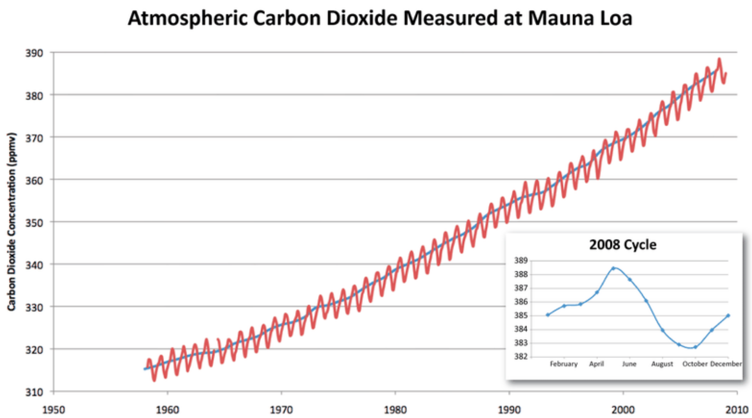

FIGURE 21.15

The Keeling Curve shows the increase in atmospheric CO_2 on Mauna Loa volcano since measurements began in 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2.

Global Warming

With more greenhouse gases trapping heat, average annual global temperatures are rising. This is known as **global warming**.

Global warming - How Humans are Affecting our Planet from NASA, discusses the basics of global warming science **(4c)**: http://www.youtube.com/watch?v=VXvGPbHXxtc (7:58).

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Temperatures are Increasing

While temperatures have risen since the end of the Pleistocene, 10,000 years ago, this rate of increase has been more rapid in the past century, and has risen even faster since 1990. The nine warmest years on record have all occurred since 1998, and the 10 of the 11 warmest years have occurred since 2001 (through 2012) (**Figure** 21.16). The 2000s were the warmest decade yet.

Annual variations aside, the average global temperature increased about 0.8°C (1.5°F) between 1880 and 2010, according to the Goddard Institute for Space Studies, NOAA. This number doesn't seem very large. Why is it important? http://www.giss.nasa.gov/research/news/20100121/

The United States has long been the largest emitter of greenhouse gases, with about 20% of total emissions in 2004 (**Figure** 21.17). As a result of China's rapid economic growth, its emissions surpassed those of the United States in 2008. However, it's also important to keep in mind that the United States has only about one-fifth the population of China. What's the significance of this? The average United States citizen produces far more greenhouse gases than the average Chinese person.

An animation of CO_2 released by different fossil fuels is seen here: CO_2 release by different fossil fuels at http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CO2BTU_3.MPG

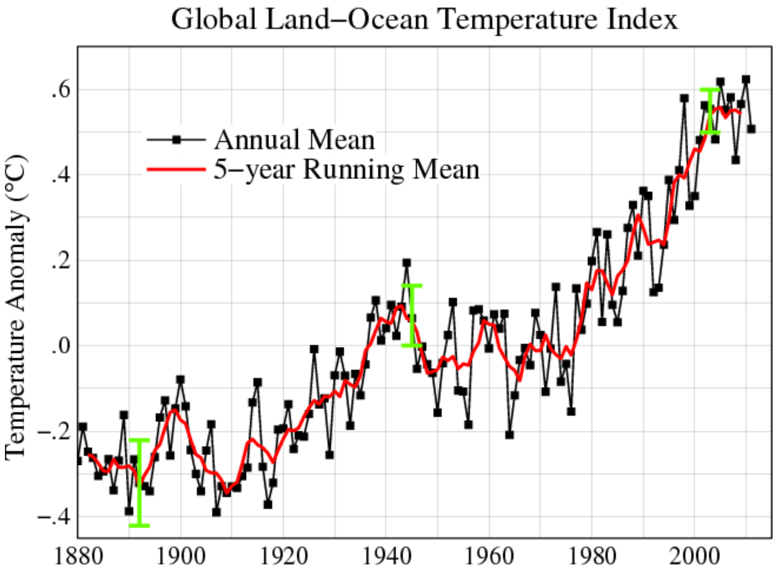

FIGURE 21.16
Recent temperature increases show how much temperature has risen since the Industrial Revolution began.

If nothing is done to decrease the rate of CO_2 emissions, by 2030, CO_2 emissions are projected to be 63% greater than they were in 2002.

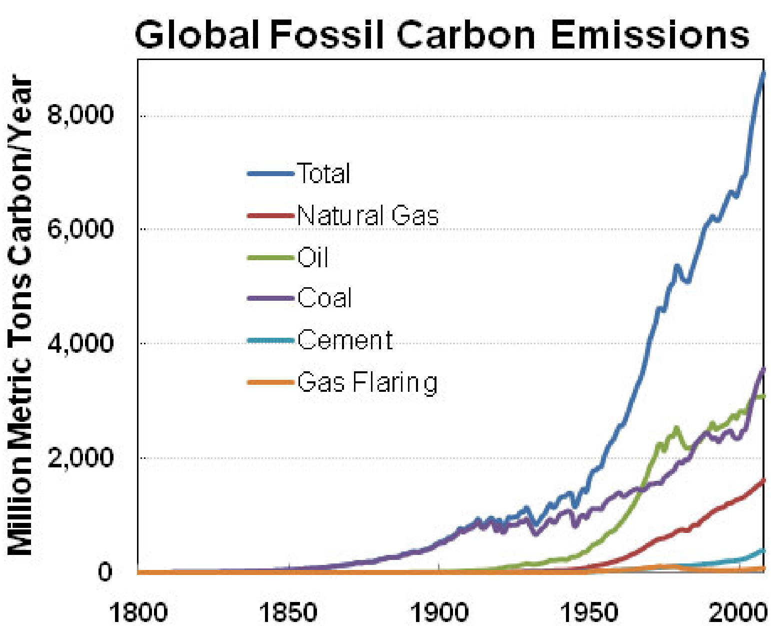

FIGURE 21.17
Global CO_2 emissions are rising rapidly. The industrial revolution began about 1850 and industrialization has been accelerating.

A number of videos on the National Geographic site deal with global warming. Go to National Geographic Videos, Environment Videos, Global Warming, http://video.nationalgeographic.com/video/player/environment/ .

- A no-nonsense look at global warming and what we can do about it is found in "A Way Forward: Facing Climate Change."
- "Antarctic Ice" describes the changes that are already happening to Antarctica and what the consequences of future melting will be.
- "Glacier Melt" looks at melting in a large alpine glacier and the effects of glacier loss to Europe.

- In “Greenhouse Gases” researchers look at the effects of additional greenhouse gases on future forests.
- Researchers look for changes in the range of a mountain-top dwelling mammal, the pika.
- Polar bears, in their specialized habitat in the Arctic, are among the species already affected by warming temperatures.

KQED: Climate Watch: California at the Tipping Point

Warming temperatures are bringing changes to much of the planet, including California. Sea level is rising, snow pack is changing and the ecology of the state is responding to these changes. Learn more at: http://science.kqed.org/quest/video/climate-watch-california-at-the-tipping-point/ .

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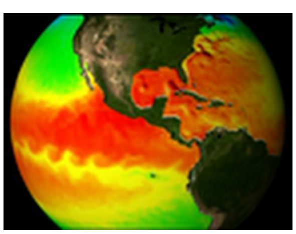
Future Warming

The amount CO_2 levels will rise in the next decades is unknown. What will this number depend on in the developed nations? What will it depend on in the developing nations? In the developed nations it will depend on technological advances or lifestyle changes that decrease emissions. In the developing nations, it will depend on how much their lifestyles improve and how these improvements are made.

Computer models are used to predict the effects of greenhouse gas increases on climate for the planet as a whole and also for specific regions. If nothing is done to control greenhouse gas emissions and they continue to increase at current rates, the surface temperature of the Earth can be expected to increase between 0.5°C and 2.0°C (0.9°F and 3.6°F) by 2050 and between 2° and 4.5°C (3.5° and 8°F) by 2100, with CO_2 levels over 800 parts per million (ppm). On the other hand, if severe limits on CO_2 emissions begin soon, temperatures could rise less than 1.1°C (2°F) by 2100.

This video explores the tools NASA scientists use to determine how the climate is changing **(6d)**: http://www.youtube.com/watch?v=JRayIgKublg (4:00).



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Whatever the temperature increase, it will not be uniform around the globe. A rise of 2.8°C (5°F) would result in 0.6° to 1.2°C (1° to 2°F) at the equator, but up to 6.7°C (12°F) at the poles. So far, global warming has affected the North Pole more than the South Pole, but temperatures are still increasing at Antarctica (**Figure** 21.18).

The following images show changes in the earth and organisms as a result of global warming: **Figure** 21.19, **Figure** 21.20, and **Figure** 21.21.

The timing of events for species is changing. Mating and migrations take place earlier in the spring months. Species that can are moving their ranges uphill. Some regions that were already marginal for agriculture are no longer

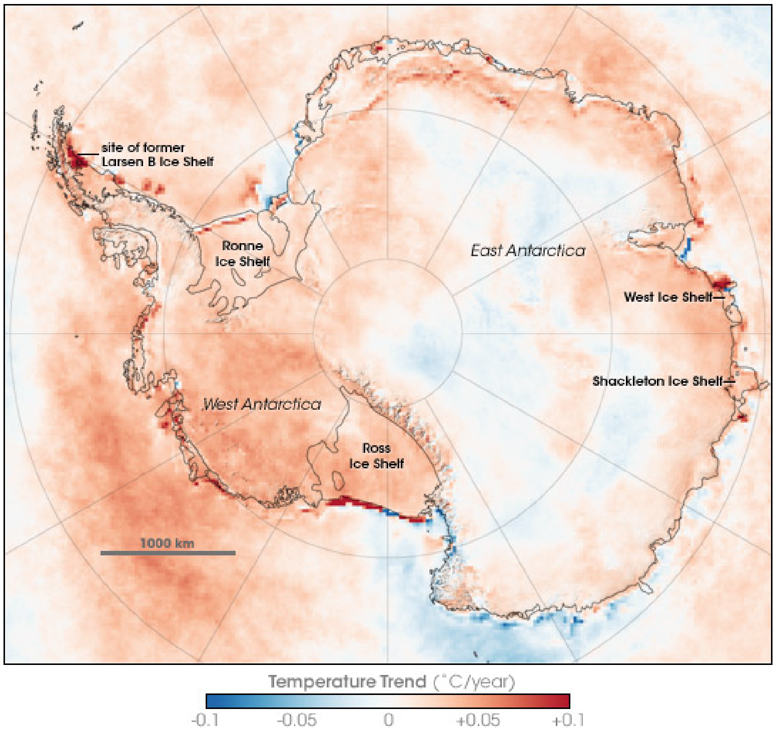

FIGURE 21.18
Temperature changes over Antarctica.

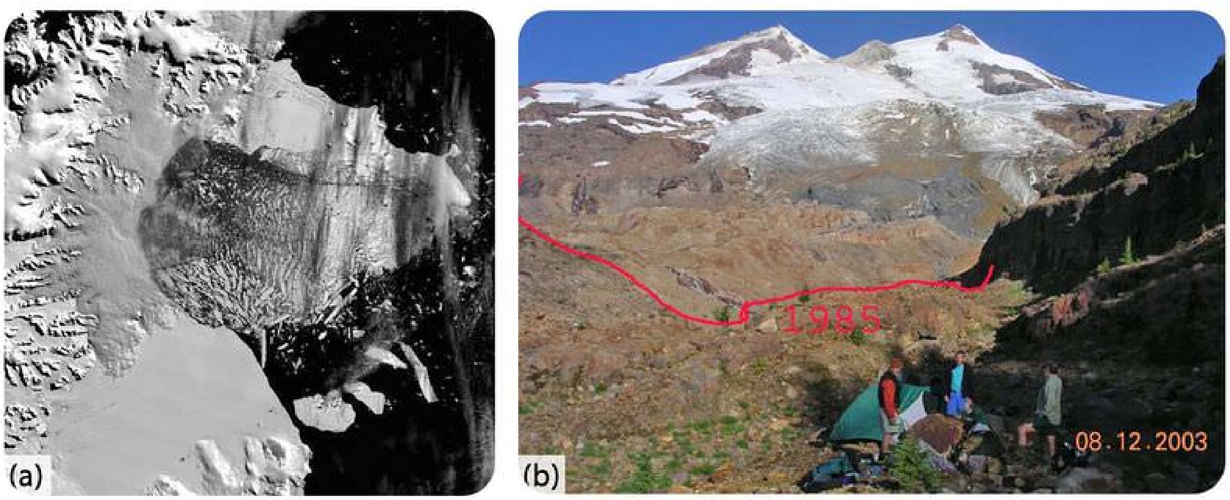

FIGURE 21.19
(a) Breakup of the Larsen Ice Shelf in Antarctica in 2002 was related to climate warming in the region. (b) The Boulder Glacier has melted back tremendously since 1985. Other mountain glaciers around the world are also melting.

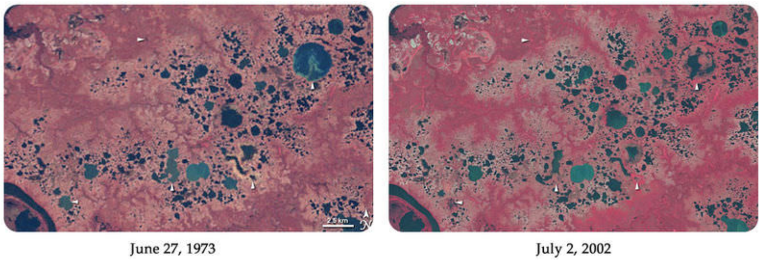

FIGURE 21.20
Permafrost is melting and its extent decreasing. There are now fewer summer lakes in Siberia.

farmable because they have become too warm or dry.

Modeled Climate Induced Glacier change in Glacier National Park 1850-2100: http://www.nrmsc.usgs.gov/research/glacier_model.htm

What are the two major effects being seen in this animation? Glaciers are melting and vegetation zones are moving uphill. If fossil fuel use exploded in the 1950s, why do these changes begin early in the animation? Does this mean that the climate change we are seeing is caused by natural processes and not by fossil fuel use?

Animations of temperature anomalies for 5- and 10-year periods: http://data.giss.nasa.gov/gistemp/animations/

As greenhouse gases increase, changes will be more extreme. Oceans will become slightly more acidic, making it more difficult for creatures with carbonate shells to grow, and that includes coral reefs. A study monitoring ocean acidity in the Pacific Northwest found ocean acidity increasing ten times faster than expected and 10% to 20% of shellfish (mussels) being replaced by acid tolerant algae.

Plant and animal species seeking cooler temperatures will need to move poleward 100 to 150 km (60 to 90 miles) or upward 150 m (500 feet) for each 1.0°C (8°F) rise in global temperature. There will be a tremendous loss of biodiversity because forest species can't migrate that rapidly. Biologists have already documented the extinction of high-altitude species that have nowhere higher to go.

Decreased snowpacks, shrinking glaciers, and the earlier arrival of spring will all lessen the amount of water available in some regions of the world, including the western United States and much of Asia. Ice will continue to melt and sea level is predicted to rise 18 to 97 cm (7 to 38 inches) by 2100 (**Figure** 21.22). An increase this large will gradually flood coastal regions where about one-third of the world's population lives, forcing billions of people to move inland.

Weather will become more extreme with heat waves and droughts. Some modelers predict that the Midwestern United States will become too dry to support agriculture and that Canada will become the new breadbasket. In all, about 10% to 50% of current cropland worldwide may become unusable if CO_2 doubles.

Although scientists do not all agree, hurricanes are likely to become more severe and possibly more frequent. Tropical and subtropical insects will expand their ranges, resulting in the spread of tropical diseases such as malaria, encephalitis, yellow fever, and dengue fever.

You may notice that the numerical predictions above contain wide ranges. Sea level, for example, is expected to rise somewhere between 18 and 97 cm —quite a wide range. What is the reason for this uncertainty? It is partly because scientists cannot predict exactly how the Earth will respond to increased levels of greenhouses gases. How quickly greenhouse gases continue to build up in the atmosphere depends in part on the choices we make.

An important question people ask is this: Are the increases in global temperature natural? In other words, can natural variations in temperature account for the increase in temperature that we see? The answer is no. Changes in the Sun's irradiance, El Niño and La Niña cycles, natural changes in greenhouse gas, and other atmospheric gases cannot account for the increase in temperature that has already happened in the past decades.

This video discusses how, by using the CERES satellite, scientists monitor energy in the atmosphere, including incoming solar energy and reflected and absorbed energy. Greenhouse warming that results from atmospheric

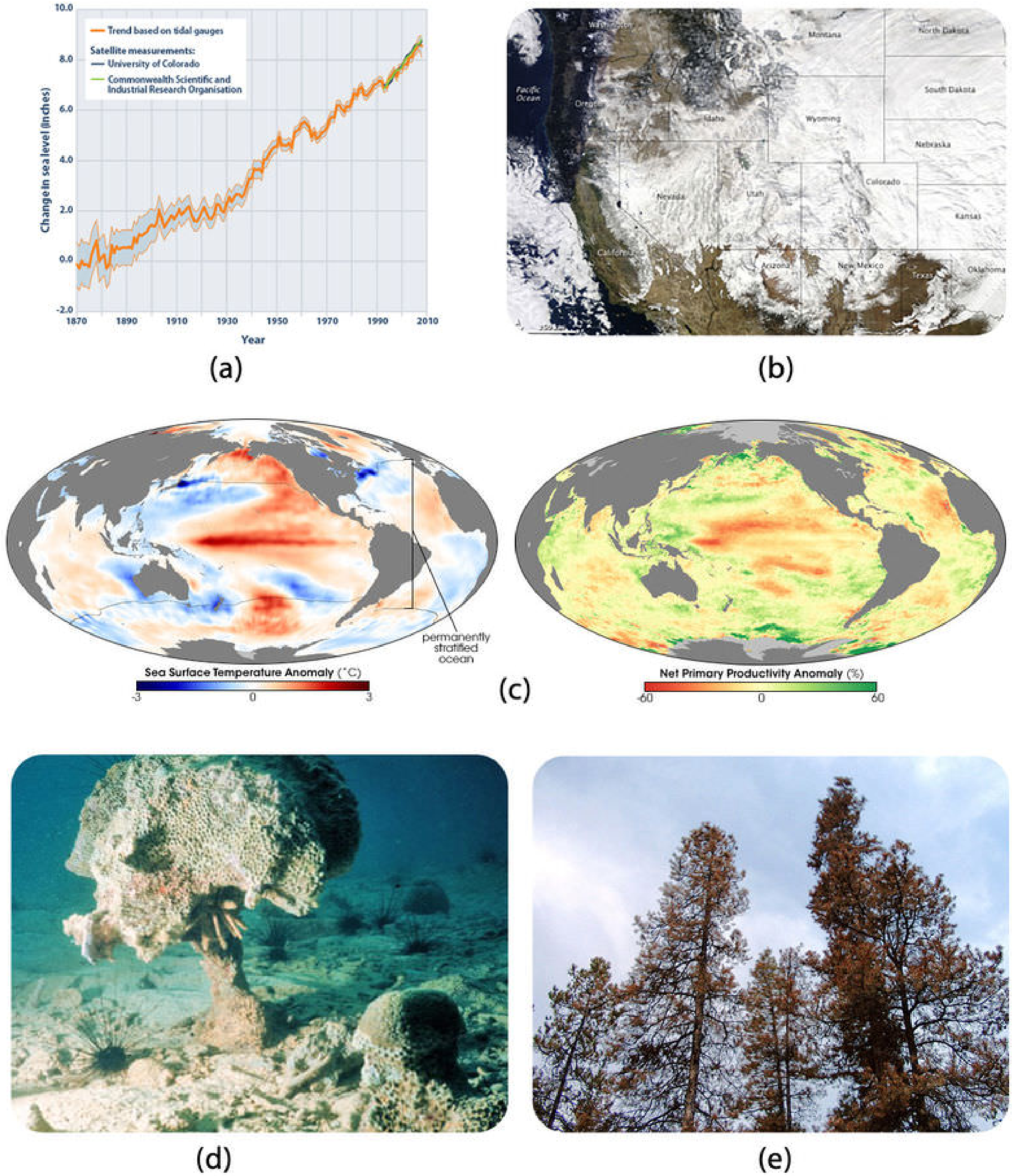

FIGURE 21.21

(a) Melting ice caps add water to the oceans, so sea level is rising. Remember that water slightly expands as it warms —this expansion is also causing sea level to rise. (b) Weather is becoming more variable with more severe storms and droughts. Snow blanketed the western United States in December 2009. (c) As surface seas warm, phytoplankton productivity has decreased. (d) Coral reefs are dying worldwide; corals that are stressed by high temperatures turn white. (e) Pine beetle infestations have killed trees in western North America The insects have expanded their ranges into areas that were once too cold.

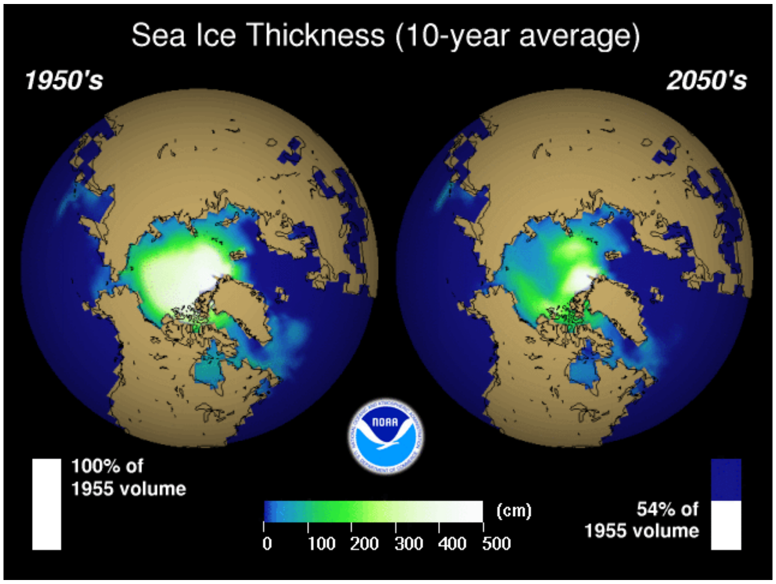

FIGURE 21.22
Sea ice thickness around the North Pole has been decreasing in recent decades and will continue to decrease in the coming decades.

greenhouse gasses is also monitored **(4c)**: http://www.youtube.com/watch?v=JFfD6jn_OvA (4:31).

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KQED: Going UP: Sea Level Rise in San Francisco Bay

Along with the rest of the world's oceans, San Francisco Bay is rising. Changes are happening slowly in the coastal arena of the San Francisco Bay Area and even the most optimistic estimates about how high and how quickly this rise will occur indicate potentially huge problems for the region. Learn more at: http://science.kqed.org/quest/video/going-up-sea-level-rise-in-san-francisco-bay/ .

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Lesson Summary

- Climate has changed throughout Earth history. In general, when greenhouse gas levels are high, temperature is high.

- Greenhouse gases are now increasing because of human activities, especially fossil fuel use.
- We are already seeing the effects of these rising greenhouse gases in higher temperatures and changes to physical and biological systems.
- Society must choose to reduce greenhouse gas emissions or face more serious consequences.

Review Questions

1. Why is the climate currently warming?

2. Why does sea level rise and fall during interglacial and glacial periods?

3. How can the human history of Greenland be related to climate cycles?

4. If climate has been much warmer in Earth history, why do we need to worry about global warming now?

5. When the weather along coastal California is especially rainy with many winter storms, what is likely to be happening in the equatorial Pacific?

6. The Peruvian anchovy fishery collapsed in 1972. Using what you know about climate and food webs, can you devise an explanation for this event?

7. What two events must occur for there to be an ice age?

8. What human activities increase greenhouse gases in the atmosphere? Explain.

9. Why are CO_2 emissions projected to increase during the next few decades?

10. What role will the developed nations play in increasing CO_2 emissions in the next few decades?

11. Why do storms increase in frequency and intensity as global temperatures increase?

12. Earth is undergoing some important changes, some of which are known about because of and monitored by satellites. Describe the sort of global change that satellites can monitor.

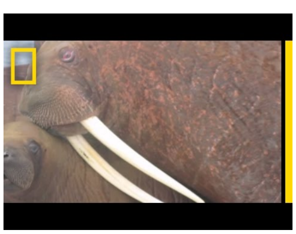
13. What will happen if sea level rises by 60 cm (2 feet) by the end of this century? Which locations will be hardest hit?

14. What can be done to reduce greenhouse gas emissions?

Virtually all credible scientists agree that Earth is warming and human actions are largely to blame. The evidence comes from many areas of science: atmospheric chemistry, earth history, glaciology, ecology, astronomy (stars, the Sun), energy (fossil fuels), oceanography, remote sensing, agricultural science, and others. Because the media like to present a "balanced" story, media outlets often present the side of climate skeptics who do not believe that global warming is happening, or that if it is happening, that human actions are largely responsible.

From the following videos you can learn basic global warming science, the effects already being seen from changing climate, and learn a bit about risk assessment:

Global Warming 101 touches on all aspects of the global warming story in just a few minutes **(1l - IE Stand.)**: http://www.youtube.com/watch?v=-lubjnPA0b0 (1:28).



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Observations made for the past decade by the TERRA satellite shows how Earth is changing because of warmer temperatures **(1l - IE Stand.)**: http://www.youtube.com/watch?v=h-VvMUseE_o (4:57).

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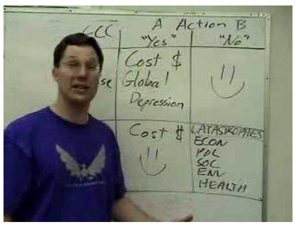
The Most Terrifying Video You'll Ever See evaluates the risks of choosing action or inaction on global warming **(1l - IE Stand.)**: http://www.youtube.com/watch?v=zORv8wwiadQ (9:34).



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There are many other videos that look at the issue of climate change, some by those who deny that it is happening. Look at some videos created by the so-called *climate skeptics* and write down their arguments, then write down the scientific counter-arguments. Next check out this series: Climate Crock of the Week *'(1l - IE Stand.)* http://www.youtube.com/watch?v=_KK8F5noCrA (2:02), which dismantles the arguments made by those who deny global warming science one by one.

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California has gone its own way by passing legislation to reduce the state's greenhouse gas emissions to 1990 levels. A strong proponent is Governor Arnold Schwarzenegger, who has broken with the Republican party in accepting that global warming is real and that something must be done to slow its effects. The following videos address California's cap-and-trade policy and the legislation:

Governor Schwarzenegger discusses why California Chose Cap-and-Trade in regulating carbon emissions **(1m - IE Stand.)**: http://www.youtube.com/watch?v=fON7t5DPQbk (3:40).

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Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/8472

Governor Arnold Schwarzenegger explains why the emissions standards adopted by California should be picked up by the rest of the country **(1m - IE Stand.)**: http://www.youtube.com/watch?v=VnZtT7Nj1rI (3:52).

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/8473

Here Governor Schwarzenegger addresses the impact of global warming on fires, attacks the Bush administration on its policies on global warming and drilling for oil off the coast of California, and reviews recent U.S. history on alternative energy research **(1m - IE Stand.)**: http://www.youtube.com/watch?v=osBNMvp2Cws (5:24).

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URL: http://www.ck12.org/flx/render/embeddedobject/8474

California water board official answers questions about California's legislation on global warming **(1m - IE Stand.)**: http://www.youtube.com/watch?v=h-ZMsNdd-34 (4:03).

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/8475

Further reading/supplemental links

Illustrating the concept of El Niño and La Niña: http://earthguide.ucsd.edu/enso/ .

Points to Consider

- Nearly all climate scientists agree that human activities are causing the accelerated warming of the planet that we see today. Why do you think that the media is still talking about the controversy about this idea when scientists are almost entirely in agreement?
- If greenhouse gas emissions must be lowered to avoid some of the more serious consequences of global warming, why have humans not done something to lower these emissions instead of letting them increase?
- In what ways can progress be made in reducing greenhouse gas emissions? Think about this on a variety of scales: for individuals, local communities, nations, and the global community.

21.3 References

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reef-bioerosion.jpg; (e) http://commons.wikimedia.org/wiki/File:Dead_pines.jpg">(a) http://commons.wikimedia.org/wiki in_global_average_absolute_sea_level,_1870-2008_%28US_EPA%29.png; (b) http://earthobservatory.nasa.gov/IOTD/vie (c) http://earthobservatory.nasa.gov/IOTD/view.php?id=7187; (d) http://commons.wikimedia.org/wiki/File:Coral-reef-bioerosion.jpg; (e) http://commons.wikimedia.org/wiki/File:Dead_pines.jpg. Public Domain

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CONCEPT 22 Unit 9: Nuclear Energy and Nuclear Processes

Questions/Observable Phenomena

CHAPTER 23 Nuclear Energy

Chapter Outline

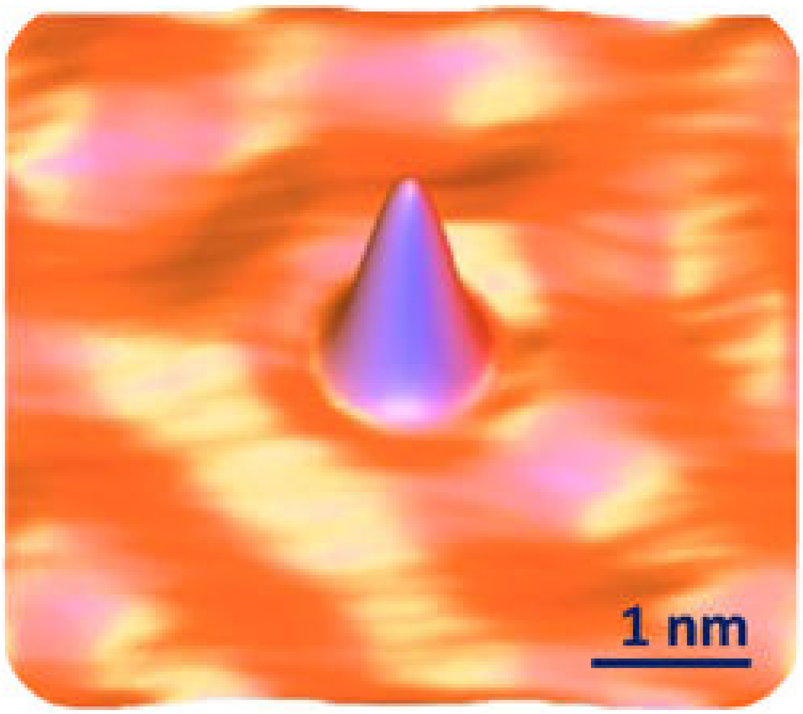
If you lived during the Middle Ages (between 400 and 1400 A.D.), you might see a scene like the one pictured here. The man in the picture is an alchemist. Alchemists were people who strived to turn lead into gold. They tried all sorts of chemical reactions involving lead, but they were never able to produce gold. As you learned in an earlier chapter, an element cannot be changed into another element by any type of chemical reaction. However, scientists now know there is a way that some elements can change into others. You'll find out what it is when you read this chapter.

Adriaen van Ostade. commons.wikimedia.org/wiki/File:Adriaen_van_Ostade_-_Alchemist_-_WGA16738.jpg. Public Domain.

23.1 Atoms

Learning Objectives

- Describe atoms and how they are related to elements.
- Identify the three main subatomic particles that make up atoms.



What could this hilly blue surface possibly be? Do you have any idea? The answer is a single atom of the element Cobalt. The picture was created using a scanning tunneling microscope. No other microscope can make images of things as small as atoms. How small are atoms? You will find out in this lesson.

What Are Atoms?

Atoms are the building blocks of matter. They are the smallest particles of an element that still have the element's properties. Elements, in turn, are pure substances—such as nickel, hydrogen, and helium—that make up all kinds of matter. All the atoms of a given element are identical in that they have the same number of protons, one of the building blocks of atoms (see below). They are also different from the atoms of all other elements, as atoms of different elements have different number of protons.

Size of Atoms

Unlike bricks, atoms are extremely small. The radius of an atom is well under 1 nanometer, which is one-billionth of a meter. If a size that small is hard to imagine, consider this: trillions of atoms would fit inside the period at the end of this sentence. Although all atoms are very small, elements vary in the size of their atoms. The **Figure** 23.1 compares the sizes of atoms of more than 40 different elements. The elements in the figure are represented by chemical symbols, such as H for hydrogen and He for helium. Of course, real atoms are much smaller than the circles representing them in the **Figure** 23.1.

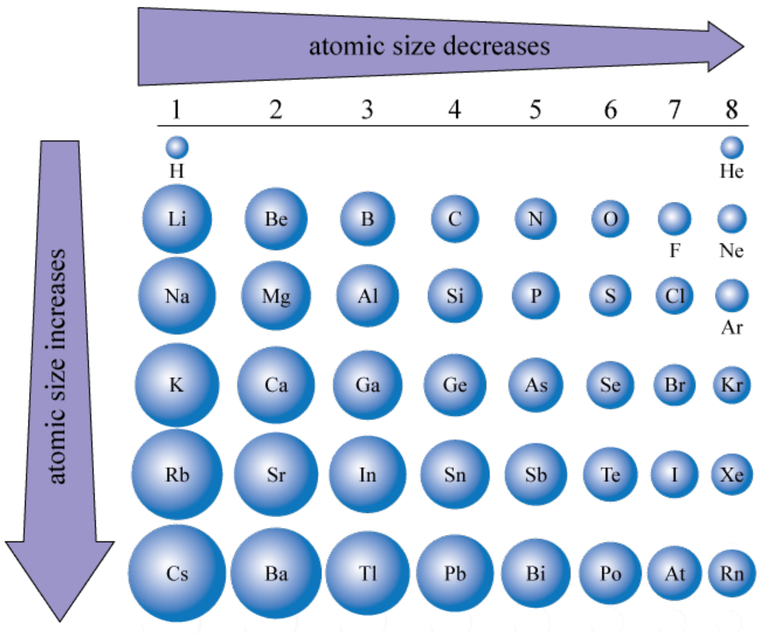


FIGURE 23.1

Q: Which element in the **Figure** 23.1 has the biggest atoms?

A: The element in the figure with the biggest atoms is cesium (Cs).

Subatomic Particles

Although atoms are very tiny, they consist of even smaller particles. Three main types of particles that make up all atoms are:

- protons, which have a positive electric charge.
- electrons, which have a negative electric charge.
- neutrons, which are neutral in electric charge.

The model in the **Figure** 23.2 shows how these particles are arranged in an atom. The particular atom represented by the model is helium, but the particles of all atoms are arranged in the same way. At the center of the atom is a dense area called the nucleus, where all the protons and neutrons are clustered closely together. The electrons constantly move around the nucleus. Helium has two protons and two neutrons in its nucleus and two electrons moving around the nucleus. Atoms of other elements have different numbers of subatomic particles, but the number of protons always equals the number of electrons. This makes atoms neutral in charge because the positive and negative charges "cancel out."

Q: Lithium has three protons, four neutrons, and three electrons. Sketch a model of a lithium atom, similar to the model 23.2 for helium.

A: Does your sketch resemble the model in the **Figure** 23.3? The model has three protons (blue) and four neutrons (gray) in the nucleus, with three electrons (red) moving around the nucleus.

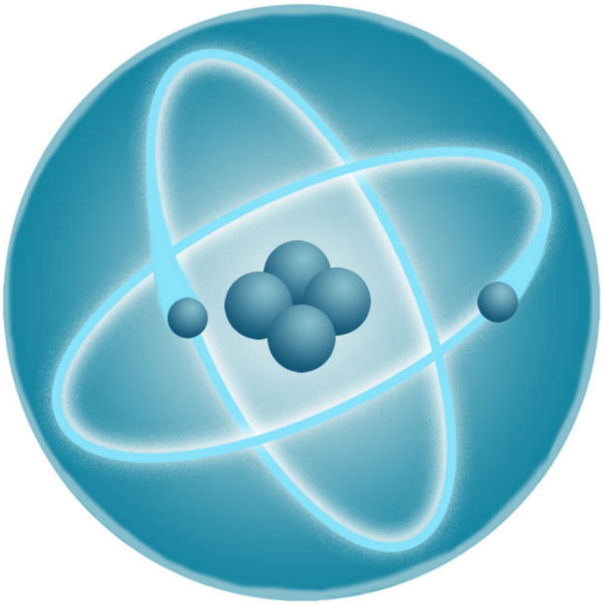


FIGURE 23.2
Model of a helium atom.

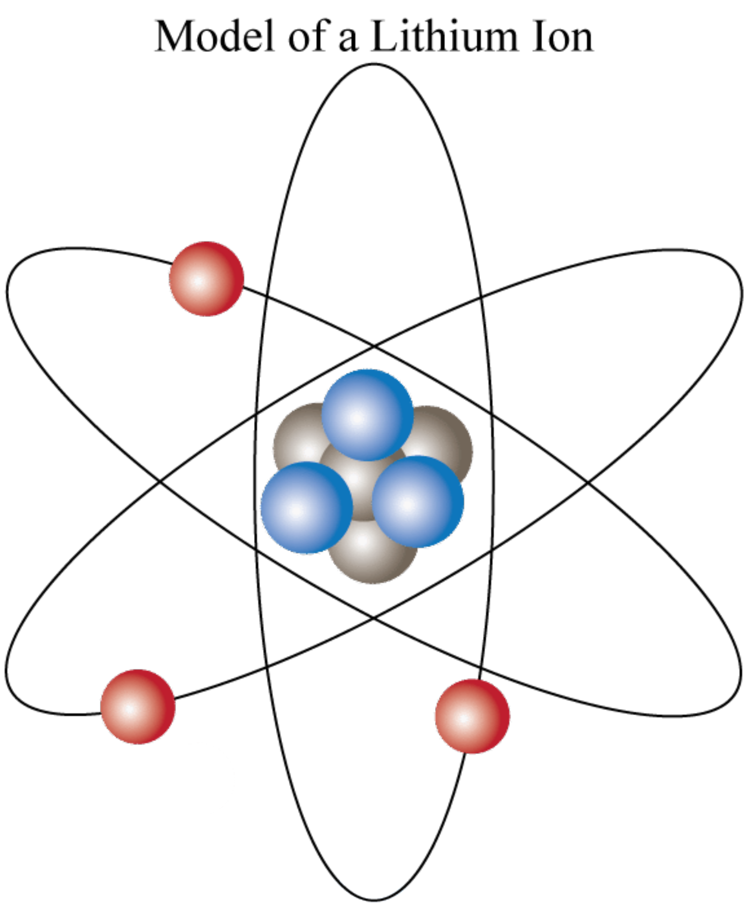


FIGURE 23.3

Q: All atoms of carbon have six protons. How many electrons do carbon atoms have?

A: Carbon atoms must have six electrons to "cancel out" the positive charges of the six protons. That's because atoms are always neutral in electric charge.

Summary

- Atoms are the building blocks of matter. They are the smallest particles of an element that still have the element's properties.
- All atoms are very small, but atoms of different elements vary in size.
- Three main types of particles that make up all atoms are protons, neutrons, and electrons.

Review

1. What is an atom?
2. Which of the following statements is true about the atoms of any element?
    a. They have the same number of protons as the atoms of all other elements.
    b. They have protons that are identical to the protons of all other elements.
    c. They have the same size as the atoms of all other elements.
    d. They have the same number of protons as neutrons.
3. Explain why atoms are always neutral in charge.

23.2 Nuclear Energy

Lesson Objectives

- Describe nuclear fission and how it is used for energy.
- Describe nuclear fusion and challenges to its use for energy.
- Relate nuclear energy to Einstein's equation, $E = mc^2$.

Lesson Vocabulary

- nuclear energy
- nuclear fission
- nuclear fusion

Introduction

Nuclear energy is the energy released in nuclear reactions. Two types of reactions that release huge amounts of energy are nuclear fission and nuclear fusion.

Energy from Nuclear Fission

Nuclear fission is the splitting of the nucleus of an atom into two smaller nuclei. This type of reaction releases a great deal of energy from a very small amount of matter. For example, nuclear fission of a tiny pellet of uranium-235, like the one pictured in **Figure** 23.4, can release as much energy as burning 1,000 kilograms of coal!

Nuclear fission of uranium-235 can be represented by this equation:

$$^{235}_{92}\text{U} + 1\text{ Neutron} \rightarrow ^{92}_{36}\text{Kr} + ^{141}_{56}\text{Ba} + 3\text{ Neutrons} + \text{Energy}$$

As shown in **Figure** 23.5, the reaction begins when a nucleus of uranium-235 absorbs a neutron. This can happen naturally or when a neutron is deliberately crashed into a uranium nucleus in a nuclear power plant. In either case, the nucleus of uranium becomes very unstable and splits in two. In this example, it forms krypton-92 and barium-141. The reaction also releases three neutrons and a great deal of energy.

Nuclear Chain Reaction

The neutrons released in this nuclear fission reaction may be captured by other uranium nuclei and cause them to fission as well. This can start a nuclear chain reaction (see **Figure** 23.6). In a chain reaction, one fission reaction

FIGURE 23.4
This pellet of uranium-235 can release a huge amount of energy if it undergoes nuclear fission.

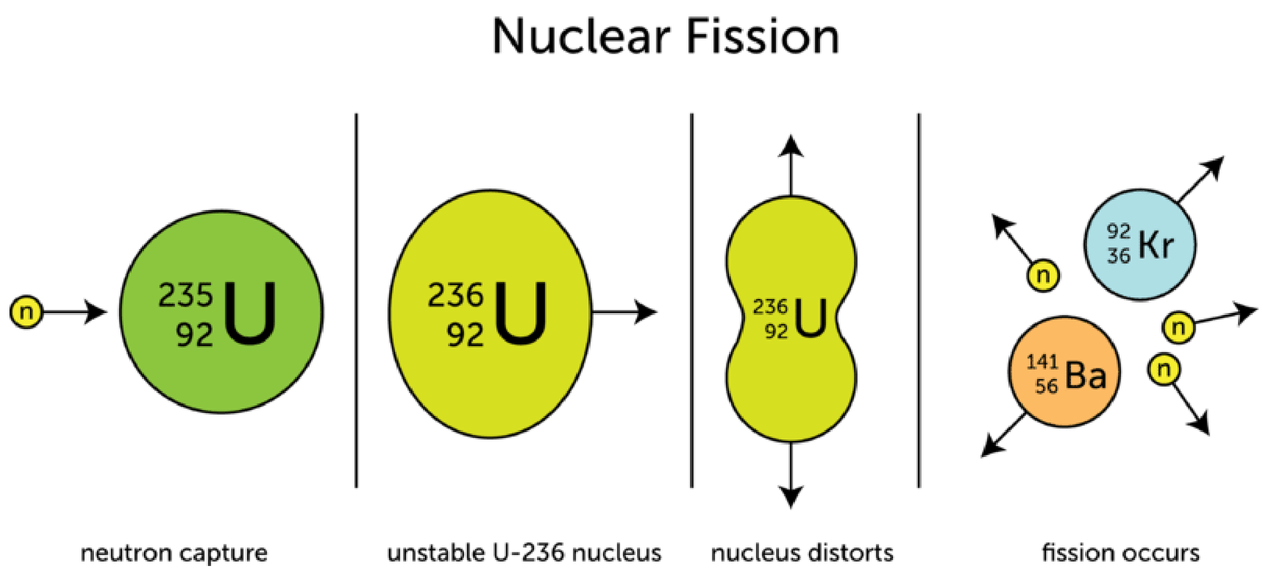
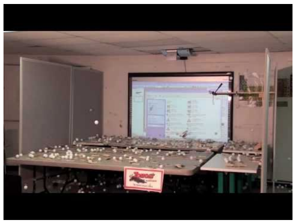


FIGURE 23.5
The fissioning of a nucleus of uranium-235 begins when it captures a neutron.

leads to others, which lead to others, and so on. A nuclear chain reaction is similar to a pile of wood burning. If you start one piece of wood burning, enough heat is produced by the burning wood to start the rest of the pile burning without any further help from you. You can see another example of a chain reaction at this URL: http://www.youtube.com/watch?v=0v8i4v1mieU (2:54).



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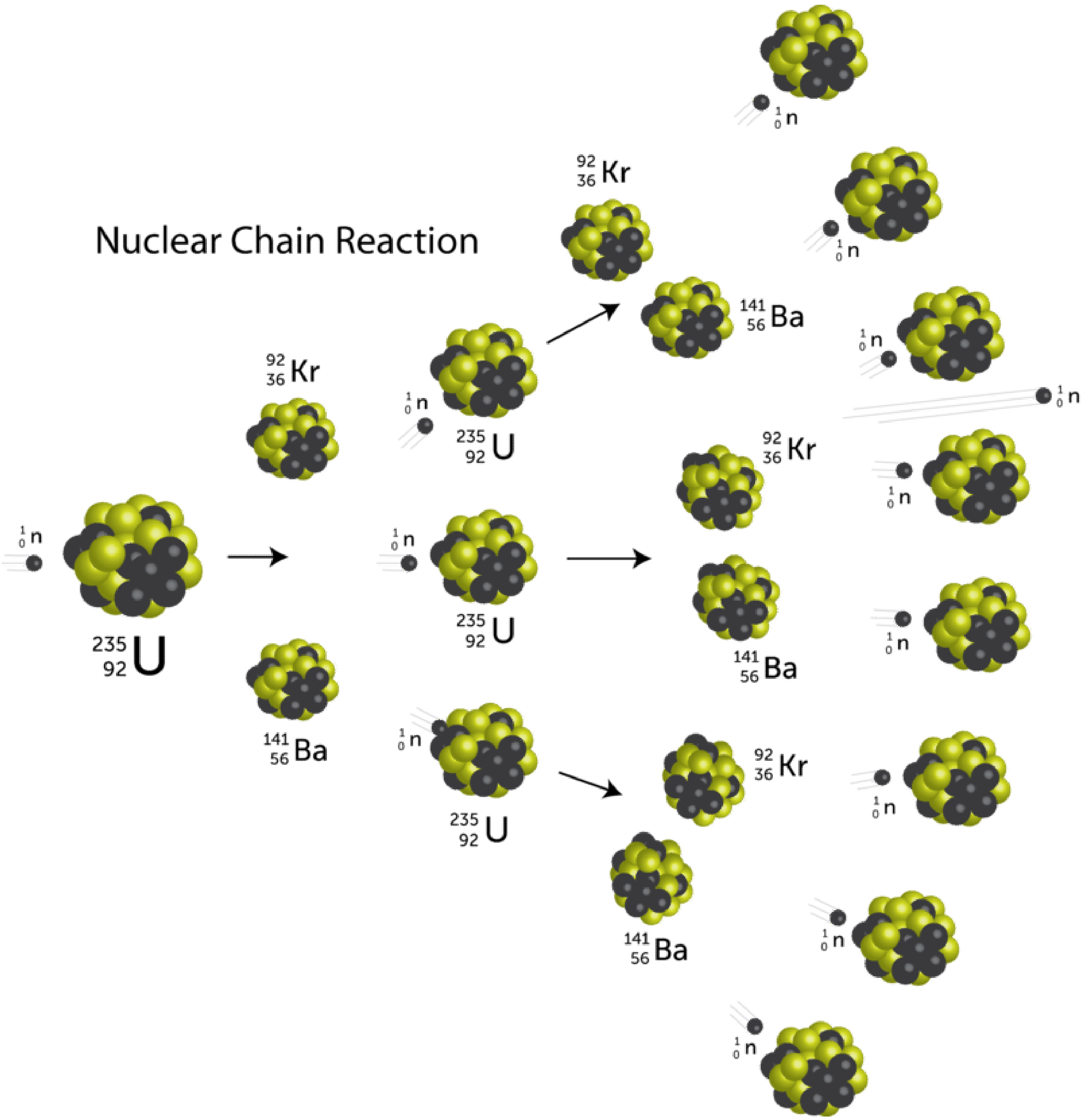


FIGURE 23.6

In a nuclear chain reaction, each nuclear reaction leads to more nuclear reactions.

Using Energy from Nuclear Fission

If a nuclear chain reaction is uncontrolled, it produces a lot of energy all at once. This is what happens in an atomic bomb. If a nuclear chain reaction is controlled, it produces energy more slowly. This is what occurs in a nuclear power plant. The reaction may be controlled by inserting rods of material that do not undergo fission into the core of fissioning material (see **Figure** 23.7). The radiation from the controlled fission is used to heat water and turn it to steam. The steam is under pressure and causes a turbine to spin. The spinning turbine runs a generator, which produces electricity.

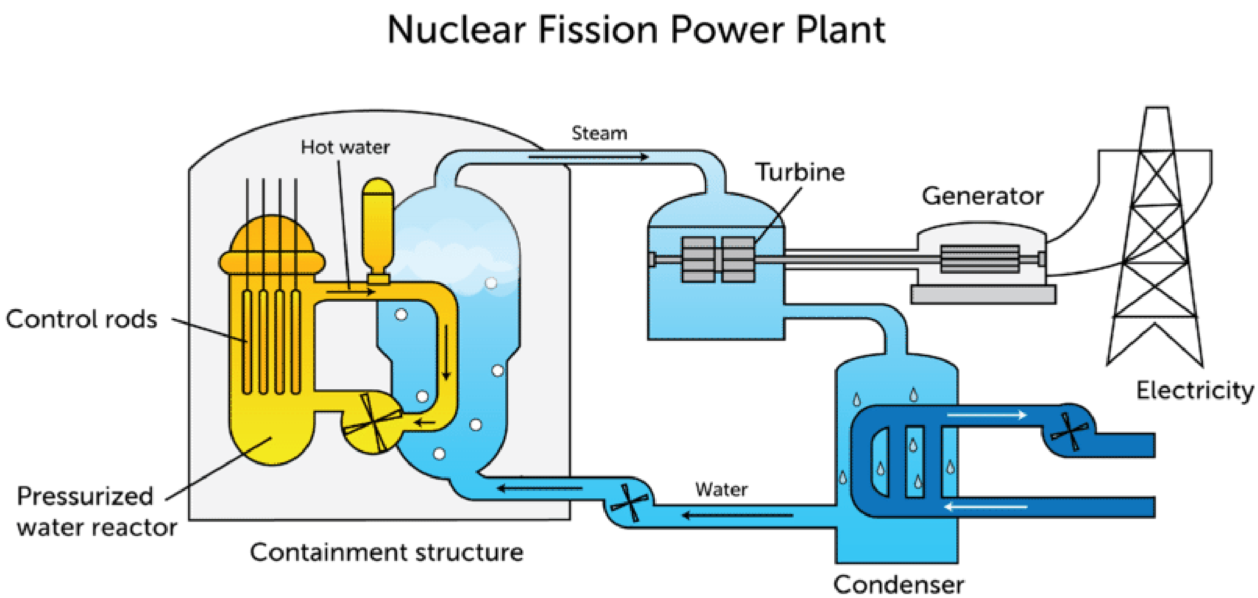


FIGURE 23.7

This diagram shows the main parts of a nuclear power plant.

Pros and Cons of Nuclear Fission

In the U.S., the majority of electricity is produced by burning coal or other fossil fuels. This causes air pollution, acid rain, and global warming. Fossil fuels are also limited and may eventually run out. Like fossil fuels, radioactive elements are limited. In fact, they are relatively rare, so they could run out sooner rather than later. On the other hand, nuclear fission does not release air pollution or cause the other environmental problems associated with burning fossil fuels. This is the major advantage of using nuclear fission as a source of energy.

The main concern over the use of nuclear fission is the risk of radiation. Accidents at nuclear power plants can release harmful radiation that endangers people and other living things. Even without accidents, the used fuel that is left after nuclear fission reactions is still radioactive and very dangerous. It takes thousands of years for it to decay until it no longer releases harmful radiation. Therefore, used fuel must be stored securely to people and other living things. You can learn more about the problem of radioactive waste at this URL: http://www.youtube.com/watch?v=OPQ97LVRuuM .

Energy from Nuclear Fusion

Nuclear fusion is the opposite of nuclear fission. In fusion, two or more small nuclei combine to form a single, larger nucleus. An example is shown in **Figure** 23.8. In this example, two hydrogen nuclei fuse to form a helium nucleus. A neutron and a great deal of energy are also released. In fact, fusion releases even more energy than fission does.

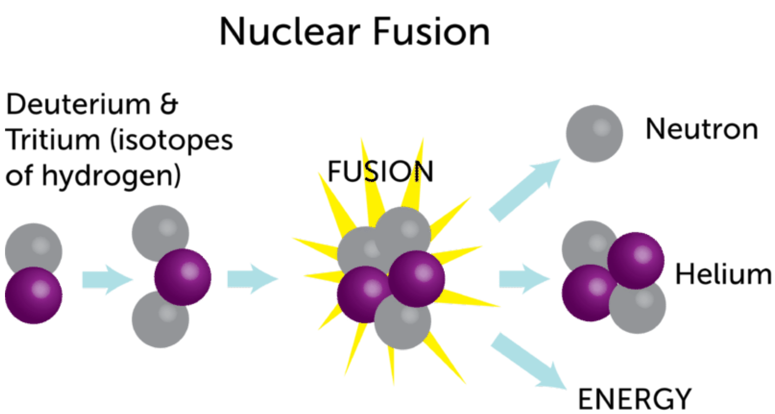


FIGURE 23.8
In this nuclear fusion reaction, nuclei of two hydrogen isotopes (tritium and deuterium) fuse together. They form a helium nucleus, a neutron, and energy.

The Power of Stars

Nuclear fusion of hydrogen to form helium occurs naturally in the sun and other stars. It takes place only at extremely high temperatures. That's because a great deal of energy is needed to overcome the force of repulsion between positively charged nuclei. The sun's energy comes from fusion in its core, where temperatures reach millions of Kelvin (see **Figure** 23.9).

Using Nuclear Fusion

Scientists are searching for ways to create controlled nuclear fusion reactions on Earth. Their goal is develop nuclear fusion power plants, where the energy from fusion of hydrogen nuclei can be converted to electricity. How this might work is shown in **Figure** 23.10.

The use of nuclear fusion for energy has several pros. Unlike nuclear fission, which involves dangerous radioisotopes, nuclear fusion involves hydrogen and helium. These elements are harmless. Hydrogen is also very plentiful. There is a huge amount of hydrogen in ocean water. The hydrogen in just a gallon of water could produce as much energy by nuclear fusion as burning 1,140 liters (300 gallons) of gasoline! The hydrogen in the oceans would generate enough energy to supply all the world's people for a very long time.

Unfortunately, using energy from nuclear fusion is far from a reality. Scientists are a long way from developing the necessary technology. One problem is raising temperatures high enough for fusion to take place. Another problem is that matter this hot exists only in the plasma state. There are no known materials that can contain plasma, although a magnet might be able to do it. That's because plasma consists of ions and responds to magnetism. You can learn more about research on nuclear fusion at the URL below.

http://www.youtube.com/watch?v=3C5hFQeZCT4

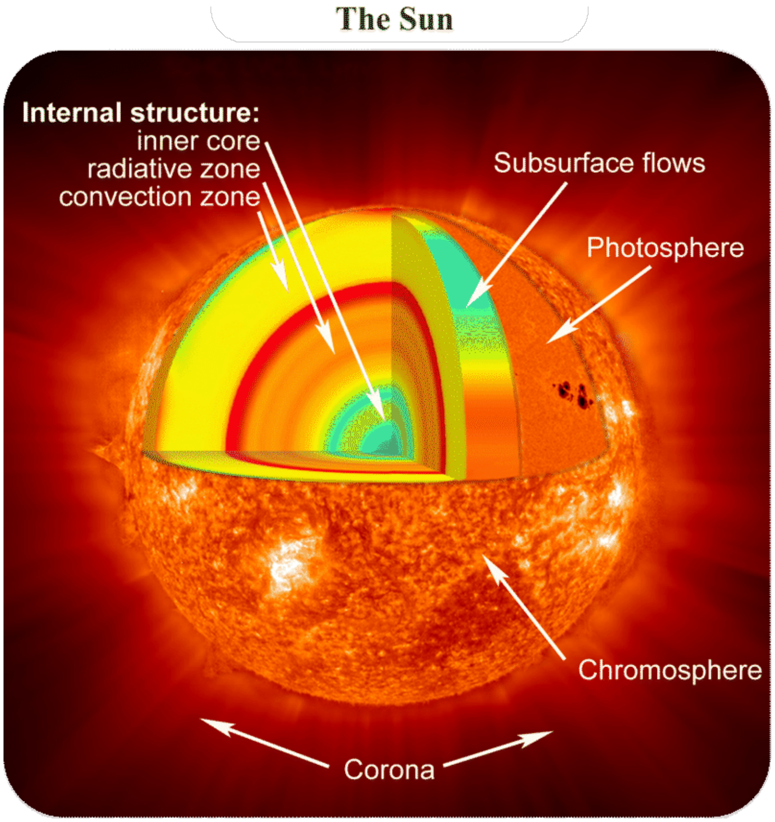


FIGURE 23.9
The extremely hot core of the sun radiates energy from nuclear fusion.

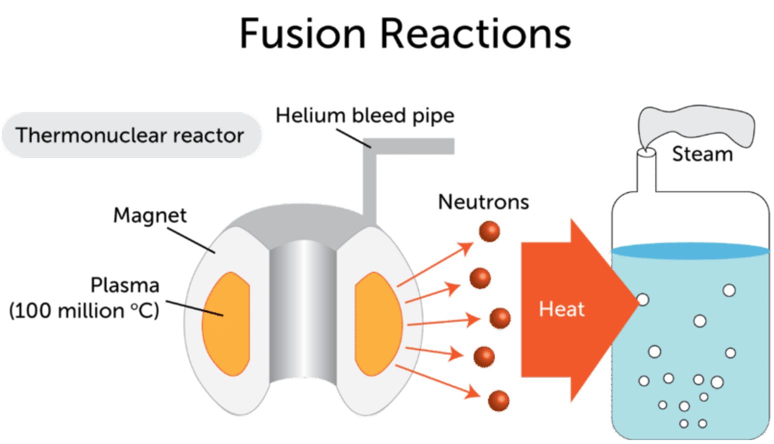


FIGURE 23.10
In the thermonuclear reactor modeled here, radiation from fusion is used to heat water and form steam. The steam can then be used to turn a turbine and generate electricity.

Nuclear Energy and Einstein's Famous Equation

Probably the most famous equation in the world is $E = mc^2$. You may have heard of it. You may have even seen it on a tee shirt or coffee mug. It's a simple equation that was derived in 1905 by the physicist Albert Einstein (see **Figure** 23.11). Although the equation is simple, it is incredibly important. It changed how scientists view two of the most basic concepts in science: matter and energy. The equation shows that matter and energy are two forms of the same thing. It also shows how matter and energy are related. In addition, Einstein's equation explains why nuclear fission and nuclear fusion produce so much energy.

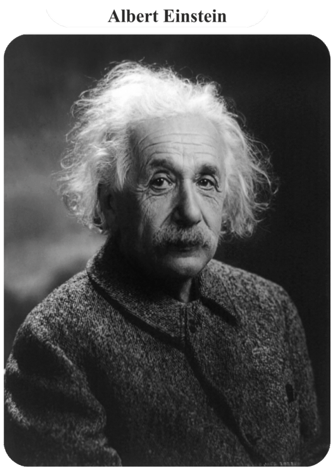


FIGURE 23.11
Albert Einstein is considered by many to be the greatest physicist of all time.

You can listen to a recording of Einstein explaining his famous equation at this URL: http://www.youtube.com/watch?v=CC7Sg41Bp-U .

What Einstein's Equation Means

In Einstein's equation, the variable E stands for energy and the variable m stands for mass. The c in the equation is a constant. It stands for the speed of light. The speed of light is 300,000 kilometers (186,000 miles) per second, so c^2 is a very big number, no matter what units are used to measure it. Einstein's equation means that the energy in a given amount of matter is equal to its mass times the square of the speed of light. That's a huge amount of energy from even a tiny amount of mass. Suppose, for example, that you have 1 gram of matter. That's about the mass of a paperclip. Multiplying that mass by the square of the speed of light yields enough energy to power 3,600 homes for a year!

Mass and Energy in Nuclear Reactions

When the nucleus of a radioisotope undergoes fission or fusion, it loses a tiny amount of mass. What happens to the lost mass? It isn't really lost at all. It is converted to energy. How much energy? $E = mc^2$. The change in mass is tiny, but it results in a great deal of energy.

What about the laws of conservation of mass and conservation of energy? Do they not apply to nuclear reactions? We don't need to throw out these laws. Instead, we just need to combine them. It is more correct to say that the sum of mass and energy is always conserved in a nuclear reaction. Mass may change to energy, but the amount of mass and energy combined remains the same.

Lesson Summary

- Nuclear fission is the splitting of the nucleus of an atom into two smaller nuclei. This releases a great deal of energy. Nuclear power plants use the energy from nuclear fission to generate electricity.
- Nuclear fusion is the fusing of two or more smaller nuclei to form a single, larger nucleus. Fusion releases even more energy than fission. Researchers are trying to find a way to use the energy from nuclear fusion to generate electricity.

- Einstein's equation, $E = mc^2$, shows that matter and energy are two forms of the same thing. In nuclear fission and nuclear fusion, a tiny amount of matter changes to a huge amount of energy. The amount of energy equals the mass of the "lost" matter times the square of the speed of light.

Lesson Review Questions

Recall

1. Describe how nuclear fission occurs.
2. What is a nuclear chain reaction?
3. Outline what happens during nuclear fusion.
4. What are advantages of using nuclear fusion as opposed to nuclear fission for energy?

Apply Concepts

5. Create a flowchart to show how nuclear fission is used to generate electricity.

Think Critically

6. Relate Einstein's equation, $E = mc^2$, to the energy released in nuclear fission and nuclear fusion.
7. Less than one-quarter of the electricity used in the U.S. is generated from nuclear energy. Some people think we should use more nuclear power. Other people think we should use less or even none at all. Take a stand on this issue, and present facts and logical arguments to support your point of view.

Points to Consider

Einstein's equation is part of a larger theory called the theory of relativity. It is concerned with concepts such as motion and forces as well as mass and energy. Motion and forces are the focus of succeeding chapters.

- Based on your real-world experiences, how would you define motion?
- Forces include gravity and friction. How might these forces be related to motion?

23.3 The Sun

Lesson Objectives

- Describe the layers of the Sun.
- Describe the surface features of the Sun.

Vocabulary

- chromosphere
- convection zone
- corona
- nuclear fusion
- photon
- photosphere
- plasma
- radiative zone
- solar flare
- solar prominence

Introduction

Consider Earth, the Moon, and all the other planets and satellites in the solar system. The mass of all of those objects together accounts for only 0.2% of the total mass of the solar system. The rest, 99.8% of all the mass in the solar system, is the Sun!

The Sun (**Figure** 23.12) is the center of the solar system and the largest object in the solar system. This nearby star provides light and heat and supports almost all life on Earth.

Layers of the Sun

The Sun is a sphere, composed almost entirely of the elements hydrogen and helium. The Sun is not solid or a typical gas. Most atoms in the Sun exist as **plasma**, a fourth state of matter made up of superheated gas with a positive electrical charge.

Internal Structure

Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure with identifiable layers (**Figure** 23.13). From inward to outward they are:

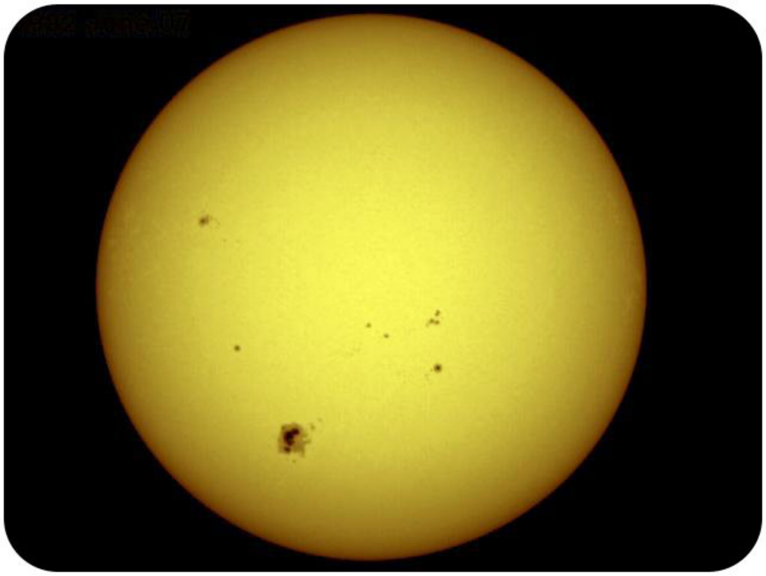


FIGURE 23.12
The Sun.

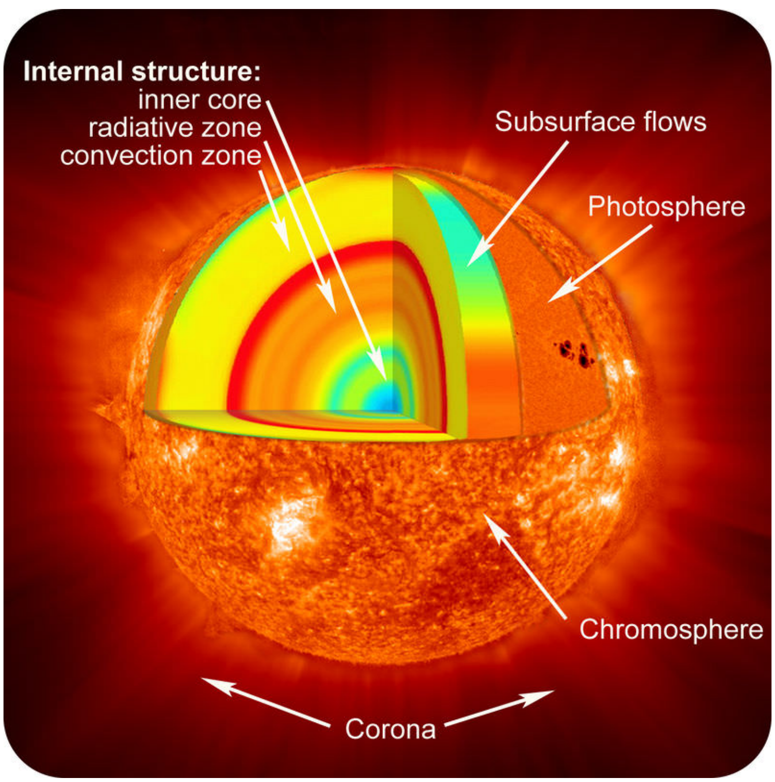


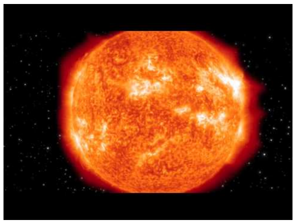
FIGURE 23.13
The layers of the Sun.

- The Sun's central core is plasma with a temperature of around 27 million^{o}C. At such high temperatures hydrogen combines to form helium by **nuclear fusion**, a process that releases vast amounts of energy. This energy moves outward, towards the outer layers of the Sun. Nuclear fusion in stars is discussed more in the *Stars, Galaxies, and the Universe* chapter.
- The **radiative zone**, just outside the core, has a temperature of about 7 million^{o}C. The energy released in the core travels extremely slowly through the radiative zone. A particle of light, called a **photon**, travels only a

few millimeters before it hits another particle. The photon is absorbed and then released again. A photon may take as long as 50 million years to travel all the way through the radiative zone.

- In the **convection zone**, hot material from near the radiative zone rises, cools at the Sun's surface, and then plunges back downward to the radiative zone. Convective movement helps to create solar flares and sunspots.

The first video describes the basics of our Sun, including how it is powered by nuclear reactions **(1e)**: http://www.youtube.com/watch?v=JHf3dG0Bx7I (8:34).



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The second video discusses what powers the sun and what is its influence on Earth and the rest of the solar system **(1e)**: http://www.youtube.com/watch?v=S6VRKKh6gyA (8:25).

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The Outer Layers

The next three layers make up the Sun's atmosphere. Since there are no solid layers to any part of the Sun, these boundaries are fuzzy and indistinct.

- The **photosphere** is the visible surface of the Sun, the region that emits sunlight. The photosphere is relatively cool – only about 6,700°C. The photosphere has several different colors; oranges, yellow and reds, giving it a grainy appearance.
- The **chromosphere** is a thin zone, about 2,000 km thick, that glows red as it is heated by energy from the photosphere (**Figure** 23.14). Temperatures in the chromosphere range from about 4,000°C to about 10,000°C. Jets of gas fire up through the chromosphere at speeds up to 72,000 km per hour, reaching heights as high as 10,000 km.

- The **corona** is the outermost plasma layer – It is the Sun's halo or 'crown.' The corona's temperature of 2 to 5 million°C is much hotter than the photosphere (**Figure** 23.15).

The movie *Seeing a Star in a New Light* can be seen here: http://sdo.gsfc.nasa.gov/gallery/youtube.php .

Surface Features

The Sun's surface features are quite visible, but only with special equipment. For example, sunspots are only visible with special light-filtering lenses.

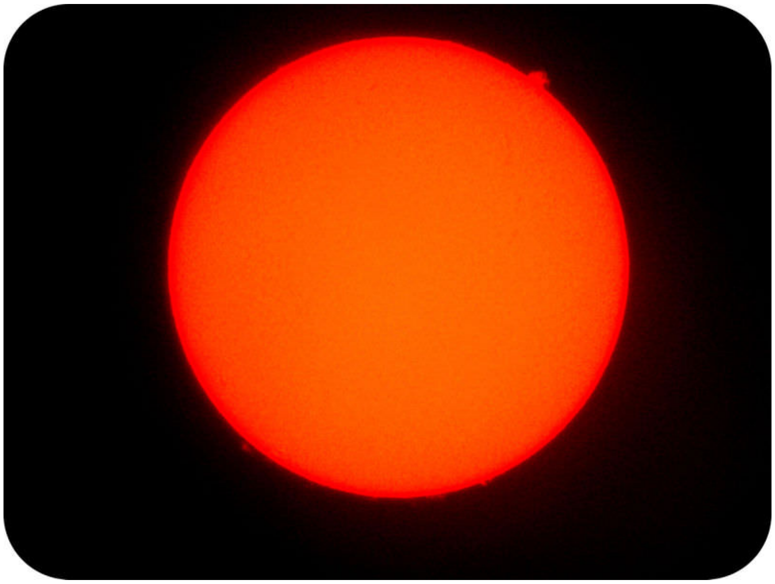


FIGURE 23.14
The chromosphere as seen through a filter.

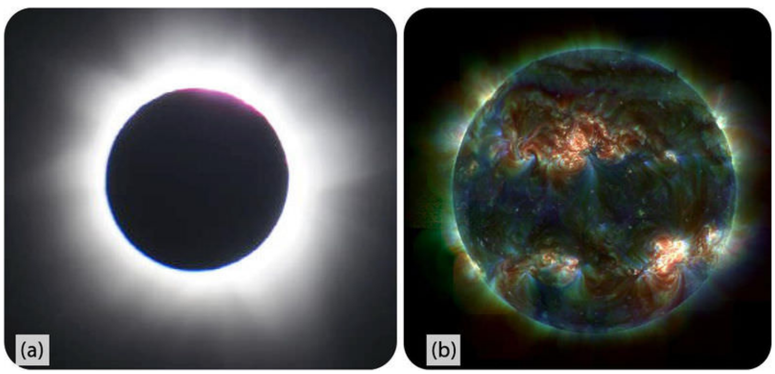


FIGURE 23.15
(a) During a solar eclipse, the Sun's corona is visible extending millions of kilometers into space. (b) The corona and coronal loops in the lower solar atmosphere taken by the TRACE space telescope.

Sunspots

The most noticeable surface feature of the Sun are cooler, darker areas known as sunspots (**Figure** 23.16). Sunspots are located where loops of the Sun's magnetic field break through the surface and disrupt the smooth transfer of heat from lower layers of the Sun, making them cooler and darker and marked by intense magnetic activity. Sunspots usually occur in pairs. When a loop of the Sun's magnetic field breaks through the surface, a sunspot is created where the loop comes out and where it goes back in again.

Solar Flares

There are other types of interruptions of the Sun's magnetic energy. If a loop of the sun's magnetic field snaps and breaks, it creates **solar flares**, which are violent explosions that release huge amounts of energy (**Figure** 23.17).

A movie of the flare is seen here: http://www.youtube.com/watch?v=MDacxUQWeRw .

A strong solar flare can turn into a coronal mass ejection (**Figure** 23.18).

A solar flare or coronal mass ejection releases streams of highly energetic particles that make up the solar wind. The solar wind can be dangerous to spacecraft and astronauts because it sends out large amounts of radiation that can

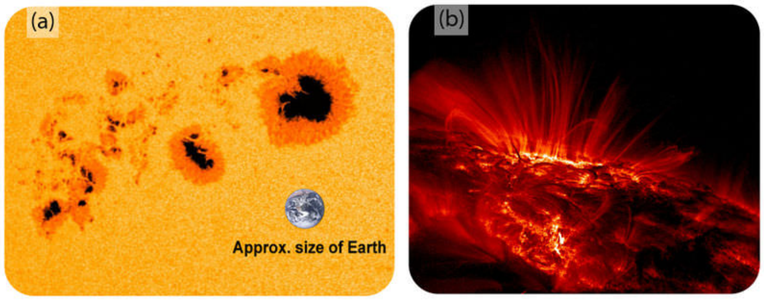


FIGURE 23.16
(a) Sunspots usually occur in 11-year cycles, increasing from a minimum number to a maximum number and then gradually decreasing to a minimum number again. (b) A close-up of a sunspot taken in ultraviolet light.

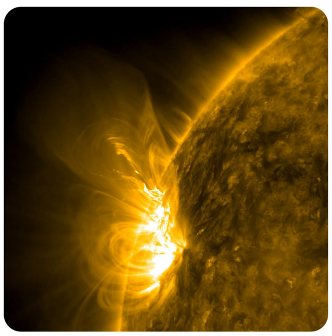


FIGURE 23.17
Magnetic activity leads up to a small solar flare.

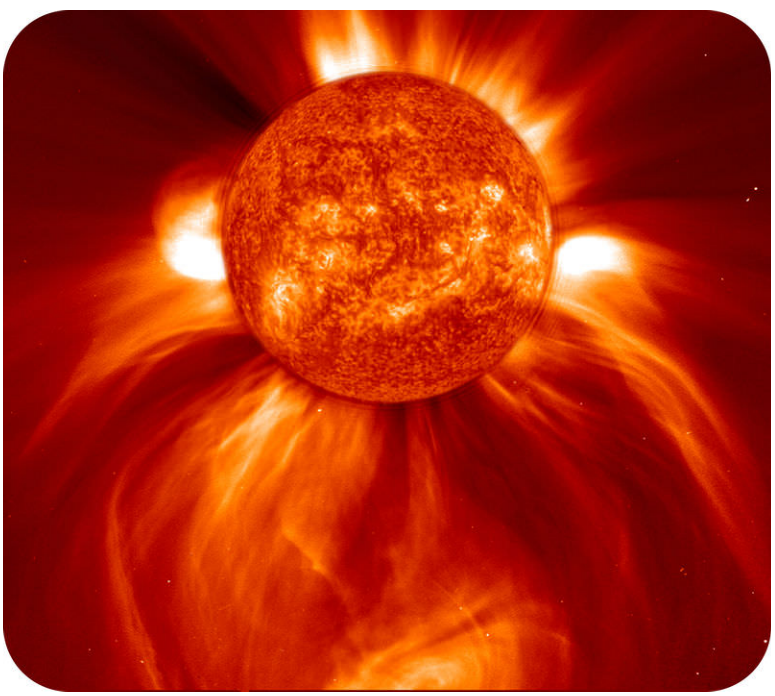
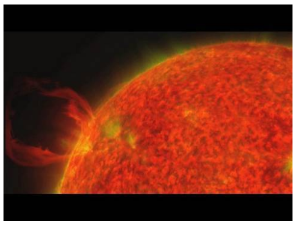


FIGURE 23.18
A coronal mass ejection is a large ejection of plasma from the star seen in this image.

harm the human body. Solar flares have knocked out entire power grids and disturbed radio, satellite, and cell phone communications.

KQED: Journey Into the Sun

The Solar Dynamics Observatory is a NASA spacecraft launched in early 2010 is obtaining IMAX-like images of the sun every second of the day, generating more data than any NASA mission in history. The data will allow researchers to learn about solar storms and other phenomena that can cause blackouts and harm astronauts. Learn more at: http://science.kqed.org/quest/video/quest-quiz-the-sun/ .



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Solar Prominences

Another highly visible feature on the Sun is **solar prominences**. If plasma flows along a loop of the Sun's magnetic field from sunspot to sunspot, it forms a glowing arch that reaches thousands of kilometers into the Sun's atmosphere. Prominences can last for a day to several months. Prominences are also visible during a total solar eclipse.

Solar prominences are displayed in this video from NASA's Solar Dynamics Observatory (SDO): http://www.youtube.com/watch?v=QrmUUcr4HXg .

Most of the imagery comes from SDO's AIA instrument; different colors represent different temperatures, a common technique for observing solar features. SDO sees the entire disk of the Sun in extremely high spatial and temporal resolution, allowing scientists to zoom in on notable events such as flares, waves, and sunspots.

Solar Dynamics Observatory

The video above was taken from the SDO, the most advanced spacecraft ever designed to study the Sun. During its five-year mission, SDO will examine the Sun's magnetic field and also provide a better understanding of the role the Sun plays in Earth's atmospheric chemistry and climate. Since just after its launch on February 11, 2010, SDO is providing images with clarity 10 times better than high-definition television and will return more comprehensive science data faster than any other solar observing spacecraft.

Lesson Summary

- The mass of the Sun is 99.8% of the mass of our solar system.
- The Sun is mostly made of hydrogen with smaller amounts of helium in the form of plasma.
- The main part of the Sun has three layers: the core, radiative zone, and convection zone.
- The Sun's atmosphere also has three layers: the photosphere, the chromosphere, and the corona.
- Nuclear fusion of hydrogen in the core of the Sun produces tremendous amounts of energy that radiate out from the Sun.
- Some features of the Sun's surface include sunspots, solar flares, and prominences.

Review Questions

1. In what way does the Sun support all life on Earth?
2. Which two elements make up the Sun almost in entirety?
3. Which process is the source of heat in the Sun and where does it take place?
4. Why would human astronauts on a trip to Mars need to be concerned about solar wind? What is solar wind?
5. Describe how movements in the convection zone contribute to solar flares.
6. Do you think fusion reactions in the Sun's core will continue forever and go on with no end? Explain your answer.

Further Reading / Supplemental Links

- To find these videos for download, check out: http://www.nasa.gov/mission_pages/sdo/news/briefing-materials-20100421.html and http://svs.gsfc.nasa.gov/Gallery/SDOFirstLight.html .
- Subscribe to NASA's Goddard Shorts HD podcast: http://svs.gsfc.nasa.gov/vis/iTunes/f0004_index.html .
- To learn more about the SDO mission, visit: http://sdo.gsfc.nasa.gov/ .
- To learn about an older solar mission, SOHO, see: http://sohowww.nascom.nasa.gov/ .

Points to Consider

- If something were to suddenly cause nuclear fusion to stop in the Sun, how would we know? When would we know?
- Are there any types of dangerous energy from the Sun? What might be affected by them?
- If the Sun is made of gases such as hydrogen and helium, how can it have layers?

Going Further - Applying Math

Have would you measure something that you cannot reach? The answer is that you can use simple geometry. We can measure the diameter of the Sun, even though we cannot go to the Sun and even though the Sun is far too large for a human being to measure. To measure the Sun we use the rules of similar triangles. The sides of similar triangles are proportional to each other. By setting up one very small triangle that is proportional to another very large triangle, we can find an unknown distance or measurement as long as we know three out of four of the parts of the equation. If you make a pinhole in an index card and project an image of the Sun onto a clipboard held 1 meter from the index card, the diameter of our projected image of the Sun will be proportional to the true diameter of the Sun. Here's the equation: $s / d = S / D$, where s = diameter of the projected image of the Sun, S = true diameter of the Sun. The calculation also requires you to know the true distance between the Earth and the Sun, $D = 1.496 \times 10^8$ km and the distance (d = 1 meter) between the clipboard and the index card. Before you can correctly solve this equation, you will need to be sure all of your measurements are in the same units - in this case, change all your measurements to km. Try this out and see how accurately you can measure the true diameter of the Sun.

23.4 References

1. Zachary Wilson. Atomic size chart. CC BY-NC 3.0
2. Laura Guerin. Model of a helium atom. CC BY-NC 3.0
3. Zachary Wilson. Model of a lithium atom. CC BY-NC 3.0
4. Courtesy of the US Nuclear Regulatory Commission. http://www.nrc.gov/images/reading-rm/photo-gallery/20071114-022.jpg. Public Domain
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12. Courtesy of NASA. <a href="http://commons.wikimedia.org/wiki/File:Sun920607.jpg">http://commons.wikimedia.org/w Public Domain
13. Courtesy of NASA. http://www.nasa.gov/mission_-pages/hinode/solar_020.html. Public Domain
14. Brian. http://commons.wikimedia.org/wiki/File:Makelessnoise_-_Close-Up_of_a_Star_in_H-Alpha_-%28by%29.jpg. CC BY 2.0
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16. (a) Courtesy of NASA/SDO; (b) Courtesy of NASA/TRACE. (a) http://www.na sunspot-ar1944/#.UvwwaoXtDZc; (b) http://commons.wikimedia.org/wiki/File:Sunspot_TRACE.jpeg. Public Domain
17. Courtesy of NASA/SDO. <a href="http://sdo.gsfc.nasa.gov/gallery/main/item/19">http://sdo.gsfc.nasa.gov/gallery/main/it Public Domain
18. Courtesy of NASA/GSFC/SOHO/ESA. <a href="http://www.flickr.com/photos/gsfc/4446276828/">http://www.flickr.com CC BY 2.0

CHAPTER 24 Stars, Galaxies, and the Universe

Chapter Outline

The Whirlpool Galaxy, also known as M51, is a spiral galaxy about 23 million light-years from Earth. Its interactions with the yellowish dwarf galaxy NGC 5195 are of interest to astronomers because the galaxies are near enough to Earth to be well-studied.

Decades ago astronomers could not tell if these two galaxies were just passing each other but radio astronomy has supplied astronomers with important data outlining their interactions. Using this data, astronomers have simulated the interaction. NGC 5195 came from behind and then passed through the main disk of M51 about 500 to 600 million years ago. The dwarf galaxy crossed the disk again between 50 and 100 million years ago and is now slightly behind M51. These interactions appear to have intensified the spiral arms that are the dominant characteristic of the Whirlpool Galaxy.

Astronomers are able to learn about objects unimaginably far away from Earth using telescopes that sense all wavelengths on the electromagnetic spectrum. Imagine what Galileo would do if he could see the images and data astronomers have available to them now.

Courtesy of NASA and European Space Agency. commons.wikimedia.org/wiki/File:Messier51_sRGB.jpg. Public Domain.

24.1 The Universe

Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.
- Define dark matter and dark energy.

Vocabulary

- Big Bang Theory
- cosmology
- dark energy
- dark matter
- Doppler Effect
- redshift
- universe

Introduction

The study of the universe is called **cosmology**. Cosmologists study the structure and changes in the present universe. The **universe** contains all of the star systems, galaxies, gas and dust, plus all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe includes all of space and time.

Evolution of Human Understanding of the Universe

What did the ancient Greeks recognize as the universe? In their model, the universe contained Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries until Galileo's telescope helped allow people to recognize that Earth is not the center of the universe. They also found out that there are many more stars than were visible to the naked eye. All of those stars were in the Milky Way Galaxy.

In the early 20th century, an astronomer named Edwin Hubble **Figure** 24.1 discovered that what scientists called the Andromeda Nebula was actually over 2 million light years away —many times farther than the farthest distances that had ever been measured. Hubble realized that many of the objects that astronomers called nebulas were not actually clouds of gas, but were collections of millions or billions of stars —what we now call galaxies.

Hubble showed that the universe was much larger than our own galaxy. Today, we know that the universe contains about a hundred billion galaxies—about the same number of galaxies as there are stars in the Milky Way Galaxy.

Expansion of the Universe

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

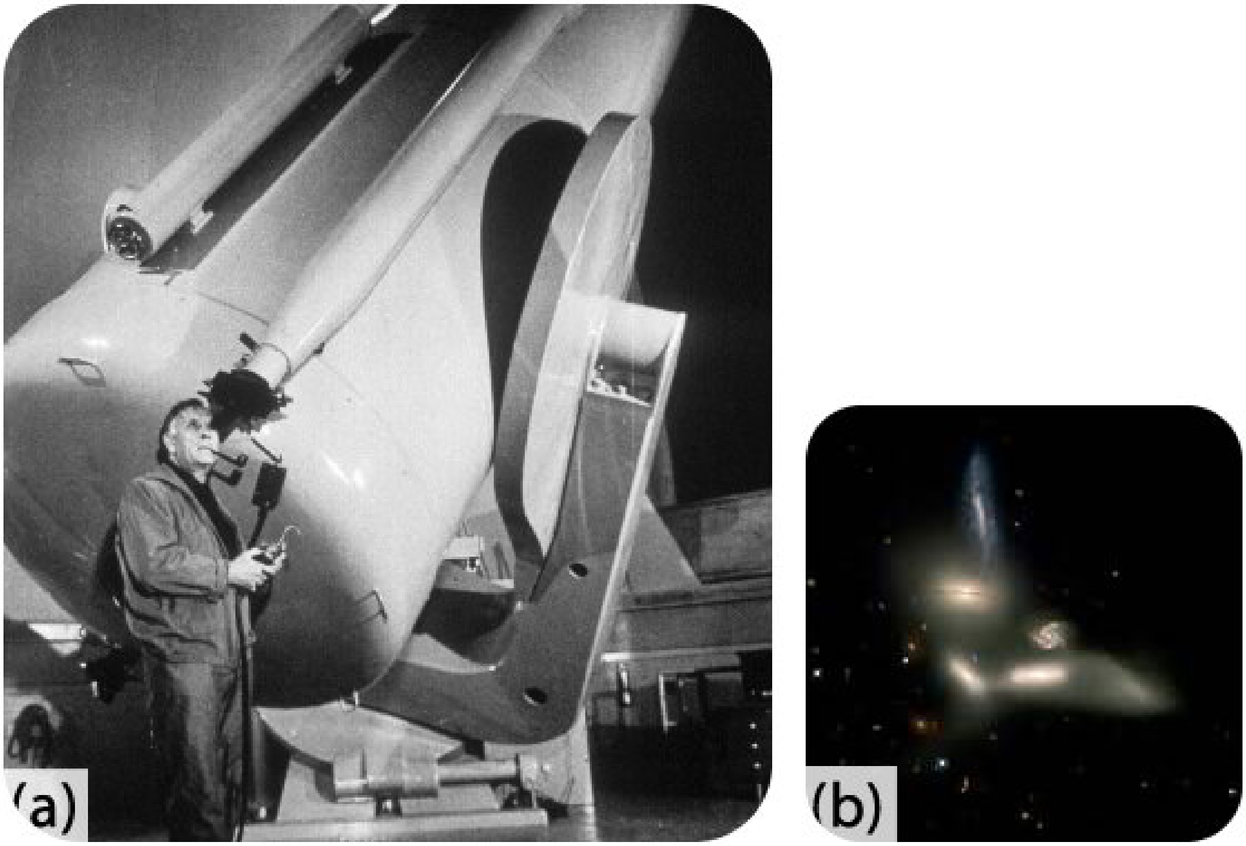

FIGURE 24.1

(a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) Hubble's namesake space telescope spotted this six galaxy group. Edwin Hubble demonstrated the existence of galaxies.

Redshift

If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain energies. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun —not on Earth —by analyzing the absorption lines in the spectrum of the Sun.

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in **Figure** 24.2. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

Redshift occurs when the light source is moving away from the observer or when the space between the observer and the source is stretched. What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth.

If galaxies were moving randomly, would some be redshifted but others be blueshifted? Of course. Since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.

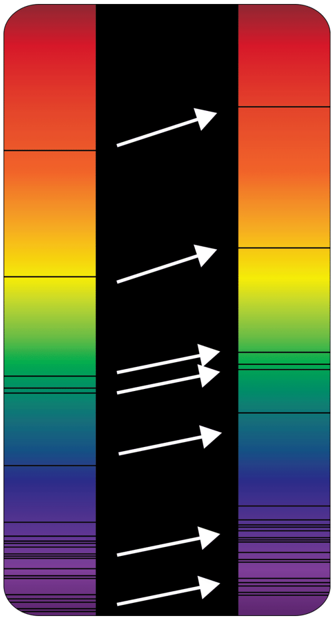

FIGURE 24.2
Redshift is a shift in absorption bands toward the red end of the spectrum. What could make the absorption bands of a star shift toward the red?

Redshift can occur with other types of waves too. This phenomenon is called the **Doppler Effect**. An analogy to redshift is the noise a siren makes as it passes you. You may have noticed that an ambulance seems to lower the pitch of its siren after it passes you. The sound waves shift towards a lower pitch when the ambulance speeds away from you. Though redshift involves light instead of sound, a similar principle operates in both situations.

An animation of Doppler Effect http://projects.astro.illinois.edu/data/Doppler/index.html .

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: The farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

Figure 24.3 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also the dots farther away from you on the balloon would move away faster than dots nearby.

Expansion of the Universe Diagram

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies like the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

An animation of an expanding universe is shown here: http://www.astro.ubc.ca/~scharein/a311/Sim/bang/BigBang.html .

One other difference between the universe and a balloon involves the actual size of the galaxies. On balloon, the dots

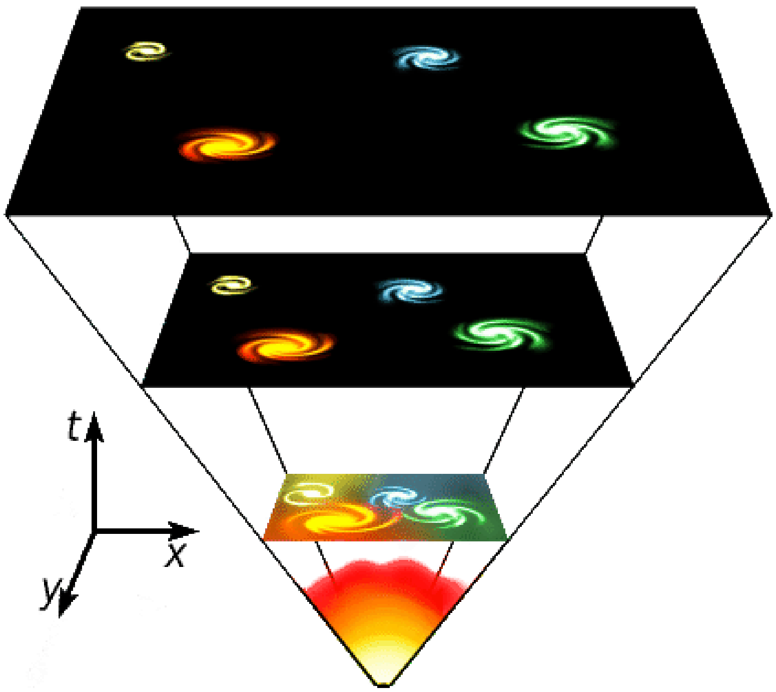

FIGURE 24.3
In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

will become larger in size as you inflate it. In the universe, the galaxies stay the same size, just the space between the galaxies increases.

Formation of the Universe

Before Hubble, most astronomers thought that the universe didn't change. But if the universe is expanding, what does that say about where it was in the past? If the universe is expanding, the next logical thought is that in the past it had to have been smaller.

The Big Bang Theory

The **Big Bang theory** is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back into the past, the universe is contracting – getting smaller and smaller. What is the end result of a contracting universe?

According to the Big Bang theory, the universe began about 13.7 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine all of the known universe in a single, hot, chaotic mass. An enormous explosion —a big bang —caused the universe to start expanding rapidly. All the matter and energy in the universe, and even space itself, came out of this explosion.

What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.

After the Big Bang

In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a few seconds, protons, neutrons, and electrons could form. After a few minutes, those subatomic particles came together to create hydrogen. Energy in the universe was great enough to initiate nuclear fusion and hydrogen nuclei were fused into helium nuclei. The first neutral atoms that included electrons did not form until about 380,000 years later.

The matter in the early universe was not smoothly distributed across space. Dense clumps of matter held close together by gravity were spread around. Eventually, these clumps formed countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

If you look at an image of galaxies at the far edge of what we can see, you are looking at great distances. But you are also looking across a different type of distance. What do those far away galaxies represent? Because it takes so long for light from so far away to reach us, you are also looking back in time (**Figure** 24.4).

FIGURE 24.4
Images from very far away show what the universe was like not too long after the Big Bang.

After the origin of the Big Bang hypothesis, many astronomers still thought the universe was static. Nearly all came around when an important line of evidence for the Big Bang was discovered in 1964. In a static universe, the space between objects should have no heat at all; the temperature should measure 0 K (Kelvin is an absolute temperature scale). But two researchers at Bell Laboratories used a microwave receiver to learn that the background radiation in the universe is not 0 K, but 3 K (**Figure** 24.5). This tiny amount of heat is left over from the Big Bang. Since nearly all astronomers now accept the Big Bang hypothesis, what is it usually referred to as?

An explanation of the Big Bang: http://dvice.com/archives/2009/08/big-bang-animat.php .

How we know about the early universe: http://www.youtube.com/watch?v=uihNu9Icaeo .

History of the Universe, part 2: http://www.youtube.com/watch?v=bK6_p5a-Hbo . *The Evidence for the Big Bang in 10 Little Minutes* provides a great deal of scientific evidence for the Big Bang (**2g**): http://www.youtube.com/watch?v=uyCkADmNdNo (10:10).

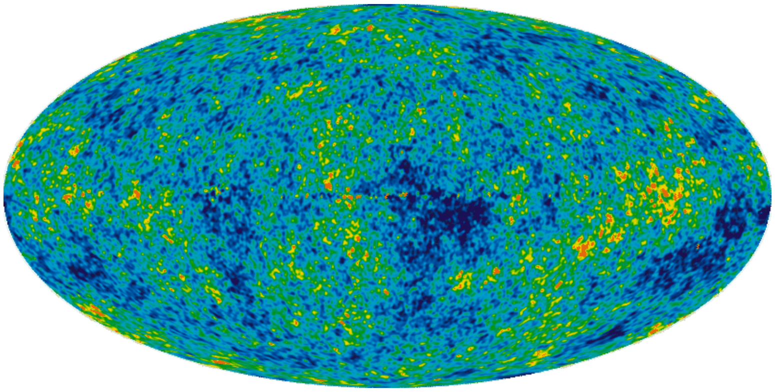

FIGURE 24.5
Background radiation in the universe was good evidence for the Big Bang Theory.

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KQED: Nobel Laureate George Smoot and the Origin of the Universe

George Smoot, a scientist at Lawrence Berkeley National Lab, shared the 2006 Nobel Prize in Physics for his work on the origin of the universe. Using background radiation detected by the Cosmic Background Explorer Satellite (COBE), Smoot was able to make a picture of the universe when it was 12 hours old. Learn more at: http://science.kqed.org/quest/video/nobel-laureate-george-smoot-and-the-origin-of-the-universe/ .

Adobe Flash

MEDIA
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Dark Matter and Dark Energy

The Big Bang theory is still the best scientific model we have for explaining the formation of the universe and many lines of evidence support it. However, recent discoveries continue to shake up our understanding of the universe. Astronomers and other scientists are now wrestling with some unanswered questions about what the universe is made of and why it is expanding. A lot of what cosmologists do is create mathematical models and computer simulations to account for these unknown phenomena.

Dark Matter

The things we observe in space are objects that emit some type of electromagnetic radiation. However, scientists think that matter that emits light makes up only a small part of the matter in the universe. The rest of the matter, about 80%, is dark matter.

Dark matter emits no electromagnetic radiation so we can't observe it directly. However, astronomers know that dark matter exists because its gravity affects the motion of objects around it. When astronomers measure how spiral galaxies rotate, they find that the outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than they can see.

Gravitational lensing occurs when light is bent from a very distant bright source around a super-massive object (**Figure** 24.6). To explain strong gravitational lensing, more matter than is observed must be present.

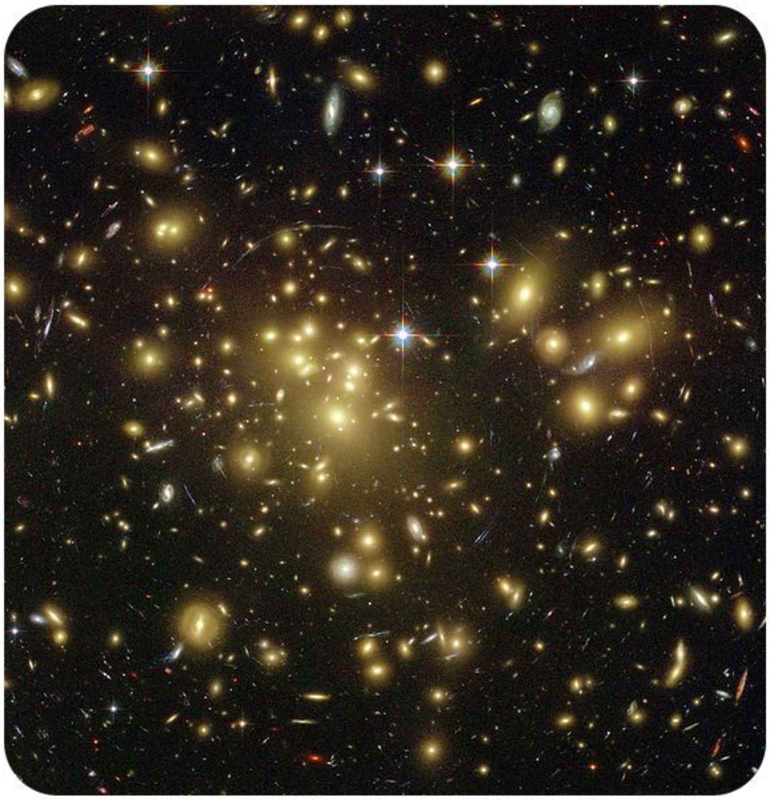

FIGURE 24.6
The arc around the galaxies at the center of this image is caused by gravitational lensing. The addition of gravitational pull from dark matter is required to explain this phenomenon.

With so little to go on, astronomers don't really know much about the nature of dark matter. One possibility is that it could just be ordinary matter that does not emit radiation in objects such as black holes, neutron stars, and brown dwarfs – objects larger than Jupiter but smaller than the smallest stars. But astronomers cannot find enough of these types of objects, which they have named MACHOS (massive astrophyiscal compact halo object), to account for all the dark matter, so they are thought to be only a small part of the total.

Another possibility is that the dark matter is thought to be much different from the ordinary matter we see. Some appear to be particles that have gravity, but don't otherwise appear to interact with other particles. Scientists call these theoretical particles WIMPs, which stands for Weakly Interactive Massive Particles.

Most scientists who study dark matter think that the dark matter in the universe is a combination of MACHOS and some type of exotic matter such as WIMPs. Researching dark matter is an active area of scientific research, and astronomers' knowledge about dark matter is changing rapidly.

A video explaining dark matter is here: http://www.youtube.com/watch?v=gCgTJ6ID6ZA .

Dark Energy

Astronomers who study the expansion of the universe are interested in knowing the rate of that expansion. Is the rate fast enough to overcome the attractive pull of gravity?

- If yes, then the universe will expand forever, although the expansion will slow down over time.
- If no, then the universe would someday start to contract, and eventually get squeezed together in a big crunch, the opposite of the Big Bang.

Recently astronomers have made a discovery that answers that question: the rate at which the universe is expanding is actually increasing. In other words, the universe is expanding faster now than ever before, and in the future it will expand even faster. So now astronomers think that the universe will keep expanding forever. But it also proposes a perplexing new question: What is causing the expansion of the universe to accelerate? One possible hypothesis involves a new, hypothetical form of energy called **dark energy** (**Figure** 24.7). Some scientists think that dark energy makes up as much as 72% of the total energy content of the universe.

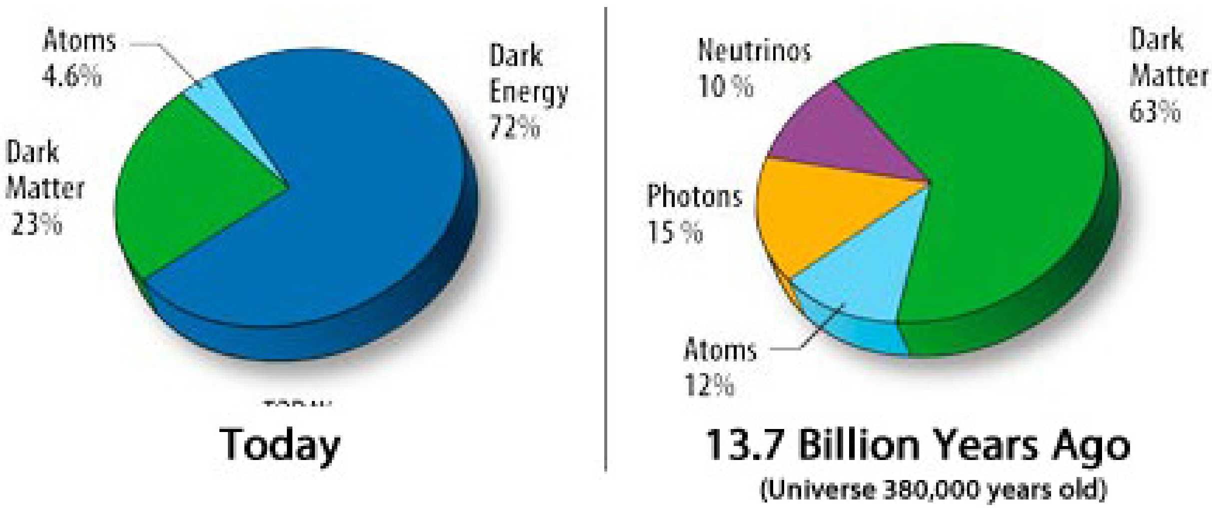

FIGURE 24.7

Today matter makes up a small percentage of the universe, but at the start of the universe it made up much more. Where did dark energy, if it even exists, come from?

Other scientists have other hypotheses about why the universe is continuing to expand; the causes of the universe's expansion is another unanswered question that scientists are researching.

KQED: Dark Energy

Meet one of the three winners of the 2011 Nobel Prize in Physics, Lawrence Berkeley Lab astrophysicist Saul Perlmutter. He explains how dark energy, which makes up 70 percent of the universe, is causing our universe to expand. Learn more at: http://science.kqed.org/quest/video/dark-energy/ .

MEDIA

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URL: http://www.ck12.org/flx/render/embeddedobject/114944

Lesson Summary

- The universe contains all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time.
- Redshift is a shift of element lines toward the red end of the spectrum. Redshift occurs when the source of light is moving away from the observer.
- Light from almost every galaxy is redshifted. The farther away a galaxy is, the more its light is redshifted, and the faster it is moving away from us.
- The redshift of galaxies means that the universe is expanding.
- The universe was squeezed into a very small volume and then exploded in the Big Bang theory about 13.7 billion years ago.
- Recent evidence shows that there is a lot of matter in the universe that we cannot detect directly. This matter is called dark matter.
- The rate of the expansion of the universe is increasing. The cause of this increase is unknown; one possible explanation involves a new form of energy called dark energy.

Review Questions

1. What is redshift, and what causes it to occur? What does redshift indicate?
2. What is Hubble's law?
3. What is the cosmological theory of the formation of the universe called?
4. How old is the universe, according to the Big Bang theory?
5. Describe two different possibilities for the nature of dark matter.
6. What makes scientists believe that dark matter exists?
7. What observation caused astronomers to propose the existence of dark energy?

Further Reading / Supplemental Links

- The science of dark matter: http://cdms.berkeley.edu/Education/DMpages/index.shtml
- More about cosmology: http://stardate.org/resources/btss/cosmology/
- The Big Bang: http://hurricanes.nasa.gov/universe/science/bang.html

Points to Consider

- The expansion of the universe is sometimes modeled using a balloon with dots marked on it, as described earlier in the lesson. In what ways is this a good model, and it what ways does it not correctly represent the expanding universe? Can you think of a different way to model the expansion of the universe?
- The Big Bang theory is currently the most widely accepted scientific theory for how the universe formed. What is another explanation of how the universe could have formed? Is your explanation one that a scientist would accept?

24.2 Stars

Lesson Objectives

- Describe the flow of energy in a star.
- Classify stars based on their properties.
- Outline the life cycle of a star.
- Use light-years as a unit of distance.

Vocabulary

- black hole
- main sequence star
- neutron star
- nuclear fusion reaction
- parallax
- red giant
- star
- supernova
- white dwarf

Introduction

When you look at the sky on a clear night, you can see dozens, perhaps even hundreds, of tiny points of light. Almost every one of these points of light is a **star**, a giant ball of glowing gas at a very, very high temperature. Stars differ in size, temperature, and age, but they all appear to be made up of the same elements and to behave according to the same principles.

Star Power

The Sun is Earth's major source of energy, yet the planet only receives a small portion of its energy and the Sun is just an ordinary star. Many stars produce much more energy than the Sun. The energy source for all stars is nuclear fusion.

Nuclear Fusion

Stars are made mostly of hydrogen and helium, which are packed so densely in a star that in the star's center the pressure is great enough to initiate nuclear fusion reactions. In a **nuclear fusion reaction**, the nuclei of two atoms combine to create a new atom. Most commonly, in the core of a star, two hydrogen atoms fuse to become a helium atom. Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy (**Figure** 24.8).

In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity. This energy moves outward through the layers of the star until it finally reaches the star's outer surface. The outer layer of

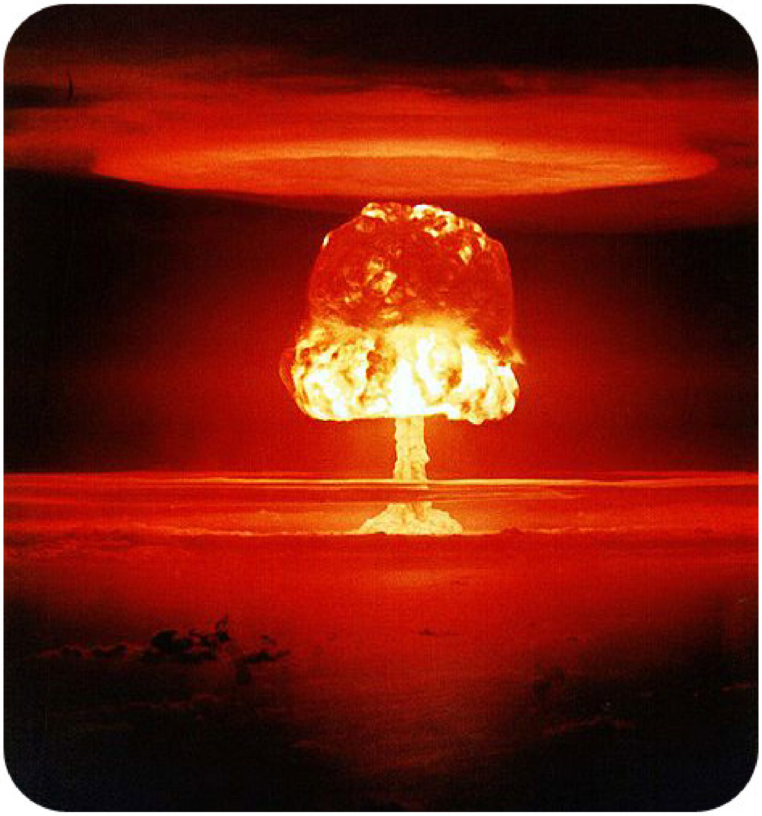


FIGURE 24.8
A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

the star glows brightly, sending the energy out into space as electromagnetic radiation, including visible light, heat, ultraviolet light, and radio waves (**Figure** 24.9).

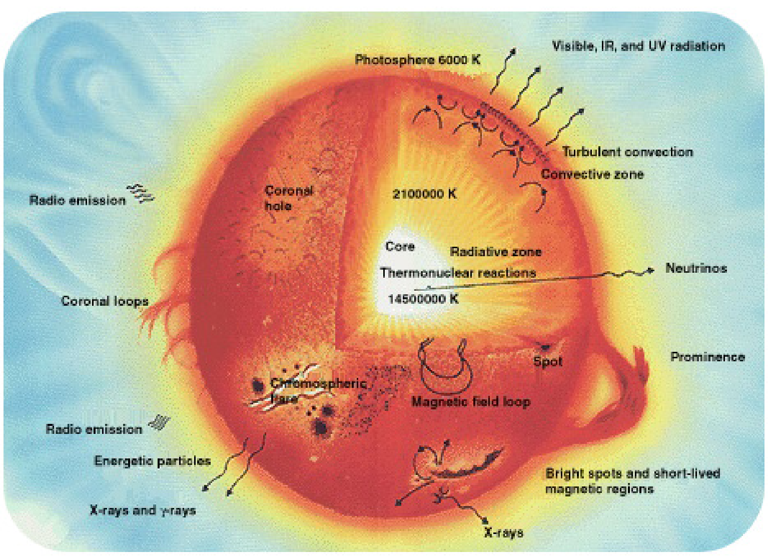
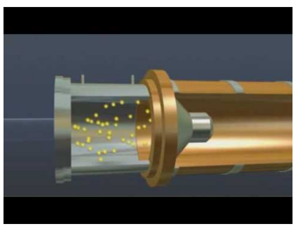


FIGURE 24.9
A diagram of a star like the Sun.

In particle accelerators, subatomic particles are propelled until they have attained almost the same amount of energy as found in the core of a star (**Figure** 24.10). When these particles collide head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. The process also simulates the conditions that allowed for the first helium atom to be produced from the collision of two hydrogen atoms in the first few minutes of the universe.

FIGURE 24.10
The SLAC National Accelerator Lab in California can propel particles a straight 2 mi (3.2 km).

The CERN Particle Accelerator presented in this video is the world's largest and most powerful particle accelerator and can boost subatomic particles to energy levels that simulate conditions in the stars and in the early history of the universe before stars formed **(2e)**: http://www.youtube.com/watch?v=sxAxV7g3yf8 (6:16).



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How Stars Are Classified

The many different colors of stars reflect the star's temperature. In Orion (as shown in the **Figure** above) the bright, red star in the upper left named Betelgeuse (pronounced BET-ul-juice) is not as hot than the blue star in the lower right named Rigel.

Color and Temperature

Think about how the color of a piece of metal changes with temperature. A coil of an electric stove will start out black but with added heat will start to glow a dull red. With more heat the coil turns a brighter red, then orange. At extremely high temperatures the coil will turn yellow-white, or even blue-white (it's hard to imagine a stove coil getting that hot). A star's color is also determined by the temperature of the star's surface. Relatively cool stars are red, warmer stars are orange or yellow, and extremely hot stars are blue or blue-white (**Figure** 24.11).

Classifying Stars by Color

Color is the most common way to classify stars. **Table** 24.1 shows the classification system. The class of a star is given by a letter. Each letter corresponds to a color, and also to a range of temperatures. Note that these letters don't match the color names; they are left over from an older system that is no longer used.

TABLE 24.1: Classification of Stars By Color and Temperature

Class	Color	Temperature Range	Sample Star
O	Blue	30,000 K or more	Zeta Ophiuchi

TABLE 24.1: (continued)

Class	Color	Temperature Range	Sample Star
B	Blue-white	10,000-30,000 K	Rigel
A	White	7,500-10,000 K	Altair
F	Yellowish-white	6,000-7,500 K	Procyon A
G	Yellow	5,500-6,000 K	Sun
K	Orange	3,500-5,000 K	Epsilon Indi
M	Red	2,000-3,500 K	Betelgeuse, Proxima Centauri

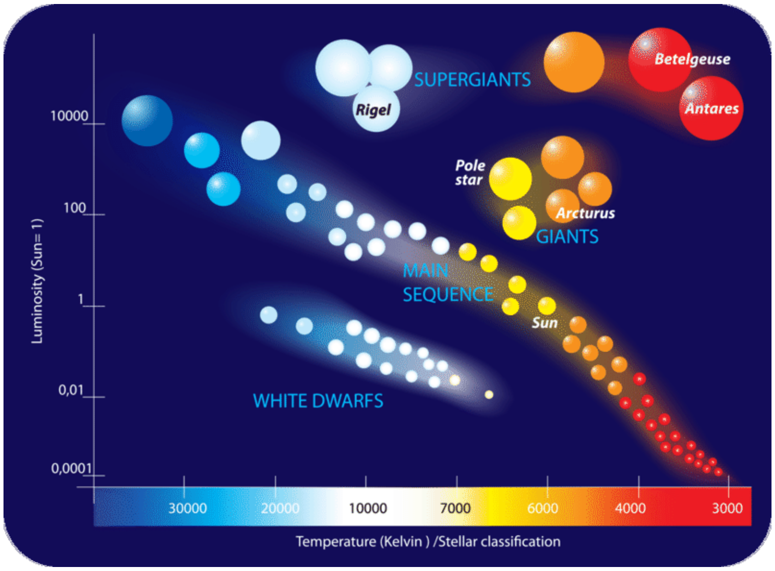


FIGURE 24.11

A Hertzsprung-Russell diagram shows the brightness and color of main sequence stars. The brightness is indicated by luminosity and is higher up the y-axis. The temperature is given in degrees Kelvin and is higher on the left side of the x-axis. How does our Sun fare in terms of brightness and color compared with other stars?

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter. These stars tend toward bluish white. Smaller stars produce less energy. Their surfaces are less hot and so they tend to be yellowish.

Lifetime of Stars

Stars have a life cycle that is expressed similarly to the life cycle of a living creature: they are born, grow, change over time, and eventually die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes.

Star Formation

As discussed in the Solar System chapter, stars are born in clouds of gas and dust called nebulas, like the one shown in **Figure** 24.12.

For more on star formation, check out http://www.spacetelescope.org/science/formation_of_stars.html and http://hurricanes.nasa.gov/universe/science/stars.html .

The Main Sequence

For most of a star's life, nuclear fusion in the core produces helium from hydrogen. A star in this stage is a **main sequence** star. This term comes from the Hertzsprung-Russell diagram shown in the **Figure** 24.11. For stars on the main sequence, temperature is directly related to brightness. A star is on the main sequence as long as it is able to balance the inward force of gravity with the outward force of nuclear fusion in its core. The more massive a star, the more it must burn hydrogen fuel to prevent gravitational collapse. Because they burn more fuel, more massive stars have higher temperatures. Massive stars also run out of hydrogen sooner than smaller stars do.

Our Sun has been a main sequence star for about 5 billion years and will continue on the main sequence for about 5 billion more years (**Figure** 24.13). Very large stars may be on the main sequence for only 10 million years. Very small stars may last tens to hundreds of billions of years.

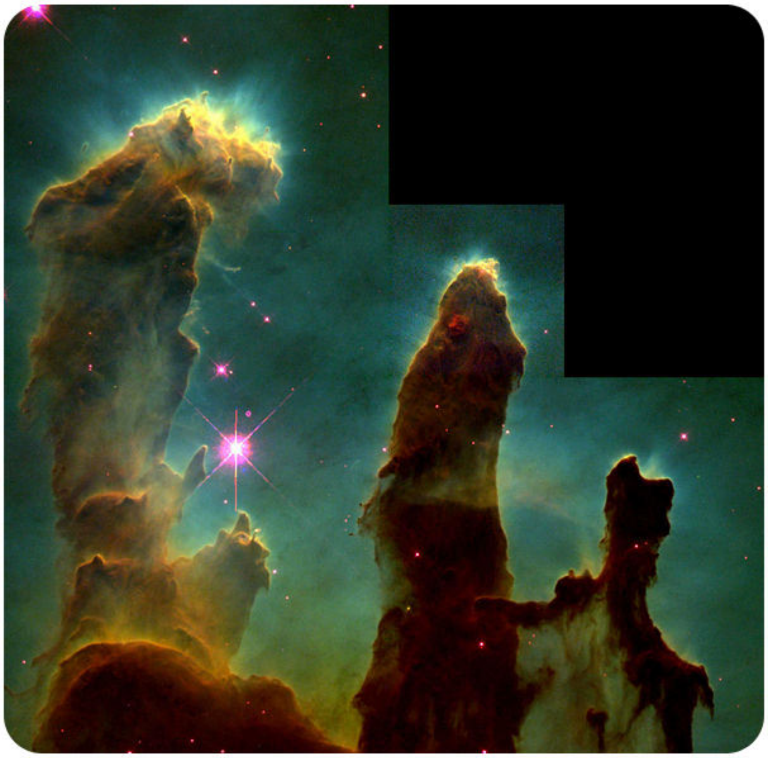


FIGURE 24.12
The Pillars of Creation within the Eagle Nebula are where gas and dust come together as a stellar nursery.

FIGURE 24.13
Our Sun is a medium-sized star in about the middle of its main sequence life.

The fate of the Sun and inner planets is explored in this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath .

Red Giants and White Dwarfs

As a star begins to use up its hydrogen, it fuses helium atoms together into heavier atoms such as carbon. A blue giant star has exhausted its hydrogen fuel and is a transitional phase. When the light elements are mostly used up the star can no longer resist gravity and it starts to collapse inward. The outer layers of the star grow outward and cool. The larger, cooler star turns red in color and so is called a **red giant**.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf** (**Figure** 24.14). A white dwarf will ultimately fade out.

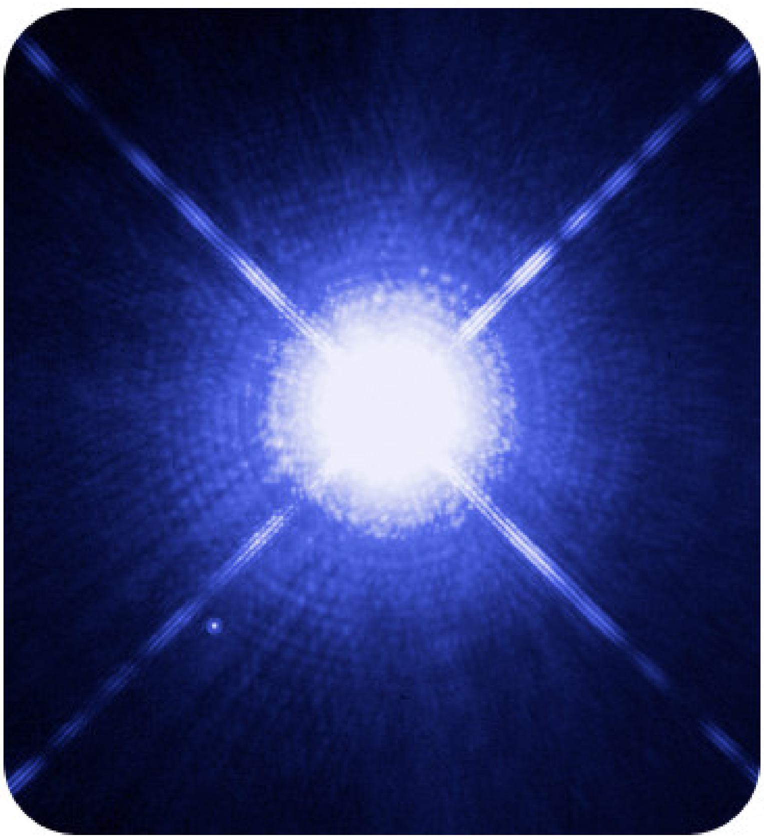


FIGURE 24.14
Sirius, the brightest star in the sky, is actually a binary star system. Sirius A is on the main sequence. Sirius B, the tiny dot on the lower left, is a white dwarf.

Supergiants and Supernovas

A star that runs out of helium will end its life much more dramatically. When very massive stars leave the main sequence, they become red supergiants (**Figure** 24.15).

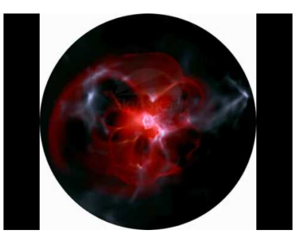
Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces so stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a **supernova** (**Figure** 24.16). A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver,

FIGURE 24.15
The red star Betelgeuse in Orion is a red supergiant.

and uranium. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of lithium were formed by nuclear fusion in stars.

An animation of the Crab Supernova is seen here: http://www.youtube.com/watch?v=0J8srN24pSQ .

This video looks at the origin of the universe, star formation, and the formation of the chemical elements in supernovas **(2c)**: http://www.youtube.com/watch?v=8AKXpBeddu0 (8:30).



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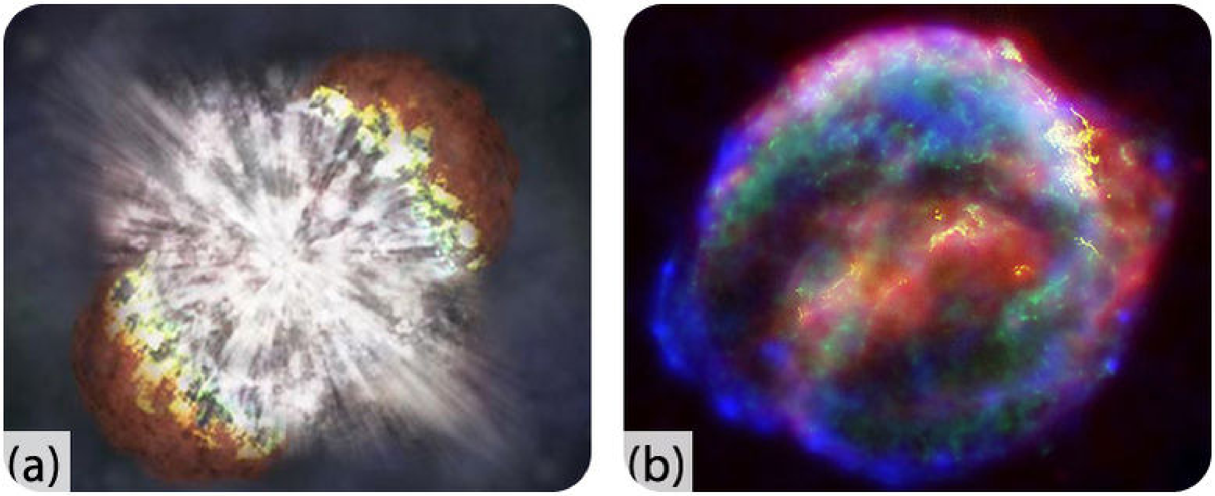

FIGURE 24.16
(a) NASA's Chandra X-ray observatory captured the brightest stellar explosion so far, 100 times more energetic than a typical supernova. (b) This false-color image of the supernova remnant SN 1604 was observed as a supernova in the Milky Way galaxy. At its peak it was brighter than all other stars and planets, except Venus, in the night sky.

Neutron Stars and Black Holes

After a supernova explosion, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star becomes a **neutron star** (**Figure** 24.17). A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge.

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a **black hole**. Black holes are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it, and by radiation that leaks out around its edges.

How to make a black hole: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop .

A video about black holes is seen on Space.com: http://www.space.com/common/media/video/player.php?videoRef=black_holes .

A Star's Life Cycle video from Discovery Channel describes how stars are born, age and die **(2f)**: http://www.youtube.com/watch?v=H8Jz6FU5D1A (3:11).

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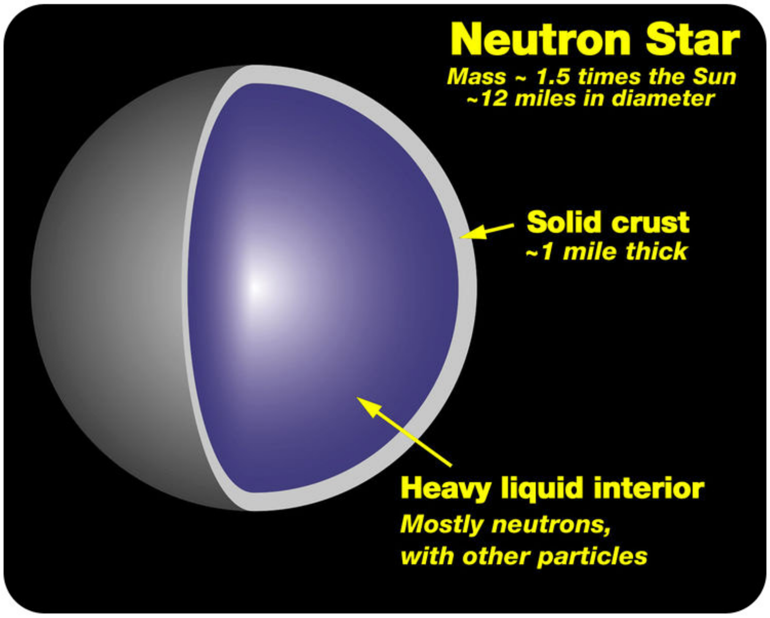

FIGURE 24.17
After a supernova, the remaining core may end up as a neutron star. A neutron star is more massive than the Sun, but only a few kilometers in diameter.

A video of neutron stars is available at: http://www.youtube.com/watch?v=VMnLVkV_ovc (4:24).

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Measuring Star Distances

How can you measure the distance of an object that is too far away to measure? Now what if you don't know the size of the object or the size or distance of any other objects like it? That would be very difficult, but that is the problem facing astronomers when they try to measure the distances to stars.

Parallax

Distances to stars that are relatively close to us can be measured using **parallax**. Parallax is an apparent shift in position that takes place when the position of the observer changes.

To see an example of parallax, try holding your finger about 1 foot (30 cm) in front of your eyes. Now, while focusing on your finger, close one eye and then the other. Alternate back and forth between eyes, and pay attention to how your finger appears to move. The shift in position of your finger is an example of parallax. Now try moving your finger closer to your eyes, and repeat the experiment. Do you notice any difference? The closer your finger is to your eyes, the greater the position changes because of parallax.

As **Figure** 24.18 shows, astronomers use this same principle to measure the distance to stars. Instead of a finger, they focus on a star, and instead of switching back and forth between eyes, they switch between the biggest possible differences in observing position. To do this, an astronomer first looks at the star from one position and notes where the star is relative to more distant stars. Now where will the astronomer go to make an observation the greatest possible distance from the first observation? In six months, after Earth moves from one side of its orbit around the Sun to the other side, the astronomer looks at the star again. This time parallax causes the star to appear in a different position relative to more distant stars. From the size of this shift, astronomers can calculate the distance to the star.

For more about parallax, visit http://starchild.gsfc.nasa.gov/docs/StarChild/questions/parallax.html .

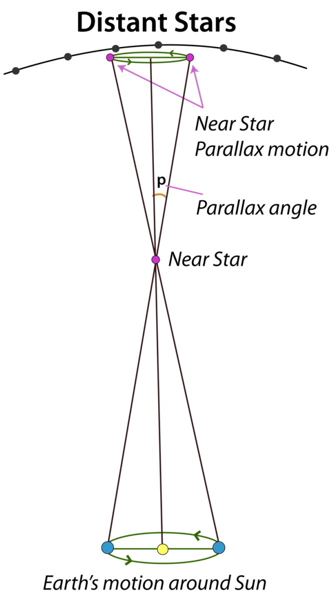


FIGURE 24.18
Parallax is used to measure the distance to stars that are relatively nearby.

A parallax exercise is seen here: http://www.astro.ubc.ca/~scharein/a311/Sim/new-parallax/Parallax.html .

Other Methods

Even with the most precise instruments available, parallax is too small to measure the distance to stars that are more than a few hundred light years away. For these more distant stars, astronomers must use more indirect methods of determining distance. Most of these methods involve determining how bright the star they are looking at really is. For example, if the star has properties similar to the Sun, then it should be about as bright as the Sun. The astronomer compares the observed brightness to the expected brightness.

Lesson Summary

- A star generates energy by nuclear fusion reactions in its core.
- The color of a star is determined by its surface temperature.
- Stars are classified by color and temperature: O (blue), B (bluish white), A (white), F (yellowish white), G (yellow), K (orange), and M (red), from hottest to coolest.
- Stars form from nebulas. Gravity causes stars to collapse until nuclear fusion begins.
- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Typical, Sun-like stars expand into red giants, then fade out as white dwarfs.
- Very large stars expand into red supergiants, explode in supernovas, and end up as neutron stars or black holes.

- Parallax is an apparent shift in an object's position when the position of the observer changes. Astronomers use parallax to measure the distance to relatively nearby stars.

Review Questions

1. What distinguishes a nebula and a star?
2. What kind of reactions provide a star with energy?
3. Stars are extremely massive. Why don't they collapse under the weight of their own gravity?
4. Of what importance are particle accelerators to scientists?
5. Which has a higher surface temperature: a blue star or a red star?
6. List the seven main classes of stars, from hottest to coolest.
7. What is the main characteristic of a main sequence star?
8. What kind of star will the Sun be after it leaves the main sequence?
9. Suppose a large star explodes in a supernova, leaving a core that is 10 times the mass of the Sun. What would happen to the core of the star?
10. Since black holes are black, how do astronomers know that they exist?
11. What is a light year?
12. Why don't astronomers use parallax to measure the distance to stars that are very far away?

Further Reading / Supplemental Links

- Myths and history of constellations: http://www.ianridpath.com/startales/contents.htm
- NASA World Book, Stars: http://www.nasa.gov/worldbook/star_worldbook.html
- NASA, parts of a star: http://imagine.gsfc.nasa.gov/docs/science/know_l1/stars.html

Points to Consider

- Stars differ in size, temperature, and age, but they all appear to be made up of the same elements and to behave according to the same principles.
- Most nebulas contain more mass than a single star. If a large nebula collapsed into several different stars, what would the result be like?

24.3 Galaxies

Lesson Objectives

- Distinguish between star systems and star clusters.
- Identify different types of galaxies.
- Describe our own galaxy, the Milky Way Galaxy.

Vocabulary

- binary star
- dwarf galaxy
- elliptical galaxy
- galaxy
- globular cluster
- irregular galaxy
- Milky Way Galaxy
- open cluster
- spiral arm
- spiral galaxy
- star cluster
- star system

Introduction

Where do you live? Sure you live in a house or apartment, on a street, in a town or city, in a state or province, and in a country. You may not think to mention that you live on planet Earth in the solar system (as if there is no other), which is in the Milky Way Galaxy. Our galaxy is just one of many billions of galaxies in the universe. These galaxies are incomprehensible distances from each other and from Earth.

Star Systems and Star Clusters

Although constellations have stars that usually only appear to be close together, stars may be found in the same portion of space. Stars that are grouped closely together are called **star systems**. Larger groups of hundreds or thousands of stars are called **star clusters**.

Star Systems

Although the star humans know best is a single star, many stars—in fact, more than half of the bright stars in our galaxy—are star systems. A system of two stars orbiting each other is a **binary star**. A system with more than two stars orbiting each other is a multiple star system. The stars in a binary or multiple star system are often so close together that they appear as one and only through a telescope can the pair be distinguished.

An animation of a solar system like ours but with two suns was created by NASA: http://www.spitzer.caltech.edu/video-audio/852-ssc2007-05v1-Two-Suns-Raise-Family-of-Planetary-Bodies-

Star Clusters

Star clusters are divided into two main types, **open clusters** and **globular clusters**. Open clusters are groups of up to a few thousand stars that are loosely held together by gravity. The Pleiades, shown in **Figure** 24.19, is an open cluster that is also called the Seven Sisters.

FIGURE 24.19
In the Pleiades, seven stars can be seen without a telescope, but the cluster has close to a thousand stars.

Open clusters tend to be blue in color and often contain glowing gas and dust. Why do you think that open clusters have these features? Open clusters are made of young stars that formed from the same nebula. The stars may eventually be pulled apart by gravitational attraction to other objects.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. **Figure** 24.20 shows an example of a globular cluster. Globular clusters have a definite, spherical shape and contain mostly reddish stars. The stars are closer together, closer to the center of the cluster. Globular clusters don't have much dust in them —the dust has already formed into stars.

Check out http://seds.org/messier/cluster.html and http://hubblesite.org/newscenter/archive/releases/star-cluster/ for more information about star clusters.

Types of Galaxies

Galaxies are the biggest groups of stars and can contain anywhere from a few million stars to many billions of stars. Every star that is visible in the night sky is part of the Milky Way Galaxy. To the naked eye the closest major galaxy

FIGURE 24.20
M80 is a large globular cluster containing hundreds of thousands of stars. Note that the cluster is spherical and contains mostly red stars.

—the Andromeda Galaxy, shown in **Figure** 24.21 —looks like only a dim, fuzzy spot. But that fuzzy spot contains one trillion stars – 1,000,000,000,000 stars!

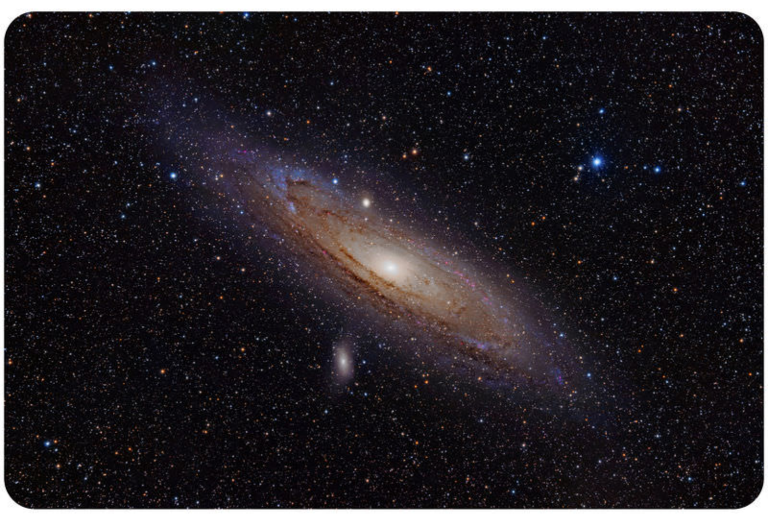


FIGURE 24.21
The Andromeda Galaxy is a large spiral galaxy similar to the Milky Way.

Galaxies are divided into three types according to shape: spiral galaxies, elliptical galaxies, and irregular galaxies.

Spiral Galaxies

Spiral galaxies spin, so they appear as a rotating disk of stars and dust, with a bulge in the middle, like the Sombrero Galaxy shown in **Figure** 24.22. Several arms spiral outward in the Pinwheel Galaxy (seen in **Figure** 24.22) and are appropriately called **spiral arms**. Spiral galaxies have lots of gas and dust and lots of young stars.

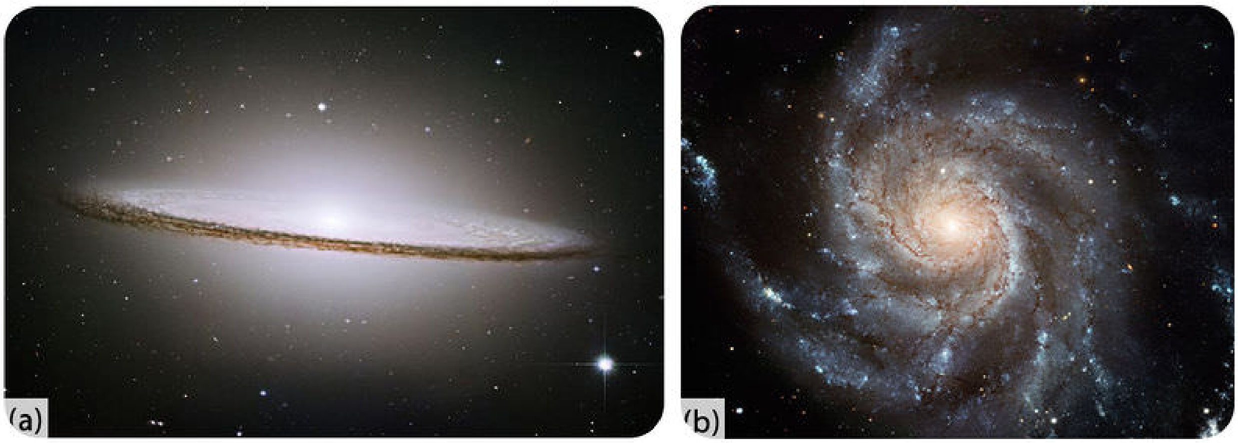


FIGURE 24.22

(a) The Sombrero Galaxy is a spiral galaxy that we see from the side so the disk and central bulge are visible. (b) The Pinwheel Galaxy is a spiral galaxy that we see face-on so we can see the spiral arms. Because they contain lots of young stars, spiral arms tend to be blue.

Elliptical Galaxies

Figure 24.23 shows a typical egg-shaped **elliptical galaxy**. The smallest elliptical galaxies are as small as some globular clusters. Giant elliptical galaxies, on the other hand, can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.

Most elliptical galaxies contain very little gas and dust because the gas and dust has already formed into stars. However, some elliptical galaxies, such as the one shown in **Figure** 24.24, contain lots of dust. Why might some elliptical galaxies contain dust?

Irregular Galaxies and Dwarf Galaxies

Is the galaxy in **Figure** 24.25 a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies or spiral galaxies are **irregular galaxies**. How might an irregular galaxy form? Most irregular galaxies were once spiral or elliptical galaxies that were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.

Dwarf galaxies are small galaxies containing only a few million to a few billion stars. Dwarf galaxies are the most common type in the universe. However, because they are relatively small and dim, we don't see as many dwarf galaxies from Earth. Most dwarf galaxies are irregular in shape. However, there are also dwarf elliptical galaxies and dwarf spiral galaxies.

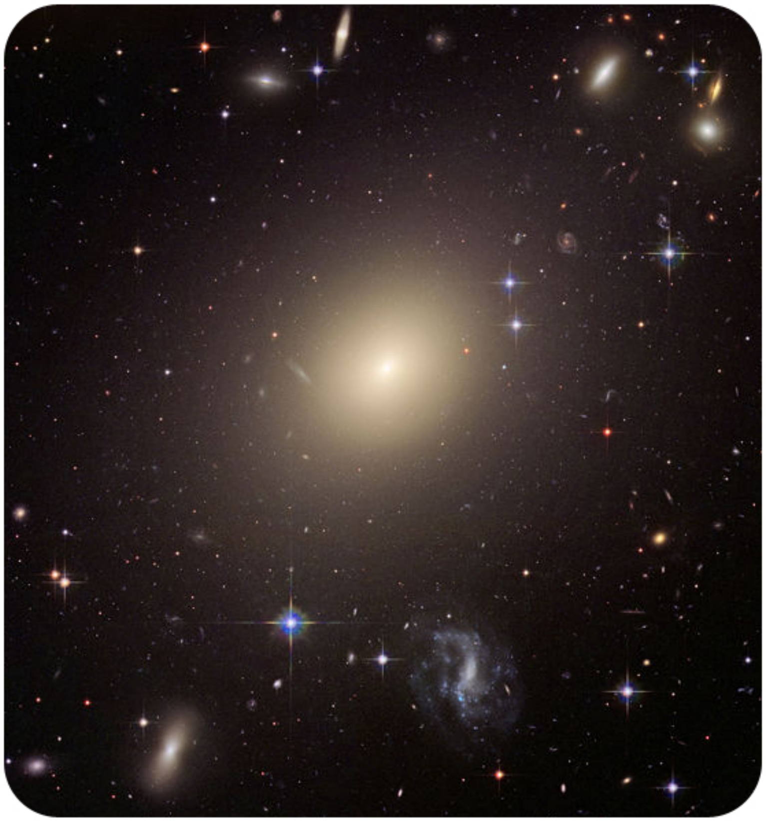


FIGURE 24.23
The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy. What other types of galaxies can you find in the figure?

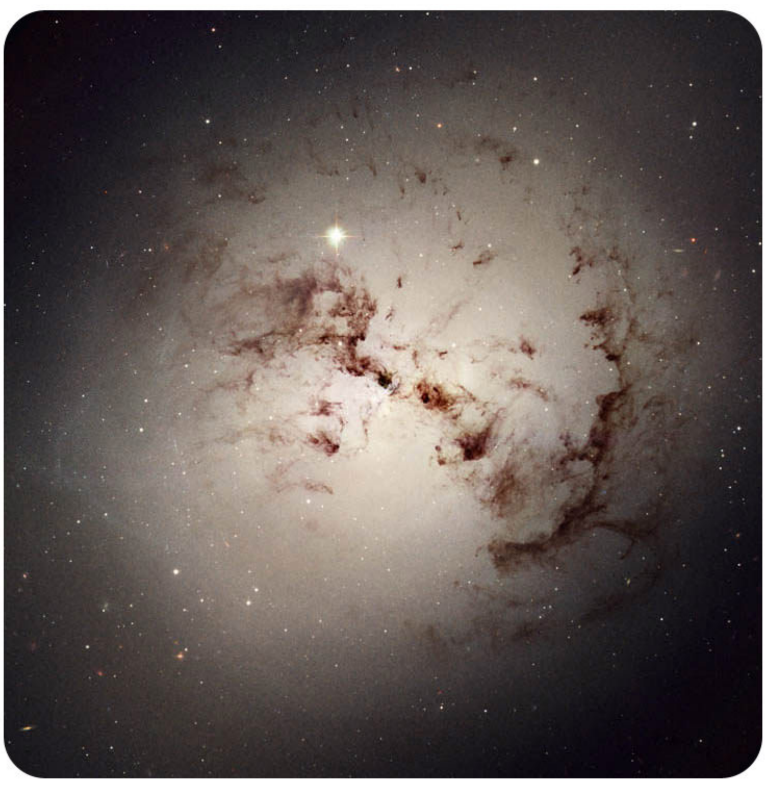


FIGURE 24.24
Astronomers believe that these dusty elliptical galaxies form when two galaxies of similar size collide.

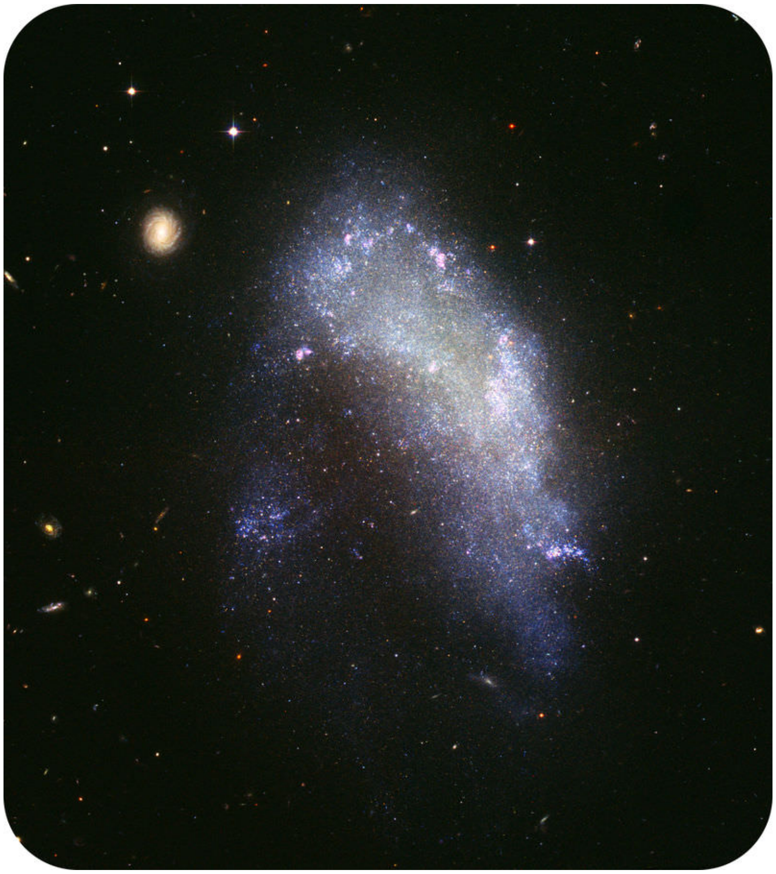


FIGURE 24.25
This galaxy, called NGC 1427A, has neither a spiral nor an elliptical shape.

Look back at the picture of the elliptical galaxy. In the figure, you can see two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere to the left of center, and the other is a long ellipse below and to the right of center. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Images from the Hubble Space Telescope are seen in this video: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop .

The Milky Way Galaxy

On a dark, clear night, you will see a milky band of light stretching across the sky, as in **Figure** 24.26 . This band is the disk of a galaxy, the **Milky Way Galaxy**, which is our galaxy. The Milky Way is made of millions of stars along with a lot of gas and dust.

Shape and Size

Although it is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it, astronomers have identified it as a typical spiral galaxy containing about 100 billion to 400 billion stars (**Figure** 24.27).

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk. What evidence do astronomers find that lets them know that the Milky Way is a spiral galaxy?

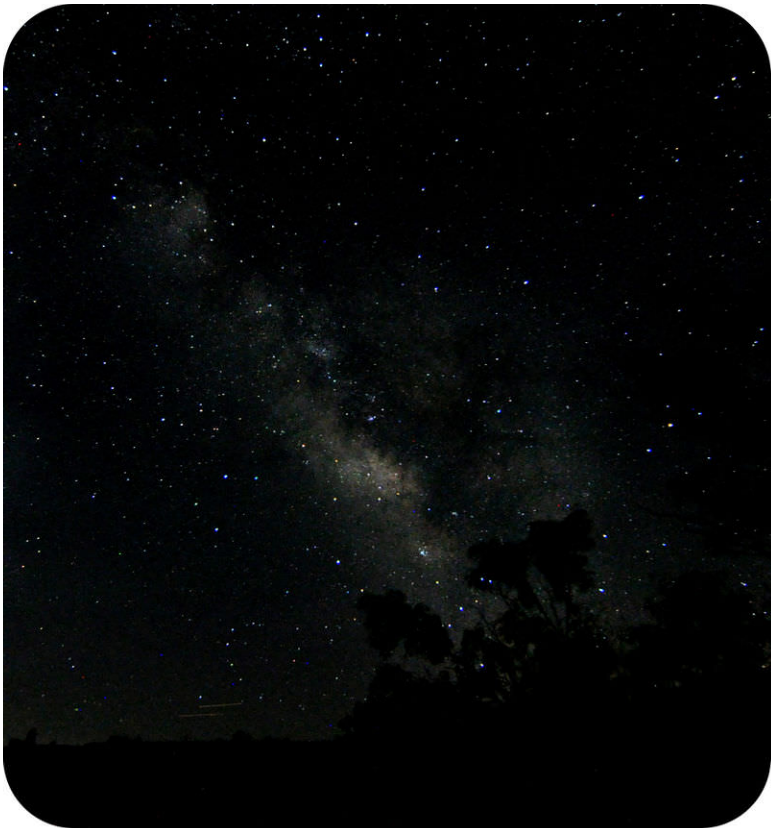


FIGURE 24.26
The Milky Way Galaxy looks different than other galaxies because we are looking along the main disk from within the galaxy.

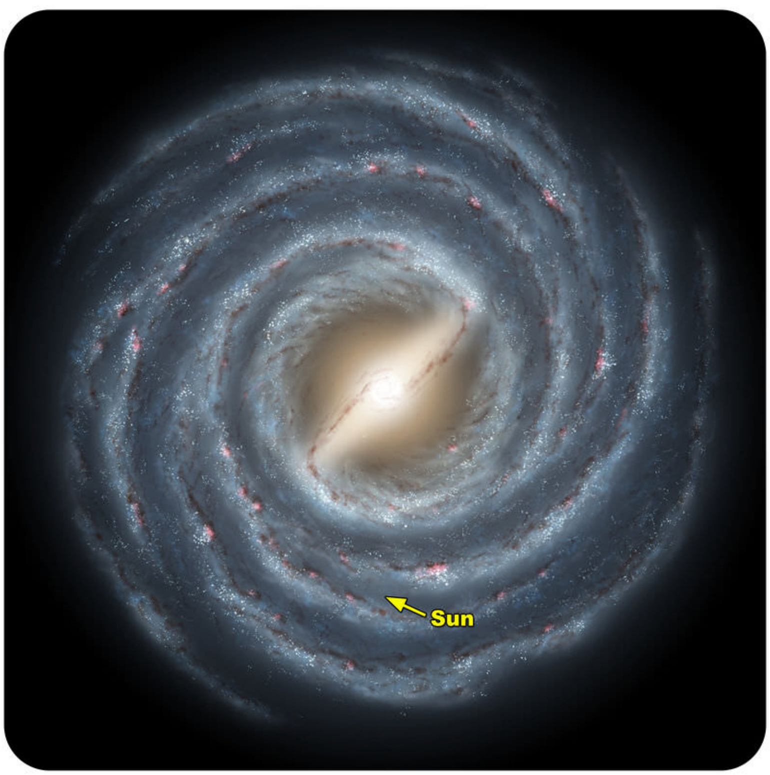


FIGURE 24.27
An artist's rendition of what astronomers think the Milky Way Galaxy would look like seen from above. The Sun is located approximately where the arrow points.

1. The shape of the galaxy as we see it (**Figure** 24.28).

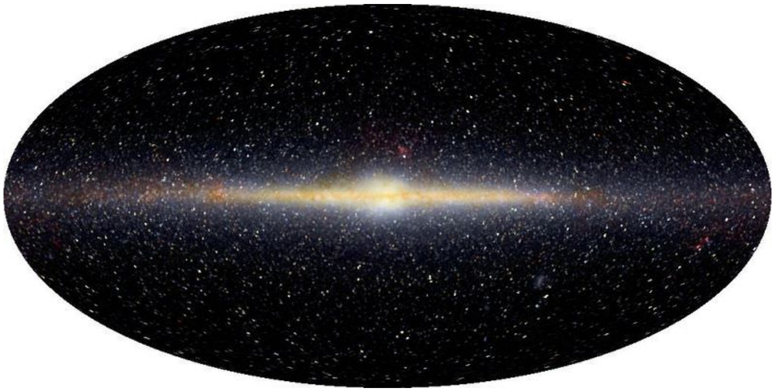


FIGURE 24.28
An infrared image of the Milky Way shows the long thin line of stars and the central bulge typical of spiral galaxies.

2. The velocities of stars and gas in the galaxy show a rotational motion.

3. The gases, color, and dust are typical of spiral galaxies.

The central bulge is about 12,000 to 16,000 light-years wide and 6,000 to 10,000 light-years thick. The central bulge contains mostly older stars and globular clusters. Some recent evidence suggests the bulge might not be spherical, but is instead shaped like a bar. The bar might be as long as 27,000 light-years long. The disk and bulge are surrounded by a faint, spherical halo, which also contains old stars and globular clusters. Astronomers have discovered that there is a gigantic black hole at the center of the galaxy.

The Milky Way Galaxy is a big place. If our solar system were the size of your fist, the Galaxy's disk would still be wider than the entire United States!

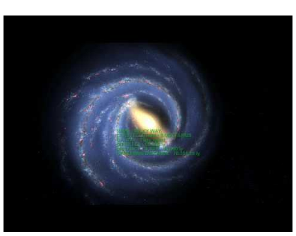
A video closeup of the Milky Way Galaxy is seen here: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTopjjj .

Where We Are

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are about 26,000 light-years from the center of the galaxy, a little more than halfway out from the center of the galaxy to the edge.

Just as Earth orbits the Sun, the Sun and solar system orbit the center of the Galaxy. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago. Astronomers have recently discovered that at the center of the Milky Way, and most other galaxies, is a supermassive black hole, although a black hole cannot be seen.

This video describes the solar system in which we live. It is located in an outer edge of the Milky Way galaxy, which spans 100,000 light years **(2a)**: http://www.youtube.com/watch?v=0Rt7FevNiRc (5:10).



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The Universe contains many billions of stars and there are many billions of galaxies. Our home, the Milky Way galaxy, is only one **(2a, 2b)**: http://www.youtube.com/watch?v=eRJvB3hM7K0 (5:59).

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Lesson Summary

- Many stars are in systems of two or more stars.
- Open clusters are groups of young stars loosely held together by gravity.
- Globular clusters are spherical groups of old stars held tightly together by gravity.
- Galaxies are collections of millions to many billions of stars.
- Spiral galaxies have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. The disk and arms contain many young, blue stars.
- Typical elliptical galaxies are egg-shaped, reddish, and contain mostly old stars.
- Galaxies that are not elliptical or spiral galaxies are called irregular galaxies. These galaxies were probably deformed by other galaxies.
- The Milky Way Galaxy is a typical spiral galaxy. Our solar system is in a spiral arm of the Milky Way Galaxy, a little more than halfway from the center to the edge of the disk.

Review Questions

1. What is a binary star?
2. Compare globular clusters with open clusters.
3. Name the three main types of galaxies.
4. List three main features of a spiral galaxy.
5. Suppose you see a round galaxy that is reddish in color and contains very little dust. What kind of galaxy is it?
6. What galaxy do we live in, and what kind of galaxy is it?
7. What is the evidence that the galaxy we live in is this type of galaxy?
8. Describe the location of our solar system in our galaxy.

Further Reading / Supplemental Links

- Variety of astronomy news: http://www.space.com
- More about galaxies: http://stardate.org/resources/btss/galaxies/

Points to Consider

- Objects in the universe tend to be grouped together. What forces or factors do you think cause objects to form and stay in groups?
- Some people used to call galaxies "island universes." Are they really universes?
- Can you think of anything, either an object or a group of objects, that is bigger than a galaxy?

24.4 References

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CONCEPT 25 Unit 10: Electrical Energy

Questions/Observable Phenomena

CONCEPT 26 Electric Charge

Lesson Objectives

- Define electric charge and electric force.
- Describe electric fields.
- Identify ways that electric charge is transferred.

Lesson Vocabulary

- electric charge
- electric field
- electric force
- law of conservation of charge
- static discharge
- static electricity

Introduction

Has this ever happened to you? You walk across a carpet, reach out to touch a metal doorknob, and get an unpleasant electric shock (see **Figure** 26.1). The reason you get a shock is because of moving electric charges. Moving electric charges also create lightning bolts and the electric current that flows through cables and wires.

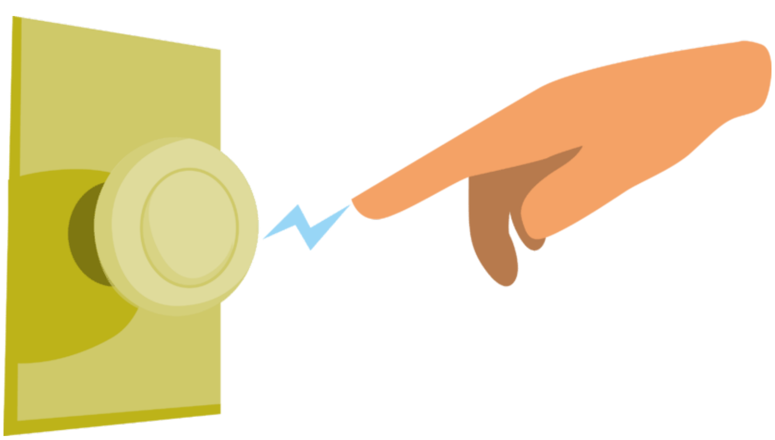

FIGURE 26.1
Moving electric charges explain why you get a shock when you touch a doorknob after walking across a carpet.

Electric Charge and Electric Force

Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. All electric charge is based on the protons and electrons in atoms. A proton has a positive electric charge, and an electron has a negative electric charge (see **Figure** 26.2).

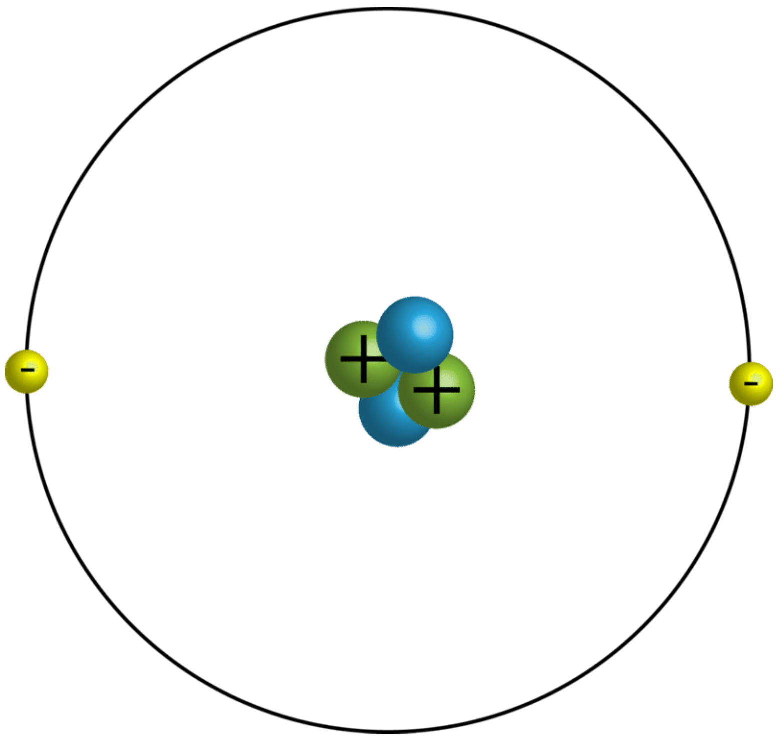

FIGURE 26.2
Positively charged protons (+) are located in the nucleus of an atom. Negatively charged electrons (-) move around the nucleus.

When it comes to electric charges, opposites attract. In other words, positive and negative particles are attracted to each other. Like charges, on the other hand, repel each other, so two positive or two negative charges push apart from each other. The force of attraction or repulsion between charged particles is called **electric force**. It is illustrated in **Figure** 26.3. The strength of electric force depends on the amount of electric charge and the distance between the charged particles. The larger the charge or the closer together the charges are, the greater is the electric force.

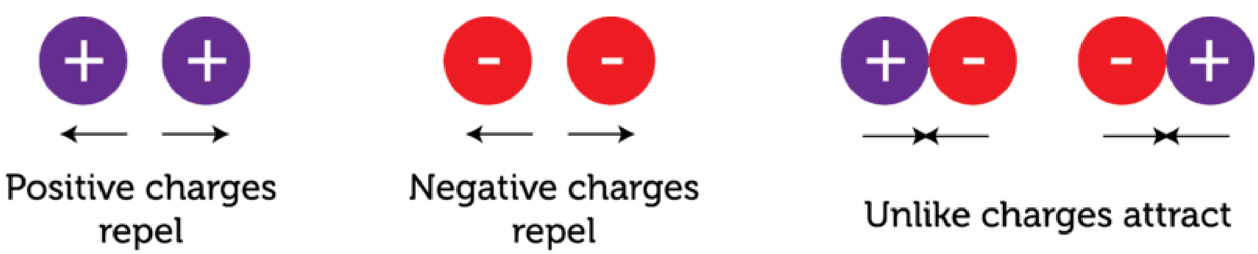

FIGURE 26.3
These diagrams illustrate the electric forces between charged particles.

Electric Fields

Electric force is exerted over a distance, so charged particles do not have to be in contact in order to exert force over each other. That's because each charged particle is surrounded by an electric field. An **electric field** is a space around a charged particle where the particle exerts electric force on other particles. Electric fields surrounding positively and negatively charged particles are illustrated in **Figure** 26.4 and at the URL below. When charged particles exert force on each other, their electric fields interact. This is also illustrated in **Figure** 26.4.

http://www.learnerstv.com/animation/animation.php?ani=86&cat=physics

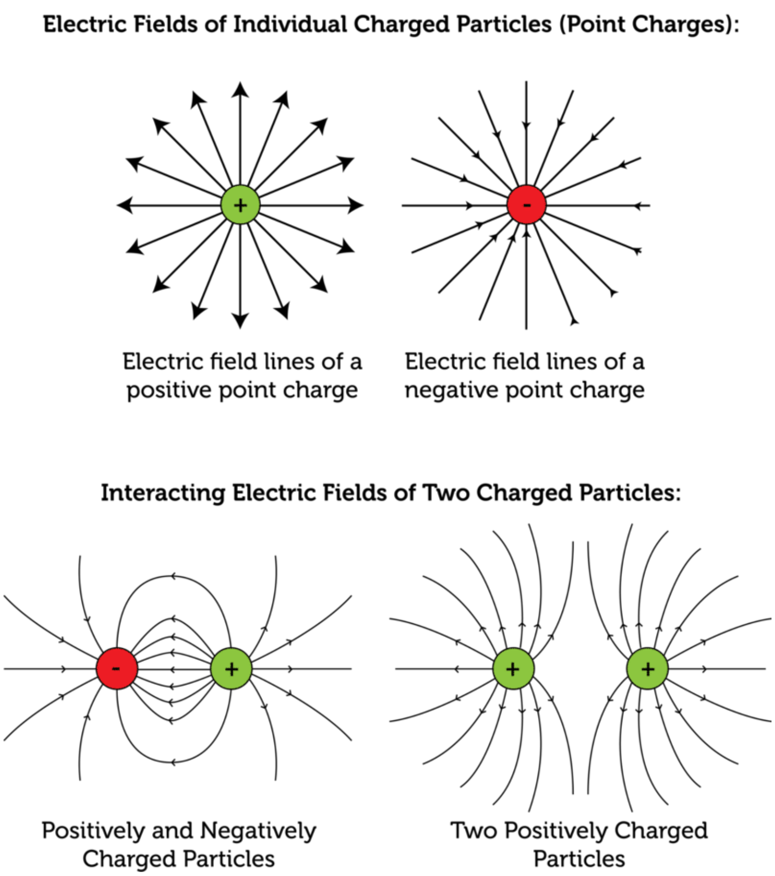

FIGURE 26.4
Field lines represent lines of force in the electric field around a charged particle. The lines bend when two particles interact. What would the lines of force look like around two negatively charged particles?

Transfer of Electric Charges

Atoms are neutral in electric charge because they have the same number of electrons as protons. However, atoms may transfer electrons and become charged ions, as illustrated in **Figure** 26.5. Positively charged ions, or cations, form when atoms give up electrons. Negatively charged ions, or anions, form when atoms gain electrons.

Like the formation of ions, the formation of charged matter in general depends on the transfer of electrons either between two materials or within a material. Three ways this can occur are friction, conduction, and polarization. In all cases, the total charge remains the same. Electrons move, but they aren't destroyed. This is the **law of conservation of charge**.

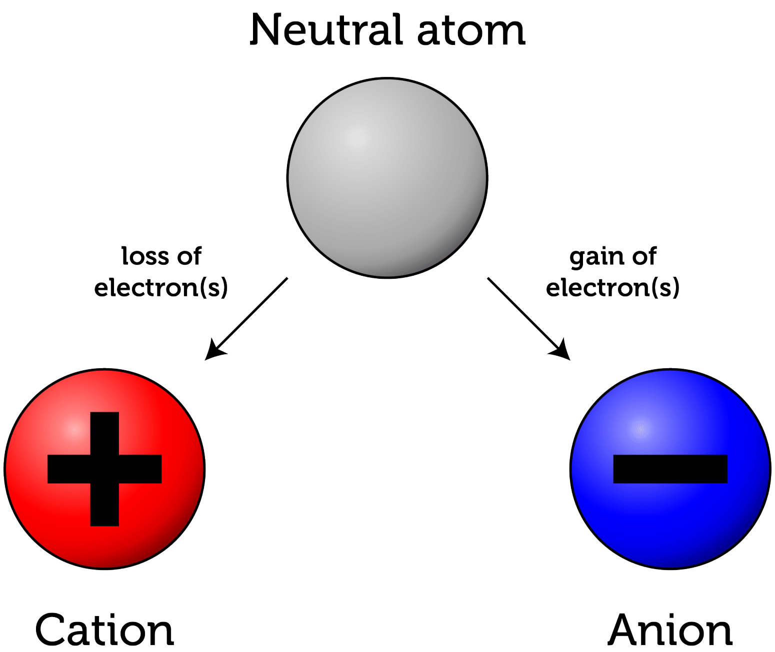

FIGURE 26.5
Atoms are electrically neutral, but if they lose or gain electrons they become charged particles called ions.

Friction

Did you ever rub an inflated balloon against your hair? You can see what happens in **Figure** 26.6. Friction between the rubber of the balloon and the baby's hair results in electrons from the hair "rubbing off" onto the balloon. That's because rubber attracts electrons more strongly than hair does. After the transfer of electrons, the balloon becomes negatively charged and the hair becomes positively charged. As a result, the individual hairs repel each other and the balloon and the hair attract each other. Electrons are transferred in this way whenever there is friction between materials that differ in their ability to give up or accept electrons.

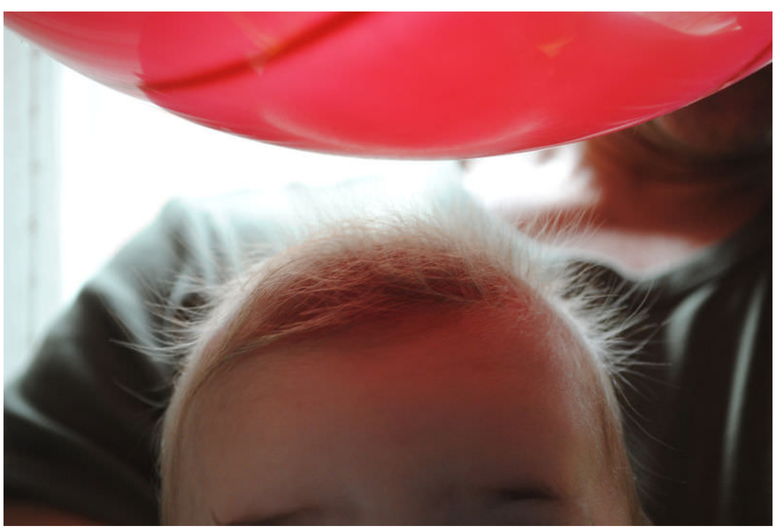

FIGURE 26.6
Electrons are transferred from hair to a balloon rubbed against the hair. Then the oppositely charged hair and balloon attract each other.

Conduction

Another way electrons may be transferred is through conduction. This occurs when there is direct contact between materials that differ in their ability to give up or accept electrons. For example, wool tends to give up electrons and rubber tends to accept them. Therefore, when you walk across a wool carpet in rubber-soled shoes, electrons transfer from the carpet to your shoes. You become negatively charged, while the carpet becomes positively charged.

Another example of conduction is pictured in **Figure** 26.7. The device this girl is touching is called a van de Graaff generator. The dome on top is negatively charged. When the girl places her hand on the dome, electrons are transferred to her, so she becomes negatively charged as well. Even the hairs on her head become negatively charged. As a result, individual hairs repel each other, causing them to stand on end. You can see a video demonstration of a van de Graff generator at this URL: http://www.youtube.com/watch?v=SREXQWAIDJk .

FIGURE 26.7
Electrons flow to the girl from the dome. She becomes negatively charged right down to the tips of her hair.

Polarization

Polarization is the movement of electrons within a neutral object due to the electric field of a nearby charged object. It occurs without direct contact between the two objects. You can see how it happens in **Figure** 26.8. When the negatively charged plastic rod in the figure is placed close to the neutral metal plate, electrons in the plate are repelled by the positive charges in the rod. The electrons move away from the rod, causing one side of the plate to become positively charged and the other side to become negatively charged.

Polarization may also occur after you walk across a wool carpet in rubber-soled shoes and become negatively charged. If you reach out to touch a metal doorknob, electrons in the neutral metal will be repelled and move away from your hand before you even touch the knob. In this way, one end of the doorknob becomes positively charged and the other end becomes negatively charged.

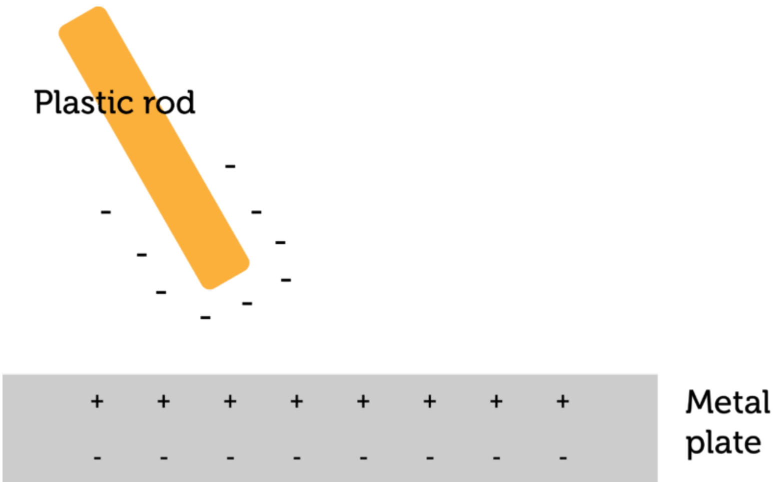

FIGURE 26.8
Polarization occurs between a charged and neutral object.

Static Electricity and Static Discharge

Polarization leads to the buildup of electric charges on objects. This buildup of charges is known as **static electricity**. Once an object becomes charged, it is likely to remain charged until another object touches it or at least comes very close to it. That's because electric charge cannot travel easily through air, especially if the air is dry.

Consider again the example of your hand and the metal doorknob. When your negatively charged hand gets very close to the positively charged doorknob, the air between your hand and the knob may become electrically charged. If that happens, it allows electrons to suddenly flow from your hand to the knob. This is the electric shock you feel when you reach for the knob. You may even see a spark as the electrons jump from your hand to the metal. This sudden flow of electrons is called **static discharge**. Another example of static discharge, on a much larger scale, is lightning. You can see how it occurs in **Figure** 26.9. At the URL below, you can watch a slow-motion lightning strike. Be sure to wait for the real-time lightning strike at the very end of the video.

http://www.youtube.com/watch?v=Y8oN0YFAXWQ

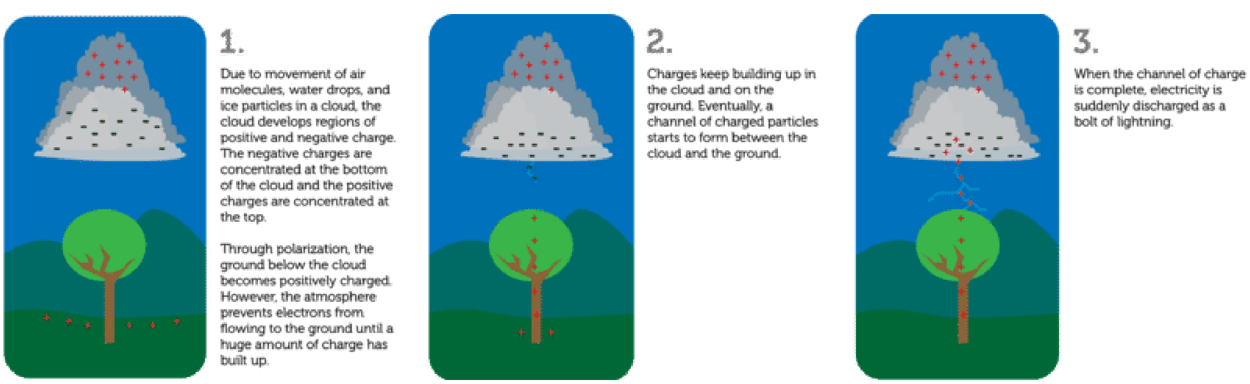

FIGURE 26.9
Lightning occurs when there is a sudden discharge of static electricity between a cloud and the ground.

Lesson Summary

- Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. Positive and negative particles attract each other. Particles with the same charge repel each other. The force of attraction or repulsion between charged particles is called electric force.
- A charged particle can attract or repel other, nearby particles without touching them because it is surrounded by an electric field. This is a space around the particle where it exerts electric force on other particles.
- Objects become charged when they transfer electrons. This can happen through friction, conduction, or polarization. Although electrons are transferred, the total charge remains the same. Polarization may cause a buildup of charges on an object known as static electricity. Static discharge occurs when the built-up charges suddenly flow from the object. An example of static discharge is lightning.

Lesson Review Questions

Recall

1. Define electric charge.
2. Describe the forces between charged particles.
3. What is an electric field?
4. State the law of conservation of charge.
5. Outline how lightning occurs.

Apply Concepts

6. If you rub a piece of tissue paper on a plastic comb, the paper and comb stick together. Based on lesson concepts, explain why this happens.

Think Critically

7. Compare and contrast the ways that friction, conduction, and polarization transfer electric charge.

Points to Consider

You read in this lesson that lightning is a flow of electric charges. The electric current that flows through wires in your home is also a flow of electric charges. You'll read about electric current in the next lesson, "Electric Current."

- How might the electric current in a wire inside the walls of a house differ from a bolt of lightning?
- Lightning strikes may injure people or start fires. How do you think current can be used safely inside the walls of buildings?

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CONCEPT 27 Coulomb's Law

Learning Objectives

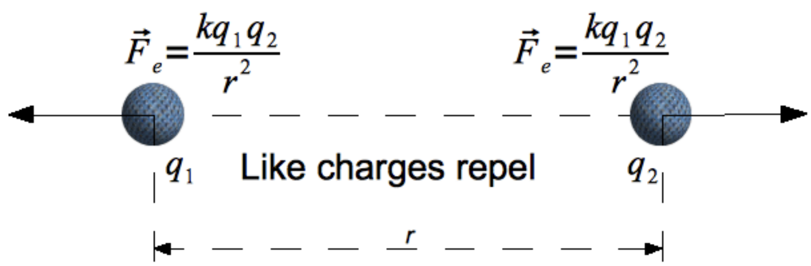
- Solve problems involving Coulomb's Law.

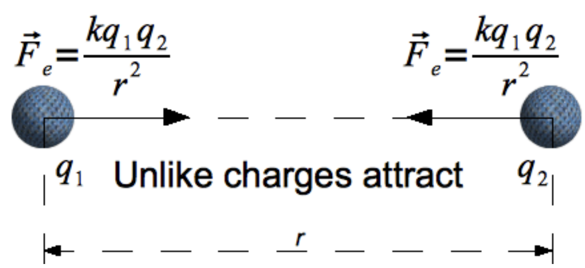
The Coulomb Force Law states that any two charged particles (q_1, q_2) — with charge measured in units of Coulombs — at a distance r from each other will experience a force of repulsion or attraction along the line joining them equal to:

$$\vec{F}_e = \frac{kq_1q_2}{r^2} \qquad \text{The Coulomb Force [1]}$$

$$\text{Where } k = 8.987 \times 10^9 \text{ N} \cdot \text{m}^2 \cdot \text{C}^{-2} \qquad \text{The Electric Constant}$$

This looks a lot like the Law of Universal Gravitation, which deals with attraction between objects with mass. The big difference is that while any two masses experience mutual *attraction*, two charges can either attract or repel each other, depending on whether the signs of their charges are alike:





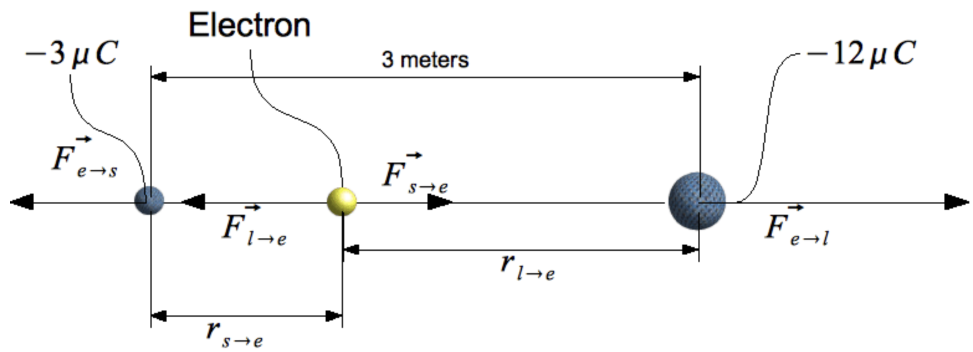
Like gravitational (and all other) forces, Coulomb forces add as vectors. Thus to find the force on a charge from an arrangement of charges, one needs to find the vector sum of the force from each charge in the arrangement.

Key Equations

$$F = \frac{kq_1q_2}{r^2} \begin{cases} k & \text{The electric constant, } k = 8.987 \times 10^9 \text{ N} \cdot \text{m}^2\text{C}^{-2}. \\ q_1,\ q_2 & \text{Magnitude of the charges, units of Coulombs (C)} \\ r & \text{Distance between charges, m} \end{cases}$$

Example

Two negatively charged spheres (one with -12μC; the other with -3μC) are 3m apart. Where could you place an electron so that it will be suspended in space between them with a net force of zero (for this problem we will ignore the force of repulsion between the two charges because they are held in place)?



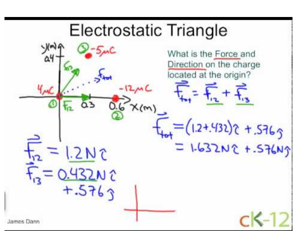
Consider the diagram above; here $r_{s\to e}$ is the distance between the electron and the small charge, while $\vec{F}_{s\to e}$ is the force the electron feels due to it. For the electron to be balanced in between the two charges, the forces of repulsion caused by the two charges on the electron would have to be balanced. To do this, we will set the equation for the force exerted by two charges on each other equal and solve for a distance ratio. We will denote the difference between the charges through the subscripts "s" for the smaller charge, "e" for the electron, and "l" for the larger charge.

$$\frac{kq_sq_e}{r_{s\to e}^2} = \frac{kq_lq_e}{r_{e\to l}^2}$$

Now we can cancel. The charge of the electron cancels. The constant k also cancels. We can then replace the large and small charges with the numbers. This leaves us with the distances. We can then manipulate the equation to produce a ratio of the distances.

$$\frac{-3\mu\text{C}}{r_{s\to e}^2} = \frac{-12\mu\text{C}}{r_{e\to l}^2} \Rightarrow \frac{r_{s\to e}^2}{r_{e\to l}^2} = \frac{-12\mu\text{C}}{-3\mu\text{C}} \Rightarrow \frac{r_{s\to e}}{r_{e\to l}} = \sqrt{\frac{1\mu\text{C}}{4\mu\text{C}}} = \frac{1}{2}$$

Given this ratio, we know that the electron is twice as far from the large charge (-12μC) as from the small charge (-3μC). Given that the distance between the small and large charges is 3m, we can determine that the electron must be located 2m away from the large charge and 1m away from the smaller charge.



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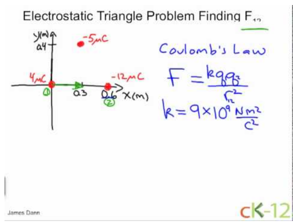

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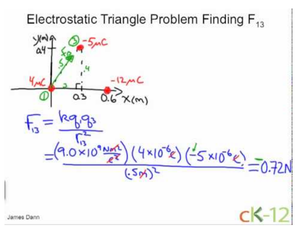

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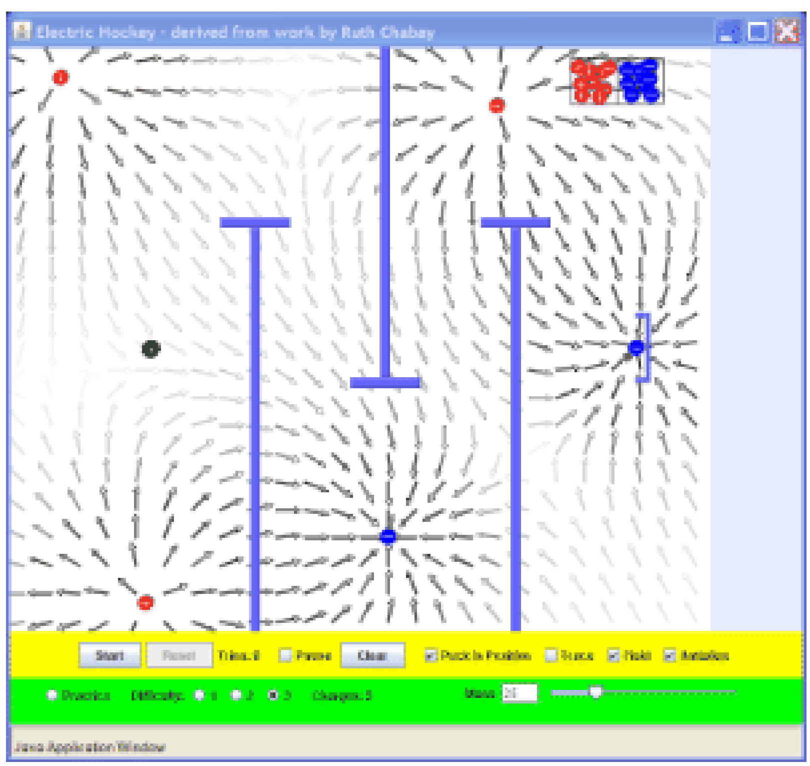
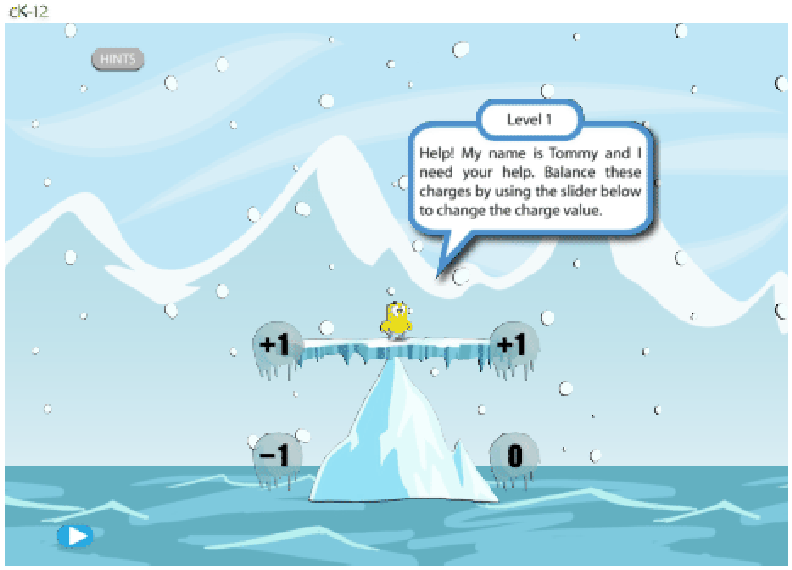
Simulation



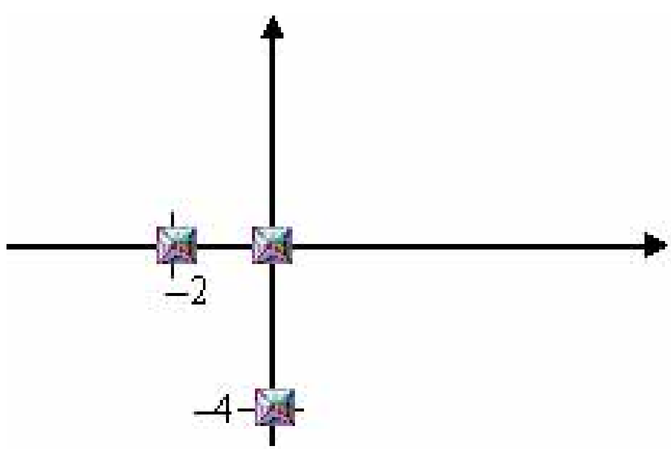
Electric Hockey (PhET Simulation)



Electric Ice Sheet (CK-12 Simulation)

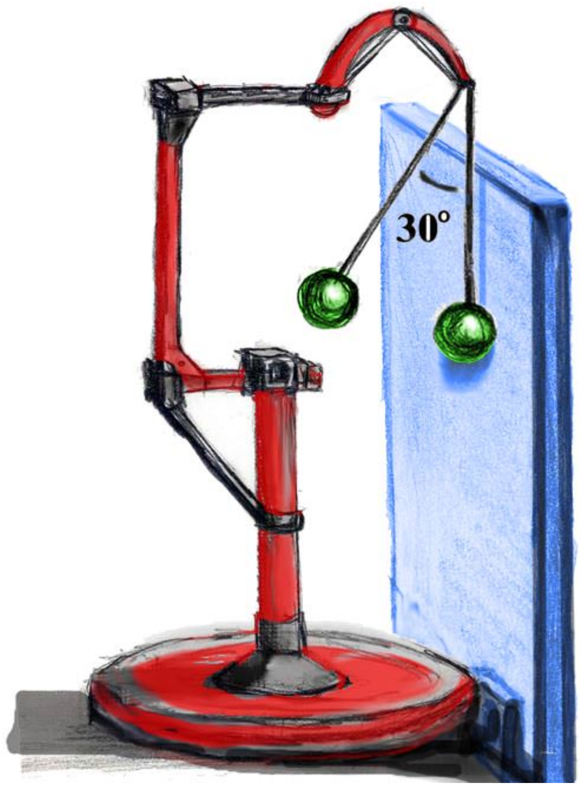
Review

1. A suspended pith ball possessing $+10\ \mu$C of charge is placed 0.02 m away from a metal plate possessing $-6\ \mu$C of charge.
   a. Are these objects attracted or repulsed?
   b. What is the force on the negatively charged object?
   c. What is the force on the positively charged object?
2. Consider the hydrogen atom. Does the electron orbit the proton due to the force of gravity or the electric force? Calculate both forces and compare them. (You may need to look up the properties of the hydrogen atom to complete this problem.)
3. Find the direction and magnitude of the force on the charge at the origin (see picture). The object at the origin has a charge of 8 μC, the object at coordinates $(-2\text{ m},\ 0)$ has a charge of 12 μC, and the object at coordinates $(0, -4\text{ m})$ has a charge of 44 μC. All distance units are in meters.



4. Two pith balls of equal and like charges are repulsed from each other as shown in the figure below. They both have a mass of 2 g and are separated by 30°. One is hanging freely from a 0.5 m string, while the other, also hanging from a 0.5 m string, is stuck like putty to the wall.
   a. Draw the free body diagram for the hanging pith ball

b. Find the distance between the leftmost pith ball and the wall (this will involve working a geometry problem)
c. Find the tension in the string (Hint: use $y-$direction force balance)
d. Find the amount of charge on the pith balls (Hint: use $x-$direction force balance)



Review (Answers)

1. a. attracted b. 1350 N c. 1350 N
2. $F_g = 1.0 \times 10^{-47}$ N and $F_e = 2.3 \times 10^{-8}$ N. The electric force is 39 orders of magnitudes bigger.
3. 0.293 N and at 42.5°
4. b. 0.25m c. $F_T = 0.022$ N d. 0.37μC

Concept 28 Forces on Charged Objects

Learning Objectives

- Describe the changes that occur in the sub-atomic arrangement in matter when charged.
- Describe how to charge an object.
- Define conductors and insulators.
- Understand the difference between conduction and induction.
- Summarize the forces between charged objects.

Lightning is the discharge of static electricity that has built up on clouds. Every year, the earth experiences an average of 25 million lightning strikes. Lightning bolts travel at speeds up to 60,000 miles per second, and can reach temperatures of 50,000°F, which is five times the temperature of the surface of the sun. The energy contained in a single lightning strike could light a 100 Watt light bulb 24 hours per day for 90 days.

Forces on Charged Objects

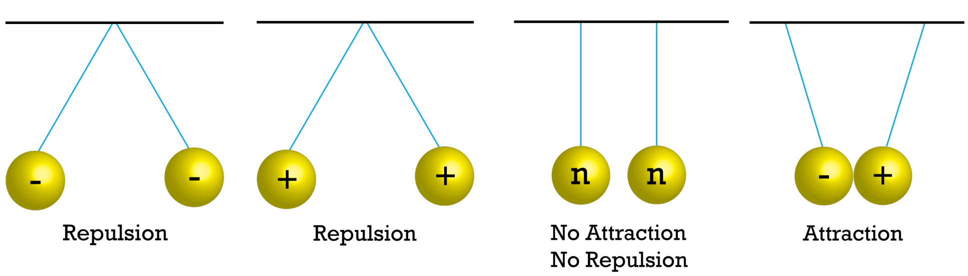
Electric charges exist within the atom. At the turn of the 20th century, J. J. Thomson and Ernest Rutherford determined that atoms contain very light-weight negatively charged particles called **electrons** and more massive, positively charged particles called **protons**. The protons are lodged in the **nucleus** of the atoms, along with the neutrally charged particles called **neutrons,** while the electrons surround the nucleus. When the number of electrons in the electron cloud and the number of protons in the nucleus are equal, the object is said to be **neutral**.

Changes to the nucleus of an atom require tremendous amounts of energy, so protons are not easily gained or lost by atoms. Electrons, on the other hand, are held fairly loosely and can often be removed quite easily. When an object loses some electrons, the remaining object is now positively charged because it has an excess of protons. The electrons may either remain free or may attach to another object. In that case, the extra electrons cause that object to become negatively charged. Atoms that have lost electrons and become positively charged are called **positive ions,** and atoms that have gained electrons and become negatively charged are called **negative ions**.

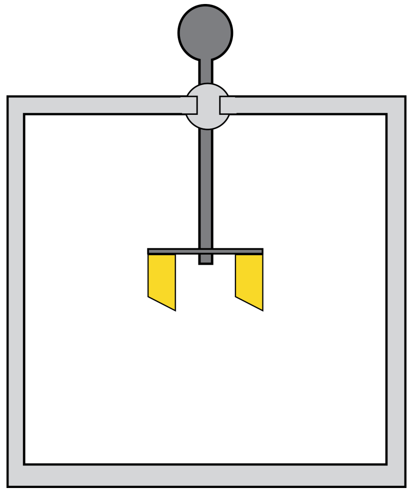
Electrons can be removed from some objects using friction, simply by rubbing one substance against another substance. There are many examples of objects becoming charged by friction, including a rubber comb through hair, and a balloon on a sweater. In both these instances, the electrons move from the second object to the first, causing the first object to become negatively charged and the second one positively charged. Friction between the tires on a moving car and the road cause the tires to become charged, and wind causes friction between clouds and air which causes clouds to become charged and can result in tremendous bolts of lightning.

A common method of producing charge in the lab is to rub cat or rabbit fur against stiff rubber, producing a negative charge on the rubber rod. If you hold a rubber rod on one end and rub only the tip of the other end with a fur, you will find that only the tip becomes charged. The electrons you add to the tip of the rod remain where you put them instead of moving around on the rod. Rubber is an **insulator.** Insulators are substances that do not allow electrons to move through them. Glass, dry wood, most plastics, cloth, and dry air are common insulators. Materials that allow electrons to flow freely are called **conductors.** Metals have at least one electron that can move around freely, and all metals are conductors.

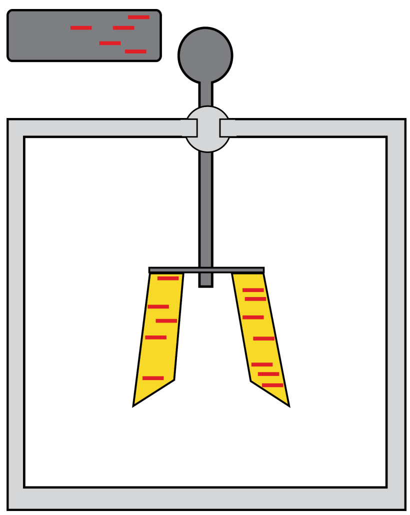
Forces are exerted on charged objects by other charged objects. You've probably heard the saying "opposites attract," which is true in regards to charged particles. Opposite charges attract each other, while like charges repulse each other. This can be seen in the image below. When two negatively charged objects are brought near each other, a repulsive force is produced. When two positively charged objects are brought near each other, a similar repulsive force is produced. When a negatively charged object is brought near a positively charged object, an attractive force is produced. Neutral objects have no influence on each other.



A laboratory instrument used to analyze and test for static charge is called an **electroscope.** Seen below, an electroscope consists of a metal knob connected by a metal stem to two very lightweight pieces of metal called leaves, shown in yellow. The leaves are enclosed in a box to eliminate stray air currents.



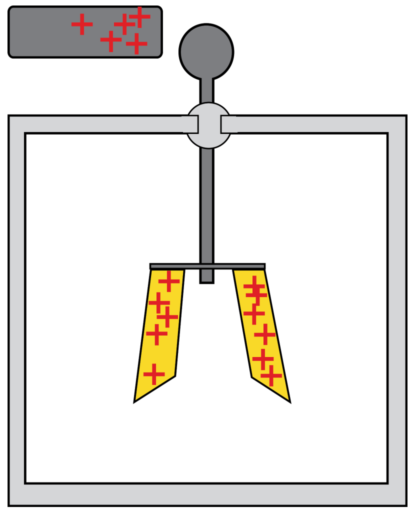
When a negatively charged object is brought near the knob of a neutral electroscope, the negative charge repels the electrons in the knob, and those electrons move down the stem into the leaves. Excess electrons flow from the rod into the ball, and then downwards making both leaves negatively charged. Since both leaves are negatively charged, they repel each other. When the rod is removed, the electroscope will remain charged because of the extra electrons added to it.



Conversely, if the rod is brought near the knob but doesn't touch it, the electroscope will appear the same while the rod is near. That is, the negative charge in the rod repels the electrons in the ball, causing them to travel down to the leaves. The leaves will separate while the rod is nearby. No extra electrons were added to the electroscope, meaning that the electrons in the electroscope will redistribute when the negatively charged rod is taken away. The leaves return to neutral, and they stop repelling each other. If the rod touches the knob, the electroscope leaves are permanently charged but if the rod is brought near but does not touch the knob, the electroscope leaves are only temporarily charged.

If the leaves are permanently charged and the rod removed, the electroscope can then be used to determine the type of unknown charge on an object. If the electroscope has been permanently negatively charged, and a negatively charge object is brought near the knob, the leaves will separate even further, showing the new object has the same charge as the leaves. If a positively charged object is brought near a negatively charged electroscope, it will attract some of the excess electrons up the stem and out of the leaves, causing the leaves to come slightly together.

Similar to the results of a negatively charged rod, if a positively charged rod is brought near the knob of a neutral electroscope, it will attract some electrons up from the leaves onto the knob. That process causes both of the leaves to be positively charged (excess protons), and the leaves will divReplaceerge. If the positively charged rob is actually touched to the knob, the rob will remove some electrons and then when the rob is removed, the electroscope will remain positively charged. This is a permanent positive charge.



Charging an object by touching it with another charged object is called **charging by conduction.** By bringing a charged object into contact with an uncharged object, some electrons will migrate to even out the charge on both objects. Charging by conduction gives the previously uncharged object a permanent charge. An uncharged object can also be charged using a method called **charging by induction**. This process allows a change in charge without actually touching the charged and uncharged objects to each other. Imagine a negatively charged rod held near the knob, but not touching. If we place a finger on the knob, some of the electrons will escape into our body, instead of down the stem and into the leaves. When both our finger and the negatively charged rod are removed, the previously uncharged electroscope now has a slight positive charge. It was charged by induction. Notice that charging by induction causes the newly charged object to have the opposite charge as the originally charged object, while charging by conduction gives them both the same charge.

Summary

- Electric charges exist with the atom.
- Atoms contain light-weight, loosely held, negatively charged particles called electrons and heavier, tightly-held, positvely charged particles called protons.
- When the number of electrons and the number of protons are equal, the object is neutral.
- The loss of electrons gives an ion a positive charge, while the gain of electrons gives it a negative charge.
- Materials that allow electrons to flow freely are called conductors, while those that do not are called insulators.
- Opposite charges attract, and like charges repel.
- Charging an object by touching it with another charged object is called charging by conduction.

Review

1. How does friction generate static electricity?
    1. Friction heats the materials, thus causing electricity.
    2. Rubbing materials together displaces atoms, causing sparks to fly.
    3. Rubbing materials together can strip electrons off atoms, causing one material to become positive and the other to become negative.
    4. Rubbing materials together causes neutrons and electrons to trade places.

5. None of the above.

2. Explain what happens to the charge of an object if an electron is removed from it. What happens to the charge of the object that gained the electrons? .
3. What happens when two charged objects are put near each other when the objects are (a) oppositely charged, (b) identically charged?
4. What makes materials good electrical (a) conductor? (b) insulator. Give two examples of each type.

Explore More

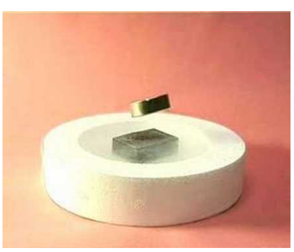
Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/63057

1. What happens to her hair when she touches a ground?
2. What happens to her hair when she steps off the platform?

Resources

This video demonstrates superconductivity that occurs at extremely low temperatures.



MEDIA
Click image to the left or use the URL below.
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Vocabulary

- **electrons:** A fundamental sub-atomic particle, meaning it cannot be broken into smaller particles. Electrons are found in the "electron cloud" surrounding an atomic nucleus, or they may break free and exist as a free electron.

- **protons:** A stable, positively charged, sub-atomic particle, found in atomic nuclei in numbers equal to the atomic number of the element.
- **neutral:** A neutral particle, object, or system is one that has a net electric charge of zero.
- **conductors:** Materials through which electric charge can pass.
- **insulator:** Substances that block or retard the flow of electrical current or charge.
- **positive ions:** An atom or a group of atoms that has acquired a net positive charge by losing one or more electrons.
- **negative ions:** An atom or a group of atoms that has acquired a net negative charge by gaining one or more electrons.
- **ions:** An atom or a group of atoms that has acquired a net electric charge by gaining or losing one or more electrons.
- **electroscope:** An instrument used to detect the presence and sign of an electric charge by the mutual attraction or repulsion of metal foils.
- **charging by conduction:** Involves the contact of a charged object to a neutral object.
- **charging by induction:** A method used to charge an object without actually touching the object to any other charged object.

References

1. Courtesy of NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL). <a href="http://www.photolib.noaa.gov/htmls/nssl0016.htm">http://www.photolib.noaa.gov/htmls/nssl0016.htm<
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3. Christopher Auyeung. CK-12 Foundation.
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6. Samantha Bacic. CK-12 Foundation.

CHAPTER 29 Electromagnetism

Chapter Outline

What's dangling from the end of this big crane? It seems to be a very large magnet because metal objects are sticking to it. That's exactly what it is. With the flick of a switch, the crane operator can turn on the magnet and use it to pick up objects off the ground. Then with another flick of the switch, the operator can turn off the magnet to drop the objects in the container. How does this happen? How can a magnet be turned on or off so easily? In this chapter, you'll find out.

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29.1 Electricity and Magnetism

Lesson Objectives

- Outline how electromagnetism was discovered.
- Describe the magnetic field created by an electric current.

Lesson Vocabulary

- electromagnetism

Introduction

The crane magnet in the opening photo is an electromagnet. Like all electromagnets, its magnetism is produced by electric current. This type of magnetism is called **electromagnetism**.

Discovery of Electromagnetism

In 1820, a physicist in Denmark, named Hans Christian Oersted, discovered how electric currents and magnetic fields are related. However, it was just a lucky accident. Oersted, who is pictured in **Figure** 29.1, was presenting a demonstration to his students. Ironically, he was trying to show that electricity and magnetism are not related. He placed a wire with electric current flowing through it next to a magnet, and nothing happened. After class, a student held the wire near the magnet again, but in a different direction. To Oersted's surprise, the pointer of the magnet swung toward the wire so it was no longer pointing to Earth's magnetic north pole. Oersted was intrigued. He turned off the current in the wire to see what would happen to the magnet. The pointer swung back to its original position, pointing north again. Oersted had discovered that an electric current creates a magnetic field. The magnetic field created by the current was strong enough to attract the pointer of the nearby compass.

Oersted wanted to learn more about the magnetic field created by a current, so he placed a magnet at different locations around a wire with current flowing through it. You can see some of his results in **Figure** 29.2. They show that the magnetic field created by a current has field lines that circle around the wire. You can learn more about Oersted's investigations of current and magnetism at the URL below.

http://www.youtube.com/watch?v=BM4m2GId3F8 (2:00)

MEDIA

Click image to the left or use the URL below.

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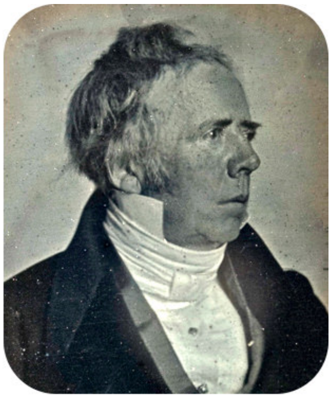

FIGURE 29.1
Hans Christian Oersted was the scientist who discovered electromagnetism.

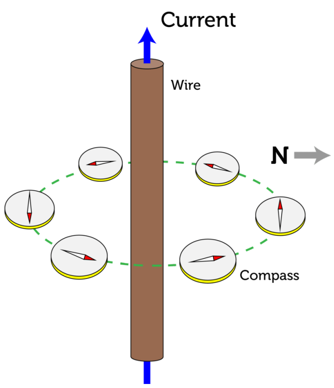

FIGURE 29.2
In Oersted's investigation, the pointer of the magnet moved continuously as it circled the wire.

Electric Currents and Magnetic Fields

The magnetic field created by a current flowing through a wire actually surrounds the wire in concentric circles. This magnetic field is stronger if more current is flowing through the wire. The direction of the magnetic field also depends on the direction that the current is flowing through the wire. A simple rule, called the right hand rule, makes it easy to find the direction of the magnetic field if the direction of the current is known. The right hand rule is illustrated in **Figure** 29.3. When the thumb of the right hand is pointing in the same direction as the current, the fingers of the right hand curl around the wire in the direction of the magnetic field. You can see the right hand rule in action at this URL: http://www.youtube.com/watch?v=eK1Ar5WPJj8 .

Lesson Summary

- Electromagnetism is magnetism produced by an electric current. Electromagnetism was discovered by Oersted in 1820.
- The magnetic field produced by a current in a wire moves around the wire in concentric circles. More current creates a stronger magnetic field, and the direction of the current determines the direction of the magnetic field.

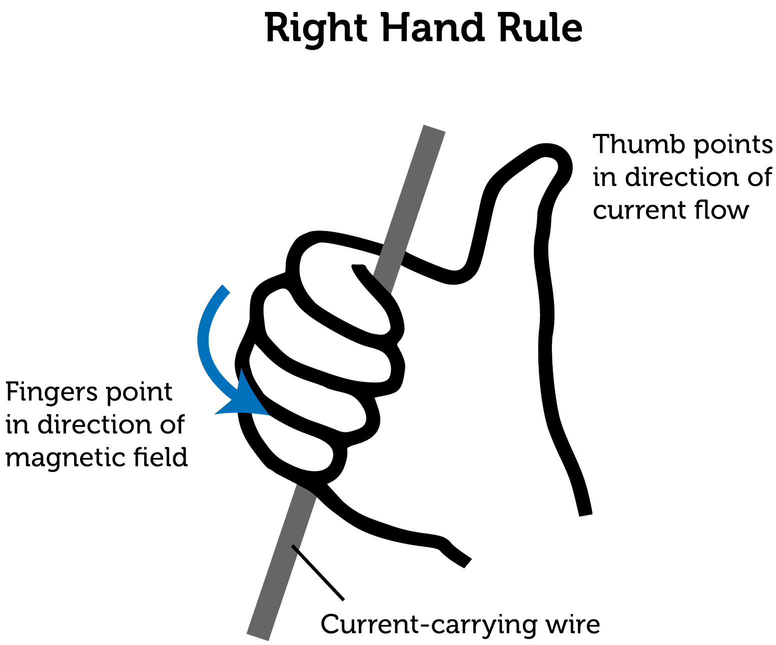

FIGURE 29.3
The right hand rule shows the direction of the magnetic field around a wire that is carrying electric current.

Lesson Review Questions

Recall

1. Define electromagnetism.
2. Describe how Oersted discovered electromagnetism.
3. What is the right hand rule?

Apply Concepts

4. The drawing below shows part of a wire that has current flowing through it. The arrow shows the direction of the current. Apply the right hand rule, and sketch the magnetic field lines around the wire.

Think Critically

5. Relate the properties of an electric current to its magnetic field.

Points to Consider

The magnetic field created by a single wire with current flowing through it is too weak to be very useful. However, technologies have been developed to make stronger electromagnetic fields. You can learn what they are in the next lesson on "Using Electromagnetism."

- What might make an electromagnetic field stronger?
- How might the wire that carries the current be arranged to increase the strength of the magnetic field?

29.2 Generating and Using Electricity

Lesson Objectives

- Describe electromagnetic induction.
- Explain how electric generators and transformers work.
- State the roles of generators and transformers in electrifying the home.

Lesson Vocabulary

- electric generator
- electric transformer
- electromagnetic induction
- Faraday's law

Introduction

You probably use many electric devices every day, including lights and appliances such as hair dryers and microwaves. Where does the electricity come from to power these devices? The answer is magnetic fields.

From Magnets to Electricity

Just about a decade after Oersted discovered that electric current produces a magnetic field, an English scientist named Michael Faraday discovered that the reverse is also true. A magnetic field produces an electric current, as long as the magnetic field is changing. This is called **Faraday's law**.

Electromagnetic Induction

The process of generating electric current with a changing magnetic field is called **electromagnetic induction**. It occurs whenever a magnetic field and an electric conductor, such as a coil of wire, move relative to one another. As long as the conductor is part of a closed circuit, current will flow through it whenever it crosses magnetic field lines. One way this can happen is pictured in **Figure** 29.4. It shows a magnet moving inside a wire coil. Another way is for the coil to move instead of the magnet.

You can watch an animated version of **Figure** 29.4 at this URL: http://jsticca.wordpress.com/2009/09/01/the-magnet-car/ .

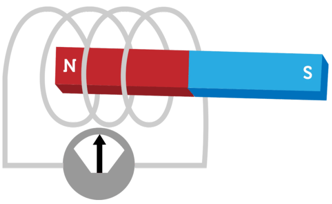

FIGURE 29.4
This simple setup shows how electromagnetic induction occurs.

The Current Produced by a Magnet

The device in the circuit in **Figure** 29.4 is an ammeter. It measures the current that flows through the wire. The faster the magnet or coil moves, the greater the amount of current that is produced. If more turns were added to the coil, this would increase the strength of the magnetic field as well. If the magnet were moved back and forth repeatedly, the current would keep changing direction. In other words, alternating current would be produced. This is illustrated in **Figure** 29.5.

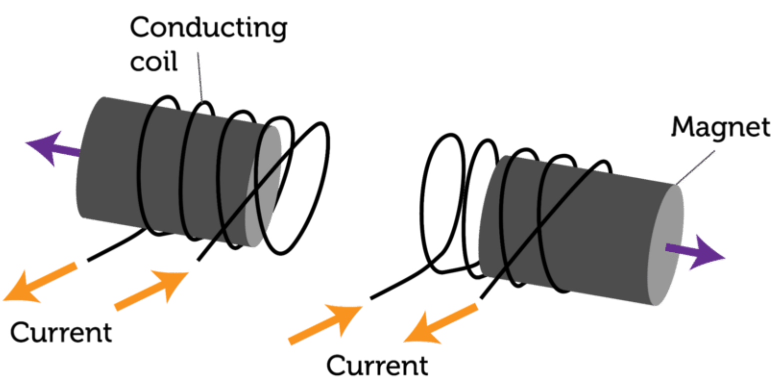

FIGURE 29.5
If a magnet is moved back and forth relative to a coil of wire, alternating current is produced.

Electric Generators and Transformers

Two important devices depend on electromagnetic induction: electric generators and electric transformers. Both devices play critical roles in producing and regulating the electric current we depend on in our daily lives.

Electric Generators

An **electric generator** is a device that changes kinetic energy to electrical energy through electromagnetic induction. A simple diagram of an electric generator is shown in **Figure** 29.6. In a generator, some form of energy is applied to turn a shaft. This causes a coil of wire to rotate between opposite poles of a magnet. Because the coil is rotating in a magnetic field, electric current is generated in the wire. If the diagram in **Figure** 29.6 looks familiar to you, that's because a generator is an electric motor in reverse. Look back at the electric motor in **Figure** above. If you were to mechanically turn the shaft of the motor (instead of using electromagnetism to turn it), the motor would generate electricity just like an electric generator. You can learn how to make a very simple electric generator by watching the video at the URL below. Making your own generator will help you understand how a generator works.

http://www.youtube.com/watch?v=k7Sz8oT8ou0

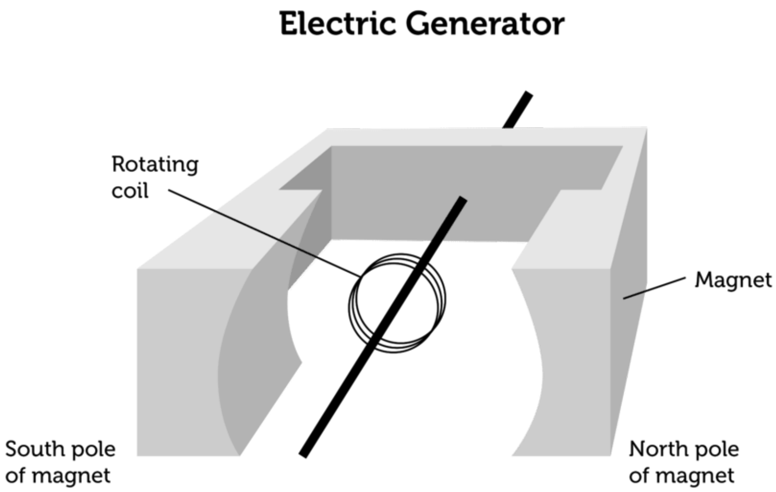

FIGURE 29.6
This diagram shows the basic parts of an electric generator. Compare the generator with the electric motor.

Generators may be set up to produce either alternating or direct current. Generators in cars and most power plants produce alternating current.

- A car generator produces electricity with some of the kinetic energy of the turning crankshaft. The electricity is used to run the car's lights, power windows, radio, and other electric devices. Some of the electricity is stored in the car's battery to provide electrical energy when the car isn't running.
- A power plant generator produces electricity with the kinetic energy of a turning turbine. The energy to turn the turbine may come from burning fuel, falling water, or some other energy source. You can see how falling water is used to generate electricity in **Figure** 29.7 and in the video at this URL: http://www.youtube.com/watch?v=cEL7yc8R42k .

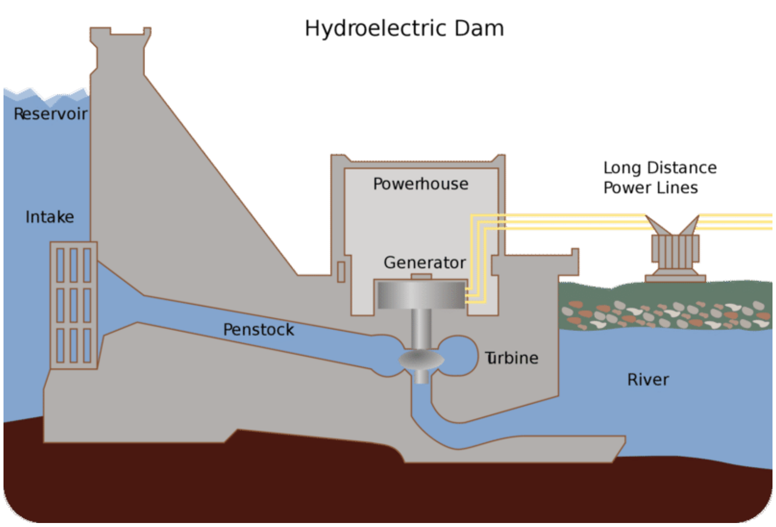

FIGURE 29.7
A hydroelectric power plant uses the kinetic energy of falling water to turn a turbine and generate electricity.

Electric Transformers

An **electric transformer** is a device that uses electromagnetic induction to change the voltage of electric current. A transformer may either increase or decrease voltage, but it only works with alternating current. You can see the components of an electric transformer in **Figure** 29.8.

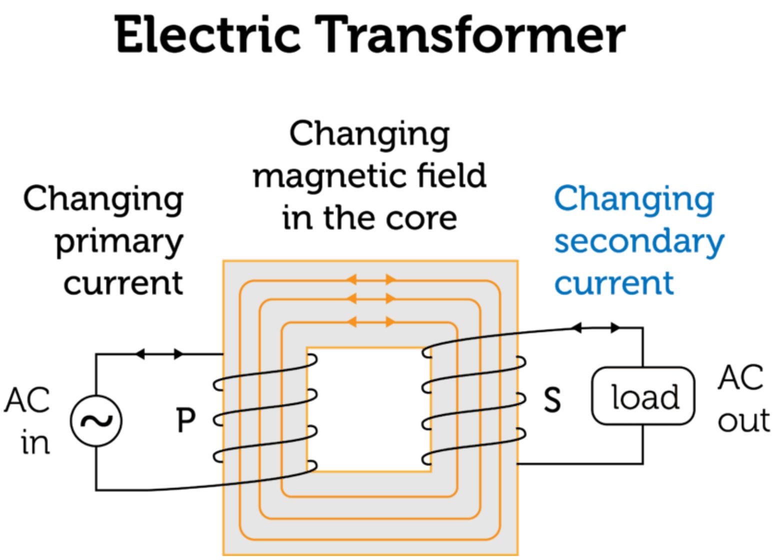

FIGURE 29.8
An electric transformer connects two circuits with an iron core that becomes an electromagnet.

As you can see in **Figure** 29.8, a transformer consists of two wire coils wrapped around an iron core. When alternating primary current passes through coil P, it magnetizes the iron core. Because the current is alternating, the magnetic field of the iron core keeps reversing. This changing magnetic field induces alternating current in coil S, which is part of another circuit. In **Figure** 29.8, coil P and coil S have the same number of turns of wire. In this case, the voltages of the primary and secondary currents are the same. However, when the two coils have different numbers of turns, the voltage of the secondary current is different than the voltage of the primary current. Both cases are illustrated in **Figure** 29.9.

- When coil S has more turns of wire than coil P, the voltage in the secondary current is greater than the voltage in the primary current. This type of transformer is called a step-up transformer.
- When coil S has fewer turns of wire than coil P, the voltage in the secondary current is less than the voltage in the primary current. This type of transformer is called a step-down transformer.

For an animation of a transformer, go to this URL: http://www.youtube.com/watch?v=VucsoEhB0NA .

Electrifying the Home

Power plant generators produce high-voltage electric current. Many power plants also use step-up transformers to increase the voltage of the current even more (see **Figure** 29.10). By increasing the voltage, the amount of current is decreased, so less power is lost as the electricity travels through the power lines. However, the voltage in power lines is too high to be safe for home circuits. The voltage in power lines may be as great as 750,000 volts, whereas most home circuits are 240 or 120 volts. One or more step-down transformers decrease the voltage of current before it enters the home. Other step-down transformers within the home lower the voltage of some of the home's circuits. For an overview of electric power generation, transmission, and distribution in the U.S., go to this URL: http://www.youtube.com/watch?v=2eU3BgrmzkY .

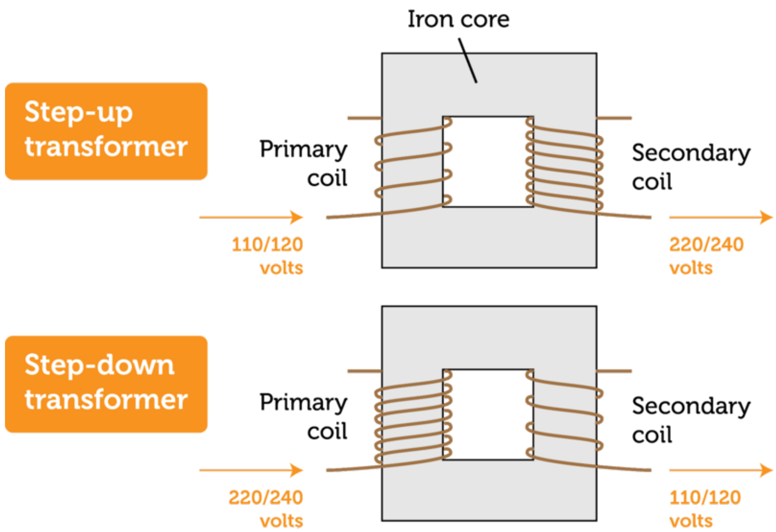

FIGURE 29.9
Whether a transformer increases or decreases voltage depends on the relative number of turns of wire in the two coils.

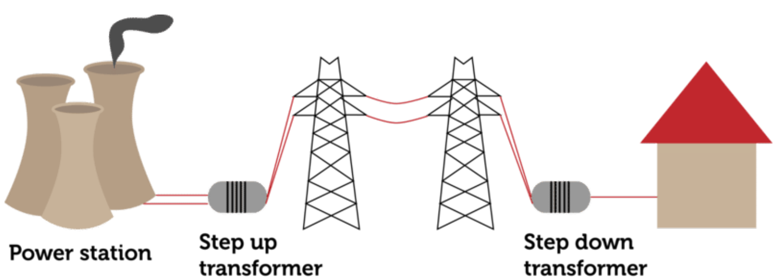

FIGURE 29.10
Transformers play an important role in supplying energy to the home. Why are both step-up and step-down transformers needed?

Lesson Summary

- A changing magnetic field produces an electric current in the process of electromagnetic induction. Current is generated whenever an electric conductor crosses magnetic field lines.
- An electric generator is a device that changes kinetic energy to electrical energy through electromagnetic induction. An electric transformer is a device that uses electromagnetic induction to change the voltage of electric current.
- Electric generators and transformers play critical roles in producing and regulating the electric current we depend on in our daily lives.

Lesson Review Questions

Recall

1. What is Faraday's law?
2. Define electromagnetic induction.
3. Describe how an electric generator uses electromagnetic induction.

Apply Concepts

4. Create a sketch to show how a coil of wire in a circuit and a bar magnet can be used to produce electric current.

Think Critically

5. Explain how an electric transformer changes the voltage of electric current. Why does a transformer work only with alternating current?

Points to Consider

This chapter explains how electric and magnetic forces are related and how they are used. Knowledge of electricity and magnetism can help you understand the electric devices you use in your daily life. In many other ways, knowledge of physical science can help you understand your natural and human-made environment.

- What have you learned by studying physical science that helps you understand the world around you?
- What else would you like to learn?

29.3 References

1. . http://commons.
Christian_%C3%98rsted_daguerreotype.jpg. Public Domain
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3. Hand by Wizard191, modified by Christopher Auyeung for CK-12 Foundation. <a href="Hand from http://commons.wikim
hand_grip_rule.svg">Hand from http://commons.wikimedia.org/wiki/File:Right-hand_grip_rule.svg. CC BY-NC 3.0 (hand available under public domain)
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CONCEPT 30 Unit 11: Waves and Their Applications

Questions/Observable Phenomena

CHAPTER 31 Waves

Chapter Outline

This immense wall of moving water gives the surfer an amazing ride. The swelling surf will raise him up and push him forward as though he's as light as a feather. All he needs to do is keep his balance on the surfboard. The incredible power of the wave will do the rest. When you think of waves, ocean waves like this one probably come to mind. But there are many other examples of waves, some that affect all of us in our daily lives. What are waves, and what causes them? What are some other examples of waves? Read on to find out.

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31.1 Characteristics of Waves

Lesson Objectives

- Define mechanical wave.
- Describe transverse waves.
- Identify longitudinal waves.
- Describe surface waves.

Lesson Vocabulary

- longitudinal wave
- mechanical wave
- surface wave
- transverse wave

Introduction

Ocean waves are among the most impressive waves in the world. They clearly show that waves transfer energy. In the case of ocean waves, energy is transferred through matter. But some waves, called electromagnetic waves, can transfer energy without traveling through matter. These waves can travel through space. You can read more about electromagnetic waves in the chapter "Electromagnetic Radiation." Waves that transfer energy through matter are the focus of the present chapter. These waves are called mechanical waves.

Mechanical Waves

A **mechanical wave** is a disturbance in matter that transfers energy from place to place. A mechanical wave starts when matter is disturbed. An example of a mechanical wave is pictured in **Figure** 31.1. A drop of water falls into a pond. This disturbs the water in the pond. What happens next? The disturbance travels outward from the drop in all directions. This is the wave. A source of energy is needed to start a mechanical wave. In this case, the energy comes from the falling drop of water.

The Medium

The energy of a mechanical wave can travel only through matter. This matter is called the medium (*plural*, media). The medium in **Figure** 31.1 is a liquid —the water in the pond. But the medium of a mechanical wave can be any state of matter, including a solid or a gas. It's important to note that particles of matter in the medium don't actually

FIGURE 31.1
A drop of water causes a disturbance that travels through the pond as a wave.

travel along with the wave. Only the energy travels. The particles of the medium just vibrate, or move back-and-forth or up-and-down in one spot, always returning to their original positions. As the particles vibrate, they pass the energy of the disturbance to the particles next to them, which pass the energy to the particles next to them, and so on.

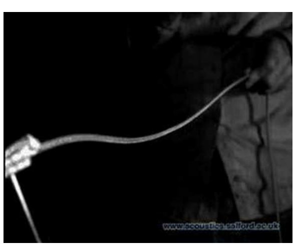
Types of Mechanical Waves

There are three types of mechanical waves. They differ in how they travel through a medium. The three types are transverse, longitudinal, and surface waves. All three types are described in detail below.

Transverse Waves

A **transverse wave** is a wave in which the medium vibrates at right angles to the direction that the wave travels. An example of a transverse wave is a wave in a rope, like the one pictured in **Figure** 31.2. In this wave, energy is provided by a person's hand moving one end of the rope up and down. The direction of the wave is down the length of the rope away from the person's hand. The rope itself moves up and down as the wave passes through it. You can see a brief video of a transverse wave in a rope at this URL: http://www.youtube.com/watch?v=TZIr9mpERbU .

To see a transverse wave in slow motion, go to this URL: http://www.youtube.com/watch?v=g49mahYeNgc (0:22).



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Crests and Troughs

A transverse wave can be characterized by the high and low points reached by particles of the medium as the wave passes through. This is illustrated in **Figure** 31.3. The high points are called crests, and the low points are called troughs.

S Waves

Another example of transverse waves occurs with earthquakes. The disturbance that causes an earthquake sends transverse waves through underground rocks in all directions from the disturbance. Earthquake waves that travel this

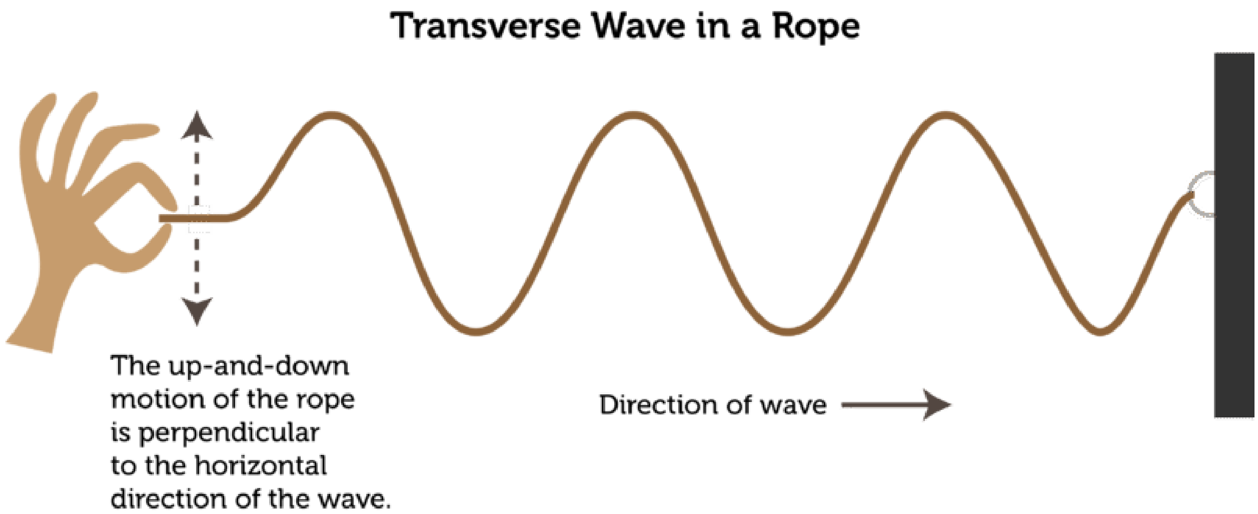


FIGURE 31.2
In a transverse wave, the medium moves at right angles to the direction of the wave.

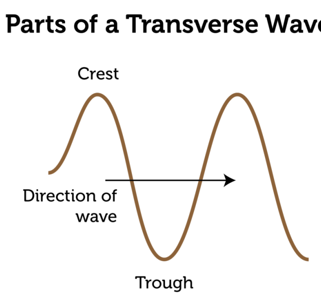


FIGURE 31.3
Crests and troughs are the high and low points of a transverse wave.

way are called secondary, or S, waves. An S wave is illustrated in **Figure** 31.4.

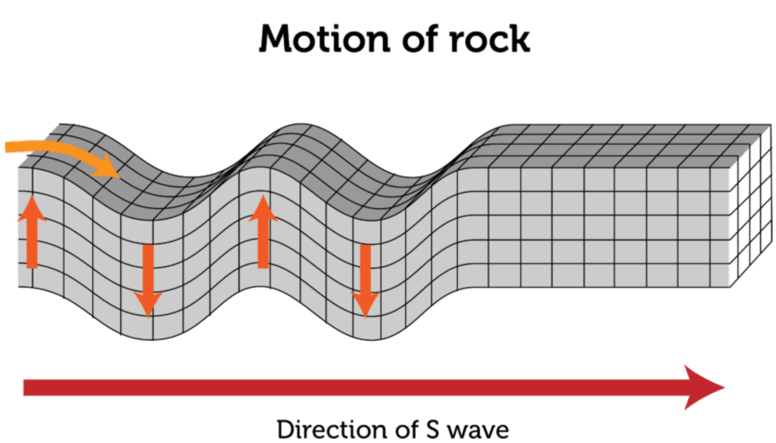


FIGURE 31.4
An S wave is a transverse wave that travels through rocks under Earth's surface.

Longitudinal Waves

A **longitudinal wave** is a wave in which the medium vibrates in the same direction that the wave travels. An example of a longitudinal wave is a wave in a spring, like the one in **Figure** 31.5. In this wave, the energy is provided by a person's hand pushing and pulling the spring. The coils of the spring first crowd closer together and then spread farther apart as the disturbance passes through them. The direction of the wave is down the length of the spring, or the same direction in which the coils move. You can see a video of a longitudinal wave in a spring at this URL: http://www.youtube.com/watch?v=ubRlaCCQfDk .

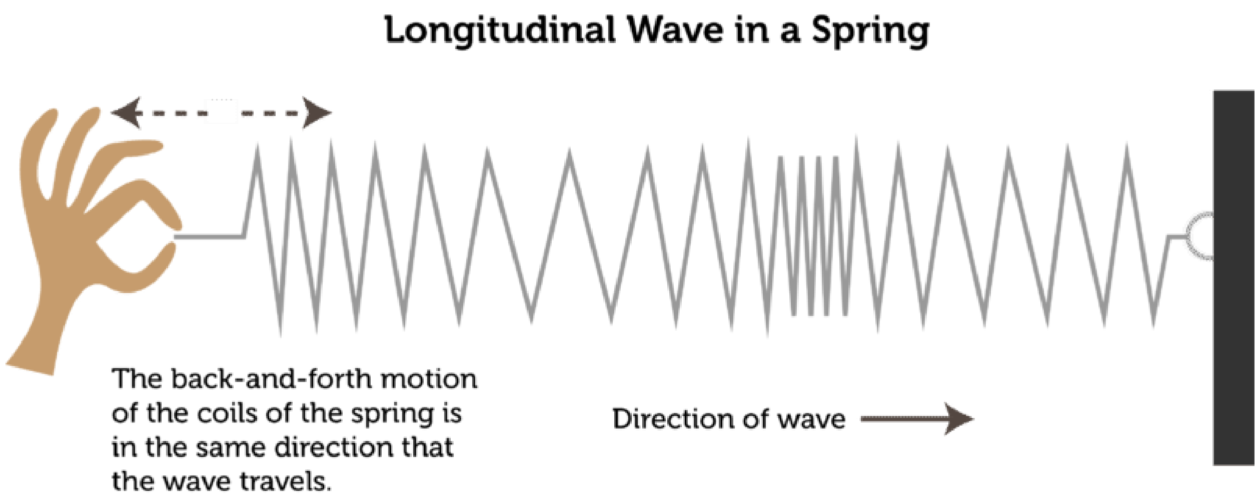


FIGURE 31.5
In a longitudinal wave, the medium moves back and forth in the same direction as the wave.

Compressions and Rarefactions

A longitudinal wave can be characterized by the compressions and rarefactions of the medium. This is illustrated in **Figure** 31.6. Compressions are the places where the coils are crowded together, and rarefactions are the places where the coils are spread apart.

P Waves

Earthquakes cause longitudinal waves as well as transverse waves. The disturbance that causes an earthquake sends longitudinal waves through underground rocks in all directions from the disturbance. Earthquake waves that travel this way are called primary, or P, waves. They are illustrated in **Figure** 31.7.

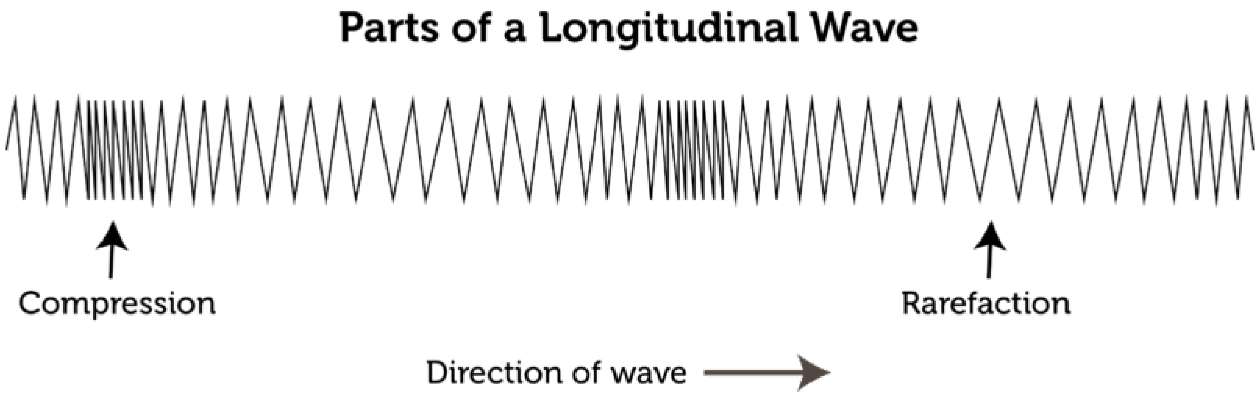


FIGURE 31.6
The compressions and rarefactions of a longitudinal wave are like the crests and troughs of a transverse wave.

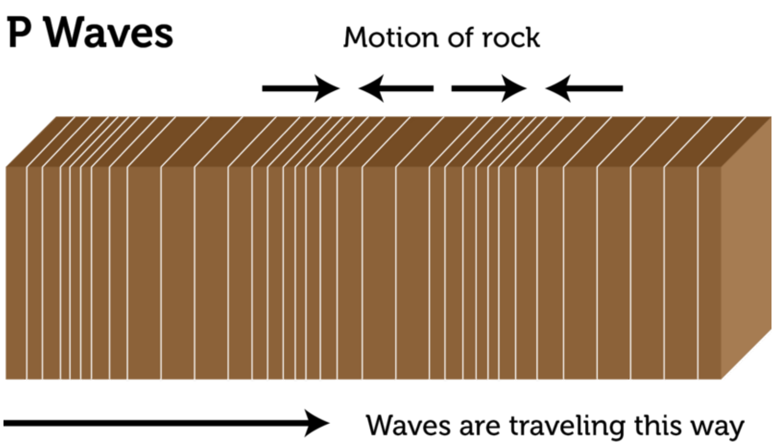
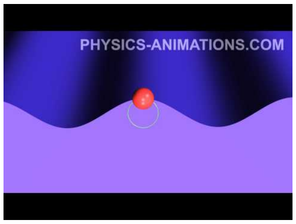


FIGURE 31.7
P waves are longitudinal waves that travel through rocks under Earth's surface.

Surface Waves

A **surface wave** is a wave that travels along the surface of a medium. It combines a transverse wave and a longitudinal wave. Ocean waves are surface waves. They travel on the surface of the water between the ocean and the air. In a surface wave, particles of the medium move up and down as well as back and forth. This gives them an overall circular motion. This is illustrated in **Figure** 31.8 and at the URL below.

http://www.youtube.com/watch?v=7yPTa8qi5X8 (0:57)



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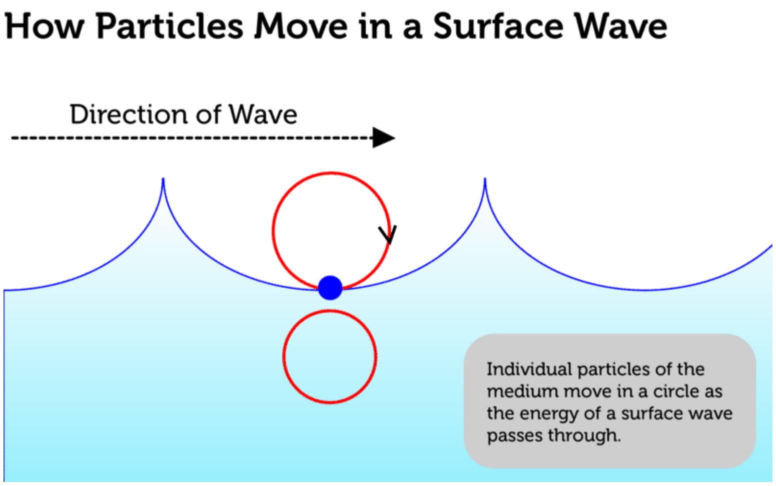


FIGURE 31.8

Surface waves are both transverse and longitudinal waves.

In deep water, particles of water just move in circles. They don't actually move closer to shore with the energy of the waves. However, near the shore where the water is shallow, the waves behave differently. They start to drag on the bottom, creating friction (see **Figure** 31.9). The friction slows down the bottoms of the waves, while the tops of the waves keep moving at the same speed. This causes the waves to get steeper until they topple over and crash on the shore. The crashing waves carry water onto the shore as surf.

Lesson Summary

- Mechanical waves are waves that transfer energy through matter, called the medium. Mechanical waves start when a source of energy causes a disturbance in the medium. Types of mechanical waves include transverse, longitudinal, and surface waves.
- In a transverse wave, such as a wave in a rope, the medium vibrates at right angles to the direction that the wave travels. The high points of transverse waves are called crests, and the low points are called troughs.
- In a longitudinal wave, such as a wave in a spring, the medium vibrates in the same direction that the wave travels. Places where the particles of the medium are closer together are called compressions, and places where they are farther apart are called rarefactions.
- A surface wave, such as an ocean wave, travels along the surface of a medium and combines a transverse wave and a longitudinal wave. Particles of the medium move in a circle as the surface wave passes through them.

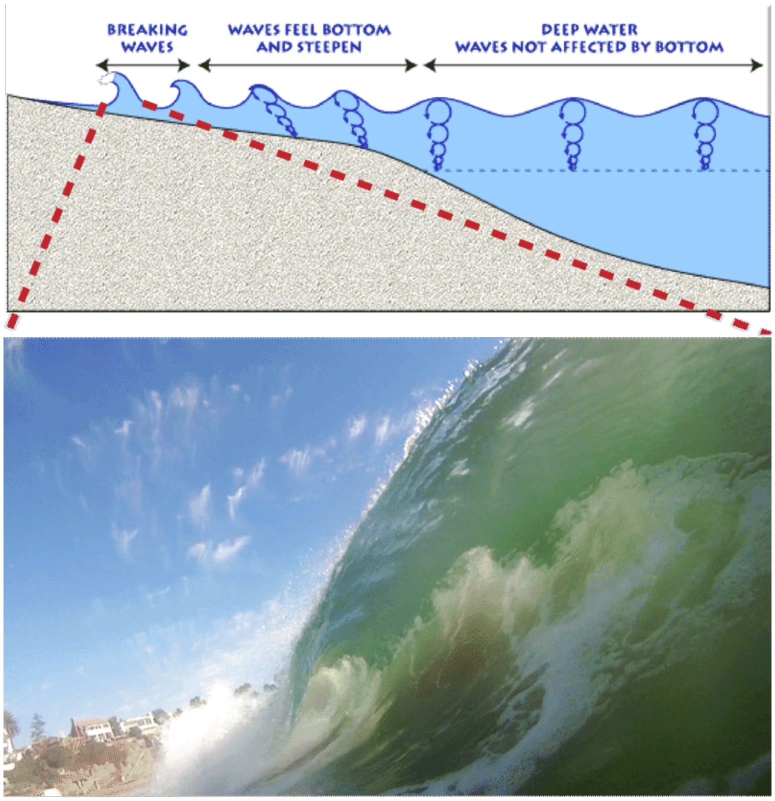


FIGURE 31.9
Waves topple over and break on the shore because of friction with the bottom in shallow water.

Lesson Review Questions

Recall

1. What is a mechanical wave?
2. Identify the medium of the wave in **Figure** 31.1.
3. Describe the compressions and rarefactions of a longitudinal wave.
4. What are surface waves? Give an example.
5. State how a particle of the medium moves when a surface wave passes through it.

Apply Concepts

6. Draw a sketch of a transverse wave. Label the crests and troughs, and add an arrow to show the direction the wave is traveling.

Think Critically

7. Compare and contrast P waves and S waves of earthquakes.

Points to Consider

When an earthquake occurs under the ocean, it sends waves through the water as well as the ground. When the energy of the earthquake reaches shore, it forms a huge wave called a tsunami.

- Do you know how large tsunamis are? How might the size of these and other waves be measured?
- What causes some waves to be bigger than others?

31.2 Measuring Waves

Lesson Objectives

- Define wave amplitude and wavelength.
- Relate wave speed to wave frequency and wavelength.

Lesson Vocabulary

- hertz (Hz)
- wave amplitude
- wave frequency
- wavelength
- wave speed

Introduction

Tsunamis, or the waves caused by earthquakes, are unusually large ocean waves. You can see an example of a tsunami in **Figure** 31.10. Because tsunamis are so big, they can cause incredible destruction and loss of life. The tsunami in the figure crashed into Thailand, sending people close to shore running for their lives. The height of a tsunami or other wave is just one way of measuring its size. You'll learn about this and other ways of measuring waves in this lesson.

FIGURE 31.10

This tsunami occurred in Thailand on December 26, 2004.

Wave Amplitude and Wavelength

The height of a wave is its amplitude. Another measure of wave size is wavelength. Both wave amplitude and wavelength are described in detail below. **Figure** 31.11 shows these wave measures for both transverse and longitudinal waves. You can also simulate waves with different amplitudes and wavelengths by doing the interactive animation at this URL: http://sci-culture.com/advancedpoll/GCSE/sine%20wave%20simulator.html .

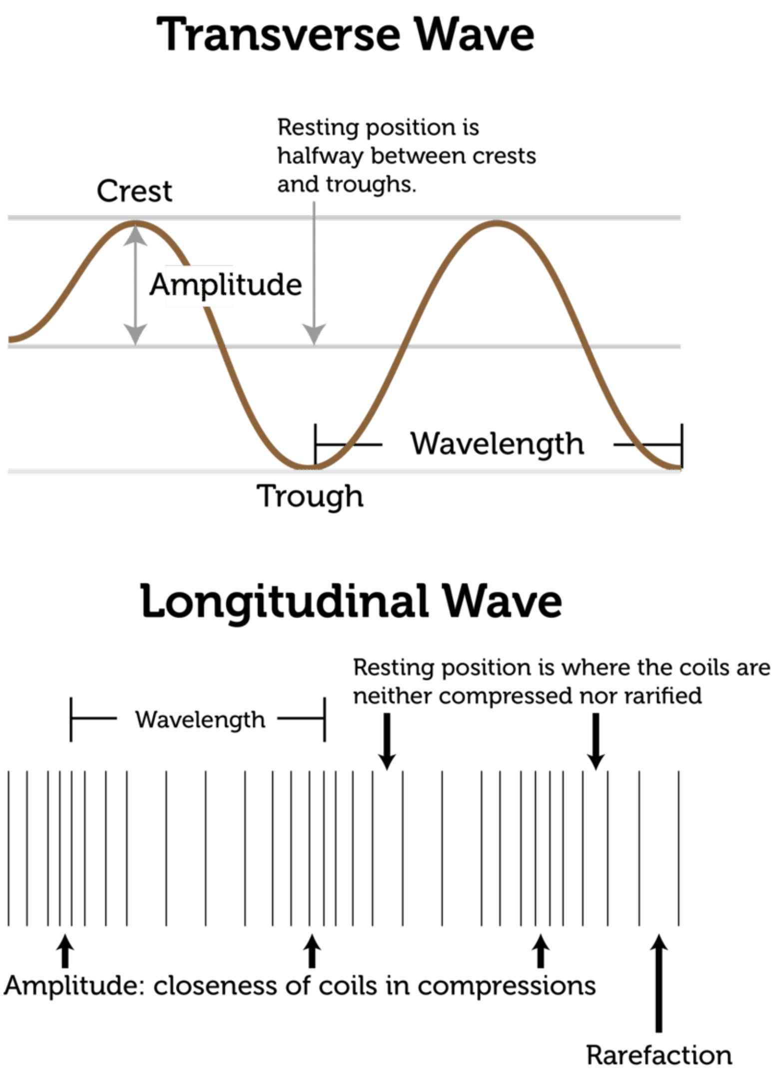


FIGURE 31.11
Wave amplitude and wavelength are two important measures of wave size.

Wave Amplitude

Wave amplitude is the maximum distance the particles of a medium move from their resting position when a wave passes through. The resting position is where the particles would be in the absence of a wave.

- In a transverse wave, wave amplitude is the height of each crest above the resting position. The higher the crests are, the greater the amplitude.
- In a longitudinal wave, amplitude is a measure of how compressed particles of the medium become when the wave passes through. The closer together the particles are, the greater the amplitude.

What determines a wave's amplitude? It depends on the energy of the disturbance that causes the wave. A wave caused by a disturbance with more energy has greater amplitude. Imagine dropping a small pebble into a pond of still water. Tiny ripples will move out from the disturbance in concentric circles, like those in **Figure** 31.1. The ripples are low-amplitude waves. Now imagine throwing a big boulder into the pond. Very large waves will be generated by the disturbance. These waves are high-amplitude waves.

Wavelength

Another important measure of wave size is wavelength. **Wavelength** is the distance between two corresponding points on adjacent waves (see **Figure** 31.11). Wavelength can be measured as the distance between two adjacent crests of a transverse wave or two adjacent compressions of a longitudinal wave. It is usually measured in meters. Wavelength is related to the energy of a wave. Short-wavelength waves have more energy than long-wavelength waves of the same amplitude. You can see examples of waves with shorter and longer wavelengths in **Figure** 31.12.

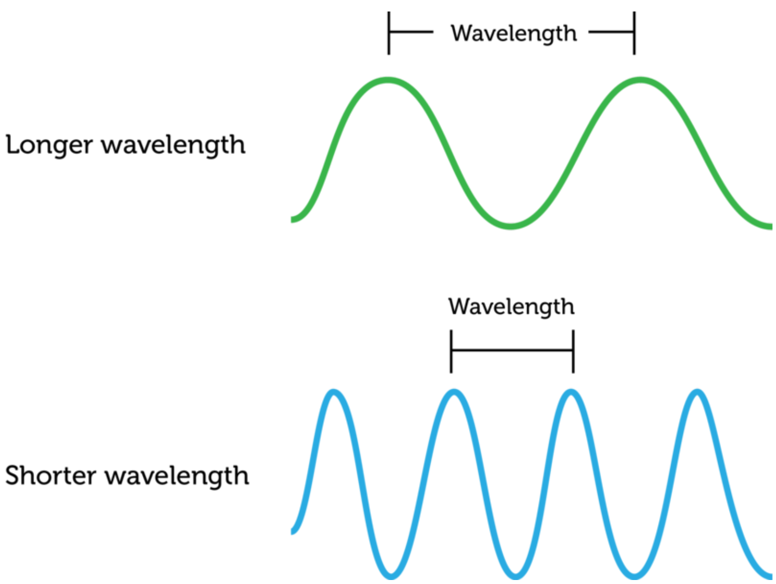


FIGURE 31.12
Both of these waves have the same amplitude, but they differ in wavelength. Which wave has more energy?

Wave Frequency and Speed

Imagine making transverse waves in a rope, like the waves in **Figure** 31.2. You tie one end of the rope to a doorknob or other fixed point and move the other end up and down with your hand. You can move the rope up and down slowly or quickly. How quickly you move the rope determines the frequency of the waves.

Wave Frequency

The number of waves that pass a fixed point in a given amount of time is **wave frequency**. Wave frequency can be measured by counting the number of crests or compressions that pass the point in 1 second or other time period. The higher the number is, the greater is the frequency of the wave. The SI unit for wave frequency is the **hertz (Hz)**, where 1 hertz equals 1 wave passing a fixed point in 1 second. **Figure** 31.13 shows high-frequency and low-frequency transverse waves. You can simulate transverse waves with different frequencies at this URL: http://zonal andeducation.com/mstm/physics/waves/partsOfAWave/waveParts.htm .

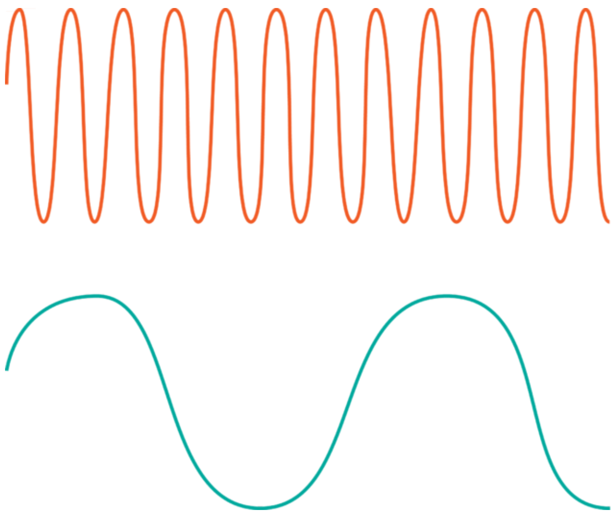


FIGURE 31.13
A transverse wave with a higher frequency has crests that are closer together.

The frequency of a wave is the same as the frequency of the vibrations that caused the wave. For example, to generate a higher-frequency wave in a rope, you must move the rope up and down more quickly. This takes more energy, so a higher-frequency wave has more energy than a lower-frequency wave with the same amplitude.

Wave Speed

Assume that you move one end of a rope up and down just once. How long will take the wave to travel down the rope to the other end? This depends on the speed of the wave. **Wave speed** is how far the wave travels in a given amount of time, such as how many meters it travels per second. Wave speed is not the same thing as wave frequency, but it is related to frequency and also to wavelength. This equation shows how the three factors are related:

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

In this equation, wavelength is measured in meters and frequency is measured in hertz, or number of waves per second. Therefore, wave speed is given in meters per second.

The equation for wave speed can be used to calculate the speed of a wave when both wavelength and wave frequency are known. Consider an ocean wave with a wavelength of 3 meters and a frequency of 1 hertz. The speed of the wave is:

$$\text{Speed} = 3 \text{ m} \times 1 \text{ wave/s} = 3 \text{ m/s}$$

You Try It!

Problem: Jera made a wave in a spring by pushing and pulling on one end. The wavelength is 0.1 m, and the wave frequency is 0.2 m/s. What is the speed of the wave?

If you want more practice calculating wave speed from wavelength and frequency, try the problems at this URL: http://www.physicsclassroom.com/class/waves/u10l2e.cfm .

The equation for wave speed (above) can be rewritten as:

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}} \text{ or Wavelength} = \frac{\text{Speed}}{\text{Frequency}}$$

Therefore, if you know the speed of a wave and either the wavelength or wave frequency, you can calculate the missing value. For example, suppose that a wave is traveling at a speed of 2 meters per second and has a wavelength of 1 meter. Then the frequency of the wave is:

$$\text{Frequency} = \frac{2 \text{ m/s}}{1 \text{ m}} = 2 \text{ waves/s, or } 2 \text{ Hz}$$

You Try It!

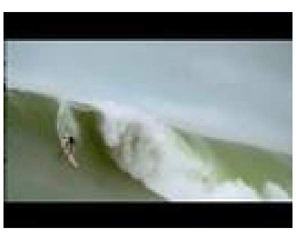
Problem: A wave is traveling at a speed of 2 m/s and has a frequency of 2 Hz. What is its wavelength?

The Medium Matters

The speed of most waves depends on the medium through which they are traveling. Generally, waves travel fastest through solids and slowest through gases. That's because particles are closest together in solids and farthest apart in gases. When particles are farther apart, it takes longer for the energy of the disturbance to pass from particle to particle.

KQED: Science of Big Waves

The organizers of the famous Maverick surf contest have voted that the conditions are right for hanging ten this weekend. The monster waves at Mavericks attract big wave surfers from around the world. But what exactly makes these Half Moon Bay waves so big? For more information on waves, see http://science.kqed.org/quest/video/science-of-big-waves/ .



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Lesson Summary

- Wave amplitude is the maximum distance the particles of a medium move from their resting positions as a wave passes through. Wavelength is the distance between two corresponding points of adjacent waves. Waves with greater amplitudes or shorter wavelengths have more energy.
- Wave frequency is the number of waves that pass a fixed point in a given amount of time. Higher frequency waves have more energy. Wave speed is calculated as wavelength multiplied by wave frequency. Wave speed is affected by the medium through which a wave travels.

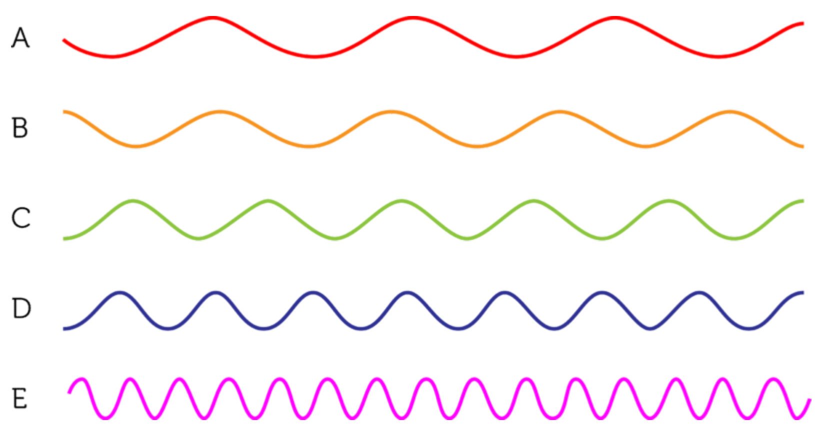
Lesson Review Questions

Recall

1. How is wave amplitude measured in a transverse wave?
2. Describe the wavelength of a longitudinal wave.
3. Define wave frequency.

Apply Concepts

4. All of the waves in the sketch below have the same amplitude and speed. Which wave has the longest wavelength? Which has the highest frequency? Which has the greatest energy?



5. A wave has a wavelength of 0.5 m/s and a frequency of 2 Hz. What is its speed?

Think Critically

6. Relate wave amplitude, wavelength, and wave frequency to wave energy.
7. Waves A and B have the same speed, but wave A has a shorter wavelength. Which wave has the higher frequency? Explain how you know.

Points to Consider

You read in this lesson that waves travel at different speeds in different media.

- When a wave enters a new medium, it may speed up or slow down. What other properties of the wave do you think might change when it enters a new medium?
- What if a wave reaches a type of matter it cannot pass through? Does it just stop moving? If not, where does it go?

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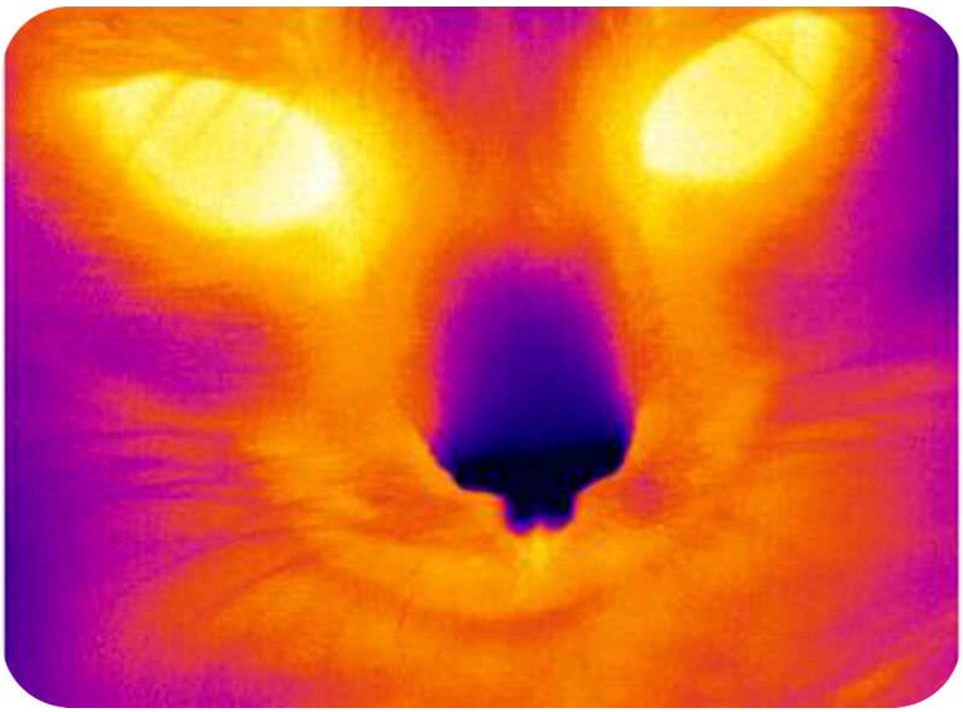
CHAPTER 32 Electromagnetic Radiation

Chapter Outline



Why is this picture of a cat so colorful? No cat looks like this to the human eye. The picture was taken with a special camera that senses infrared light. This is a form of energy given off by warm objects. Areas that appear yellow are the warmest, and areas that appear purple are the coolest. The picture shows that the cat's eyes are the warmest part of its head. Why can't people see images like this without a camera? The answer has to do with the wavelengths of infrared light. Its wavelengths are too long for the human eye to detect. In fact, the human eye can detect light only in a very narrow range of wavelengths, called visible light. You'll learn more about infrared light, visible light, and other forms of electromagnetic radiation in this chapter.

32.1 Electromagnetic Waves

Lesson Objectives

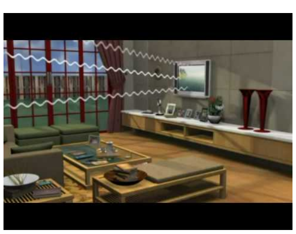
- Describe electromagnetic waves.
- Explain how electromagnetic waves begin.
- State how electromagnetic waves travel.
- Summarize the wave-particle theory of light.
- Identify sources of electromagnetic waves.

Lesson Vocabulary

- electromagnetic radiation
- electromagnetic wave
- photon

Introduction

Both infrared light and visible light are examples of electromagnetic radiation. **Electromagnetic radiation** is the transfer of energy by waves traveling through matter or across empty space. The waves that transfer this energy are called electromagnetic waves. In this lesson, you'll learn how electromagnetic waves differ from mechanical waves such as ocean waves and sound waves. For an excellent video introduction to electromagnetic waves, go to this URL: http://www.youtube.com/watch?v=cfXzwh3KadE (5:20).



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What Are Electromagnetic Waves?

An **electromagnetic wave** is a wave that consists of vibrating electric and magnetic fields. A familiar example will help you understand the fields that make up an electromagnetic wave. Think about a common bar magnet. It exerts magnetic force in an area surrounding it, called the magnetic field. You can see the magnetic field of a bar magnet in **Figure** 32.1. Because of this force field, a magnet can exert force on objects without touching them. They just have to be in its magnetic field. An electric field is similar to a magnetic field (see **Figure** 32.1). An electric field is an area of electrical force surrounding a charged particle. Like a magnetic field, an electric field can exert force on objects over a distance without actually touching them.

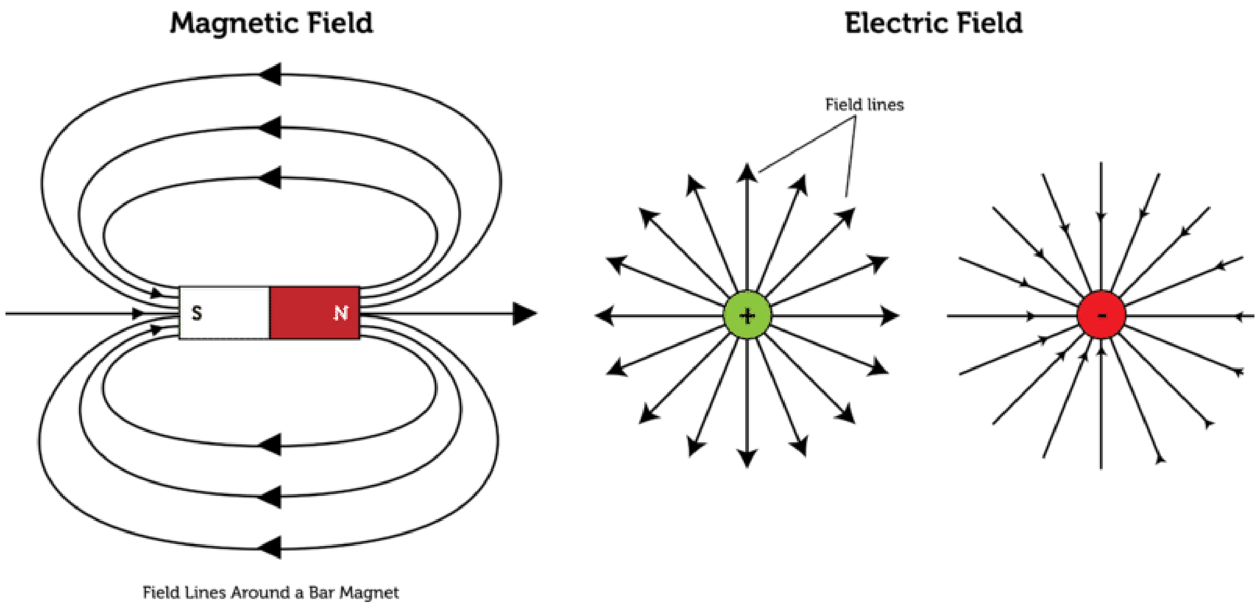

FIGURE 32.1
Magnetic and electric fields are invisible areas of force surrounding magnets and charged particles. The field lines in the diagrams represent the direction and location of the force.

How Electromagnetic Waves Begin

An electromagnetic wave begins when an electrically charged particle vibrates. This is illustrated in **Figure** 32.2. When a charged particle vibrates, it causes the electric field surrounding it to vibrate as well. A vibrating electric field, in turn, creates a vibrating magnetic field (you can learn how this happens in the chapter "Electromagnetism"). The two types of vibrating fields combine to create an electromagnetic wave. You can see an animation of an electromagnetic wave at this URL: http://www.youtube.com/watch?v=Qju7QnbrOhM (1:31).

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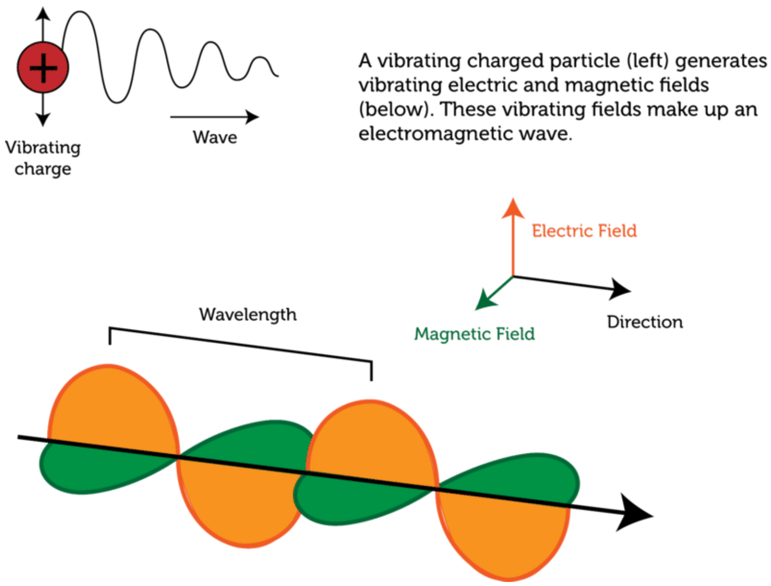


FIGURE 32.2
An electromagnetic wave starts with a vibrating charged particle.

How Electromagnetic Waves Travel

As you can see in **Figure** 32.2, the electric and magnetic fields that make up an electromagnetic wave occur are at right angles to each other. Both fields are also at right angles to the direction that the wave travels. Therefore, an electromagnetic wave is a transverse wave.

No Medium Required

Unlike a mechanical transverse wave, which requires a medium, an electromagnetic transverse wave can travel through space without a medium. Waves traveling through a medium lose some energy to the medium. However, when an electromagnetic wave travels through space, no energy is lost, so the wave doesn't get weaker as it travels. However, the energy is "diluted" as it spreads out over an ever-larger area as it travels away from the source. This is similar to the way a sound wave spreads out and becomes less intense farther from the sound source.

Wave Interactions

Electromagnetic waves can travel through matter as well as across space. When they strike matter, they interact with it in the same ways that mechanical waves interact with matter. They may reflect (bounce back), refract (bend when traveling through different materials), or diffract (bend around objects). They may also be converted to other forms of energy. Microwaves are a familiar example. They are a type of electromagnetic wave that you can read about later on in this chapter, in the lesson "The Electromagnetic Spectrum." When microwaves strike food in a microwave oven, they are converted to thermal energy, which heats the food.

Wave or Particle?

Electromagnetic radiation behaves like waves of energy most of the time, but sometimes it behaves like particles. As evidence accumulated for this dual nature of electromagnetic radiation, the famous physicist Albert Einstein developed a new theory about electromagnetic radiation, called the wave-particle theory. This theory explains how electromagnetic radiation can behave as both a wave and a particle. In brief, when an electron returns to a lower energy level, it is thought to give off a tiny "packet" of energy called a **photon** (see **Figure** 32.3). The amount of energy in a photon may vary. It depends on the frequency of electromagnetic radiation. The higher the frequency is, the more energy a photon has.

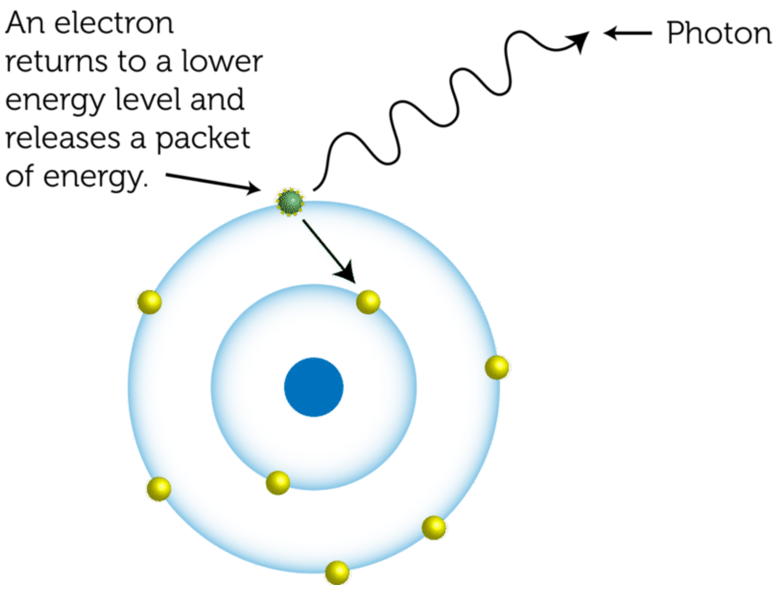


FIGURE 32.3
A photon of light energy is given off when an electron returns to a lower energy level.

Sources of Electromagnetic Radiation

The most important source of electromagnetic radiation on Earth is the sun. Electromagnetic waves travel from the sun to Earth across space and provide virtually all the energy that supports life on our planet. Many other sources of electromagnetic waves that people use depend on technology. Radio waves, microwaves, and X rays are examples. We use these electromagnetic waves for communications, cooking, medicine, and many other purposes. You'll learn about all these types of electromagnetic waves in this chapter's lesson on "The Electromagnetic Spectrum."

Lesson Summary

- An electromagnetic wave consists of vibrating electric and magnetic fields.
- An electromagnetic wave begins when an electrically charged particle vibrates.
- Electromagnetic waves are transverse waves that can travel across space without a medium. When the waves strike matter, they may reflect, refract, or diffract, or they may be converted to other forms of energy.
- Electromagnetic radiation behaves like particles as well as waves. This prompted Albert Einstein to develop his wave-particle theory.
- The most important source of electromagnetic waves on Earth is the sun, which provides virtually all the energy that supports life on Earth. Other sources of electromagnetic radiation depend on technology and are used for communications, cooking, and other purposes.

Lesson Review Questions

Recall

1. Define electromagnetic radiation.
2. What is an electromagnetic wave?
3. How do electromagnetic waves interact with matter?
4. What is a photon?
5. Identify sources of electromagnetic waves.

Apply Concepts

6. Create a diagram to represent an electromagnetic wave. Explain your diagram to another student who has no prior knowledge of electromagnetic waves.

Think Critically

7. Explain how an electromagnetic wave begins.
8. Compare and contrast mechanical transverse waves and electromagnetic transverse waves.

Points to Consider

In this lesson, you learned that electromagnetic waves are transverse waves. Like other transverse waves, electromagnetic waves have certain properties.

- Based on your knowledge of other transverse waves, such as waves in a rope, what is the wavelength of an electromagnetic wave? How is it measured?
- How do you think the wavelengths of electromagnetic waves are related to their frequencies? (*Hint:* How is the speed of waves calculated?)

32.2 Properties of Electromagnetic Waves

Lesson Objectives

- Describe the speed of electromagnetic waves.
- Relate wavelength and frequency of electromagnetic waves.

Lesson Vocabulary

- speed of light

Introduction

Some electromagnetic waves are harmless. The light we use to see is a good example. Other electromagnetic waves are very harmful. They can penetrate virtually anything and destroy living cells. Why do electromagnetic waves vary in these ways? It depends on their properties. Like other waves, electromagnetic waves have properties of speed, wavelength, and frequency.

Speed of Electromagnetic Waves

All electromagnetic waves travel at the same speed through empty space. That speed, called the **speed of light**, is 300 million meters per second (3.0×10^8 m/s). Nothing else in the universe is known to travel this fast. If you could move that fast, you would be able to travel around Earth 7.5 times in just 1 second! The sun is about 150 million kilometers (93 million miles) from Earth, but it takes electromagnetic radiation only 8 minutes to reach Earth from the sun. Electromagnetic waves travel more slowly through a medium, and their speed may vary from one medium to another. For example, light travels more slowly through water than it does through air (see **Figure** 32.4). You can learn more about the speed of light at this URL: http://videos.howstuffworks.com/discovery/29407-assignment-discovery-speed-of-light-video.htm .

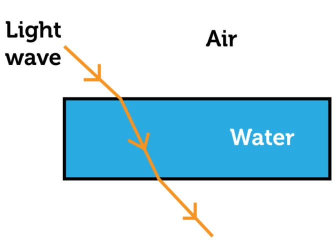


FIGURE 32.4
Light slows down when it enters water from the air. This causes the wave to refract, or bend.

Wavelength and Frequency of Electromagnetic Waves

Although all electromagnetic waves travel at the same speed, they may differ in their wavelength and frequency.

Defining Wavelength and Frequency

Wavelength and frequency are defined in the same way for electromagnetic waves as they are for mechanical waves. Both properties are illustrated in **Figure** 32.5.

- Wavelength is the distance between corresponding points of adjacent waves. Wavelengths of electromagnetic waves range from many kilometers to a tiny fraction of a millimeter.
- Frequency is the number of waves that pass a fixed point in a given amount of time. Frequencies of electromagnetic waves range from thousands to trillions of waves per second. Higher frequency waves have greater energy.

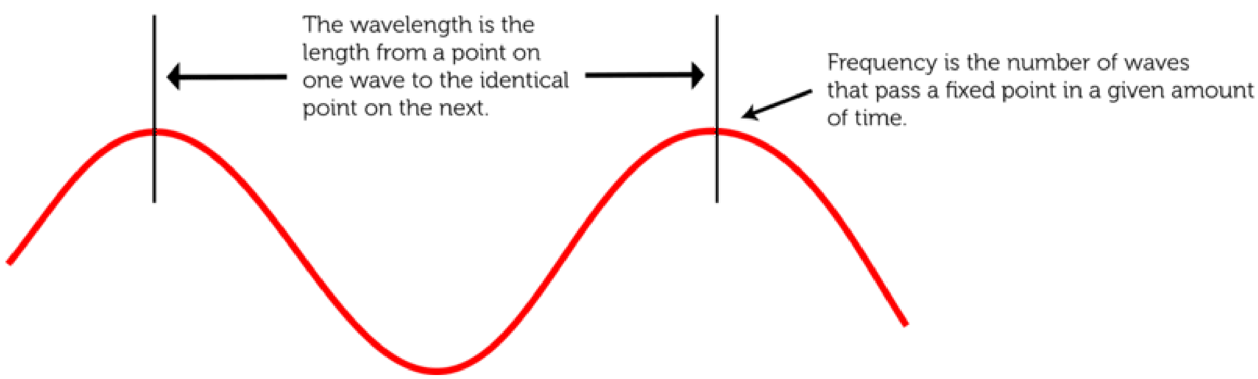


FIGURE 32.5
Wavelength and frequency of electromagnetic waves.

Speed, Wavelength, and Frequency

The speed of a wave is a product of its wavelength and frequency. Because all electromagnetic waves travel at the same speed through space, a wave with a shorter wavelength must have a higher frequency, and vice versa. This relationship is represented by the equation:

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

The equation for wave speed can be rewritten as:

$$\text{Frequency} = \frac{\text{Speed}}{\text{Wavelength}} \text{ or Wavelength} = \frac{\text{Speed}}{\text{Frequency}}$$

Therefore, if either wavelength or frequency is known, the missing value can be calculated. Consider an electromagnetic wave that has a wavelength of 3 meters. Its speed, like the speed of all electromagnetic waves, is 3.0×10^8 meters per second. Its frequency can be found by substituting these values into the frequency equation:

$$\text{Frequency} = \frac{3.0 \times 10^8 \text{ m/s}}{3.0 \text{ m}} = 1.0 \times 10^8 \text{ waves/s, or } 1.0 \times 10^8 \text{ hertz (Hz)}$$

You Try It!

Problem: What is the wavelength of an electromagnetic wave that has a frequency of 3.0×10^8 hertz?

For more practice calculating the frequency and wavelength of electromagnetic waves, go to these URLs:

- http://www.youtube.com/watch?v=GwZvtfZRNKk
- http://www.youtube.com/watch?v=wjPk108Ua8k

Lesson Summary

- All electromagnetic waves travel at the same speed through space, called the speed of light, which equals 3.0×10^8 meters per second. Electromagnetic waves travel more slowly through a medium.
- Electromagnetic waves differ in their wavelengths and frequencies. The higher the frequency of an electromagnetic wave, the greater its energy. The speed of an electromagnetic wave is the product of its wavelength and frequency, so a wave with a shorter wavelength has a higher frequency, and vice versa.

Lesson Review Questions

Recall

1. What is the speed of light?
2. What is the wavelength of an electromagnetic wave?
3. Describe the range of frequencies of electromagnetic waves.

Apply Concepts

4. If an electromagnetic wave has a wavelength of 1 meter, what is its frequency?

Think Critically

5. Explain why light waves bend when they pass from air to water at an angle.
6. Explain the relationship between frequency and wavelength of electromagnetic waves.

Points to Consider

In this lesson, you learned that electromagnetic waves vary in their wavelength and frequency. The complete range of wavelengths and frequencies of electromagnetic waves is outlined in the next lesson, "The Electromagnetic

Spectrum."

- What do you think are the longest-wavelength electromagnetic wave?
- What might be the electromagnetic waves with the highest frequencies?

32.3 The Electromagnetic Spectrum

Lesson Objectives

- Define the electromagnetic spectrum.
- Describe radio waves and their uses.
- Identify three forms of light.
- Describe X rays and gamma rays.

Lesson Vocabulary

- electromagnetic spectrum
- gamma ray
- infrared light
- microwave
- radar
- radio wave
- ultraviolet light
- visible light
- X ray

Introduction

Imagine playing beach volleyball, like the young men in **Figure** 32.6. They may not realize it, but they are being bombarded by electromagnetic radiation as play in the sunlight. The only kinds of radiation they can detect are visible light, which allows them to see, and infrared light, which they feel as warmth on their skin. What other kinds of electromagnetic radiation are they being exposed to in sunlight? In this lesson, you'll find out.

What Is The Electromagnetic Spectrum?

Electromagnetic radiation occurs in waves of different wavelengths and frequencies. Infrared light and visible light make up just a small part of the full range of electromagnetic radiation, which is called the **electromagnetic spectrum**. The electromagnetic spectrum is summarized in the diagram in **Figure** 32.7.

- On the far left of the diagram are radio waves, which include microwaves. They have the longest wavelengths and lowest frequencies of all electromagnetic waves. They also have the least amount of energy.
- On the far right are X rays and gamma rays. The have the shortest wavelengths and highest frequencies of all electromagnetic waves. They also have the greatest amount of energy.

FIGURE 32.6
Electromagnetic radiation from the sun reaches Earth across space. It strikes everything on Earth's surface, including these volleyball players.

- Between these two extremes, wavelength, frequency, and energy change continuously from one side of the spectrum to the other. Waves in this middle section of the electromagnetic spectrum are commonly called light.

As you will read below, the properties of electromagnetic waves influence how the different waves behave and how they can be used.

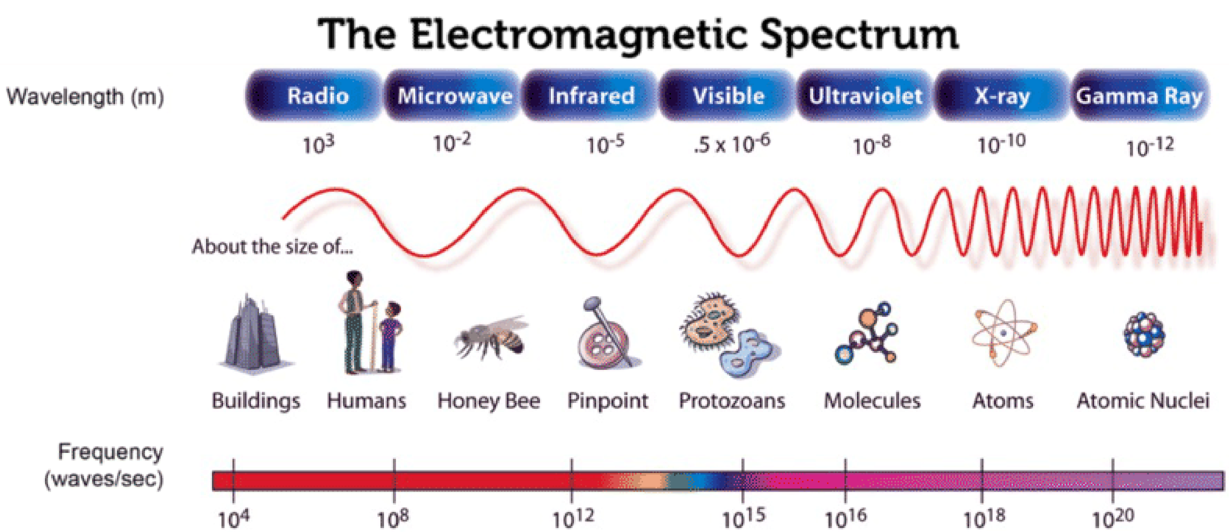
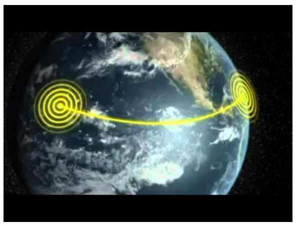


FIGURE 32.7
How do the wavelength and frequency of waves change across the electromagnetic spectrum?

Radio Waves

Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. In **Figure** 32.7, you can see that the wavelength of radio waves may be longer than a soccer field. With their low frequencies, radio waves have the least energy of electromagnetic waves, but they still are extremely useful. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar. You can learn more about radio waves, including how they were discovered, at this URL: http://www.youtube.com/watch?v=al7sFP4C2TY (3:58).



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AM and FM Radio

In radio broadcasts, sounds are encoded in radio waves that are sent out through the atmosphere from a radio tower. A receiver detects the radio waves and changes them back to sounds. You've probably listened to both AM and FM radio stations. How sounds are encoded in radio waves differs between AM and FM broadcasts.

- AM stands for amplitude modulation. In AM broadcasts, sound signals are encoded by changing the amplitude of radio waves. AM broadcasts use longer–wavelength radio waves than FM broadcasts. Because of their longer wavelengths, AM radio waves reflect off a layer of the upper atmosphere called the ionosphere. You can see how this happens in **Figure** 32.8. This allows AM radio waves to reach radio receivers that are very far away from the radio tower.
- FM stands for frequency modulation. In FM broadcasts, sound signals are encoded by changing the frequency of radio waves. Frequency modulation allows FM waves to encode more information than does amplitude modulation, so FM broadcasts usually sound clearer than AM broadcasts. However, because of their shorter wavelength, FM waves do not reflect off the ionosphere. Instead, they pass right through it and out into space (see **Figure** 32.8). As a result, FM waves cannot reach very distant receivers.

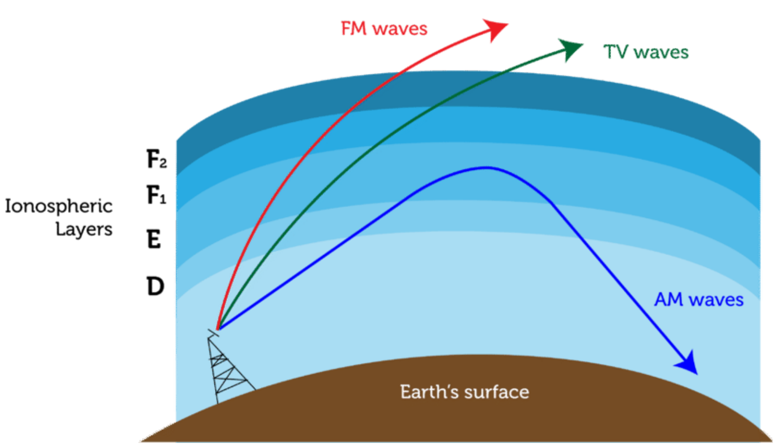

FIGURE 32.8

AM radio waves reflect off the ionosphere and travel back to Earth. Radio waves used for FM radio and television pass through the ionosphere and do not reflect back.

Television

Television broadcasts also use radio waves. Sounds are encoded with frequency modulation, and pictures are encoded with amplitude modulation. The encoded radio waves are broadcast from a TV tower like the one in **Figure** 32.9. When the waves are received by television sets, they are decoded and changed back to sounds and pictures.

FIGURE 32.9
This television tower broadcasts signals using radio waves.

Microwaves

The shortest wavelength, highest frequency radio waves are called **microwaves** (see **Figure** 32.7). Microwaves have more energy than other radio waves. That's why they are useful for heating food in microwave ovens. Microwaves have other important uses as well, including cell phone transmissions and **radar**, which is a device for determining the presence and location of an object by measuring the time for the echo of a radio wave to return from it and the direction from which it returns. These uses are described in **Figure** 32.10. You can learn more about microwaves and their uses in the video at this URL: http://www.youtube.com/watch?v=YgQQb1BVnu8 (3:23).

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Light

Mid-wavelength electromagnetic waves are commonly called light. This range of electromagnetic waves has shorter wavelengths and higher frequencies than radio waves, but not as short and high as X rays and gamma rays. Light includes visible light, infrared light, and ultraviolet light. If you look back at **Figure** 32.7, you can see where these different types of light waves fall in the electromagnetic spectrum.

Visible Light

The only light that people can see is called **visible light**. It refers to a very narrow range of wavelengths in the electromagnetic spectrum that falls between infrared light and ultraviolet light. Within the visible range, we see light

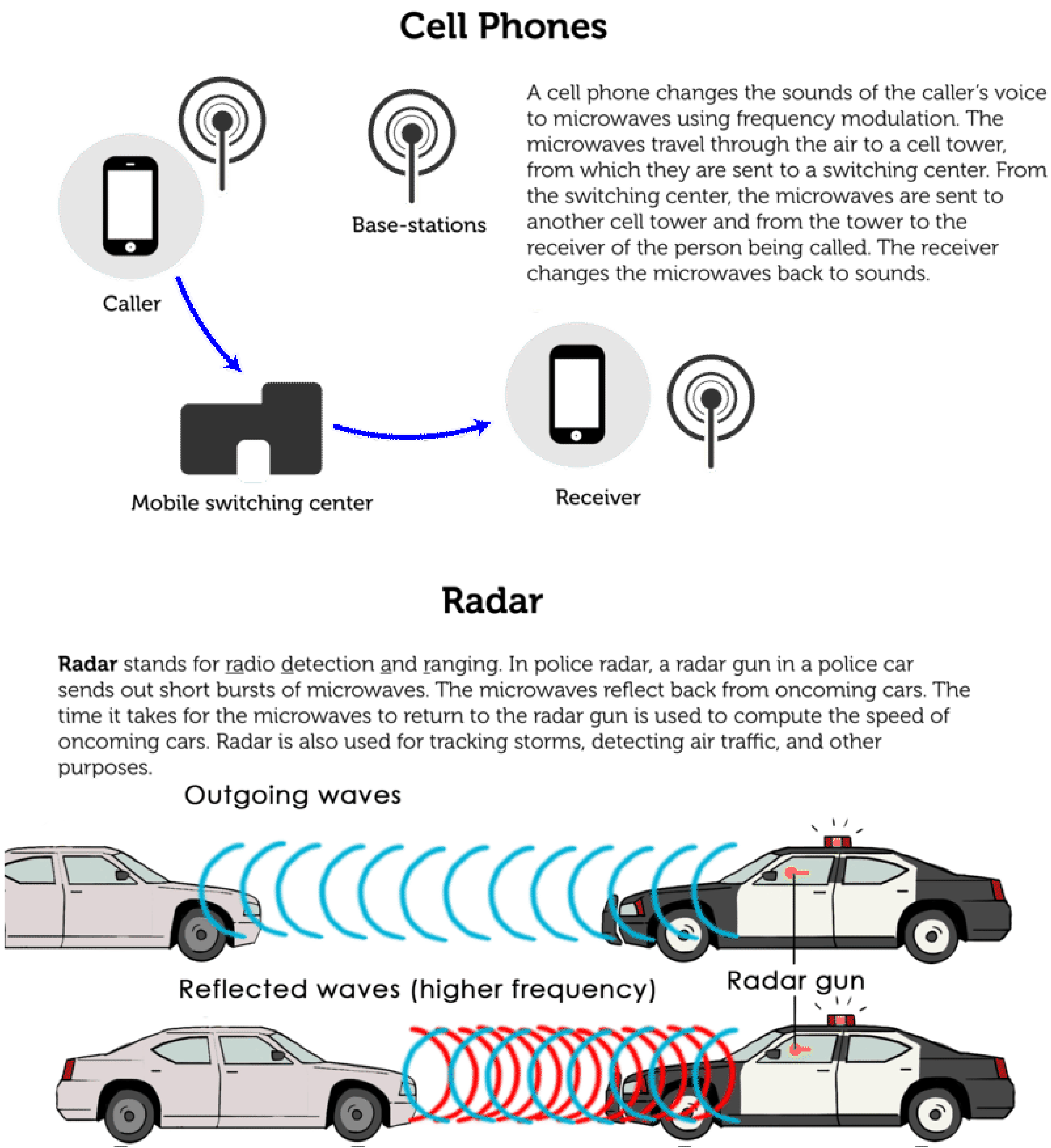
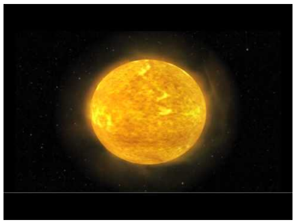


FIGURE 32.10
Microwaves are used for cell phones and radar.

of different wavelengths as different colors of light, from red light, which has the longest wavelength, to violet light, which has the shortest wavelength. You can see the spectrum of colors of visible light in **Figure** 32.11. When all of the wavelengths are combined, as they are in sunlight, visible light appears white. You can learn more about visible light in the chapter "Visible Light" and at the URL below.

http://www.youtube.com/watch?v=PMtC34pzKGc (4:50)



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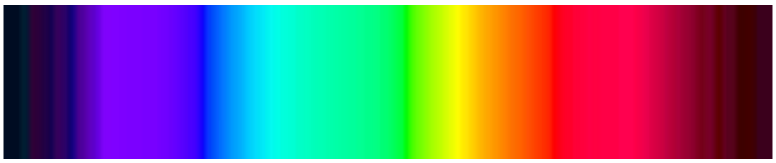

FIGURE 32.11
Red light (right) has the longest wavelength, and violet light (left) has the shortest wavelength.

Infrared Light

Light with the longest wavelengths is called **infrared light**. The term *infrared* means "below red." Infrared light is the range of light waves that have longer wavelengths than red light in the visible spectrum. You can't see infrared light waves, but you can feel them as heat on your skin. The sun gives off infrared light as do fires and living things. The picture of a cat that opened this chapter was made with a camera that detects infrared light waves and changes their energy to colored light in the visible range. Night vision goggles, which are used by law enforcement and the military, also detect infrared light waves. The goggles convert the invisible waves to visible images. For a deeper understanding of infrared light, watch the video at this URL: http://www.youtube.com/watch?v=2–0q0XlQJ0 (6:46).

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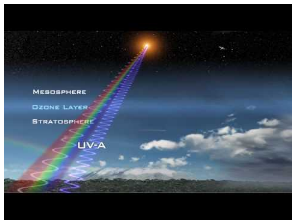
Ultraviolet Light

Light with wavelengths shorter than visible light is called **ultraviolet light**. The term *ultraviolet* means "above violet." Ultraviolet light is the range of light waves that have shorter wavelengths than violet light in the visible spectrum. Humans can't see ultraviolet light, but it is very useful nonetheless. It has higher-frequency waves than visible light, so it has more energy. It can be used to kill bacteria in food and to sterilize laboratory equipment (see **Figure** 32.12). The human skin also makes vitamin D when it is exposed to ultraviolet light. Vitamin D is needed for strong bones and teeth. You can learn more about ultraviolet light and its discovery at this URL: http://www.youtube.com/watch?v=QW5zeVy8aE0 (3:40).



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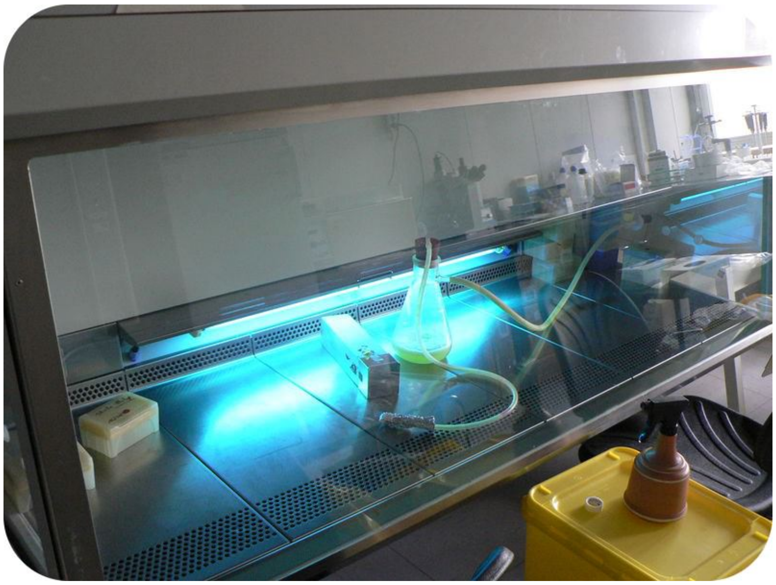

FIGURE 32.12
This sterilizer for laboratory equipment uses ultraviolet light to kill bacteria.

Too much exposure to ultraviolet light can cause sunburn and skin cancer. You can protect your skin from ultraviolet light by wearing clothing that covers your skin and by applying sunscreen to any exposed areas. The SPF, or sun-protection factor, of sunscreen gives a rough idea of how long it protects the skin from sunburn (see **Figure** 32.13). A sunscreen with a higher SPF protects the skin longer. You should use sunscreen with an SPF of at least 15 even on cloudy days, because ultraviolet light can travel through clouds. Sunscreen should be applied liberally and often. You can learn more about the effects of ultraviolet light on the skin at this URL: http://www.youtube.com/watch?v=np-BBJyl-go (5:59).

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X Rays and Gamma Rays

The shortest-wavelength, highest-frequency electromagnetic waves are X rays and gamma rays. These rays have so much energy that they can pass through many materials. This makes them potentially very harmful, but it also makes them useful for certain purposes.

FIGURE 32.13
If your skin normally burns in 10 minutes of sun exposure, using sunscreen with an SPF of 30 means that, ideally, your skin will burn only after 30 times 10 minutes, or 300 minutes, of sun exposure. How long does sunscreen with an SPF of 50 protect skin from sunburn?

X Rays

X rays are high-energy electromagnetic waves. They have enough energy to pass through soft tissues such as skin but not enough to pass through bones and teeth, which are very dense. The bright areas on the X ray film in **Figure** 32.14 show where X rays were absorbed by the teeth. X rays are used not only for dental and medical purposes but also to screen luggage at airports (see **Figure** 32.14). Too much X ray exposure may cause cancer. If you've had dental X rays, you may have noticed that a heavy apron was placed over your body to protect it from stray X rays. The apron is made of lead, which X rays cannot pass through. You can learn about the discovery of X rays as well as other uses of X rays at this URL: http://www.guardian.co.uk/science/blog/2010/oct/26/x-ray-visions-disease-for geries .

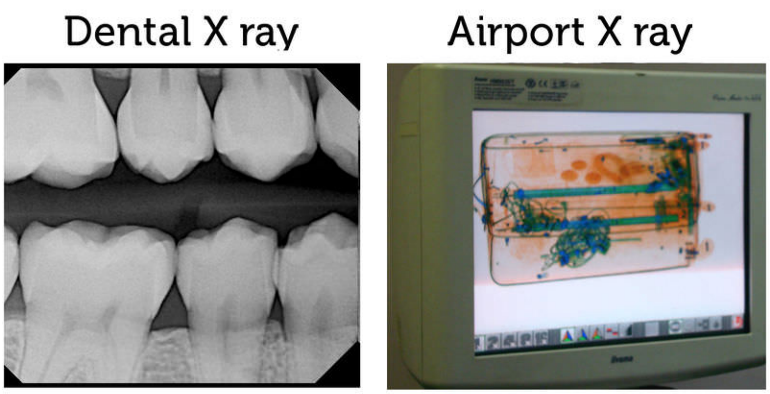
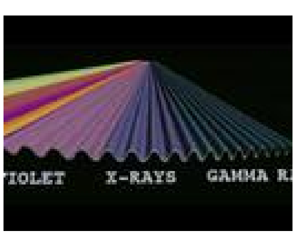


FIGURE 32.14
Two common uses of X rays are illustrated here.

Gamma Rays

Gamma rays are the most energetic of all electromagnetic waves. They can pass through most materials, including bones and teeth. Nonetheless, even these waves are useful. For example, they can be used to treat cancer. A medical device sends gamma rays the site of the cancer, and the rays destroy the cancerous cells. If you want to learn more about gamma rays, watch the video at the URL below.

http://www.youtube.com/watch?v=okyynBaSOtA (2:45)



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KQED: Seeing Cells in 3-D

Scientists in Berkeley have developed a powerful new microscope which uses X rays to scan a whole cell and in a manner of minutes, generate a 3D view of the cell and its genetic material. This groundbreaking tool is helping to advance research into the development of biofuels, the treatment of malaria and it may even help to more rapidly diagnose cancer. For more information on X ray microscopes, see http://science.kqed.org/quest/video/x-ray-microscope-seeing-cells-in-3-d/ .

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Lesson Summary

- The electromagnetic spectrum is the full range of wavelengths and frequencies of electromagnetic radiation. Wavelength, frequency, and energy change continuously across the electromagnetic spectrum.
- Radio waves are the broad range of electromagnetic waves with the longest wavelengths and lowest frequencies. They are used for radio and television broadcasts, microwave ovens, cell phone transmissions, and radar.
- Mid-wavelength electromagnetic waves are called light. Light consists of visible, infrared, and ultraviolet light. Humans can see only visible light. Infrared light has longer wavelengths than visible light and is perceived as warmth. Ultraviolet light has shorter wavelengths than visible light and has enough energy to kill bacteria. It can also harm the skin.
- X rays and gamma rays are the electromagnetic waves with the shortest wavelengths and highest frequencies. X rays are used in medicine and dentistry and to screen luggage at airports. Gamma rays are used to kill cancer cells.

Lesson Review Questions

Recall

1. What is the electromagnetic spectrum?
2. Describe how wave frequency changes across the electromagnetic spectrum, from radio waves to gamma rays.
3. List three uses of radio waves.
4. How are X rays and gamma rays used in medicine?

Apply Concepts

5. Create a public service video warming people of the dangers of ultraviolet light. Include tips for protecting the skin from ultraviolet light.

Think Critically

6. Explain two ways that sounds can be encoded in electromagnetic waves.
7. Explain how radar works.
8. Compare and contrast infrared, visible, and ultraviolet light.

Points to Consider

This chapter introduces visible light. The chapter "Visible Light" discusses visible light in greater detail.

- In this lesson, you read that visible light consists of light of different colors. Do you know how visible light can be separated into its different colors? (*Hint:* How does a rainbow form?)
- In the next chapter, *Visible Light*, you'll read that visible light interacts with matter in certain characteristic ways. Based on your own experiences with visible light, how does it interact with matter? (*Hint:* What happens to visible light when it strikes a wall, window, or mirror?)

32.4 References

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