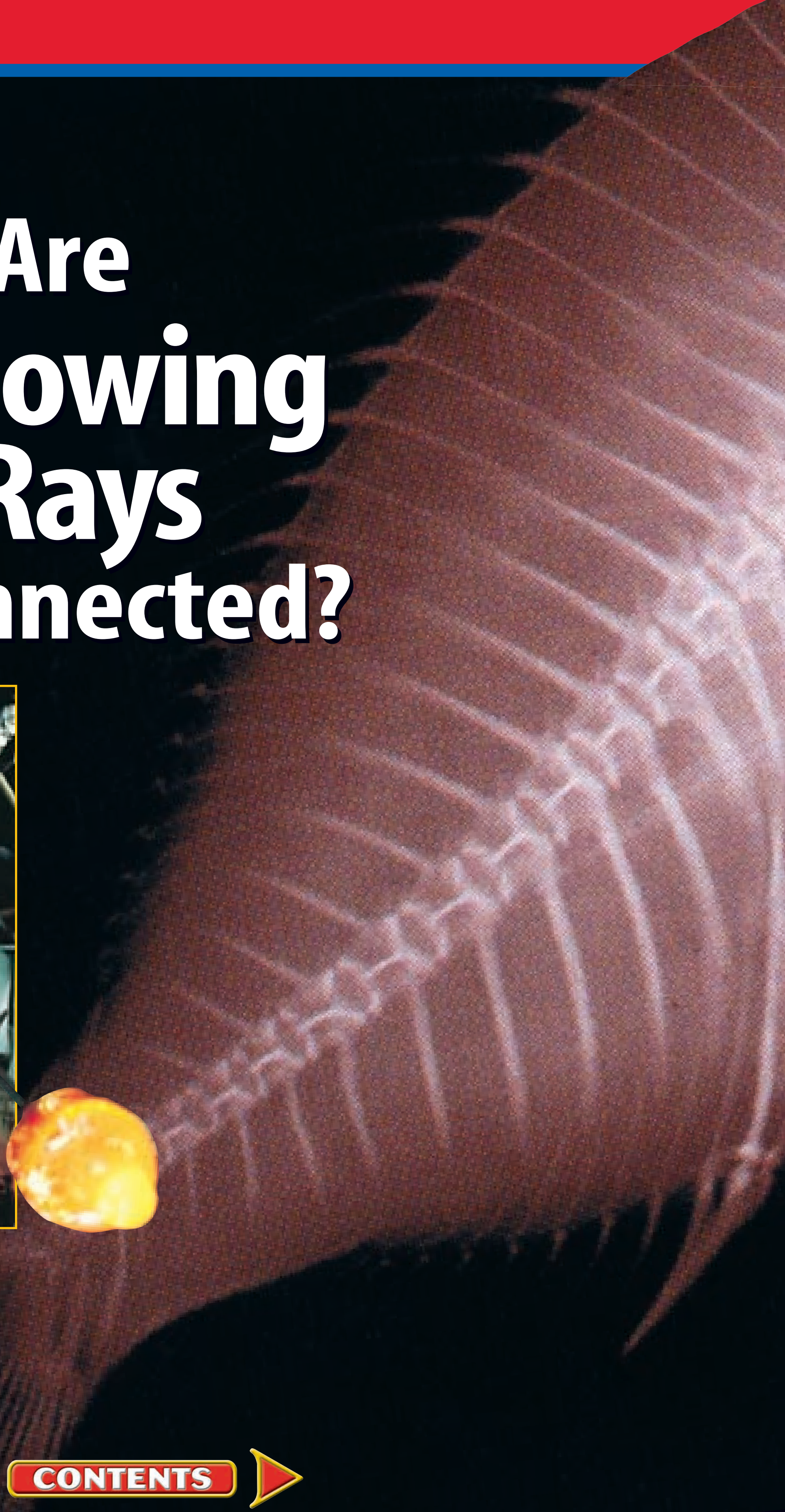
How Are Glassblowing & X Rays Connected?



NATIONAL GEOGRAPHIC

Glassblowing (far left) is an art in which air is blown through a tube to shape melted glass. In the mid-1800s, a glassblower created a glass tube, sealed metal electrodes into the ends, and removed most of the air from inside. When electricity was passed through the tube, it glowed. The glow aroused the curiosity of scientists, who began experimenting with similar tubes. In order to observe the glow more closely, one physicist surrounded a tube with black cardboard and darkened the laboratory. When the electric current was turned on, the tube glowed—but so did an object across the room! Apparently the tube was emitting some kind of radiation that could pass through cardboard. The mysterious radiation became known as X rays. Scientists eventually learned that X rays are a form of electromagnetic radiation, similar to visible light but with shorter wavelengths and higher energy. Since X rays pass through many substances, they have become important in medicine and science, making it possible to "see" structures inside the bodies of people—and also fish.

SCIENCE CONNECTION

X RAYS AND BODY STRUCTURES X rays are used routinely by doctors to examine bones and some other structures inside the body. On a piece of drawing paper, use a pencil to trace around one of your hands, including all the fingers. Inside the outline, sketch what you think an X-ray image of your hand might look like. Compare your drawing to a real X ray of a human hand. What types of body structures are most visible in X rays? What types of body structures are hard to see?

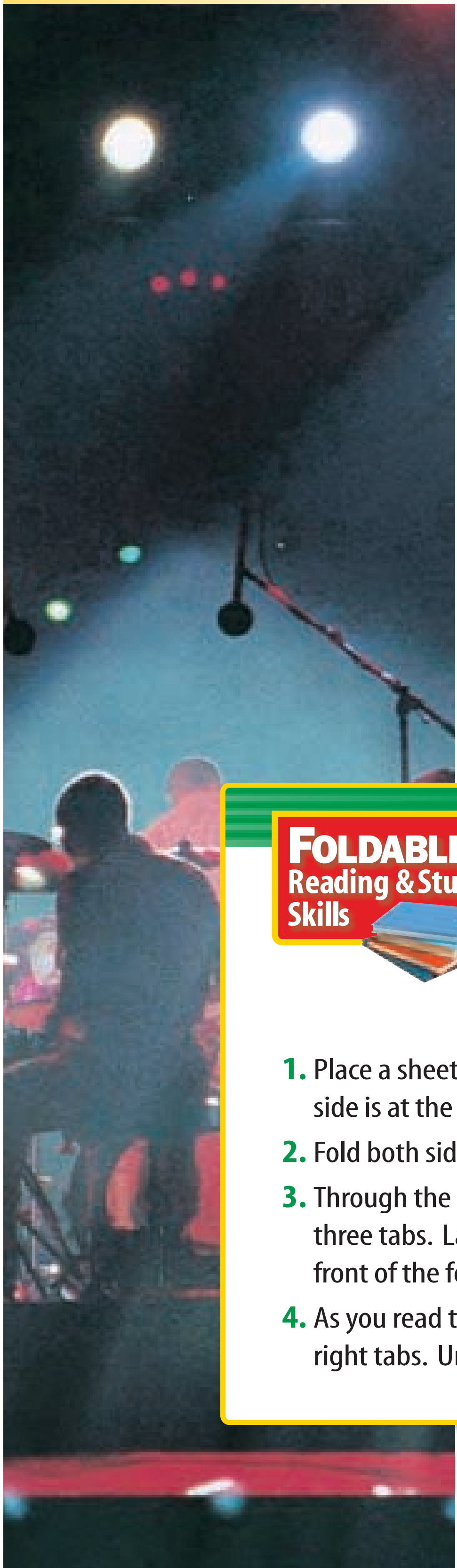
CHAPTER 11

Waves

The lights flash, guitar strings vibrate, keyboards wail, and the beat of the drums makes you want to get up and dance. All the sights and sounds of this concert are brought to you by waves. Waves are all around you. Some, like water and light waves, you can see. Others, like sound and radio waves, you cannot see. In this chapter, you will learn what waves are and how they travel. You will learn about the different kinds of waves and the properties all waves have in common. You also will find out how waves interact to transform energy into bright lights and spectacular sound.

What do you think?

Science Journal Look at the picture below with a classmate. Discuss what this might be. Here's a hint: *They make movies out of events like this.* Write your answer or best guess in your Science Journal.



EXPLORE ACTIVITY

Light enters your eyes and sound strikes your ears, enabling you to sense the world around you. Light and sound are waves that carry energy from one place to another. What else gets transferred from place to place when a wave carries energy? Does a wave transfer matter as well as energy? In this activity you'll observe one way that waves can transfer energy.

Demonstrating energy transfer

1. Line up four marbles on the groove formed by the spine of your textbook so that the marbles are touching each other.
2. Hold the first three marbles in place using three fingers of one hand.
3. Use your other hand to tap the first marble with a pen or pencil.
4. Observe what happens to the fourth marble.

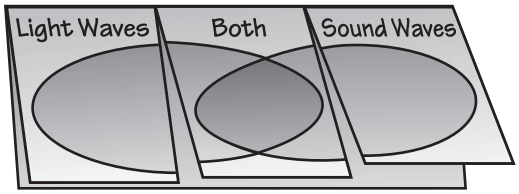
Observe

Write a paragraph in your Science Journal explaining how the fourth marble reacted to the pen tap. Draw a diagram showing the energy transfer through the marbles.

Before You Read

FOLDABLES Reading & Study Skills

Making a Venn Diagram Study Fold **Make the following Foldable to compare and contrast two types of waves.**



1. Place a sheet of paper in front of you so the long side is at the top. Fold the paper in half from top to bottom.
2. Fold both sides in. Unfold the paper so three sections show.
3. Through the top thickness of paper, cut along each of the fold lines to the top fold, forming three tabs. Label the tabs *Light Waves*, *Sound Waves*, and *Both* and draw ovals across the front of the foldable, as shown.
4. As you read the chapter, write characteristics of light and sound waves under the left and right tabs. Under the middle tab, write what light and sound waves have in common.

SECTION 1

The Nature of Waves

As You Read

What You'll Learn

- **Recognize** that waves carry energy but not matter.
- **Define** mechanical waves.
- **Distinguish** between transverse waves and compressional waves.

Vocabulary

wave
medium
transverse wave
compressional wave

Why It's Important

You hear and see the world around you because of the energy carried by waves.

What's in a wave?

A surfer bobs in the ocean waiting for the perfect wave, microwaves warm up your leftover pizza, and sound waves from your CD player bring music to your ears. Do these and other types of waves have anything in common with one another?

A **wave** is a repeating disturbance or movement that transfers energy through matter or space. For example, ocean waves disturb the water and transfer energy through it. During earthquakes, energy is transferred in powerful waves that travel through Earth. Light is a type of wave that can travel through empty space to transfer energy from one place to another, such as from the Sun to Earth.

Waves and Energy

Kerplop! A pebble falls into a pool of water and ripples form. As **Figure 1** shows, the pebble causes a disturbance that moves outward in the form of a wave. Because it is moving, the falling pebble has energy. As it splashes into the pool, the pebble transfers some of its energy to nearby water molecules, causing them to move. Those molecules then pass the energy along to neighboring water molecules, which, in turn, transfer it to their neighbors. The energy moves farther and farther from the source of the disturbance. What you see is energy traveling in the form of a wave on the surface of the water.

Figure 1
Falling pebbles transfer their kinetic energy to the particles of water in a pond, forming waves.
Where else have you seen waves?

Waves and Matter Imagine you're in a boat on a lake. Approaching waves bump against your boat, but they don't carry it along with them as they pass. The boat does move up and down and maybe even a short distance back and forth because the waves transfer some of their energy to it. But after the waves have moved on, the boat is still in nearly the same place. The waves don't even carry the water along with them. Only the energy carried by the waves moves forward. All waves have this property—they carry energy without transporting matter from place to place.

Reading Check *What do waves carry?*

Making Waves A wave will travel only as long as it has energy to carry. For example, when you drop a pebble into a puddle, the ripples soon die out and the surface of the water becomes still again.

Suppose you are holding a rope at one end, and you give it a shake. You would create a pulse that would travel along the rope to the other end, and then the rope would be still again, as **Figure 2** shows. Now suppose you shake your end of the rope up and down for a while. You would make a wave that would travel along the rope. When you stop shaking your hand up and down, the rope will be still again. It is the up-and-down motion of your hand that creates the wave.

Anything that moves up and down or back and forth in a rhythmic way is vibrating. The vibrating movement of your hand at the end of the rope created the wave. In fact, all waves are produced by something that vibrates.

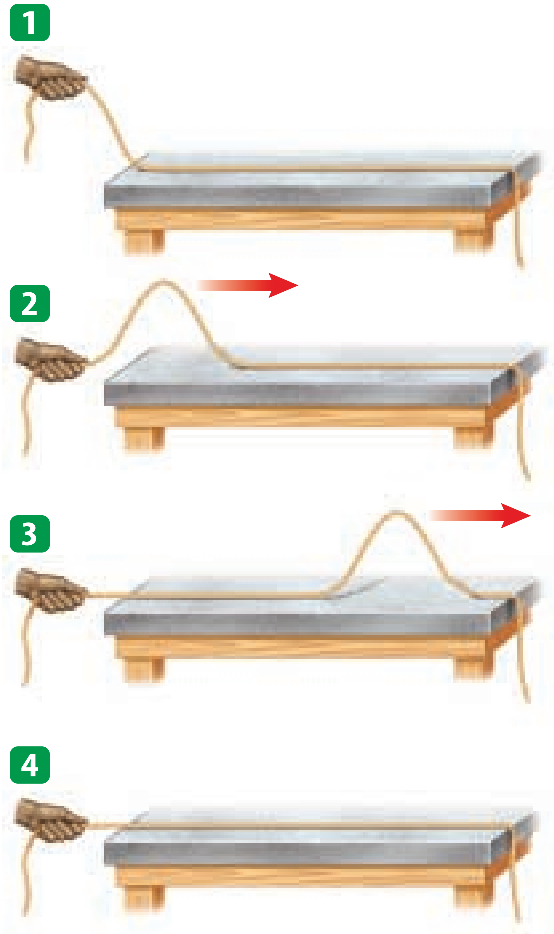


Figure 2
A wave will exist only as long as it has energy to carry. *What happened to the energy that was carried by the wave in this rope?*

Mechanical Waves

Sound waves travel through the air to reach your ears. Ocean waves move through water to reach the shore. In both cases, the matter the waves travel through is called a **medium.** The medium can be a solid, a liquid, a gas, or a combination of these. For sound waves the medium is air, and for ocean waves the medium is water. Not all waves need a medium. Some waves, such as light and radio waves, can travel through space. Waves that can travel only through matter are called mechanical waves. The two types of mechanical waves are transverse waves and compressional waves.

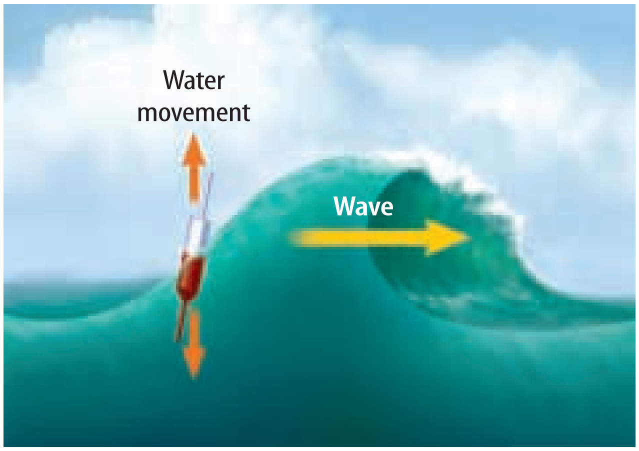


Figure 3
A water wave travels horizontally as the water moves vertically up and down.

Transverse Waves In a **transverse wave,** matter in the medium moves back and forth at right angles to the direction that the wave travels. For example, **Figure 3** shows how a wave in the ocean moves horizontally, but the water that the wave passes through moves up and down. When you shake one end of a rope while your friend holds the other end, you are making transverse waves. The wave and its energy travel from you to your friend as the rope moves up and down.

Compressional Waves In a **compressional wave**, matter in the medium moves back and forth in the same direction that the wave travels. You can model compressional waves with a coiled spring toy, as shown in **Figure 4.** Squeeze several coils together at one end of the spring. Then let go of the coils, still holding onto coils at both ends of the spring. A wave will travel along the spring. As the wave moves, it looks as if the whole spring is moving toward one end. Suppose you watched the coil with yarn tied to it as in **Figure 4.** You would see that it moves back and forth as the wave passes, and then stops moving after the wave has passed. The wave carries energy, but not matter, forward along the spring.

Sound Waves Sound waves are compressional waves. When a noise is made, such as when a locker door slams shut and vibrates, nearby air molecules are pushed together by the vibrations. The air molecules are squeezed together like the coils in a coiled spring toy are when you make a compressional wave with it. The compressions travel through the air to make a wave.

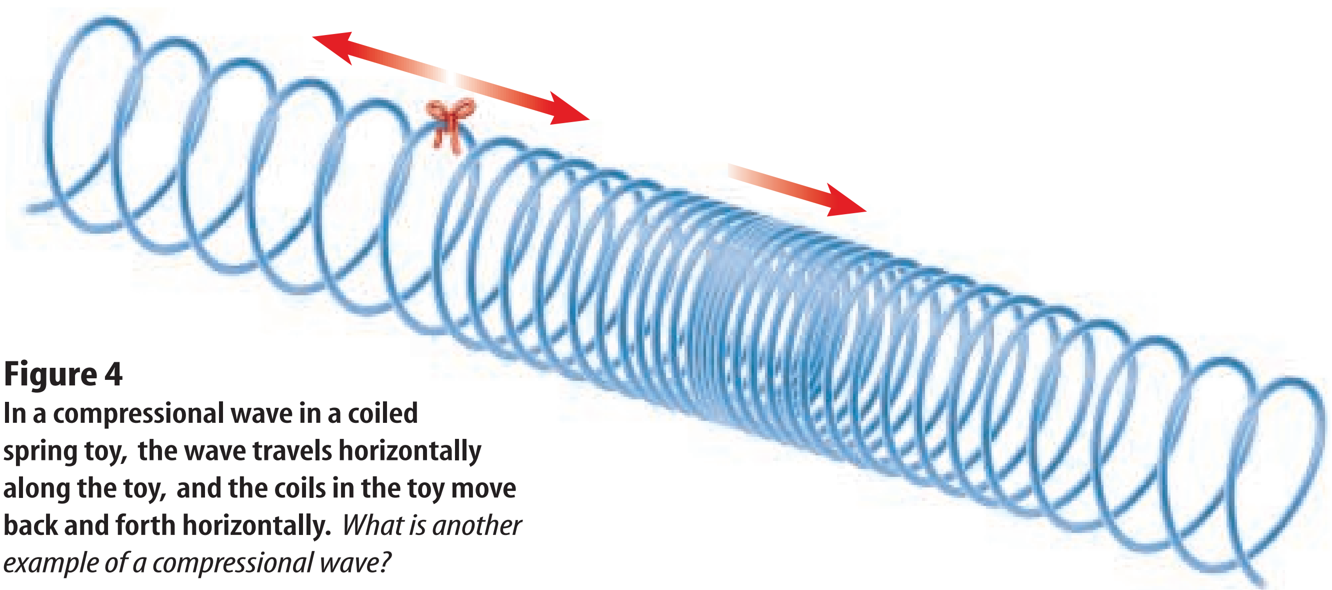


Figure 4
In a compressional wave in a coiled spring toy, the wave travels horizontally along the toy, and the coils in the toy move back and forth horizontally. *What is another example of a compressional wave?*

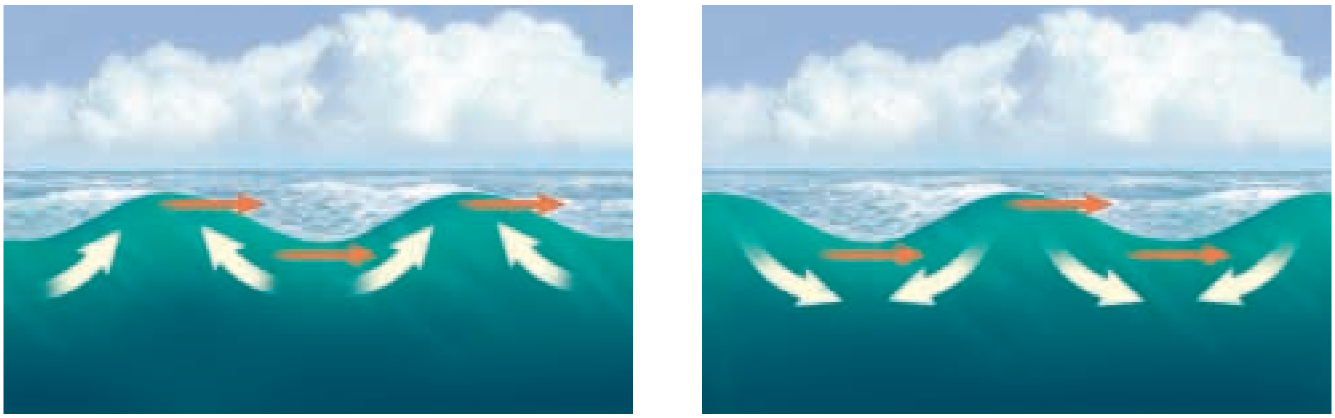
Sound in Other Materials Sound waves also can travel through other mediums, such as water and wood. Particles in these mediums also are pushed together and move apart as the sound waves travel through them. When a sound wave reaches your ear, it causes your eardrum to vibrate. Your inner ear then sends signals to your brain, and your brain interprets the signals as sound.

Reading Check *How do sound waves travel in solids?*

Water Waves Water waves are not purely transverse waves. The surface of the water moves up and down as the waves go by. But the water also moves a short distance back and forth. This movement happens because the low part of the wave can be formed only by pushing water forward or backward toward the high part of the wave, as in **Figure 5A.** Then as the wave passes, the water that was pushed aside moves back to its initial position, as in **Figure 5B.** In fact, if you looked closely, you would see that the combination of this up-and-down and back-and-forth motion causes water to move in circles. Anything floating on the surface of the water absorbs some of the waves' energy and bobs in a circular motion.

Ocean waves are formed most often by wind blowing across the ocean surface. As the wind blows faster and slower, the changing wind speed is like a vibration. The size of the waves that are formed depends on the wind speed, the distance over which the wind blows, and how long the wind blows. **Figure 6** on the next page shows this process.

Figure 5
When a wave passes, the surface of the water doesn't just move up and down.

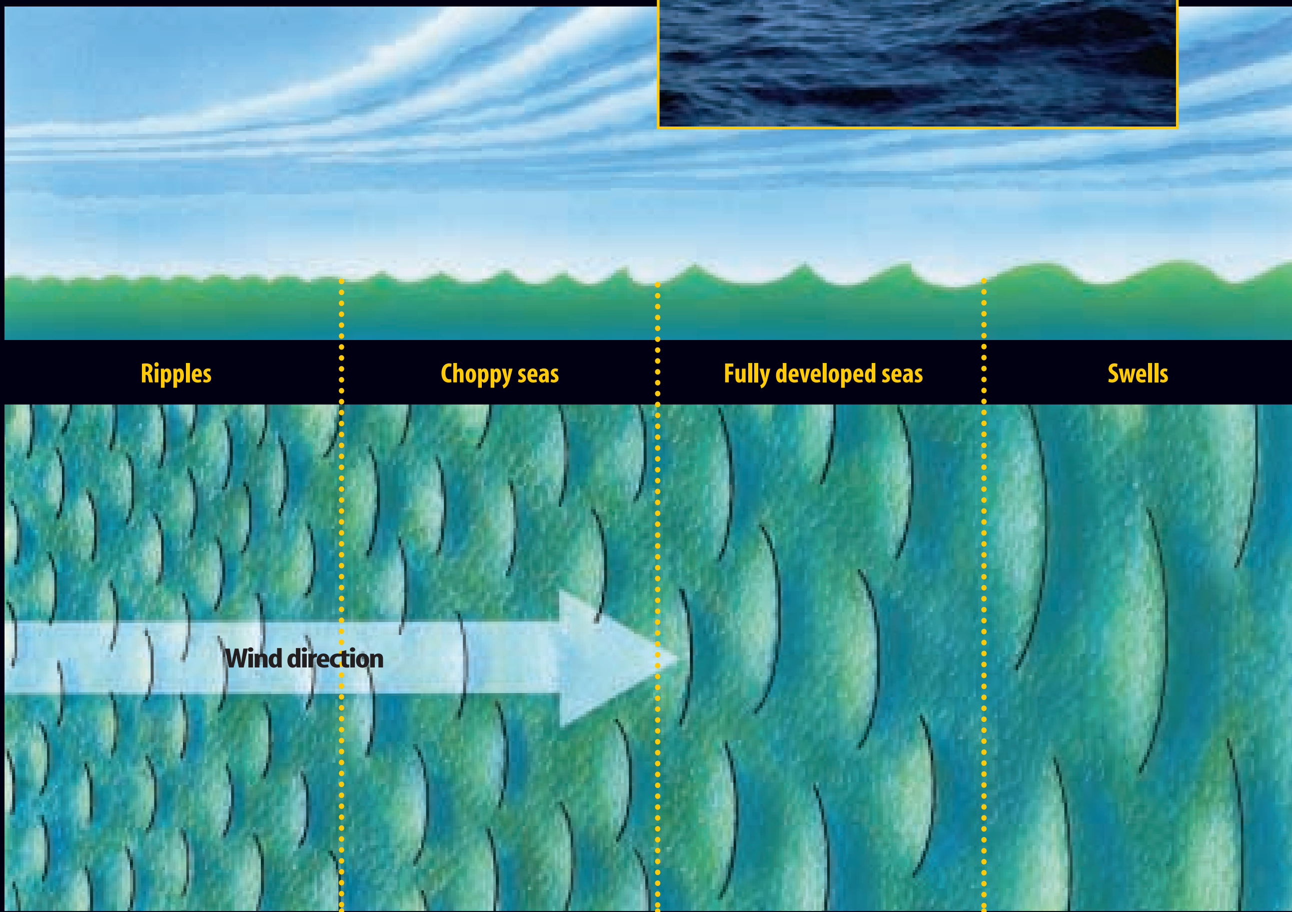


A **The low point of a water wave is formed when water is pushed aside and up to the high point of the wave.**

B **The water that is pushed aside returns to its initial position.**

Figure 6

When wind blows across an ocean, friction between the moving air and the water causes the water to move. As a result, energy is transferred from the wind to the surface of the water. The waves that are produced depend on the length of time and the distance over which the wind blows, as well as the wind speed.



▲ Wind causes ripples to form on the surface of the water. As ripples form, they provide an even larger surface area for the wind to strike, and the ripples increase in size.

▲ Waves that are higher and have longer wavelengths grow faster as the wind continues to blow, but the steepest waves break up, forming whitecaps. The surface is said to be choppy.

▲ The shortest-wavelength waves break up, while the longest-wavelength waves continue to grow. When these waves have reached their maximum height, they form fully developed seas.

▲ After the wind dies down, the waves lose energy and become lower and smoother. These smooth, long-wavelength ocean waves are called swells.

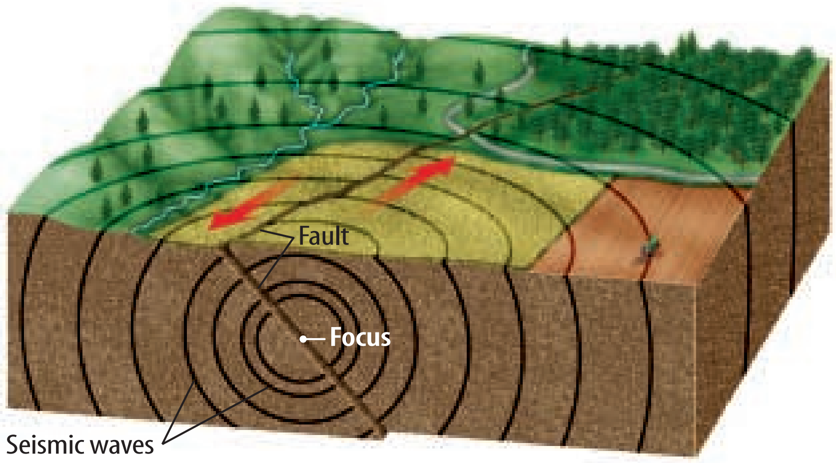


Figure 7
When Earth's crust breaks, the energy that is released is transmitted outward, causing an earthquake. *Why are earthquakes mechanical waves?*

Earth Science INTEGRATION

Seismic Waves If you pulled too hard on a guitar string, the string would break and you would hear a noise. The noise occurs because the string vibrates for a short time after it breaks, and creates a sound wave. In a similar way, forces in Earth's crust can cause regions of the crust to shift, bend, or even break. The breaking crust vibrates, creating seismic (SIZE mihk) waves that carry energy outward, as shown in **Figure 7.** Seismic waves are a combination of compressional and transverse waves. They can travel through Earth and along Earth's surface. When objects on Earth's surface absorb some of the energy carried by seismic waves, they move and shake. The more the crust moves during an earthquake, the more energy is released.

CLICK HERE

SCIENCE Online

Research Seismic waves generated by earthquakes are used to map the interior of Earth. Visit the Glencoe Science Web site at **science.glencoe.com** to find out more about interpreting seismic waves. Write a summary of what you learn.

Section 1 Assessment

1. Give one example of a transverse wave and one example of a compressional wave.
2. Why doesn't a boat on a lake move forward when a water wave passes? Describe the boat's motion.
3. Describe how to model compressional waves using a coiled spring toy.
4. What is a mechanical wave?
5. **Think Critically** If ocean waves do not carry matter forward, why do boats need anchors?

Skill Builder Activities

6. **Comparing and Contrasting** Compare and contrast transverse and compressional waves. What does each type of wave carry? How does matter in the medium move? **For more help, refer to the Science Skill Handbook.**
7. **Communicating** In your Science Journal, describe waves you have observed. Have you ever observed the effects of a wave without being able to see it? Explain. **For more help, refer to the Science Skill Handbook.**

SECTION 2

Wave Properties

As You Read

What You'll Learn

- **Compare and contrast** transverse and compressional waves.
- **Describe** the relationship between frequency and wavelength.
- **Explain** how a wave's amplitude is related to the wave's energy.
- **Calculate** wave speed.

Vocabulary

crest	wavelength
trough	frequency
rarefaction	amplitude

Why It's Important

Changing the properties of waves enables them to be used in many ways.

The Parts of a Wave

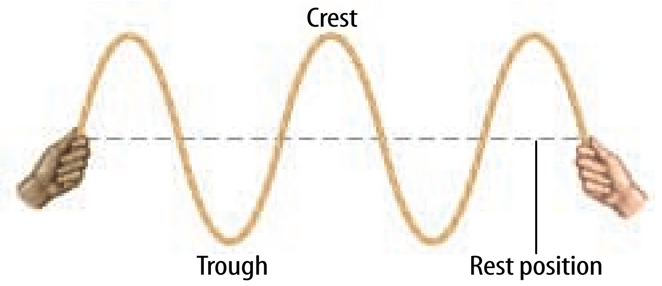
Besides the fact that sound waves, water waves, and seismic waves travel in different mediums, what makes these waves different from each other? Waves can differ in how much energy they carry and in how fast they travel. Waves also have other characteristics that make them different from each other. These characteristics can be used to describe waves.

Suppose you shake the end of a rope and make a transverse wave. The transverse wave has alternating high points and low points. **Figure 8A** shows that the highest points of a transverse wave are called the **crests,** and the lowest points are called the **troughs.**

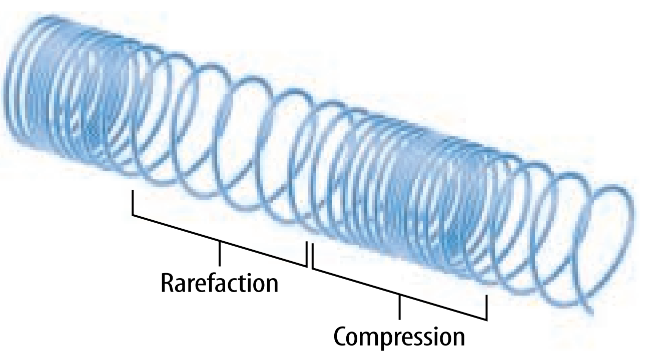
Reading Check *What are the highest and lowest points of a transverse wave?*

On the other hand, a compressional wave has no crests and troughs. When a compressional wave passes through a medium, it creates a region where the medium becomes crowded together and more dense, as in **Figure 8B.** This region is called the compression. When you make compressional waves in a coiled spring, the compression is the region where the coils are close together. **Figure 8B** also shows that the coils in the region next to a compression are spread apart, or less dense. This less-dense region of a compressional wave is called a **rarefaction** (rar uh FAK shun).

Figure 8
Transverse and compressional waves have different characteristics.

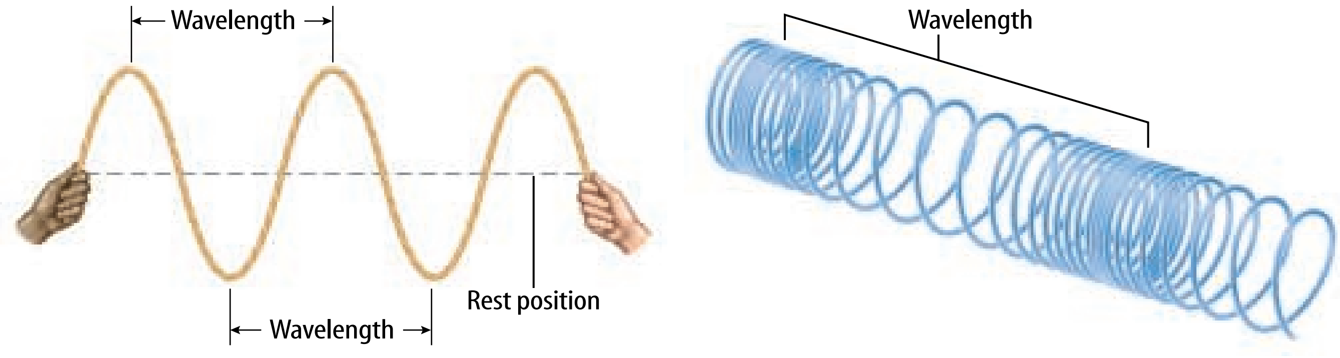


A **The highest point of a transverse wave is a crest. The lowest point is a trough.**



B **The densest parts of a compressional wave are compressions. The least dense parts are rarefactions.**

Figure 9
One wavelength starts at any point on a wave and ends at the nearest point just like it.



A **For transverse waves, a wavelength can be measured from crest to crest or trough to trough.**

B **The wavelength of a compressional wave can be measured from the start of one compression to the start of the next or the start of one rarefaction to the start of the next.** *How many compressions are in each wavelength?*

Wavelength

Waves also have a property called wavelength. A **wavelength** is the distance between one point on a wave and the nearest point just like it. For example, in transverse waves you can measure wavelength from crest to crest or from trough to trough, as shown in **Figure 9A.**

A wavelength in a compressional wave is the distance between two neighboring compressions or two neighboring rarefactions, as shown in **Figure 9B.** You can measure from the start of one compression to the start of the next compression or from the start of one rarefaction to the start of the next rarefaction. The wavelengths of sound waves that you can hear range from a few centimeters for the highest-pitched sounds to about 15 m for the deepest sounds.

Frequency

What is your favorite radio station? When you tune your radio to a station, you are choosing radio waves of a certain frequency. The **frequency** of a wave is the number of wavelengths that pass a fixed point each second. You can find the frequency of a transverse wave by counting the number of crests or troughs that pass by a point each second. The frequency of a compressional wave is the number of compressions or rarefactions that pass a point every second. Frequency is expressed in hertz (Hz). A frequency of 1 Hz means that one wavelength passes by in 1 s. In SI units, 1 Hz is the same as 1/s.

Reading Check *What does a frequency of 7 Hz mean?*

Observing Wavelength

1. Fill a pie plate or other wide pan with about 2 cm of water.
2. Lightly tap your finger once per second on the surface of the water and observe the spacing of the water waves.
3. Increase the rate of your tapping, and observe the spacing of the water waves.

Analysis

1. How is the spacing of the water waves related to their wavelength?
2. How does the spacing of the water waves change when the rate of tapping increases?

Wavelength Is Related to Frequency If you make transverse waves with a rope, you increase the frequency by moving the rope up and down faster. Moving the rope faster also makes the wavelength shorter. This relationship is always true—as frequency increases, wavelength decreases. **Figure 10** compares the wavelengths and frequencies of two different waves.

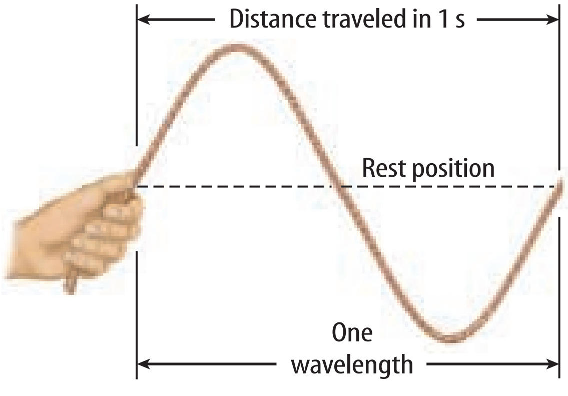
The frequency of a wave is always equal to the rate of vibration of the source that creates it. If you move the rope up, down, and back up in 1 s, the frequency of the wave you generate is 1 Hz. If you move the rope up, down, and back up five times in 1 s, the resulting wave has a frequency of 5 Hz.

Wave Speed

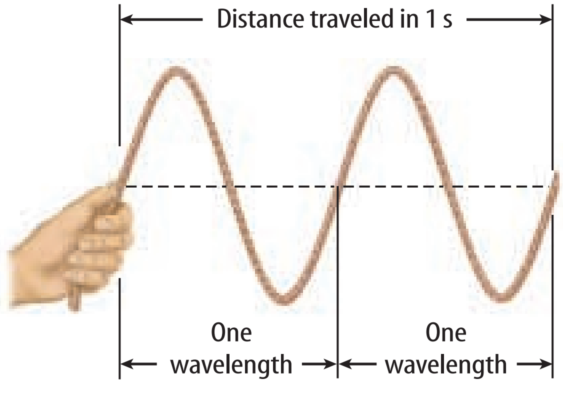
You're at a large stadium watching a baseball game, but you're high up in the bleachers, far away from the action. The batter swings and you see the ball rising in the air. An instant later you hear the crack of the bat hitting the ball. You see the impact before you hear it because all waves do not travel at the same speed. Light waves travel much faster than sound waves do. Therefore, the light waves reflected from the flying ball reach your eyes before the sound waves created by the crack of the bat reach your ears.

The speed of a wave depends on the properties of the medium it is traveling through. For example, sound waves usually travel faster in liquids and solids than they do in gases. On the other hand, light waves travel more slowly in liquids and solids than they do in gases or in empty space. Also, sound waves usually travel faster in a material if the temperature of the material is increased. For example, sound waves travel faster in air at 20°C than in air at 0°C.

Figure 10
The wavelength of a wave decreases as the frequency increases.



A The rope is moved down, up, and down again one time in 1 s. One wavelength is created on the rope.



B The rope is shaken down, up, and down again twice in 1 s. Two wavelengths are created on the rope.

Calculating Wave Speed Sometimes people want to know how fast a wave is traveling. For example, earthquakes beneath the ocean floor can produce giant water waves called tsunamis. Knowing how fast the wave is moving helps determine when the wave will reach land. Wave velocity (v) describes how fast the wave moves forward. You can calculate the velocity of a wave by multiplying its frequency times its wavelength. Wavelength is represented by the Greek letter lambda (λ) and frequency is represented by f.

$$\text{velocity} = \text{wavelength} \times \text{frequency}$$
$$v = \lambda \times f$$

For example, what is the speed of a wave with a wavelength of 2 m and a frequency of 3 Hz? Because 3 Hz equals 3 wavelengths/second or $3 \times 1/\text{s}$, the wave's speed is:

$$v = \lambda \times f = 2 \text{ m} \times 3 \text{ Hz} = 2 \text{ m} \times 3/\text{s} = 6 \text{ m/s}$$

Earth Science INTEGRATION

Tsunamis can cause serious damage when they hit land. These waves can be up to 30 m tall and can travel more than 700 km/h. Research areas of the world where tsunamis are most likely to occur.

Math Skills Activity

Calculating Wave Speed

Example Problem

A wave is traveling at a velocity of 12 m/s and its wavelength is 3 m. Calculate the wave frequency.

Solution

1	*This is what you know:*	velocity (v) = 12 m/s wavelength (λ) = 3 m
2	*This is what you want to find:*	wave frequency (f)
3	*This is the equation you need to use:*	$v = \lambda \times f$
4	*Solve for f and then substitute the known values in the equation.*	$f = v/\lambda$ $f = 12 \text{ m/s} / 3 \text{ m} = 4 \times 1/\text{s} = 4 \text{ Hz}$

Check your answer by substituting the frequency and given wavelength into the original equation. Do you calculate the velocity that was given?

Practice Problem

1. A wave is traveling at a speed of 18 m/s with a frequency of 3 Hz. A second wave is traveling at a speed of 16 m/s with a frequency of 4 Hz. What is the difference between these two wavelengths?

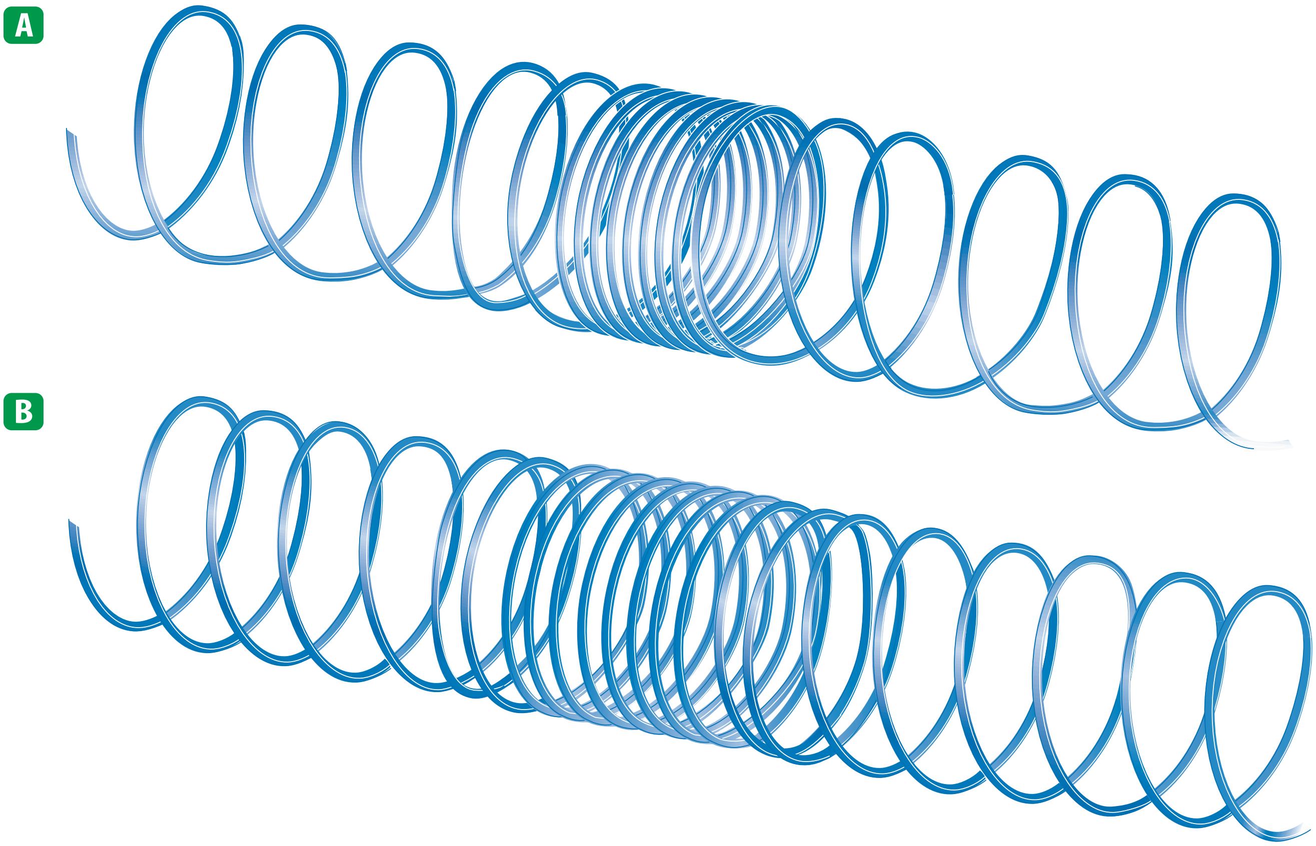
For more help, refer to the Math Skill Handbook.

Amplitude and Energy

Why do some earthquakes cause terrible damage, while others are hardly felt? This is because the amount of energy a wave carries can vary. **Amplitude** is related to the energy carried by a wave. The greater the wave's amplitude is, the more energy the wave carries. Amplitude is measured differently for compressional and transverse waves.

Amplitude of Compressional Waves The amplitude of a compressional wave is related to how tightly the medium is pushed together at the compressions. The denser the medium is at the compressions, the larger its amplitude is and the more energy the wave carries. For example, it takes more energy to push the coils in a coiled spring toy tightly together than to barely move them. The closer the coils are in a compression, the farther apart they are in a rarefaction. So the less dense the medium is at the rarefactions, the more energy the wave carries. **Figure 11** shows compressional waves with different amplitudes.

Figure 11
The amplitude of a compressional wave depends on how dense its medium is at each compression. A This coiled spring has the greater amplitude. B This coiled spring has the smaller amplitude.



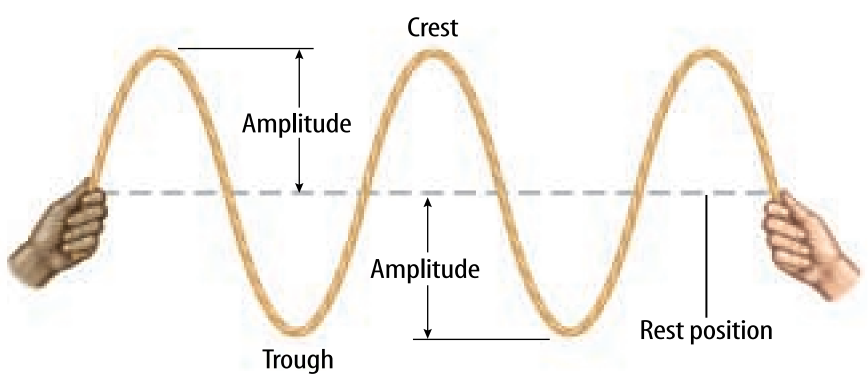


Figure 12
The amplitude of a transverse wave is the distance between a crest or a trough and the position of the medium at rest. *How could you create waves with different amplitudes in a piece of rope?*

Amplitude of Transverse Waves How can you tell the difference between a transverse wave that carries a lot of energy from one that carries little energy? If you've ever been knocked over by an ocean wave, you know that the higher the wave, the more energy it carries. Remember that the amplitude of a wave increases as the energy carried by the wave increases. So a tall ocean wave has a greater amplitude than a short ocean wave does. The amplitude of any transverse wave is the distance from the crest or trough of the wave to the rest position of the medium, as shown in **Figure 12.**

Section 2 Assessment

1. Sketch a transverse wave and label the crest, trough, wavelength, rest position, and amplitude.
2. How does the wavelength of a wave change when frequency decreases? When frequency increases?
3. How is the density at a compression in a compressional wave like the height of a transverse wave?
4. A wave travels at a speed of 4.0 m/s and has a frequency of 3.5 Hz. What is the wavelength?
5. **Think Critically** Remember that sound waves are compressional waves. Why do you think sound waves travel faster in solids than in gases?

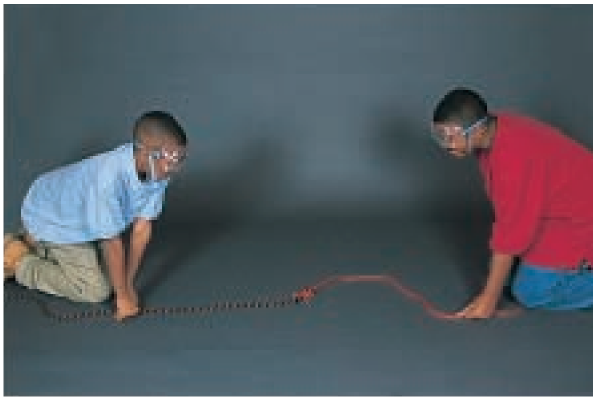
Skill Builder Activities

6. **Concept Mapping** Create a concept map that shows the relationships among the following: *crest, trough, compression, rarefaction, wavelength, wave frequency, amplitude,* and *wave speed.* **For more help, refer to the Science Skill Handbook.**
7. **Drawing Conclusions** The unit *megahertz (MHz)* means "1 million Hertz." Your favorite FM radio station broadcasts at a frequency of 104.1 MHz, or 104.1 million Hz. Your friend prefers a station at 101.9 MHz. If the radio waves from both stations travel at the same speed, which station uses longer wavelengths? Explain. **For more help, refer to the Science Skill Handbook.**

Activity

Waves in Different Mediums

Have you ever swum underwater? If so, even with your head underwater, you probably still heard some sounds. Sound waves can travel through more than one medium, including air and water. The noises probably sounded different underwater than they do in air. How do waves change when they pass through different mediums?



What You'll Investigate

How is the speed of a wave affected by the type of material it is traveling through?

Possible Materials

small coiled spring toys (made out of metal and plastic)
rope, both heavy and light
string
long rubber band, such as those used for exercising
strip of heavy cloth, such as a towel
strip of light cloth, such as nylon panty hose
stopwatch

Goals

- **Demonstrate** transverse and compressional waves.
- **Compare** the speed of waves traveling through different mediums.

Safety Precautions

Procedure

1. Use pieces of each material that are about the same length. For each material, have a partner hold one end of the material still while you shake the material back and forth between two set points to make a wave. Identify the points by placing markers or chairs on the floor. Shake each material in the same way.
2. Have someone time how long a pulse takes to reach the opposite end of the material.
3. Tie the two different types of rope together or tie a heavy piece of cloth to a lighter piece. **Observe** how the wave changes when it moves from one material to the other.
4. **Observe** compressional waves using coiled spring toys. You can connect two different types of coiled spring toys together to see how a compressional wave changes in different mediums.

Conclude and Apply

1. Did the waves traveling through the different mediums have the same amplitude? Explain why or why not.
2. Did the waves travel at the same speed through the different mediums? **Explain.**
3. **Explain** how the waves changed when they moved from one material to another.
4. Waves carry energy. Where did the waves created in this activity get their energy?

SECTION

3 The Behavior of Waves

Reflection

If you are one of the last people to leave your school building at the end of the day, you'll probably find the hallways quiet and empty. When you close your locker door, the sound echoes down the empty hall. Your footsteps also make a hollow sound. Thinking you're all alone, you may be startled by your own reflection in a classroom window. The echoes and your image looking back at you from the window are caused by wave reflection.

Reflection occurs when a wave strikes an object and bounces off of it. All types of waves—including sound, water, and light waves—can be reflected. How does the reflection of light allow the boy in **Figure 13** to see himself in the mirror? It happens in two steps. First, light strikes his face and bounces off. Then, the light reflected off his face strikes the mirror and is reflected into his eyes.

A similar thing happens to sound waves when your footsteps echo. Sound waves form when your foot hits the floor and the waves travel through the air to both your ears and other objects. Sometimes when the sound waves hit another object, they reflect off it and come back to you. Your ears hear the sound again, a few seconds after you first heard your footstep.

Bats and dolphins use echoes to learn about their surroundings. A dolphin makes a clicking sound and listens to the echoes. These echoes enable the dolphin to locate nearby objects.

As You Read

***What* You'll Learn**

- **Identify** the law of reflection.
- **Recognize** what makes waves bend.
- **Explain** how waves combine.

Vocabulary

refraction
diffraction
interference
standing wave
resonance

***Why* It's Important**

You can check your reflection in a mirror, hear an echo, and see shadows because of how waves behave.

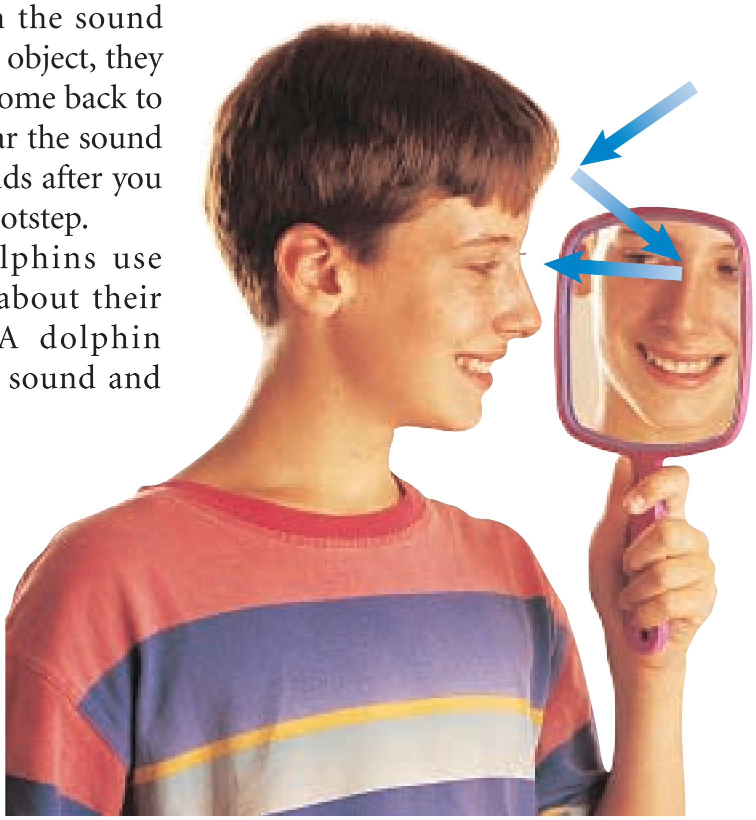
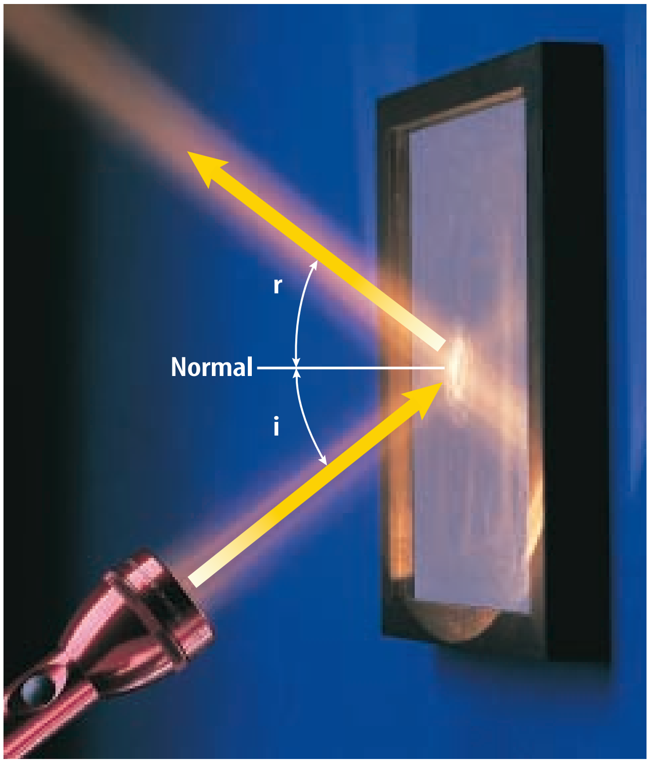


Figure 13
The light that strikes the boy's face is reflected into the mirror. The light then reflects off the mirror into his eyes. *What kinds of waves can be reflected?*



The Law of Reflection Look at the two light beams in **Figure 14.** The beam striking the mirror is called the incident beam. The beam that bounces off the mirror is called the reflected beam. The line drawn perpendicular to the surface of the mirror is called the normal. The angle formed by the incident beam and the normal is the angle of incidence, labeled *i*. The angle formed by the reflected beam and the normal is the angle of reflection, labeled *r*. According to the law of reflection, the angle of incidence is equal to the angle of reflection. All reflected waves obey this law. Objects that bounce from a surface sometimes behave like waves that are reflected from a surface. For example, suppose you throw a bounce pass while playing basketball. The angle between the ball's direction and the normal to the floor is the same before and after it bounces.

Figure 14
A flashlight beam is made of light waves. When any wave is reflected, the angle of incidence, *i*, equals the angle of reflection, *r*.

Refraction

Do you notice anything unusual in **Figure 15?** The pencil looks as if it is broken into two pieces. But if you pulled the pencil out of the water, you would see that it is unbroken. This illusion is caused by refraction. How does it work?

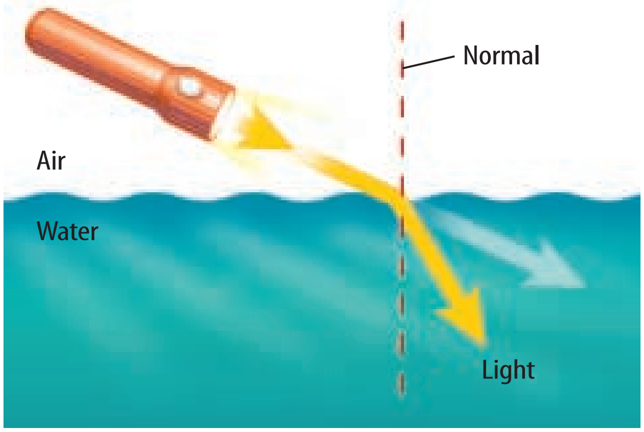
Remember that a wave's speed depends on the medium it is moving through. When a wave passes from one medium to another—such as when a light wave passes from air to water—it changes speed. If the wave is traveling at an angle when it passes from one medium to another, it changes direction, or bends, as it changes speed. **Refraction** is the bending of a wave caused by a change in its speed as it moves from one medium to another. The greater the change in speed is, the more the wave bends.

Reading Check *When does refraction occur?*

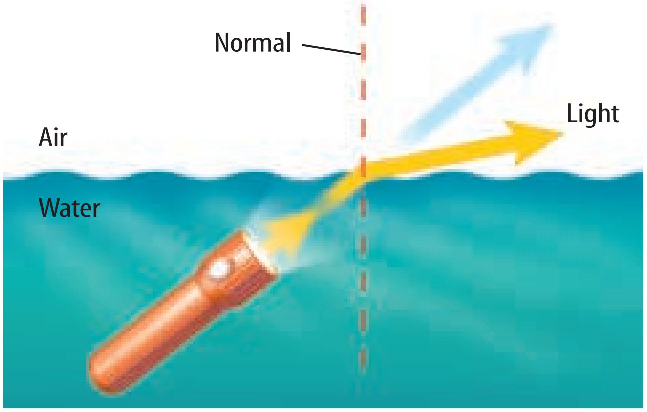
Figure 16A on the next page shows what happens when a wave passes into a material in which it slows down. The wave is refracted (bent) toward the normal. **Figure 16B** shows what happens when a wave passes into a medium in which it speeds up. Then the wave is refracted away from the normal.

Figure 15
The pencil looks like it is broken at the surface of the water because of refraction. *Does light travel faster in water or air?*

Figure 16
Light travels slower in water than in air.



A **When light travels from air to water, it slows down and bends toward the normal.**



B **When light leaves water and travels to air, it speeds up and bends away from the normal.** *How would the beam bend if the speed were the same in both air and water?*

Refraction of Light in Water You may have noticed that objects that are underwater seem closer to the surface than they really are. **Figure 17** shows how refraction causes this illusion. In the figure, the light waves reflected from the swimmer's foot are refracted away from the normal and enter your eyes. However, your brain assumes that all light waves have traveled in a straight line. The light waves that enter your eyes seem to have come from a foot that was higher in the water. This is also why the pencil in **Figure 15** seems broken. The light waves coming from the part of the pencil that is underwater are refracted, but your brain interprets them as if they have traveled in a straight line. However, the light waves coming from the part of the pencil above the water are not refracted. So, the part of the pencil that is underwater looks as if it has shifted.

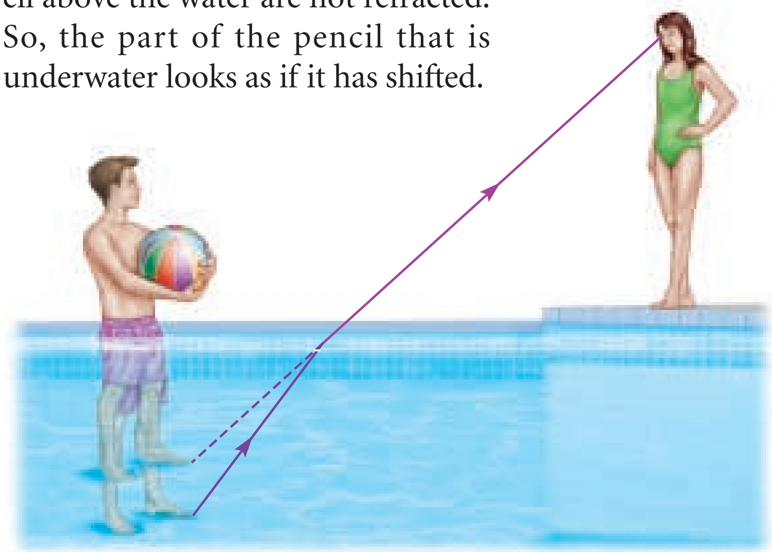


Figure 17
To the observer on the side of the pool, the swimmer's foot looks closer to the surface than it actually is. *When the boy looks down at his feet, will they seem closer to the surface than they really are?*

Figure 18
Ocean waves change direction as they pass a group of islands. *How are the waves different before and after they pass the islands?*

Diffraction

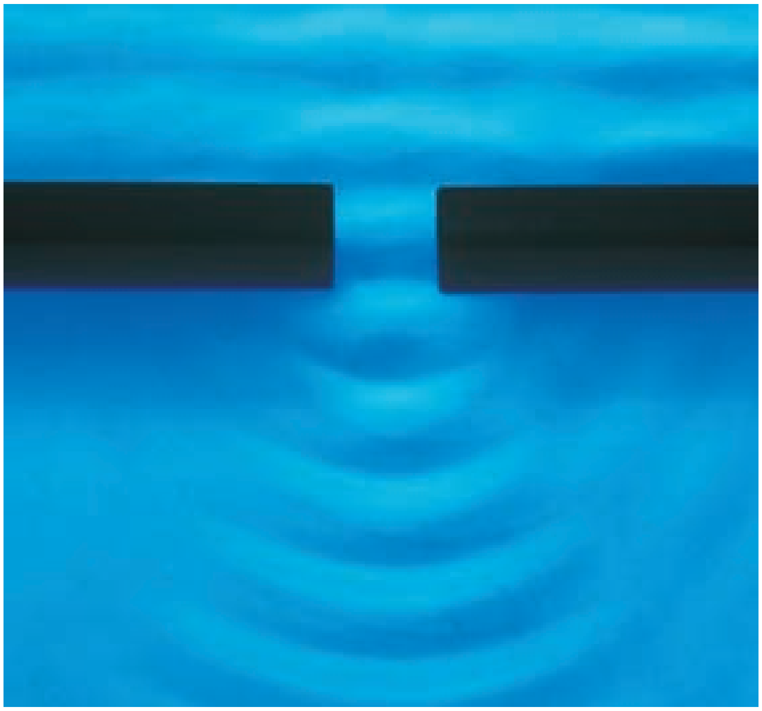
When waves strike an object, several things can happen. The waves can bounce off, or be reflected. If the object is transparent, light waves can be refracted as they pass through it. Sometimes the waves may be both reflected and refracted. If you look into a glass window, sometimes you can see your reflection in the window, as well as objects behind it. Light is passing through the window and is also being reflected at its surface.

Waves also can behave another way when they strike an object. The waves can bend around the object. **Figure 18** shows how ocean waves change direction and bend after they strike an island. **Diffraction** occurs when an object causes a wave to change direction and bend around it. Diffraction and refraction both cause waves to bend. The difference is that refraction occurs when waves pass through an object, while diffraction occurs when waves pass around an object.

Reading Check *What is diffraction?*

Waves also can be diffracted when they pass through a narrow opening, as shown in **Figure 19.** After they pass through the opening, the waves spread out. In this case the waves are bending around the corners of the opening.

Figure 19
When water waves pass through a small opening in a barrier, they diffract and spread out after they pass through the hole.



Diffraction and Wavelength How much does a wave bend when it strikes an object or an opening? The amount of diffraction that occurs depends on how big the obstacle or opening is compared to the wavelength. When an obstacle is smaller than the wavelength, the waves bend around it. But if the obstacle is larger than the wavelength, the waves do not diffract as much. In fact, if the obstacle is much larger than the wavelength, almost no diffraction occurs. The obstacle casts a shadow because almost no waves bend around it. The larger the obstacle is compared to the wavelength, the less the waves will diffract, as shown in **Figure 20.**

For example, you're walking down the hallway and you can hear sounds coming from the lunchroom before you reach the open lunchroom door. However, you can't see into the room until you reach the doorway. Why can you hear the sound waves but not see the light waves while you're still in the hallway? The wavelengths of sound waves are similar in size to a door opening. Sound waves diffract around the door and spread out down the hallway. Light waves have a much shorter wavelength. They are hardly diffracted at all by the door. The light waves from the lunchroom bend only slightly around the doorway, and you can't see into the room until you get close to the door.

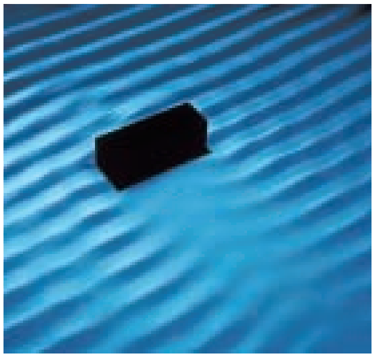
Radio Waves Diffraction also affects your radio's reception. AM radio waves have longer wavelengths than FM radio waves do. Because of their longer wavelengths, AM radio waves diffract around obstacles like buildings and mountains. The FM waves with their short wavelengths do not diffract as much. As a result, AM radio reception is often better than FM reception around tall buildings and natural barriers.

SCIENCE Online

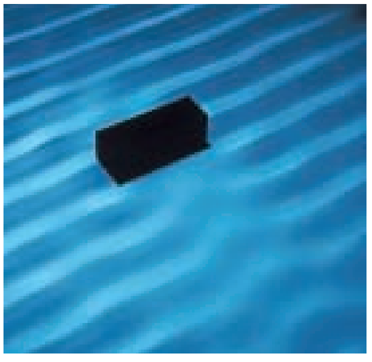
Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about diffraction. Communicate to your class what you learned.

CLICK HERE

Figure 20
The diffraction of waves around an obstacle depends on the wavelength and the size of the obstacle.



A Less diffraction occurs if the wavelength is smaller than the obstacle.



B More diffraction occurs if the wavelength is the same size as the obstacle.

Interference

Suppose two waves are traveling toward each other on a long rope as in **Figure 21A.** What will happen when the two waves meet? If you did this experiment, you would find that the two waves pass right through each other, and each one continues to travel in its original direction, as shown in **Figure 21B** and **Figure 21C.** If you look closely at the waves when they meet each other in **Figure 21B,** you see a wave that looks different than either of the two original waves. When the two waves arrive at the same place at the same time, they combine to form a new wave. When two or more waves overlap and combine to form a new wave, the process is called **interference.** This new wave exists only while the two original waves continue to overlap. The two ways that the waves can combine are called constructive interference and destructive interference.

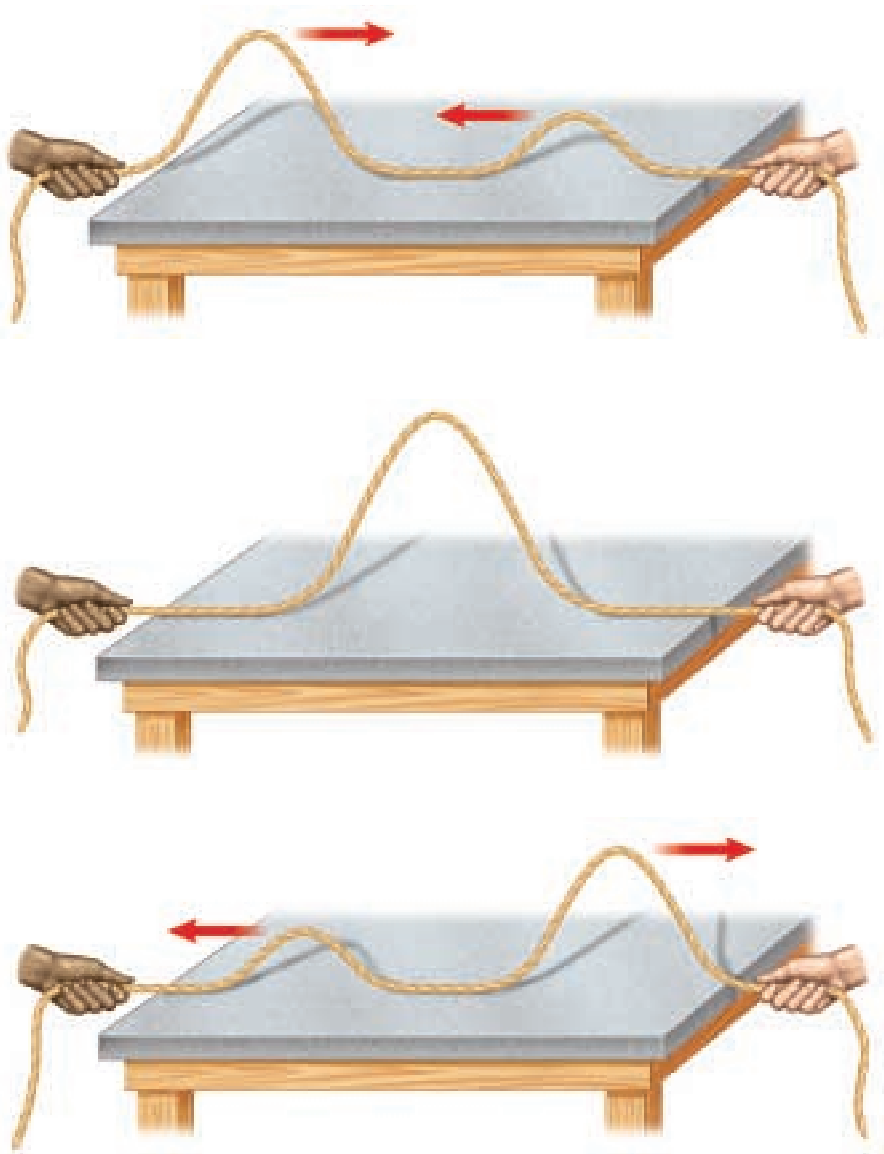


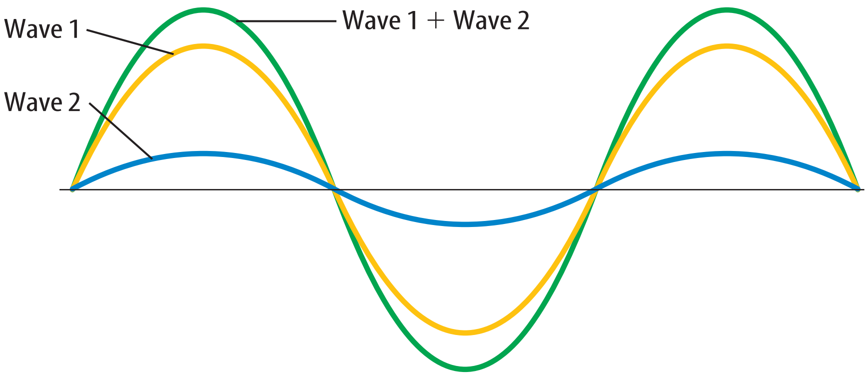
Figure 21
At the ocean, when one wave retreats from shore, it can meet a new wave coming in. The two waves combine to form a new wave. The same thing happens with the waves on this rope.

A **Two waves move toward each other on a rope.**

B **As the waves overlap, they interfere to form a new wave.** *What is the amplitude of the new wave?*

C **When the two waves overlap, they move right through each other. Afterward, they continue moving unchanged, as if they had never met.**

CONTENTS



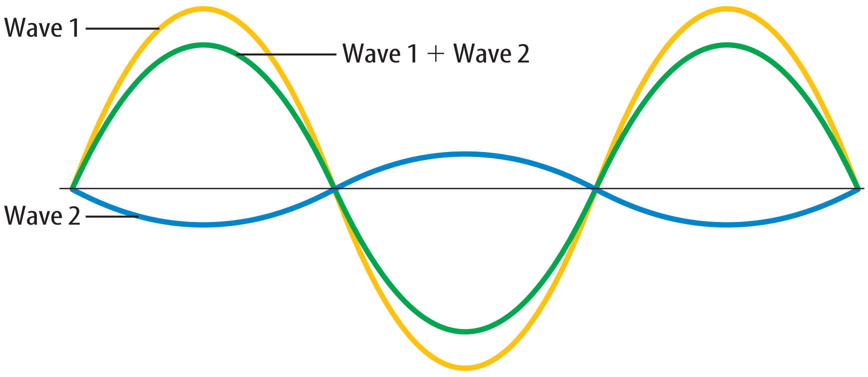


Figure 22
Two types of interference are possible.

A **If Wave 1 and Wave 2 were moving toward each other on a rope, they would constructively interfere and form the green wave. Wave 1 and Wave 2 are in phase.**

B **If Wave 1 and Wave 2 were traveling toward each other on a rope, they would destructively interfere and form the green wave. Wave 1 and Wave 2 are out of phase.**

Constructive Interference In constructive interference, shown in **Figure 22A,** the waves add together. This happens when the crests of two or more transverse waves arrive at the same place at the same time and overlap. The amplitude of the new wave that forms is equal to the sum of the amplitudes of the original waves. Constructive interference also occurs when the compressions of different compressional waves overlap. If the waves are sound waves, for example, constructive interference produces a louder sound. Waves undergoing constructive interference are said to be in phase.

Destructive Interference In destructive interference, the waves subtract from each other as they overlap. This happens when the crests of one transverse wave meet the troughs of another transverse wave, as shown in **Figure 22B.** The amplitude of the new wave is the difference between the amplitudes of the waves that overlapped. With compressional waves, destructive interference occurs when the compression of one wave overlaps with the rarefaction of another wave. The compressions and rarefactions combine and form a wave with reduced amplitude. When destructive interference happens with sound waves, it causes a decrease in loudness. Waves undergoing destructive interference are said to be out of phase.

Health INTEGRATION

People who are exposed to constant loud noises, such as those made by airplane engines, can suffer hearing damage. Scientists have developed ways to reduce loud noises by using destructive interference. Special ear protectors use destructive interference to cancel damaging noise. With a classmate, list all the jobs you can think of that require ear protectors.

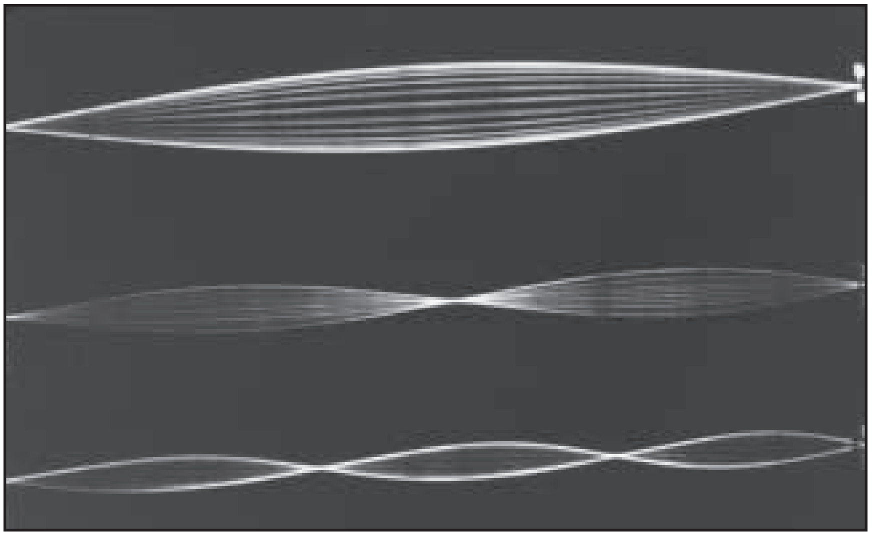


Figure 23
Standing waves seem to stay in the same place. *How do nodes form?*

Standing Waves

When you make transverse waves with a rope, you might shake one end while your friend holds the other end still. What would happen if you both shook the rope continuously to create identical waves moving toward each other? As the two waves travel in opposite directions down the rope, they continually pass through each other. Interference takes place as the waves from each end overlap along the rope. At any point where a crest meets a crest, a new wave with a larger amplitude forms. But at points where crests meet troughs, the waves cancel each other and no motion occurs.

The interference of the two identical waves makes the rope vibrate in a special way, as shown in **Figure 23.** The waves create a pattern of crests and troughs that do not seem to be moving. Because the wave pattern stays in one place, it is called a standing wave. A **standing wave** is a special type of wave pattern that forms when waves equal in wavelength and amplitude, but traveling in opposite directions, continuously interfere with each other. The places where the two waves always cancel are called nodes. The nodes always stay in the same place on the rope. Meanwhile, the wave vibrates between the nodes.

Standing Waves in Music When the string of a violin is played with a bow, it vibrates and creates standing waves. The standing waves in the string help produce a rich, musical tone. Other instruments also rely on standing waves to produce music. Some instruments, like flutes, create standing waves in a column of air. In other instruments, like drums, a tightly stretched piece of material vibrates in a special way to create standing waves. As the material in a drum vibrates, nodes are created on the surface of the drum.

Resonance

You may have noticed that bells of different sizes and shapes create different notes. When you strike a bell, you cause it to vibrate to produce sound. The bell vibrates at a certain frequency called the natural frequency. The note you hear depends on the bell's natural frequency. The natural frequency of vibration depends on the bell's size, shape, and the material it is made from. Other objects, including windows, bridges, and columns of air, also vibrate at their own natural frequencies.

There is another way to make something vibrate at its natural frequency. Suppose you have a tuning fork that has a natural frequency of 440 Hz. Imagine that a sound wave of the same frequency strikes the tuning fork. Because the sound wave has the same frequency as the natural frequency of the tuning fork, the tuning fork will vibrate. The ability of an object to vibrate by absorbing energy at its natural frequency is called **resonance** (RE zun unts).

Sometimes resonance can cause an object to absorb a large amount of energy. What happens to the tuning fork if it continues to absorb energy from the sound wave? Remember that the amplitude of a wave increases as the energy it carries increases. In the same way, an object vibrates more strongly as it continues to absorb energy at its natural frequency. If enough energy is absorbed, the object can vibrate so strongly that it breaks apart.

Mini LAB

Experimenting with Resonance

Procedure

1. Strike a **tuning fork** with a **mallet.**
2. Hold the vibrating tuning fork near a **second tuning fork** that has the same frequency.
3. Strike the tuning fork again. Hold it near a **third tuning fork** that has a different frequency.

Analysis

What happened when you held the vibrating tuning fork near each of the other two? Explain.

Section 3 Assessment

1. Describe how the reflection of light rays allows you to see your image in a mirror.
2. Sketch a diagram showing what happens when a wave enters a medium and slows down. Also sketch a wave speeding up as it enters a new medium. In each diagram, label the normal, the angle of incidence, and the angle of refraction.
3. What happens when waves overlap?
4. What is resonance?
5. **Think Critically** Aluminum foil is shiny like a mirror, yet you can't see your reflection in a piece of crumpled aluminum foil. Explain.

Skill Builder Activities

6. **Recognizing Cause and Effect** Imagine you are on the shore of a large lake and see waves moving toward you from the center of the lake. However, before reaching shore, the waves pass by a boat dock. The waves then move toward you at a slightly different angle. What would you infer is happening? **For more help, refer to the Science Skill Handbook.**
7. **Using a Word Processor** Use a word processor to make an outline showing important points about constructive interference and destructive interference. **For more help, refer to the Technology Skill Handbook.**

Activity

Measuring Wave Properties

Some waves travel through space; others pass through a medium such as air, water, or earth. Each wave has a wavelength, speed, frequency, and amplitude. In this activity you will make waves in the classroom, and observe, measure, and change some of the properties of these waves.

What You'll Investigate

How can the speed of a wave be measured?
How can the wavelength be determined from the frequency?

Materials

long spring, rope, or hose
meterstick
stopwatch

Goals

- **Measure** the speed of a transverse wave.
- **Create** waves with different amplitudes.
- **Measure** the wavelength of a transverse wave.

Safety Precautions

Procedure

1. With a partner, stretch your spring across an open floor and measure the length of the spring. Record this measurement in the data table. Make sure the spring is stretched to the same length for each step.
2. Have your partner hold one end of the spring. Create a single wave pulse by shaking the other end of the spring back and forth.
3. Have a third person use a stopwatch to measure the time needed for the pulse to travel the length of the spring. Record this measurement in the "Wave Time" column of your data table.
4. Repeat steps 2 and 3 two more times.
5. **Calculate** the speed of waves 1, 2, and 3 in your data table by using the formula:

   speed = distance / time

   Average the speeds of waves 1, 2, and 3 to find the speed of waves on your spring.

6. **Create** a wave with several wavelengths. You make one wavelength when your hand moves up, down, and up again. Count the number of wavelengths that you generate in 10 s. Record this measurement for wave 4 in the Wavelength Count column in your data table.
7. Repeat step 6 two more times. Each time, create a wave with a different wavelength by shaking the spring faster or slower.
8. **Calculate** the frequency of waves 4, 5, and 6 by dividing the number of wavelengths by 10 s.

9. Calculate the wavelength of waves 4, 5, and 6 using the formula

wavelength = wave speed / frequency

Use the average speed calculated in step 5 for the wave speed.

Wave Property Measurements

	Spring Length	Wave Time	Wave Speed
Wave 1			
Wave 2			
Wave 3			
	Wavelength Count	**Frequency**	**Wavelength**
Wave 4			
Wave 5			
Wave 6			

Conclude and Apply

1. Was the wave speed different for the three different pulses you created? Why or why not?
2. Why would you average the speeds of the three different pulses to calculate the speed of waves on your spring?
3. How did the wavelength of the waves you created depend on the frequency of the waves?

Communicating Your Data

Ask your teacher to set up a contest between the groups in your class. Have each group compete to determine who can create waves with the longest wavelength, the highest frequency, and the largest wave speed. Record the measurements of each group's efforts on the board. **For more help, refer to the Science Skill Handbook.**

MAKING WAVES

Sonar Helps Create Deep-Sea Pictures and Save Lives

What is sonar?

Sonar is a device that uses sound waves to find the location and distance of underwater objects. Its name is a shortened version of SOund NAvigation and Ranging.

Sonar was used to find enemy subs during World War II.

How does sonar work?

There are two kinds of sonar—active and passive. Active sonar sends out a ping sound that is reflected back when it hits an underwater object. Since sound travels through water at a known speed (1,500 m/s), scientists use the time the sound takes to return to calculate the distance. Passive sonar only listens for sounds given off by underwater objects, such as the noise made by a submarine's engines or by torpedoes.

Why was it invented?

Sonar was first developed by scientists in the early twentieth century as a way to detect icebergs and prevent boating disasters. Its technical advancement was hurried by the Allies' need to detect German submarines in World War I. Before 1916, antisubmarine sonar was passive—a series of microphones towed underwater. By 1918, the United States and Britain had developed an active sonar system placed in submarines sent to attack other subs.

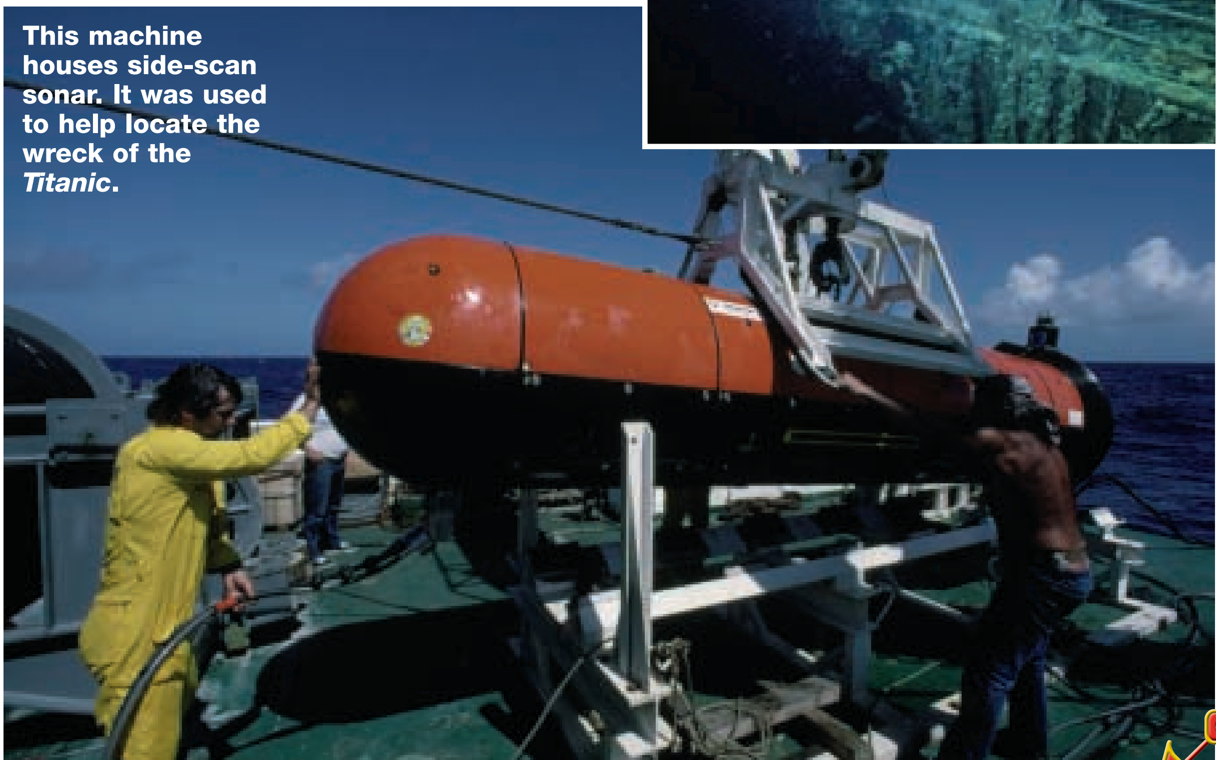
The range of early sonar was only 1.6 km. (Today it is more than 16 km.) Even so, in World War II, sonar allowed ships to defend themselves effectively from enemy subs.

Their strategy was to use sonar to find subs and then fire rocket-fueled depth charges from a safe distance. After the war, quieter nuclear submarines were developed. Sonar-absorbing hulls and quiet engines and machinery ensured that the subs could partly shield themselves from sonar.

Since the war, sonar has been used to help scientists find schools of fish. It also has been used by oceanographers to map ocean and lake floors. Most dramatically, sonar has been vital in the discovery of submerged wrecks, such as downed airplanes and ships, including the *Titanic*—the passenger liner that sank in 1912.

In 1985, a French and American team used a new type of sonar device called the side-scan sonar to locate the *Titanic*. This kind of sonar projects a tight beam of sound that can create accurate images of the sea bed. Members of the expedition towed this sonar device about 170 m above the seabed across a section of the Atlantic Ocean where the *Titanic* went down. Although the expedition's ship passed above the *Titanic* early on, the sonar readings were misinterpreted. Weeks later, video cameras finally spotted the wreck. In 1996, a French expedition to the *Titanic* used a special sonar device that produced 3D images of the wreck site. This sonar was also powerful enough to penetrate the 15 m of mud that covered the bow of the ship. It enabled researchers to see how the hull had been damaged when the ship had collided with an iceberg.


The *Titanic* was found thanks to sonar.


This machine houses side-scan sonar. It was used to help locate the wreck of the *Titanic*.

CONNECTIONS Report **Research how sonar was used by navies in World War I and World War II. Did sonar affect each war's outcome? How did it save lives? What uses can you think of for sonar if it could be used in every-day life?**

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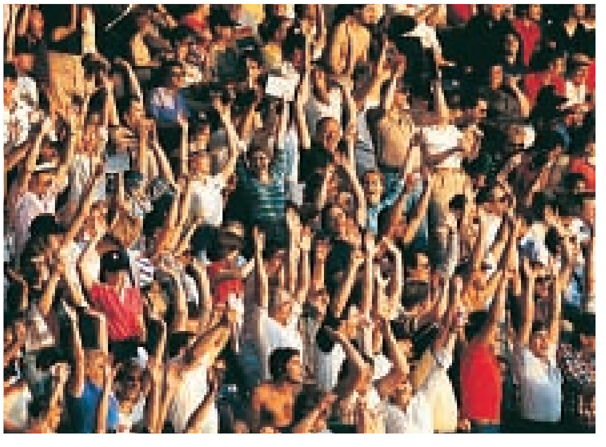
For more information, visit science.glencoe.com
CONTENTS

Chapter 11 Study Guide

Reviewing Main Ideas

Section 1 The Nature of Waves

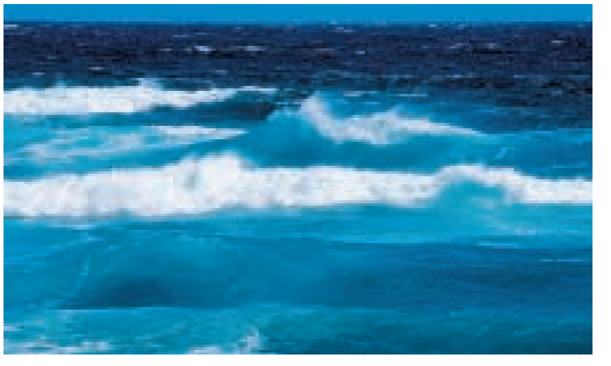
1. Waves are rhythmic disturbances that transfer energy through matter or space.
2. Waves transfer only energy, not matter. *Is a human "wave" in a stadium really a wave? Explain.*



3. Mechanical waves need matter to travel through. Mechanical waves can be compressional or transverse.
4. When a transverse wave passes through a medium, matter in the medium moves at right angles to the direction the wave travels. For a compressional wave, matter moves back and forth in the same direction as the wave travels. Matters returns to its original position after the wave passes.

Section 2 Wave Properties

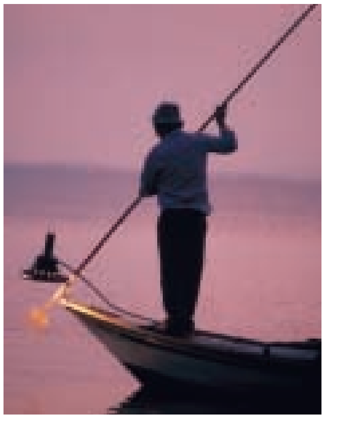
1. Transverse waves have high points (crests) and low points (troughs). Compressional waves have more dense areas (compressions) and less dense areas (rarefactions).
2. Transverse and compressional waves can be described by their wavelengths, frequencies, and amplitudes. As frequency increases, wavelength always decreases.
3. The greater a wave's amplitude is, the more energy it carries. *How would you measure the amplitude of these ocean waves?*



4. A wave's velocity can be calculated by multiplying its frequency times its wavelength.

Section 3 The Behavior of Waves

1. For all waves, the angle of incidence equals the angle of reflection.
2. A wave is bent, or refracted, when it changes speed as it enters a new medium. *How does refraction affect how this fisher aims with his spear?*



3. When two or more waves overlap, they combine to form a new wave. This process is called interference.

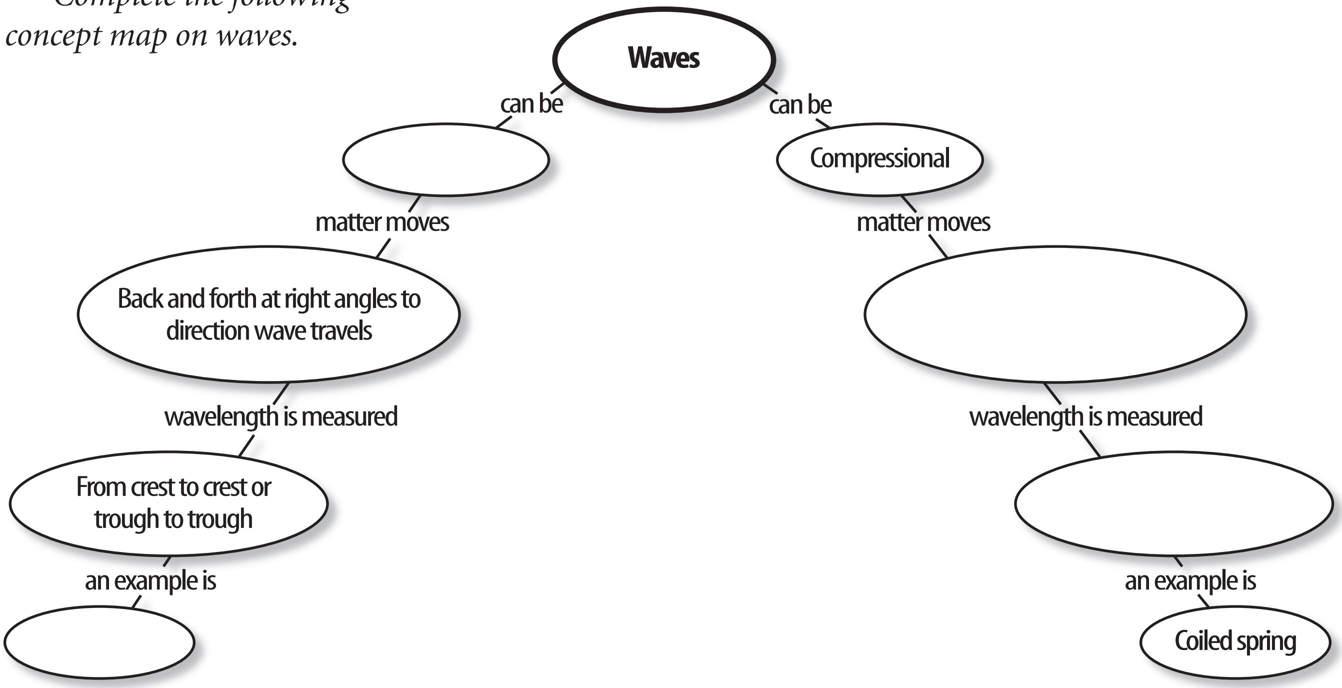
FOLDABLES Reading & Study Skills

After You Read

Use your Foldable to help you review characteristics of light and sound waves.

Visualizing Main Ideas

Complete the following concept map on waves.



Vocabulary Review

Vocabulary Words

a. amplitude
b. compressional wave
c. crest
d. diffraction
e. frequency
f. interference
g. medium
h. rarefaction
i. refraction
j. resonance
k. standing wave
l. transverse wave
m. trough
n. wave
o. wavelength

Study Tip

THE PRINCETON REVIEW

Use word webs. Write down the main idea of the chapter on a piece of paper and circle it. Connect other related facts to it with lines and arrows.

Using Vocabulary

Answer the following questions using complete sentences.

1. Compare and contrast reflection and refraction.
2. Which type of wave has points called nodes that do not move?
3. Which part of a compressional wave has the lowest density?
4. Find two words in the vocabulary list that describe the bending of a wave.
5. Describe what happens when waves overlap.
6. What is the relationship among amplitude, crest, and trough?
7. What does frequency measure?
8. What does a mechanical wave always travel through?

Chapter 11 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

1. Which of the following do waves carry?
   A) matter **C)** matter and energy
   B) energy **D)** the medium

2. When a compressional wave travels through a medium, which way does matter in the medium move?
   A) backward
   B) all directions
   C) at right angles to the direction the wave travels
   D) in the same direction the wave travels

3. What is the formula for calculating wave speed?
   A) $v = \lambda \times f$ **C)** $v = \lambda / f$
   B) $v = f$ **D)** $v = \lambda + f$

4. What is the highest point of a transverse wave called?
   A) crest **C)** wavelength
   B) compression **D)** trough

5. As the frequency of a wave increases, what happens to the wavelength?
   A) It moves forward. **C)** It vibrates.
   B) It decreases. **D)** It increases.

6. What is the amplitude of a wave related to?
   A) the wave's energy **C)** wave speed
   B) frequency **D)** refraction

7. Which term describes the bending of a wave around a barrier?
   A) resonance **C)** diffraction
   B) interference **D)** reflection

8. What types of waves have nodes?
   A) seismic waves **C)** water waves
   B) radio waves **D)** standing waves

9. What is equal to the angle of reflection?
   A) refraction angle **C)** bouncing angle
   B) normal angle **D)** angle of incidence

10. When two or more waves arrive at the same place at the same time, what do they do?
    A) turn around
    B) bend toward the normal
    C) stop
    D) combine

Thinking Critically

11. An earthquake on the ocean floor produces a tsunami that hits a remote island. Is the water that hits the island the same water that was above the earthquake? Explain.

12. When a wave's amplitude increases, does its frequency change? Explain.

13. Use the law of reflection to explain why you see only a portion of the area behind you when you look in a mirror.

14. Explain why you can hear a fire engine coming around a street corner before you can see it.

15. Describe what vibrated to produce three of the sounds you've heard today.

Developing Skills

16. **Forming Hypotheses** In 1981, swaying dancers on the balconies of a Kansas City, Missouri, hotel caused the balconies to collapse. Use what have you learned about wave behavior to form a hypothesis that explains why this happened.

17. **Comparing and Contrasting** Compare and contrast diffraction and refraction.

18. Interpreting Data According to the data in the table below, approximately how many times faster does sound travel in steel than in air?

Sound Transmission

Substance	Speed of Sound at 25°C (m/s)
Air	347
Brick	3,650
Cork	500
Water	1,498
Steel	5,200

19. Making and Using Tables Find newspaper articles describing five recent earthquakes. Construct a table that shows for each earthquake the date, location, magnitude, and whether the damage caused by each earthquake was light, moderate, or heavy.

20. Concept Mapping Design a concept map that shows the characteristics of transverse waves. Include the terms *crest, trough, medium, wavelength, frequency,* and *amplitude.*

Performance Assessment

21. Oral Presentation A seismograph is an instrument that measures the magnitude of earthquakes. Research seismographs, and make an oral presentation explaining how they work.

TECHNOLOGY

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THE PRINCETON REVIEW

Test Practice

A scientist is studying the formation of ocean waves during windy storms. Her observations are listed in the table below.

Ocean Wave Observations

Wind Conditions	Wind Speed (km/h)	Ocean Wave Height (m)	Description of Ocean Waves
Calm	1-5	0.05	Like a Small Lake
Light Breeze	6-11	0.10	Small Wavelets
Gentle Breeze	?	0.60	Small Waves
Mod. Breeze	20-28	1.00	Large Wavelets
Fresh Breeze	29-38	2.00	Mod. Waves
Strong Breeze	39-49	3.00	Large Waves
Gale	62-75	7.00	Breaking Waves

Study the chart and answer the following questions.

1. What wind speeds are considered a “gentle breeze?”
A) 9–17 (km/h)
B) 10–18 (km/h)
C) 12–19 (km/h)
D) 12–20 (km/h)

2. According to the table, a 33 km/h wind produced ______.
F) large wavelets
G) moderate waves
H) large waves
J) breaking waves

3. What is the height of a large wave?
A) 1.50 m
B) 0.25 m
C) 1.00 m
D) 0.10 m