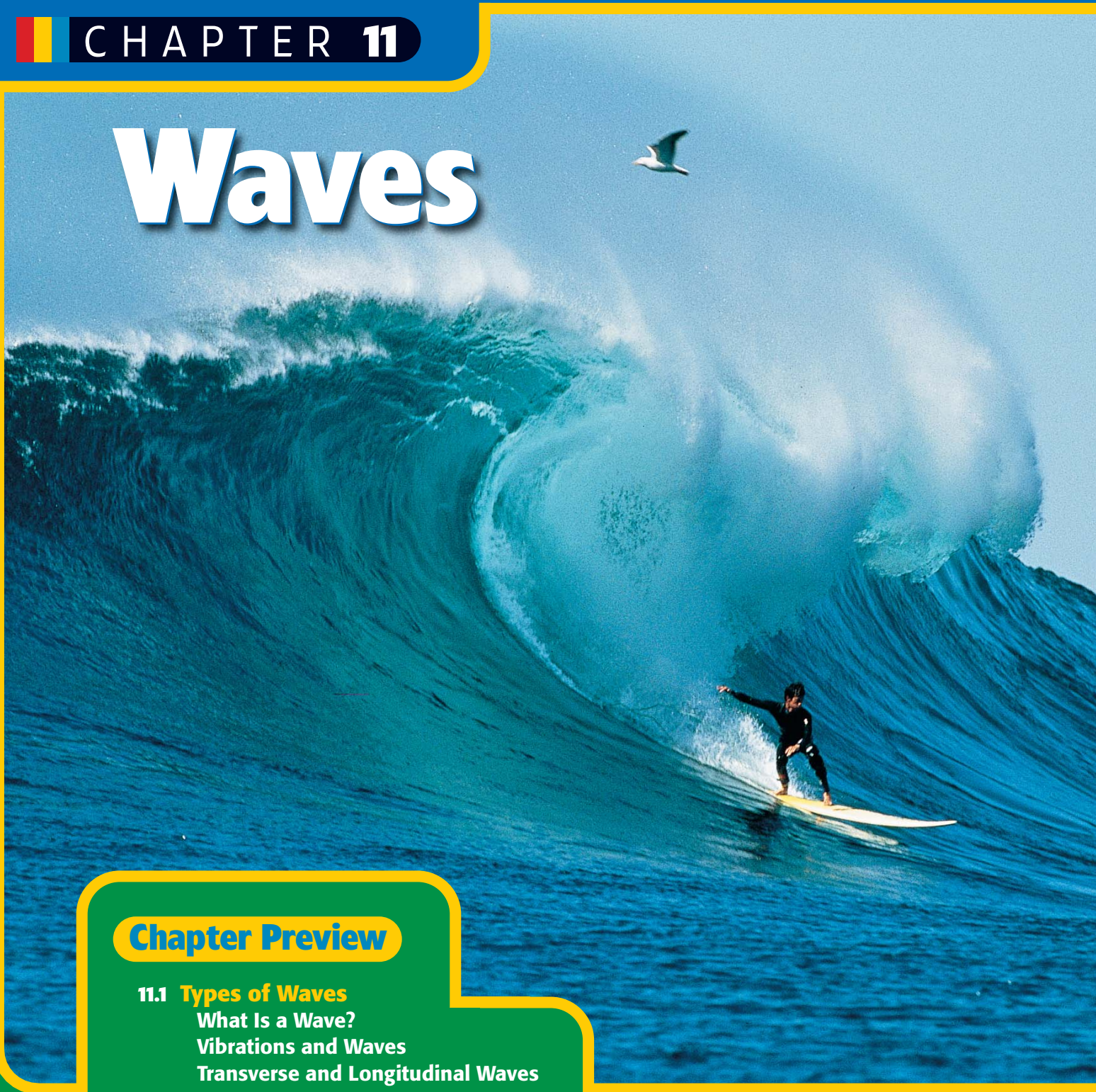


Waves



Chapter Preview

11.1 Types of Waves

What Is a Wave?
Vibrations and Waves
Transverse and Longitudinal Waves

11.2 Characteristics of Waves

Wave Properties
Wave Speed
The Doppler Effect

11.3 Wave Interactions

Reflection, Diffraction, and Refraction
Interference
Standing Waves

Focus ACTIVITY

Background The energy in an ocean wave can lift a surfboard up into the air and carry the surfer into shore. Ocean waves get most of their energy from the wind. A wave may start as a small ripple in a calm sea, then build up as the wind pushes it along. Waves that start on the coast of northern Canada may be very large by the time they reach a beach in the Hawaiian Islands.

The winds that create ocean waves are caused by convection currents in the atmosphere, which are driven by energy from the sun. Energy travels across empty space from the sun to Earth—in the form of waves.

Waves are all around us. As you read this book, you are depending on light waves. Light bounces off the pages and into your eyes. When you talk with a friend you are depending on sound waves traveling through the air. Sometimes the waves can be gentle, such as those that rock a canoe in a pond. Other times waves can be very destructive, such as those created by earthquakes.

Activity 1 Fill a long, rectangular pan with water. Experiment with making waves in different ways. Try making waves by sticking the end of a pencil into the water, by moving a wide stick or board back and forth, and by striking the side of the pan. Place wooden blocks or other obstacles into the pan, and watch how the waves change when they encounter the obstacles.

Activity 2 Make a list of things that you do every day that depend on waves. Next to each item, write down what kind of waves you think are involved. Write a short paragraph describing some properties that you think these different kinds of waves may have in common.

A surfer takes advantage of the energy in ocean waves. Energy travels from the sun to Earth in the form of waves.

	
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Types of Waves

▶ KEY TERMS

wave
medium
mechanical wave
electromagnetic wave
transverse wave
longitudinal wave

OBJECTIVES

- ▶ Recognize that waves transfer energy.
- ▶ Distinguish between mechanical waves and electromagnetic waves.
- ▶ Explain the relationship between particle vibration and wave motion.
- ▶ Distinguish between transverse waves and longitudinal waves.

When a stone is thrown into a pond, it creates ripples on the surface of the water, as shown in **Figure 11-1**. If there is a leaf floating on the water, the leaf will bob up and down and back and forth as each ripple, or wave, disturbs it. But after the waves pass, the leaf will return to its original position on the water.

What Is a Wave?

Like the leaf, individual drops of water do not travel outward with a wave. They move only slightly from their resting place as each ripple passes by. If drops of water do not move very far as a wave passes, and neither does a leaf on the surface of the water, then what moves along with the wave? Energy does. A wave is not made of matter. A **wave** is a disturbance that carries energy through matter or space.

▶ **wave** a disturbance that transmits energy through matter or space

Figure 11-1

A stone thrown into a pond creates waves.



Most waves travel through a medium

The waves in a pond are disturbances traveling through water. Sound also travels as a wave. The sound from a stereo is a pattern of changes in the air between the stereo speakers and your ear. Earthquakes create waves, called *seismic waves*, that travel through Earth.

In each of these examples, the waves involve the movement of some kind of matter. The matter through which a wave travels is called the **medium**. In the example of the pond, the water is the medium. For sound from a stereo, air is the medium. And in earthquakes, Earth itself is the medium.

Waves that require a medium are called **mechanical waves**. Almost all waves are mechanical waves, with one important exception: electromagnetic waves.

Light does not require a medium

Light can travel from the sun to Earth across the empty space between them. This is possible because light waves do not need a medium through which to travel. Instead, light waves consist of changing electric and magnetic fields in space. For that reason, light waves are also called **electromagnetic waves**.

Visible light waves are just one example of a wide range of electromagnetic waves. Radio waves, such as those that carry signals to your radio or television, are also electromagnetic waves. Other kinds of electromagnetic waves will be introduced in Section 11-2. *In this book, the terms light and light wave may refer to any electromagnetic wave, not just visible light.*

Waves transfer energy

In Chapter 9, you learned that energy can be defined as the ability to do work. We know that waves carry energy because they can do work. For example, water waves can do work on a leaf, on a boat, or on a beach. Sound waves can do work on your eardrum. Light waves can do work on your eye or on photographic film.

A wave caused by dropping a stone in a pond might carry enough energy to move a leaf up and down several centimeters. The bigger the wave is, the more energy it carries. A cruise ship moving through water in the ocean could create waves big enough to move a fishing boat up and down a few meters.

If you have ever been hit by an ocean wave at the beach, you know these waves carry a lot of energy. Could this energy be put to good use?

Research is currently underway to find ways to harness the energy of ocean waves. Some small floating navigation buoys, which shine lights to help ships find their way in the dark, obtain energy solely from the waves. A few larger systems are in place that harness wave energy to provide electricity for small coastal communities.

Making the Connection

1. In a library or on the Internet, research different types of devices that harness wave energy. How much power do some of these devices provide? Is that a lot of power?
2. Design a device of your own to capture the energy from ocean waves. The device should take the motion of waves and convert it into a motion that could be used to drive a machine, such as a pump or a wheel.

- ▶ **medium** the matter through which a wave travels
- ▶ **mechanical wave** a wave that requires a medium through which to travel
- ▶ **electromagnetic wave** a wave caused by a disturbance in electric and magnetic fields and that does not require a medium; also called a light wave



Figure 11-2
This portrait of a tsunami was created by the Japanese artist Hokusai in 1830.

Figure 11-2 shows a woodblock print of a *tsunami*, a huge ocean wave caused by earthquakes. A tsunami may be as high as 30 m when it reaches shore, taller than a 10-story building. Such waves carry enough energy to cause a lot of damage to coastal towns and shorelines. Normal-sized ocean waves do work on the shore, too, breaking up rocks into tiny pieces to form sandy beaches.

Energy may spread out as a wave travels

If you stand next to the speakers at a rock concert, the sound waves may damage your ears. Likewise, if you look at a bright light bulb from too close, the light may damage your eyes. But if you are 100 m away, the sound of the rock band or the light from the bulb is harmless. Why?

Think about waves created when a stone falls into a pond. The waves spread out in circles that get bigger as the waves move farther from the center. Each of these circles, called a *wave front*, has the same amount of total energy. But as the circles get larger, the energy spreads out over a larger area.

When sound waves travel in air, the waves spread out in spheres, as shown in **Figure 11-3**. These spheres are similar to the circular ripples on a pond. As they travel outward, the spherical wave fronts get bigger, so the energy in the waves spreads out over a larger area. This is why large amplifiers and speakers are needed to fill a concert hall with sound, even though the same music can sound just as loud if it is played on a portable radio and listened to with a small pair of headphones.



Figure 11-3
Sound waves from a stereo speaker spread out in spherical wave fronts.

Vibrations and Waves

When a singer sings a note, vocal cords in the singer's throat move back and forth. That motion makes the air in the throat vibrate, creating sound waves that eventually reach your ears. The vibration of the air in your ears causes your eardrums to vibrate. The motion of the eardrum triggers a series of electrical pulses to your brain, and your brain interprets them as sounds.

Waves are related to vibrations. Most waves are caused by a vibrating object. Electromagnetic waves may be caused by vibrating charged particles. In a mechanical wave, the particles in the medium also vibrate as the wave passes through the medium.

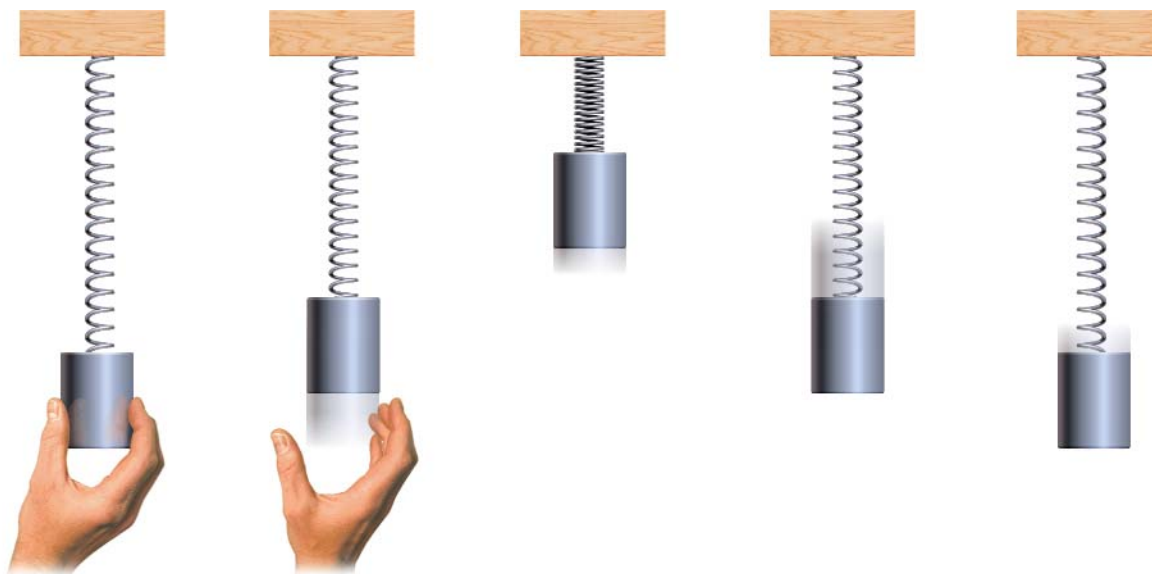
Vibrations involve transformations of energy

Figure 11-4 shows a mass hanging on a spring. If the mass is pulled down slightly and released, it will begin to move up and down around its original resting position. This vibration involves transformations of energy, much like those in a swinging pendulum.

When the mass is pulled away from its resting place, the mass-spring system gains elastic potential energy. The spring exerts a force that pulls the mass back to its original position.

As the spring moves back toward the original position, the potential energy in the system changes to kinetic energy. The mass moves beyond its original resting position to the other side.

At the top of its motion, the mass has lost all its kinetic energy. But the system now has both elastic potential energy and gravitational potential energy. The mass moves downward again, past the resting position, and back to the beginning of the cycle.



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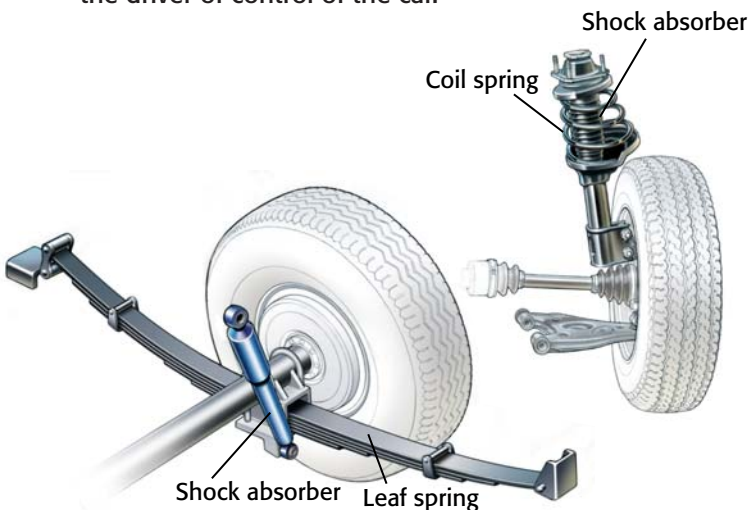
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Figure 11-4
When a mass hanging on a spring is disturbed from rest, it starts to vibrate up and down around its original position.

Shock Absorbers: Why Are They Important?

Bumps in the road are certainly a nuisance, but without strategic use of dampening devices, they could also be very dangerous. To control a car going 100 km/h (60 mi/h), a driver needs all the wheels of the vehicle on the ground. Bumps in the road lift the wheels off the ground and may rob the driver of control of the car.



Springs Absorb Energy

To solve this problem, cars are fitted with springs at each wheel. When the wheel of a car goes over a bump, the spring absorbs kinetic energy so that the energy is not transferred to the rest of the car. The energy becomes elastic potential energy in the spring, which then allows the spring to push the wheel back down onto the road.

Springs Alone Prolong Vibrations

Once a spring is set in motion, it tends to continue vibrating up and down in simple harmonic motion. This can create an uncomfortable ride, and it may also affect the driver's control of the car. One way to cut down on unwanted vibrations is to use stiff springs that compress only a few centimeters with thousands of newtons of force. However, the stiffer the spring is, the rougher the ride is and the more likely the wheels are to come off the road.

Shock Absorbers Dampen Vibrations

Modern automobiles are fitted with devices known as shock absorbers that absorb energy without prolonging vibrations. Shock absorbers are fluid-filled tubes that turn the simple harmonic motion of the springs into a damped harmonic motion. In a damped harmonic motion, each cycle of stretch and compression of the spring is much smaller than the previous cycle. Modern auto suspensions are set up so that all a spring's energy is absorbed by the shock absorbers in just one up-and-down cycle.

Shock Absorbers and Springs Come in Different Arrangements

Different types of springs and shock absorbers are combined to give a wide variety of responses. For example, many passenger cars have coil springs with shock absorbers parallel to the springs, or even inside the springs, as shown at near left. Some larger vehicles have heavy-duty leaf springs made of stacks of steel strips. Leaf springs are stiffer than coil springs, but they can bear heavier loads. In this type of suspension system, the shock absorber is perpendicular to the spring, as shown at far left.

The stiffness of the spring can affect steering response time, traction, and the general feel of the car. Because of the variety of combinations, your driving experiences can range from the luxurious "floating-on-air" ride of a limousine to the bone-rattling feel of a true sports car.

Your Choice

- 1. Making Decisions** If you were going to haul heavy loads, would you look for a vehicle with coil springs or leaf springs? Why?
- 2. Critical Thinking** How do shock absorbers stop an automobile from continually bouncing?

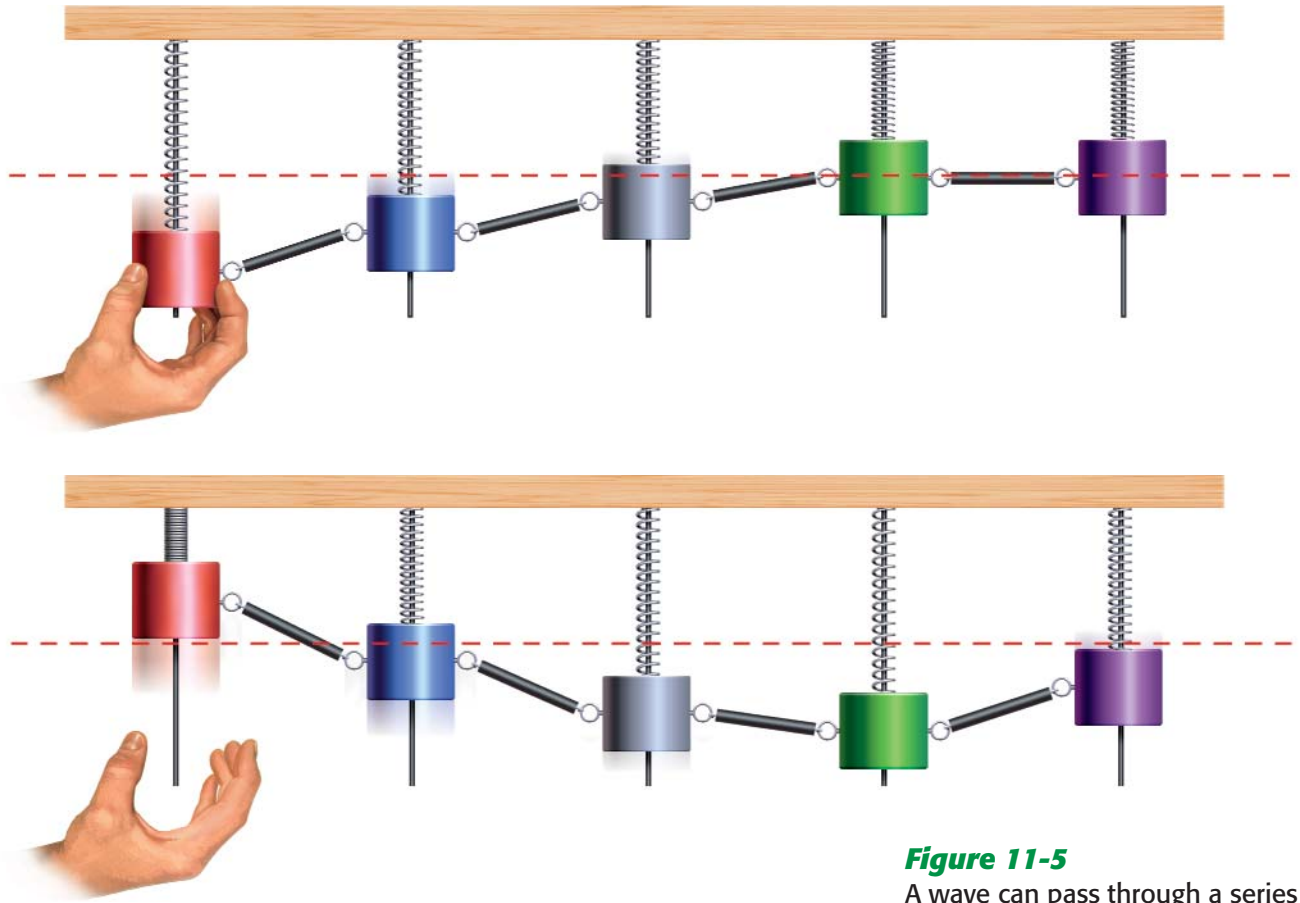


Figure 11-5
A wave can pass through a series of masses on springs. The masses act like the particles in a medium.

At every point in the motion of the mass, the spring is exerting a force that pushes it back to the original resting position. As a result, the mass could keep bouncing up and down forever. This type of vibration is called *simple harmonic motion*.

A wave can pass through a series of vibrating objects

Imagine a series of masses and springs tied together in a row, as shown in **Figure 11-5**. If you push down on a mass at the end of the row, that mass will begin to vibrate up and down. As the mass on the end moves, it pulls on the mass next to it, causing that mass to vibrate. The energy in the vibration of the first mass, which is a combination of kinetic energy and elastic potential energy, is transferred to the mass-spring system next to it. In this way, the disturbance that started with the first mass travels down the row. This disturbance is a wave that carries energy from one end of the row to the other.

If the first mass were not connected to the other masses, it would keep vibrating up and down on its own. However, because it transfers its energy to the second mass, it slows down and then returns to its resting position. A vibration that fades out as energy is transferred from one object to another is called *damped harmonic motion*.

Inquiry

Lab

How do particles move in a medium?

Materials ✓ long, flexible spring ✓ colored ribbon

Procedure

1. Have two people each grab an end of the spring and stretch it out along a smooth floor. Have another person tie a small piece of colored ribbon to a coil near the middle of the spring.
2. Swing one end of the spring from side to side. This will start a wave traveling along the spring. Observe the motion of the ribbon as the wave passes by.
3. Take a section of the spring and bunch it together as shown in the figure at right. Release the spring. This will create a different kind of wave traveling along the spring. Observe the motion of the ribbon as this wave passes by.



Analysis

1. How would you describe the motion of the ribbon in step 2? How would you describe its motion in step 3?
2. How can you tell that energy is passing along the spring? Where does that energy come from?

The motion of particles in a medium is like the motion of masses on springs

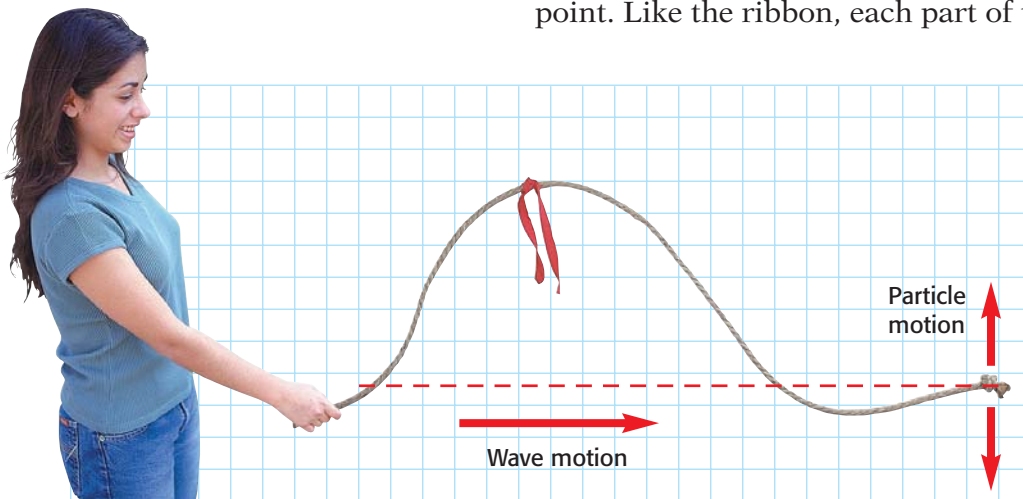
If you tie one end of a rope to a doorknob, pull it straight, and then rapidly move your hand up and down once, you will generate a single wave along the rope, as shown in **Figure 11-6**. A small ribbon tied to the middle of the rope can help you visualize the motion of a single particle of matter in the rope.

As the wave approaches, the ribbon moves up in the air, away from its resting position. As the wave passes farther along the rope, the ribbon drops below its resting position. Finally, after the wave passes by, the ribbon returns to its original starting point. Like the ribbon, each part of the rope moves up and down as the wave passes by.

The motion of each part of the rope is like the vibrating motion of a mass hanging on a spring. As one part of the rope moves up and down, it pulls on the part next to it, transferring energy. In this way, a wave passes along the length of the rope.

Figure 11-6

As this wave passes along a rope, the ribbon moves up and down while the wave moves to the right.



Transverse and Longitudinal Waves

Particles in a medium can vibrate either up and down or back and forth. Waves are often classified by the direction that the particles in the medium move as a wave passes by.

Transverse waves have perpendicular motion

When a crowd does “the wave” at a sporting event, people in the crowd stand up and raise their hands into the air as the wave reaches their part of the stadium. The wave travels around the stadium in a circle, but the people move straight up and down. This is similar to the wave in the rope. Each particle in the rope moves straight up and down as the wave passes by from left to right.

In these cases, the motion of the particles in the medium (in the stadium, the people in the crowd) is perpendicular to the motion of the wave as a whole. Waves in which the motion of the particles is perpendicular to the motion of the wave as a whole are called **transverse waves**.

Light waves are another example of transverse waves. The fluctuations in electric and magnetic fields that make up a light wave are perpendicular to the direction the light travels. For an illustration, see Section 14.3.

Longitudinal waves have parallel motion

Suppose you stretch out a long, flexible spring on a table or a smooth floor, grab one end, and move your hand back and forth, directly toward and directly away from the other end of the spring. You would see a wave travel along the spring as it bunches up in some spots and stretches in others, as shown in **Figure 11-7**.

As a wave passes along the spring, a ribbon tied to one of the coils of the spring will move back and forth, parallel to the direction that the wave travels. Waves that cause the particles in a medium to vibrate parallel to the direction of wave motion are called **longitudinal waves**.

Sound waves are an example of longitudinal waves that we encounter every day. Sound waves traveling in air compress and expand the air in bands. As sound waves pass by molecules in the air move backward and forward parallel to the direction that the sound travels.

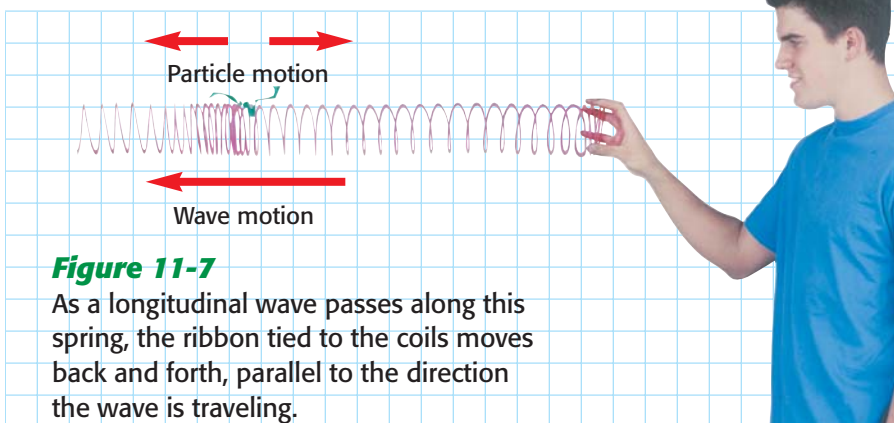


Figure 11-7

As a longitudinal wave passes along this spring, the ribbon tied to the coils moves back and forth, parallel to the direction the wave is traveling.

Quick Activity

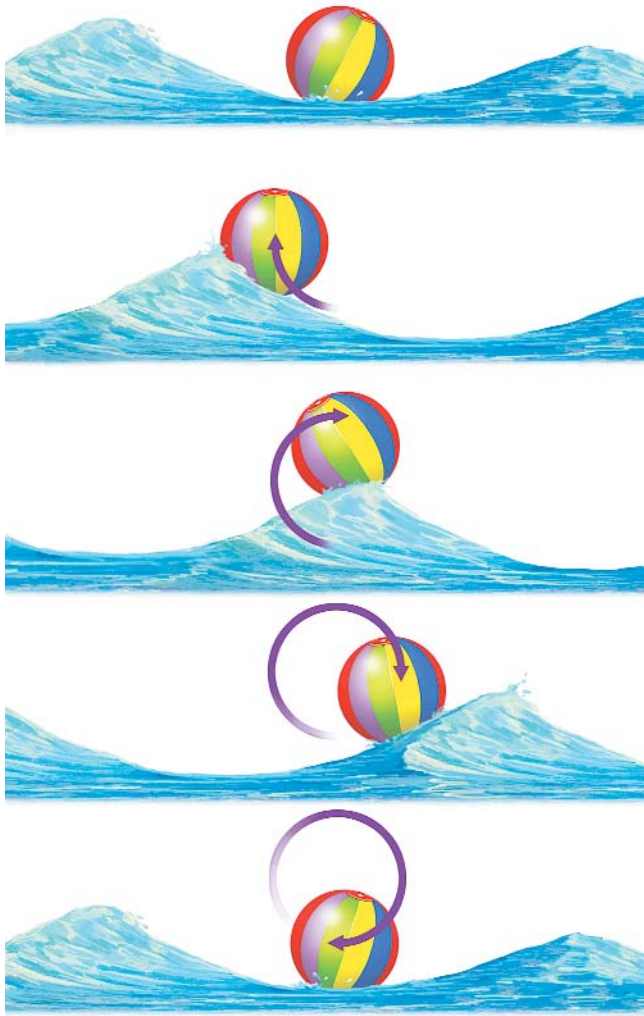
Polarization

Polarizing filters block all light except those waves that oscillate in a certain direction. Look through two polarizing filters at once. Then rotate one by 90° and look again. What do you observe?

▶ transverse wave

a wave that causes the particles of the medium to vibrate perpendicularly to the direction the wave travels

▶ **longitudinal wave** a wave that causes the particles of the medium to vibrate parallel to the direction the wave travels



In a surface wave, particles move in circles

Waves on the ocean or in a swimming pool are not simply transverse waves or longitudinal waves. Water waves are an example of *surface waves*. Surface waves occur at the boundary between two different mediums, such as between water and air. The particles in a surface wave move both perpendicularly and parallel to the direction that the wave travels.

Follow the motion of the beach ball in **Figure 11-8** as a wave passes by traveling from left to right. At first, the ball is in a trough. As the crest approaches, the ball moves to the left and upward. When the ball is very near the crest, it starts to move to the right. Once the crest has passed, the ball starts to fall back downward, then to the left. The up and down motions combine with the side to side motions to produce a circular motion overall.

The beach ball helps to make the motion of the wave more visible. Particles near the surface of the water also move in a similar circular pattern.

Figure 11-8

Ocean waves are surface waves at the boundary between air and water.

SECTION 11.1 REVIEW

SUMMARY

- ▶ A wave is a disturbance that carries energy through a medium or through space.
- ▶ Mechanical waves require a medium through which to travel. Light waves, also called electromagnetic waves, do not require a medium.
- ▶ Particles in a medium may vibrate perpendicularly to or parallel to the direction a wave is traveling.

CHECK YOUR UNDERSTANDING

1. **Identify** the medium for the following waves:
 - a. ripples on a pond
 - b. the sound waves from a stereo speaker
 - c. seismic waves
2. **Name** the one kind of wave that does not require a medium.
3. **Describe** the motion of a mass vibrating on a spring. How does this relate to wave motion?
4. **Explain** the difference between transverse waves and longitudinal waves. Give an example of each type.
5. **Describe** the motion of a water molecule on the surface of the ocean as a wave passes by.
6. **Critical Thinking** Describe a situation that demonstrates that water waves carry energy.

Characteristics of Waves

OBJECTIVES

- ▶ Identify the crest, trough, amplitude, and wavelength of a wave.
- ▶ Define the terms *frequency* and *period*.
- ▶ Solve problems involving wave speed, frequency, and wavelength.
- ▶ Describe the Doppler effect.

KEY TERMS

crest
trough
amplitude
wavelength
period
frequency
wave speed
Doppler effect

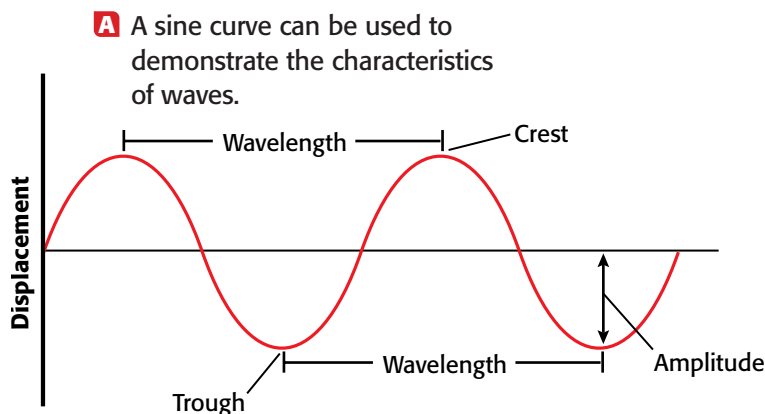
If you have spent any time at the beach or on a boat, you have probably observed many properties of waves. Sometimes the waves are very large; other times they are smaller. Sometimes they are close together, and sometimes they are farther apart. How can these differences be described and measured in more detail?

Wave Properties

All transverse waves have somewhat similar shapes, no matter how big they are or what medium they travel through. An ideal transverse wave has the shape of a *sine curve*, such as the curve on the graph in **Figure 11-9A**. A sine curve looks like an S lying on its side. Sine curves can be used to represent waves and to describe their properties.

Waves that have the shape of a sine curve, such as those on the rope in **Figure 11-9B**, are called *sine waves*. Although many waves, such as water waves, are not ideal sine waves, they can still be modeled with the graph of a sine curve.

Figure 11-9



B This transverse wave on a rope is a simple sine wave.



- ▶ **crest** the highest point of a transverse wave
- ▶ **trough** the lowest point of a transverse wave
- ▶ **amplitude** the greatest distance that particles in a medium move from their normal position when a wave passes

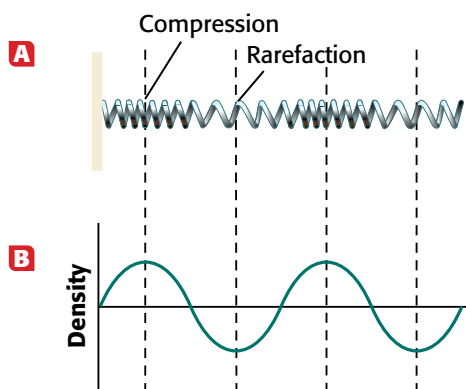


Figure 11-10

(A) A longitudinal wave has compressions and rarefactions. (B) The high and low points of this sine curve correspond to compressions and rarefactions in the spring.

- ▶ **wavelength** the distance between any two successive identical parts of a wave



Disc Two, Module 12:
Frequency and Wavelength
 Use the Interactive Tutor to learn more about these topics.

Amplitude measures the amount of particle vibration

The highest points of a transverse wave are called **crests**. The lowest parts of a transverse wave are called **troughs**. The greatest distance that particles are displaced from their normal resting positions because of a wave is called the **amplitude**. The amplitude is also half the vertical distance between a crest and a trough. Larger waves have bigger amplitudes and carry more energy.

But what about longitudinal waves? These waves do not have crests and troughs because they cause particles to move back and forth instead of up and down. If you make a longitudinal wave in a spring, you will see a moving pattern of areas where the coils are bunched up alternating with areas where the coils are stretched out. The crowded areas are called *compressions*. The stretched-out areas are called *rarefactions*. **Figure 11-10A** illustrates these properties of a longitudinal wave.

Figure 11-10B shows a graph of a longitudinal wave. Density or pressure of the medium is plotted on the vertical axis; the horizontal axis represents the distance along the spring. The resulting curve is a sine curve. The amplitude of a longitudinal wave is the maximum deviation from the normal density or pressure of the medium, which is shown by the high and low points on the graph.

Wavelength measures the distance between two equivalent parts of a wave

Waves crashing on the shore at a beach may be several meters apart, while ripples in a pond may be only a few centimeters apart. Crests of a light wave may be separated by only billionths of a meter.

The distance from one crest of a wave to the next crest, or from one trough to the next trough, is called the **wavelength**. In a longitudinal wave, the wavelength is the distance between two compressions or between two rarefactions. The wavelength is the measure of the distance between any two successive identical parts of a wave.

When used in equations, wavelength is represented by the Greek letter lambda, λ . Because wavelength is a distance measurement, it is expressed in the SI unit meters.

The period measures how long it takes for waves to pass by

If you swim out into the ocean until your feet can no longer touch the bottom, your body will be free to move up and down as waves come into shore. As your body rises and falls, you can count off the number of seconds between two successive waves.

The time required for one full wavelength of a wave to pass a certain point is called the **period** of the wave. The period is also the time required for one complete vibration of a particle in a medium—or of a swimmer in the ocean. In equations, the period is represented by the symbol T . Because the period is a time measurement, it is expressed in the SI unit seconds.

Frequency measures the rate of vibrations

While swimming in the ocean or floating in an inner tube, as shown in **Figure 11-11**, you could also count the number of crests that pass by in a certain time, say in 1 minute. The **frequency** of a wave is the number of full wavelengths that pass a point in a given time interval. The frequency of a wave also measures how rapidly vibrations occur in the medium, at the source of the wave, or both.

The symbol for frequency is f . The SI unit for measuring frequency is hertz (Hz), named after Heinrich Hertz, who in 1888 became the first person to experimentally demonstrate electromagnetic waves. Hertz units measure the number of vibrations per second. One vibration per second is 1 Hz, two vibrations per second is 2 Hz, and so on. You can hear sounds with frequencies as low as 20 Hz and as high as 20 000 Hz. When you hear a sound at 20 000 Hz, there are 20 000 compressions hitting your ear every second.

The frequency and period of a wave are related. If more vibrations are made in a second, each one takes a shorter amount of time. In other words, the frequency is the inverse of the period.

Frequency-Period Equation

$$\text{frequency} = \frac{1}{\text{period}} \quad f = \frac{1}{T}$$

In the inner tube example, a wave crest passes the inner tube every 2 s, so the period is 2 s. The frequency can be found by dividing the number of crests in a 4 s time interval by 4 s. Because 2 waves pass every 4 s, the frequency is 0.5 Hz, or half a wave per second. Note that 0.5 (1/2) is the inverse of 2.

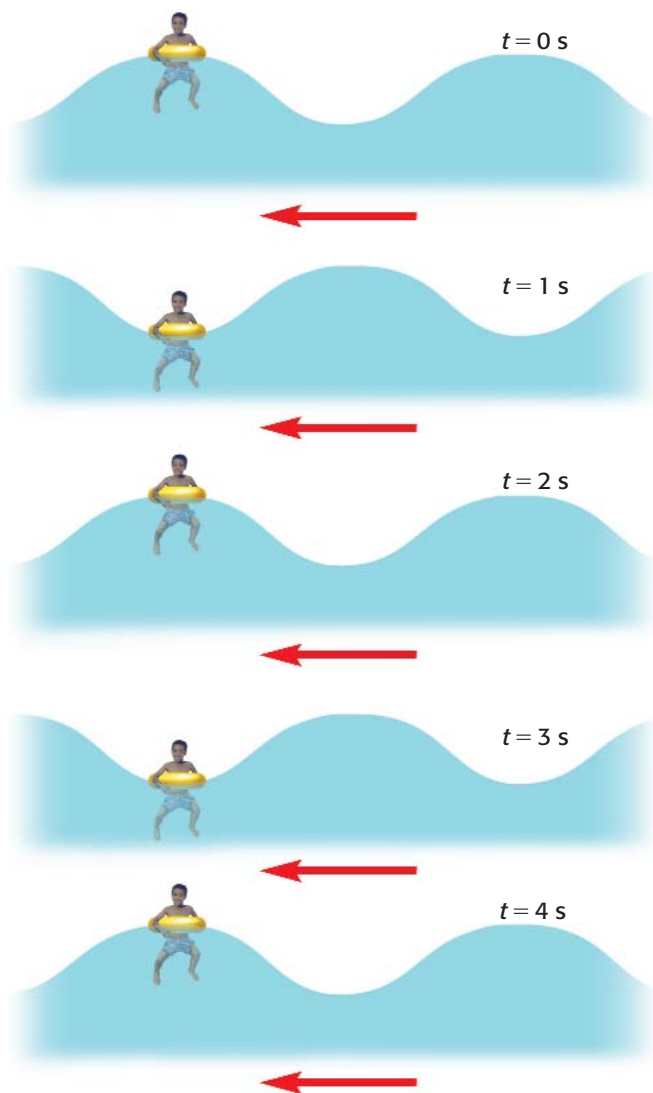


Figure 11-11

A person floating in an inner tube can determine the period and frequency of the waves by counting off the number of seconds between wave crests.

- ▶ **period** the time required for one full wavelength to pass a certain point
- ▶ **frequency** the number of vibrations that occur in a 1 s time interval

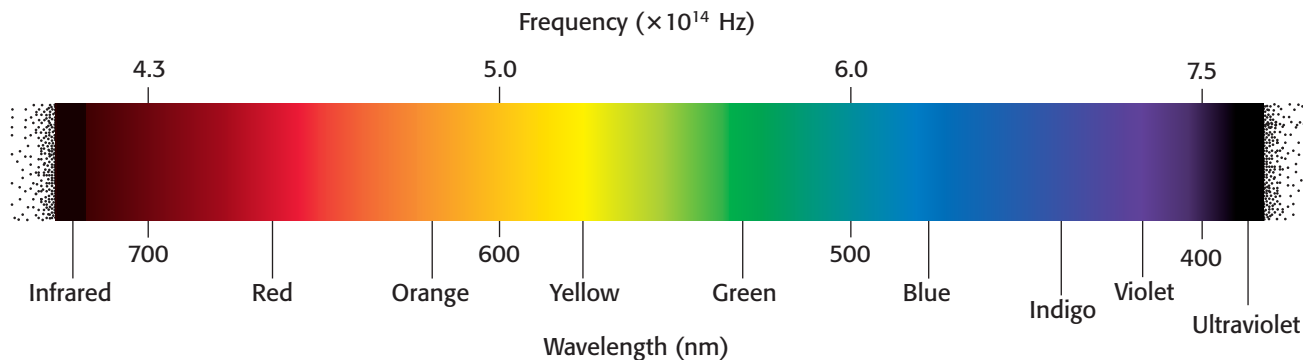


Figure 11-12

The part of the electromagnetic spectrum that we can see is called visible light.

Light comes in a wide range of frequencies and wavelengths

Our eyes can detect light with frequencies ranging from 4.3×10^{14} Hz to 7.5×10^{14} Hz. Light in this range is called *visible light*. The differences in frequency in visible light account for the different colors we see, as shown in **Figure 11-12**.

Electromagnetic waves also exist at other frequencies that we cannot see directly. The full range of light at different frequencies and wavelengths is called the *electromagnetic spectrum*. **Table 11-1** lists several different parts of the electromagnetic spectrum, along with some real-world applications of the different kinds of waves.

Table 11-1 The Electromagnetic Spectrum

Type of waves	Range of frequency and wavelength	Applications
Radio waves	$f < 1 \times 10^9$ Hz $\lambda > 30$ cm	AM and FM radio; television broadcasting; radar; aircraft navigation
Microwaves	1×10^9 Hz $< f < 3 \times 10^{11}$ Hz 30 cm $> \lambda > 1$ mm	Atomic and molecular research; microwave ovens
Infrared (IR) waves	3×10^{11} Hz $< f < 4.3 \times 10^{14}$ Hz 1 mm $> \lambda > 700$ nm	Infrared photography; physical therapy; heat radiation
Visible light	4.3×10^{14} Hz $< f < 7.5 \times 10^{14}$ Hz 700 nm (red) $> \lambda > 400$ nm (violet)	Visible-light photography; optical microscopes; optical telescopes
Ultraviolet (UV) light	7.5×10^{14} Hz $< f < 5 \times 10^{15}$ Hz 400 nm $> \lambda > 60$ nm	Sterilizing medical instruments; identifying fluorescent minerals
X rays	5×10^{15} Hz $< f < 3 \times 10^{21}$ Hz 60 nm $> \lambda > 1 \times 10^{-4}$ nm	Medical examination of bones, teeth, and organs; cancer treatments
Gamma rays	3×10^{18} Hz $< f < 3 \times 10^{22}$ Hz 0.1 nm $> \lambda > 1 \times 10^{-5}$ nm	Food irradiation; studies of structural flaws in thick materials

Wave Speed

Imagine watching as water waves move past a post at a dock such as the one in **Figure 11-13**. If you count the number of crests passing the post for 10 s, you can determine the frequency of the waves by dividing the number of crests you count by 10 s. If you measure the distance between crests, you can find the wavelength of the wave. But how fast are the water waves moving?

Wave speed equals frequency times wavelength

In Chapter 8, you learned that the speed of a moving object is found by dividing the distance an object travels by the time interval during which it travels that distance. Recall the speed equation from Section 8.1.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$
$$v = \frac{d}{t}$$

The **wave speed** is simply how fast a wave moves. Finding the speed of a wave is just like finding the speed of a moving object. You need to measure how far a wave travels in a certain amount of time.

For a wave, it is most convenient to use the wavelength as the distance traveled. The amount of time it takes the wave to travel a distance of one wavelength is the period. Substituting these into the speed equation gives an equation that can be used to calculate the speed of a wave.

$$\text{speed} = \frac{\text{wavelength}}{\text{period}}$$
$$v = \frac{\lambda}{T}$$

Because the period is the inverse of the frequency, dividing by the period is equivalent to multiplying by the frequency. Therefore, the speed of a wave can also be calculated by multiplying the wavelength by the frequency.

Wave Speed Equation

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

Suppose that waves passing by a post at a dock have a wavelength of 5 m, and two waves pass by in 10 s. In other words, 10 m of wave pass by in 10 s. Each second 1 m of the wave passes by the post. The waves in this case travel with a wave speed of 1 m/s.

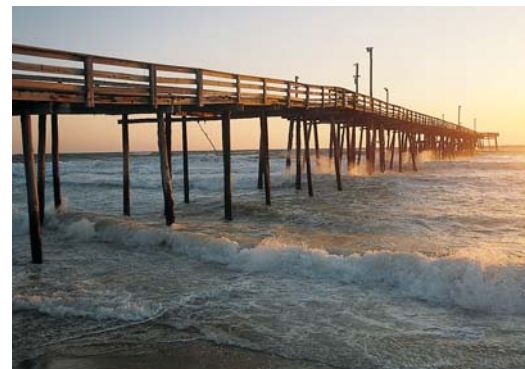


Figure 11-13

By observing the frequency and wavelength of waves passing a dock, you can calculate the speed of the waves.

▶ **wave speed** the speed at which a wave passes through a medium

INTEGRATING



EARTH SCIENCE

Earthquakes create waves, called *seismic waves*, that travel

through Earth. There are two main types of seismic waves, *P waves* (primary waves) and *S waves* (secondary waves).

P waves travel faster than S waves, so the P waves arrive at a given location first. P waves are longitudinal waves that tend to shake the ground from side to side.

S waves move more slowly than P waves but also carry more energy. S waves are transverse waves that shake the ground up and down, often damaging buildings and roads.

Practice HINT

- ▶ When a problem requires you to calculate wave speed, you can use the wave speed equation on the previous page.
- ▶ The wave speed equation can also be rearranged to isolate frequency on the left in the following way:

$$v = f \times \lambda$$

Divide both sides by λ .

$$\frac{v}{\lambda} = \frac{f \times \lambda}{\lambda}$$

$$f = \frac{v}{\lambda}$$

You will need to use this form of the equation in Practice Problem 3.

- ▶ In Practice Problem 4, you will need to rearrange the equation to isolate wavelength on the left.

Math Skills

Wave Speed The string of a piano that produces the note middle C vibrates with a frequency of 264 Hz. If the sound waves produced by this string have a wavelength in air of 1.30 m, what is the speed of sound in air?

1 List the given and unknown values.

Given: frequency, $f = 264$ Hz
wavelength, $\lambda = 1.30$ m

Unknown: wave speed, $v = ?$ m/s

2 Write the equation for wave speed.

$$v = f \times \lambda$$

3 Insert the known values into the equation, and solve.

$$v = 264 \text{ Hz} \times 1.30 \text{ m} = 264 \text{ s}^{-1} \times 1.30 \text{ m}$$
$$v = 343 \text{ m/s}$$

Practice

Wave Speed

1. The average wavelength in a series of ocean waves is 15.0 m. A wave arrives on average every 10.0 s, so the frequency is 0.100 Hz. What is the average speed of the waves?
2. An FM radio station broadcasts electromagnetic waves at a frequency of 94.5 MHz (9.45×10^7 Hz). These radio waves have a wavelength of 3.17 m. What is the speed of the waves?
3. Green light has a wavelength of 5.20×10^{-7} m. The speed of light is 3.00×10^8 m/s. Calculate the frequency of green light waves with this wavelength.
4. The speed of sound in air is about 340 m/s. What is the wavelength of a sound wave with a frequency of 220 Hz (on a piano, the A below middle C)?

The speed of a wave depends on the medium

Sound waves travel through air. If they didn't, you wouldn't be able to have a conversation with a friend or hear music from a radio across the room. Because sound travels very fast, you don't notice a time delay in most normal situations. The speed of sound in air is about 340 m/s.

If you swim with your head underwater, you may hear certain sounds very clearly. Sound waves travel better—and three to four times faster—in water than in air. Dolphins, such as those in **Figure 11-14**, use sound waves to communicate with one another over long distances underwater. Sound waves travel even faster in solids than in air or in water. Sound waves have speeds 15 to 20 times faster in rock or metal than in air.

If someone strikes a long steel rail with a hammer at one end and you listen for the sound at the other end, you might hear two bangs. The first sound comes through the steel rail itself and reaches you shortly before the second sound, which travels through the air.

The speed of a wave depends on the medium. In a given medium, though, the speed of waves is constant. No matter how fast you shake your hand up and down to create waves on a rope, the waves will travel the same speed. Shaking your hand faster just increases the frequency and decreases the wavelength.

Kinetic theory explains differences in wave speed

The arrangement of particles in a medium determines how well waves travel through it. As you learned in Chapter 2, the different states of matter are due to different degrees of organization at the particle level.

In gases, the molecules are far apart and move around randomly. A molecule must travel through a lot of empty space before it bumps into another molecule. Waves don't travel as fast in gases.

In liquids, such as water, the molecules are much closer together. But they are also free to slide past one another. As a result, vibrations are transferred more quickly from one molecule to the next than they are in a gas. This situation can be compared to vibrating masses on springs that are so close together that the masses rub against each other.

In a solid, molecules are not only closer together but also tightly bound to each other. The effect is like having vibrating masses that are glued together. When one mass starts to vibrate, all the others start to vibrate almost immediately. As a result, waves travel very quickly through solids.

Light has a finite speed

When you flip a light switch, light seems to fill the room instantly. However, light does take time to travel from place to place. All electromagnetic waves in empty space travel at the same speed, the speed of light, which is 3×10^8 m/s (186 000 mi/s). The speed of light constant is often represented by the symbol c . Light travels slower when it has to pass through a medium such as air or water.



Figure 11-14

Dolphins use sound waves to communicate with one another. Sound travels three to four times faster in water than in air.

Quick ACTIVITY

Wave Speed

1. Place a rectangular pan on a level surface, and fill the pan with water to a depth of about 2 cm.
2. Cut a wooden dowel (3 cm in diameter or thicker) to a length slightly less than the width of the pan, and place the dowel in one end of the pan.
3. Move the dowel slowly back and forth, and observe the length of the wave generated.
4. Now roll the dowel back and forth faster (increased frequency). How does that affect the wavelength?
5. Do the waves always travel the same speed in the pan?

The Doppler Effect

Imagine that you are standing on a corner as an ambulance rushes by. As the ambulance passes, the sound of the siren changes from a high pitch to a lower pitch. Why? Do the sound waves produced by the siren change as the ambulance goes by? How does the motion of the ambulance affect the sound?

Pitch is determined by the frequency of sound waves

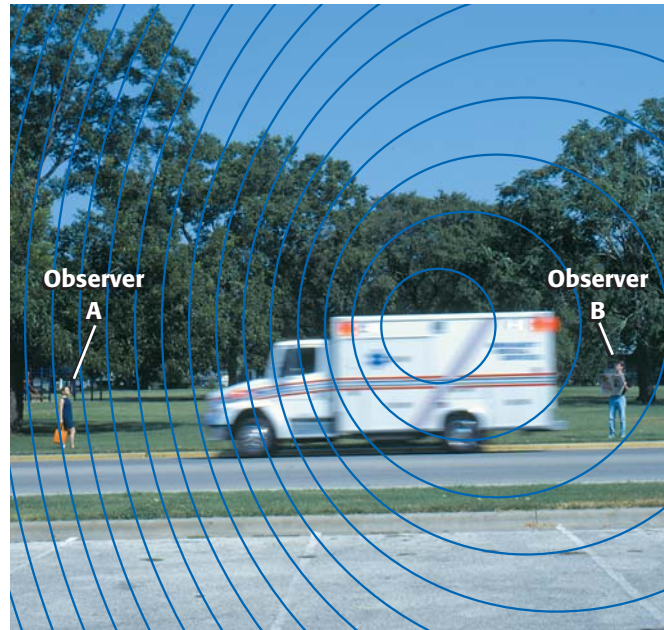
The *pitch* of a sound, how high or low it is, is determined by the frequency at which sound waves strike the eardrum in your ear. A higher-pitched sound is caused by sound waves of higher frequency. As you know from the wave speed equation, frequency and wavelength are also related to the speed of a wave.

Suppose you could see the sound waves from the ambulance siren when the ambulance is at rest. You would see the sound waves traveling out from the siren in circular wave fronts, as shown in **Figure 11-15A**. The distance between two successive wave fronts shows the wavelength of the sound waves. When the sound waves reach your ears, they have a frequency equal to the number of wave fronts that strike your eardrum each second. That frequency determines the pitch of the sound that you hear.

Figure 11-15



A When an ambulance is not moving, the sound waves produced by the siren spread out in circles. The frequency of the waves is the same at any location.





B When an ambulance is moving, the sound waves produced by the siren are closer together in front and farther apart behind. Observer A hears a higher-pitched sound than Observer B hears.

Frequency changes when the source of waves is moving

If the ambulance is moving toward you, the sound waves from the siren are compressed in the direction of motion, as shown in **Figure 11-15B**. Between the time that one sound wave and the next sound wave are emitted by the siren, the ambulance moves a short distance. This shortens the distance between successive wave fronts. As a result, the sound waves reach your ear at a faster rate, that is, at a higher frequency.

Because the waves now have a higher frequency, you hear a higher-pitched sound than you would if the ambulance were at rest. Similarly, if the ambulance were moving away from you, the frequency at which the waves reached your ear would be less than if the ambulance were at rest, and you would hear the sound of the siren at a lower pitch. This change in the observed frequency of a wave resulting from the motion of the source or observer is called the **Doppler effect**. The Doppler effect occurs for light and other types of waves as well.



TOPIC: Doppler effect
GO TO: www.scilinks.org
KEYWORD: HK1114

▶ **Doppler effect** an observed change in the frequency of a wave when the source or observer is moving

SECTION 11.2 REVIEW

SUMMARY

- ▶ The highest points of a transverse wave are called crests; the lowest parts are called troughs.
- ▶ The amplitude of a transverse wave is half the vertical distance between a crest and a trough.
- ▶ The wavelength is the distance between two successive identical parts of a wave.
- ▶ The period of a wave is the time it takes a wavelength to pass a certain point.
- ▶ The frequency of a wave is the number of vibrations that occur in 1 s. (1 Hz = 1 vibration/s)
- ▶ The speed of a wave equals the frequency times the wavelength. ($v = f \times \lambda$)

CHECK YOUR UNDERSTANDING

1. **Draw** a sine curve, and label a crest, a trough, and the amplitude.
2. **State** the SI units used for wavelength, period, frequency, and wave speed.
3. **Describe** how the frequency and period of a wave are related.
4. **Explain** why sound waves travel faster in liquids or solids than in air.
5. **Critical Thinking** What happens to the wavelength of a wave when the frequency of the wave is doubled but the wave speed stays the same?
6. **Critical Thinking** Imagine you are waiting for a train to pass at a railroad crossing. Will the train whistle have a higher pitch as the train approaches you or after it has passed you by?

Math Skills

7. A wave along a guitar string has a frequency of 440 Hz and a wavelength of 1.5 m. What is the speed of the wave?
8. The speed of sound in air is about 340 m/s. What is the wavelength of sound waves produced by a guitar string vibrating at 440 Hz?
9. The speed of light is 3×10^8 m/s. What is the frequency of microwaves with a wavelength of 1 cm?

Wave Interactions

KEY TERMS

reflection
 diffraction
 refraction
 interference
 constructive interference
 destructive interference
 standing wave



Disc Two, Module 13: Reflection

Use the Interactive Tutor to learn more about this topic.

OBJECTIVES

- ▶ Describe how waves behave when they meet an obstacle, pass into another medium, or pass through another wave.
- ▶ Explain what happens when two waves interfere.
- ▶ Distinguish between constructive interference and destructive interference.
- ▶ Explain how standing waves are formed.

When waves are simply moving through a medium or through space, they may move in straight lines like waves on the ocean, spread out in circles like ripples on a pond, or spread out in spheres like sound waves in air. But what happens when a wave meets an object or another wave in the medium? And what happens when a wave passes into another medium?

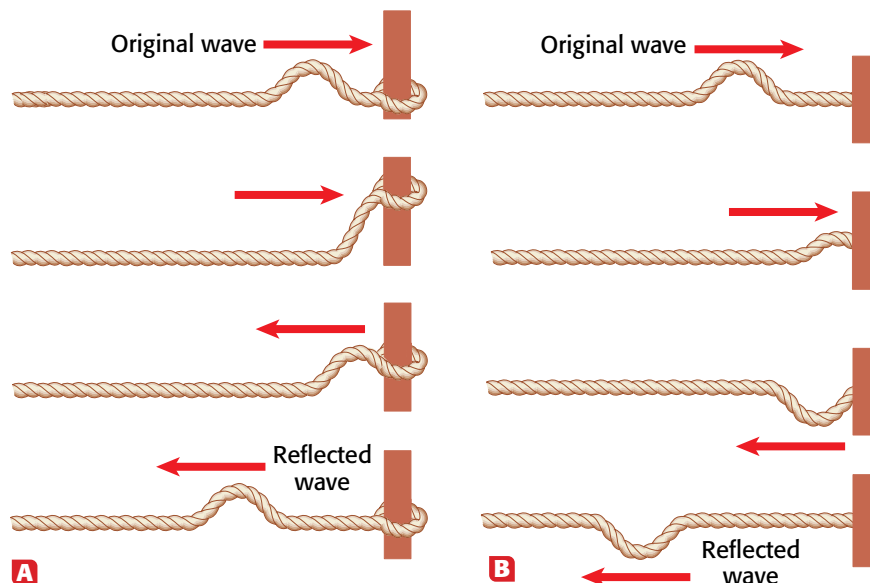
Reflection, Diffraction, and Refraction

You probably already know what happens when light waves strike a shiny surface: they reflect off the surface. Other waves reflect, too. **Figure 11-16** shows two ways that a wave on a rope may be reflected. **Reflection** is simply the bouncing back of a wave when it meets a surface or boundary.

▶ **reflection** the bouncing back of a wave as it meets a surface or boundary

Figure 11-16

(A) If the end of a rope is free to slide up and down a post, a wave on the rope will reflect from the end. (B) If the end of the rope is fixed, the reflected wave is turned upside down.



Waves reflect at a free boundary

Figure 11-16A shows the reflection of a single wave traveling on a rope. The end of the rope is free to move up and down on a post. When the wave reaches the post, the loop on the end moves up and then back down. This is just what would happen if someone were shaking that end of the rope to create a new wave. The reflected wave in this case is exactly like the original wave.

At a fixed boundary, waves reflect and turn upside down

Figure 11-16B shows a slightly different situation. In this case, the end of the rope is not free to move because it is attached to a wall. When the wave reaches the wall, the rope exerts an upward force on the wall. The wall is too heavy to move, but it exerts an equal and opposite downward force on the rope, following Newton's third law. The force exerted by the wall causes another wave to start traveling down the rope. This reflected wave is like the original wave, but it is turned upside down and travels in the opposite direction.

Diffraction is the bending of waves around an edge

If you stand outside the doorway of a classroom, you may be able to hear the sound of voices inside the room. But if the sound waves cannot travel in a straight line to your ear, how are you able to hear the voices?

When waves pass the edge of an object or pass through an opening, such as a door, they spread out as if a new wave were created there. In effect, the waves bend around an object or opening. This bending of waves as they pass an edge is called **diffraction**.

Figure 11-17A shows waves passing around a block in a tank of water. Before they reach the block, the waves travel in a straight line. After they pass the block, the waves near the edge bend and spread out into the space behind the block.

The tank in **Figure 11-17B** contains two blocks placed end to end with a small gap in between. In this case, waves bend around two edges and spread out as they pass through the opening. Sound waves passing through a door behave the same way. Because sound waves spread out into the space beyond the door, a person near the door on the outside can hear sounds from inside the room.

internetconnect

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TOPIC: Reflection, refraction, diffraction
GO TO: www.scilinks.org
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▶ **diffraction** the bending of a wave as it passes an edge or an opening

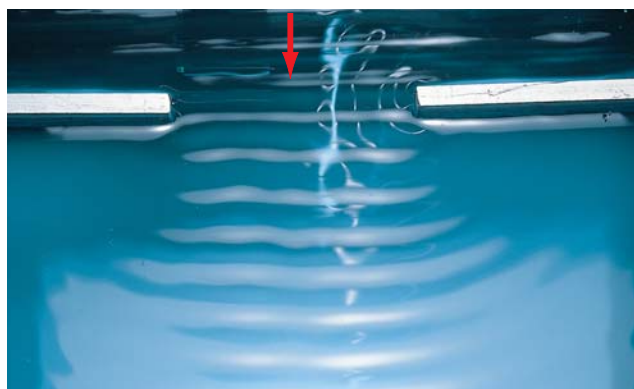
Figure 11-17

(A) Waves bend when they pass the edge of an obstacle.

(B) When they pass through an opening, waves bend around both edges.



A



B



Figure 11-18

Because light waves bend when they pass from one medium to another, this spoon looks like it is in two pieces.

- ▶ **refraction** the bending of waves as they pass from one medium to another
- ▶ **interference** the combination of two or more waves that exist in the same place at the same time

Figure 11-19

Water waves passing through each other produce interference patterns.



Waves can also bend by refraction

Figure 11-18 shows a spoon in a glass of water. Why does the spoon look like it is broken into two pieces? This strange sight results from light waves bending, but not because of diffraction. This time, the waves are bending because of **refraction**. Refraction is the bending of waves when they pass from one medium into another. All waves are refracted when they pass from one medium to another at an angle.

Light waves from the top of the spoon handle pass straight through the air from the spoon to your eyes. But the light waves from the rest of the spoon start out in the water, then pass into the glass, then into the air. Each time the waves enter a new medium, they bend slightly. By the time those waves reach your eyes, they are coming from a different angle than the waves from the top of the spoon handle. But your eyes don't know that; they just see that one set of light waves are coming from one direction, and another set of waves are coming from a different direction. As a result, the spoon appears to be broken.

Interference

What would happen if you and another person tried to walk through the exact same place at the same time? You would run into each other. Material objects, such as a human body, cannot share space with other material objects. More than one wave, however, can exist in the same place at the same time.

Waves in the same place combine to produce a single wave

When several waves are in the same location, the waves combine to produce a single, new wave that is different from the original waves. This is called **interference**. **Figure 11-19** shows interference occurring as water waves pass through each other. Once the

waves have passed through each other and moved on, they return to their original shape.

You can show the interference of two waves by drawing one wave on top of another on a graph, as in **Figure 11-20**. The resulting wave can be found by adding the height of the waves at each point. Crests are considered positive, and troughs are considered negative.

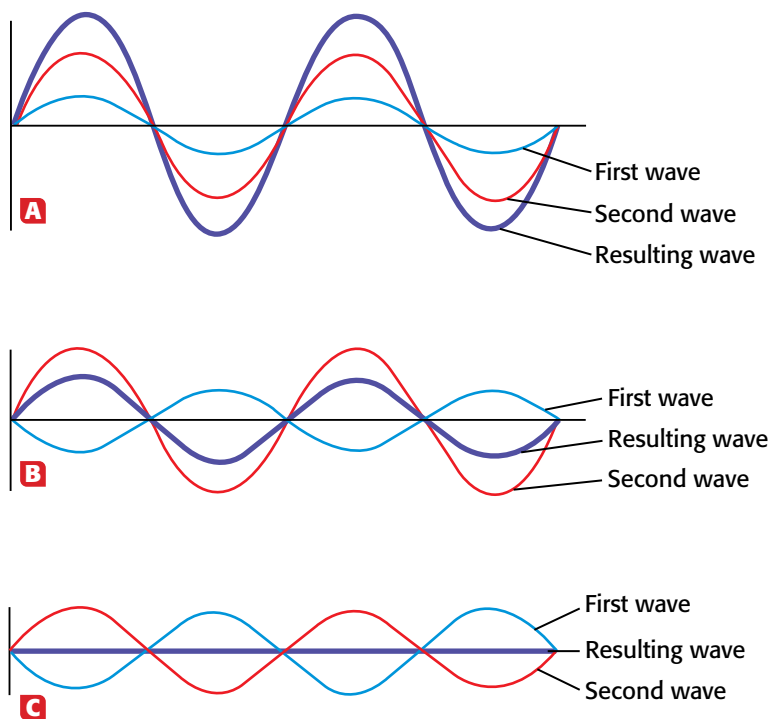


Figure 11-20
Constructive and Destructive Interference

(A) When two waves line up so their crests overlap, they add together to make a larger wave. (B) When the crest of a large wave overlaps with the trough of a smaller wave, subtraction occurs. (C) Two waves of the same size may completely cancel each other out.



Disc Two, Module 14: Refraction
 Use the Interactive Tutor to learn more about this topic.

In constructive interference, amplitudes are added

When the crest of one wave overlaps the crest of another wave, the waves reinforce each other, as shown in **Figure 11-20A**. Think about what happens at the particle level. Suppose the crest of one wave would move a particle up 4 cm from its original position, and another wave crest would move the particle up 3 cm.

When both waves hit at the same time, the particle moves up 4 cm due to one wave and 3 cm due to the other for a total of 7 cm. The result is a wave whose amplitude is the sum of the amplitudes of the two individual waves. This is called **constructive interference**.

In destructive interference, amplitudes are subtracted

When the crest of one wave meets the trough of another wave, the resulting wave has a smaller amplitude than the larger of the two waves, as shown in **Figure 11-20B**. This is called **destructive interference**.

To understand how this works, imagine again a single particle. Suppose the crest of one wave would move the particle up 4 cm, and the trough of another wave would move it down 3 cm. If the waves hit the particle at the same time, the particle would move in response to both waves, and the new wave would have an amplitude of just 1 cm. When destructive interference occurs between two waves that have the same amplitude, the waves may completely cancel each other out, as shown in **Figure 11-20C**.

▶ **constructive interference**
 any interference in which waves combine so that the resulting wave is bigger than the original waves

▶ **destructive interference**
 any interference in which waves combine so that the resulting wave is smaller than the largest of the original waves



Figure 11-21

The colorful swirls on a bubble result from the constructive interference of some colors and the destructive interference of other colors.

Interference of light waves creates colorful displays

The interference of light waves often produces colorful displays. You can see a rainbow of colors when oil is spilled onto a watery surface. Soap bubbles, like the ones shown in **Figure 11-21**, have reds, blues, and yellows on their surfaces. The colors in these examples are not due to pigments or dyes. Instead, they are due to the interference of light.

When you look at a soap bubble, some light waves bounce off the outside of the bubble and travel directly to your eye. Other light waves travel into the thin shell of the bubble, bounce off the inner side of the bubble's shell, then travel back through the shell, into the air and to your eye. Those waves travel farther than the waves reflected directly off the outside of the bubble. At times the two sets of waves are out of step with each other. The two sets of waves interfere constructively at some frequencies (colors) and destructively at other frequencies (colors). The result is a swirling rainbow effect.

Interference of sound waves produces beats

The sound waves from two tuning forks of slightly different frequencies will interfere with each other as shown in **Figure 11-22A**. Because the frequencies of the tuning forks are different, the compressions arrive at your ear at different rates.

When the compressions from the two tuning forks arrive at your ear at the same time, constructive interference occurs, and the sound is louder. A short time later, the compression from one and the rarefaction from the other arrive together. When this happens, destructive interference occurs, and a softer sound is heard. After a short time, the compressions again arrive at the same time, and again a loud sound is heard. Overall, you hear a series of loud and soft sounds called *beats*.

Figure 11-22

(A) When two waves of slightly different frequencies interfere with each other, they produce beats. (B) A piano tuner can listen for beats to tell if a string is out of tune.

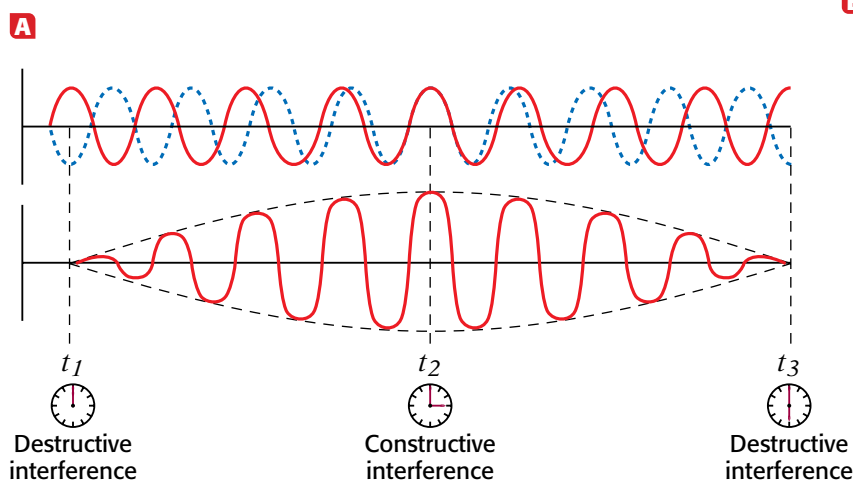


Figure 11-22B shows a piano tuner tuning a string. Piano tuners listen for beats between a tuning fork of known frequency and a string on a piano. By adjusting the tension in the string, the tuner can change the pitch (frequency) of the string's vibration. When no beats are heard, the string is vibrating with the same frequency as the tuning fork. In that case, the string is said to be in tune.

Standing Waves

Waves can also interfere in another way. Suppose you send a wave through a rope tied to a wall at the other end. The wave is reflected from the wall and travels back along the rope. If you continue to send waves down the rope, the waves that you make will interfere with those waves that reflect off the wall and travel back toward you.

Interference can cause standing waves

If the reflected waves have the same amplitude, frequency, and speed as the original waves, then **standing waves** are formed. Standing waves look very different from normal traveling waves. Standing waves do not move through the medium. Instead, the waves cause the medium to vibrate in a loop or in a series of loops.

Standing waves have nodes and antinodes

Each loop of a standing wave is separated from the next loop by points that have no vibration, called *nodes*. Nodes lie at the points where the crests of the original waves meet the troughs of the reflected waves, causing complete destructive interference.

One of the nodes on a fixed rope string lies at the point of reflection, where the rope cannot vibrate. Another node is near your hand. If you shake the rope up and down fast enough, you can create standing waves with several nodes along the length of the string.

Midway between the nodes lie points of maximum vibration, called *antinodes*. Antinodes form where the crests of the original waves line up with the crests of the reflected waves so that complete constructive interference occurs.

Connection to ARCHITECTURE

You might have experienced destructive interference in an auditorium or a concert hall. As sound waves reflect from the walls, there are places, known as *dead spots*, where the waves interfere destructively and cancel out.

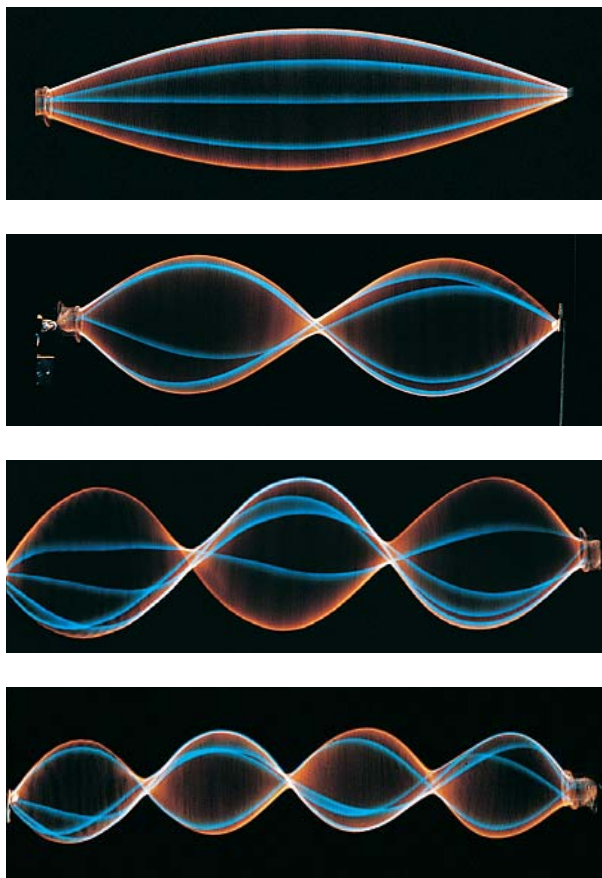
Dead spots are produced by the interference of sound waves coming directly from the stage and waves reflected off the walls. For this reason, architects design concert halls so that the dimensions are not simple multiples of each other. They also try to avoid smooth, parallel walls in the design. Irregularities in the wall and ceiling contribute to reducing the direct reflections of waves and the possible interference.

Making the Connection

1. With a friend, go to a square or rectangular room with walls made of brick, cinder block, or concrete. Have one person talk or sing loudly while the other person moves around the room to locate dead spots.
2. Draw an overhead view of the room, and mark the locations of the dead spots. Why do you think the dead spots are in those places?
3. Write a short paragraph explaining how the room could be changed to reduce or eliminate the dead spots.



▶ **standing wave** a wave form caused by interference that appears not to move along the medium and that shows some regions of no vibration (nodes) and other regions of maximum vibration (antinodes)



Standing waves can have only certain wavelengths

Figure 11-23 shows several different possible standing waves on a string fixed at both ends. Only a few waves with specific wavelengths can form standing waves in any given string.

The simplest standing waves occur when the wavelength of the waves is twice the length of the string. In that case, it just looks like the entire string is shaking up and down. The only nodes are on the two ends of the string.

If the string vibrates with a higher frequency, the wavelength becomes shorter. At a certain frequency, the wavelength is exactly equal to the length of the string. In the middle of the string, complete destructive interference occurs, producing a node.

In general, standing waves can exist whenever a multiple of half-wavelengths will fit exactly in the length of the string.

Figure 11-23

These photos of standing waves were captured using a strobe light that flashes different colors at different times.

SECTION 11.3 REVIEW

SUMMARY

- ▶ Waves bouncing off a surface is called reflection.
- ▶ Diffraction is the bending of waves as they pass an edge or corner.
- ▶ Refraction is the bending of waves as they pass from one medium to another.
- ▶ Interference results when two waves exist in the same place and combine to make a single wave.
- ▶ Interference may cause standing waves.

CHECK YOUR UNDERSTANDING

- 1. Describe** what may happen when ripples on a pond encounter a large rock in the water.
- 2. Explain** why you can hear two people talking even after they walk around a corner.
- 3. Name** the conditions required for two waves to interfere constructively.
- 4. Explain** why colors appear on the surface of a soap bubble.
- 5. Draw** a standing wave, and label the nodes and antinodes.
- 6. Critical Thinking** What conditions are required for two waves on a rope to interfere completely destructively?
- 7. Critical Thinking** Imagine that you and a friend are trying to tune the lowest strings on two different guitars to the same pitch. Explain how you could use beats to determine if the strings are properly tuned.
- 8. Critical Thinking** Determine the longest possible wavelength of a standing wave on a string that is 2 m long.

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 364, 373, and 380. The key vocabulary terms are listed on pages 356, 365, and 374.

UNDERSTANDING CONCEPTS

- Waves that need a medium in which to travel are called _____.
 - longitudinal waves
 - transverse waves
 - mechanical waves
 - All of the above
- Most waves are caused by _____.
 - velocity
 - amplitude
 - a vibration
 - earthquakes
- For which type of waves do particles in the medium vibrate perpendicularly to the direction in which the waves are traveling?
 - transverse waves
 - longitudinal waves
 - P waves
 - none of the above
- A sound wave is an example of _____.
 - an electromagnetic wave
 - a transverse wave
 - a longitudinal wave
 - a surface wave
- In an ocean wave, the molecules of water _____.
 - move perpendicularly to the direction of wave travel
 - move parallel to the direction of wave travel
 - move in circles
 - don't move at all
- Half the vertical distance between the crest and trough of a wave is called the _____.
 - frequency
 - crest
 - wavelength
 - amplitude
- The number of waves passing a given point each second is called the _____.
 - frequency
 - wave speed
 - wavelength
 - amplitude
- The Doppler effect of a passing siren results from an apparent change in _____.
 - loudness
 - wave speed
 - frequency
 - interference
- The combining of waves as they meet is known as _____.
 - a crest
 - noise
 - interference
 - the Doppler effect
- Waves bend when they pass through an opening. This is called _____.
 - interference
 - diffraction
 - refraction
 - the Doppler effect

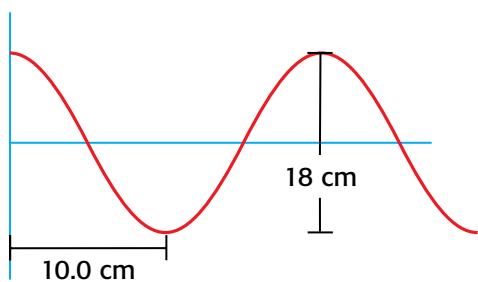
Using Vocabulary

- How is an *electromagnetic wave* different from a *mechanical wave*?
- You have a long metal rod and a hammer. How would you hit the metal rod to create a *longitudinal wave*? How would you hit it to create a *transverse wave*?
- Identify each of the following as a distance measurement, a time measurement, or neither.
 - amplitude*
 - wavelength*
 - period*
 - frequency*
 - wave speed*
- Imagine a train approaching a crossing where you are standing safely behind the gate. Explain the changes in sound of the horn that you may hear as the train passes. Use the following terms in your answer: *frequency*, *wavelength*, *wave speed*, *Doppler effect*.
- Explain the difference between *constructive interference* and *destructive interference*.
- Draw a picture of a *standing wave*, and label a *node* and an *antinode*.

BUILDING MATH SKILLS

- 17. Graphing** Draw a sine curve, and label a crest, a trough, and the amplitude.
- 18. Interpreting Graphics** The wave shown in the figure below has a frequency of 25.0 Hz. Find the following values for this wave:

- a. amplitude c. speed
b. wavelength d. period



- 19. Wave Speed** Suppose you tie one end of a rope to a doorknob and shake the other end with a frequency of 2 Hz. The waves you create have a wavelength of 3 m. What is the speed of the waves along the rope?
- 20. Wave Speed** Ocean waves are hitting a beach at a rate of 2.0 Hz. The distance between wave crests is 12 m. Calculate the speed of the waves.
- 21. Wavelength** All electromagnetic waves have the same speed in empty space, 3.0×10^8 m/s. Using that speed, find the wavelengths of the electromagnetic waves at the following frequencies:
- a. radio waves at 530 kHz
b. visible light at 6.0×10^{14} Hz
c. X rays at 3.0×10^{18} Hz
- 22. Frequency** Microwaves range in wavelength from 1 mm to 30 cm. Calculate their range in frequency. Use 3×10^8 m/s as the speed of electromagnetic waves.

THINKING CRITICALLY

- 23. Understanding Systems** A friend standing 2 m away strikes two tuning forks at the same time, one at a frequency of 256 Hz and the other at 240 Hz. Which sound will reach your ear first? Explain.
- 24. Applying Knowledge** When you are watching a baseball game, you may hear the crack of the bat a short time after you see the batter hit the ball. Why does this happen? (**Hint:** Consider the relationship between the speed of sound and the speed of light.)
- 25. Understanding Systems** You are standing on a street corner, and you hear a fire truck approaching. Does the pitch of the siren stay constant, increase, or decrease as it approaches you? Explain.
- 26. Applying Knowledge** If you yell or clap your hands while standing at the edge of a large rock canyon, you may hear an echo a few seconds later. Explain why this happens.
- 27. Interpreting Graphics** Draw the wave that results from interference between the two waves shown below.



- 28. Understanding Systems** An orchestra is playing in a huge outdoor amphitheater, and thousands of listeners sit on a hillside far from the stage. To help those listeners hear the concert, the amphitheater has speakers halfway up the hill. How could you improve this system? A computer delays the signal to the speakers by a fraction of a second. Why is this computer used? What might happen if the signal were not delayed at all?

DEVELOPING LIFE/WORK SKILLS

29. Applying Knowledge Describe how you interact with waves during a typical school day. Document the types of waves you encounter and how often you interact with each. Decide if one type of wave is more important in your life than the others.

30. Applying Technology With your teacher's help, use a microphone and an oscilloscope or a CBL interface to obtain an image of a sound. Determine the frequency and wavelength of the sound.

COMPUTER SKILL

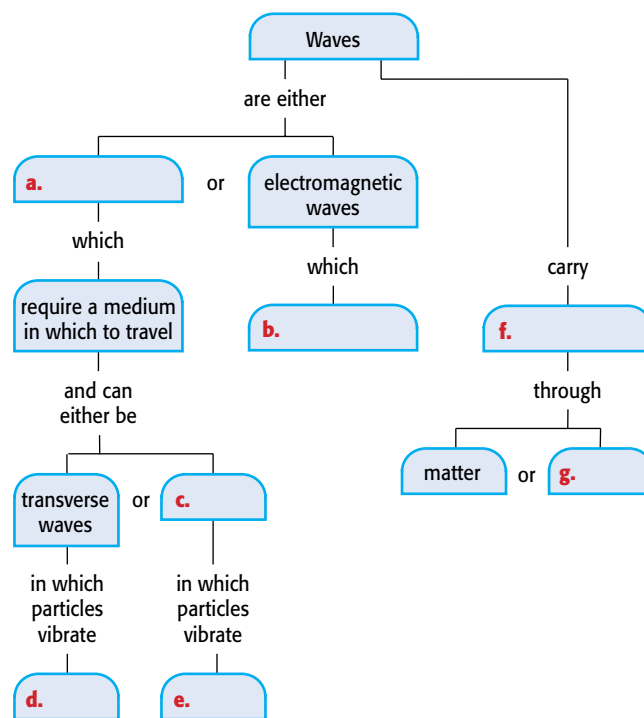
31. Making Decisions A new car is advertised as having antinoise technology. The manufacturer claims that inside the car any sounds are negated. Evaluate the possibility of such a claim. What would have to be created to cause destructive interference with any sound in the car? Would it be possible to have destructive interference everywhere inside the car? Do you believe that the manufacturer is correct in its statement?

32. Working Cooperatively Work with two other classmates to research the types of architectural acoustics that would affect a restaurant. Investigate some of the acoustics problems in places where many people gather. How do odd-shaped ceilings, decorative panels, and glass windows affect echoes and noise. Prepare a model of your school cafeteria showing what changes you would make to reduce the level of noise.

33. Applying Knowledge A piano tuner listens to a tuning fork vibrating at 440 Hz to tune the string of a piano. He hears beats between the tuning fork and the piano string. Is the string in tune? Explain your answer.

INTEGRATING CONCEPTS

34. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



35. Connection to Earth Science What is the medium for seismic waves?

36. Connection to Architecture Explore and describe research on earthquake-proof buildings and materials. Evaluate the impact of this research on society in terms of building codes and architectural styles in earthquake-prone areas such as Los Angeles, San Francisco, and Tokyo.

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Design Your Own Lab

Modeling Transverse Waves

Introduction

A model of a transverse wave may be created with a sand pendulum. What characteristics of waves can you measure using such a model?

Objectives

- ▶ **Create** sine curves by pulling paper under a sand pendulum.
- ▶ **Measure** the amplitude, wavelength, and period of transverse waves using sine curves as models.
- ▶ **Predict** how changes to the experiment may change the amplitude and wavelength.
- ▶ **Calculate** frequency and wave speed using your measurements.

Materials

paper or plastic-foam cup
nail
string and scissors
masking tape
colored sand
ring stand or other support
rolls of white paper, about 30 cm wide
meterstick
stopwatch

Safety Needs



safety glasses, gloves

▶ Making Sine Curves with a Sand Pendulum

1. Review the discussion in Section 11.2 on the use of sine curves to represent transverse waves.
2. On a blank sheet of paper, prepare a table like the one shown at right.
3. Use a nail to puncture a small hole in the bottom of a paper cup. Also punch two holes on opposite sides of the cup near the rim. Tie strings of equal length through the upper holes. Make a pendulum by tying the strings from the cup to a ring stand or other support. Clamp the stand down at the end of a table, as shown in the photograph at right. Cover the bottom hole with a piece of tape, then fill the cup with sand.

SAFETY CAUTION Wear gloves while handling the nails and punching holes.



4. Unroll some of the paper, and mark off a length of 1 m using two dotted lines. Then roll the paper back up, and position the paper under the pendulum, as shown in the photograph at right.
5. Remove the tape over the hole. Start the pendulum swinging as your lab partner pulls the paper in a direction perpendicular to the cup's swing. Another lab partner should loosely hold the paper roll. Try to pull the paper in a straight line with a constant speed. The sand should trace a sine curve on the paper, as in the photograph at right.
6. As your partner pulls the paper under the pendulum, start the stopwatch when the sand trace reaches the first dotted line marking the length of 1 m. When the sand trace reaches the second dotted line, stop the watch. Record the time in your table.
7. When you are finished making a curve, stop the pendulum and cover the hole in the bottom of the cup. Be careful not to jostle the paper; if you do, your trace may be erased. You may want to tape the paper down.

Length along paper = 1 m	Time (s)	Average wavelength (m)	Average amplitude (m)
Curve 1			
Curve 2			
Curve 3			

- For the part of the curve between the dotted lines, measure the distance from the first crest to the last crest, then divide that distance by the total number of crests. Record your answer in the table under "Average wavelength."
- For the same part of the curve, measure the vertical distance between the first crest and the first trough, between the second crest and the second trough, and so on. Add the distances together, then divide by the number of distances you measured. Record your answer in the table under "Average amplitude."



► Designing Your Experiment

- With your lab partners, decide how you will work together to make two additional sine curve traces, one with a different average wavelength than the first trace and one with a different average amplitude.
- In your lab report, write down your plan for changing these two factors. Before you carry out your experiment, your teacher must approve your plan.

► Performing Your Experiment

- After your teacher approves your plan, carry out your experiment. For each curve, measure and record the time, the average wavelength, and the average amplitude.
- After each trace, return the sand to the cup and roll the paper back up.

► Analyzing Your Results

- For each of your three curves, calculate the average speed at which the paper was pulled by dividing the length of 1 m by the time measurement. This is equivalent to the speed of the wave that the curve models or represents.
- For each curve, use the wave speed equation to calculate average frequency.

$$\text{average frequency} = \frac{\text{average wave speed}}{\text{average wavelength}} \quad f = \frac{v}{\lambda}$$

► Defending Your Conclusions

- What factor did you change to alter the average wavelength of the curve? Did your plan work? If so, did the wavelength increase or decrease?
- What factor did you change to alter the average amplitude? Did your plan work?

Ultrasonographer

Most people have seen a sonogram showing an unborn baby inside its mother's womb. Ultrasound technologists make these images with an ultrasound machine, which sends harmless, high-frequency sound waves into the body. Ultrasonographers work in hospitals, clinics, and doctors' offices. Besides checking on the health of unborn babies, ultrasonographers use their tools to help diagnose cancer, heart disease, and other health problems. To find out more about this career, read the interview with Estela Zavala, a registered diagnostic medical sonographer who works at Austin Radiological Association in Austin, Texas.

"Ultrasound is a helpful diagnostic tool that allows you to see inside the body without the use of X rays."



Estela Zavala uses an ultrasound machine to check this man's kidneys.



What does an ultrasonographer do?

We scan various organs of the body with an ultrasound machine to see if there are any abnormalities. For example, we can check a gallbladder to see if there are any stones in it. We already know what healthy organs look like, so anything unusual shows up in these pictures. This can help a doctor make a diagnosis.



How does the ultrasound machine make pictures?

The machine creates high-frequency sound waves. When the sound waves reflect off of the organs in the body, the waves strike a piezoelectric crystal in the detector. Piezoelectric crystals can convert the pressure energy from the ultrasound wave into an electrical signal. The ultrasound system processes the signal to create an image.



What part of your job do you find most satisfying?

I like helping people find out what is wrong with them in a noninvasive way. Before ultrasound, invasive surgery was often the only option.



What is challenging about your job?

The technology is constantly changing. We are using ultrasound in more ways than ever before. For example, we can create images of veins and arteries with vascular technology.



What skills does an ultrasonographer need?

First you need excellent hand-eye coordination, so you can move the equipment over the parts of the body you need to image. You also have to know a lot about all of the organs in the body. It is very important to be able to work quickly, because sometimes patients are uncomfortable because they are sick.



How much training and education did you receive before becoming an ultrasonographer?

After graduating from high school, I went to an X-ray school to be licensed as an X-ray technologist. A medical background like this is necessary for entering ultrasound training. First I went to an intensive 1-month training program, which involved 2 weeks of hands-on work and 2 weeks of classwork. After that, I worked for a licensed radiologist for about a year. Finally, I attended an accredited year-long ultrasound program at a local community college before becoming fully licensed.



What part of your education do you think was the most valuable?

The best part was the on-the-job training that was involved. You need to do a lot of ultrasounds before you can become proficient.

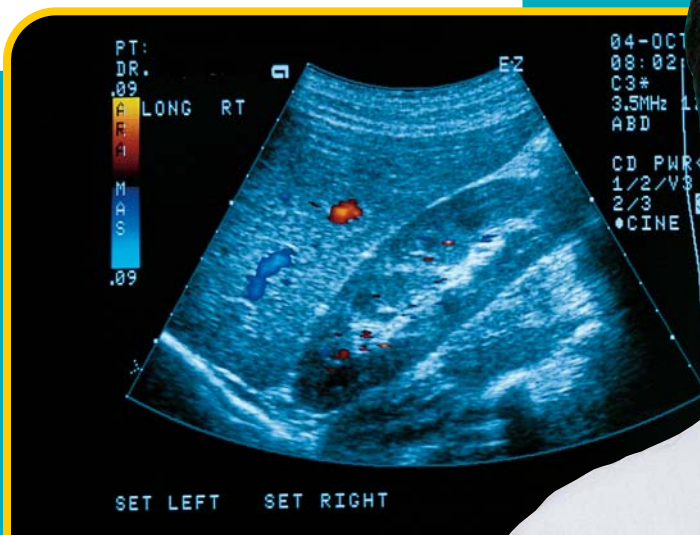


Would you recommend ultrasound technology as a career to students?

Yes, I would recommend it. Just remember that you must have some medical experience first, such as being a nurse or an X-ray technician, if you want to continue into other areas of radiology, like ultrasound.

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“I’ve seen many changes and innovations in ultrasound since I began. Because of this, the job always seems new.”
—**ESTELA ZAVALA**

