8th Grade Physical Science

Ashley Eckerty

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AUTHOR
Ashley Eckerty

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Contents

CONCEPT 1 Distance and Direction

Lesson Objectives

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

Lesson Vocabulary

- distance
- frame of reference
- motion
- vector

Introduction

You can see several examples of people or things in motion in **Figure** 1.1. 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** 1.2, 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 1.1
These are just a few examples of people or things in motion. If you look around, you're likely to see many more.

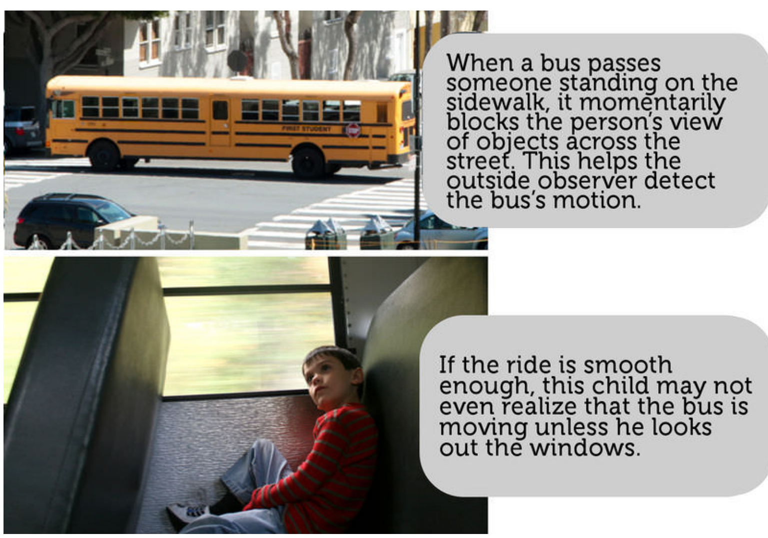

FIGURE 1.2
To a person outside the bus, the bus's motion is obvious. To children riding the bus, its motion may not be as obvious.

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

Distance

Did you ever go to a track meet like the one pictured in **Figure** 1.3? 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 1.3
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** 1.4. 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.

Direction

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** 1.4). 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!

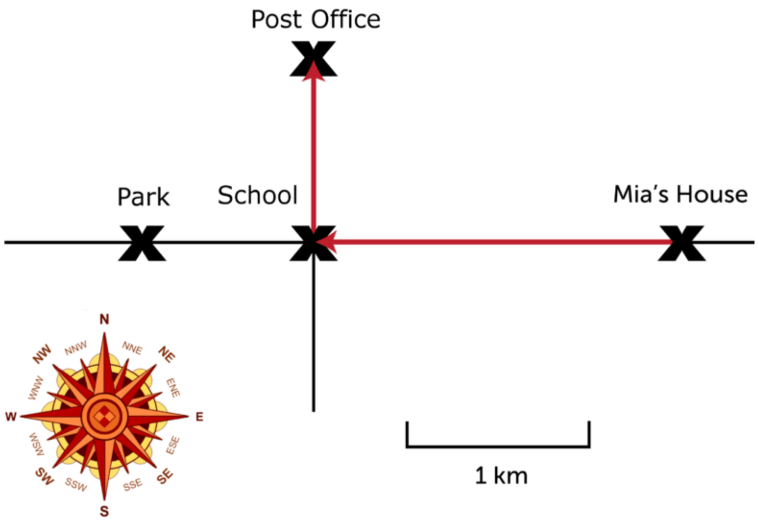
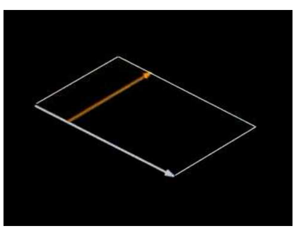


FIGURE 1.4
This map shows the routes from Mia's house to the school, post office, and park.

Problem: What is the distance from the post office to the park in **Figure** 1.4?

Direction 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." When both distance and direction are considered, motion is a vector. A **vector** is a quantity that includes both size and direction. A vector is represented by an arrow. The length of the arrow represents distance. The way the arrow points shows direction. The red arrows in **Figure** 1.4 are vectors for Mia's route to the school and post office. 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** 1.4.

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** 1.4, 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?

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CONCEPT 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** 2.1, 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 2.1

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** 2.2). 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 2.2
Speed limit signs like this one warn drivers to reduce their speed on dangerous roads.

Instantaneous vs. Average Speed

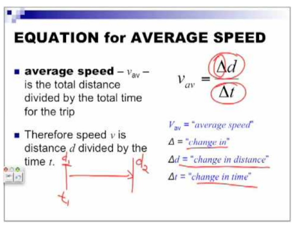
When you travel by car, you usually don't move at a constant speed. Instead you go faster or slower depending on speed limits, traffic, traffic lights, and many other factors. For example, you might travel 65 miles per hour on a highway but only 20 miles per hour on a city street (see **Figure** 2.3). 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.

FIGURE 2.3
Cars race by in a blur of motion on an open highway but crawl at a snail's pace when they hit city traffic.

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:

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

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** 2.4. A distance-time graph shows how the distance from the starting point changes over time. The graph in **Figure** 2.4 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** 2.4, 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):

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

For example, the speed between A and B in **Figure** 2.4 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:

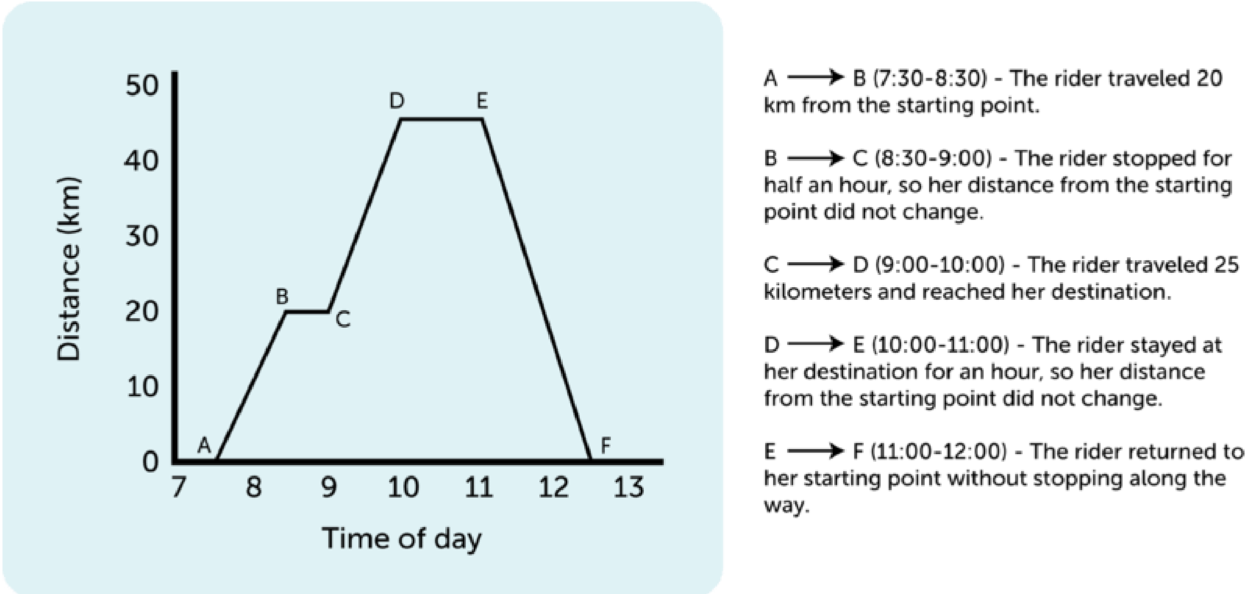

FIGURE 2.4

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

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

You Try It!

Problem: In **Figure** 2.4, 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** 2.5 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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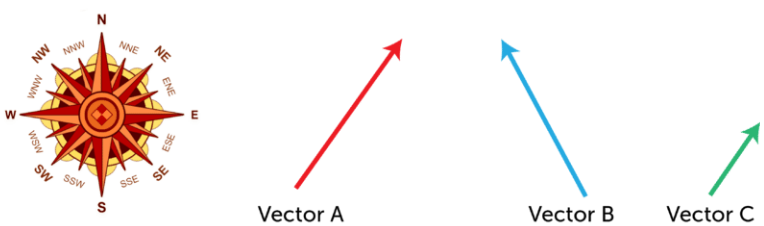

FIGURE 2.5

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** 2.5), they have different velocities. If two objects are moving in the same direction but at a different speed (like A and C in **Figure** 2.5), 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 change in distance divided by the change in time.
- 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.

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?

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CONCEPT 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** 3.1. 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 3.1
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** 3.2.

FIGURE 3.2
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) by the change in time (represented by Δt). The formula for acceleration in this case is:

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

Consider this example. The cyclist in **Figure** 3.3 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?

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

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 3.3
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** 3.4. 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** 3.4 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.

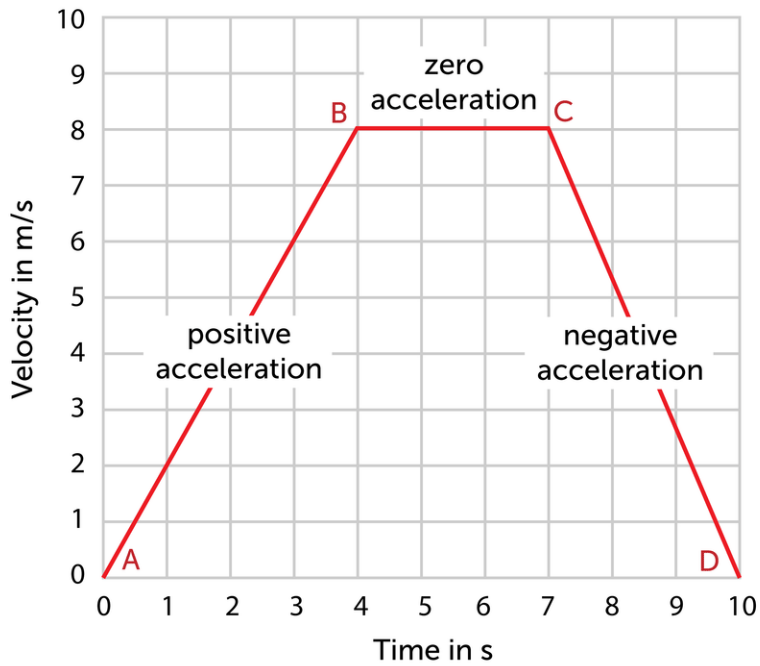

FIGURE 3.4
This graph shows how the velocity of a runner changes during a 10-second sprint.

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** 3.4, 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** 3.3.)

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CONCEPT 4 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** 4.1. 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** 4.1 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** 4.2 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** 4.1?

FIGURE 4.1
When this girl pushes the swing away from her, it causes the swing to move in that direction.

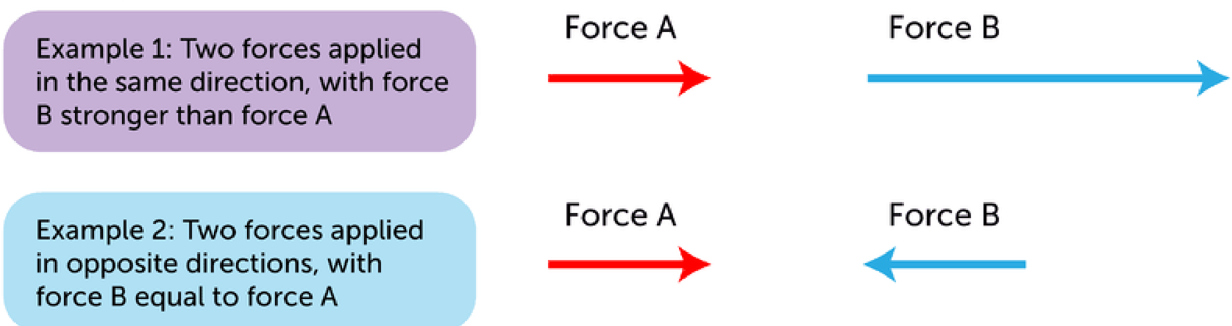


FIGURE 4.2
Forces can vary in both strength and direction.

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** 4.3. 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 .

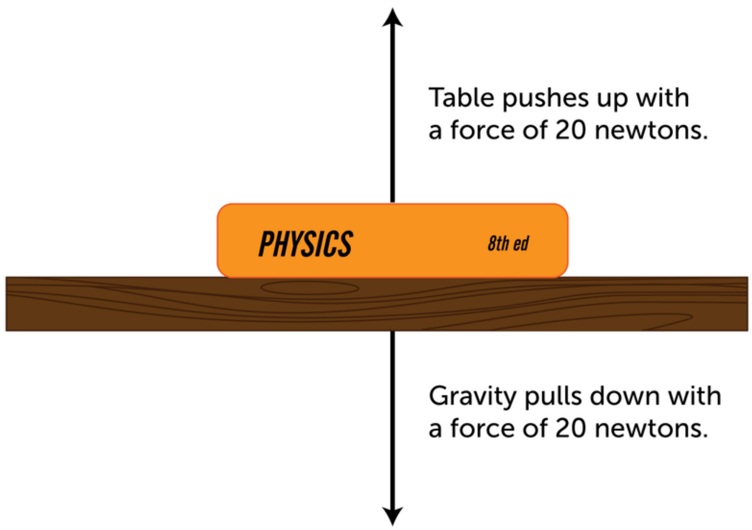


FIGURE 4.3
A book resting on a table is acted on by two opposing forces.

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** 4.4. 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** 4.5. 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!

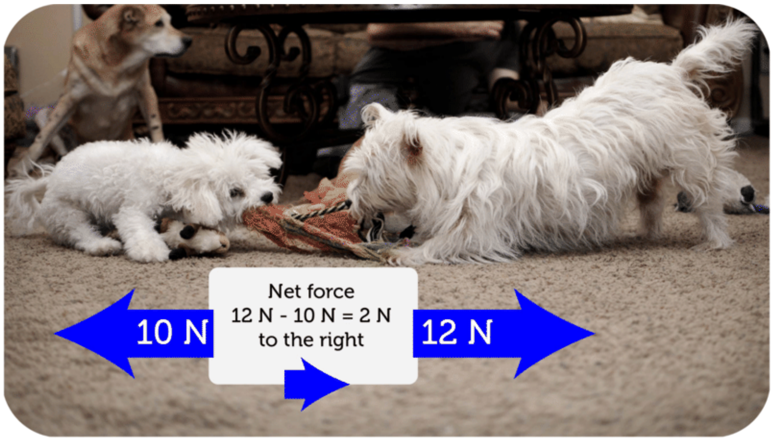


FIGURE 4.4
When unbalanced forces are applied to an object in opposite directions, the smaller force is subtracted from the larger force to yield the net force.

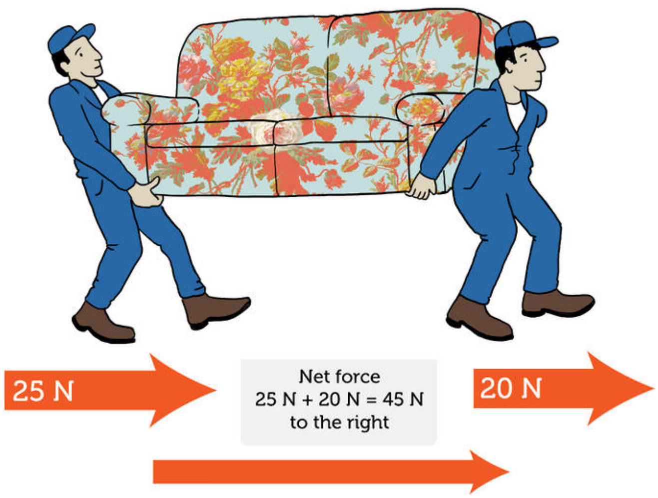
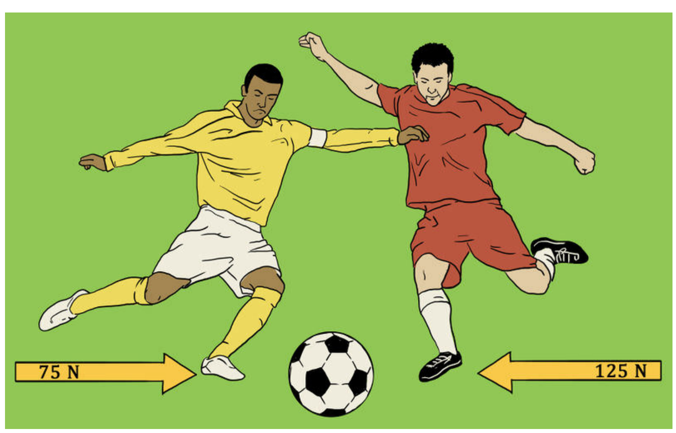


FIGURE 4.5
When two forces are applied to an object in the same direction, the two forces are added to yield the net force.



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

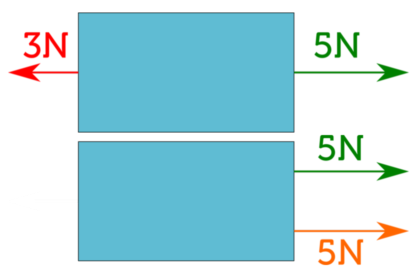
Recall

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?

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CONCEPT 5 Friction

Lesson Objectives

- Describe friction and how it opposes motion.
- Identify types of friction.

Lesson Vocabulary

- fluid
- friction

Introduction

Did you ever rub your hands together to warm them up, like the girl in **Figure** 5.1? Why does this make your hands warmer? The answer is friction.

FIGURE 5.1
This girl is using friction to make her hands warmer.

What Is Friction?

Friction is a force that opposes motion between two surfaces that are touching. Friction can work for or against us. For example, putting sand on an icy sidewalk increases friction so you are less likely to slip. On the other hand, too much friction between moving parts in a car engine can cause the parts to wear out. Other examples of friction are illustrated in **Figure** 5.2. You can see an animation showing how friction opposes motion at this URL: http://www.darvill.clara.net/enforcemot/friction.htm .

FIGURE 5.2

Sometimes friction is useful. Sometimes it's not.

Why Friction Occurs

Friction occurs because no surface is perfectly smooth. Even surfaces that look smooth to the unaided eye appear rough or bumpy when viewed under a microscope. Look at the metal surfaces in **Figure** 5.3. The metal foil is so smooth that it is shiny. However, when highly magnified, the surface of metal appears to be very bumpy. All those mountains and valleys catch and grab the mountains and valleys of any other surface that contacts the metal. This creates friction.

Factors That Affect Friction

Rougher surfaces have more friction between them than smoother surfaces. That's why we put sand on icy sidewalks and roads. The blades of skates are much smoother than the soles of shoes. That's why you can't slide as far across ice with shoes as you can with skates (see **Figure** 5.4). The rougher surface of shoes causes more friction and slows you down. Heavier objects also have more friction because they press together with greater force. Did you ever try

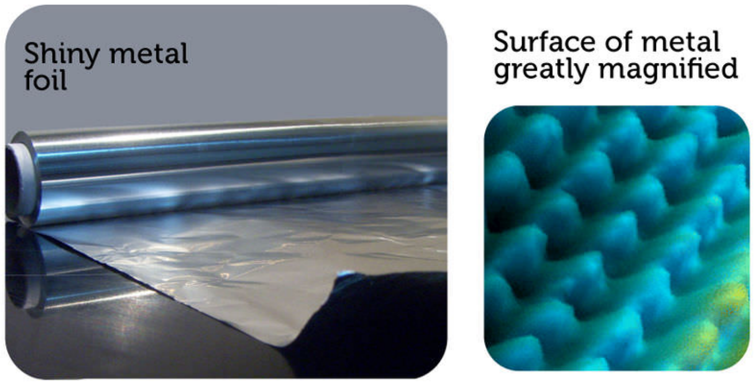

FIGURE 5.3
The surface of metal looks very smooth unless you look at it under a high-powered microscope.

to push boxes or furniture across the floor? It's harder to overcome friction between heavier objects and the floor than it is between lighter objects and the floor.

FIGURE 5.4
The knife-like blades of speed skates minimize friction with the ice.

Friction Produces Heat

You know that friction produces heat. That's why rubbing your hands together makes them warmer. But do you know why the rubbing produces heat? Friction causes the molecules on rubbing surfaces to move faster, so they have more heat energy. Heat from friction can be useful. It not only warms your hands. It also lets you light a match (see **Figure** 5.5). On the other hand, heat from friction can be a problem inside a car engine. It can cause the car to overheat. To reduce friction, oil is added to the engine. Oil coats the surfaces of moving parts and makes them slippery so there is less friction.

Types of Friction

There are different ways you could move heavy boxes. You could pick them up and carry them. You could slide them across the floor. Or you could put them on a dolly like the one in **Figure** 5.6 and roll them across the floor.

FIGURE 5.5
When you rub the surface of a match head across the rough striking surface on the matchbox, the friction produces enough heat to ignite the match.

This example illustrates three types of friction: static friction, sliding friction, and rolling friction. Another type of friction is fluid friction. All four types of friction are described below. In each type, friction works opposite the direction of the force applied to a move an object. You can see a video demonstration of the different types of friction at this URL: http://www.youtube.com/watch?v=0bXpYblzkR0 (1:07).

FIGURE 5.6
A dolly with wheels lets you easily roll boxes across the floor.

Static Friction

Static friction acts on objects when they are resting on a surface. For example, if you are walking on a sidewalk, there is static friction between your shoes and the concrete each time you put down your foot (see **Figure** 5.7). Without this static friction, your feet would slip out from under you, making it difficult to walk. Static friction also allows you to sit in a chair without sliding to the floor. Can you think of other examples of static friction?

FIGURE 5.7
Static friction between shoes and the sidewalk makes it possible to walk without slipping.

Sliding Friction

Sliding friction is friction that acts on objects when they are sliding over a surface. Sliding friction is weaker than static friction. That's why it's easier to slide a piece of furniture over the floor after you start it moving than it is to get it moving in the first place. Sliding friction can be useful. For example, you use sliding friction when you write with a pencil and when you put on your bike's brakes.

Rolling Friction

Rolling friction is friction that acts on objects when they are rolling over a surface. Rolling friction is much weaker than sliding friction or static friction. This explains why it is much easier to move boxes on a wheeled dolly than by carrying or sliding them. It also explains why most forms of ground transportation use wheels, including cars, 4-wheelers, bicycles, roller skates, and skateboards. Ball bearings are another use of rolling friction (see **Figure** 5.8). They allow parts of a wheel or other machine to roll rather than slide over one another.

Fluid Friction

Fluid friction is friction that acts on objects that are moving through a fluid. A **fluid** is a substance that can flow and take the shape of its container. Fluids include liquids and gases. If you've ever tried to push your open hand through the water in a tub or pool, then you've experienced fluid friction between your hand and the water. When a skydiver is falling toward Earth with a parachute, fluid friction between the parachute and the air slows the descent (see **Figure** 5.9). Fluid pressure with the air is called air resistance. The faster or larger a moving object is, the greater is the fluid friction resisting its motion. The very large surface area of a parachute, for example, has greater air resistance than a skydiver's body.

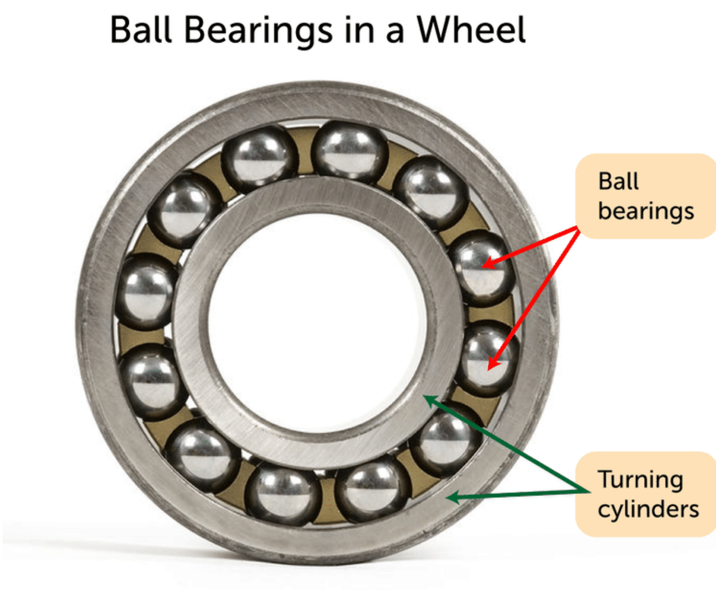

FIGURE 5.8
The ball bearings in this wheel reduce friction between the inner and outer cylinders when they turn.

Lesson Summary

- Friction is a force that opposes motion between two surfaces that are touching. Friction occurs because no surface is perfectly smooth. Friction is greater when objects have rougher surfaces or are heavier so they press together with greater force.
- Types of friction include static friction, sliding friction, rolling friction, and fluid friction. Fluid friction with air is called air resistance.

Lesson Review Questions

Recall

1. What is friction?
2. List factors that affect friction.
3. How does friction produce heat?

Apply Concepts

4. Identify two forms of friction that oppose the motion of a moving car.

Think Critically

5. Explain why friction occurs.
6. Compare and contrast the four types of friction described in this lesson.

FIGURE 5.9
Fluid friction of the parachute with the air slows this skydiver as he falls.

Points to Consider

A skydiver like the one in **Figure** 5.9 falls to the ground despite the fluid friction of his parachute with the air. Another force pulls him toward Earth. That force is gravity, which is the topic of the next lesson.

- What do you already know about gravity?
- What do you think causes gravity?

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CONCEPT 6 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** 6.1). 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.

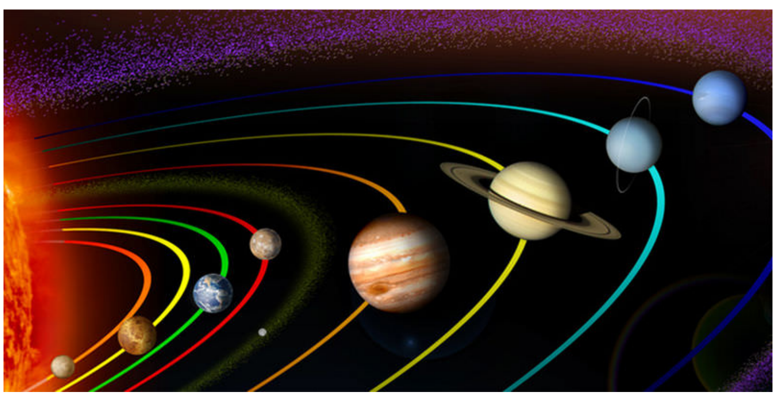

FIGURE 6.1
Gravity helped to form our solar system and all the other solar systems in the universe.

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** 6.2. The scale measures the force with which gravity pulls an object downward.

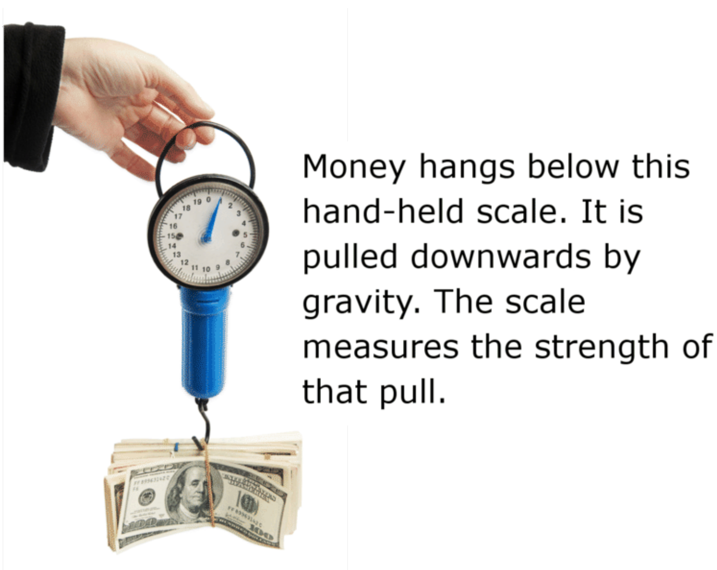

FIGURE 6.2
A scale measures the pull of gravity on an object.

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** 6.3.

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

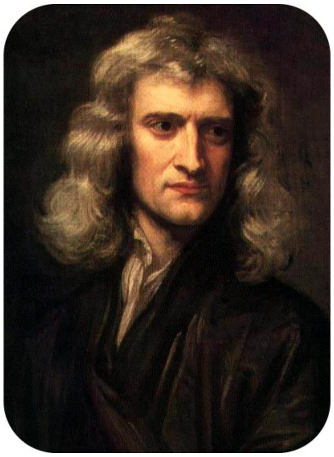

FIGURE 6.3
Sir Isaac Newton discovered that gravity is universal.

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** 6.4.

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, 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** 6.5. 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

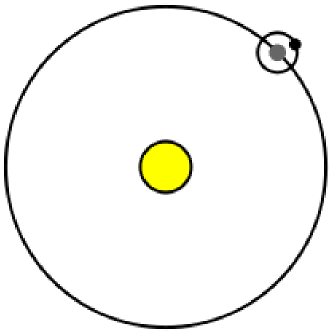

FIGURE 6.4
The moon keeps moving around Earth rather than the sun because it is much closer to Earth.

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/ .

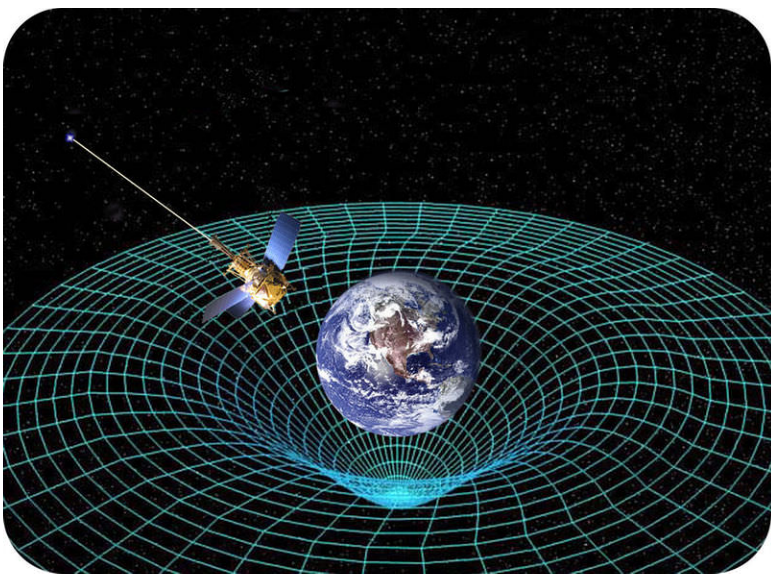

FIGURE 6.5
Einstein thought that gravity is the effect of curves in space and time around massive objects such as Earth. He proposed that the curves in space and time cause nearby objects to follow a curved path. How does this differ from Newton's idea of gravity?

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** 6.6. 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/ .

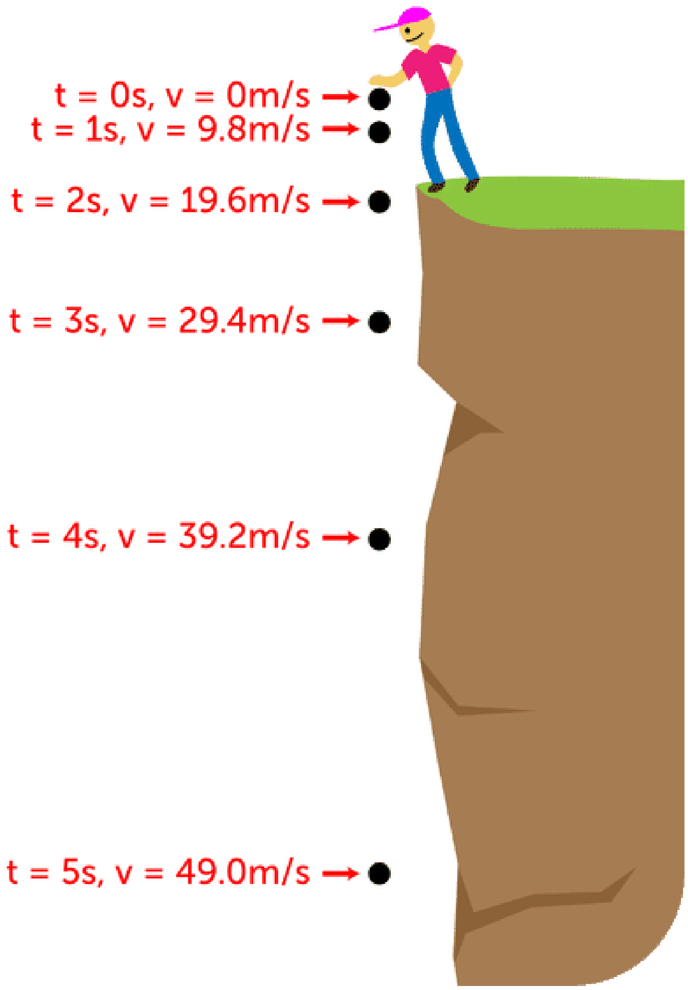

FIGURE 6.6

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** 6.7. 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**.

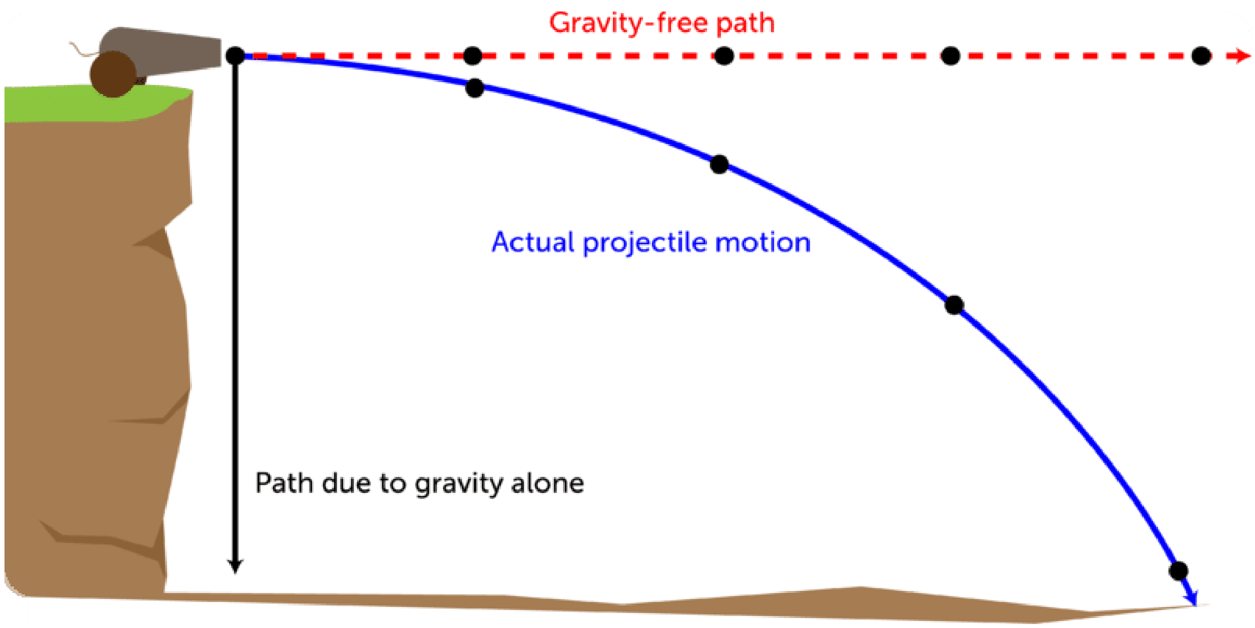

FIGURE 6.7
The cannon ball moves in a curved path because of the combined horizontal and downward forces.

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** 6.8 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.")*

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** 6.9 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 .

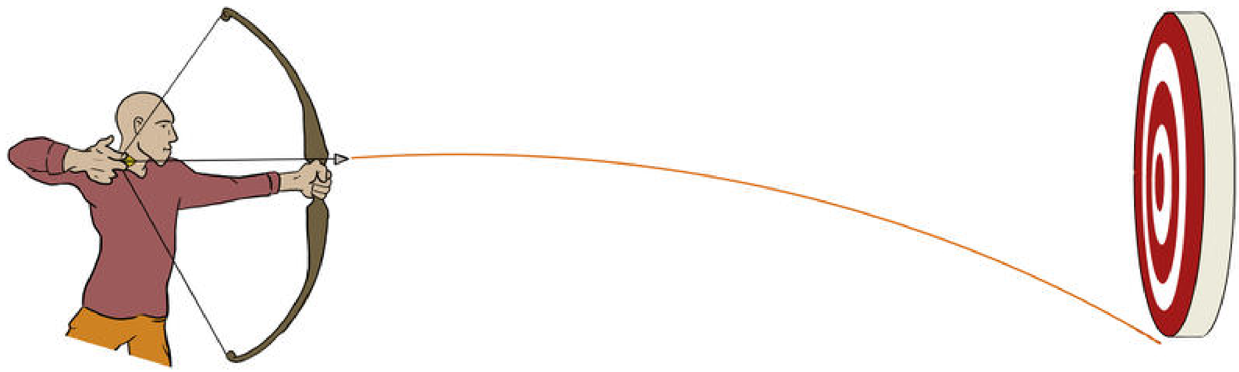

FIGURE 6.8
Aiming at the center of a target is likely to result in a hit below the bull's eye.

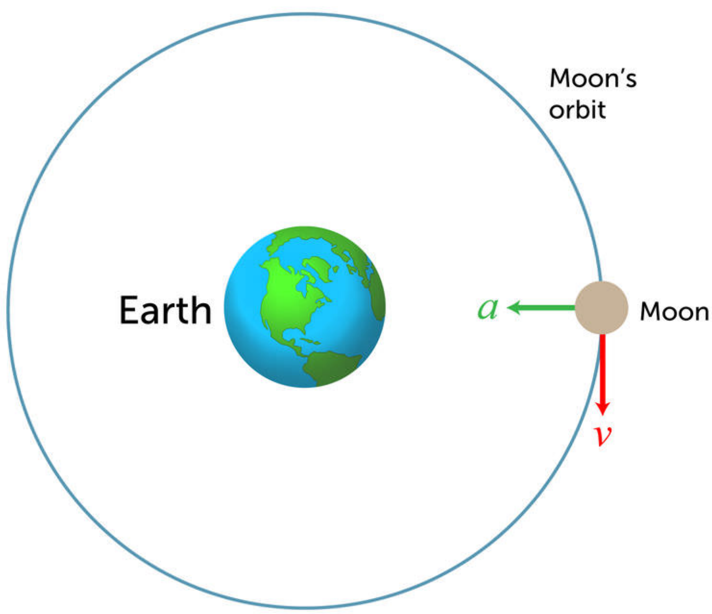

FIGURE 6.9
In this diagram, "v" represents the forward velocity of the moon, and "a" represents the acceleration due to gravity. The line encircling Earth shows the moon's actual orbit, which results from the combination of "v" and "a."

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).
- 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** 6.2 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?

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CONCEPT 7 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** 7.1? 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 7.1
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** 7.2 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 7.2
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** 7.3 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 greater velocity has more kinetic energy. The kinetic energy of a moving object can be calculated with the equation:

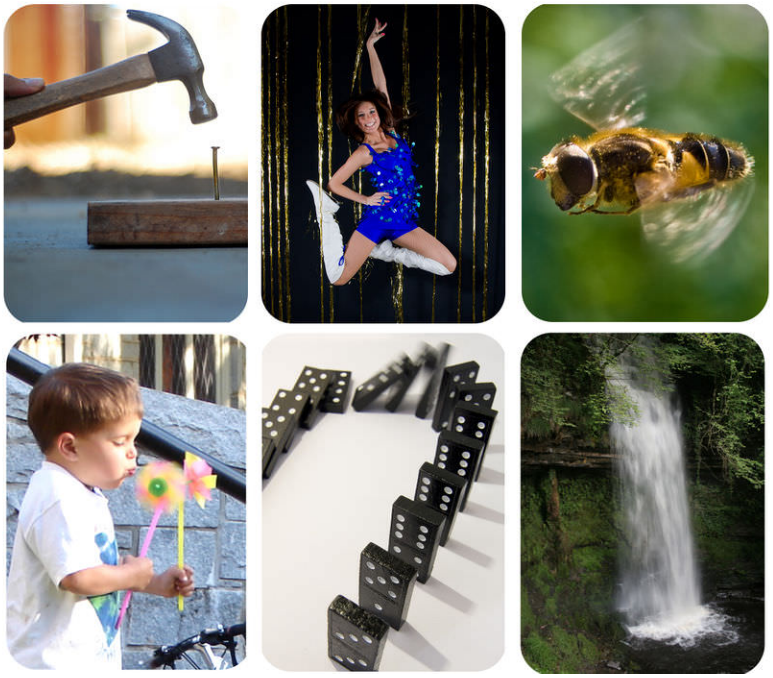

FIGURE 7.3
All of these photos show things that have kinetic energy because they are moving.

$$\text{Kinetic Energy (KE)} = \frac{1}{2}\text{mass} \times \text{velocity}^2$$

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** 7.4? 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.

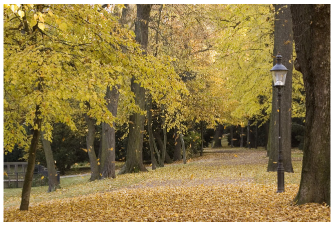

FIGURE 7.4
Before leaves fall from trees in autumn, they have potential energy. Why do they have the potential to fall?

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** 7.5.

FIGURE 7.5
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** 7.5. 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** 7.6 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?

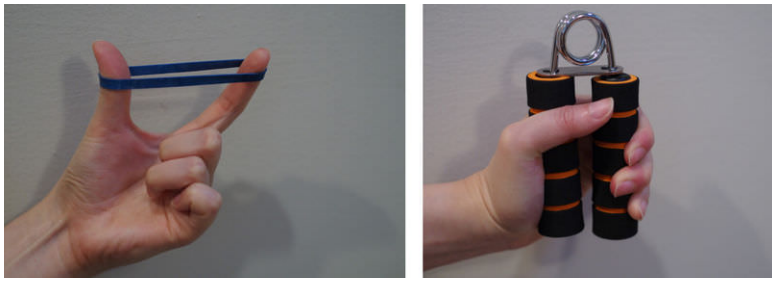

FIGURE 7.6
Changing the shape of an elastic material gives it potential energy.

Energy Conversion

Remember the diver in **Figure** 7.5? 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** 7.7 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

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/ .

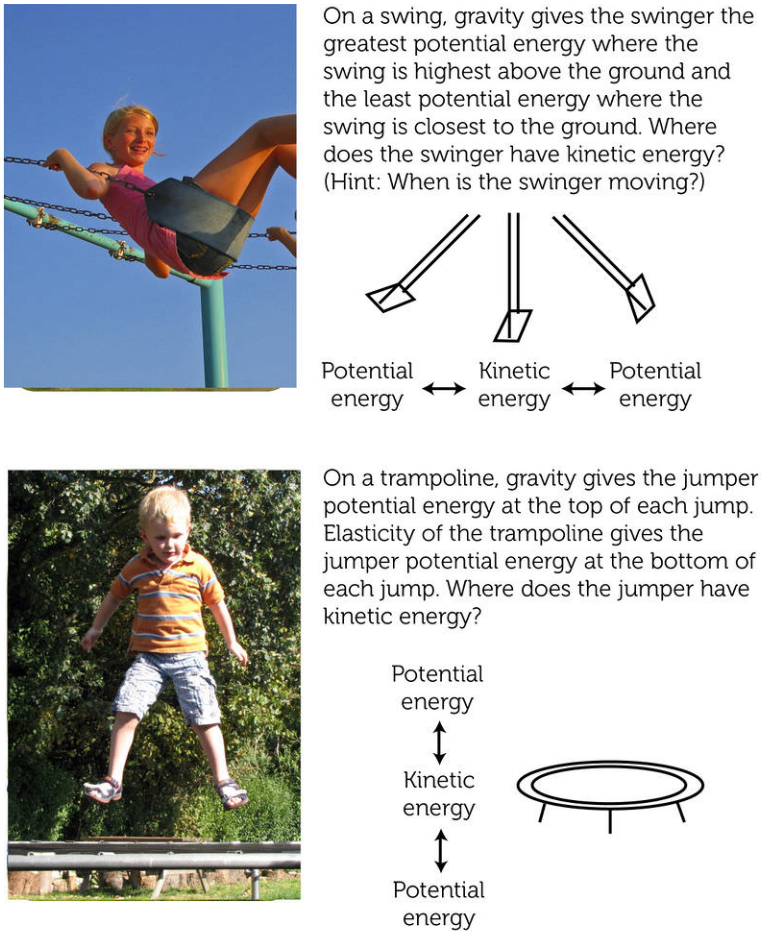

FIGURE 7.7

Energy continuously changes back and forth between potential and kinetic energy on a swing or trampoline.

MEDIA

Click image to the left or use the URL below.

URL: https://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?

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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. 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/barryskeates/6803422544/; Waterfall: http://www.flickr.com/photos/hisgett/422399097/ . Hammer and nail: CC BY-NC 3.0; Rest: CC BY 2.0
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CONCEPT 8 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** 8.1 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 8.1
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** 8.2. 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.

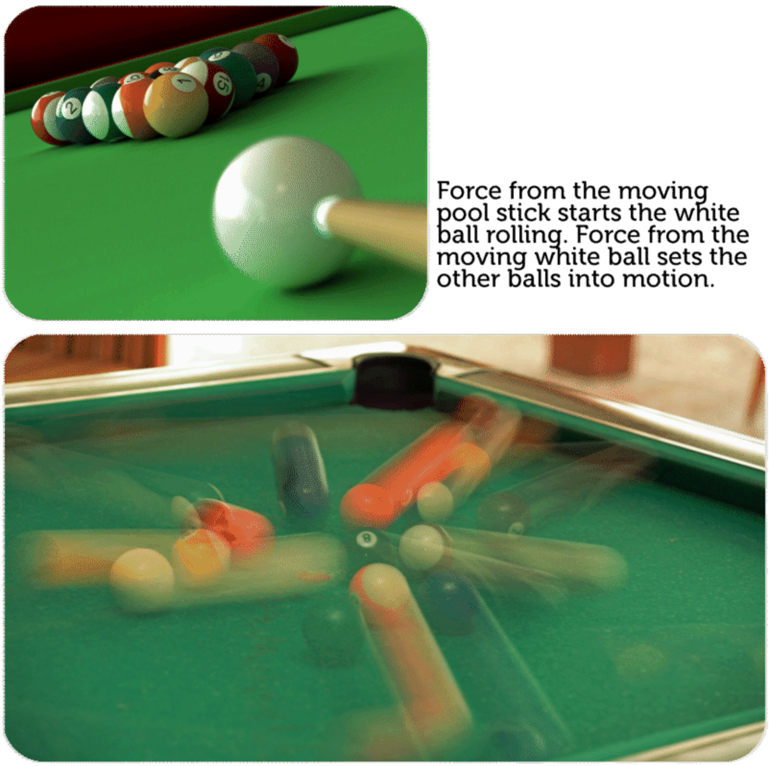

FIGURE 8.2

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** 8.1. 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** 8.3. 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.

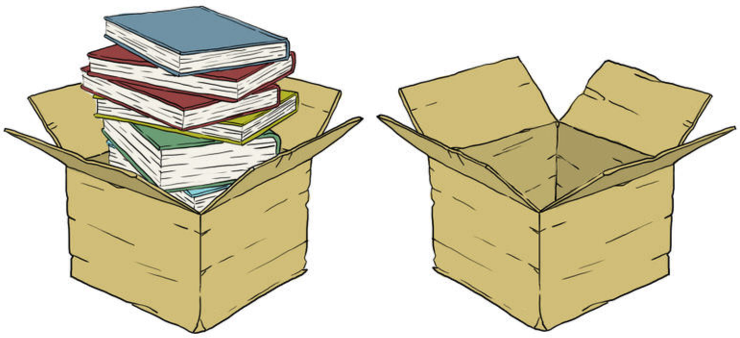

FIGURE 8.3
The tendency of an object to resist a change in its motion depends on its mass. Which box has greater inertia?

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** 8.4, 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 8.4
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?

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Concept 9 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** 9.1, 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 9.1
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** 9.2. 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 9.2
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** 9.3. 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.

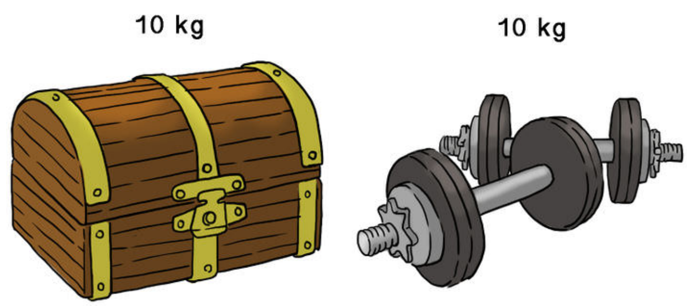

FIGURE 9.3

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** 9.3. 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?

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CONCEPT 10 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** 10.1. 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.

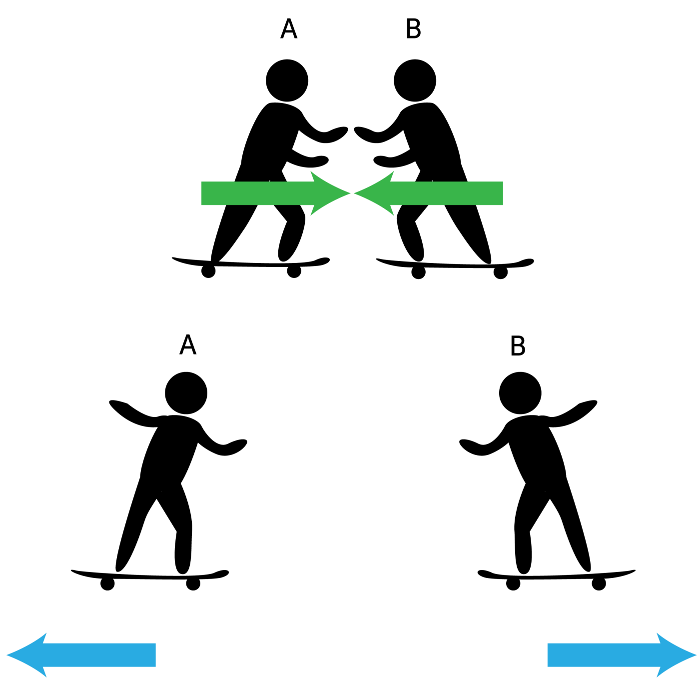

FIGURE 10.1
A and B move apart by first pushing together.

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** 10.2. You can watch a video about actions and reactions at this URL: http://www.nasa.gov/mov/192449main_019_law_of_action.mov .

FIGURE 10.2
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** 10.2, 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** 10.2 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** 10.3? 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 10.3

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** 10.4. 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 .

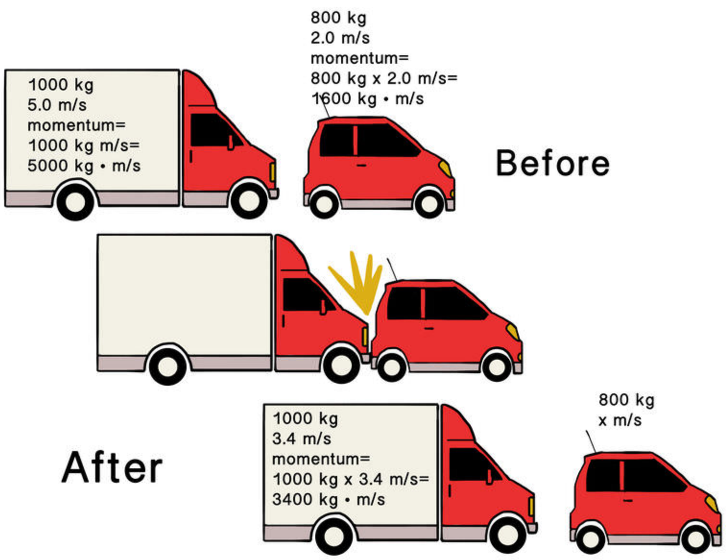

FIGURE 10.4
How can you tell momentum has been conserved in this collision?

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/ .

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URL: https://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/ .

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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?

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3. Bowling ball: Casey Fleser (Flickr:somegeekintn); Softball: KT King. Bowling ball: http://www.flickr.com/photos/somegeekintn/3899126494/; Softball: http://www.flickr.com/photos/xtrah/5660012808/ . CC BY 2.0
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CONCEPT 11 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** 11.1). 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.

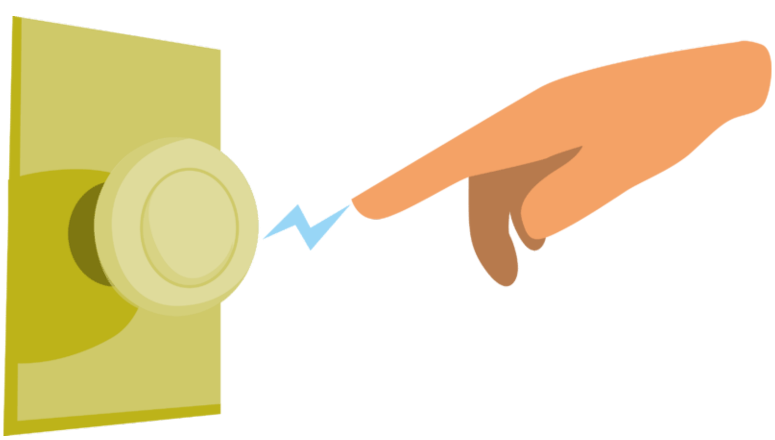

FIGURE 11.1
Moving electric charges explain why you get a shock when you touch a doorknob after walking across a carpet.

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** 11.2).

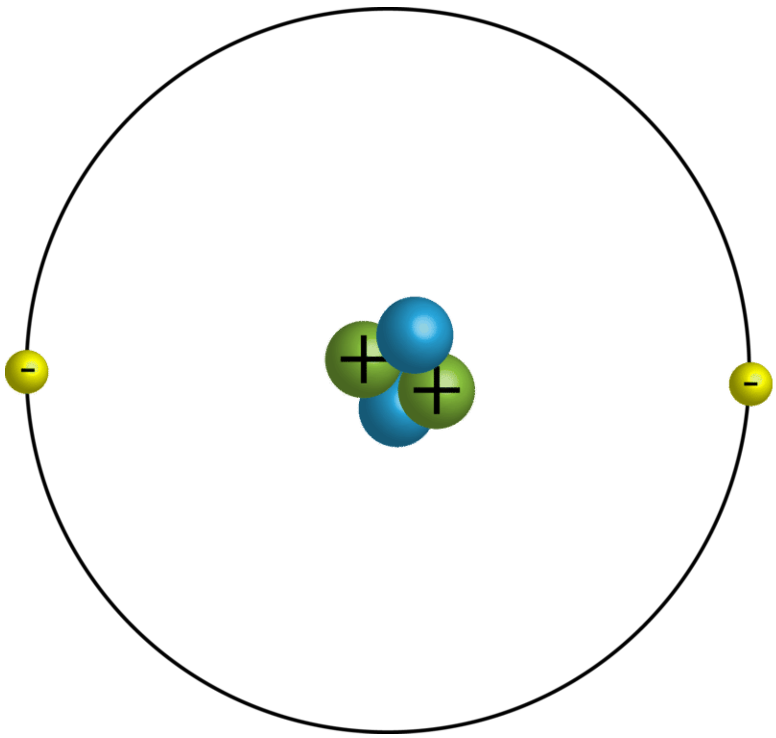

FIGURE 11.2

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** 11.3. 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.

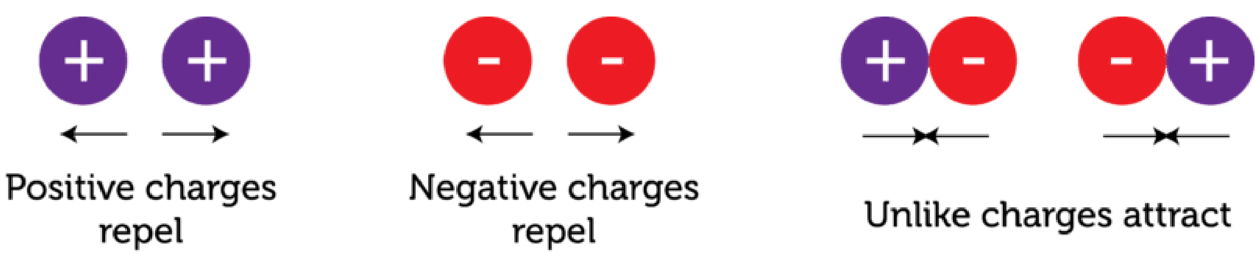

FIGURE 11.3

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** 11.4 and at the URL below. When charged particles exert force on each other, their electric fields interact. This is also illustrated in **Figure** 11.4.

http://www.learnerstv.com/animation/animation.php?ani=86&cat=physics

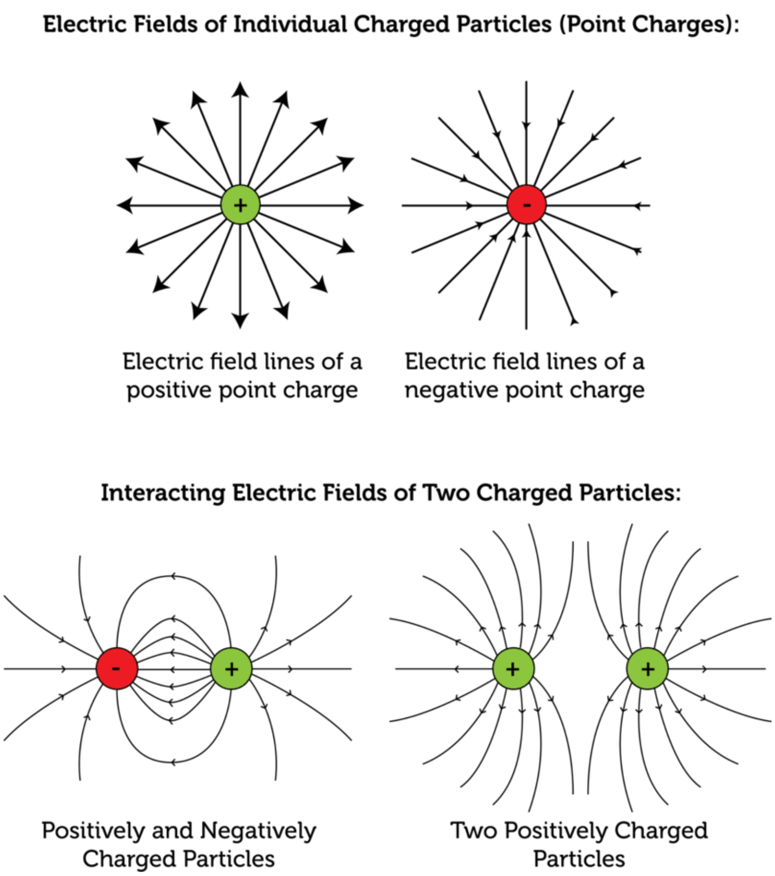

FIGURE 11.4
Field lines represent lines of force in the electric field around a charged particle. The lines bend when two particles interact. What would the lines of force look like around two negatively charged particles?

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** 11.5. 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**.

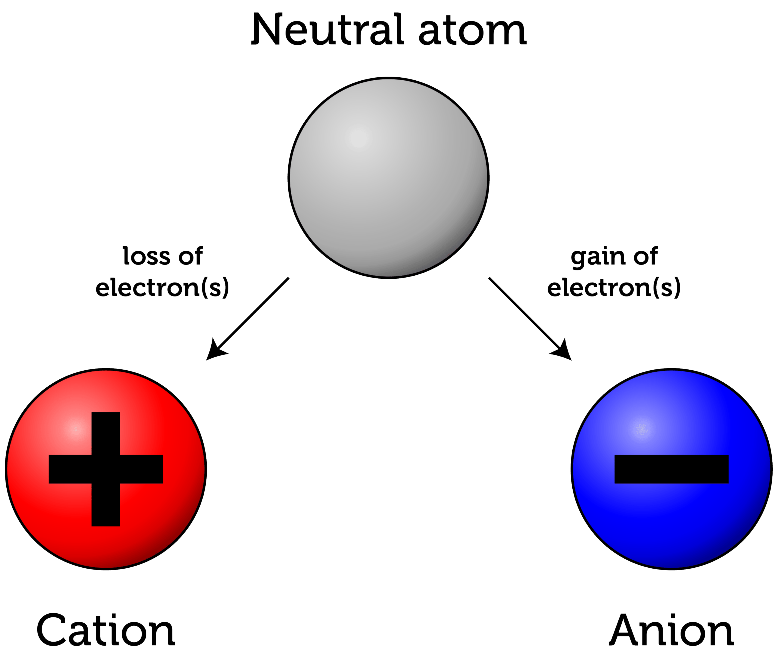

FIGURE 11.5
Atoms are electrically neutral, but if they lose or gain electrons they become charged particles called ions.

Friction

Did you ever rub an inflated balloon against your hair? You can see what happens in **Figure** 11.6. 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.

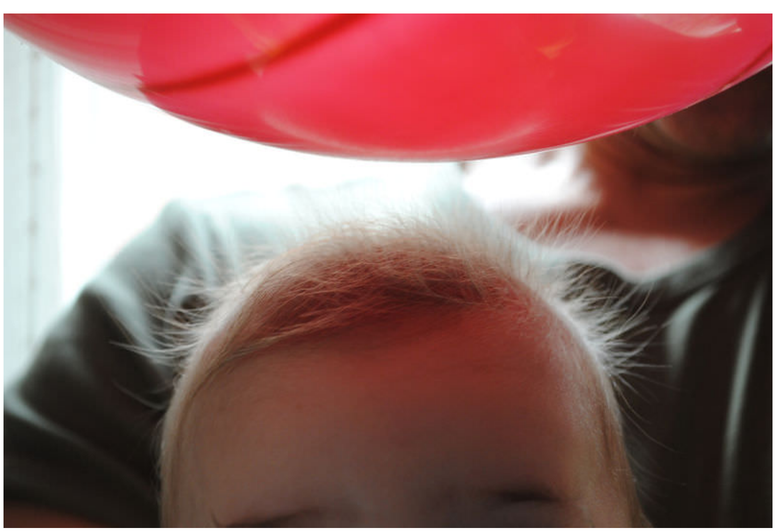

FIGURE 11.6
Electrons are transferred from hair to a balloon rubbed against the hair. Then the oppositely charged hair and balloon attract each other.

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** 11.7. 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 11.7
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** 11.8. 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.

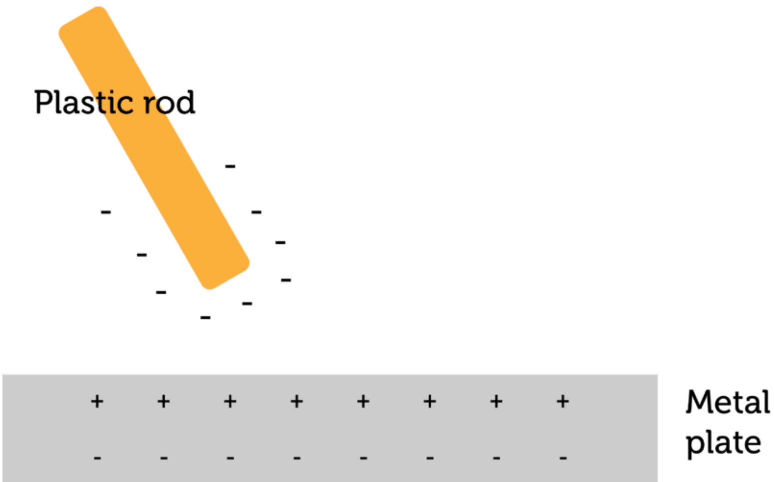

FIGURE 11.8
Polarization occurs between a charged and neutral object.

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** 11.9. 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

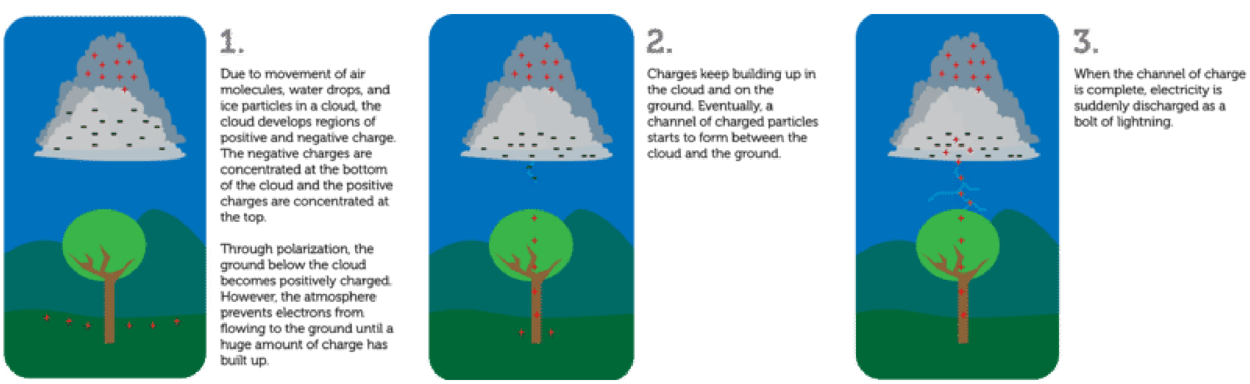

FIGURE 11.9
Lightning occurs when there is a sudden discharge of static electricity between a cloud and the ground.

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 12 Magnets and Magnetism

Lesson Objectives

- Identify properties of magnets.
- Explain why some materials are magnetic.

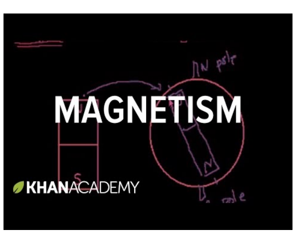
Lesson Vocabulary

- ferromagnetic material
- magnet
- magnetic domain
- magnetic field
- magnetic force
- magnetic pole
- magnetism

Introduction

The futuristic-looking train in **Figure** 12.1 is called a maglev train. The word "maglev" stands for "magnetic levitation." Magnets push the train upward so it hovers, or levitates, above the track without actually touching it. This eliminates most of the friction acting against the train when it moves. Other magnets pull the train forward along the track. Because of these magnets, the train can go very fast. It can fly over the countryside at speeds up to 480 kilometers (300 miles) per hour! What are magnets and how do they exert such force? In this lesson, you'll find out.

You can watch a video introduction to lesson concepts at this URL: http://www.youtube.com/watch?v=8Y4JSp5U82I (10:44).



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Properties of Magnets

A **magnet** is an object that attracts certain materials such as iron. You're probably familiar with common bar magnets, like the one in **Figure** 12.2. Like all magnets, this bar magnet has north and south poles and attracts objects such as paper clips that contain iron.

FIGURE 12.1
Magnets cause this maglev train to speed along its track.

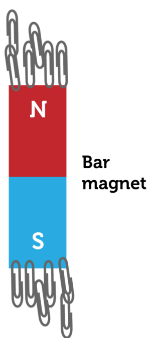

FIGURE 12.2
The north and south poles of a bar magnet attract paper clips.

Magnetic Poles

All magnets have two **magnetic poles**. The poles are regions where the magnet is strongest. The poles are called north and south because they always line up with Earth's north-south axis if the magnet is allowed to move freely. (Earth's axis is the imaginary line around which the planet rotates.) What do you suppose would happen if you cut the bar magnet in **Figure** 12.2 in half along the line between the north and south poles? Both halves would also have north and south poles. If you cut each of the halves in half, all those pieces would have north and south poles as well. Pieces of a magnet always have both north and south poles no matter how many times you cut the magnet.

Magnetic Force

The force that a magnet exerts on certain materials is called **magnetic force**. Like electric force, magnetic force is exerted over a distance and includes forces of attraction and repulsion. North and south poles of two magnets attract each other, while two north poles or two south poles repel each other.

Magnetic Field

Like the electric field that surrounds a charged particle, a **magnetic field** surrounds a magnet. This is the area around the magnet where it exerts magnetic force. **Figure** 12.3 shows the magnetic field surrounding a bar magnet. Tiny bits of iron, called iron filings, were placed under a sheet of glass. When the magnet was placed on the glass, it attracted the iron filings. The pattern of the iron filings shows the lines of force that make up the magnetic field of the magnet. The concentration of iron filings near the poles indicates that these areas exert the strongest force. To see an animated magnetic field of a bar magnet, go to this URL: http://elgg.norfolk.e2bn.org/jsmith112/files/68/149/Bar+magnet.swf .

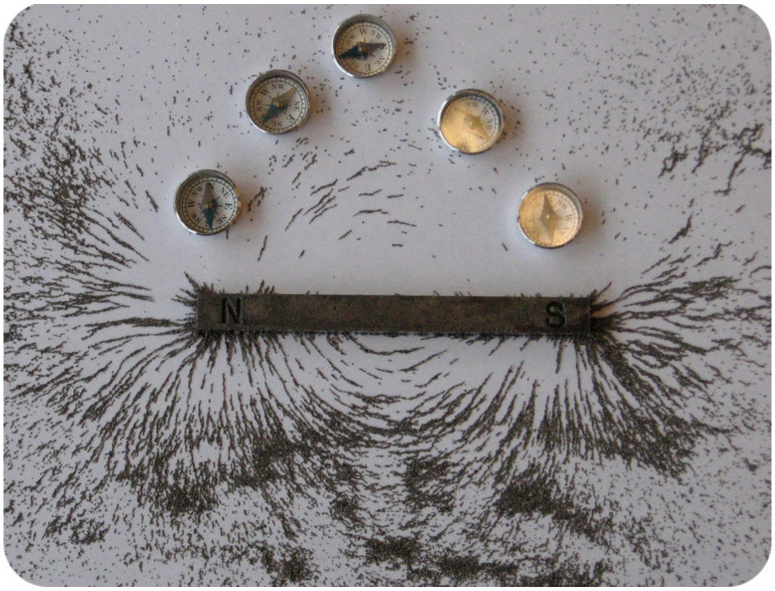

FIGURE 12.3
Lines of magnetic force are revealed by the iron filings attracted to this magnet.

When two magnets are brought close together, their magnetic fields interact. You can see how in **Figure** 12.4. The drawings show how lines of force of north and south poles attract each other whereas those of two north poles repel each other. The animations at the URL below show how magnetic field lines change as two or more magnets move in relation to each other.

http://www.coolmagnetman.com/magmotion.htm

You can take an animated quiz to check your understanding of magnetic field interactions at this URL: http://elgg.norfolk.e2bn.org/jsmith112/files/68/151/Law+of+magnetism.swf .

Magnetism and Materials

Magnetism is the ability of a material to be attracted by a magnet and to act as a magnet. No doubt you've handled refrigerator magnets like the ones in **Figure** 12.5. You probably know first-hand that they stick to a metal refrigerator but not to surfaces such as wooden doors and glass windows. Wood and glass aren't attracted to a magnet, whereas the steel refrigerator is. Obviously, only certain materials respond to magnetic force.

What Makes a Material Magnetic?

Magnetism is due to the movement of electrons within atoms of matter. When electrons spin around the nucleus of an atom, it causes the atom to become a tiny magnet, with north and south poles and a magnetic field. In most materials, the electrons orbiting the nuclei of the atoms are arranged in such a way that the materials have no magnetic properties. Also, in most types of matter, the north and south poles of atoms point in all different directions, so overall the matter is not magnetic. Examples of nonmagnetic materials include wood, glass, plastic,

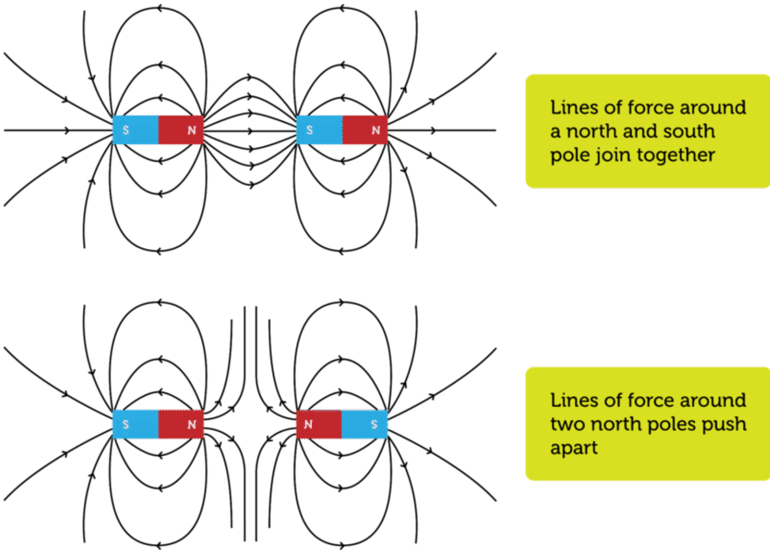

FIGURE 12.4
When it come to magnets, there is a force of attraction between opposite poles and a force of repulsion between like poles.

FIGURE 12.5
Refrigerator magnets stick to a refrigerator door because it contains iron. Why won't the magnets stick to wooden cabinet doors?

paper, copper, and aluminum. These materials are not attracted to magnets and cannot become magnets.

In other materials, electrons fill the orbitals of the atoms that make up the material in a way to allow for each atom to have a tiny magnetic field, giving each atom a tiny north and south pole. There are large areas where the north and south poles of atoms are all lined up in the same direction. These areas are called **magnetic domains**. Generally, the magnetic domains point in different directions, so the material is still not magnetic. However, the material can be magnetized by placing it in a magnetic field. When this happens, all the magnetic domains become aligned, and the material becomes a magnet. This is illustrated in **Figure** 12.6. Materials that can be magnetized are called **ferromagnetic materials**. They include iron, cobalt, and nickel.

Temporary and Permanent Magnets

Materials that have been magnetized may become temporary or permanent magnets. An example of each type of magnet is described below. Both are demonstrated in **Figure** 12.7.

- If you bring a bar magnet close to pile of paper clips, the paper clips will become temporarily magnetized, as all their magnetic domains align. As a result, the paper clips will stick to the magnet and also to each other.

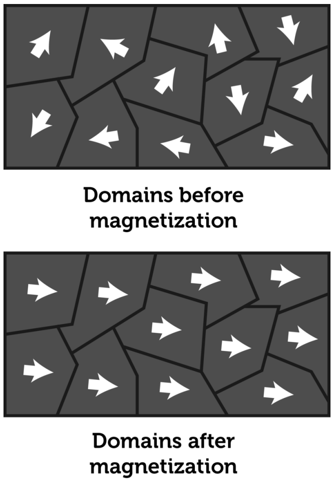

FIGURE 12.6
Magnetic domains must be aligned by an outside magnetic field for most ferromagnetic materials to become magnets.

However, if you remove the paper clips from the bar magnet's magnetic field, their magnetic domains will no longer align. As a result, the paper clips will no longer be magnetized or stick together.

- If you stroke an iron nail with a bar magnet, the nail will become a permanent (or at least long-lasting) magnet. Its magnetic domains will remain aligned even after you remove it from the magnetic field of the bar magnet. Permanent magnets can be demagnetized, however, if they are dropped or heated to high temperatures. These actions move the magnetic domains out of alignment.

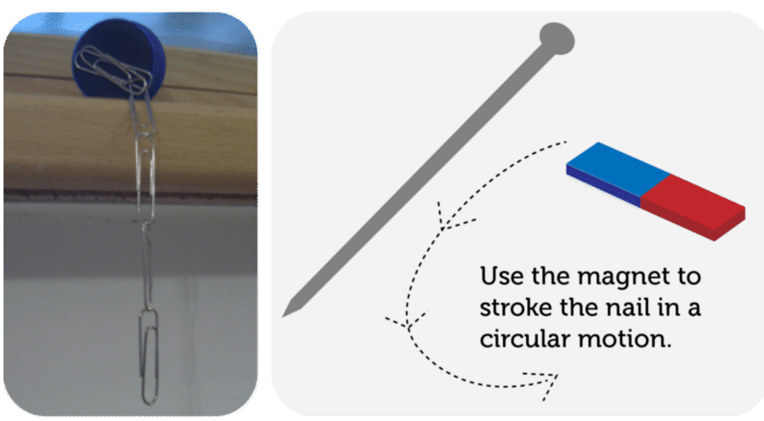

FIGURE 12.7
Paper clips become temporary magnets when placed in a magnetic field. An iron nail becomes a permanent magnet when stroked with a bar magnet.

Some materials are natural permanent magnets. The most magnetic material in nature is the mineral magnetite, also called lodestone. The magnetic domains of magnetite naturally align with Earth's axis. **Figure** 12.8 shows a chunk of magnetite attracting iron nails and iron filings. The magnetic properties of magnetite have been recognized for thousands of years. The earliest compasses used magnetite pointers to show direction. The magnetite spoon compass in **Figure** 12.8 dates back about 2000 years and comes from China.

Lesson Summary

- A magnet is an object that attracts certain materials such as iron. All magnets have two magnetic poles and a magnetic field over which they exert force. Opposite magnetic poles attract each other, and like magnetic

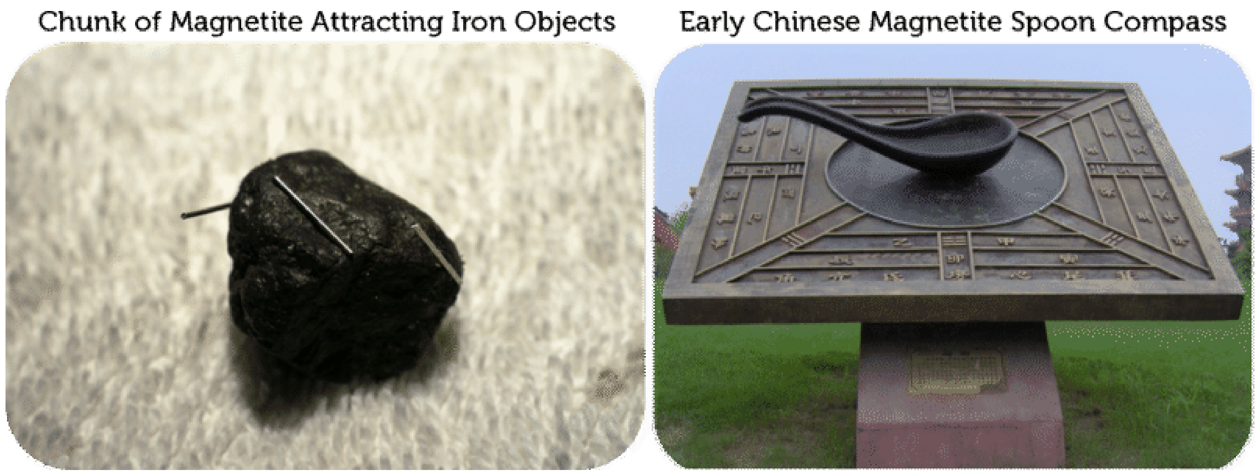

FIGURE 12.8
Magnetite naturally attracts iron nails and filings. Its natural magnetism was discovered thousands of years ago.

poles repel each other.
- Magnetism is the ability to be attracted by a magnet and to act as a magnet. Only ferromagnetic materials have this property. They include iron, cobalt, and nickel. When these materials are magnetized, they become temporary or permanent magnets. Magnetite is a natural permanent magnet.

Lesson Review Questions

Recall

1. What is a magnet?
2. Define magnetic force.
3. Give examples of objects that are attracted by magnets.
4. Identify ferromagnetic materials.

Apply Concepts

5. Draw magnetic field lines around the bar two magnets pictured below.

6. Sasha dropped a magnet on the sidewalk. Now it no longer attracts paper clips. Apply lesson concepts to explain why.

Think Critically

7. Explain how and why a ferromagnetic material can be magnetized.

Points to Consider

The northern lights that you saw in the opening photo of this chapter are caused by Earth's magnetic field. You will read about Earth's magnetic field in the next lesson, "Earth as a Magnet."

- If you could see Earth's magnetic field, what do you think it would look like? (*Hint:* Look at **Figure** 12.3.)
- After reading this lesson, can you predict why northern lights are most likely to be visible near Earth's poles?

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CONCEPT 13 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** 13.1, 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.

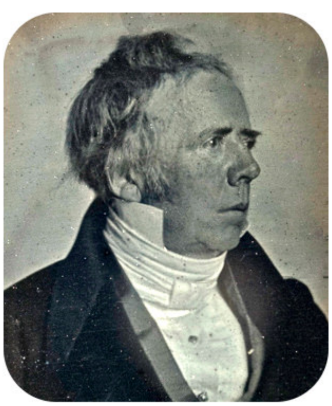
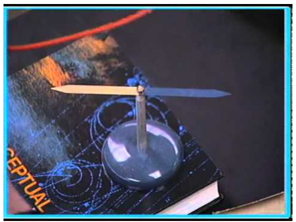


FIGURE 13.1
Hans Christian Oersted was the scientist who discovered electromagnetism.

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** 13.2. 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)



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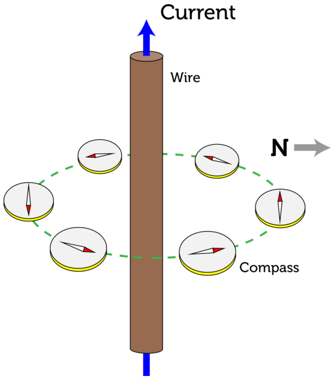

FIGURE 13.2

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** 13.3. 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.

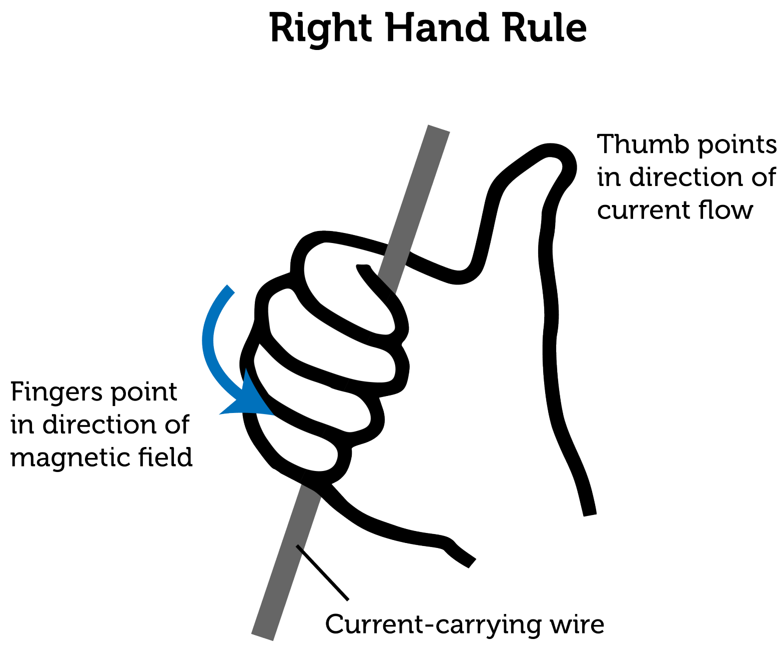

FIGURE 13.3
The right hand rule shows the direction of the magnetic field around a wire that is carrying electric current.

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?

References

1. . http://commons.wikimedia.org/wiki/File:Hans_Christian_%C3%98rsted_daguerreotype.jpg . Public Domain
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CONCEPT 14 Using Electromagnetism

Lesson Objectives

- State how a solenoid increases electromagnetic force.
- Explain why electromagnets can be very strong.
- Describe how doorbells and electric motors use electromagnetism.

Lesson Vocabulary

- electric motor
- electromagnet
- solenoid

Introduction

Do you believe in ghosts? The man in the **Figure** 14.1 does. He's hoping to record sights or sounds of ghost on his video camera. The other device he's holding is an electromagnetic field detector. Ghost hunters often use detectors like this one because they believe that ghosts cause changes in electromagnetic fields. The problem for ghost hunters is that electromagnetic fields can be produced by many devices. You can read about some of them in this lesson. They may not be as exciting as ghosts, but they are a lot more useful!

FIGURE 14.1
This man is trying to detect "evidence" of a ghost.

Solenoids

A **solenoid** is a coil of wire with electric current flowing through it, giving it a magnetic field (see **Figure** 14.2). Recall that current flowing through a straight wire produces a weak electromagnetic field that circles around the wire. Current flowing through a coil of wire, in contrast, produces a magnetic field that has north and south poles like a bar magnet. The magnetic field around a coiled wire is also stronger than the magnetic field around a straight wire because each turn of the wire has its own magnetic field. Adding more turns increases the strength of the field, as does increasing the amount of current flowing through the coil. You can see an actual solenoid with a compass showing its magnetic north pole at this URL: http://www.youtube.com/watch?v=AgZHqfIBkUI .

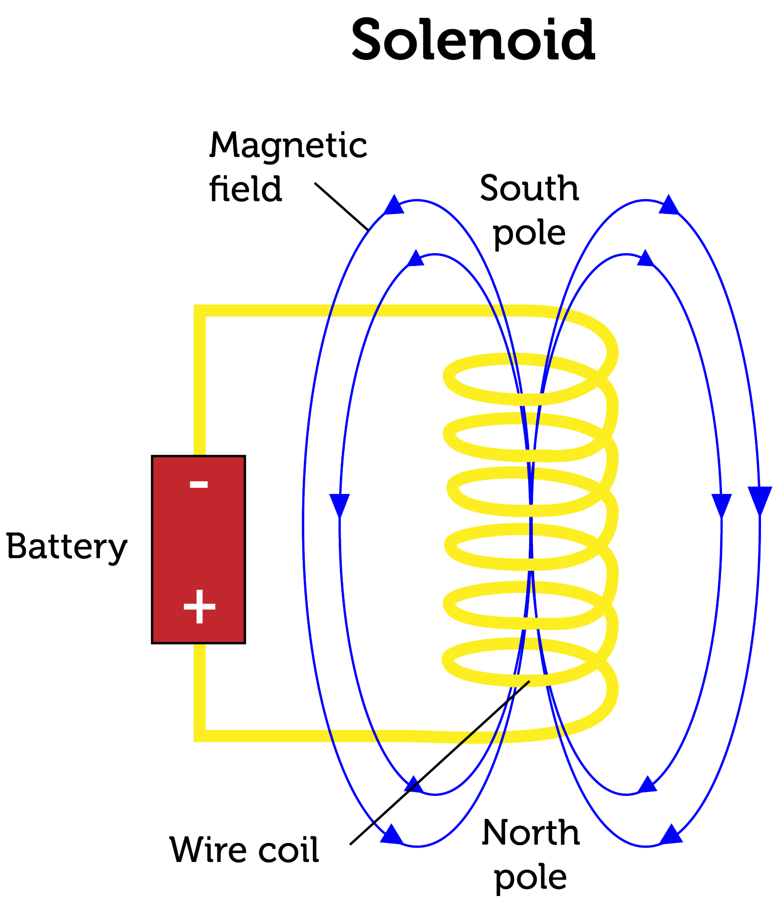

FIGURE 14.2
How does a solenoid resemble a bar magnet?

Electromagnets

Solenoids are the basis of electromagnets. An **electromagnet** is a solenoid wrapped around a bar of iron or other ferromagnetic material (see **Figure** 14.3). The electromagnetic field of the solenoid magnetizes the iron bar by aligning its magnetic domains. The combined magnetic force of the magnetized iron bar and the wire coil makes an electromagnet very strong. In fact, electromagnets are the strongest magnets made. Some of them are strong enough to lift a train. The maglev train described earlier, in the lesson "Electricity and Magnetism," contains permanent magnets. Strong electromagnets in the track repel the train magnets, causing the train to levitate above the track.

Like a solenoid, an electromagnet is stronger if there are more turns in the coil or more current is flowing through it.

A bigger bar or one made of material that is easier to magnetize also increases an electromagnet's strength. You can see how to make a simple electromagnet at this URL: http://www.youtube.com/watch?v=emlzh9XXWgQ (4:57).

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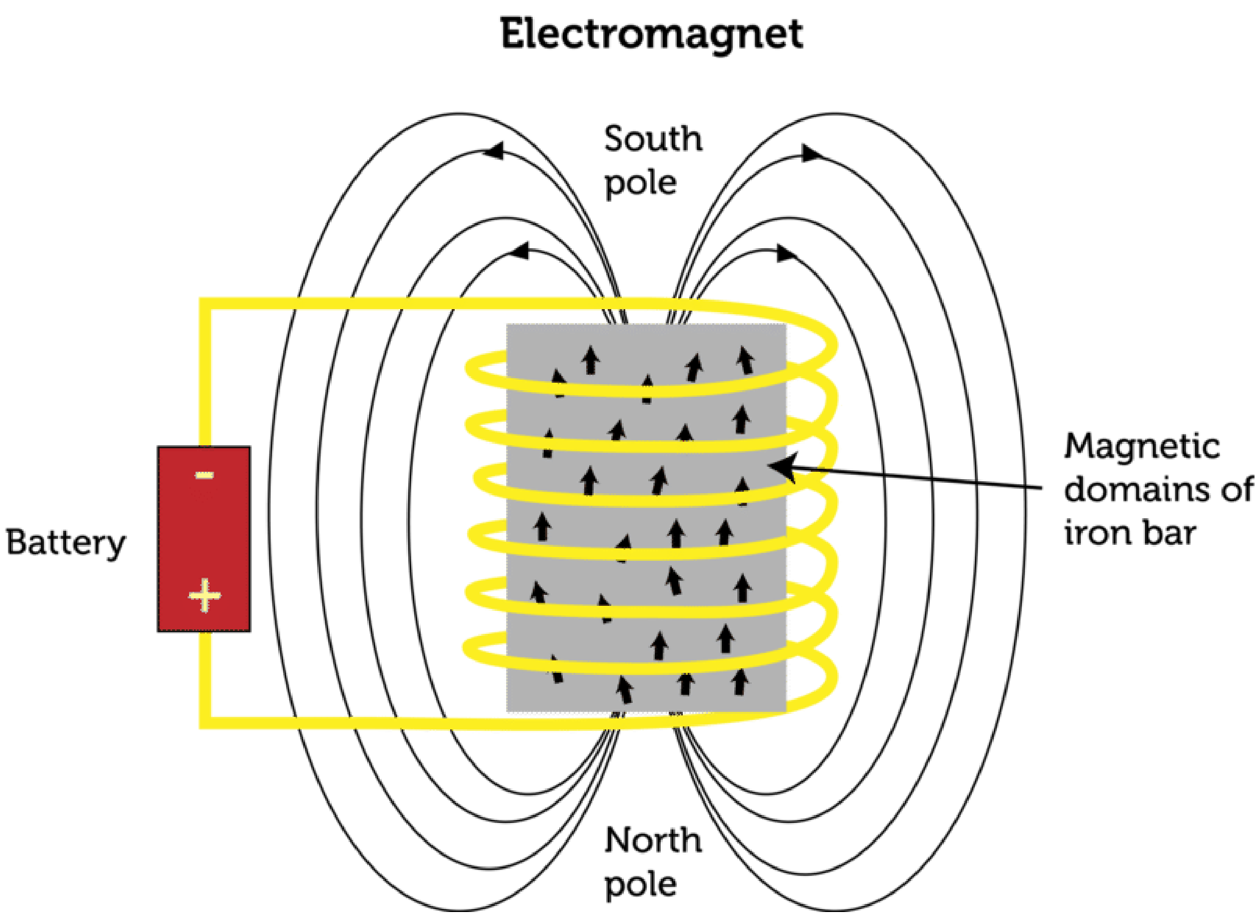

FIGURE 14.3

An electromagnet uses a solenoid and an iron bar to create a very strong magnetic field.

Electromagnetic Devices

Many common electric devices contain electromagnets. Some examples include hair dryers, fans, CD players, telephones, and doorbells. Most electric devices that have moving parts contain electric motors. You can read below how doorbells and electric motors use electromagnets.

How a Doorbell Works

Figure 14.4 shows a diagram of a simple doorbell. Like most doorbells, it has a button located by the front door. Pressing the button causes two electric contacts to come together and complete an electric circuit. In other words, the button is a switch. The circuit is also connected to a voltage source, an electromagnet, and the clapper of a bell. When current flows through the circuit, the electromagnet turns on, and its magnetic field attracts the clapper. This causes the clapper to hit the bell, making it ring. Because the clapper is part of the circuit, when it moves to strike the bell, it breaks the circuit. Without current flowing through the circuit, the electromagnet turns off. The clapper returns to its original position, which closes the circuit again and turns the electromagnet back on. The electromagnet again attracts the clapper, which hits the bell once more. This sequence of events keeps repeating as long as the button by the front door is being pressed.

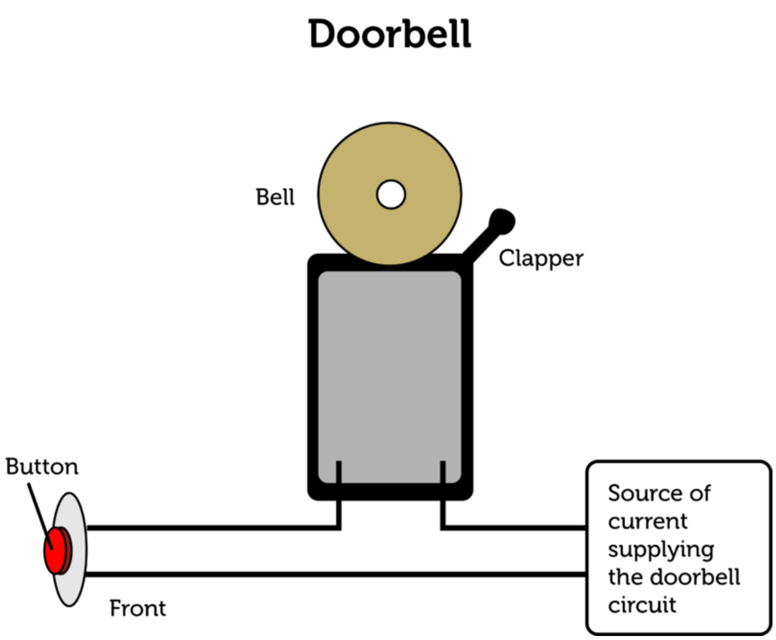

FIGURE 14.4
A doorbell uses an electromagnet to move the clapper of a bell.

Electric Motors

An **electric motor** is a device that uses an electromagnet to change electrical energy to kinetic energy. **Figure** 14.5 shows a simple diagram of an electric motor. The motor contains an electromagnet that is connected to a shaft. When current flows through the motor, the electromagnet turns, causing the shaft to turn as well. The rotating shaft moves other parts of the device.

Why does the motor's electromagnet turn? Notice that the electromagnet is located between the north and south poles of two permanent magnets. When current flows through the electromagnet, it becomes magnetized, and its poles are repelled by the like poles of the permanent magnets. This causes the electromagnet to turn toward the unlike poles of the permanent magnets. A device called a commutator then changes the direction of the current so the poles of the electromagnet are reversed. The reversed poles are once again repelled by the like poles of the permanent magnets. This causes the electromagnet to continue to turn. These events keep repeating, so the electromagnet rotates continuously. You can make a very simple electric motor with a battery, wire, and magnet following instructions at this URL: http://www.youtube.com/watch?v=VhaYLnjkf1E .

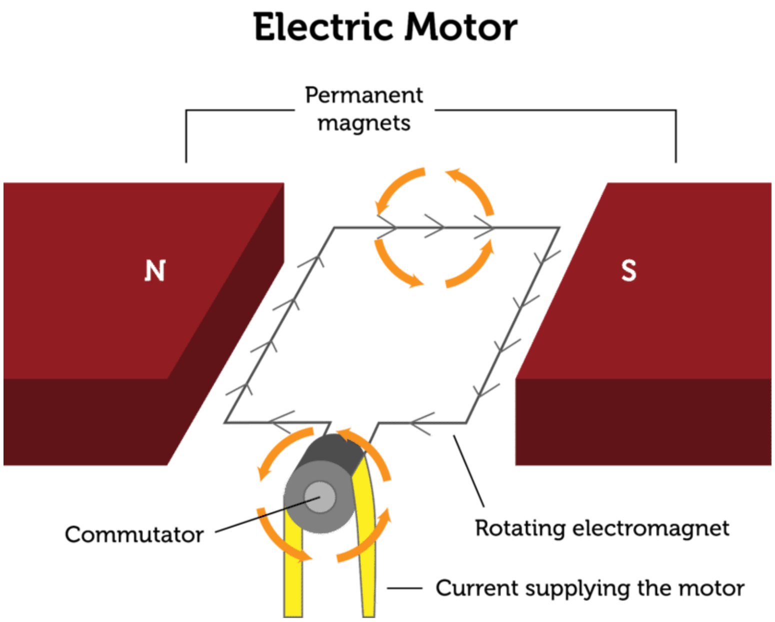

FIGURE 14.5
In this simple diagram of an electric motor, the electromagnet is represented by a rectangular wire. It actually consists of an iron bar surrounded by a wire coil.

Lesson Summary

- A solenoid is a coil of wire with electric current flowing through it. It produces a strong magnetic field with north and south poles like a bar magnet.
- An electromagnet is a solenoid wrapped around a bar of iron or other ferromagnetic material. The magnetic field of the coil magnetizes the bar, which adds to the strength of the magnetic field. Electromagnets are the strongest magnets made.
- Many common electric devices, such as doorbells, contain electromagnets. If they have moving parts, they are likely to have an electric motor. An electric motor is a device that uses an electromagnet to change electrical energy to kinetic energy.

Lesson Review Questions

Recall

1. What is a solenoid?
2. What determines the strength of a solenoid's magnetic field?
3. Describe how a doorbell uses an electromagnet.

Apply Concepts

4. Draw a labeled sketch of an electric motor to show how it uses electromagnetism to convert electrical energy to kinetic energy.

Think Critically

5. Assume that an electromagnet and a solenoid have the same number of turns in their wire coil and the same amount of current flowing through the wire. Which device has the stronger magnetic field? Explain your answer.

Points to Consider

In this lesson, you saw how electric current can be used to create a strong electromagnetic field. In the next lesson, "Generating and Using Electricity," you'll find out how a magnetic field can be used to generate an electric current.

- Can you predict how this might be done?
- A device that uses a magnetic field to generate electricity is called a generator. What do you already know about generators from previous chapters? (*Hint:* Look at the figure on how energy constantly changes form in the "Introduction to Energy" chapter.)

References

1. Image copyright Peter Kim, 2013. http://www.shutterstock.com . Used under license from Shutterstock.com
2. Christopher Auyeung. CK-12 Foundation .
3. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
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CONCEPT 15 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** 15.1. 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.

FIGURE 15.1
A drop of water causes a disturbance that travels through the pond as a wave.

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** 15.1 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 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.

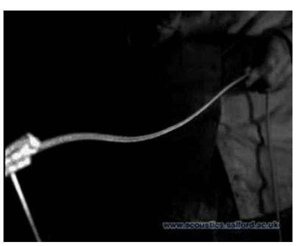
Types of Mechanical Waves

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** 15.2. 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** 15.3. 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 way are called secondary, or S, waves. An S wave is illustrated in **Figure** 15.4.

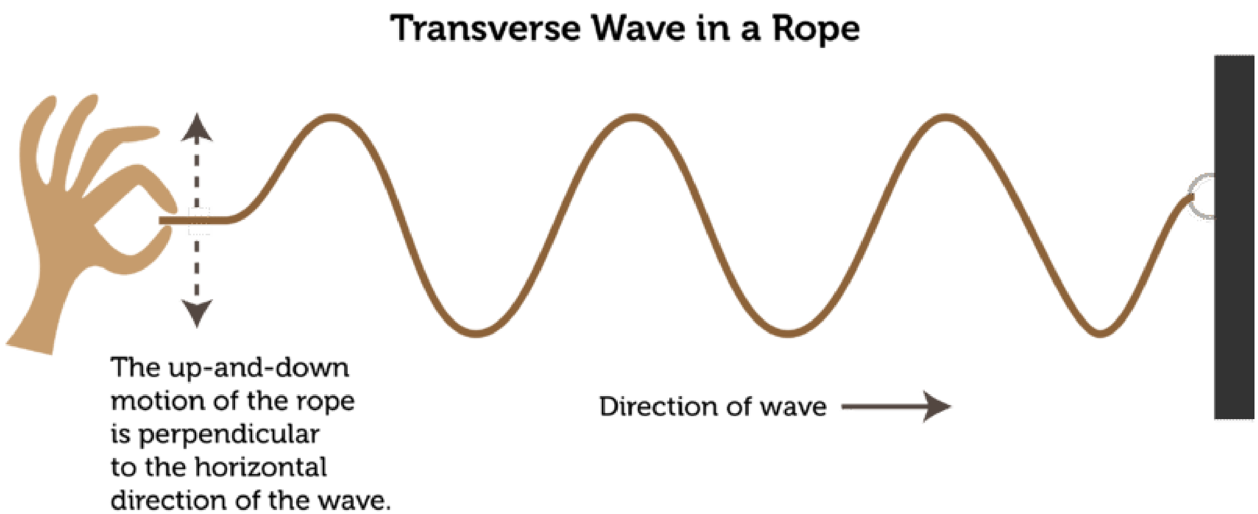


FIGURE 15.2
In a transverse wave, the medium moves at right angles to the direction of the wave.

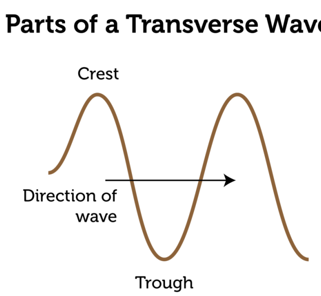


FIGURE 15.3
Crests and troughs are the high and low points of a transverse wave.

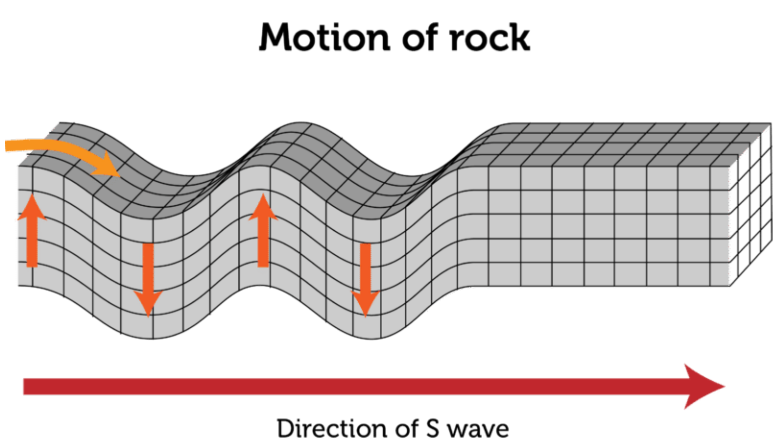


FIGURE 15.4
An S wave is a transverse wave that travels through rocks under Earth's surface.

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** 15.5. 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 .

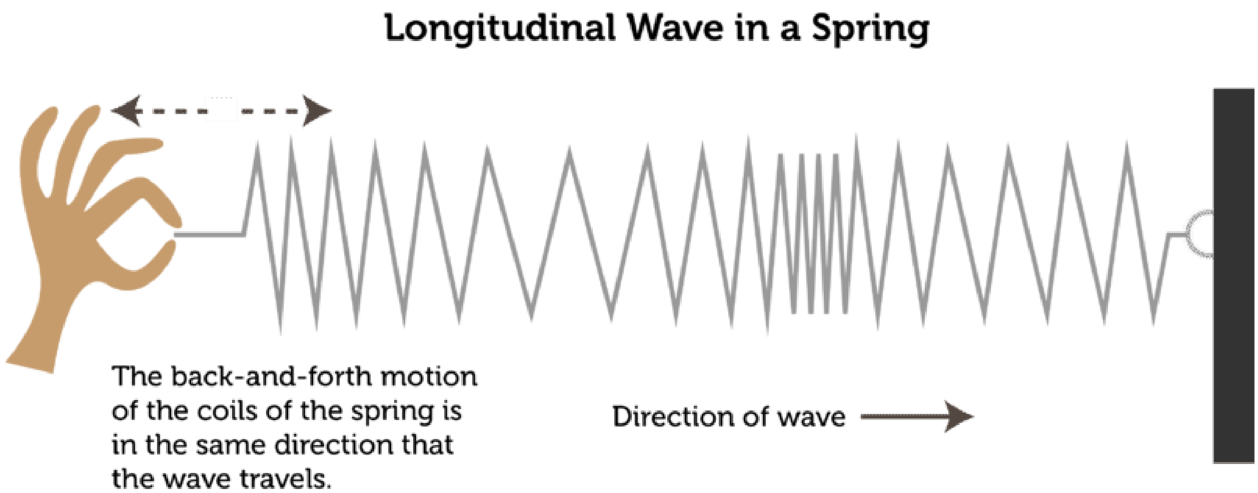


FIGURE 15.5
In a longitudinal wave, the medium moves back and forth in the same direction as the wave.

Compressions and Rarefactions

A longitudinal wave can be characterized by the compressions and rarefactions of the medium. This is illustrated in **Figure** 15.6. 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** 15.7.

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

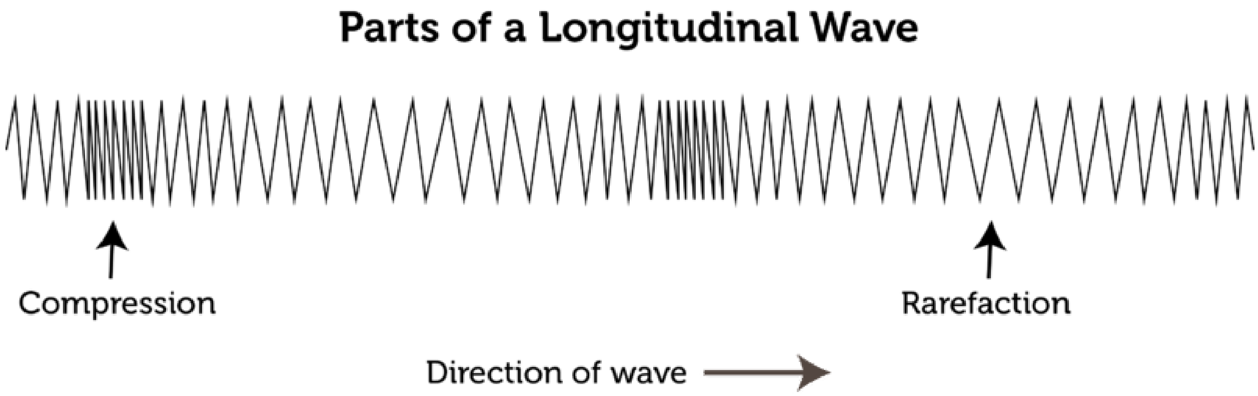


FIGURE 15.6
The compressions and rarefactions of a longitudinal wave are like the crests and troughs of a transverse wave.

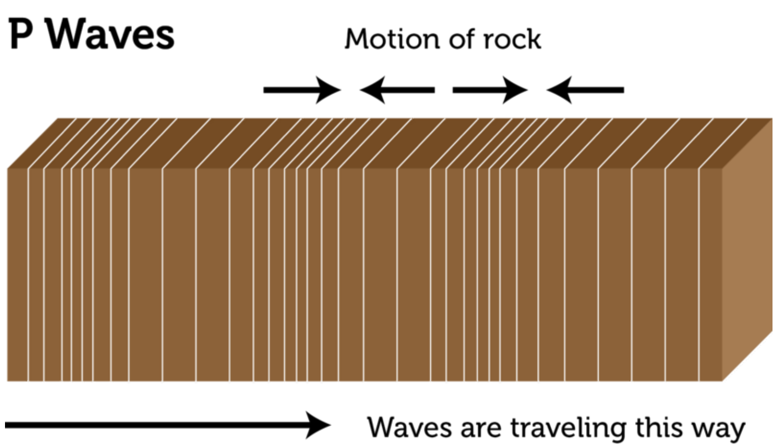
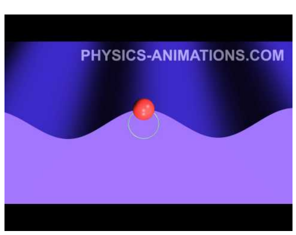


FIGURE 15.7
P waves are longitudinal waves that travel through rocks under Earth's surface.

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** 15.8 and at the URL below.

http://www.youtube.com/watch?v=7yPTa8qi5X8 (0:57)



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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** 15.9). The friction slows down the bottoms of the waves, while the tops of

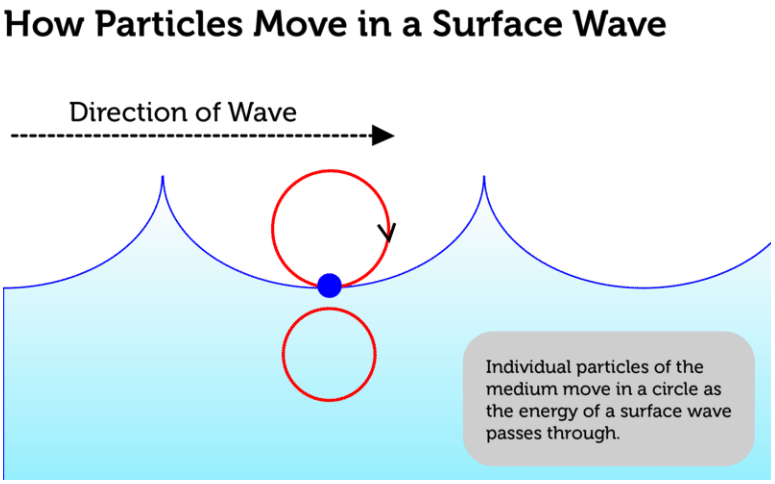


FIGURE 15.8
Surface waves are both transverse and longitudinal waves.

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.

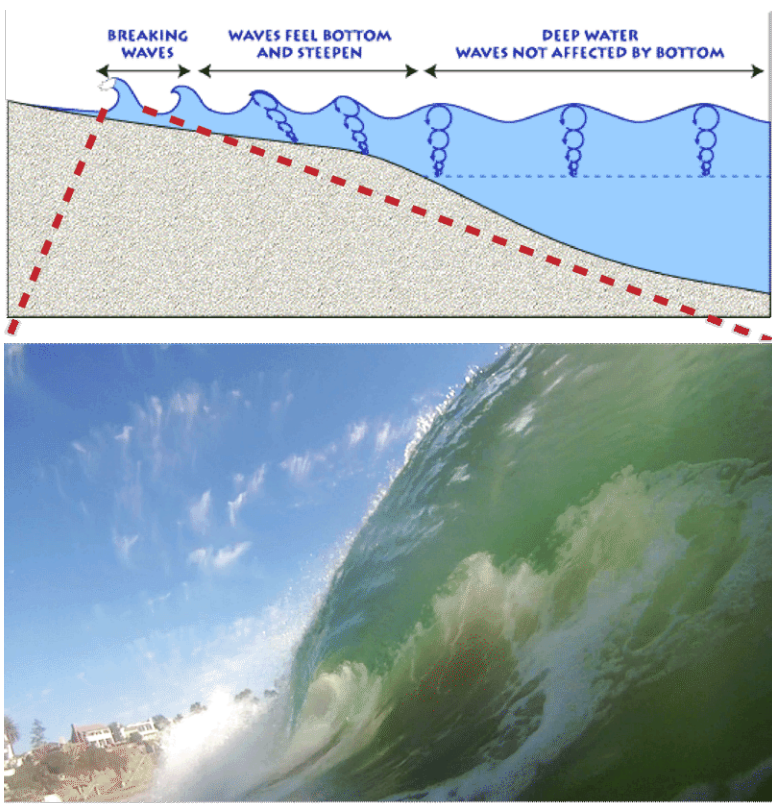


FIGURE 15.9
Waves topple over and break on the shore because of friction with the bottom in shallow water.

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.

Lesson Review Questions

Recall

1. What is a mechanical wave?
2. Identify the medium of the wave in **Figure** 15.1.
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?

References

1. Tim Fields. http://www.flickr.com/photos/24327829@N04/6737005997/ . CC BY 2.0

CONCEPT 16 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** 16.1. 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 16.1

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** 16.2 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 .

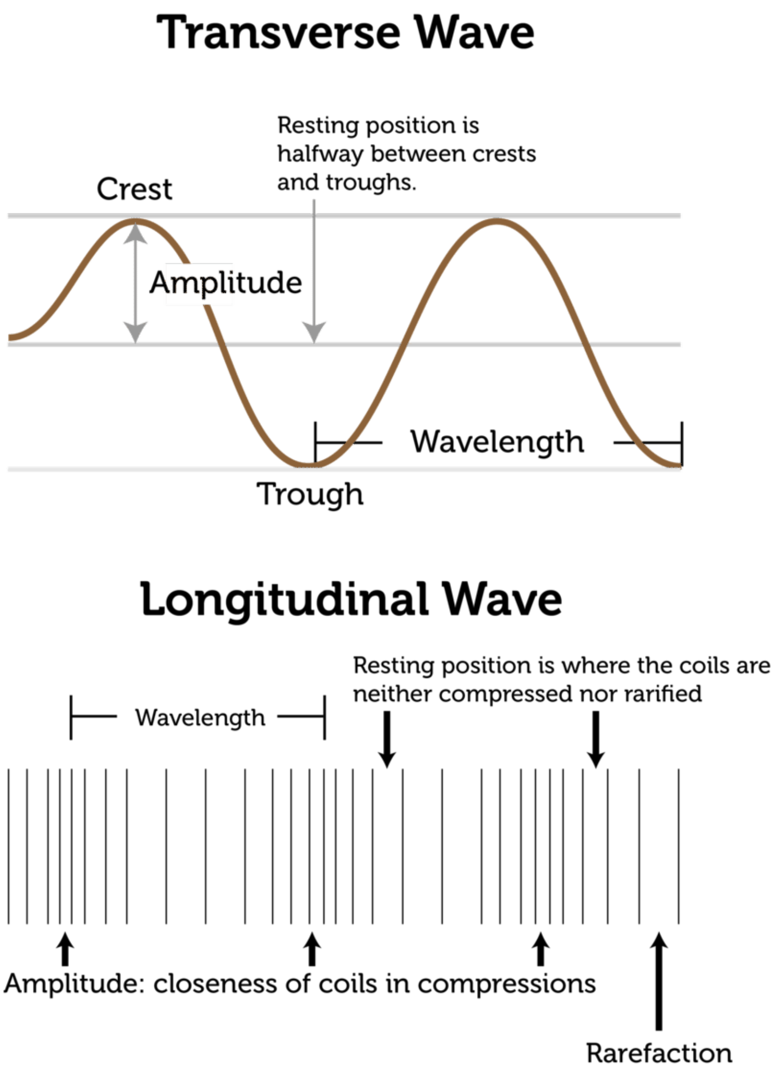


FIGURE 16.2
Wave amplitude and wavelength are two important measures of wave size.

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** above. 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** 16.2). 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** 16.3.

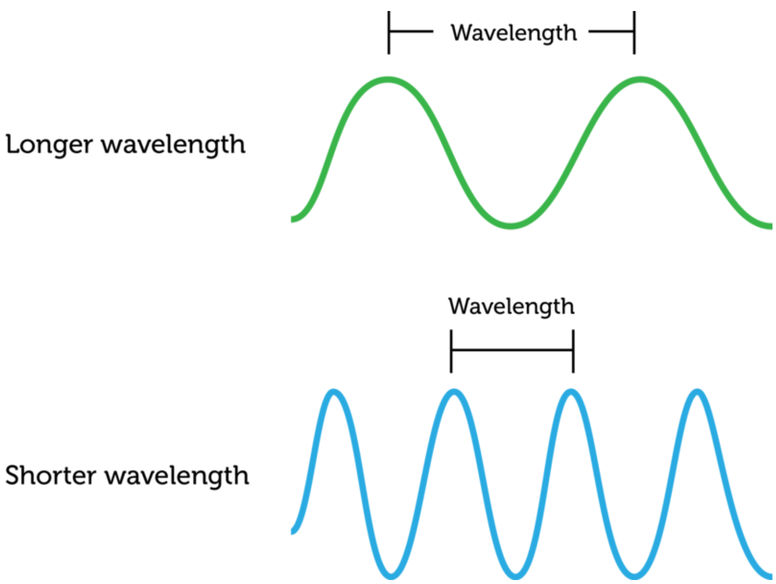


FIGURE 16.3
Both of these waves have the same amplitude, but they differ in wavelength. Which wave has more energy?

Wave Frequency and Speed

Imagine making transverse waves in a rope, like the waves in **Figure** above. 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** 16.4 shows high-frequency and low-frequency transverse waves. You can simulate transverse waves with different frequencies at this URL: http://zonalandeducation.com/mstm/physics/waves/partsOfAWave/waveParts.htm .

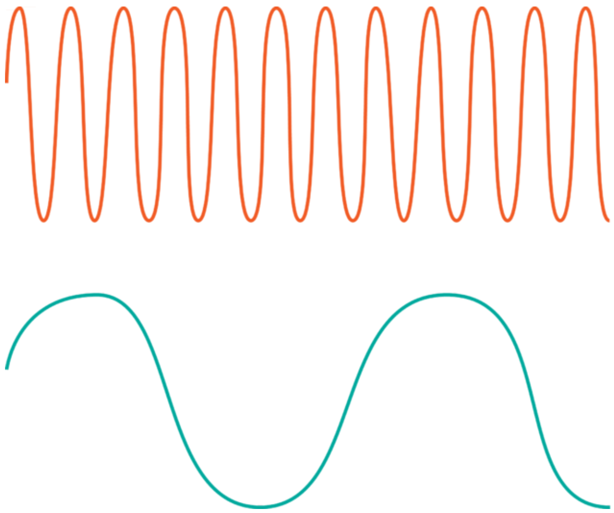


FIGURE 16.4
A transverse wave with a higher frequency has crests that are closer together.

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:

$$\text{Frequency} = \frac{2 \text{ m/s}}{1 \text{ m}} = 2 \text{ waves/s, or 2 Hz}$$

You Try It!

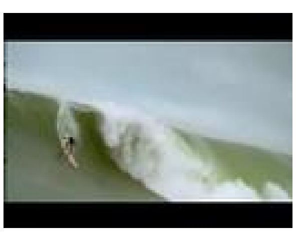
Problem: A wave is traveling at a speed of 2 m/s and has a frequency of 2 Hz. What is its wavelength?

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/ .



MEDIA

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URL: https://www.ck12.org/flx/render/embeddedobject/116517

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.

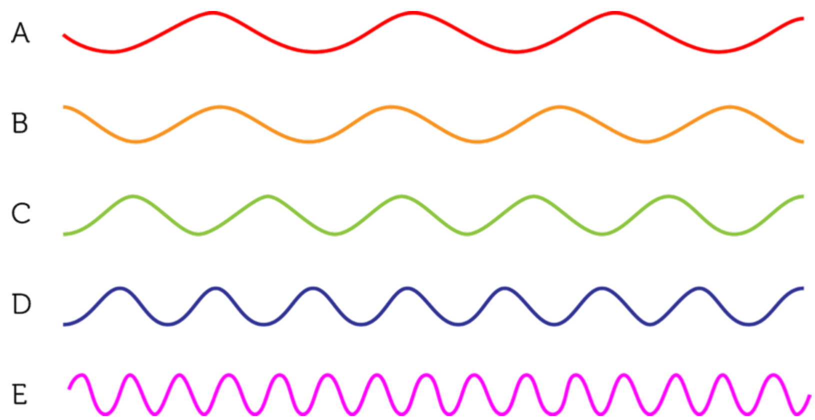
Lesson Review Questions

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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CONCEPT 17 Wave Interactions and Interference

Lesson Objectives

- Describe wave reflection, refraction, and diffraction.
- Explain how wave interference affects the amplitude of waves.

Lesson Vocabulary

- diffraction
- reflection
- refraction
- standing wave
- wave interference

Introduction

Did you ever hear an echo of your own voice? An echo occurs when sound waves bounce back from a hard object. The man in **Figure** 17.1 is trying to create an echo by shouting toward a rock wall. When the sound waves strike the rock wall, they can't pass through. Instead, they bounce back toward the man, and he hears an echo of his voice. An echo is just one example of how waves interact with matter.

Wave Interactions

Waves interact with matter in several ways. The interactions occur when waves pass from one medium to another. Besides bouncing back like an echo, waves may bend or spread out when they strike a new medium. These three ways that waves may interact with matter are called reflection, refraction, and diffraction. Each type of interaction is described in detail below. For animations of the three types of wave interactions, go to this URL: http://www.acoustics.salford.ac.uk/schools/teacher/lesson3/flash/whiteboardcomplete.swf .

Reflection

An echo is an example of wave reflection. Reflection occurs when waves bounce back from a barrier they cannot pass through. **Reflection** can happen with any type of waves, not just sound waves. For example, **Figure** 17.2 shows the reflection of ocean waves off a rocky coast. Light waves can also be reflected. In fact, that's how we see most objects. Light from a light source, such as the sun or a light bulb, shines on the object and some of the light is reflected. When the reflected light enters our eyes, we can see the object.

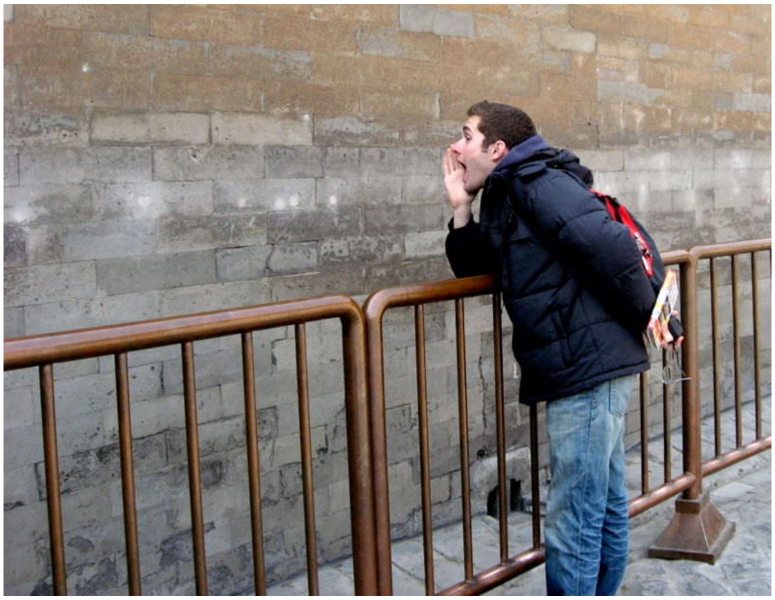

FIGURE 17.1
This man is sending sound waves toward a rock wall so he can hear an echo.

FIGURE 17.2
Ocean waves are reflected by rocks on shore.

Reflected waves have the same speed and frequency as the original waves before they were reflected. However, the direction of the reflected waves is different. When waves strike an obstacle head on, the reflected waves bounce straight back in the direction they came from. When waves strike an obstacle at any other angle, they bounce back at the same angle but in a different direction. This is illustrated in **Figure** 17.3.

Refraction

Refraction is another way that waves interact with matter. **Refraction** occurs when waves bend as they enter a new medium at an angle. You can see an example of refraction in **Figure** 17.4. Light bends when it passes from air to water. The bending of the light causes the pencil to appear broken.

Why do waves bend as they enter a new medium? Waves usually travel at different speeds in different media. For example, light travels more slowly in water than air. This causes it to refract when it passes from air to water.

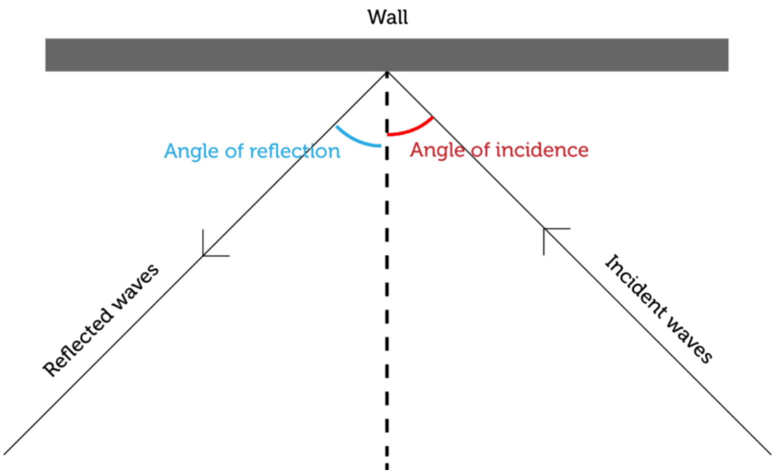

FIGURE 17.3
Waves strike a wall at an angle, called the angle of incidence. The waves are reflected at the same angle, called the angle of reflection, but in a different direction. Both angles are measured relative to a line that is perpendicular to the wall.

FIGURE 17.4
This pencil looks broken where it enters the water because of refraction of light waves.

Diffraction

Did you ever notice that when you're walking down a street, you can hear sounds around the corners of buildings? **Figure** 17.5 shows why this happens. As you can see from the figure, sound waves spread out and travel around obstacles. This is called **diffraction**. It also occurs when waves pass through an opening in an obstacle. All waves may be diffracted, but it is more pronounced in some types of waves than others. For example, sound waves bend around corners much more than light does. That's why you can hear but not see around corners.

For a given type of waves, such as sound waves, how much the waves diffract depends on two factors: the size of the obstacle or opening in the obstacle and the wavelength. This is illustrated in **Figure** 17.6.

- Diffraction is minor if the length of the obstacle or opening is greater than the wavelength.
- Diffraction is major if the length of the obstacle or opening is less than the wavelength.

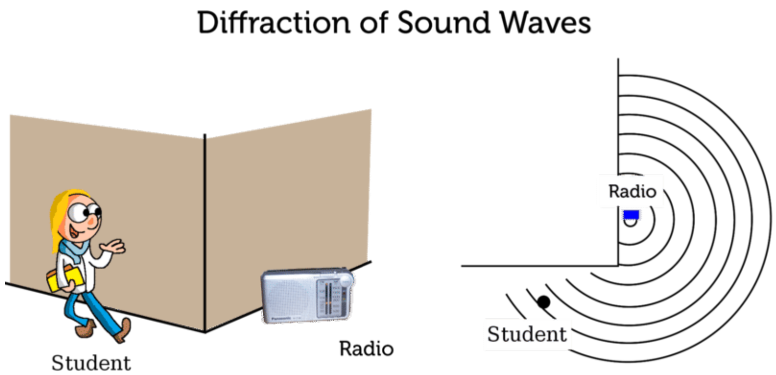

FIGURE 17.5
The person can hear the radio around the corner of the building because of the diffraction of sound waves.

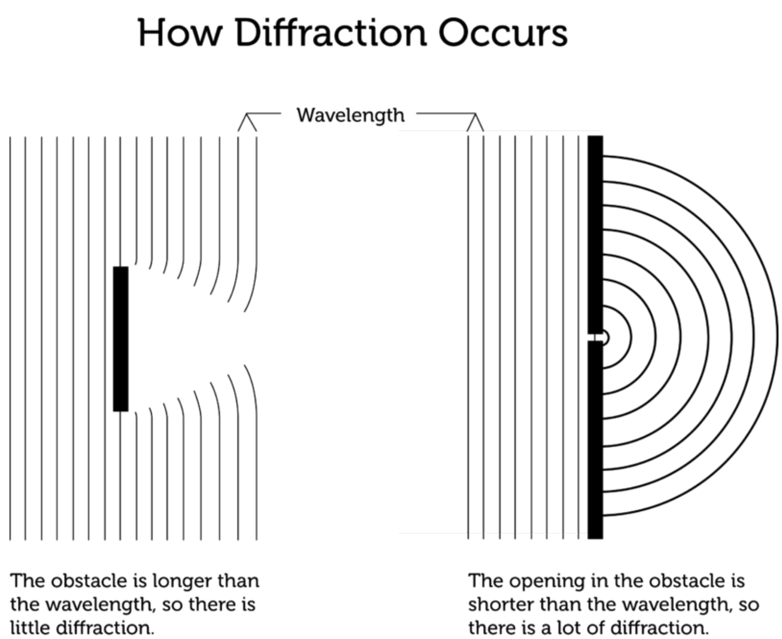

FIGURE 17.6
An obstacle or opening that is shorter than the wavelength causes greater diffraction of waves.

Wave Interference

Waves interact not only with matter in the ways described above. Waves also interact with other waves. This is called **wave interference**. Wave interference may occur when two waves that are traveling in opposite directions meet. The two waves pass through each other, and this affects their amplitude. How amplitude is affected depends on the type of interference. Interference can be constructive or destructive.

Constructive Interference

Constructive interference occurs when the crests of one wave overlap the crests of the other wave. This is illustrated in **Figure** 17.7. As the waves pass through each other, the crests combine to produce a wave with greater amplitude. You can see an animation of constructive interference at this URL: http://phys23p.sl.psu.edu/phys_anim/waves/embederQ1.20100.html .

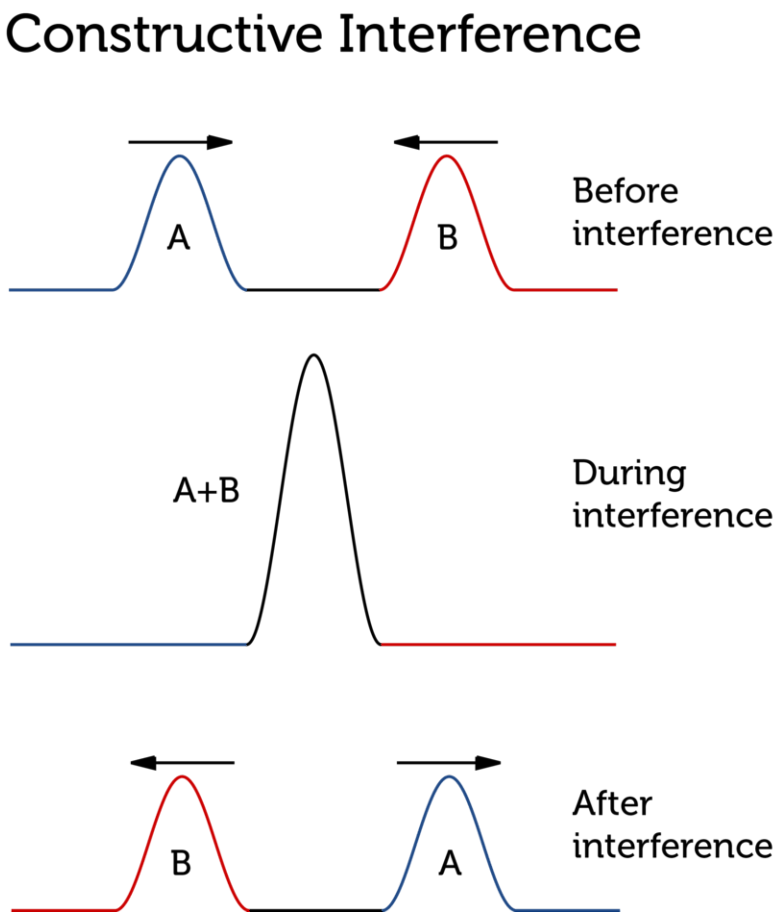

FIGURE 17.7
Constructive interference increases wave amplitude.

Destructive Interference

Destructive interference occurs when the crests of one wave overlap the troughs of another wave. This is illustrated in **Figure** 17.8. As the waves pass through each other, the crests and troughs cancel each other out to produce a wave with less amplitude. You can see an animation of destructive interference at this URL: http://phys23p.sl.psu.edu/phys_anim/waves/embederQ1.20200.html .

Standing Waves

When a wave is reflected straight back from an obstacle, the reflected wave interferes with the original wave and creates a **standing wave**. This is a wave that appears to be standing still. A standing wave occurs because of a combination of constructive and destructive interference between a wave and its reflected wave. You can see animations of standing waves at the URLs below.

- http://skullsinthestars.com/2008/05/04/classic-science-paper-otto-wieners-experiment-1890/
- http://www.physicsclassroom.com/mmedia/waves/swf.cfm

It's easy to generate a standing wave in a rope by tying one end to a fixed object and moving the other end up and down. When waves reach the fixed object, they are reflected back. The original wave and the reflected wave interfere to produce a standing wave. Try it yourself and see if the wave appears to stand still.

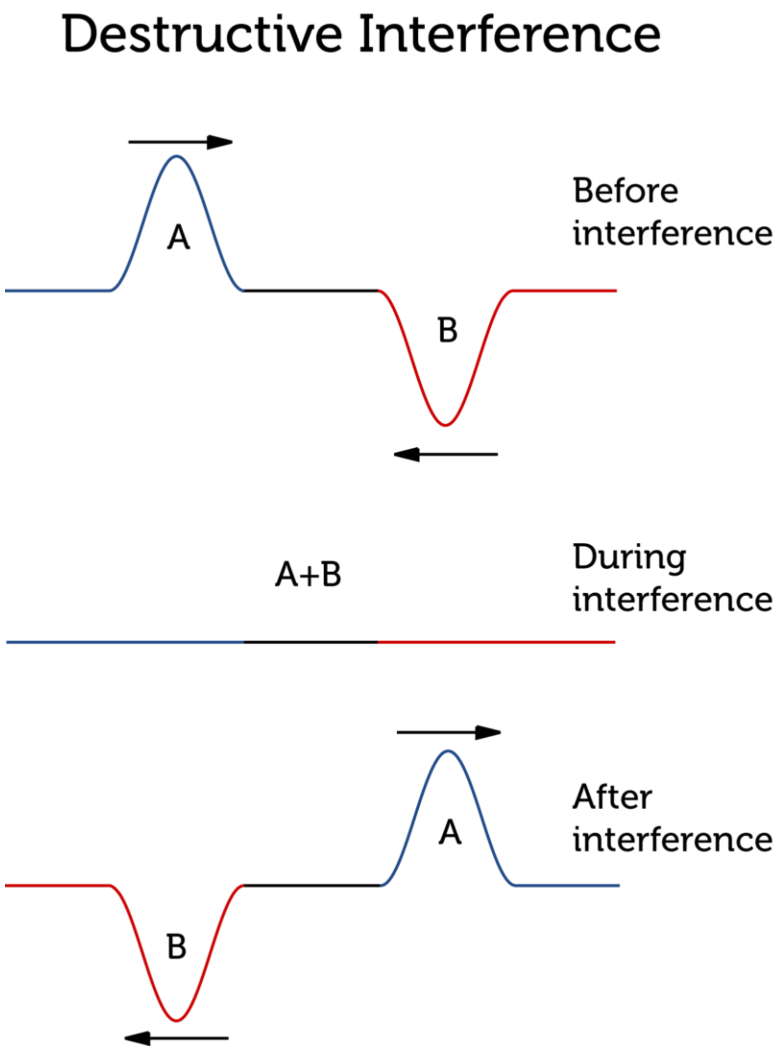

FIGURE 17.8
Destructive interference decreases wave amplitude.

Lesson Summary

- Reflection occurs when waves bounce back from a barrier they cannot pass through. Refraction occurs when waves bend as they enter a new medium at an angle. Diffraction occurs when waves spread out around an obstacle or after passing through an opening in an obstacle.
- Wave interference occurs when waves interact with other waves. Constructive interference increases wave amplitude. Destructive interference decreases wave amplitude.

Lesson Review Questions

Recall

1. What is reflection? Give an example.
2. Define constructive interference.
3. State how destructive interference affects wave amplitude.

4. What is a standing wave?

Apply Concepts

5. Create a sketch of sound waves to show why you can hear a sound on the other side of brick wall.

Think Critically

6. Explain why the pencil in **Figure** 17.4 appears broken.
7. A sound wave meets an obstacle it cannot pass through. Relate the amount of diffraction of the sound wave to the length of the obstacle and the wavelength.

Points to Consider

You were introduced to sound waves in this chapter, and you will learn more about them in the chapter "Sound."

- How do you think we hear sound waves?
- What properties of sound waves might determine how loud a sound is?

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8th Grade Life Science

Ashley Eckerty
Jessica Harwood
Douglas Wilkin, Ph.D.

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AUTHORS
Ashley Eckerty
Jessica Harwood
Douglas Wilkin, Ph.D.

EDITOR
Douglas Wilkin, Ph.D.

CONTRIBUTORS
Doris Kraus, Ph.D.
Niamh Gray-Wilson
Jean Brainard, Ph.D.
Sarah Johnson
Jane Willan
Corliss Karasov

Contents

CONCEPT 1 Protein Synthesis

Lesson Objectives

- Identify the structure and functions of RNA.
- Describe the genetic code and how to read it.
- Explain how proteins are made.
- List causes and effects of mutations.

Lesson Vocabulary

- codon
- genetic code
- mutagen
- mutation
- protein synthesis
- RNA (ribonucleic acid)
- transcription
- translation

Introduction

Blueprints, like those pictured in **Figure** 1.1, contain the instructions for building a house. Your cells also contain "blueprints." They are encoded in the DNA of your chromosomes.

DNA, RNA, and Proteins

DNA and RNA are nucleic acids. DNA stores genetic information. RNA helps build proteins. Proteins, in turn, determine the structure and function of all your cells. Proteins consist of chains of amino acids. A protein's structure and function depends on the sequence of its amino acids. Instructions for this sequence are encoded in DNA.

In eukaryotic cells, chromosomes are contained within the nucleus. But proteins are made in the cytoplasm at structures called ribosomes. How do the instructions in DNA reach the ribosomes in the cytoplasm? RNA is needed for this task.

Comparing RNA with DNA

RNA stands for ribonucleic acid. RNA is smaller than DNA. It can squeeze through pores in the membrane that encloses the nucleus. It copies instructions in DNA and carries them to a ribosome in the cytoplasm. Then it helps build the protein.

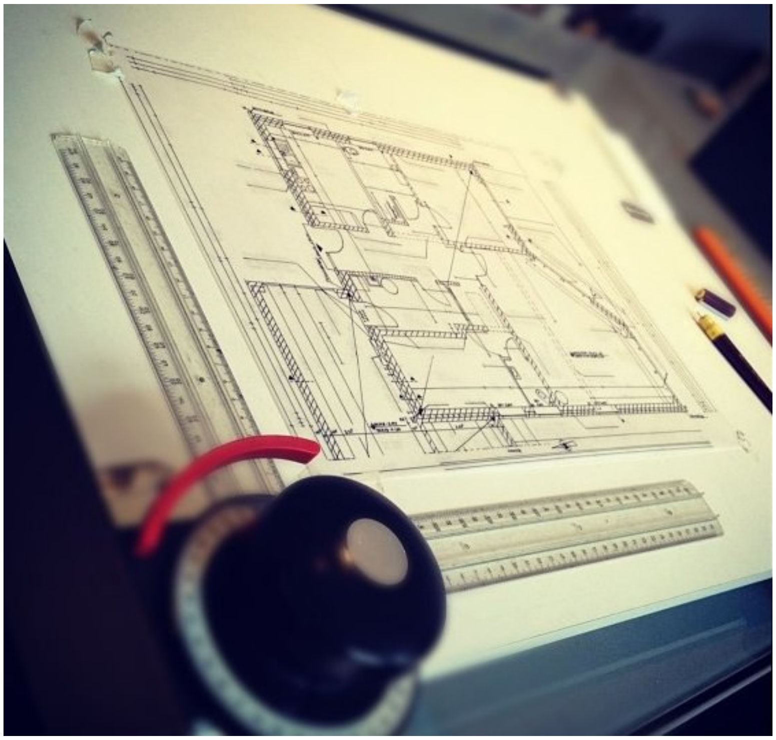


FIGURE 1.1
Blueprints for a house

RNA is not only smaller than DNA. It differs from DNA in other ways as well. It consists of one nucleotide chain rather than two chains as in DNA. It also contains the nitrogen base uracil (U) instead of thymine (T). In addition, it contains the sugar ribose instead of deoxyribose. You can see these differences in **Figure** 1.2.

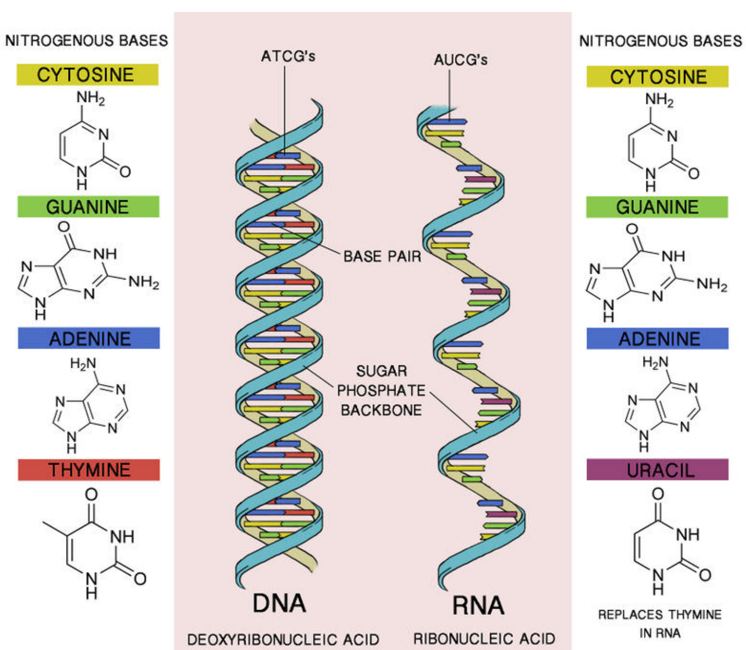


FIGURE 1.2
Comparison of RNA and DNA

Types of RNA

There are three different types of RNA. All three types are needed to make proteins.

- Messenger RNA (mRNA) copies genetic instructions from DNA in the nucleus. Then it carries the instructions to a ribosome in the cytoplasm.
- Ribosomal RNA (rRNA) helps form a ribosome. This is where the protein is made.
- Transfer RNA (tRNA) brings amino acids to the ribosome. The amino acids are then joined together to make the protein.

The Genetic Code

How is the information for making proteins encoded in DNA? The answer is the genetic code. The genetic code is based on the sequence of nitrogen bases in DNA. The four bases make up the "letters" of the code. Groups of three bases each make up code "words." These three-letter code words are called codons. Each codon stands for one amino acid or else for a start or stop signal.

There are 20 amino acids that make up proteins. With three bases per codon, there are 64 possible codons. This is more than enough to code for the 20 amino acids plus start and stop signals. You can see how to translate the genetic code in **Figure** 1.3. Start at the center of the chart for the first base of each three-base codon. Then work your way out from the center for the second and third bases.

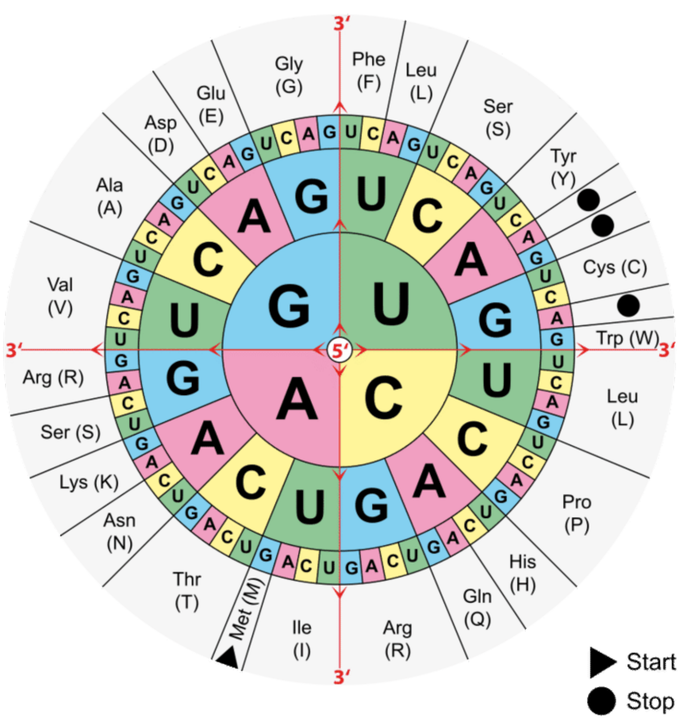


FIGURE 1.3
Translating the genetic code

Find the codon AUG in **Figure** 1.3. It codes for the amino acid methionine. It also codes for the start signal. After an AUG start codon, the next three letters are read as the second codon. The next three letters after that are read as the third codon, and so on. You can see how this works in **Figure** 1.4. The figure shows the bases in a molecule of

RNA. The codons are read in sequence until a stop codon is reached. UAG, UGA, and UAA are all stop codons. They don't code for any amino acids.

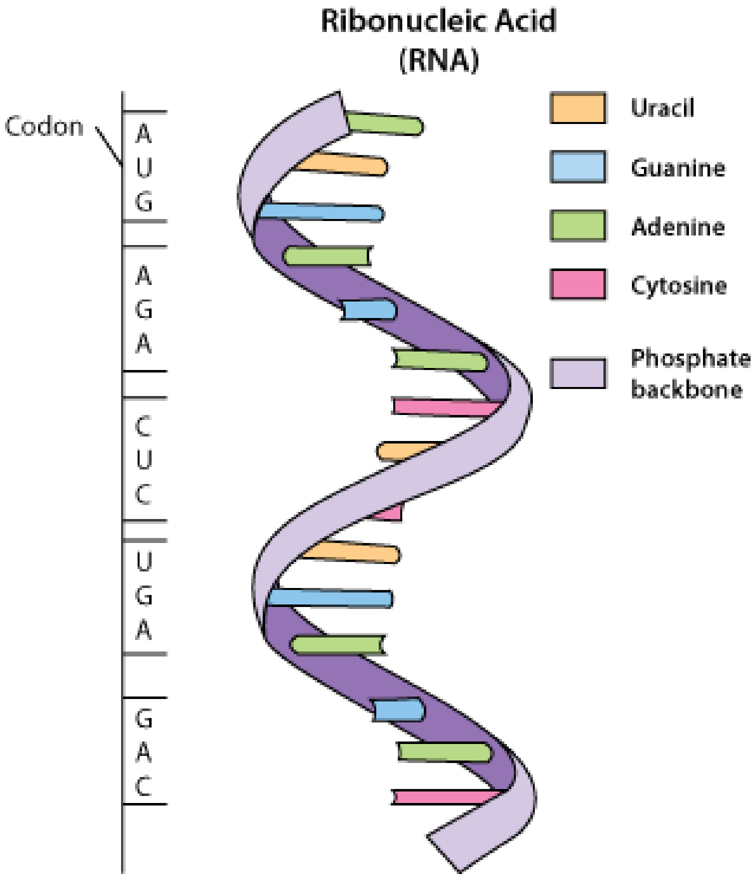


FIGURE 1.4
How the genetic code is read

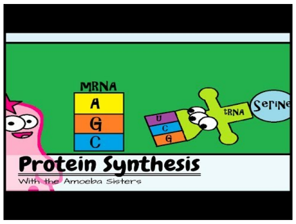
Characteristics of the Genetic Code

The genetic code has three other important characteristics.

- The genetic code is the same in all living things. This shows that all organisms are related by descent from a common ancestor.
- Each codon codes for just one amino acid (or start or stop). This is necessary so the correct amino acid is always selected.
- Most amino acids are encoded by more than one codon. This is helpful. It reduces the risk of the wrong amino acid being selected if there is a mistake in the code.

Protein Synthesis

The process in which proteins are made is called protein synthesis. It occurs in two main steps. The steps are transcription and translation. Watch this video for a good introduction to both steps of protein synthesis: http://www.youtube.com/watch?v=h5mJbP23Buo .



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Transcription: DNA $\rightarrow$ RNA

Transcription is the first step in protein synthesis. It takes place in the nucleus. During transcription, a strand of DNA is copied to make a strand of mRNA. How does this happen? It occurs by the following steps, as shown in **Figure** 1.5.

1. An enzyme binds to the DNA. It signals the DNA to unwind.
2. After the DNA unwinds, the enzyme can read the bases in one of the DNA strands.
3. Using this strand of DNA as a template, nucleotides are joined together to make a complementary strand of mRNA. The mRNA contains bases that are complementary to the bases in the DNA strand.

FIGURE 1.5

Transcription step of protein synthesis

Translation is the second step in protein synthesis. It is shown in **Figure** 1.6. Translation takes place at a ribosome in the cytoplasm. During translation, the genetic code in mRNA is read to make a protein. Here's how it works:

1. The molecule of mRNA leaves the nucleus and moves to a ribosome.
2. The ribosome consists of rRNA and proteins. It reads the sequence of codons in mRNA.
3. Molecules of tRNA bring amino acids to the ribosome in the correct sequence.
4. At the ribosome, the amino acids are joined together to form a chain of amino acids.
5. The chain of amino acids keeps growing until a stop codon is reached. Then the chain is released from the ribosome.

Causes of Mutations

Mutations have many possible causes. Some mutations occur when a mistake is made during DNA replication or transcription. Other mutations occur because of environmental factors. Anything in the environment that causes a

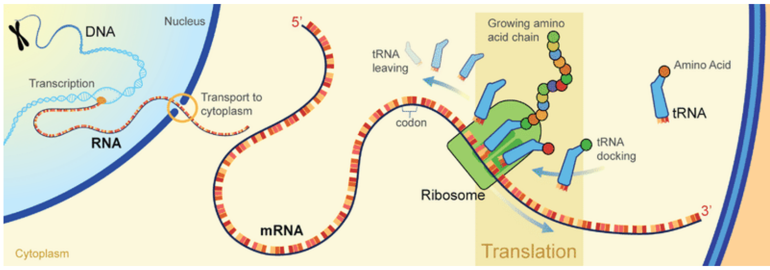

FIGURE 1.6
Translation step of protein synthesis

mutation is known as a **mutagen**. Examples of mutagens are shown in **Figure** 1.7. They include ultraviolet rays in sunlight, chemicals in cigarette smoke, and certain viruses and bacteria.

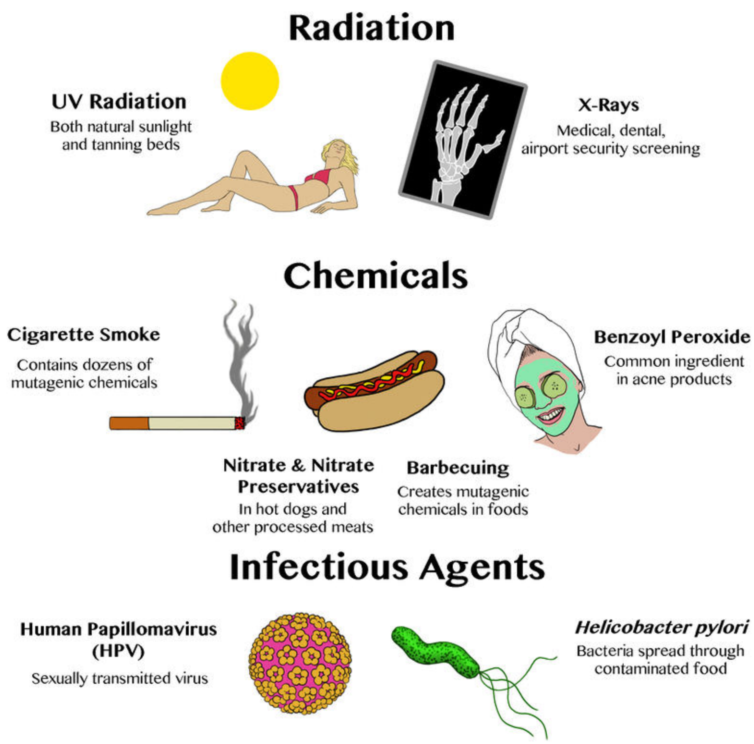

FIGURE 1.7
Examples of mutagens

Effects of Mutations

Many mutations have no effect on the proteins they encode. These mutations are considered neutral. Occasionally, a mutation may make a protein even better than it was before. Or the protein might help the organism adapt to a new environment. These mutations are considered beneficial. An example is a mutation that helps bacteria resist antibiotics. Bacteria with the mutation increase in numbers, so the mutation becomes more common. Other mutations are harmful. They may even be deadly. Harmful mutations often result in a protein that no longer can do its job. Some harmful mutations cause cancer or other genetic disorders.

Mutations also vary in their effects depending on whether they occur in gametes or in other cells of the body.

- Mutations that occur in gametes can be passed on to offspring. An offspring that inherits a mutation in a gamete will have the mutation in all of its cells.

- Mutations that occur in body cells cannot be passed on to offspring. They are confined to just one cell and its daughter cells. These mutations may have little effect on an organism.

Types of Mutations

The effect of a mutation is likely to depend as well on the type of mutation that occurs.

- A mutation that changes all or a large part of a chromosome is called a chromosomal mutation. This type of mutation tends to be very serious. Sometimes chromosomes are missing or extra copies are present. An example is the mutation that causes Down syndrome. In this case, there is an extra copy of one of the chromosomes.
- Deleting or inserting a nitrogen base causes a frameshift mutation. All of the codons following the mutation are misread. This may be disastrous. To see why, consider this English-language analogy. Take the sentence "The big dog ate the red cat." If the second letter of "big" is deleted, then the sentence becomes: "The bgd oga tet her edc at." Deleting a single letter makes the rest of the sentence impossible to read.
- Some mutations change just one or a few bases in DNA. A change in just one base is called a point mutation. **Table** 1.1 compares different types of point mutations and their effects.

TABLE 1.1: Types of point mutations

Type	Description	Example	Effect
Silent	mutated codon codes for the same amino acid	CAA (glutamine) → CAG (glutamine)	none
Missense	mutated codon codes for a different amino acid	CAA (glutamine) → CCA (proline)	variable
Nonsense	mutated codon is a premature stop codon	CAA (glutamine) → UAA (stop)	serious

Lesson Summary

- DNA encodes instructions for proteins. RNA copies the genetic code in DNA and carries it to a ribosome. There, amino acids are joined together in the correct sequence to make a protein.
- The genetic code is based on the sequence of nitrogen bases in DNA. A code "word," or codon, consists of three bases. Each codon codes for one amino acid or for a *Protein synthesis is the process in which proteins are made. In the first step, called transcription, the genetic code in DNA is copied by RNA. In the second step, called translation, the genetic code in RNA is read to make a protein.
- A mutation is a change in the base sequence of DNA or RNA. Environmental causes of mutations are called mutagens. The effects of a mutation depend on the type of mutation and whether it occurs in a gamete or body cell.

Lesson Review Questions

Recall

1. What are three types of RNA? What role does each type play in protein synthesis?

2. Describe the genetic code and its characteristics.
3. Give an overview of the transcription step of protein synthesis. Where does it take place?
4. What is a mutation? What are some causes of mutations?

Apply Concepts

5. Use Figure 1.3 to translate the following sequence of RNA bases into a chain of amino acids: AUGUACCC-CACAGACUAA.

Think Critically

6. Compare and contrast RNA and DNA.
7. Explain what happens during the translation step of protein synthesis.
8. Why is a single base insertion or deletion likely to drastically change how the rest of the genetic code is read?

Points to Consider

Offspring generally resemble their parents. This is true even when the offspring are not genetically identical to the parents.

- Can you apply your knowledge of reproduction and protein synthesis to explain why offspring and parents have similar traits?

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4. Zachary Wilson. Codons in RNA . CC BY-NC 3.0
5. National Human Genome Research Institute. Transcription step of protein synthesis . Public Domain
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7. Laura Guerin. Examples of mutagens . CC BY-NC 3.0

Concept 2 Mutations

- Define mutation.
- Distinguish between point mutations and chromosomal mutations.
- Explain the outcome from a frameshift mutation.
- Describe the types of chromosomal mutations.
- Explain how mutations occur.

Would a mutation make you a superhero?

In the comic books, a mutation can give a person superpowers. Do you think this really happens? In real life, a mutation can be beneficial, or it can harm an organism. For example, beneficial mutations lead to evolution, and harmful mutations can lead to diseases like cancer. A mutation, however, is not going to turn you into a superhero!

Mutations

The process of DNA replication is not always 100% accurate. Sometimes the wrong base is inserted in the new strand of DNA. This wrong base could become permanent. A permanent change in the sequence of DNA is known as a **mutation**. Small changes in the DNA sequence are usually **point mutations**, which is a change in a single nucleotide. Once DNA has a mutation, that mutation will be copied each time the DNA replicates. After cell division, each resulting cell will carry the mutation.

A mutation may have no effect. However, sometimes a mutation can cause a protein to be made incorrectly. A defect in the protein can affect how well the protein works, or whether it works at all. Usually the loss of a protein function is detrimental to the organism.

In rare circumstances, though, the mutation can be beneficial. Mutations are a mechanism for how species evolve. For example, suppose a mutation in an animal's DNA causes the loss of an enzyme that makes a dark pigment in the animal's skin. If the population of animals has moved to a light colored environment, the animals with the mutant gene would have a lighter skin color and be better camouflaged. So in this case, the mutation is beneficial.

Point Mutations

If a single base is deleted (called a deletion, which is also a point mutation), there can be huge effects on the organism, because this may cause a **frameshift mutation**. Remember that the bases in the mRNA are read in groups of three by the tRNA. If the reading frame is off by even one base, the resulting sequence will consist of an entirely different set of codons.

The reading of an mRNA is like reading three-letter words of a sentence. Imagine the sentence: "The big dog ate the red cat." If you take out the second letter from "big," the frame will be shifted so now it will read: "The bgd oga tet her edc at." One single deletion makes the whole "sentence" impossible to read. A point mutation that adds a base (known as an insertion) would also result in a frameshift.

Chromosomal Mutations

Mutations may also occur in chromosomes (**Figure** 2.1). These mutations are going to be fairly large mutations, possible affecting many genes. Possible types of mutations in chromosomes include:

1. Deletion: When a segment of DNA is lost, so there is a missing segment in the chromosome. These usually result in many genes missing from the chromosome.
2. Duplication: When a segment of DNA is repeated, creating a longer chromosome. These usually result in multiple copies of genes in the chromosome.
3. Inversion: When a segment of DNA is flipped and then reattached to the same chromosome.
4. Insertion: When a segment of DNA from one chromosome is added to another, unrelated chromosome.
5. Translocation: When two segments from different chromosomes change positions.

Causes of Mutations

Many mutations are not caused by errors in replication. Mutations can happen spontaneously, and they can be caused by **mutagens** in the environment. Some chemicals, such as those found in tobacco smoke, can be mutagens. Sometimes mutagens can also cause cancer. Tobacco smoke, for example, is often linked to lung cancer.

Summary

- A mutation is a permanent change in the sequence of bases in DNA.
- Mutations occur in the DNA through deletion, duplication, inversion, insertion, and translocation within the chromosome.
- Mutations can occur due to errors during DNA replication or by mutagens in the environment.

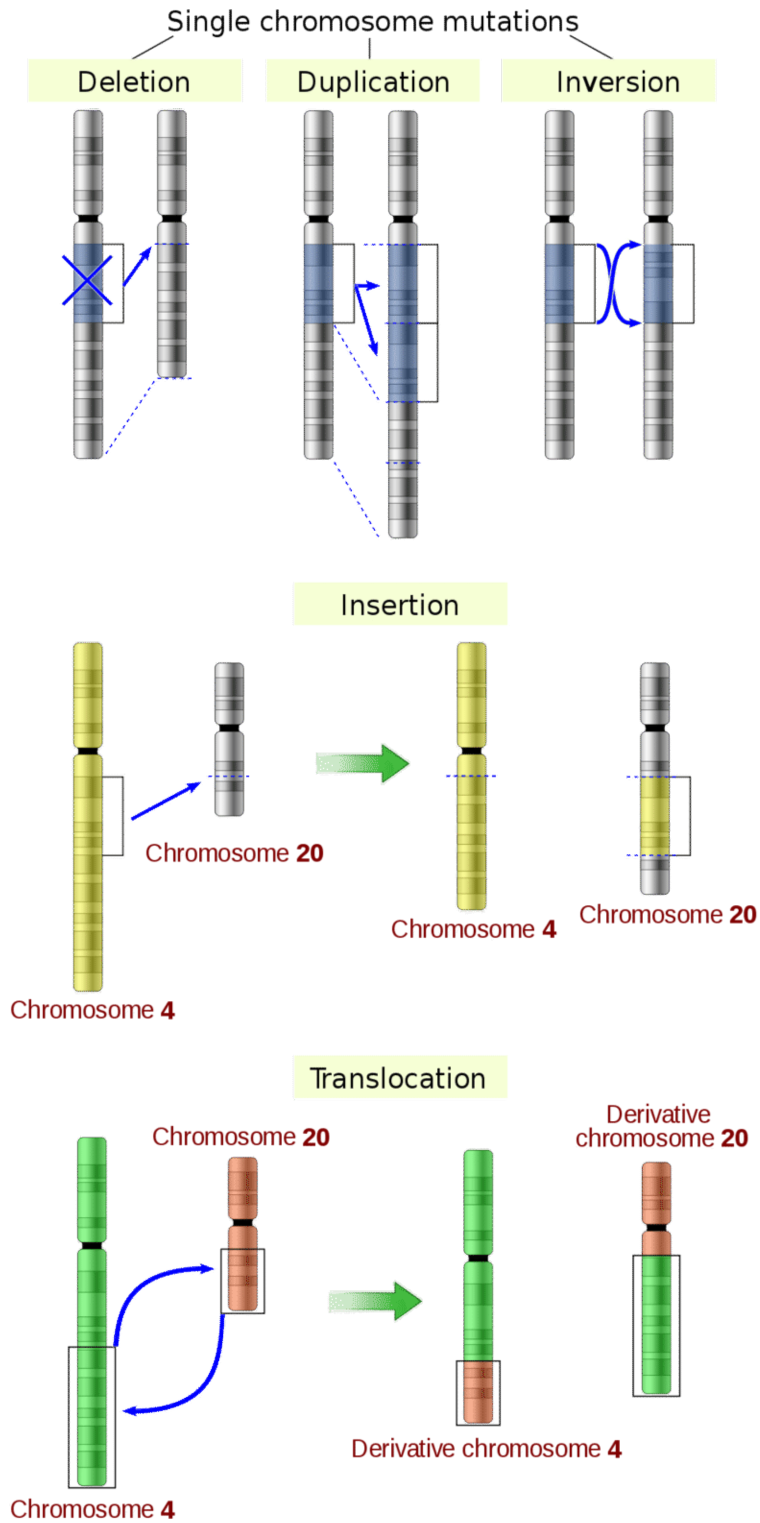

FIGURE 2.1
Mutations can arise in DNA through deletion, duplication, inversion, insertion, and translocation within the chromosome.

Explore More

Use the resources below to answer the questions that follow.

Explore More I

- **Types of Mutations - Understanding Evolution** at http://evolution.berkeley.edu/evolibrary/article/mutations_03

1. What is an example of a genetic disorder caused by a substitution mutation?
2. How can a substitution mutation change a protein?
3. Explain a frameshift mutation.
4. What can cause a frameshift mutation?

Explore More II

- **Gene Regulation** at http://www.teachersdomain.org/asset/novat10_int_evodevo/

Go to this link to see how mutations affect gene regulation. Make sure you make more than one animal and see the effects of more than one mutation occurring at a time.

1. How do mutations in a part of DNA not associated with a gene generally affect the expression of that gene?
2. What do transcription factor proteins do in an organism?

Review

1. Are mutations typically beneficial to the organism?
2. What can cause DNA to mutate?
3. What is a frameshift mutation?
4. Describe two types of chromosomal mutations.

References

1. Yassine Mrabet. Mutations in chromosomes include deletion, duplication, inversion, insertion, and translocation . Public Domain

CONCEPT 3 Darwin's Theory of Evolution

Lesson Objectives

- State Darwin's theory of evolution by natural selection.
- Describe Darwin's voyage on the Beagle.
- Identify other influences on Darwin.
- Explain how Darwin arrived at his theory.

Lesson Vocabulary

- Darwin
- evolution
- Galápagos Islands
- natural selection
- theory of evolution by natural selection

Introduction

Charles Darwin is one of the best-known scientists of all time. **Figure** 3.1 shows Darwin as a young man in the 1830s. Why is Darwin so famous? His theory of evolution was a major leap forward in human understanding. It explains and unifies all of life science.

Darwin's Theory in a Nutshell

Darwin's **theory of evolution by natural selection** contains two major ideas:

- One idea is that evolution happens. **Evolution** is a change in the inherited traits of organisms over time. Living things have changed as descendants diverged from common ancestors in the past.
- The other idea is that evolution occurs by natural selection. **Natural selection** is the process in which living things with beneficial traits produce more offspring. As a result, their traits increase in the population over time.

Voyage of the

How did Darwin come up with the theory of evolution by natural selection? A major influence was an amazing scientific expedition he took on a ship called the *Beagle*. Darwin was only 22 years old when the ship set sail. The

FIGURE 3.1
Charles Darwin as a young man in the 1830s

trip lasted for almost five years and circled the globe. **Figure** 3.2 shows the route the ship took. It set off from Plymouth, England in 1831. It wouldn't return to Plymouth until 1836. Imagine setting out for such an incredible adventure at age 22, and you'll understand why the trip had such a big influence on Darwin.

Darwin's job on the voyage was to observe and collect specimens whenever the ship went ashore. This included plants, animals, rocks, and fossils. Darwin loved nature, so the job was ideal for him. During the long voyage, he made many observations that helped him form his theory of evolution. Some of his most important observations were made on the Galápagos Islands.

The 16 **Galápagos Islands** lie 966 kilometers (about 600 miles) off the west coast of South America. (You can see their location on the map in Figure 7.2.) Some of the animals Darwin observed on the islands were giant tortoises and birds called finches. Watch this video for an excellent introduction to Darwin, his voyage, and the Galápagos:

http://www.sciencechannel.com/video-topics/earth-science/galapagos-beyond-darwin-charles-darwin.htm

Giant Tortoises

The Galápagos Islands are still famous for their giant tortoises. These gentle giants are found almost nowhere else in the world. Darwin was amazed by their huge size. He was also struck by the variety of shapes of their shells. You can see two examples in **Figure** 3.3. Each island had tortoises with a different shell shape. The local people even

FIGURE 3.2
Route of the Beagle

could tell which island a tortoise came from based on the shape of its shell.

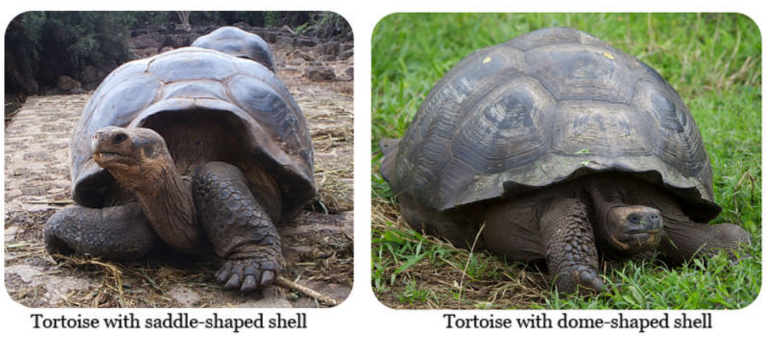

FIGURE 3.3
Giant tortoises on the Galápagos Islands varied in shell shape, depending on which island they inhabited.

Darwin wondered how each island came to have its own type of tortoise. He found out that tortoises with dome-shaped shells lived on islands where the plants they ate were abundant and easy to reach. Tortoises with saddle-shaped shells, in contrast, lived on islands that were drier. On those islands, food was often scarce. The saddle shape of their shells allowed tortoises on those islands to reach up and graze on vegetation high above them. This made sense, but how had it happened?

Darwin's Finches

Darwin also observed that each of the Galápagos Islands had its own species of finches. The finches on different islands had beaks that differed in size and shape. You can see four examples in **Figure** 3.4.

Darwin investigated further. He found that the different beaks seemed to suit the birds for the food available on their island. For example, finch number 1 in **Figure** 3.4 used its large, strong beak to crack open and eat big, tough seeds. Finch number 4 had a long, pointed beak that was ideal for eating insects. This seemed reasonable, but how had it come about?

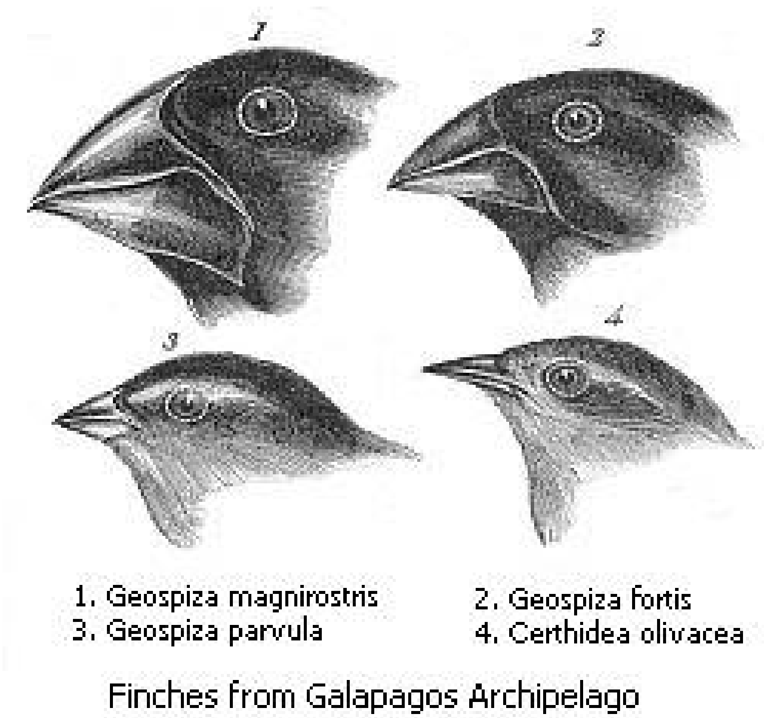

FIGURE 3.4
Variation in beak size and shape in Galápagos finches

More Influences on Darwin

Besides his observations on the Beagle, other influences helped Darwin develop his theory of evolution by natural selection. These included his knowledge of plant and animal breeding and the ideas of other scientists.

Plant and Animal Breeding

Darwin knew that people could breed plants and animals to have useful traits. By selecting which individuals were allowed to reproduce, they could change an organism's traits over several generations. Darwin called this type of change in organisms artificial selection. You can see an example in **Figure** 3.5. Keeping and breeding pigeons was a popular hobby in Darwin's day. Both types of pigeons in the bottom row were bred from the common rock pigeon at the top of the figure.

Other Scientists

There were three other scientists in particular that influenced Darwin. Their names are Lamarck, Lyell, and Malthus. All three were somewhat older than Darwin, and he was familiar with their writings.

- Jean Baptiste Lamarck was a French naturalist. He was one of the first scientists to propose that species change over time. In other words, he proposed that evolution occurs. Lamarck also tried to explain how it happens, but he got that part wrong. Lamarck thought that the traits an organism developed during its life time could be passed on to its offspring. He called this the inheritance of acquired characteristics.
- Charles Lyell was an English geologist. He wrote a famous book called *Principles of Geology*. Darwin took the book with him on the *Beagle*. Lyell argued that geological processes such as erosion change Earth's surface

FIGURE 3.5
Variation in pigeons as a result of artificial selection

very gradually. To account for all the changes that had occurred on the planet, Earth must be a lot older than most people believed.

- Thomas Malthus was an English economist. He wrote a popular essay called "On Population." He argued that human populations have the potential to grow faster than the resources they need. When populations get too big, disease and famine occur. These calamities control population size by killing off the weakest people.

Putting It All Together

Darwin spent many years thinking about his own observations and the writings of Lamarck, Lyell, and Malthus. What did it all mean? How did it all fit together? The answer, of course, is the theory of evolution by natural selection.

Evolution of Darwin's Theory

Here's how Darwin thought through his theory:

- Like Lamarck, Darwin assumed that species evolve, or change their traits over time. Fossils Darwin found on his voyage helped convince him that evolution occurs.
- From Lyell, Darwin realized that Earth is very old. This meant that living things had a long time in which to evolve. There was enough time to produce the great diversity of living things that Darwin had observed.
- From Malthus, Darwin saw that populations could grow faster than their resources. This "overproduction of offspring" led to a "struggle for existence," in Darwin's words. In this struggle, only the "fittest" survive.

- From Darwin's knowledge of artificial selection, he knew how traits can change over time. Breeders artificially select the traits that they find beneficial. These traits become more common over many generations.
- In nature, Darwin reasoned, individuals with certain traits might be more likely to survive the "struggle for existence" and have offspring. Their traits would become more common over time. In this case, nature selects the traits that are beneficial. That's why Darwin called this process natural selection. Darwin used the word fitness to refer to the ability to reproduce and pass traits to the next generation

Darwin's Book

Darwin finally published his theory of evolution by natural selection in 1859. He presented it in his book *On the Origin of Species*. The book is very detailed and includes a lot of evidence for the theory. Darwin's book changed science forever. The theory of evolution by natural selection became the unifying theory of all life science.

Lesson Summary

- Darwin proposed the theory of evolution by natural selection. Evolution is a change in the inherited traits of organisms over time. Natural selection is the process by which living things with beneficial traits produce more offspring, so their traits become more common over time.
- During Darwin's voyage on the *Beagle*, he made many observations that helped him form his theory of evolution. Some of his most important observations were made on the Galápagos Islands. They included observations of giant tortoises and finches.
- Darwin was also influenced by his knowledge of artificial selection and the ideas of Lamarck, Lyell, and Malthus.
- Darwin spent many years working on a book about his theory of evolution by natural selection. He finally published *On the Origin of Species* in 1859.

Lesson Review Questions

Recall

1. State Darwin's theory of evolution by natural selection.
2. Identify three scientists who influenced Darwin and their contributions to his theory.

Apply Concepts

3. Apply the concept of artificial selection to explain how new dog breeds come about.

Think Critically

4. Explain how Darwin's observations on the Galápagos Islands helped him form his theory of evolution by natural selection.

Points to Consider

On his voyage, Darwin saw fossils of ancient organisms. They showed him that living things had changed over time.

- What are fossils?
- How do fossils form?

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4. John Gould. Variation in beak size and shape in Galápagos finches . Public Domain
5. Common rock pigeon: Image copyright Marketa Mark, 2014; Carrier pigeon: Image copyright guentermanaus, 2014; Fantail pigeon: Image copyright Ulrike Haberkorn, 2014. Variation in pigeons as a result of artificial selection . Used under licenses from Shutterstock.com

Concept 4 Evidence for Evolution

Lesson Objectives

- Explain what fossils are, how they form, and how they are dated.
- Identify evidence for evolution provided by living organisms.
- Describe recent evolution by natural selection in Darwin's finches.

Lesson Vocabulary

- absolute dating
- fossil
- molecular clock
- paleontologist
- relative dating
- vestigial structure

Introduction

In his book *On the Origin of Species*, Darwin included a lot of evidence for evolution. Since then, much more evidence has accumulated. The evidence includes millions of fossils, like the one in **Figure** 4.1. It also includes detailed knowledge of living organisms.

What Are Fossils?

Fossils are the preserved remains or traces of organisms that lived during earlier ages. Remains that become fossils are generally the hard parts of organisms—mainly bones, teeth, or shells. Traces include any evidence of life, such as footprints like the dinosaur footprint in **Figure** 4.2. Fossils are like a window into the past. They provide direct evidence of what life was like long ago. A scientist who studies fossils to learn about the evolution of living things is called a **paleontologist**.

How Fossils Form

The soft parts of organisms almost always decompose quickly after death. That's why most fossils consist of hard parts such as bones. It's rare even for hard parts to remain intact long enough to become fossils. Fossils form when water seeps through the remains and deposits minerals in them. The remains literally turn to stone. Remains are more likely to form fossils if they are covered quickly by sediments.

Once in a while, remains are preserved almost unchanged. For example, they may be frozen in glaciers. Or they may be trapped in tree resin that hardens to form amber. That's what happened to the wasp in **Figure** 4.3. The wasp lived about 20 million years ago, but even its fragile wings have been preserved by the amber.

FIGURE 4.1
Most of what we know about dinosaurs is based on fossils such as this one.

How Fossils Are Dated

Fossils are useful for reconstructing the past only if they can be dated. Scientists need to determine when the organisms lived who left behind the fossils. Fossils can be dated in two different ways: absolute dating and relative dating.

- **Absolute dating** determines about how long ago a fossil organism lived. This gives the fossil an approximate age in years. Absolute dating is often based on the amount of carbon-14 or other radioactive element that remains in a fossil. You can learn how carbon-14 dating works by watching this short video:

http://www.scientificamerican.com/video/how-does-radiocarbon-dating-work-i2012-11-30/

- **Relative dating** determines which of two fossils is older or younger than the other but not their age in years. Relative dating is based on the positions of fossils in rock layers. Lower rock layers were laid down earlier, so they are assumed to contain older fossils. This is illustrated in **Figure** 4.4.

FIGURE 4.2
Fossil footprint of a three-toed dinosaur

FIGURE 4.3
Wasp encased in amber

Using Fossils to Understand Evolution

The evolution of whales is a good example of how fossils can help us understand evolution. Scientists have long known that mammals first evolved on land about 200 million years ago. It's been a mystery, however, how whales evolved. Whales are mammals that live completely in the water. Did they evolve from earlier land mammals? Or did they evolve from animals that already lived in the water?

Starting in the late 1970s, a growing number of fossils have allowed scientists to piece together the story of whale evolution. The fossils represent ancient, whale-like animals. They show that an ancient land mammal made its way back to the sea more than 50 million years ago. It became the ancestor of modern whales. In doing so, it lost its legs and became adapted to life in the water.

In **Figure** 4.5 you can see an artist's rendition of such a whale ancestor. It had legs and could walk on land, but it was also a good swimmer. Watch this short video to learn more about the amazing story of whale evolution based

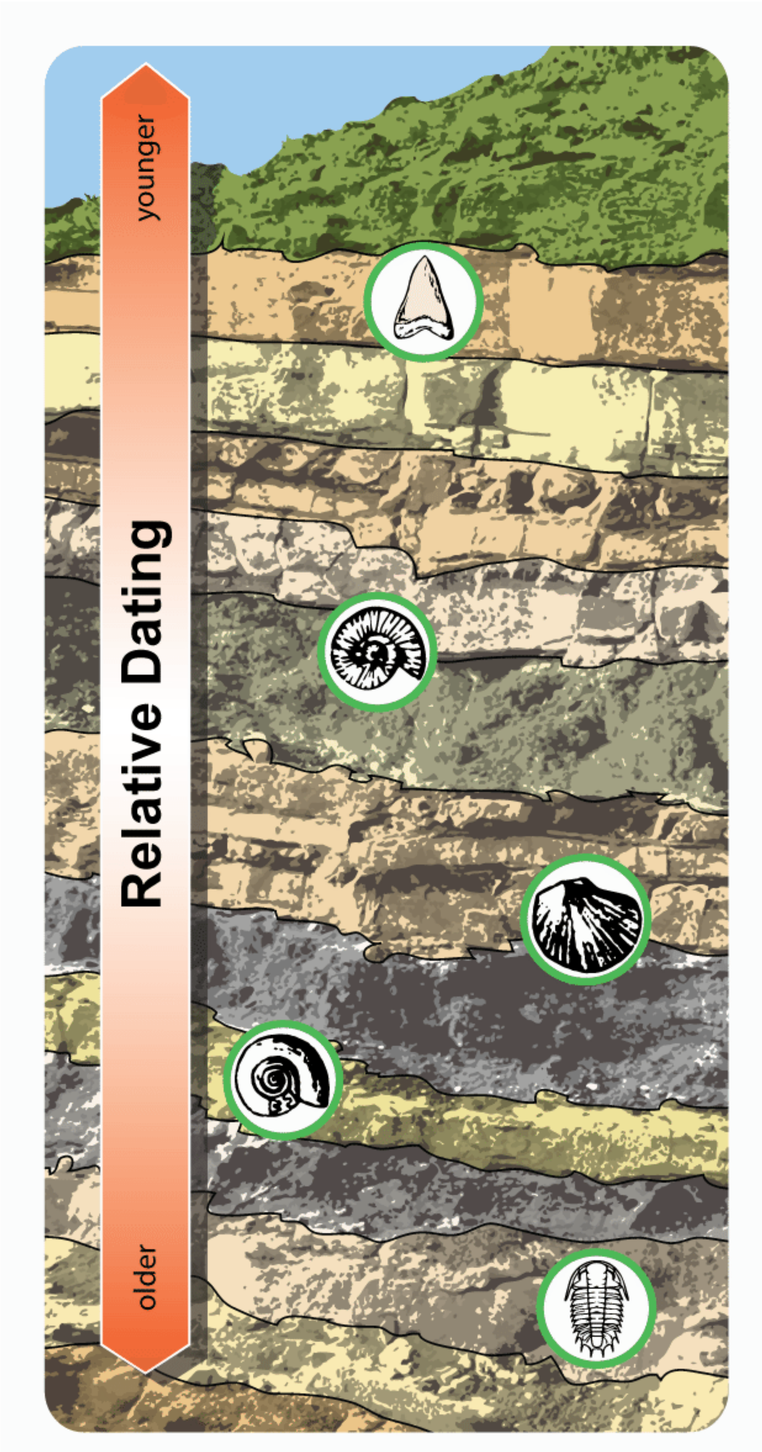

FIGURE 4.4
Fossils found in lower rock layers are generally older than fossils found in rock layers closer to the surface.

on the fossils:

http://www.pbs.org/wgbh/evolution/library/03/4/l_034_05.html

FIGURE 4.5
This whale ancestor, called *Ambulocetus*, lived about 48 million years ago.

Evidence from Living Organisms

Scientists have learned a lot about evolution by comparing living organisms. They have compared body parts, embryos, and molecules such as DNA and proteins.

Comparing Body Parts

Comparing body parts of different species may reveal evidence for evolution. For example, all mammals have front limbs that look quite different and are used for different purposes. Bats use their front limbs to fly, whales use them to swim, and cats use them to run and climb. However, the front limbs of all three animals—as well as humans—have the same basic underlying bone structure. You can see this in **Figure** 4.6. The similar bones provide evidence that all four animals evolved from a common ancestor.

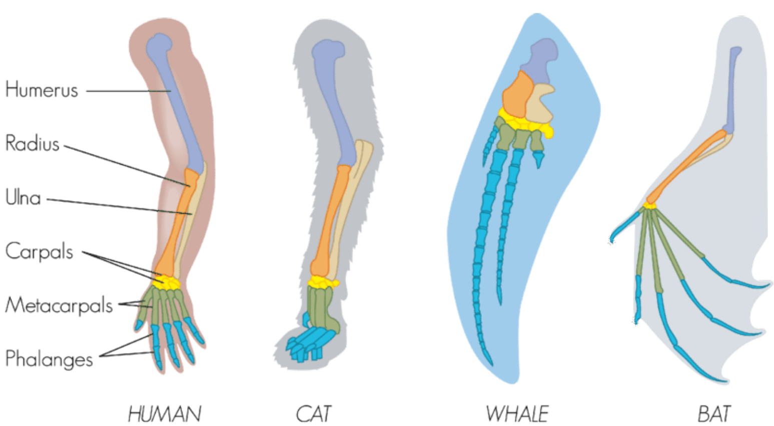

FIGURE 4.6
Front limb bones of different mammals

Vestigial Structures

Some of the most interesting evidence for evolution comes from **vestigial structures**. These are body parts that are no longer used but are still present in modern organisms. Examples in humans include tail bones and the appendix.

- Human beings obviously don't have tails, but our ancestors did. We still have bones at the base of our spine that form a tail in other, related animals, such as monkeys.

- The appendix is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. If your appendix becomes infected, a surgeon can remove it. You won't miss it because it no longer has any purpose in the human body.

Comparing Embryos

An embryo is an organism in the earliest stages of development. Embryos of different species may look quite similar, even when the adult forms look very different. Look at the drawings of embryos in **Figure** 4.7. They represent very early life stages of a chicken, turtle, pig, and human being. The embryos look so similar that it's hard to tell them apart. Such similarities provide evidence that all four types of animals are related. They help document that evolution has occurred.

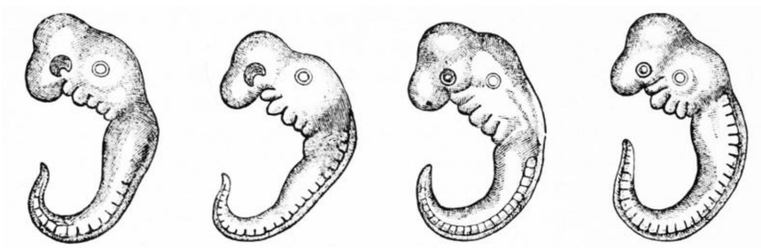

FIGURE 4.7
From left to right, embryos of a chicken, turtle, pig, and human being

Comparing Molecules

Scientists can compare the DNA or proteins of different species. If the molecules are similar, this shows that the species are related. The more similar the molecules are, the closer the relationship is likely to be. When molecules are used in this way, they are called **molecular clocks**. This method assumes that random mutations occur at a constant rate for a given protein or segment of DNA. Over time, the mutations add up. The longer the amount of time since species diverged, the more differences there will be in their DNA or proteins.

Table 4.1 compares the DNA of four different organisms with modern human DNA. The DNA of chimpanzees is almost 99 percent the same as the DNA of modern humans. This shows that chimpanzees are very closely related to us. We are less closely related to the other organisms in the table. It's no surprise that grapes, which are plants, are less like us than the animals in the table.

TABLE 4.1: Comparing DNA sequences

Organism	Similarity with Human DNA (percent the same)
Chimpanzee	98.8
Cow	85
Chicken	65
Honeybee	44
Grape	24

Observing Evolution in Action

The best evidence for evolution comes from actually observing changes in organisms through time. In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands to do fieldwork. They wanted to re-study

Darwin's finches. They spent the next 40 years on the project. Their hard work paid off. They were able to document evolution by natural selection taking place in the finches.

A period of very low rainfall occurred while the Grants were on the islands. The drought resulted in fewer seeds for the finches to eat. Birds with smaller beaks could eat only the smaller seeds. Birds with bigger beaks were better off. They could eat seeds of all sizes. Therefore, there was more food available to them. Many of the small-beaked birds died in the drought. More of the big-beaked birds survived and reproduced. Within just a couple of years, the average beak size in the finches increased. This was clearly evolution by natural selection.

Lesson Summary

- Fossils are the preserved remains or traces of organisms that lived long ago. They form mainly when minerals in water turn remains to stone. Fossils can be dated using methods such as carbon-14 dating or their positions in rock layers.
- Scientists have learned a lot about evolution from species that are living today. They have compared body parts, vestigial organs, embryos, and molecules in different species. Species that are the most similar in these ways are generally the most closely related.
- The best evidence for evolution is seeing it in action. An example is the work of Peter and Rosemary Grant. They documented recent evolution by natural selection in Darwin's finches.

Lesson Review Questions

Recall

1. Describe how fossils usually form.
2. What are vestigial structures? Give an example.

Apply Concepts

3. Apply the molecular clock concept to the data in the table below. Explain which of the three species in the table shared the most recent common ancestor with the human species.

TABLE 4.2: Human Percent DNA

Species	Percent of DNA that is the Same as Human DNA
African gorilla	98.4
Orangutan	97
Rhesus monkey	93

4.

Think Critically

4. Compare and contrast relative and absolute dating.
5. How did scientists use fossils to solve the mystery of whale evolution?
6. Explain why Peter and Rosemary Grant were eyewitnesses to evolution.

Points to Consider

Understanding how evolution occurs requires knowledge of genetics.

- How is variation in traits within a species related to genes?
- How would you define evolution in genetic terms?

References

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2. Jon Sullivan. Fossil footprint of a three-toed dinosaur . Public Domain
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8th Grade Earth Science

Ashley Eckerty

AUTHOR
Ashley Eckerty

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Contents

CONCEPT 1

Introduction to the Solar System

Lesson Objectives

- Describe some early ideas about our solar system.
- Name the planets, and describe their motion around the Sun.
- Explain how the solar system formed.

Vocabulary

- astronomical unit
- dwarf planet
- nebula
- nuclear fusion
- planet
- solar system

Introduction

We can learn a lot about the universe and about Earth history by studying our nearest neighbors. The solar system has planets, asteroids, comets, and even a star for us to see and understand. It's a fascinating place to live!

Changing Views of the Solar System

The Sun and all the objects that are held by the Sun's gravity are known as the **solar system**. These objects all revolve around the Sun. The ancient Greeks recognized five planets. These lights in the night sky changed their position against the background of stars. They appeared to wander. In fact, the word "planet" comes from a Greek word meaning "wanderer." These objects were thought to be important, so they named them after gods from their mythology. The names for the planets Mercury, Venus, Mars, Jupiter, and Saturn came from the names of gods and a goddess.

Earth at the Center of the Universe

The ancient Greeks thought that Earth was at the center of the universe, as shown in **Figure** 1.1. The sky had a set of spheres layered on top of one another. Each object in the sky was attached to one of these spheres. The object moved around Earth as that sphere rotated. These spheres contained the Moon, the Sun, and the five planets they recognized: Mercury, Venus, Mars, Jupiter, and Saturn. An outer sphere contained all the stars. The planets appear to move much faster than the stars, so the Greeks placed them closer to Earth. Ptolemy published this model of the solar system around 150 AD.

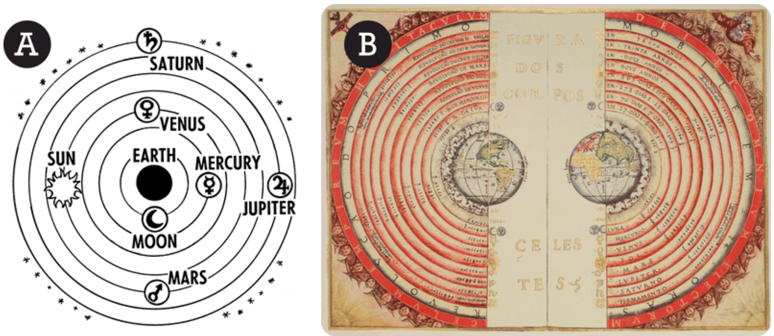

FIGURE 1.1
On left is a line art drawing of the Ptolemaic system with Earth at the center. On the right is a drawing of the Ptolemaic system from 1568 by a Portuguese astronomer.

The Sun at the Center of the Universe

About 1,500 years after Ptolemy, Copernicus proposed a startling idea. He suggested that the Sun is at the center of the universe. Copernicus developed his model because it better explained the motions of the planets. **Figure** 1.2 shows both the Earth-centered and Sun-centered models.

FIGURE 1.2
Copernicus proposed a different idea that had the Sun at the center of the universe

Copernicus did not publish his new model until his death. He knew that it was heresy to say that Earth was not the center of the universe. It wasn't until Galileo developed his telescope that people would take the Copernican model more seriously. Through his telescope, Galileo saw moons orbiting Jupiter. He proposed that this was like the planets orbiting the Sun.

Planets and Their Motions

Today we know that we have eight planets, five dwarf planets, over 165 moons, and many, many asteroids and other small objects in our solar system. We also know that the Sun is not the center of the universe. But it is the center of the solar system.

FIGURE 1.3
This artistic composition shows the eight planets, a comet, and an asteroid.

Figure 1.3 shows our solar system. The planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. **Table** 1.1 gives some data on the mass and diameter of the Sun and planets relative to Earth.

TABLE 1.1: 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

What Is (and Is Not) a Planet?

You've probably heard about Pluto. When it was discovered in 1930, Pluto was called the ninth planet. Astronomers later found out that Pluto was not like other planets. For one thing, what they were calling Pluto was not a single object. They were actually seeing Pluto and its moon, Charon. In older telescopes, they looked like one object. This one object looked big enough to be a planet. Alone, Pluto was not very big. Astronomers also discovered many objects like Pluto. They were rocky and icy and there were a whole lot of them.

Astronomers were faced with a problem. They needed to call these other objects planets. Or they needed to decide that Pluto was something else. In 2006, these scientists decided what a planet is. According to the new definition, a **planet** must:

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

If the first three are true but not the fourth, then that object is a **dwarf planet**. We now call Pluto a dwarf planet. There are other dwarf planets in the solar system. They are Eris, Ceres, Makemake and Haumea. There are many other reasons why Pluto does not fit with the other planets in our solar system.

The Size and Shape of Orbits

FIGURE 1.4

The Sun and planets with the correct sizes. The distances between them are not correct.

Figure 1.4 shows the Sun and planets with the correct sizes. The distances between them are way too small. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next.

Figure 1.5 shows those distances correctly. In the upper left are the orbits of the inner planets and the asteroid belt. The asteroid belt is a collection of many small objects between the orbits of Mars and Jupiter. In the upper right are the orbits of the outer planets and the Kuiper belt. The Kuiper belt is a group of objects beyond the orbit of Neptune.

In **Figure** 1.5, you can see that the orbits of the planets are nearly circular. Pluto's orbit is a much longer ellipse. Some astronomers think Pluto was dragged into its orbit by Neptune.

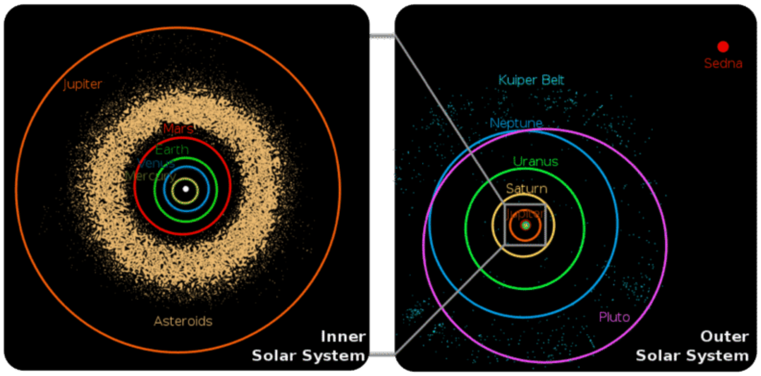

FIGURE 1.5
In this image, distances are shown to scale.

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 (93 million miles). **Table** 1.2 shows the distance from the Sun to each planet in AU. The table shows how long it takes each planet to spin on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus!

TABLE 1.2: 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

The Role of Gravity

Planets are held in their orbits by the force of gravity. What would happen without gravity? Imagine that you are swinging a ball on a string in a circular motion. Now let go of the string. The ball will fly away from you in a straight line. It was the string pulling on the ball that kept the ball moving in a circle. The motion of a planet is very similar to the ball on a string. The force pulling the planet is the pull of gravity between the planet and the Sun.

Every object is attracted to every other object by gravity. The force of gravity between two objects depends on the mass of the objects. It also depends on how far apart the objects are. When you are sitting next to your dog, there is a gravitational force between the two of you. That force is far too weak for you to notice. You can feel the force of gravity between you and Earth because Earth has a lot of mass. The force of gravity between the Sun and planets is also very large. This is because the Sun and the planets are very large objects. Gravity is great enough to hold the planets to the Sun even though the distances between them are enormous. Gravity also holds moons in orbit around planets.

Extrasolar Planets

Since the early 1990s, astronomers have discovered other solar systems. A solar system has one or more planets orbiting one or more stars. We call these planets "extrasolar planets," or "exoplanets". They are called exoplanets because they orbit a star other than the Sun. As of June 2013, 891 exoplanets have been found. More exoplanets are found all the time. You can check out how many we have found at http://planetquest.jpl.nasa.gov/.

planets orbit in the same direction around the Sun. These two features are clues to how the solar system formed.

A Giant Nebula

Scientists think the solar system formed from a big cloud of gas and dust, called a **nebula**. This is the solar nebula hypothesis. The nebula was made mostly of hydrogen and helium. There were heavier elements too. Gravity caused the nebula to contract (**Figure** 1.6).

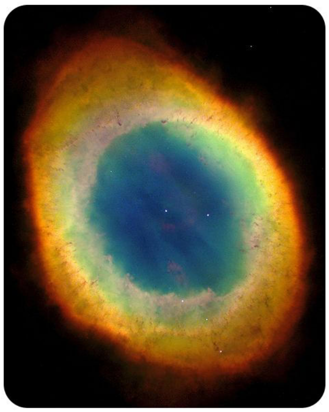

FIGURE 1.6
The nebula was drawn together by gravity.

As the nebula contracted, it started to spin. As it got smaller and smaller, it spun faster and faster. This is what happens when an ice skater pulls her arms to her sides during a spin move. She spins faster. The spinning caused the nebula to form into a disk shape.

This model explains why all the planets are found in the flat, disk-shaped region. It also explains why all the planets revolve in the same direction. The solar system formed from the nebula about 4.6 billion years ago

Formation of the Sun and Planets

The Sun was the first object to form in the solar system. Gravity pulled matter together to the center of the disk. Density and pressure increased tremendously. **Nuclear fusion** reactions begin. In these reactions, the nuclei of atoms come together to form new, heavier chemical elements. Fusion reactions release huge amounts of nuclear energy. From these reactions a star was born, the Sun.

Meanwhile, the outer parts of the disk were cooling off. Small pieces of dust started clumping together. These clumps collided and combined with other clumps. Larger clumps attracted smaller clumps with their gravity. Eventually, all these pieces grew into the planets and moons that we find in our solar system today.

The outer planets — Jupiter, Saturn, Uranus, and Neptune — condensed from lighter materials. Hydrogen, helium, water, ammonia, and methane were among them. It's so cold by Jupiter and beyond that these materials can form solid particles. Closer to the Sun, they are gases. Since the gases can escape, the inner planets — Mercury, Venus, Earth, and Mars — formed from denser elements. These elements are solid even when close to the Sun.

Lesson Summary

- The Sun and all the objects held by its gravity make up the solar system.

- There are eight planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Neptune. Pluto, Eris, Ceres, Makemake and Haumea are dwarf planets.
- The ancient Greeks believed Earth was at the center of the universe and everything else orbited Earth.
- Copernicus proposed that the Sun at the center of the universe and the planets and stars orbit the Sun.
- Planets are held by the force of gravity in elliptical orbits around the Sun.
- The solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.
- This model explains why the planets all lie in one plane and orbit in the same direction around the Sun.

Lesson Review Questions

Recall

1. What are the names of the planets from the Sun outward? What are the names of the dwarf planets?

2. How old is the Sun? How old are the planets?

Apply Concepts

3. Describe the role of gravity in how the solar system functions. Why don't the planets fly off into space? Why don't the planets ram into the Sun?

4. Why does the nebular hypothesis explain how the solar system originated?

Think Critically

5. Why do you think so many people for so many centuries thought that Earth was the center of the universe?

6. People were pretty upset when Pluto was made a dwarf planet. Why do you think they were upset? How do you feel about it?

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?

References

1. Left: Pearson Scott Foresman; Right: Bartolomeu Velho. Left: http://commons.wikimedia.org/wiki/File:Ptolemaic_system_2_%28PSF%29.png; Right: http://commons.wikimedia.org/wiki/File:Bartolomeu_Velho_1568.jpg . Public Domain
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Concept 2 Planet Earth

Lesson Objectives

- Describe some of the characteristics of Earth.
- Describe how gravity affects Earth in the solar system.
- Explain Earth's magnetism, and its effects.
- Describe Earth's rotation on its axis.
- Describe Earth's revolution around the Sun.

Vocabulary

- axis
- biosphere
- gravity
- hemisphere
- hydrosphere
- magnetic field
- revolution
- rotation

Introduction

This section is called *Planet Earth*. Isn't that what nearly this whole book has been about so far? Yes! In this section we will look at Earth as a planet. Some information will be review from other chapters. Some will be new information.

Earth's Shape, Size, and Mass

As you walk, the ground usually looks pretty flat, even though the Earth is round. How do we know this? We have pictures of Earth taken from space that show that Earth is round. Astronauts aboard the Apollo 17 shuttle took this one, called "The Blue Marble" (**Figure** 2.1). Earth looks like a giant blue and white ball.

Long before spacecraft took photos of Earth from space, people knew that Earth was round. How? One way was to look at ships sailing off into the distance. What do you see when you watch a tall ship sail over the horizon of the Earth? The bottom part of the ship disappears faster than the top part. What would that ship look like if Earth was flat? No part of it would disappear before the other. It would all just get smaller as it moved further away.

In the solar system, the planets orbit around the Sun. The Sun and each of the planets of our solar system are round. Earth is the third planet from the Sun. It is one of the inner planets. Jupiter is an outer planet. It is the largest planet in the solar system at about 1,000 times the size of Earth. The Sun is about 1,000 times bigger than Jupiter! (**Figure** 2.2).

FIGURE 2.1
This is how the Earth looks from space - like a blue and white marble.

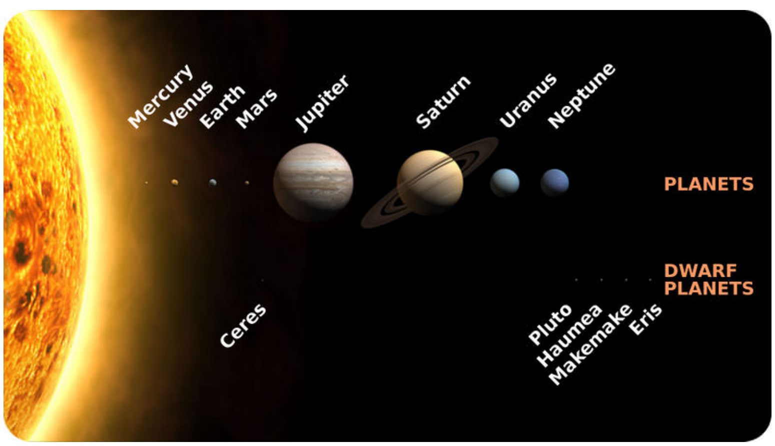

FIGURE 2.2
Compare the Sun with the other planets and see how the Sun is much bigger than all the other planets.

The outer planets in the solar system are giant balls of swirling gas. Earth and the other inner planets are relatively small, dense, and rocky. Most of Earth's surface is covered with water. As far as we know, Earth is also the only planet that has liquid water. Earth's atmosphere has oxygen. The water and oxygen are crucial to life as we know it. Earth appears to be the only planet in the solar system with living creatures. You can learn more about the planets in the *Our Solar System* chapter.

Some of the different parts of the Earth are our:

- Atmosphere: the thin layer of air, mostly nitrogen and oxygen, that surrounds the Earth.
- **Hydrosphere**: all the water on Earth.
- **Biosphere**: all the living organisms on Earth.

- Lithosphere: the solid rock part of Earth, including mountains, valleys, continents, and all of the rock beneath the oceans.

Since Earth is round, the layers all have the word sphere at the end (**Figure** 2.3). All of Earth's layers interact. Therefore, Earth's surface is constantly undergoing change.

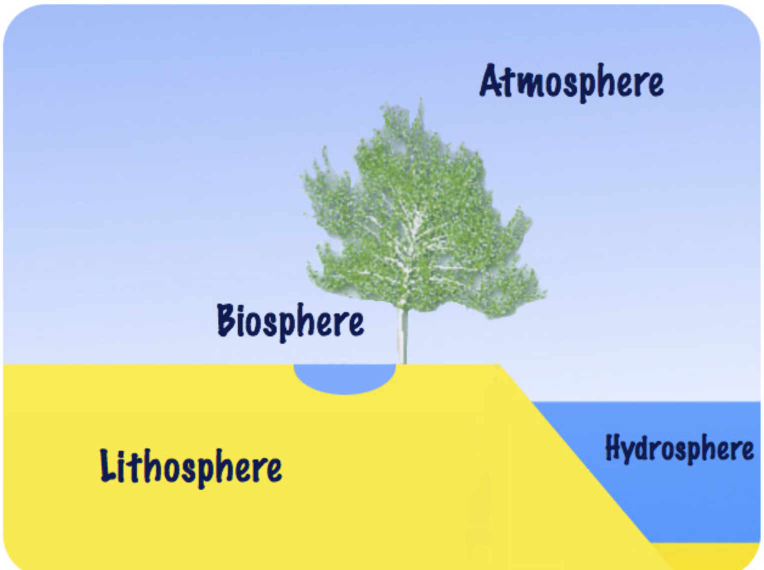

FIGURE 2.3
Earth has four layers: atmosphere, hydrosphere, biosphere, and lithosphere.

Earth's Gravity

Earth and Moon orbit each other. This Earth-Moon system orbits the Sun in a regular path (**Figure** 2.4). **Gravity** is the force of attraction between all objects. Gravity keeps the Earth and Moon in their orbits. Earth's gravity pulls the Moon toward Earth's center. Without gravity, the Moon would continue moving in a straight line off into space.

All objects in the universe have a gravitational attraction to each other (**Figure** 2.5). The strength of the force of gravity depends on two things. They are the mass of the objects and the distance between them. The greater the objects' mass, the greater the force of attraction. As the distance between the objects increases, the force of attraction decreases.

Earth's Magnetism

Earth has a **magnetic field** (**Figure** 2.6). The magnetic field has north and south poles. The field extends several thousand kilometers into space. Earth's magnetic field is created by the movements of molten metal in the outer core.

Earth's magnetic field shields us from harmful radiation from the Sun (**Figure** 2.7).

If you have a large bar magnet, you can hang it from a string. Then watch as it aligns itself in a north-south direction, in response to Earth's magnetic field. A compass needle also aligns with Earth's magnetic field. People can navigate by finding magnetic north (**Figure** 2.8).

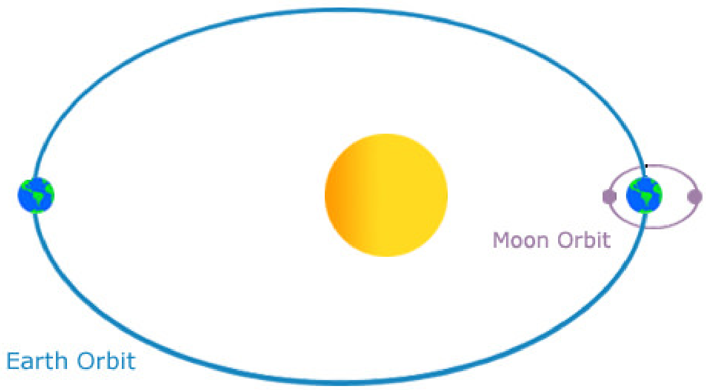

FIGURE 2.4
The Moon orbits the Earth, and the Earth-Moon system orbits the Sun.

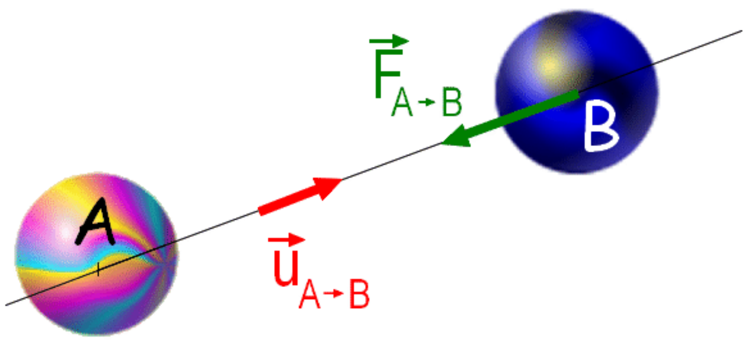

FIGURE 2.5
The strength of the force of gravity between objects A and B depends on the mass of the objects and the distance (*u*) between them.

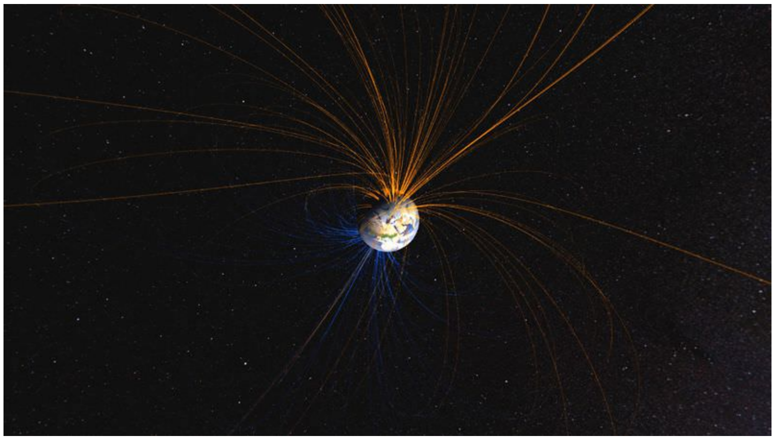

FIGURE 2.6
Earth's magnetic field extends into space.

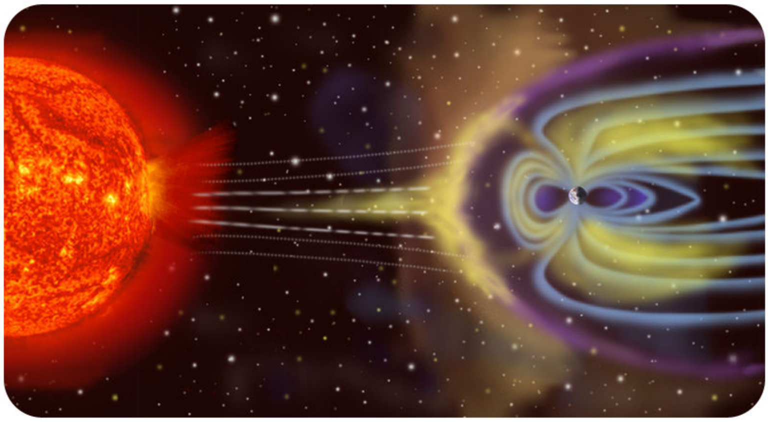

FIGURE 2.7
Earth's magnetic field protects the planet from harmful radiation.

FIGURE 2.8
The needle of a compass will align with Earth's magnetic field, making the compass a useful device for navigation.

Earth's Motions

Earth's **axis** is an imaginary line passing through the North and South Poles. Earth's**rotation** is its spins on its axis. Rotation is what a top does around its spindle. As Earth spins on its axis, it also orbits around the Sun. This is called Earth's **revolution**. These motions lead to the cycles we see. Day and night, seasons, and the tides are caused by Earth's motions.

Earth's Rotation

In 1851, Léon Foucault, a French scientist, hung a heavy iron weight from a long wire. He pulled the weight to one side and then released it. The weight swung back and forth in a straight line. If Earth did not rotate, the pendulum would not change direction as it was swinging. But it did, or at least it appeared to. The direction of the pendulum appeared to change because Earth rotated beneath it. **Figure** 2.9 shows how this might look.

FIGURE 2.9
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.

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 .

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/145419

Earth's Day and Night

How long does it take Earth to spin once on its axis? One rotation is 24 hours. That rotation is the length of a day! Whatever time it is, the side of Earth facing the Sun has daylight. The side facing away from the Sun is dark. If you look at Earth from the North Pole, the planet spins counterclockwise. As the Earth rotates, you see the Sun moving across the sky from east to west. We often say that the Sun is "rising" or "setting." The Sun rises in the east and sets in the west. Actually, it is the Earth's rotation that makes it appear that way. The Moon and the stars at night also seem to rise in the east and set in the west. Earth's rotation is also responsible for this too. As Earth turns, the Moon and stars change position in the sky.

Earth's Seasons

The Earth is tilted 23 $1/2^\circ$ on its axis (**Figure** 2.10). This means that as the Earth rotates, one hemisphere has longer days with shorter nights. At the same time the other hemisphere has shorter days and longer nights. For example, in the Northern hemisphere summer begins on June 21. On this date, the North Pole is pointed directly toward the Sun. This is the longest day and shortest night of the year in the Northern Hemisphere. The South Pole is pointed away from the Sun. This means that the Southern Hemisphere experiences its longest night and shortest day (**Figure** 2.11).

The hemisphere that is tilted away from the Sun is cooler because it receives less direct rays. As Earth orbits the

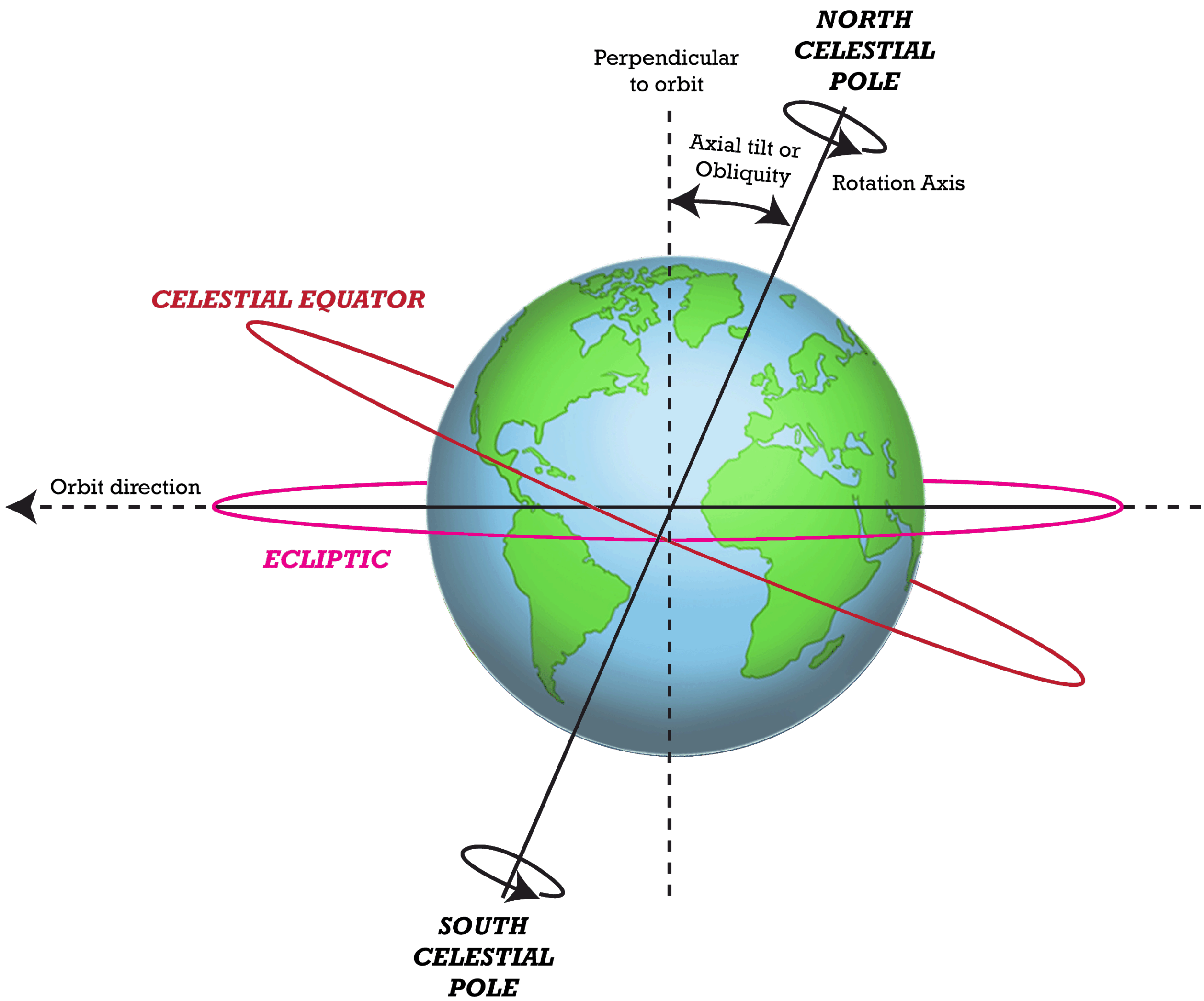

FIGURE 2.10

The Earth tilts on its axis.

Sun, the Northern Hemisphere goes from winter to spring, then summer and fall. The Southern Hemisphere does the opposite from summer to fall to winter to spring. When it is winter in the Northern hemisphere, it is summer in the Southern hemisphere, and vice versa.

Earth's Revolution

Earth's revolution around the Sun takes 365.24 days. That is equal to one year. The Earth stays in orbit around the Sun because of the Sun's gravity (**Figure** 2.12). Earth's orbit is not a circle. It is somewhat elliptical. So as we travel around the Sun, sometimes we are a little farther away from the Sun. Sometimes we are closer to the Sun.

Students sometimes think the slightly oval shape of our orbit causes Earth's seasons. That's not true! The seasons are due to the tilt of Earth's axis, as discussed above.

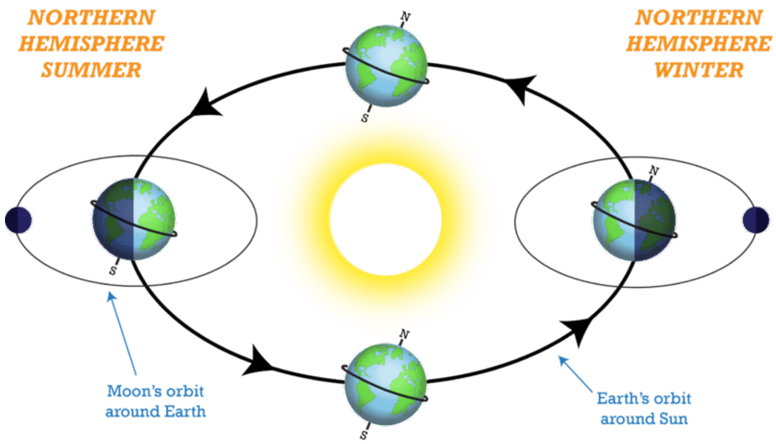

FIGURE 2.11
Earth's tilt changes the length of the days and nights during different seasons.

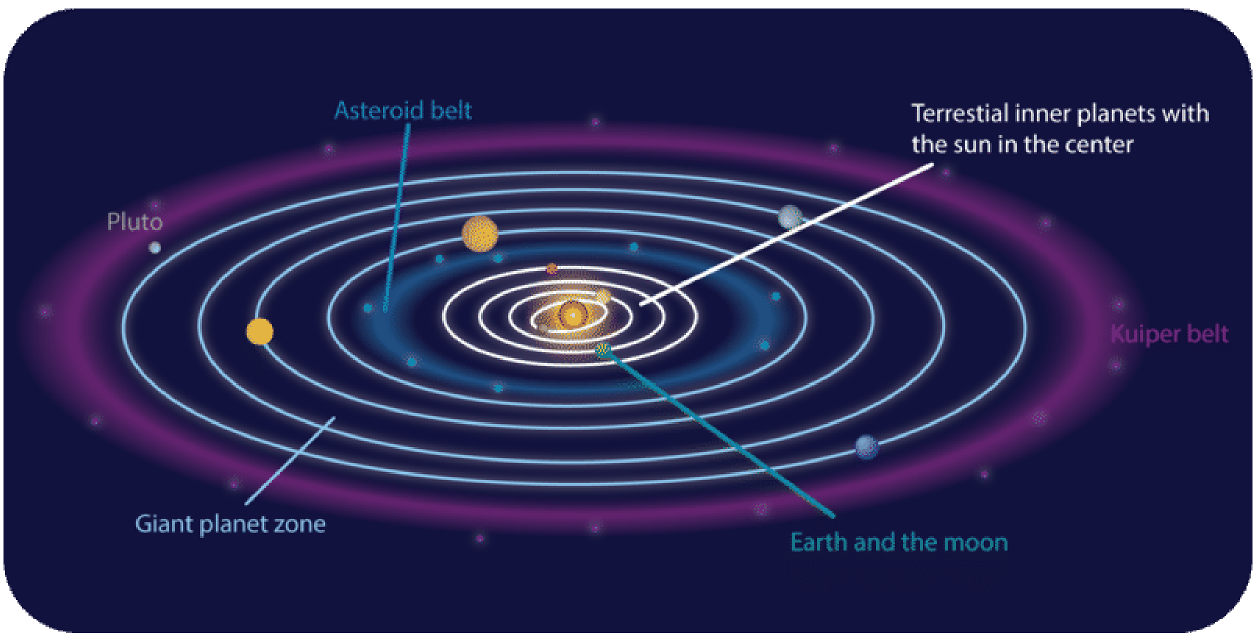

FIGURE 2.12
Earth and the other planets in the solar system make elliptical orbits around the Sun.

The distance between the Earth and the Sun is about 150 million kilometers. Earth revolves around the Sun at an average speed of about 27 kilometers (17 miles) per second. Mercury and Venus are closer to the Sun, so they take shorter times to make one orbit. Mercury takes only about 88 Earth days to make one trip around the Sun. All of the other planets take longer amounts of time. The exact amount depends on the planet's distance from the Sun. Saturn takes more than 29 Earth years to make one revolution around the Sun.

Lesson Summary

- The planets in our solar system all spin as they revolve around the Sun in fixed paths called orbits.
- The balance between gravity and our motion around the Sun, keep the planets in orbit at fixed distances from the Sun.
- Earth has a magnetic field, created by motion within Earth's outer, liquid iron core. The magnetic field shields us from harmful radiation.
- Earth rotates on its axis once each day and revolves around the Sun once every year.
- The tilt of Earth's axis produces seasons.

Lesson Review Questions

Recall

1. What was the evidence that Earth was round before there were photos from space?
2. What two substances does Earth have that allow it to support life?
3. What does a compass have that allows you to tell direction?
4. Describe Earth's rotation. Describe Earth's revolution.

Apply Concepts

5. Earth's "spheres" all interact. Given what you know about Earth science, can you give some examples?
6. What would happen to Earth-Moon if Earth suddenly shrunk to half its current size?

Think Critically

7. Why do the planets that are furthest from the Sun take longer to make one orbit around the Sun? Explain your answer.

8. Even though Earth is closest to the Sun in January, people in the Northern hemisphere experience winter weather. Why do you think people in the Northern Hemisphere have winter in January?

Points to Consider

- What would other planets need to have if they were able to support life?
- 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 due to Earth's tilted axis?
- If Earth suddenly increased in mass, what might happen to its orbit around the Sun?

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Concept 3 The Sun and the Earth-Moon System

Lesson Objectives

- Explain solar and lunar eclipses.
- Describe the phases of the Moon and explain why they occur.

Vocabulary

- crescent
- gibbous
- lunar eclipse
- penumbra
- solar eclipse
- umbra

Introduction

The Earth, Moon and Sun are linked together in space. Monthly or daily cycles continually remind us of these links. Every month, you can see the Moon change. This is due to where it is relative to the Sun and Earth. In one phase, the Moon is brightly illuminated - a full moon. In the opposite phase it is completely dark - a new moon. In between, it is partially lit up. When the Moon is in just the right position, it causes an eclipse. The daily tides are another reminder of the Moon and Sun. They are caused by the pull of the Moon and the Sun on the Earth. Tides were discussed in the *Oceans* chapter.

Solar Eclipses

When a new moon passes directly between the Earth and the Sun, it causes a **solar eclipse** (**Figure** 3.1). The Moon casts a shadow on the Earth and blocks our view of the Sun. This happens only all three are lined up and in the same plane. This plane is called the ecliptic. The ecliptic is the plane of Earth's orbit around the Sun.

The Moon's shadow has two distinct parts. The **umbra** is the inner, cone-shaped part of the shadow. It is the part in which all of the light has been blocked. The **penumbra** is the outer part of Moon's shadow. It is where the light is only partially blocked.

When the Moon's shadow completely blocks the Sun, it is a total solar eclipse (**Figure** 3.2). If only part of the Sun is out of view, it is a partial solar eclipse. Solar eclipses are rare events. They usually only last a few minutes. That is because the Moon's shadow only covers a very small area on Earth and Earth is turning very rapidly.

Solar eclipses are amazing to experience. It appears like night only strange. Birds may sing as they do at dusk. Stars become visible in the sky and it gets colder outside. Unlike at night, the Sun is out. So during a solar eclipse, it's

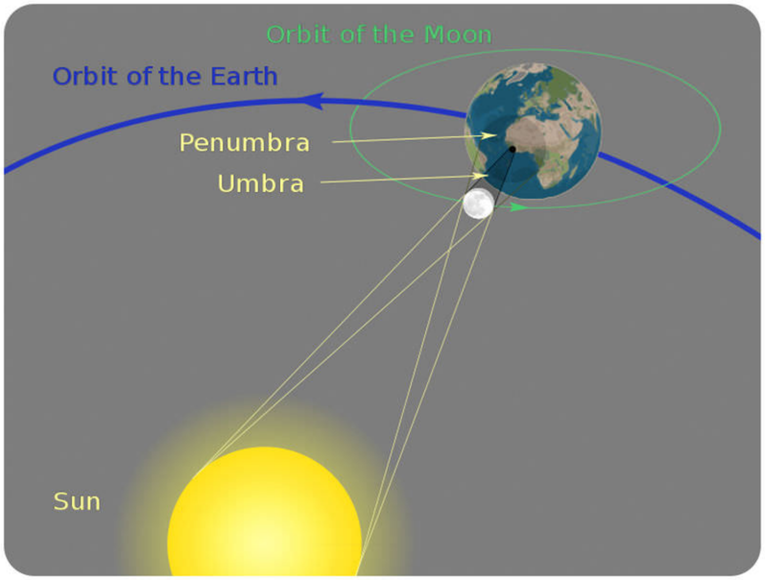

FIGURE 3.1
During a solar eclipse, the Moon casts a shadow on the Earth. The shadow is made up of two parts: the darker umbra and the lighter penumbra.

easy to see the Sun's corona and solar prominences. This NASA page will inform you on when solar eclipses are expected: http://eclipse.gsfc.nasa.gov/solar.html

FIGURE 3.2
A photo of a total solar eclipse.

A Lunar Eclipse

Sometimes a full moon moves through Earth's shadow. This is a **lunar eclipse** (**Figure** 3.3). During a total lunar eclipse, the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. When the Moon passes through Earth's penumbra, it is a penumbral eclipse. Since Earth's shadow is large, a lunar eclipse lasts for hours. Anyone with a view of the Moon can see a lunar eclipse.

Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common. The Moon glows with a dull red coloring during a total lunar eclipse.

FIGURE 3.3
A lunar eclipse is shown in a series of pictures.

The Phases of the Moon

The Moon does not produce any light of its own. It only reflects light from the Sun. As the Moon moves around the Earth, we see different parts of the Moon lit up by the Sun. This causes the phases of the Moon. As the Moon revolves around Earth, it changes from fully lit to completely dark and back again.

A full moon occurs when the whole side facing Earth is lit. This happens when Earth is between the Moon and the Sun. About one week later, the Moon enters the quarter-moon phase. Only half of the Moon's lit surface is visible from Earth, so it appears as a half circle. When the Moon moves between Earth and the Sun, the side facing Earth is completely dark. This is called the new moon phase. Sometimes you can just barely make out the outline of the new moon in the sky. This is because some sunlight reflects off the Earth and hits the Moon. Before and after the quarter-moon phases are the gibbous and crescent phases. During the **crescent** moon phase, the Moon is less than half lit. It is seen as only a sliver or crescent shape. During the **gibbous** moon phase, the Moon is more than half lit. It is not full. The Moon undergoes a complete cycle of phases about every 29.5 days.

Lesson Summary

- When the new moon comes between the Earth and the Sun along the ecliptic, a solar eclipse is produced.
- When the Earth comes between the full moon and the Sun along the ecliptic, a lunar eclipse occurs.
- Observing the Moon from Earth, we see a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again once every 29.5 days.

Review Questions

Recall

1. What is happening with Earth and the Sun during Northern Hemisphere summer? What is happening in the Southern Hemisphere at that time?

2. Draw a picture of Earth, Moon, and Sun during a new moon. Draw picture during a full moon.

Apply Concepts

3. Why do lunar eclipses happen more often and last longer than solar eclipses?

4. The same side of the Moon always faces Earth. What would Earth be like if its same side always faced the Sun?

Think Critically

5. Why is it a different time in San Francisco and in Denver? Why is the time different in Denver and Chicago? What would things be like if the entire United States decided to have all places be the same time always?

6. People think that Earth's season are caused by its elliptical orbit around the Sun. Explain why this is not so.

Points to Consider

- Why don't eclipses occur every single month at the full and new moons?
- The planet Mars has a tilt that is very similar to Earth's. What does this produce on Mars?
- Venus comes between the Earth and the Sun. Why don't we see an eclipse when this happens?

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CONCEPT 4 Galaxies

Lesson Objectives

- Identify different types of galaxies.
- Describe our own galaxy, the Milky Way Galaxy.

Vocabulary

- elliptical galaxy
- galaxy
- globular cluster
- irregular galaxy
- Milky Way Galaxy
- open cluster
- spiral arm
- spiral galaxy
- star cluster

Introduction

Compared to Earth, the solar system is a big place. But galaxies are bigger - a lot bigger. A **galaxy** is a very large group of stars held together by gravity. How enormous a galaxy is and how many stars it contains are impossible for us to really understand. A galaxy contains up to a few billion stars! Our solar system is in the Milky Way Galaxy. It is so large that if our solar system were the size of your fist, the galaxy's disk would be wider than the entire United States! There are several different types of galaxies, and there are billions of galaxies in the universe.

Star Clusters

Star clusters are groups of stars smaller than a galaxy. There are two main types, open clusters and globular clusters. **Open clusters** are groups of up to a few thousand stars held together by gravity. The Jewel Box, shown in **Figure** 4.1, is an open cluster. Open clusters tend to be blue in color, and often contain glowing gas and dust. The stars in an open cluster are young stars that all formed from the same nebula.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. Globular clusters have a definite, spherical shape. They contain mostly old, reddish stars. Near the center of a globular cluster, the stars are closer together. **Figure** 4.2 shows a globular cluster. The heart of the globular cluster M13 has hundreds of thousands of stars. M13 is 145 light years in diameter. The cluster contains red and blue giant stars.

FIGURE 4.1
These hot blue stars are in an open cluster known as the Jewel Box. The red star is a young red supergiant.

FIGURE 4.2
The globular cluster, M13, contains red and blue giant stars.

Types of Galaxies

The biggest groups of stars are called galaxies. A few million to many billions of stars may make up a galaxy. With the unaided eye, every star you can see is part of the Milky Way Galaxy. All the other galaxies are extremely far away. The closest spiral galaxy, the Andromeda Galaxy, shown in **Figure** 4.3, is 2,500,000 light years away and contains one trillion stars!

Spiral Galaxies

Galaxies are divided into three types, according to shape. There are spiral galaxies, elliptical galaxies, and irregular galaxies. **Spiral galaxies** are a rotating disk of stars and dust. In the center is a dense bulge of material. Several

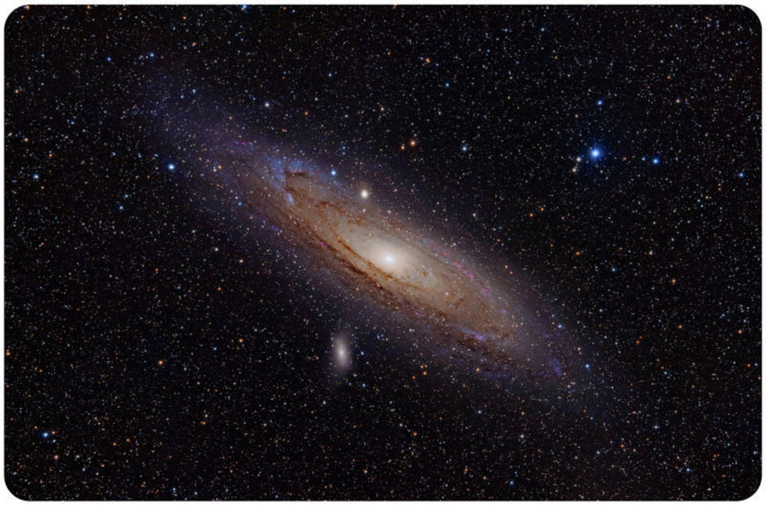

FIGURE 4.3
The Andromeda Galaxy is the closest major galaxy to our own.

arms spiral out from the center. Spiral galaxies have lots of gas and dust and many young stars. **Figure** 4.4 shows a spiral galaxy from the side. You can see the disk and central bulge.

FIGURE 4.4
The Pinwheel Galaxy is a spiral galaxy displaying prominent arms.

Elliptical Galaxies

Figure 4.5 shows a typical elliptical galaxy. **Elliptical galaxies** are oval in shape. The smallest are called dwarf elliptical galaxies. Look back at the image of the Andromeda Galaxy. It has two dwarf elliptical galaxies as its companions. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Giant elliptical galaxies contain over a trillion stars. Elliptical galaxies are red to yellow in color because they contain mostly old stars. Most contain very little gas and dust because the material has already formed into stars.

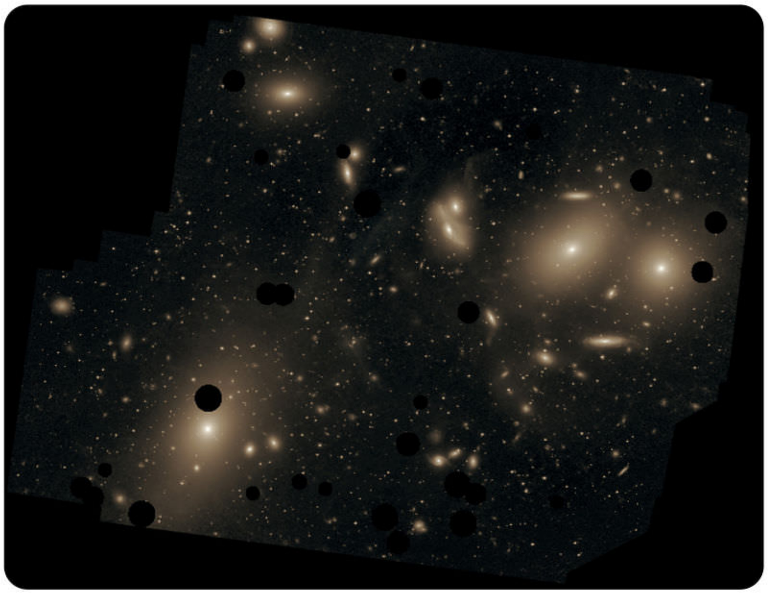

FIGURE 4.5
M87 is an elliptical galaxy in the lower left of this image. How many elliptical galaxies do you see? Are there other types of galaxies displayed?

Irregular Galaxies

Look at the galaxy in **Figure** 4.6. Do you think this is a spiral galaxy or an elliptical galaxy? It doesn't look like either! If a galaxy is not spiral or elliptical, it is an **irregular galaxy**. Most irregular galaxies have been deformed. This can occur either by the pull of a larger galaxy or by a collision with another galaxy.

The Milky Way Galaxy

If you get away from city lights and look up in the sky on a very clear night, you will see something spectacular. A band of milky light stretches across the sky, as in **Figure** 4.7. This band is the disk of the **Milky Way Galaxy**. This is the galaxy where we all live. The Milky Way Galaxy looks different to us than other galaxies because our view is from inside of it!

Shape and Size

The Milky Way Galaxy is a spiral galaxy that contains about 400 billion stars. Like other spiral galaxies, it has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across. It is about 3,000 light years thick. Most of the galaxy's gas, dust, young stars, and open clusters are in the disk. Some astronomers think that there is a gigantic black hole at the center of the galaxy. **Figure** 4.8 shows what the Milky Way probably looks like from the outside.

Our solar system is within one of the spiral arms. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are a little more than halfway out from the center of the Galaxy to the edge, as shown in **Figure** 4.8.

Our solar system orbits the center of the galaxy as the galaxy spins. 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.

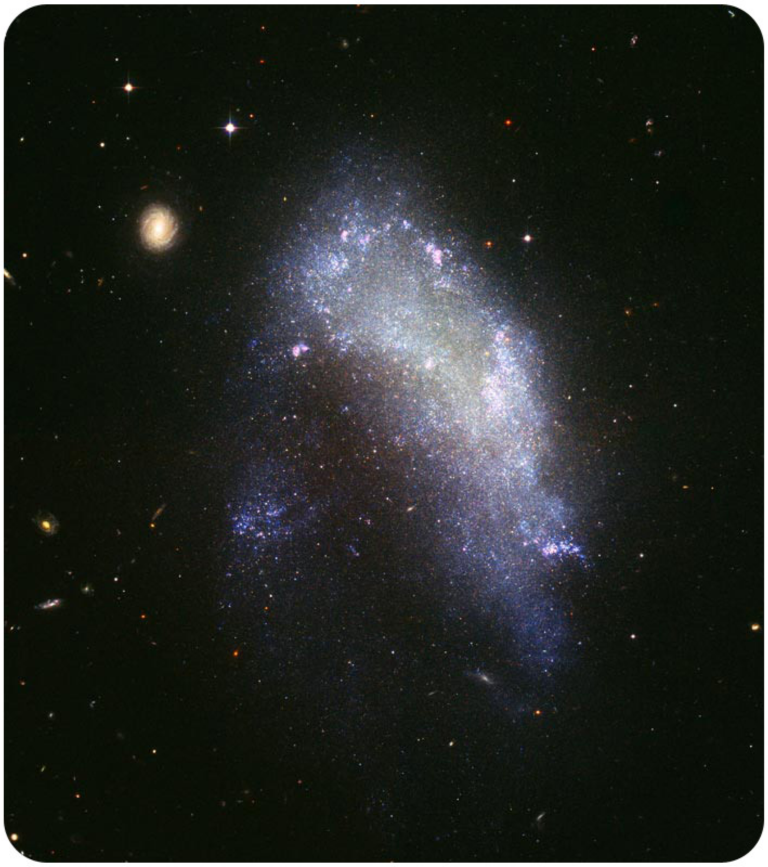

FIGURE 4.6
This irregular galaxy, NGC 55, is neither spiral nor elliptical.

FIGURE 4.7
The Milky Way Galaxy in the night sky above Death Valley.

Lesson Summary

- 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 oval shaped, red or yellow, and contain mostly old stars.
- A galaxy that is not elliptical or spiral is an irregular galaxy. These galaxies were deformed by other galaxies.
- The band of light called the Milky Way is the disk of our galaxy, the Milky Way Galaxy, which is a typical spiral galaxy.

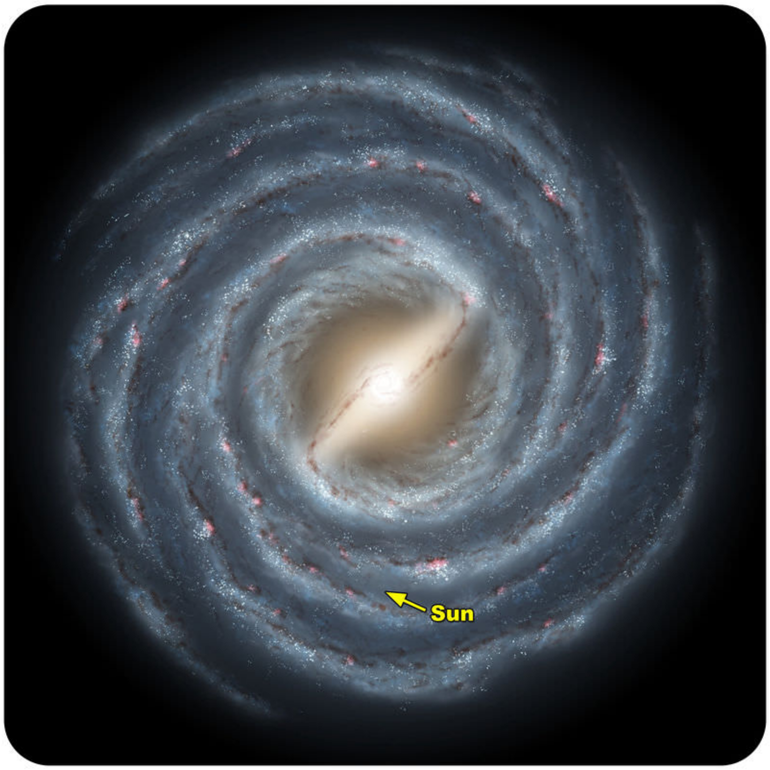

FIGURE 4.8
This is an artist's rendering of the Milky Way Galaxy seen from above. The Sun and solar system (and you!) are a little more than halfway out from the center.

- 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. Most of the stars we see are in our spiral arm.

Lesson Review Questions

Recall

1. What is the difference between a globular cluster and an open cluster?
2. What are the features of a spiral galaxy?
3. What are the features of an elliptical galaxy?

Apply Concepts

4. Where in the Milky Way galaxy is Earth?
5. How do irregular galaxies become irregular? Why do astronomers think that?

Think Critically

6. How do astronomers know that we live in a spiral galaxy if we're inside it?
7. How can astronomers tell the age of a galaxy?

Points to Consider

- Objects in the universe tend to be grouped together. What might cause them to form and stay in groups?
- Can you think of anything that is bigger than a galaxy?

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CONCEPT 5 Telescopes

Lesson Objectives

- Explain how astronomers use light to study the universe beyond Earth.
- Describe some different types of telescopes.
- Discuss what we have learned by using telescopes.

Vocabulary

- constellation
- electromagnetic radiation
- electromagnetic spectrum
- frequency
- gamma rays
- infrared light
- light-year
- microwaves
- planet
- radio telescope
- radio waves
- reflecting telescope
- refracting telescope
- space telescope
- spectrometer
- ultraviolet
- wavelength
- visible light
- X rays

Introduction

Many scientists can touch the materials they study. Most can do experiments to test those materials. Biologists can collect cells, seeds, or sea urchins to study in the laboratory. Physicists can test the strength of metal or smash atoms into each other. Geologists can chip away at rocks and test their chemistry. But astronomers study the universe far beyond Earth. They have to observe their subjects at a very large distance! A meteorite that lands on Earth is one of the few actual objects that astronomers could study.

Electromagnetic Spectrum

Earth is just a tiny speck in the universe. Our planet is surrounded by lots of space. Light travels across empty space. Astronomers can study light from stars to learn about the universe. Light is the visible part of the **electromagnetic spectrum**. Astronomers use the light that comes to us to gather information about the universe.

The Speed of Light

In space, light travels at about 300,000,000 meters per second (670,000,000 miles per hour). How fast is that? A beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even at that amazing rate, objects in space are so far away that it takes a lot of time for their light to reach us. Even light from the nearest star, our Sun, takes about 8 minutes to reach Earth.

Light-Years

We need a really big unit to measure distances out in space because distances between stars are so great. A **light-year**, 9.5 trillion kilometers (5.9 trillion miles), is the distance that light travels in one year. That's a long way! Out in space, it's actually a pretty short distance.

Proxima Centauri is the closest star to us after the Sun. This near neighbor is 4.22 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. Our galaxy, the Milky Way Galaxy, is about 100,000 light-years across. So it takes light 100,000 years to travel from one side of the galaxy to the other! It turns out that even 100,000 light years is a short distance. The most distant galaxies we have detected are more than 13 billion light-years away. That's over a hundred-billion-trillion kilometers!

Looking Back in Time

When we look at stars and galaxies, we are seeing over great distances. More importantly, we are also seeing back in time. When we see a distant galaxy, we are actually seeing how the galaxy used to look. For example, the Andromeda Galaxy, shown in **Figure** 5.1, is about 2.5 million light-years from Earth. When you see an image of the galaxy what are you seeing? You are seeing the galaxy as it was 2.5 million years ago!

Since scientists can look back in time they can better understand the Universe's history. Check out http://science.nasa.gov/headlines/y2002/08feb_gravlens.htm to see how this is true.

Electromagnetic Waves

Light is one type of **electromagnetic radiation**. Light is energy that travels in the form of an electromagnetic wave. **Figure** 5.2 shows a diagram of an electromagnetic wave. An electromagnetic (EM) wave has two parts: an electric field and a magnetic field. The electric and magnetic fields vibrate up and down, which makes the wave.

The **wavelength** is the horizontal distance between two of the same points on the wave, like wave crest to wave crest. A wave's **frequency** measures the number of wavelengths that pass a given point every second. As wavelength increases, frequency decreases. This means that as wavelengths get shorter, more waves move past a particular spot in the same amount of time.

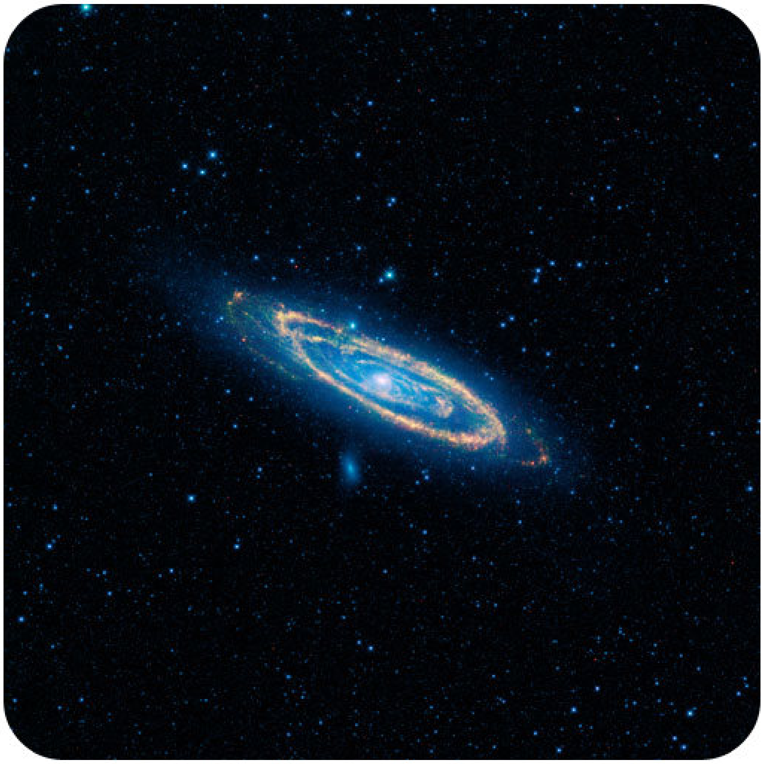

FIGURE 5.1
The Andromeda Galaxy as it appeared 2.5 million years ago. How would you find out how it looks right now?

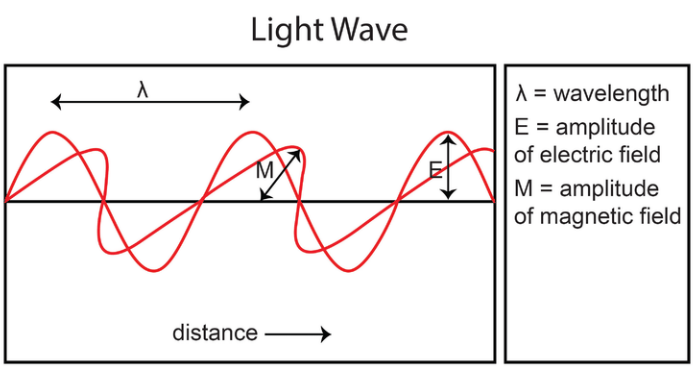

FIGURE 5.2
An electromagnetic wave has oscillating electric and magnetic fields.

The Electromagnetic Spectrum

Visible light is the part of the electromagnetic spectrum (**Figure** 5.3) that humans can see. Visible light includes all the colors of the rainbow. Each color is determined by its wavelength. Visible light ranges from violet wavelengths of 400 nanometers (nm) through red at 700 nm.

There are parts of the electromagnetic spectrum that humans cannot see. This radiation exists all around you. You just can't see it! Every star, including our Sun, emits radiation of many wavelengths. Astronomers can learn a lot from studying the details of the spectrum of radiation from a star.

Many extremely interesting objects can't be seen with the unaided eye. Astronomers use telescopes to see objects at wavelengths all across the electromagnetic spectrum. Some very hot stars emit light primarily at **ultraviolet**

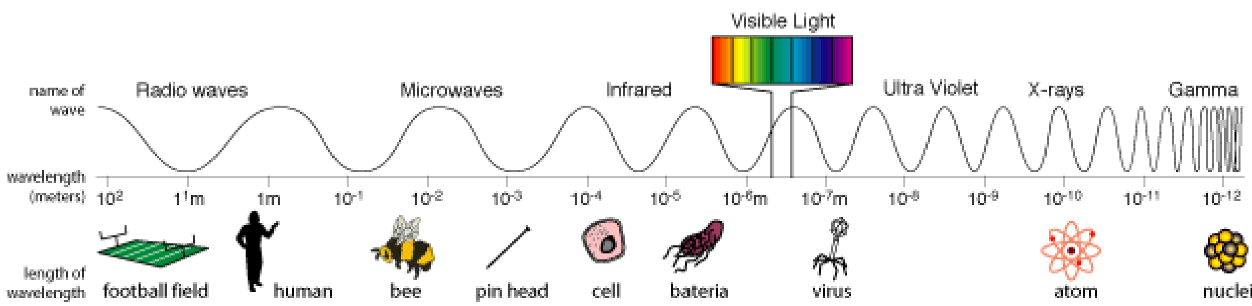

FIGURE 5.3
The electromagnetic spectrum from radio waves to gamma rays.

wavelengths. There are extremely hot objects that emit **X-rays** and even **gamma rays**. Some very cool stars shine mostly in the **infrared light** wavelengths. **Radio waves** come from the faintest, most distant objects.

To learn more about stars' spectra, visit http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/quantumzone/ .

Types of Telescopes

Optical Telescopes

Humans have been making and using magnifying lenses for thousands of years. The first telescope was built by Galileo in 1608. His telescope used two lenses to make distant objects appear both nearer and larger.

Telescopes that use lenses to bend light are called **refracting telescopes**, or refractors (**Figure** 5.4). The earliest telescopes were all refractors. Many amateur astronomers still use refractors today. Refractors are good for viewing details within our solar system. Craters on the surface of Earth's Moon or the rings around Saturn are two such details.

Around 1670, Sir Isaac Newton built a different kind of telescope. Newton's telescope used curved mirrors instead of lenses to focus light. This type of telescope is called a **reflecting telescope**, or reflector (see **Figure** 5.5). The mirrors in a reflecting telescope are much lighter than the heavy glass lenses in a refractor. This is important because a refracting telescope must be much stronger to support the heavy glass.

It's much easier to precisely make mirrors than to precisely make glass lenses. For that reason, reflectors can be made larger than refractors. Larger telescopes can collect more light. This means that they can study dimmer or more distant objects. The largest optical telescopes in the world today are reflectors. Telescopes can also be made to use both lenses and mirrors.

For more on how telescopes were developed, visit http://galileo.rice.edu/sci/instruments/telescope.html .

Radio Telescopes

Radio telescopes collect radio waves. These telescopes are even larger telescopes than reflectors. Radio telescopes look a lot like satellite dishes. In fact, both are designed to collect and focus radio waves or microwaves from space.

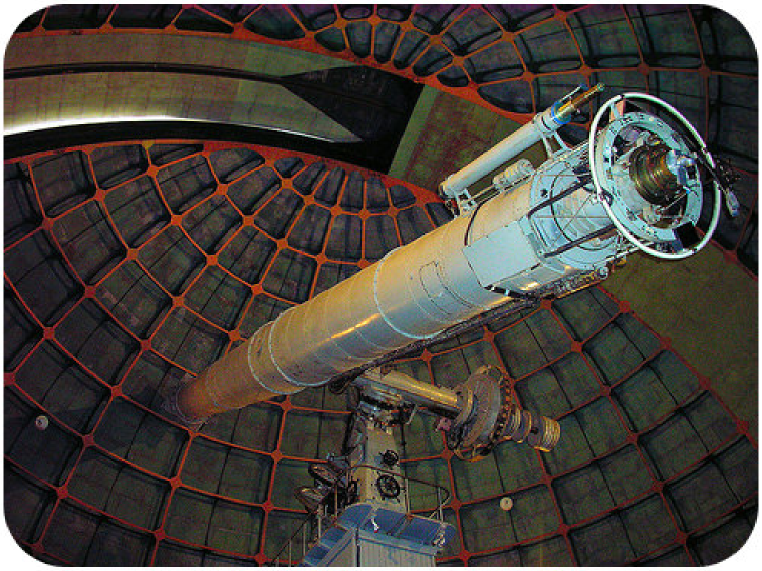

FIGURE 5.4
Refracting telescopes can be very large.

FIGURE 5.5
Newtonian reflector telescopes are fairly easy to make. These telescopes can be built by school students.

The largest single radio telescope in the world is at the Arecibo Observatory in Puerto Rico (see **Figure** 5.6). This telescope is located in a natural sinkhole. The sinkhole formed when water flowing underground dissolved the limestone. This telescope would collapse under its own weight if it were not supported by the ground. There is a big disadvantage to this design. The telescope can only observe the part of the sky that happens to be overhead at a given time.

A group of radio telescopes can be linked together with a computer. The telescopes observe the same object. The computer then combines the data from each telescope. This makes the group function like one single telescope. An example is shown in **Figure** 5.7.

To learn more about radio telescopes and radio astronomy in general, go to http://www.nrao.edu/whatisra/index.shtml .

FIGURE 5.6
The radio telescope at the Arecibo Observatory in Puerto Rico.

FIGURE 5.7
The Very Large Array in New Mexico consists of 27 radio telescopes.

Space Telescopes

Telescopes on Earth all have one big problem: Incoming light must pass through the atmosphere. This blocks some wavelengths of radiation. Also, motion in the atmosphere distorts light. You see this when you see stars twinkling in the night sky. Many observatories are built on high mountains. There is less air above the telescope, so there is less interference from the atmosphere. **Space telescopes** avoid such problems completely since they orbit outside the atmosphere.

The Hubble Space Telescope is the best known space telescope. Hubble is shown in **Figure** 5.8. Hubble began operations in 1994. Since then it has provided huge amounts of data. The telescope has helped astronomers answer many of the biggest questions in astronomy.

The National Aeronautics and Space Administration (NASA) has placed three other major space telescopes in orbit. Each uses a different part of the electromagnetic spectrum. The James Webb Space Telescope will launch in 2014.

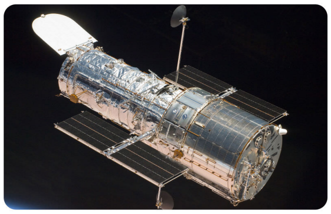

FIGURE 5.8
The Hubble Space Telescope has opened up the universe to human observation.

The telescope will replace the aging Hubble.

To learn more about NASA's great observatories, check out http://www.nasa.gov/audience/forstudents/postsecondary/features/F_NASA_Great_Observatories_PS.html .

FIGURE 5.9
Stars in the star cluster appear as points of light. Observations like these must be made with a space telescope.

Observations with Telescopes

Before Telescopes

Humans have been studying the night sky for thousands of years. Knowing the motions of stars helped people keep track of seasons. With this information they could know when to plant crops. Stars were so important that the patterns they made in the sky were named. These patterns are called **constellations**. Even now, constellations help astronomers know where they are looking in the night sky.

The ancient Greeks carefully observed the locations of stars in the sky. They noticed that some of the "stars" moved across the background of other stars. They called these bright spots in the sky **planets**. The word in Greek means "wanderers." Today we know that the planets are not stars. They are objects in the solar system that orbit the Sun. Ancient astronomers made all of their observations without the aid of a telescope.

Galileo's Observations

In 1610, Galileo looked at the night sky through the first telescope. This tool allowed him to make the following discoveries (among others):

- There are more stars in the night sky than the unaided eye can see.
- The band of light called the Milky Way consists of many stars.
- The Moon has craters (see **Figure** 5.10).
- Venus has phases like the Moon.

- Jupiter has moons orbiting around it.
- There are dark spots that move across the surface of the Sun.

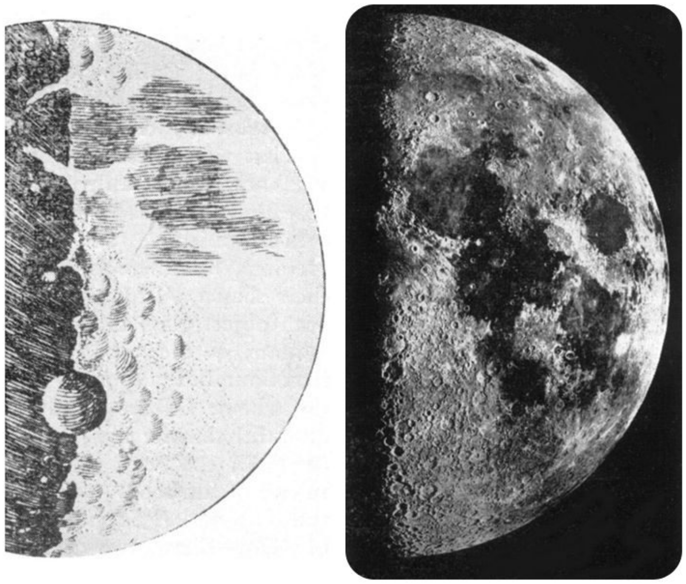

FIGURE 5.10
Galileo made the drawing on the left in 1610. On the right is a modern photograph of the Moon.

Galileo's observations made people think differently about the universe. They made them think about the solar system and Earth's place in it. Until that time, people believed that the Sun and planets revolved around Earth. One hundred years before Galileo, Copernicus had said that the Earth and the other planets revolved around the Sun. No one would believe him. But Galileo's observations through his telescope proved that Copernicus was right.

Observations with Modern Telescopes

Galileo's telescope got people to think about the solar system in the right way. Modern tools have also transformed our way of thinking about the universe. Imagine this: Today you can see all of the things Galileo saw using a good pair of binoculars. You can see sunspots if you have special filters on the lenses. (Never look directly at the Sun without using the proper filters!) With the most basic telescope, you can see polar caps on Mars, the rings of Saturn, and bands in the atmosphere of Jupiter.

You can see many times more stars with a telescope than without a telescope. Still, stars seen in a telescope look like single points of light. They are so far away. Only the red supergiant star Betelgeuse is large enough to appear as a disk. Except for our Sun, of course.

Today, astronomers attach special instruments to telescopes. This allows them to collect a wide variety of data. The data is fed into computers so that it can be studied. An astronomer may take weeks to analyze all of the data collected from just a single night!

Studying Starlight with Spectrometers

A **spectrometer** is a special tool that astronomers commonly use. Spectrometers allow them to study the light from a star or galaxy. A spectrometer produces a spectrum, like the one shown in **Figure** 5.11. A prism breaks light into all its colors. Gases from the outer atmosphere of a star absorb light. This forms dark lines in the spectrum. These dark lines reveal what elements the star contains.

Astronomers use the spectrum to learn even more about the star. One thing they learn is how hot the star is. They also learn the direction the star is going and how fast. By carefully studying light from many stars, astronomers

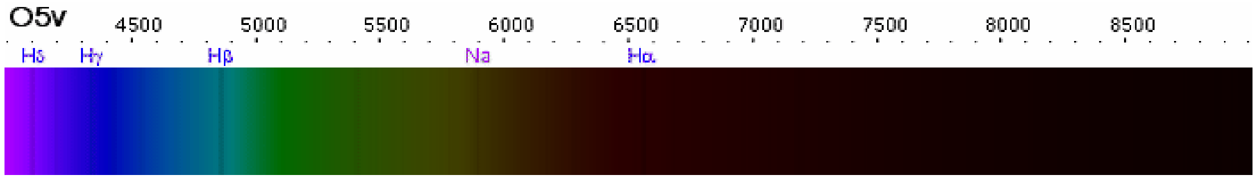

FIGURE 5.11
The dark lines indicate the elements that this star contains.

know how stars evolve. They have learned about the distribution and kinds of matter found throughout the universe. They even know something about how the universe might have formed.

To find out what you can expect to see when looking through a telescope, check out http://www.astronomics.com/main/category.asp/catalog_name/Astronomics/category_name/V1X41SU50GJB8NX88JQB360067/Page/1 .

Lesson Summary

- Astronomers study light from stars and galaxies.
- Light travels at 300,000,000 meters per second—faster than anything else in the universe.
- A light-year is a unit of distance equal to the distance light travels in one year, 9.5 trillion kilometers.
- When we see a star or galaxy, we see them as they were in the past, because their light has been traveling to us for many years.
- Light is energy that travels as a wave.
- Visible light is part of the electromagnetic spectrum.
- Telescopes make distant objects appear both nearer and larger. You can see many more stars through a telescope than with the unaided eye.
- Optical telescopes are designed to collect visible light. The two types of optical telescopes are reflecting telescopes and refracting telescopes.
- Radio telescopes collect and focus radio waves from distant objects.
- Space telescopes are telescopes orbiting Earth. They can collect wavelengths of light that are normally blocked by the atmosphere.
- Galileo was the first person known to use a telescope to study the sky. His discoveries helped change the way humans think about the universe.
- Modern telescopes collect data that can be stored on a computer.
- A spectrometer produces a spectrum from starlight. Astronomers can learn a lot about a star by studying its spectrum.

Lesson Review Questions

Recall

1. Define what is one "light year." What is a light year in numbers? Don't forget the units!

2. What is the speed of light? Why is this important to astronomers?

3. How do refracting telescopes work?

4. What are constellations? Why were they important to ancient people?

5. What did Galileo observe about Jupiter?

Apply Concepts

6. Picture the visible light spectrum. Where do ultraviolet wavelengths fall? Where do infrared wavelengths fall?

7. You look through a telescope at Rigel. Rigel is the brightest star in the Orion constellation. Rigel is around 800 light years from Earth. What are you looking at when you look through that telescope? What does Rigel look like today?

8. What can you learn from studying starlight through a spectrometer?

Think Critically

9. Why do astronomers need to look at more than just visible objects when studying space? What can they learn from objects in other wavelengths of radiation?

10. Identify four regions of the electromagnetic spectrum that astronomers use when observing objects in space.

11. How do reflecting telescopes work? What are the advantages and disadvantages of reflecting telescopes over refracting telescopes?

12. If you wanted to study the most distant galaxies what sort of tool would you design and why?

Points to Consider

- Radio waves are used for communicating with spacecraft. A round-trip communication from Earth to Mars takes anywhere from 6 to 42 minutes. What challenges might this present for sending unmanned spacecraft and probes to Mars?
- The Hubble Space Telescope is a very important source of data for astronomers. The fascinating and beautiful images from the Hubble also help to maintain public support for science. However, the Hubble is growing old. Missions to service and maintain the telescope are extremely expensive and put the lives of astronauts at risk. Do you think there should be another servicing mission to the Hubble?

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10. The Moon as drawn by Galileo Galilei and published in "Sidereus Nuncius" in 1610; composition made by ECeDee. http://commons.wikimedia.org/wiki/File:Galileos_Moon.jpg . Public Domain
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CONCEPT 6 Recent Space Exploration

Lesson Objectives

- Outline the history of space stations and space shuttles.
- Describe recent developments in space exploration.

Vocabulary

- orbiter
- space shuttle
- space station

Space Shuttles and Space Stations

While the United States continued missions to the Moon in the early 1970s, the Soviets worked to build a space station. A **space station** is a large spacecraft. People can live on this craft for a long period of time.

Early Space Stations

Between 1971 and 1982, the Soviets put a total of seven Salyut space stations into orbit. **Figure** 6.1 shows the last of these, Salyut 7. These were all temporary stations. They were launched and later inhabited by a human crew. Three of the Salyut stations were used for secret military purposes. The others were used to study the problems of living in space. Cosmonauts aboard the stations performed a variety of experiments in astronomy, biology, and Earth science. Salyut 6 and Salyut 7 each had two docking ports. One crew could dock a spacecraft to one end. A replacement crew could dock to the other end.

The U.S. only launched one space station during this time. It was called Skylab. Skylab was launched in May 1973. Three crews visited Skylab, all within its first year in orbit. Skylab was used to study the effects of staying in space for long period. Devices on board were and for studying the Sun. Skylab reentered Earth's atmosphere in 1979, sooner than expected.

Modular Space Stations

The first space station designed for long-term use was the Mir space station (**Figure** 6.2). Mir was launched in several separate pieces. These pieces were put together in space. Mir holds the current record for the longest continued presence in space. There were people living on Mir continuously for almost 10 years!

Mir was the first major space project in which the United States and Russia worked together. American space shuttles transported supplies and people to and from Mir. American astronauts lived on Mir for many months. This cooperation allowed the two nations to learn from each other. The U.S. learned about Russia's experiences with long-duration space flights. Mir was taken out of orbit in 2001. It fell into the Pacific Ocean.

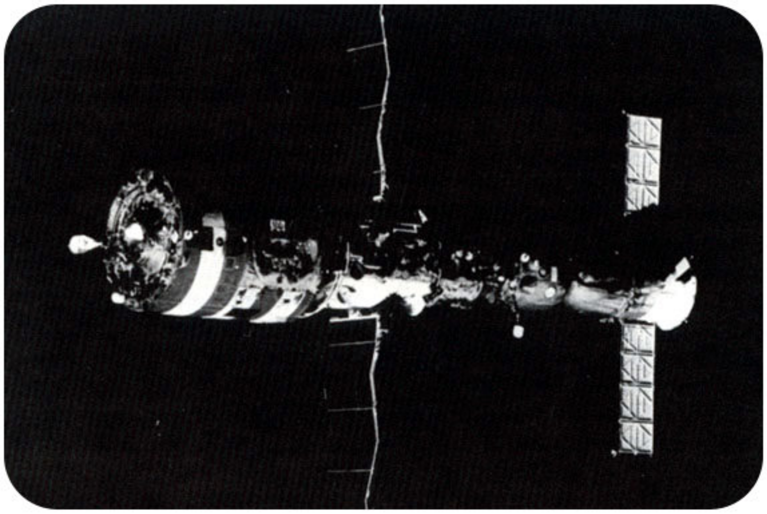

FIGURE 6.1
Salyut 7 with a docked spacecraft to bring crew on and off.

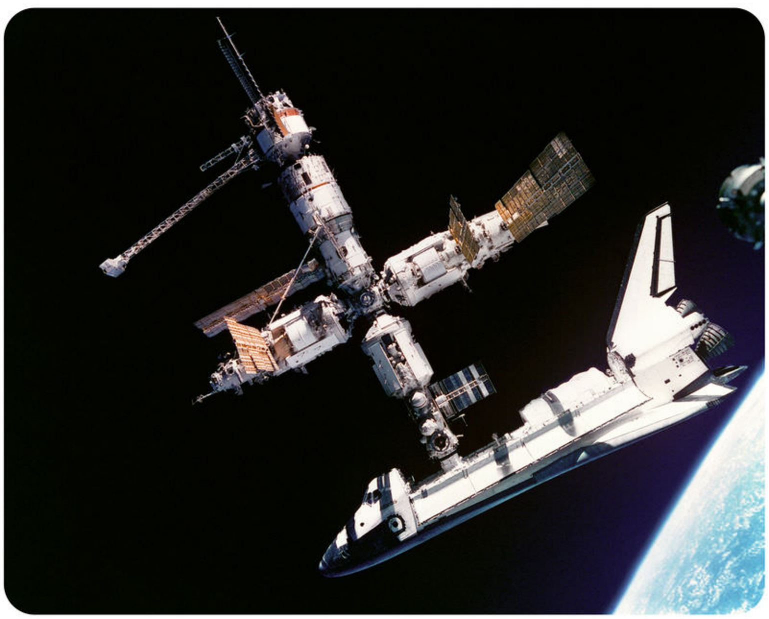

FIGURE 6.2
Mir, with an American space shuttle attached.

The International Space Station

The International Space Station, shown in **Figure** 6.3 is a joint project between the space agencies of many nations These include the United States (NASA), Russia (RKA), Japan (JAXA), Canada (CSA), several European countries (ESA) and the Brazilian Space Agency.

The International Space Station is a very large station. It has many different sections and is still being assembled. The station has had people on board since 2000. American space shuttles deliver most of the supplies and equipment to the station. Russian Soyuz spacecraft carry people. The primary purpose of the station is scientific research. This is important because the station has a microgravity environment. Experiments are done in the fields of biology, chemistry, physics, physiology and medicine.

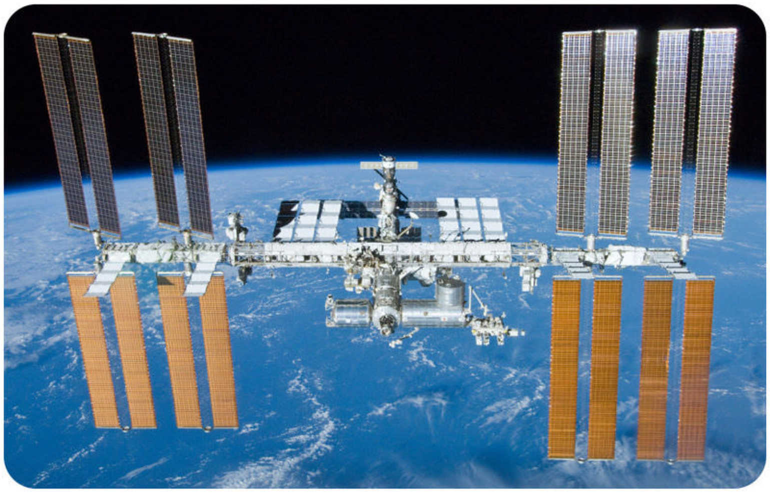

FIGURE 6.3
The International Space Station, as photographed from the Space Shuttle Atlantis in May 2010.

Space Shuttles

NASA wanted a new kind of space vehicle. This vehicle had to be reusable. It had to able to carry large pieces of equipment, such as satellites, space telescopes, or sections of a space station. The new vehicle was called a **space shuttle**, shown in **Figure** 6.4. There have been five space shuttles: Columbia, Challenger, Discovery, Atlantis, and Endeavor.

FIGURE 6.4
The space shuttle Atlantis rides a specialized Boeing 747 from its landing site in California back to Florida.

A space shuttle has three main parts. You are probably most familiar with the **orbiter**. This part has wings like an airplane. The shuttle is launched from Kennedy Space Center in Cape Canaveral, Florida. During launches, the orbiter is attached to a huge fuel tank that contains liquid fuel. On the sides of the fuel tank are two large booster rockets.

Figure 6.5 shows the stages of a normal space shuttle mission. Once in space, the orbiter can deliver equipment or supplies to the International Space Station. Astronauts can to repair orbiting equipment such as the Hubble Space Telescope. They may also do experiments directly on board the orbiter.

FIGURE 6.5
The stages of a shuttle mission. The orbiter takes off like a rocket and lands like an airplane.

At the end of the mission, the orbiter re-enters Earth's atmosphere. The outside heats up as it descends. Pilots have to steer the shuttle to the runway very precisely. Space shuttles usually land at Kennedy Space Center or at Edwards Air Force Base in California. The orbiter is later hauled back to Florida on the back of a jet airplane.

Space Shuttle Disasters

The space shuttle program has been very successful. Over 100 mission have been flown. Space shuttle missions have made many scientific discoveries. Crews have launched many satellites. There have been other great achievements in space. However, the program has also had two tragic disasters.

The first came just 73 seconds after launch, on January 28, 1986. The space shuttle Challenger disintegrated in mid-air, as shown in **Figure** 6.6. On board were seven crew members. All of them died. One of them was Christa McAuliffe, who was to be the first teacher in space. The problem was later shown to be an O-ring. This small part was in one of the rocket boosters. Space shuttle missions were put on hold while NASA improved the safety of the shuttles.

The second occurred during the takeoff of the Columbia on January 16, 2003. A small piece of insulating foam broke off the fuel tank. The foam smashed into a tile on the shuttle's wing. The tile was part of the shuttle's heat shield. The shield protects the shuttle from extremely high temperatures as it reenters the atmosphere. When Columbia

FIGURE 6.6
The disasters on the Challenger space shuttle mission showed just how dangerous space travel can be.

returned to Earth on February 3, 2003, it could not withstand the high temperatures. The shuttle broke apart. Again, all seven crew members died.

The space shuttle will be retired in 2011. All the remaining shuttle missions will be to the ISS. Orion will replace the shuttle. Known as a Crew Exploration Vehicle, Orion is expected to be ready by 2016.

Recent Space Missions

The disasters have caused NASA to focus on developing unmanned missions. Missions without a crew are less expensive and less dangerous. These missions still provide a great deal of valuable information.

Space Telescopes

Incredible images have come from the Hubble Space Telescope (HST). Even more incredible scientific discoveries have come from HST. The Hubble was the first telescope in space. It was put into orbit by the space shuttle Discovery in 1990. Since then, four shuttle missions have gone to the Hubble to make repairs and upgrades. The last repair mission to the Hubble happened in 2009. An example of a HST image is in **Figure** 6.7,

Solar System Exploration

We continue to explore the solar system. A rover is like a spacecraft on wheels (**Figure** 6.8). It can wheel around on the surface. Scientists on Earth tell it where to go. The craft then collects and sends back data from that locations. The Mars Pathfinder studied the red planet for nearly three months in 1997. Two more rovers, Spirit and Opportunity, landed on Mars in 2004. Both were only designed to last 90 days, but have lasted many times longer. Spirit sent back data until it became stuck in January 2010. Opportunity continues to explore Mars. Several spacecraft are currently in orbit, studying the Martian surface and thin atmosphere.

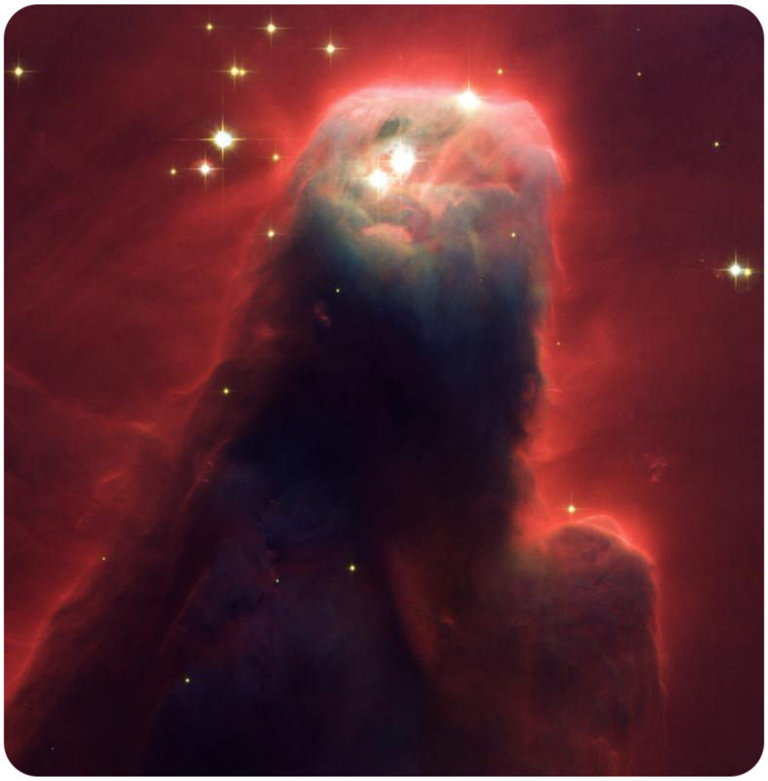

FIGURE 6.7

The Cone Nebula is a star-forming pillar of gas and dust.

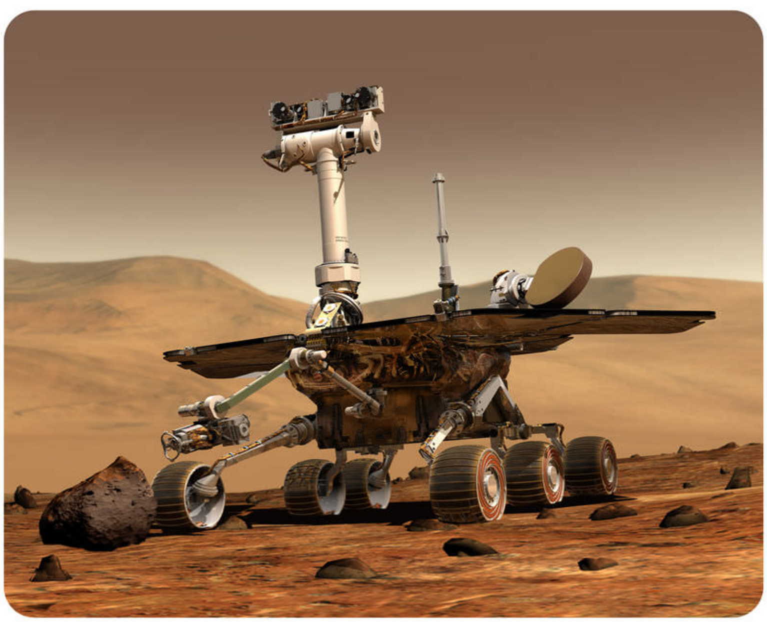

FIGURE 6.8

This artist's painting of one of the two Mars rovers shows the six wheels, as well as a set of instruments being extended forward by a robotic arm.

The Cassini mission has been studying Saturn, including its rings and moons, since 2004. The Huygens probe is studying Saturn's moon Titan. Titan has some of the conditions that are needed to support life.

Some missions visit the smaller objects in our solar system. The Deep Impact Probe collided with a comet in 2005. The probe sent back data from the impact. The Stardust mission visited another comet. There it collected tiny dust particles. Missions are underway to study some asteroids and Pluto. Small objects in our solar system may help us to understand how the solar system formed.

Future Missions

Budget concerns have impacted NASA in recent years. Many scientists have come together to discuss the goals of the U.S. space program. Some would like to further explore the Moon. Others are interested in landing on Mars. A variety of destinations in the inner solar system may also be visited. Private aerospace companies will play more of a role in the coming years.

MITK12 Videos: Science Out Loud

How to Discover a New Planet

Thousands of planets - ones that look totally different than what we're used to, and possibly could support life, exist outside of our solar system. But we're only just now starting to find them. In the video below, Ashley takes you behind the simple technique that astronomers have been using to discover these curious new planets.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/142990

Lesson Summary

- The Soviet Union put seven Salyut space stations into orbit between 1971 and 1982.
- The United States' first space station was Skylab. Skylab was in orbit from 1973 to 1979.
- The Soviet (later Russian) space station Mir was the first modular space station.
- The International Space Station involves many countries.
- Space shuttles are reusable vehicles for American astronauts to get into space.
- Recent space missions have mostly used small spacecraft, such as satellites and space probes, without crews.

Lesson Review Questions

Recall

1. What is a space station?

2. What is a space shuttle?

Apply Concepts

3. What is the purpose of a rover visiting a planet?
4. How is international cooperation helpful in space exploration?
5. How is international cooperation maybe harmful to space exploration?

Think Critically

6. Why don't we send astronauts to Mars?
7. What feature or features would you put in a future shuttle to avoid disasters?
8. Would you go into space in a shuttle? Why or why not?
9. Given the potential for disaster do you support manned space flight?

Points to Consider

- To date, a total of 22 people have died on space missions. In the two space shuttle disasters alone, 14 people died. However, space exploration and research have led to many great discoveries and new technologies. Do you think sending people into space is worth the risk? Why or why not?
- In the past several years, private companies have been developing vehicles and launch systems that can take people into space. What applications can you think of for such vehicles? What advantages and disadvantages are there to private companies building and launching spacecraft?

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CONCEPT 7 Fossils

Lesson Objectives

- Explain what fossils are.
- Describe how fossils form.
- State what scientists can learn from fossils.

Vocabulary

- fossilization
- index fossil

Introduction

For thousands of years, people have discovered fossils. They have wondered about the creatures that left them. In ancient times, fossils inspired myths. Stories were told about monsters and other incredible creatures. For example, dinosaur fossils discovered in China two thousand years ago were thought to be dragon bones.

Do you know what fossils are? Do you know how they form? And do you know what they can tell us about the past?

What Are Fossils?

Fossils are preserved remains or traces of organisms that lived in the past. Most preserved remains are hard parts, such as teeth, bones, or shells. Examples of these kinds of fossils are pictured in **Figure** 7.1. Preserved traces can include footprints, burrows, or even wastes. Examples of trace fossils are also shown in **Figure** 7.1.

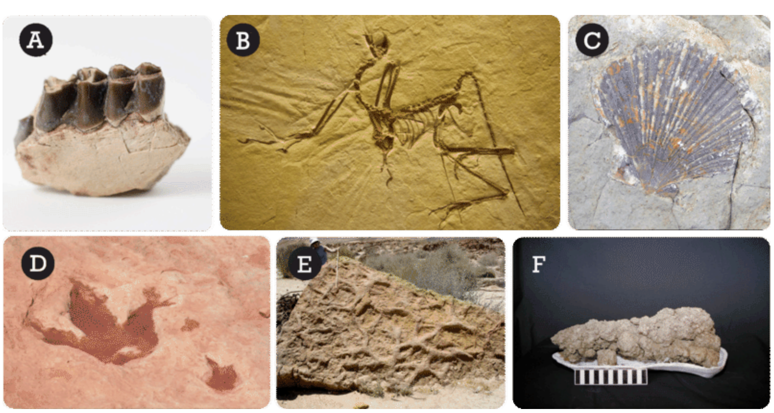

FIGURE 7.1

A variety of fossil types are pictured here. Preserved Remains: (A) teeth of a cow, (B) nearly complete dinosaur skeleton embedded in rock, (C) sea shell preserved in a rock. Preserved Traces: (D) dinosaur tracks in mud, (E) fossil animal burrow in rock, (F) fossil feces from a meat-eating dinosaur in Canada.

How Fossils Form

The process by which remains or traces of living things become fossils is called **fossilization**. Most fossils are preserved in sedimentary rocks.

Fossils in Sedimentary Rock

Most fossils form when a dead organism is buried in sediment. Layers of sediment slowly build up. The sediment is buried and turns into sedimentary rock. The remains inside the rock also turn to rock. The remains are replaced by minerals. The remains literally turn to stone. Fossilization is illustrated in **Figure** 7.2.

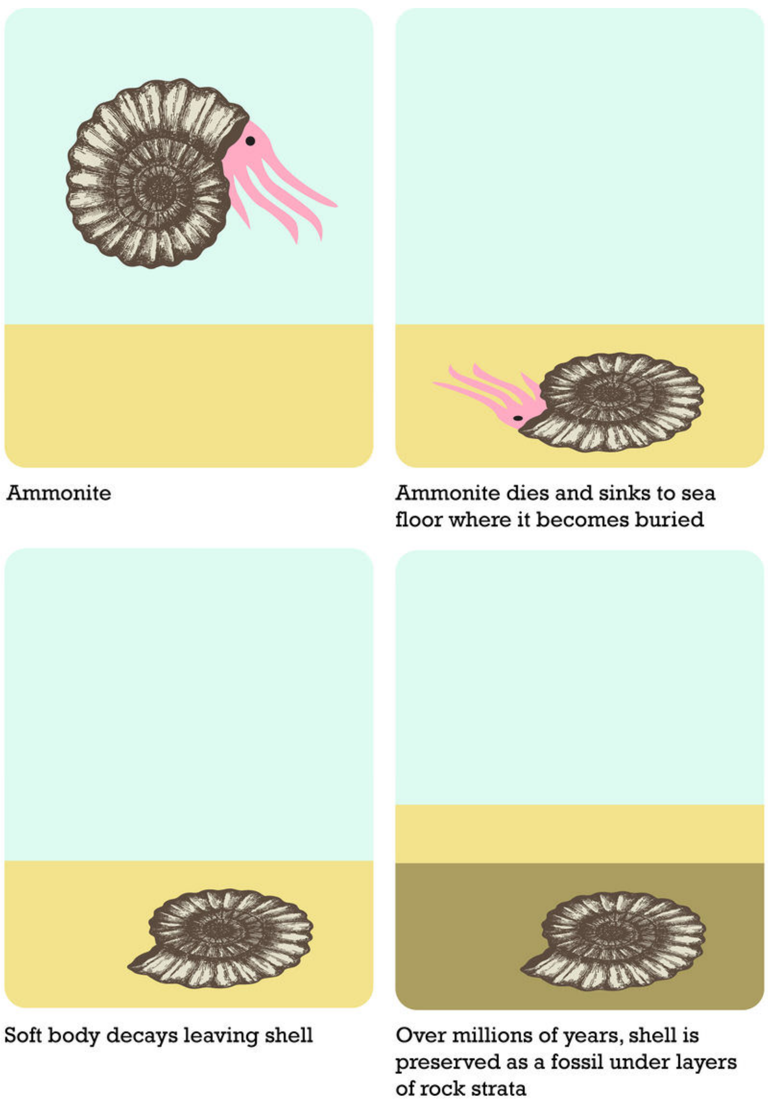

FIGURE 7.2
Fossilization. This flowchart shows how most fossils form.

Other Ways Fossils Form

Fossils may form in other ways. With complete preservation, the organism doesn't change much. As seen below, tree sap may cover an organism and then turn into amber. The original organism is preserved so that scientists might be able to study its DNA. Organisms can also be completely preserved in tar or ice. Molds and casts are another way organisms can be fossilized. A mold is an imprint of an organism left in rock. The organism's remains break down completely. Rock that fills in the mold resembles the original remains. The fossil that forms in the mold is called a cast. Molds and casts usually form in sedimentary rock. With compression, an organism's remains are put under great pressure inside rock layers. This leaves behind a dark stain in the rock.

You can read about them in **Figure** 7.3.

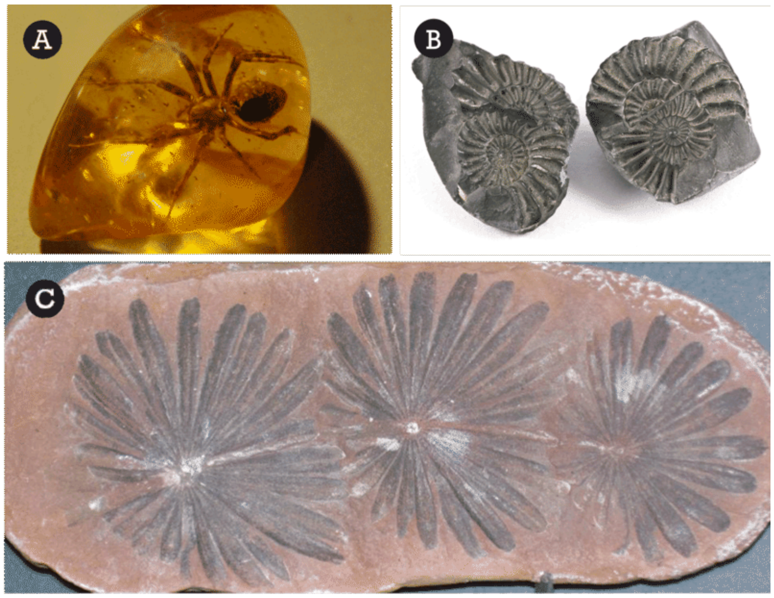

FIGURE 7.3
Ways Fossils Form. (A) Complete Preservation. This spider looks the same as it did the day it died millions of years ago! (B) Molds and Casts. A mold is a hole left in rock after an organism's remains break. A cast forms from the minerals that fill that hole and solidify. (C) Compression. A dark stain is left on a rock that was compressed. These ferns were fossilized by compression.

Why Fossilization is Rare

It's very unlikely that any given organism will become a fossil. The remains of many organisms are consumed. Remains also may be broken down by other living things or by the elements. Hard parts, such as bones, are much more likely to become fossils. But even they rarely last long enough to become fossils. Organisms without hard parts are the least likely to be fossilized. Fossils of soft organisms, from bacteria to jellyfish, are very rare.

Learning from Fossils

Of all the organisms that ever lived, only a tiny number became fossils. Still, scientists learn a lot from fossils. Fossils are our best clues about the history of life on Earth.

Fossil Clues

Fossils give clues about major geological events. Fossils can also give clues about past climates.

- Fossils of ocean animals are found at the top of Mt. Everest. Mt. Everest is the highest mountain on Earth. These fossils show that the area was once at the bottom of a sea. The seabed was later uplifted to form the Himalaya mountain range. An example is shown in the **Figure** 7.4.
- Fossils of plants are found in Antarctica. Currently, Antarctica is almost completely covered with ice. The fossil plants show that Antarctica once had a much warmer climate.

FIGURE 7.4
What can we learn from fossil clues like this fish fossil found in the Wyoming desert?

Index Fossils

Fossils are used to determine the ages of rock layers. **Index fossils** are the most useful for this. Index fossils are of organisms that lived over a wide area. They lived for a fairly short period of time. An index fossil allows a scientist to determine the age of the rock it is in.

Trilobite fossils, as shown in **Figure** 7.5, are common index fossils. Trilobites were widespread marine animals. They lived between 500 and 600 million years ago. Rock layers containing trilobite fossils must be that age. Different species of trilobite fossils can be used to narrow the age even more.

FIGURE 7.5
Trilobites are good index fossils. Why are trilobite fossils useful as index fossils?

Lesson Summary

- Fossils are preserved remains or traces of organisms that lived in the past. Most fossils form in sedimentary rock. Fossils can also be preserved in other ways. Fossilization is rare. It's very unlikely for any given organism to become a fossil.
- Fossils are the best form of evidence about the history of life on Earth. Fossils also give us clues about major geological events and past climates. Index fossils are useful for determining the ages of rock layers.

Lesson Review Questions

Recall

1. What are fossils?

2. Give examples of trace fossils.

3. Why are most preserved remains teeth, bones, or shells?

4. Describe how fossils form in sedimentary rock.

5. Why is fossilization rare?

Apply Concepts

6. Create an original diagram to explain the concept of index fossil. Your diagram should include sedimentary rock layers and fossils.

Think Critically

7. Compare and contrast the frog fossil in **Figure** 7.3 and the fossil dinosaur tracks in **Figure** 7.1. Infer what you might learn from each type of fossil.

8. Earth's climate became much cooler at different times in the past. Predict what fossil evidence you might find for this type of climate change.

Points to Consider

Fossils can help scientists estimate the ages of rocks. Some types of evidence show only that one rock is older or younger than another. Other types of evidence reveal a rock's actual age in years.

- What evidence might show that one rock is older or younger than another?
- What evidence might reveal how long ago rocks formed?

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CONCEPT 8 Relative Ages of Rocks

Lesson Objectives

- Explain how stratigraphy can be used to determine the relative ages of rocks.
- State how unconformities occur.
- Identify ways to match rock layers in different areas.
- Describe how Earth's history can be represented by the geologic time scale.

Vocabulary

- geologic time scale
- key bed
- law of superposition
- relative age
- stratigraphy
- unconformity

Introduction

The way things happen now is the same way things happened in the past. Earth processes have not changed over time. Mountains grow and mountains slowly wear away, just as they did billions of years ago. As the environment changes, living creatures adapt. They change over time. Some organisms may not be able to adapt. They become **extinct**, meaning that they die out completely.

Historical geologists study the Earth's past. They use clues from rocks and fossils to figure out the order of events. They think about how long it took for those events to happen.

Laws of Stratigraphy

The study of rock strata is called **stratigraphy**. The laws of stratigraphy can help scientists understand Earth's past. The laws of stratigraphy are usually credited to a geologist from Denmark named Nicolas Steno. He lived in the 1600s. The laws are illustrated in **Figure** 8.1. Refer to the figure as you read about the laws below.

Law of Superposition

Superposition refers to the position of rock layers and their relative ages. **Relative age** means age in comparison with other rocks, either younger or older. The relative ages of rocks are important for understanding Earth's history. New rock layers are always deposited on top of existing rock layers. Therefore, deeper layers must be older than layers closer to the surface. This is the **law of superposition**. You can see an example in **Figure** 8.2.

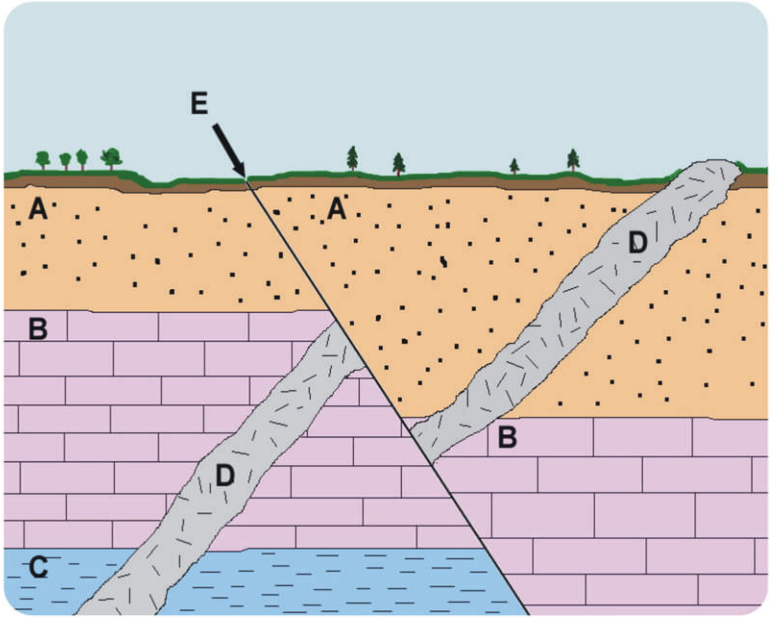


FIGURE 8.1
Laws of Stratigraphy. This diagram illustrates the laws of stratigraphy. A = Law of Superposition, B = Law of Lateral Continuity, C = Law of Original Horizontality, D = Law of Cross-Cutting Relationships

FIGURE 8.2
Superposition. The rock layers at the bottom of this cliff are much older than those at the top. What force eroded the rocks and exposed the layers?

Law of Lateral Continuity

Rock layers extend laterally, or out to the sides. They may cover very broad areas, especially if they formed at the bottom of ancient seas. Erosion may have worn away some of the rock, but layers on either side of eroded areas will still "match up."

Look at the Grand Canyon in **Figure** 8.3. It's a good example of lateral continuity. You can clearly see the same rock layers on opposite sides of the canyon. The matching rock layers were deposited at the same time, so they are the same age.

FIGURE 8.3
Lateral Continuity. Layers of the same rock type are found across canyons at the Grand Canyon.

Law of Original Horizontality

Sediments were deposited in ancient seas in horizontal, or flat, layers. If sedimentary rock layers are tilted, they must have moved after they were deposited.

Law of Cross-Cutting Relationships

Rock layers may have another rock cutting across them, like the igneous rock in **Figure** 8.4. Which rock is older? To determine this, we use the law of cross-cutting relationships. The cut rock layers are older than the rock that cuts across them.

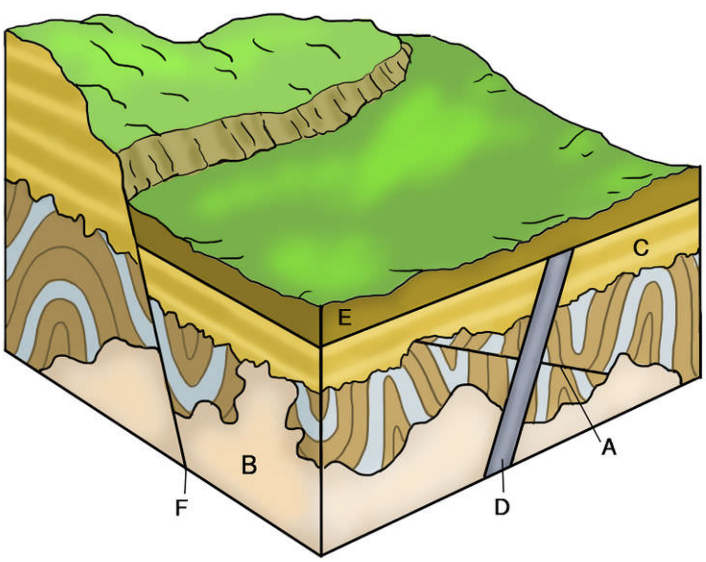


FIGURE 8.4
Cross-cutting relationships in rock layers. Rock D is a dike that cuts across all the other rocks. Is it older or younger than the other rocks?

Unconformities

Geologists can learn a lot about Earth's history by studying sedimentary rock layers. But in some places, there's a gap in time when no rock layers are present. A gap in the sequence of rock layers is called an **unconformity**.

Look at the rock layers in **Figure** 8.5. They show a feature called Hutton's unconformity. The unconformity was discovered by James Hutton in the 1700s. Hutton saw that the lower rock layers are very old. The upper layers are much younger. There are no layers in between the ancient and recent layers. Hutton thought that the intermediate rock layers eroded away before the more recent rock layers were deposited.

Hutton's discovery was a very important event in geology! Hutton determined that the rocks were deposited over time. Some were eroded away. Hutton knew that deposition and erosion are very slow. He realized that for both to occur would take an extremely long time. This made him realize that Earth must be much older than people thought. This was a really big discovery! It meant there was enough time for life to evolve gradually.

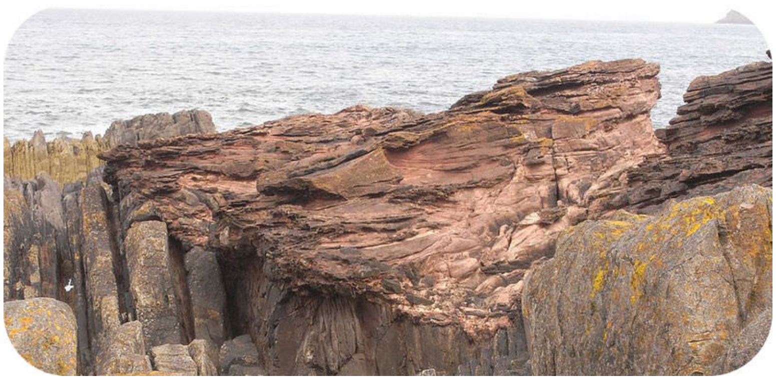


FIGURE 8.5
Hutton's unconformity, in Scotland.

Matching Rock Layers

When rock layers are in the same place, it's easy to give them relative ages. But what if rock layers are far apart? What if they are on different continents? What evidence is used to match rock layers in different places?

Widespread Rock Layers

Some rock layers extend over a very wide area. They may be found on more than one continent or in more than one country. For example, the famous White Cliffs of Dover are on the coast of southeastern England. These distinctive rocks are matched by similar white cliffs in France, Belgium, Holland, Germany, and Denmark (see **Figure** 8.6). It is important that this chalk layer goes across the English Channel. The rock is so soft that the Channel Tunnel connecting England and France was carved into it!

Key Beds

Like index fossils, key beds are used to match rock layers. A **key bed** is a thin layer of rock. The rock must be unique and widespread. For example, a key bed from around the time that the dinosaurs went extinct is very important. A thin layer of clay was deposited over much of Earth's surface. The clay has large amount of the element iridium.

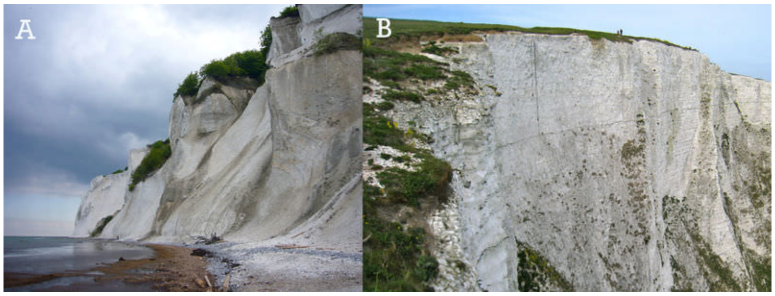


FIGURE 8.6
Chalk Cliffs. (A) Matching chalk cliffs in Denmark and (B) in Dover, U.K.

Iridium is rare on Earth but common in asteroids. This unusual clay layer has been used to match rock up layers all over the world. It also led to the hypothesis that a giant asteroid struck Earth and caused the dinosaurs to go extinct.

Using Index Fossils

Index fossils are commonly used to match rock layers in different places. You can see how this works in **Figure** 8.7. If two rock layers have the same index fossils, then they're probably about the same age.

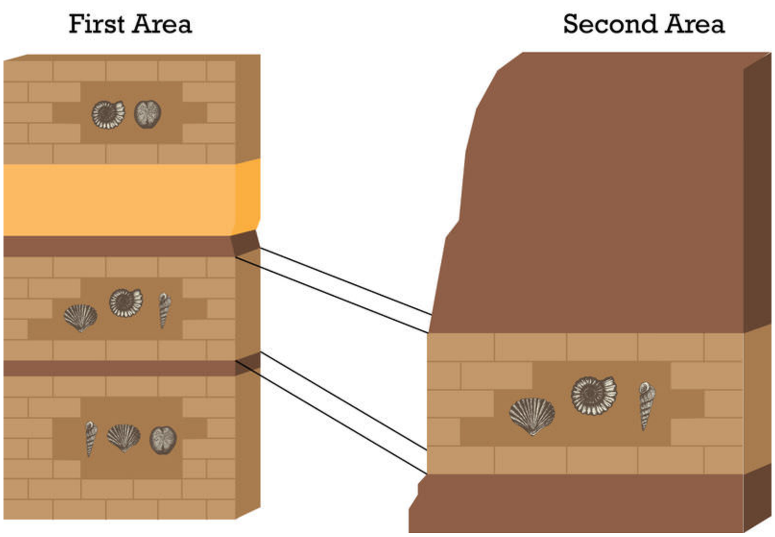


FIGURE 8.7
Using Index Fossils to Match Rock Layers. Rock layers with the same index fossils must have formed at about the same time. The presence of more than one type of index fossil provides stronger evidence that rock layers are the same age.

The Geologic Time Scale

Earth formed 4.5 billion years ago. Geologists divide this time span into smaller periods. Many of the divisions mark major events in life history.

Dividing Geologic Time

Divisions in Earth history are recorded on the **geologic time scale**. For example, the Cretaceous ended when the dinosaurs went extinct. European geologists were the first to put together the geologic time scale. So, many of the names of the time periods are from places in Europe. The Jurassic Period is named for the Jura Mountains in France and Switzerland, for example.

Putting Events in Order

To create the geologic time scale, geologists correlated rock layers. Steno's laws were used to determine the relative ages of rocks. Older rocks are at the bottom and younger rocks are at the top. The early geologic time scale could only show the order of events. The discovery of radioactivity in the late 1800s changed that. Scientists could determine the exact age of some rocks in years. They assigned dates to the time scale divisions. For example, the Jurassic began about 200 million years ago. It lasted for about 55 million years.

Divisions of the Geologic Time Scale

The largest blocks of time on the geologic time scale are called "eons." Eons are split into "eras." Each era is divided into "periods." Periods may be further divided into "epochs." Geologists may just use "early" or "late." An example is "late Jurassic," or "early Cretaceous." **Figure** 8.8 shows you what the geologic time scale looks like.

EON	ERA	PERIOD	MILLIONS OF YEARS AGO
Phanerozoic	Cenozoic	Quaternary	1.6
		Tertiary	66
	Mesozoic	Cretaceous	138
		Jurassic	205
		Triassic	240
	Paleozoic	Permian	290
		Pennsylvanian	330
		Mississippian	360
		Devonian	410
		Silurian	435
		Ordovician	500
		Cambrian	570
Proterozoic	Late Proterozoic Middle Proterozoic Early Proterozoic		2500
Archean	Late Archean Middle Archean Early Archean		3800?
Pre-Archean			

FIGURE 8.8
The Geologic Time Scale.

Life and the Geologic Time Scale

The geologic time scale may include illustrations of how life on Earth has changed. Major events on Earth may also be shown. These include the formation of the major mountains or the extinction of the dinosaurs. **Figure** 8.9 is a different kind of the geologic time scale. It shows how Earth's environment and life forms have changed.

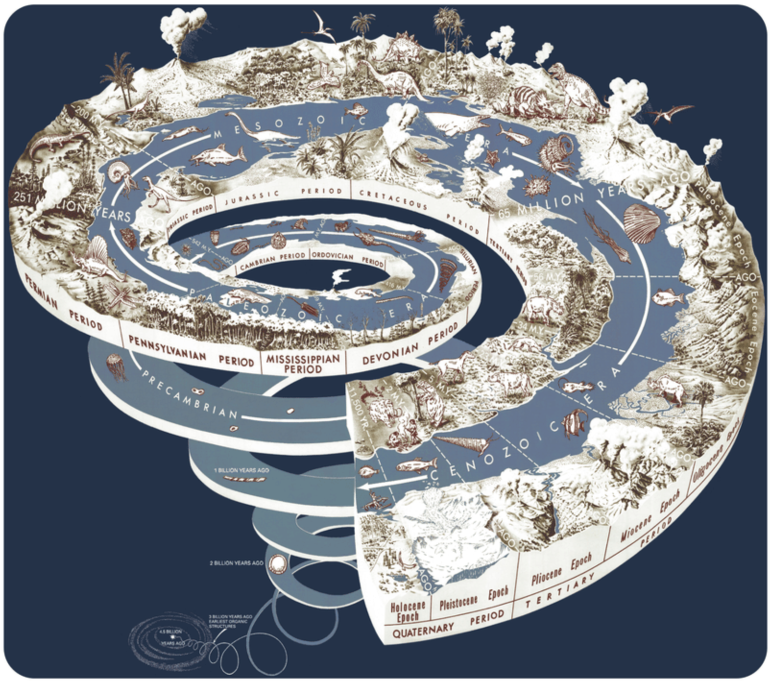


FIGURE 8.9
The evolution of life is shown on this spiral.

Your Place in Geologic Time

We now live in the Phanerozoic Eon, the Cenozoic Era, the Quaternary Period, and the Holocene Epoch. "Phanerozoic" means visible life. During this eon, rocks contain visible fossils. Before the Phanerozoic, life was microscopic. The Cenozoic Era means new life. It encompasses the most recent forms of life on Earth. The Cenozoic is sometimes called the Age of Mammals. Before the Cenozoic came the Mesozoic and Paleozoic. The Mesozoic means middle life. This is the age of reptiles, when dinosaurs ruled the planet. The Paleozoic is old life. Organisms like invertebrates and fish were the most common lifeforms.

Lesson Summary

- The study of rock layers is called stratigraphy. Laws of stratigraphy help scientists determine the relative ages of rocks. The main law is the law of superposition. This law states that deeper rock layers are older than layers closer to the surface.
- An unconformity is a gap in rock layers. They occur where older rock layers eroded away completely before new rock layers were deposited.
- Other clues help determine the relative ages of rocks in different places. They include key beds and index fossils.
- Scientists use the geologic time scale to illustrate the order in which events on Earth have happened.
- The geologic time scale was developed after scientists observed changes in the fossils going from oldest to youngest sedimentary rocks. They used relative dating to divide Earth's past in several chunks of time when similar organisms were on Earth.
- The geologic time scale is divided into eons, eras, periods, and epochs.

Lesson Review Questions

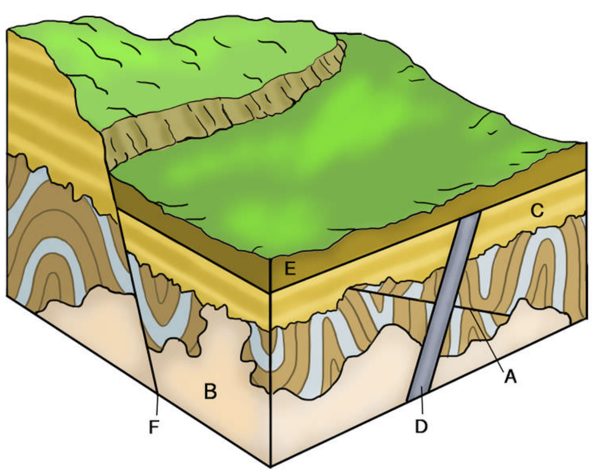
Recall

1. Define stratigraphy.
2. What is the relative age of a rock?
3. State the law of superposition.
4. What are unconformities?
5. How do key beds help date rock layers?

Apply Concepts

6. Apply laws of stratigraphy to explain the rock formation below.

7. Which rock in the illustration below formed first, the igneous rock (A) or the sedimentary rock (B)? Apply lesson concepts to support your answer.



8. Why did early geologic time scales not include the number of years ago that events happened?

Think Critically

9. Use the law of lateral continuity to explain why the same rock layers are found on opposite sides of the Grand Canyon.

10. Dinosaurs went extinct about 66 million years ago. Which period of geologic time was the last in which dinosaurs lived?

11. Why are sedimentary rocks more useful than metamorphic or igneous rocks in establishing the relative ages of rock?

Points to Consider

In this lesson, you read how scientists determine the relative ages of sedimentary rock layers. The law of superposition determines which rock layers are younger or older than others.

- What about the actual ages of rocks? Is there a way to estimate their ages in years?
- And what about other kinds of rocks? For example, is there a way to estimate the ages of igneous rocks?

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CONCEPT 9 Loss of Soil

Lesson Objectives

- Identify human actions that increase soil erosion.
- List ways to reduce soil loss.

Vocabulary

- contour cropping
- cover crop
- no-till planting
- strip cropping
- terracing
- windbreak

Introduction

It may "just" be dirt, but soil is one of our most important resources. We would starve without it. In fact, human beings — and most other land organisms — would never have evolved if it weren't for soil. That's because humans and other consumers rely on plants for food, and plants need soil. Soil anchors plant roots and provides them with water and nutrients.

People have always depended on soil. But for many generations, they took soil for granted. They didn't realize that their actions would cause so much soil erosion. The Dust Bowl dramatically showed people what being careless with soil could do.

Human Actions and Soil Erosion

Runoff carved channels in the soil in **Figure** 9.1. Running water causes most soil erosion, but wind can carry soil away too. What humans do to soil makes it more or less likely to be eroded by wind or water. Human actions that can increase soil erosion are described below.

Growing Crops

The photos in **Figure** 9.2 show how farming practices can increase soil erosion. Plant roots penetrate the soil and keep it from eroding. Plowing turns over bare soil and cuts through plant roots. Bare soil is exposed to wind and water. In the past, farmers always plowed fields before planting. Some farmers now use no-till farming, which does not disturb the soil as much.

The problem doesn't stop with plowing. Crops are usually planted in rows, with bare soil in between the rows. In places where crops grow only during part of the year, the land may be bare for a few months.

FIGURE 9.1
Runoff carried away the bare soil in this field. Why do you think the soil bare to begin with?

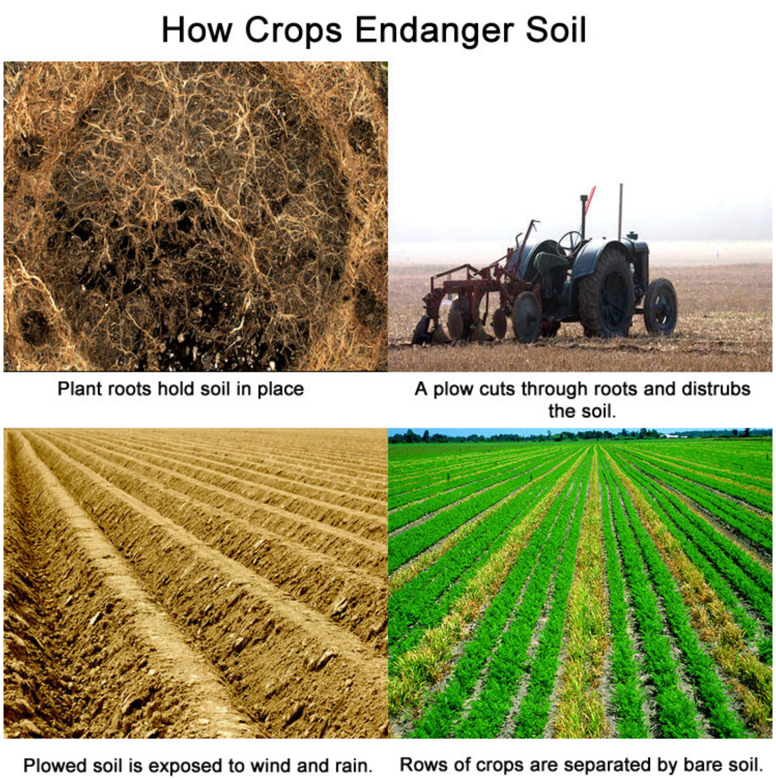

FIGURE 9.2
Farming leaves some soil exposed to erosion.

Grazing Animals

As you can see in **Figure** 9.3, some grazing animals, especially sheep and goats, eat grass right down to the roots. They may even pull the grass entirely out of the ground. Grazing animals can kill the grass or thin it out so much that it offers little protection to the soil. If animals are kept in the same place too long, the soil may become completely bare. The bare soil is easily eroded by wind and water.

FIGURE 9.3
Sheep and goats can damage plants and leave the soil bare.

Logging, Mining, and Construction

Other human actions that put soil at risk include logging, mining, and construction. You can see examples of each in **Figure** 9.4.

- When forests are cut down, the soil is suddenly exposed to wind and rain. Without trees, there is no leaf litter to cover the ground and protect the soil. When leaf litter decays, it adds humus and nutrients to the soil.
- Mining and construction strip soil off the ground and leave the land bare.
- Paved roads and parking lots prevent rainwater from soaking into the ground. This increases runoff and the potential for soil erosion.

Recreation

Even things that people do for fun can expose soil to erosion. For example, overuse of hiking trails can leave bare patches of soil. Off-road vehicles cause even more damage. You can see examples of this in **Figure** 9.5.

Preventing Soil Erosion

Soil is a renewable resource, but it can take thousands of years to form. That's why people need to do what they can to prevent soil erosion.

Farming Methods that Reduce Soil Erosion

The Dust Bowl taught people that soil could be lost by plowing and growing crops. This led to the development of new ways of farming that help protect the soil. Some of the methods are described in **Figure** 9.6.

Other Ways to Reduce Soil Erosion

There are several other ways to help prevent soil loss. Some of them are shown in **Figure** 9.7.

FIGURE 9.4

Logging, mining, construction, and paving surfaces are some of the ways that soil erosion increases.

FIGURE 9.5

What's fun for people may be bad for soil. Off-road vehicles can destroy plants and leave the ground bare. This sets up the soil for erosion.

- Prevent overgrazing. Frequently move animals from field to field. This gives the grass a chance to recover.
- Avoid logging steep hillsides. Cut only a few trees in any given place. Plant new trees to replace those that are cut down.
- Reclaim mine lands. Save the stripped topsoil and return it to the land. Once the soil is in place, plant trees and other plants to protect the bare soil.
- Use barriers to prevent runoff and soil erosion at construction sites. Plant grass to hold the soil in place.
- Develop paving materials that absorb water and reduce runoff.
- Restrict the use of off-road vehicles, especially in hilly areas.

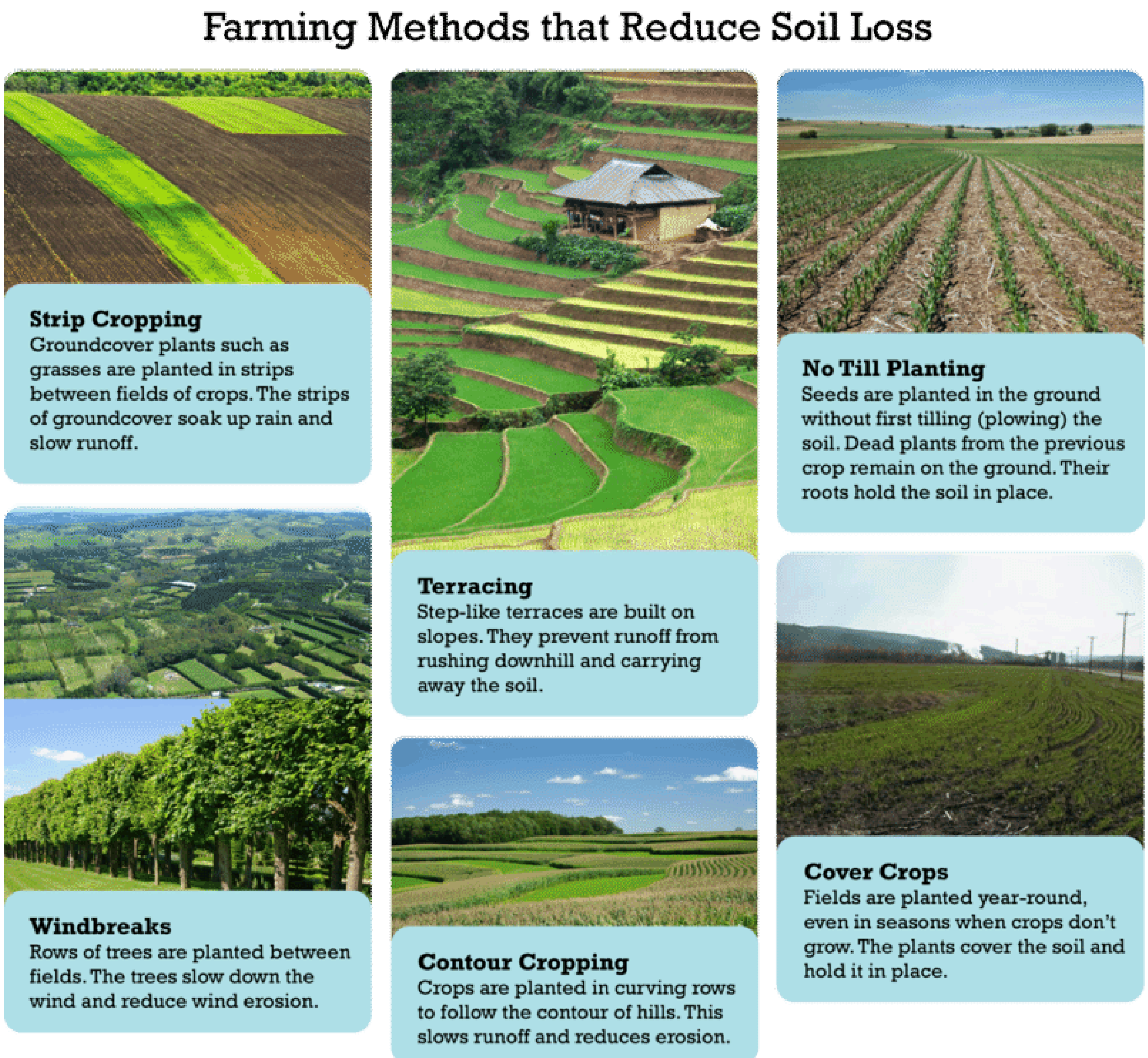

FIGURE 9.6

There are many farming methods that help prevent soil erosion.

Lesson Summary

- Many human actions make it easier for wind and water to carry away soil. They include plowing, logging, construction, and even some types of recreation.
- Farming methods such as strip cropping and terracing help prevent soil erosion. Other ways to protect soil include replanting forests and reclaiming mine land.

FIGURE 9.7
Taking steps to control erosion can help save soil.

Lesson Review Questions

Recall

1. How do plants help prevent soil loss?
2. How does logging endanger soil?
3. Describe the effects of construction on soil.
4. How do paved parking lots contribute to soil loss?
5. What is terracing? How does it reduce soil erosion?
6. What are cover crops, and why are they grown?

Apply Concepts

7. Off-road vehicles are popular in Pleasant Valley. Many people like to ride on a nearby grassy hillside. Write a letter to the editor of the Pleasant Valley Newspaper urging residents to protect the soil on the hillside. Your letter should explain why soil is important and why the soil on the hillside is at risk. Describe a better place to ride that is less likely to put soil at risk.

8. Look at **Figure** 9.8. Identify two farming methods that have been used to reduce soil loss. How do they help prevent erosion?

FIGURE 9.8

Think Critically

9. Explain why plowing before planting can lead to soil loss. What is the alternative? Why does it reduce soil loss?

Points to Consider

Increasing soil erosion isn't the only way that human actions can affect the land. Many human actions also pollute the land.

- What is pollution?
- What human actions might pollute the land?

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CONCEPT 10 The Human Population

Lesson Objectives

- Explain how populations grow.
- Describe how the human population has grown.
- State how the human population affects the environment.

Vocabulary

- carrying capacity
- demographic transition
- green revolution
- population growth rate (r)
- sustainable development

Introduction

Right now, there are almost 7 billion people in the world. As you read this sentence, at least three more people will be added. Think about that for second or so, and there's another three. You can actually watch the number of people increase, second by the second, at this link: http://www.intmath.com/Exponential-logarithmic-functions/world-population-live.php

Why is the human population growing so fast? Has it always grown this fast? What causes populations to grow? In this lesson, you'll find answers to all these questions.

How Populations Grow

A population usually grows when it has what it needs. If there's plenty of food and other resources, the population will get bigger. Look at **Table** 10.1. It shows how a population of bacteria grew. A single bacteria cell was added to a container of nutrients. Conditions were ideal. The bacteria divided every 30 minutes. After just 10 hours, there were more than a million bacteria! Assume the bacteria population keeps growing at this rate. How many bacteria will there be at 10.5 hours? Or at 12 hours?

TABLE 10.1: Growth of a Bacterial Population

Time (hours)	Number of Bacteria
0	1
0.5	2
1.0	4
1.5	8

TABLE 10.1: (continued)

Time (hours)	Number of Bacteria
2.0	16
2.5	32
3.0	64
3.5	128
4.0	256
4.5	512
5.0	1,024
5.5	2,048
6.0	4,096
6.5	8,192
7.0	16,384
7.5	32,768
8.0	65,536
8.5	131,072
9.0	262,144
9.5	524,288
10	1,048,576

Population Growth Rate

The **population growth rate** is how fast a population is growing. The letter *r* stands for the growth rate. The growth rate equals the number of new members added to the population in a year for each 100 members already in the population. The growth rate includes new members added to the population and old members removed from the population. Births add new members to the population. Deaths remove members from the population. The formula for population growth rate is:

$r = b - d$, where

b = birth rate (number of births in 1 year per 100 population members)
d = death rate (number of deaths in 1 year per 100 population members)

If the birth rate is greater than the death rate, *r* is positive. This means that the population is growing bigger. For example, if $b = 10$ and $d = 8$, $r = 2$. This means that the population is growing by 2 individuals per year for every 100 members of the population. This may not sound like much, but it's a fairly high rate of growth. A population growing at this rate would double in size in just 35 years!

If the birth rate is less than the death rate, *r* is negative. This means that the population is becoming smaller. What do you think might cause this to happen?

Carrying Capacity

A population can't keep growing bigger and bigger forever. Sooner or later, it will run out of things it needs. For a given species, there is a maximum population that can be supported by the environment. This maximum is called the **carrying capacity**. When a population gets close to the carrying capacity, it usually grows more slowly. You can see this in **Figure** 10.1. When the population reaches the carrying capacity, it stops growing.

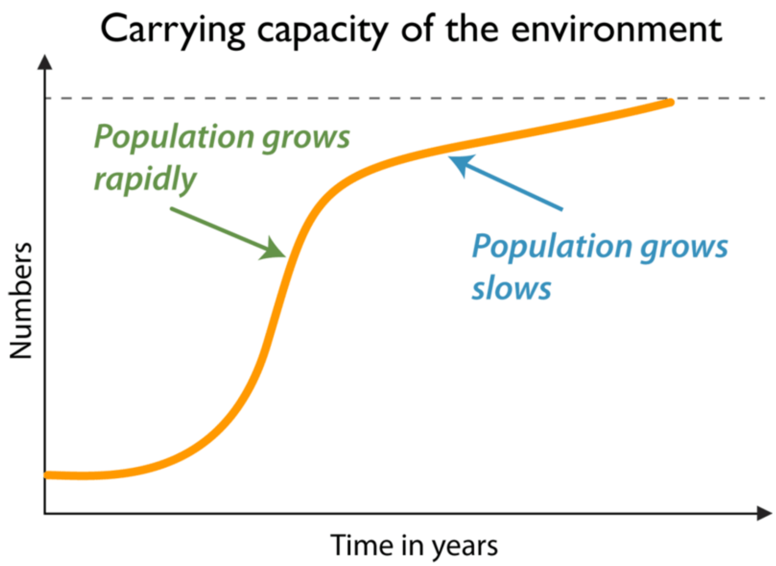

FIGURE 10.1
A population can't get much larger than the carrying capacity. What might happen if it did?

Human Population Growth

Figure 10.2 shows how the human population has grown. It grew very slowly for tens of thousands of years. Then, in the 1800s, something happened to change all that. The human population started to grow much faster.

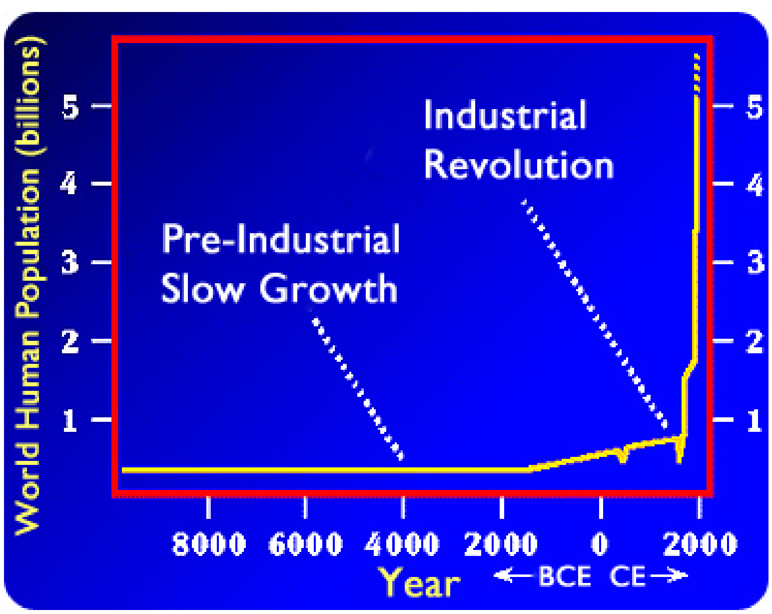

FIGURE 10.2
Growth of the human population. Until recently, the human population grew very slowly.

The Demographic Transition

The industrial revolution is what happened. The industrial revolution began in the late 1700s in Europe, North America, and a few other places. In these places, the human population grew faster. While there had always been a lot of births, the population grew because the death rate fell. It fell for several reasons:

1. New farm machines were invented. They increased the amount of food that could be produced. With more food, people were healthier and could live longer.
2. Steam engines and railroads were built. These machines could quickly carry food long distances. This made food shortages less likely.
3. Sanitation was improved. Sewers were dug to carry away human wastes (see **Figure** 10.3). This helped reduce the spread of disease.

FIGURE 10.3
Digging a London sewer (1840s). Before 1800, human wastes were thrown into the streets of cities such as London. In the early 1800s, sewers were dug to carry away the wastes.

With better food and less chance of disease, the death rate fell. More children lived long enough to reach adulthood and have children of their own. As the death rate fell, the birth rate stayed high for a while. This caused rapid population growth. However, the birth rate in these countries has since fallen to a rate close to that of the low death rate.

The result was slow population growth once again. These changes are called the **demographic transition**.

Recent Population Growth

More recently, the death rate has fallen because of the availability of more food and medical advances:

- A **green revolution** began in the mid 1900s. New methods and products increased how much food could be grown. For example, chemicals were developed that killed weeds without harming crops. Pesticides were developed that killed pests that destroyed crops.
- Vaccinations were developed that could prevent many diseases (see **Figure** 10.4). Antibiotics were discovered that could cure most infections caused by bacteria. Together, these two advances saved countless lives.

FIGURE 10.4
This child is getting a polio vaccine. He will never get sick with polio, which could save his live or keep him from becoming crippled.

Today in many countries, death rates have gone down but birth rates remain high. This means that the population is growing. **Figure** 10.5 shows the growth rates of human populations all over the world.

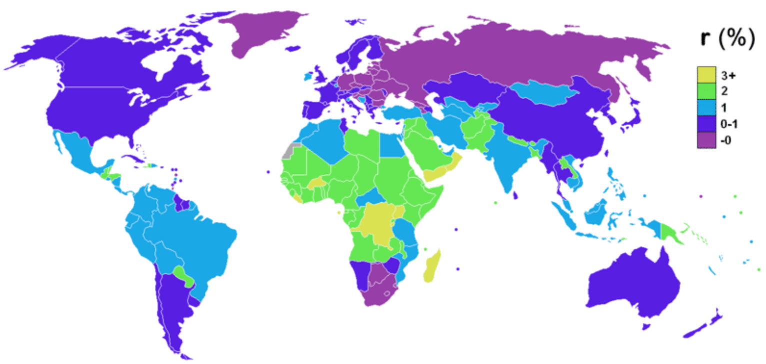

FIGURE 10.5
World population growth rates. Is the population growing faster in the wealthiest countries or the poorest countries?

Future Population Growth

The growth of the human population has started to slow down. You can see this in **Figure** 10.6. It may stop growing by the mid 2000s. Scientists think that the human population will peak at about 9 billion people. What will need to change for the population to stop growing then?

Human Population and the Environment

Are 9 billion people the human carrying capacity? It looks that way in **Figure** 10.6. But some people think there are too many of us already. That's because we are harming the environment.

- Supplying all those people with energy creates a lot of pollution. For example, huge oil spills have killed millions of living things.

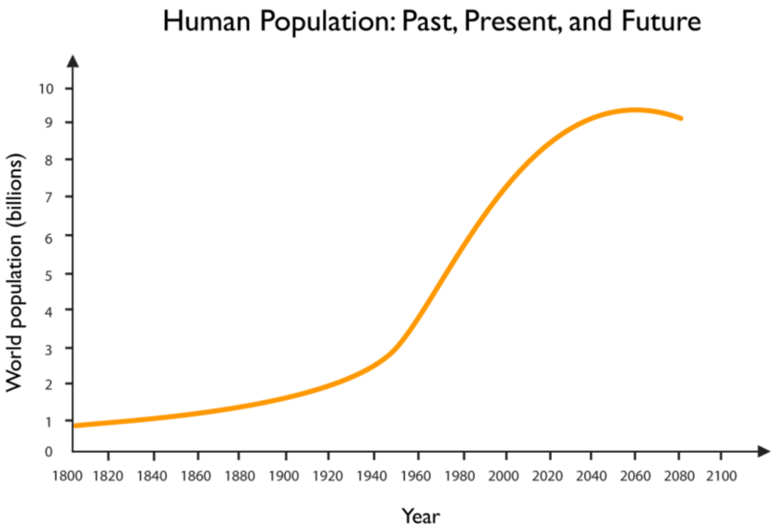

FIGURE 10.6
Compare this graph with the graph of the carrying capacity. What do you think is the carrying capacity of the human population?

- Burning fossil fuels pollutes the air. This also increases causes global warming.
- Fossil fuels and other resources are being used up. We may run out of oil by the mid 2000s. Many other resources will run out sooner or later.
- People are killing too many animals for food. For example, some of the best fishing grounds in the oceans have almost no fish left.
- People have destroyed many habitats. For example, they've drained millions of acres of wetlands. Wetlands have a great diversity of species. As wetlands shrink, species go extinct.
- People have allowed alien or invasive species - species originally from a different area - to invade new habitats. Often, the aliens have no natural enemies in their new home. They may drive native species extinct. **Figure** 10.7 gives an example.

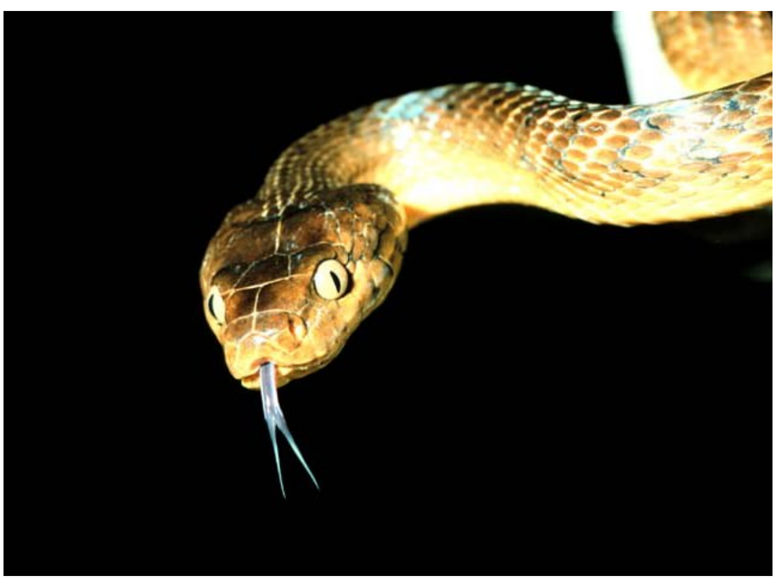

FIGURE 10.7
In the mid 1900s, Australian tree snakes invaded Guam and other islands in the Pacific. The snakes "stowed away" on boats and planes. Tree snakes had no natural enemies on the islands. Their populations exploded and they drove several island species extinct.

People themselves are also affected by the large size of the human population. A minority of people use most of the world's energy and other resources. Many other people lack resources. Many don't have enough to eat or live with the threat of hunger. Many also do not have safe, clean water. Some people live in crowded, run-down housing or something that is barely considered housing.

Sustainable Development

Is it possible for all the world's people to live well and still protect the planet? That's the aim of **sustainable development**. Its goals are to:

1. Distribute resources fairly.
2. Conserve resources so they won't run out.
3. Use resources in ways that won't harm ecosystems.

A smaller human population may be part of the solution. Better use of resources is another part. For example, when forests are logged, new trees should be planted. Everyone can help in the effort. What will you do?

Lesson Summary

- Populations usually grow bigger when they have what they need. How fast they grow depends on birth and death rates. They grow more slowly as they get close to the carrying capacity. This is the biggest population the environment can support.
- Human population growth was slow until the 1800s. Both birth and death rates were high. Then, the death rate started to fall. In industrial countries, the birth rate soon fell as well. However, in many other places, the birth rate is still high. As a result, the human population is growing rapidly. It may reach 9 billion by the mid 2000s.
- The human population is already harming the environment. Many people don't get enough resources. They may lack shelter, food, or clean water.
- Sustainable development is needed. This means using resources in such a way that they won't run out and the planet won't be harmed.

Lesson Review Questions

Recall

1. Define carrying capacity.

2. Describe how the human population grew up until the 1800s.

3. List two reasons the death rate fell in industrial countries in the 1800s.

4. What was the green revolution? When did happen? How did it affect the human population?

5. How is the human population harming the environment?

Apply Concepts

6. Compare the three populations in the **Table** 10.2. Which one is growing fastest? Explain your answer.

TABLE 10.2: Population Data for Question 6

Population	Birth Rate (per 100 people)	Death rate (per 100 people)
A	14	3
B	16	6
C	18	8

7. Draw a graph of population growth for North America. It should show how the rate of growth changed during the demographic transition.

Think Critically

8. Do you think the human population is already too big? Has it reached its carrying capacity? Why or why not?

9. What could you do to help sustainable development?

Points to Consider

In this chapter, you read how humans are harming the environment. For example, we are quickly using up many natural resources. Soil is one of our most precious natural resources. It takes a very long time to form. But it can be washed away in a single rainstorm.

- How do you think human actions are affecting the soil?
- What can people do to protect this important resource?

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7. Courtesy of NPS. http://commons.wikimedia.org/wiki/File:Brown_tree_snake_Boiga_irregularis_2_USGS_-Photograph.jpg . Public Domain