SECTION

1

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 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 almost 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 just the movement of matter from one place to another. A **wave** is a disturbance that carries energy through matter or space.

wave a periodic disturbance in a solid, liquid, or gas as energy is transmitted through a medium

Figure 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 ears. 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: light 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 2. In this book, the terms *light* and *light wave* may refer to any electromagnetic wave, not just visible light.

Waves transfer energy

Energy is the ability to exert a force over a certain distance. It is also known 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.

Connection to ENGINEERING

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** a physical environment in which phenomena occur

■ **mechanical wave** a wave that requires a medium through which to travel

■ **electromagnetic wave** a wave that consists of oscillating electric and magnetic fields, which radiate outward at the speed of light

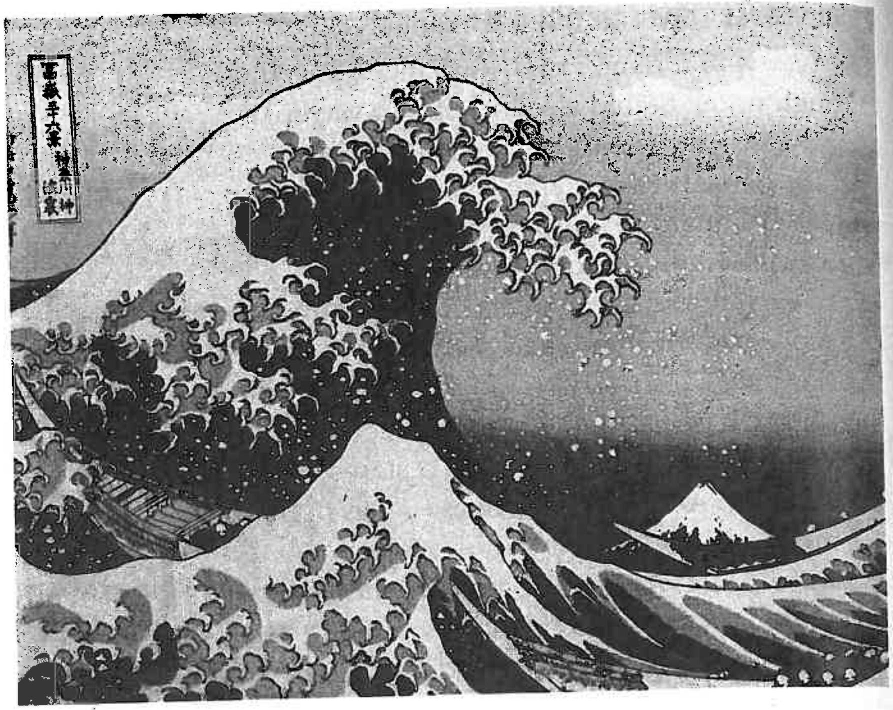

Figure 2
This portrait of a tsunami was created by the Japanese artist Hokusai in 1830.

Figure 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 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.

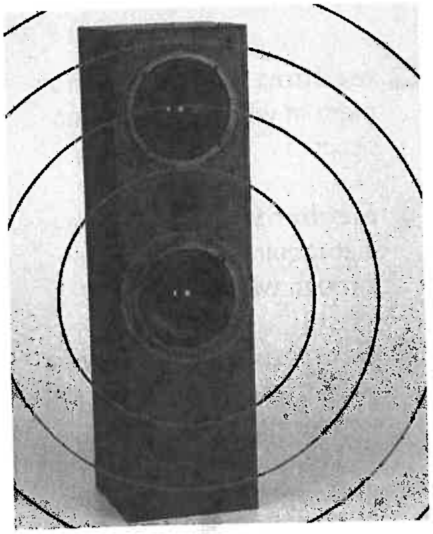

Figure 3
Sound waves from a stereo speaker spread out in spherical wave fronts.

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.

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Vibrations involve transformations of energy

Figure 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.

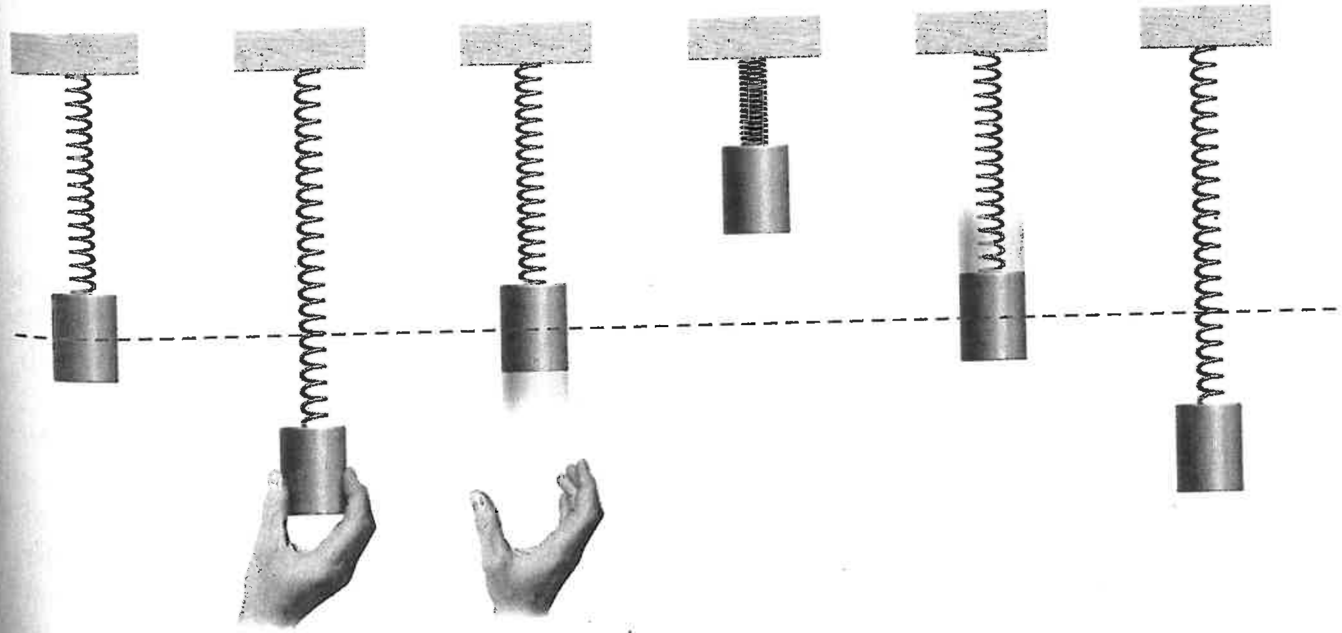
When the mass is pulled away from its resting place, the mass-spring system gains elastic potential energy. The spring exerts a force that pulls the mass back to its original position.

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.

Figure 4

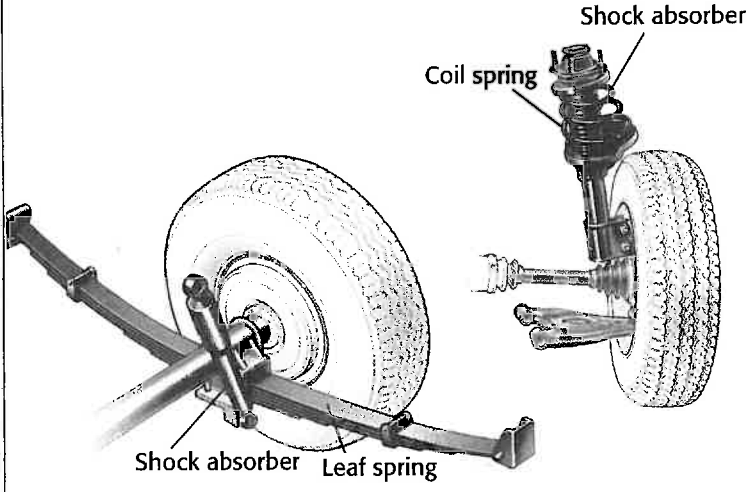
When a mass hanging on a spring is disturbed from rest, it starts to vibrate up and down around its original position.



Science
and the Consumer

Shock Absorbers: Why Are They Important?

Bumps in the road are certainly a nuisance, but without strategic use of damping 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?

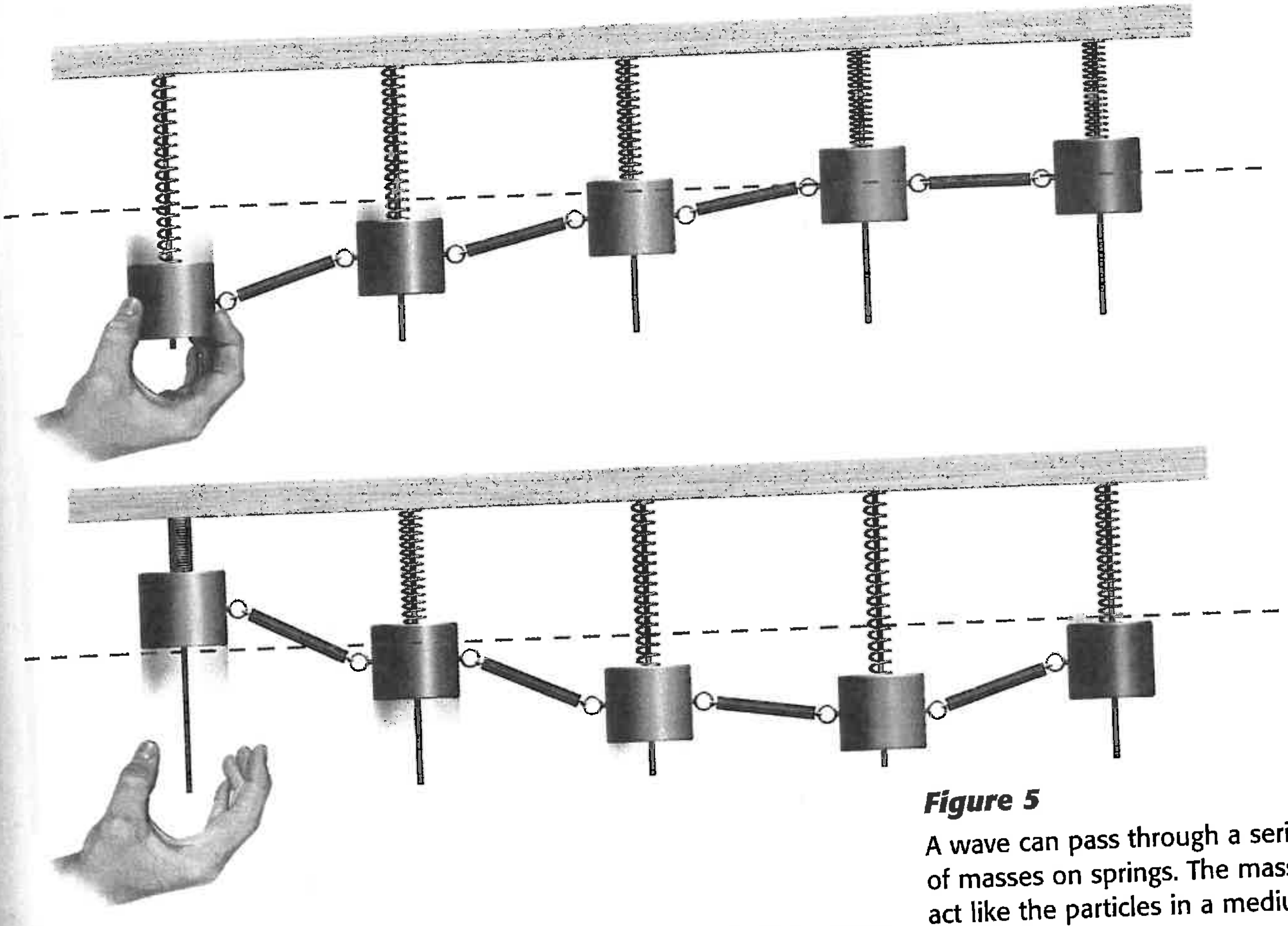


Figure 5

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

Whenever the spring is expanded or compressed, it is exerting a force that pushes the mass back almost to the original resting position. As a result, the mass will continue to bounce up and down. 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 5.** If you pull 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.

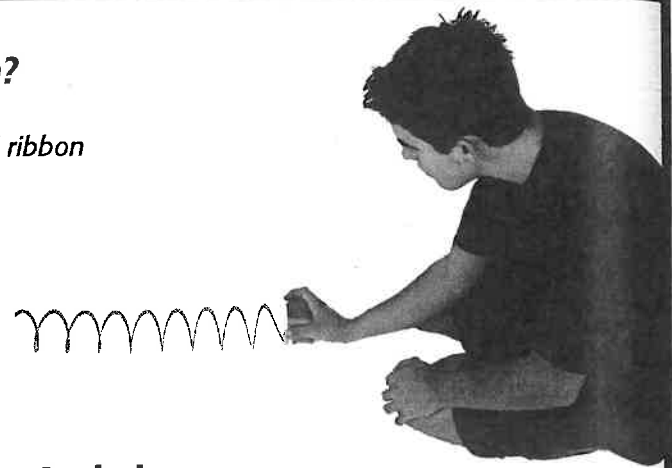
If the first mass were not connected to the other masses, it would keep vibrating up and down on its own. However, because it transfers its energy to the second mass, it slows down and then returns to its resting position. A vibration that fades out as energy is transferred from one object to another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

Quick Lab

How do particles move in a medium?

Materials ✓ *long, flexible spring* ✓ *colored ribbon*

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

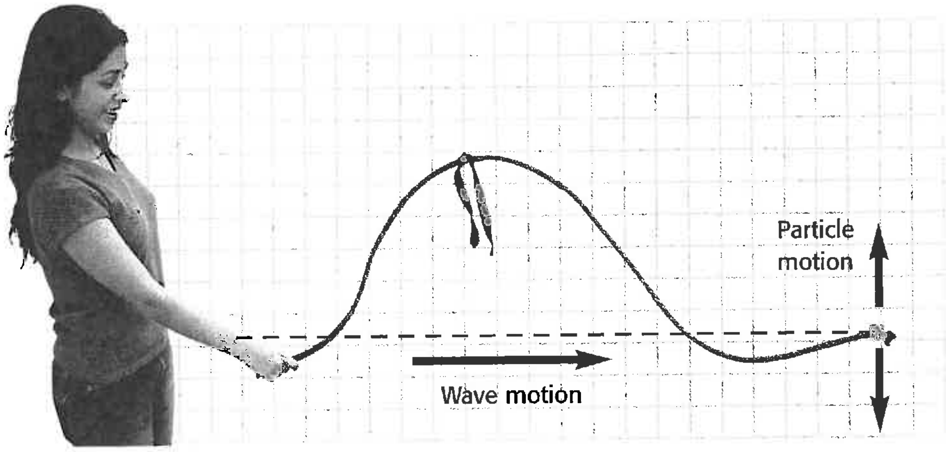
If you tie one end of a rope to a doorknob, pull it straight, and then rapidly move your hand up and down once, you will generate a single wave along the rope, as shown in ***Figure 6.*** A small ribbon tied to the middle of the rope can help you visualize the motion of a single particle of matter in 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, it pulls on the part next to it, transferring energy. In this way, a wave passes along the length of the rope.

Figure 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 fluctuating electric and magnetic fields that make up a light wave are perpendicular to one another and are also perpendicular to the direction the light travels.

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 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.

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 in which the particles of the medium move perpendicular to the direction the wave is traveling

longitudinal wave a wave in which the particles of the medium vibrate parallel to the direction of wave motion

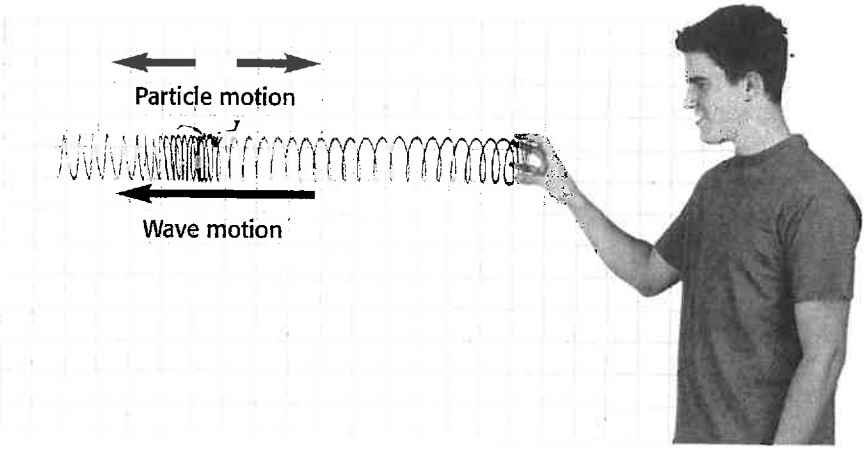


Figure 7

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.

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 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.

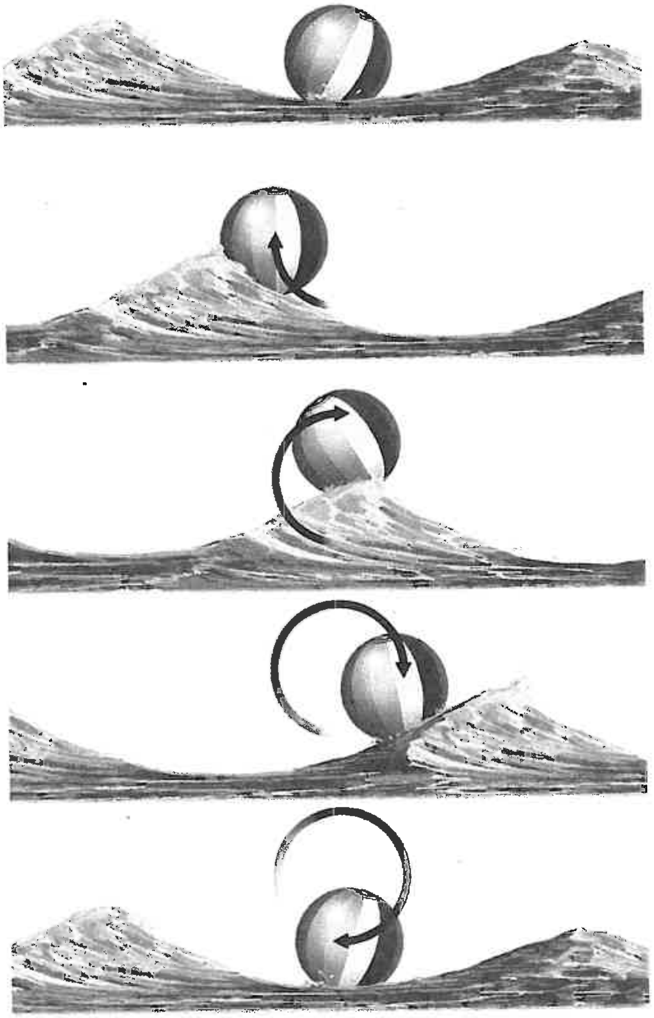


Figure 8

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

SECTION 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.

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.

SECTION
2

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
Doppler effect

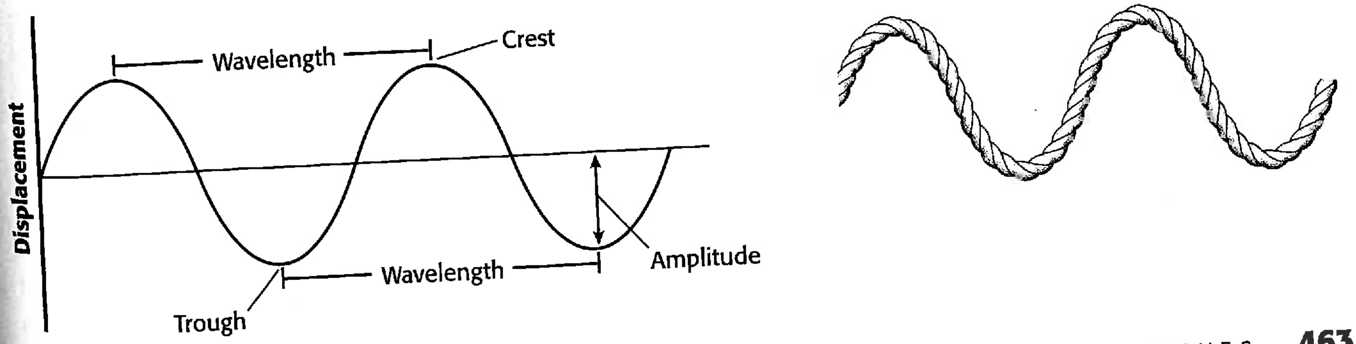
If you have spent any time at the beach or on a boat, you have probably observed many properties of waves. Sometimes the waves are very large; other times they are smaller. Sometimes they are close together, and sometimes they are farther apart. How can these differences be described and measured in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

Wave Properties

The simplest 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 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 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 9



A A sine curve can be used to demonstrate the characteristics of waves.

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

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.

PHYSICAL SCIENCE INTERACTIVE TUTOR

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

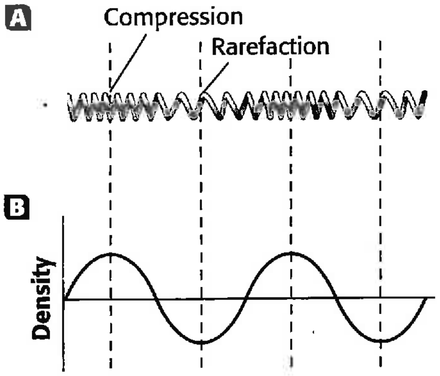


Figure 10

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.

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 10A*** illustrates these properties of a longitudinal wave.

Figure 10B shows a graph of a longitudinal wave. Density of the medium is plotted on the vertical axis; the horizontal axis represents the distance along the spring. The result 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

The crests of ocean waves at a beach may be separated by several meters, 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 distance between any two successive identical parts of a wave.

Not all waves have a single wavelength that is easy to measure. Most sound waves have a very complicated shape, so the wavelength may be difficult to determine. If the source of a wave vibrates in an irregular way, the wavelength may change over time.

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.

- **crest** the highest point of a wave
- **trough** the lowest point of a wave
- **amplitude** the maximum distance that the particles of a wave's medium vibrate from their rest position
- **wavelength** the distance from any point on a wave to an identical point on the next wave

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 wave crests.

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.

period the time that it takes a complete cycle or wave oscillation to occur

frequency the number of cycles or vibrations per unit of time

Frequency measures the rate of vibrations

While swimming in the ocean or floating in an inner tube, as shown in ***Figure 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 the existence of 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.

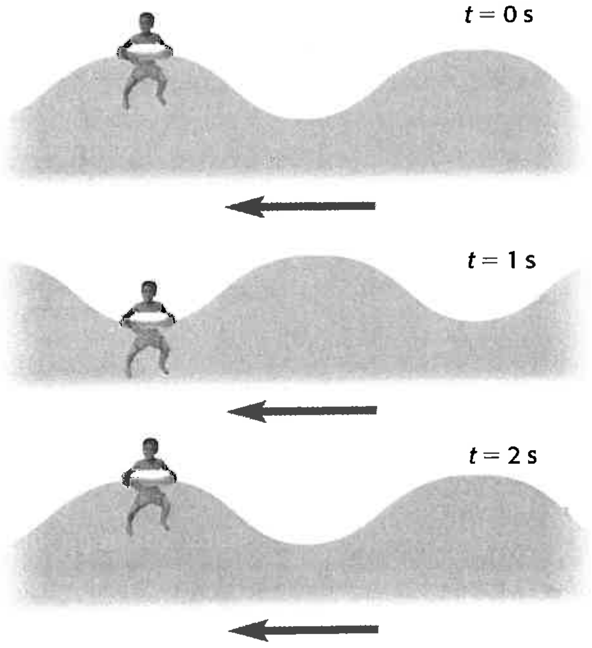


Figure 11
A person floating in an inner tube can determine the period and frequency of the waves by counting off the number of seconds between wave crests.

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

$$\textit{frequency} = \frac{1}{\textit{period}} \qquad f = \frac{1}{T}$$

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 using the frequency-period equation above. Because 0.5 (1/2) is the inverse of 2, the frequency is 0.5 Hz, or half a wave per second.

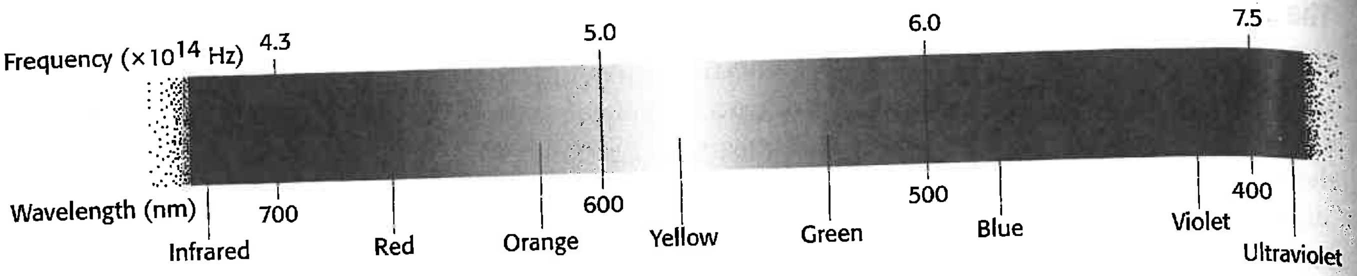


Figure 12

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 about 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 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 1*** lists several different parts of the electromagnetic spectrum, along with some real-world applications of the different kinds of waves.

Table 1 **The Electromagnetic Spectrum**

Type of wave	Range of frequency and wavelength	Applications
Radio wave	$f < 1 \times 10^9$ Hz $\lambda > 30$ cm	AM and FM radio; television broadcasting; radar; aircraft navigation
Microwave	1×10^9 Hz $< f < 3 \times 10^{11}$ Hz 30 cm $> \lambda >$ 1 mm	Atomic and molecular research; microwave ovens
Infrared (IR) wave	3×10^{11} Hz $< f < 4.3 \times 10^{14}$ Hz 1 mm $> \lambda >$ 700 nm	Infrared photography; remote-control devices; 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 ray	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 ray	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 pier such as the one in ***Figure 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?

Figure 13
By observing the frequency and wavelength of waves passing a pier, you can calculate the speed of the waves.

Wave speed equals frequency times wavelength

The speed of a moving object is found by dividing the distance the object travels by the time it takes to travel that distance. Speed can be calculated using the speed equation:

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

$$v = \frac{d}{t}$$

If SI units are used for measuring distance and time, speed is expressed as meters per second (m/s). 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 the 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.

$$speed = \frac{wavelength}{period}$$

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

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

$$wave\ speed = frequency \times wavelength$$

$$v = f \times \lambda$$

Suppose that waves passing by a post at a pier have a wavelength of 10 m, and two waves pass by in 5 s. The period is therefore 2.5 s, and the frequency is the inverse of 2.5 s, or 0.4 Hz. The waves in this case travel with a wave speed of 4 m/s.

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.

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

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

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 crest arrives at the shore 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 can travel through air. If they couldn't, you would not be able to have a conversation with a friend or hear music from a radio across the room. Because sound travels very fast in air (about 340 m/s), you don't notice a time delay in most normal situations.

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 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; it does not depend on the frequency of the wave. 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.

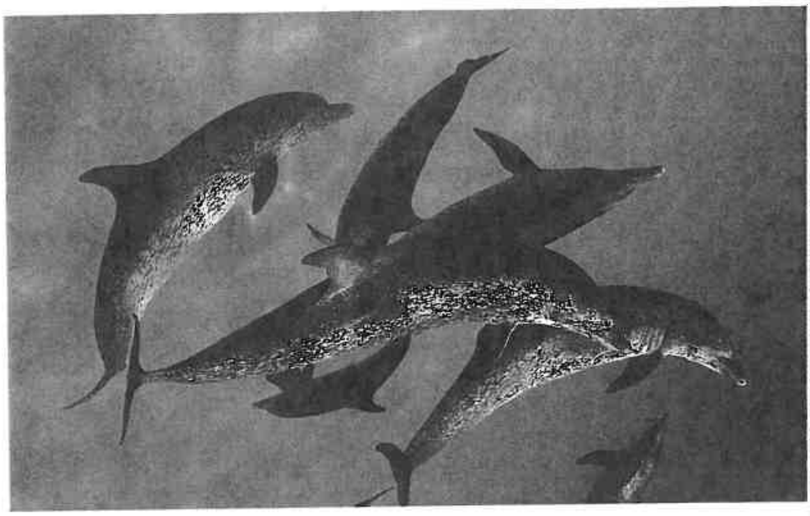


Figure 14

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

Kinetic theory explains differences in wave speed

The arrangement of particles in a medium determines how well waves travel through it. 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 most 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 3.00×10^8 m/s (186 000 mi/s). The speed of light in empty space is a constant that is often represented by the symbol c. Light travels slower when it has to pass through a medium such as air or water.

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 or roll the dowel slowly back and forth, and observe the length of the wave generated.
4. Now move 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

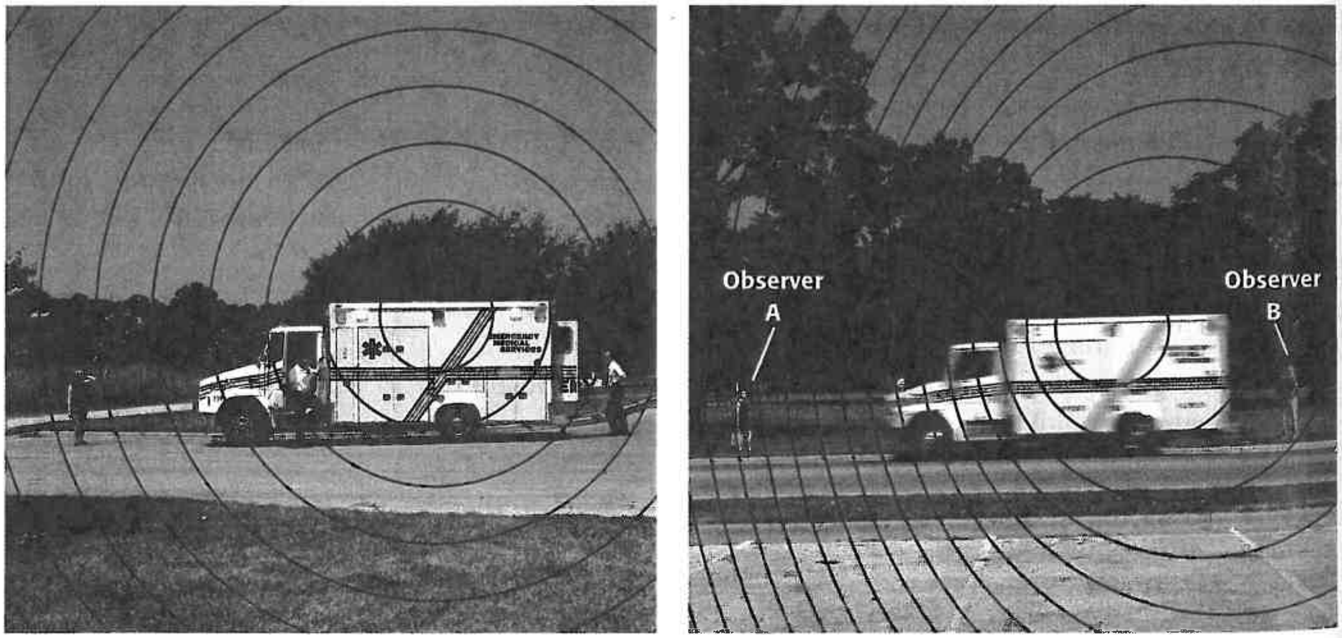
Imagine that you are standing on a corner as an ambulance rushes by. As the ambulance passes, the sound of the siren changes from a high pitch to a lower pitch. Why? Do the sound waves produced by the siren change as the ambulance goes by? How does the motion of the ambulance affect the sound?

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 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 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 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 wave fronts, while the wave speed remains the same. As a result, the sound waves reach your ear 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.

internet connect

www.scilinks.org
Topic: Doppler Effect
SciLinks code: HK4032

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

SECTION 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 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 a given amount of time. (1 Hz = 1 vibration/s)
- The speed of a wave equals the frequency times the wavelength. ($v = f \times \lambda$)

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?

Practice

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?

SECTION 3

Wave Interactions

KEY TERMS

reflection
diffraction
refraction
interference
constructive interference
destructive interference
standing wave

OBJECTIVES

- **Describe** how waves behave when they meet an obstacle or pass into another medium.
- **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?

PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc Two, Module 13: **Reflection**
Use the Interactive Tutor to learn more about this topic.

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 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 ray of light, sound, or heat when the ray hits a surface that it does not go through

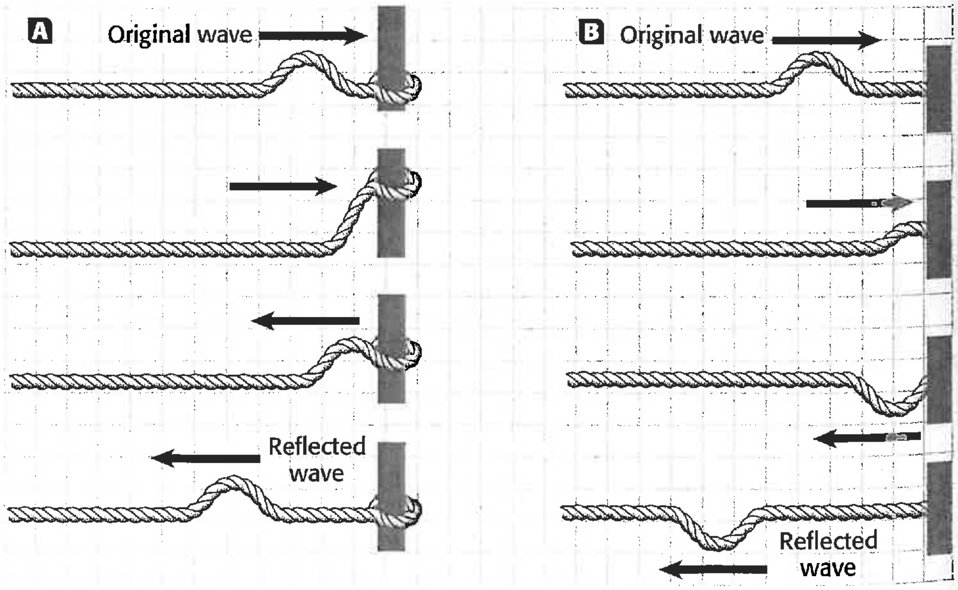

Figure 16

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 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 except that the reflected wave is traveling in the opposite direction to the direction of the original wave.

internet connect

www.scilinks.org
Topic: Reflection, Refraction, Diffraction
SciLinks code: HK4119

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At a fixed boundary, waves reflect and turn upside down

Figure 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 travels in the opposite direction and is turned upside down.

■ **diffraction** a change in the direction of a wave when the wave finds an obstacle or an edge, such as an opening

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

Figure 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. Diffraction is the reason that shadows never have perfectly sharp edges.

The tank in ***Figure 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.

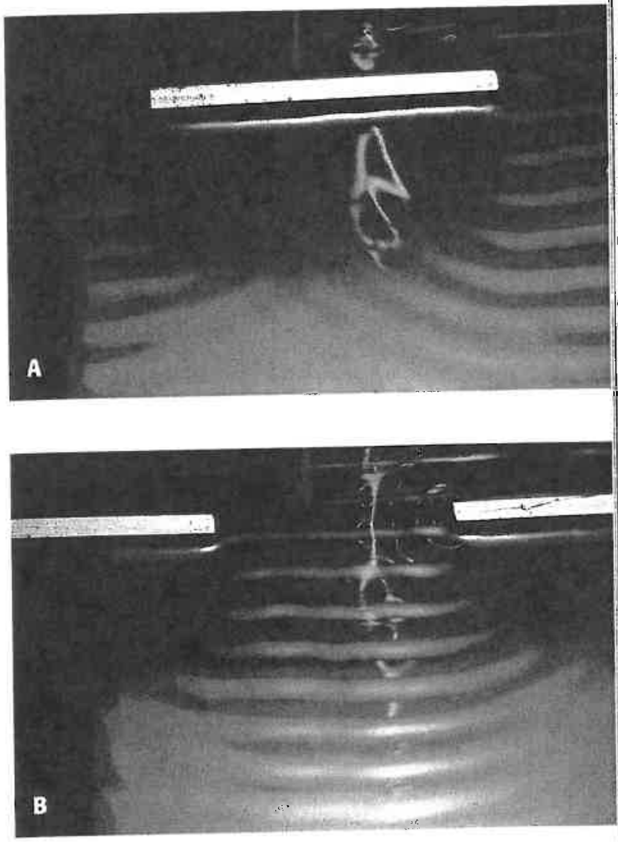


Figure 17

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

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

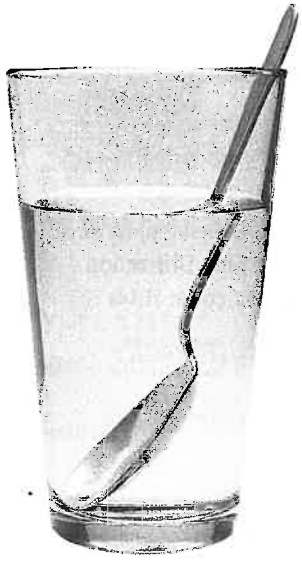


Figure 18

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

Waves can also bend by refraction

Figure 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 and the glass 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 because of a change in speed. 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 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.

- **refraction** the bending of a wavefront as the wavefront passes between two substances in which the speed of the wave differs
- **interference** the combination of two or more waves of the same frequency that results in a single wave

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 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 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. This method of adding waves is sometimes known as the *principle of superposition.*

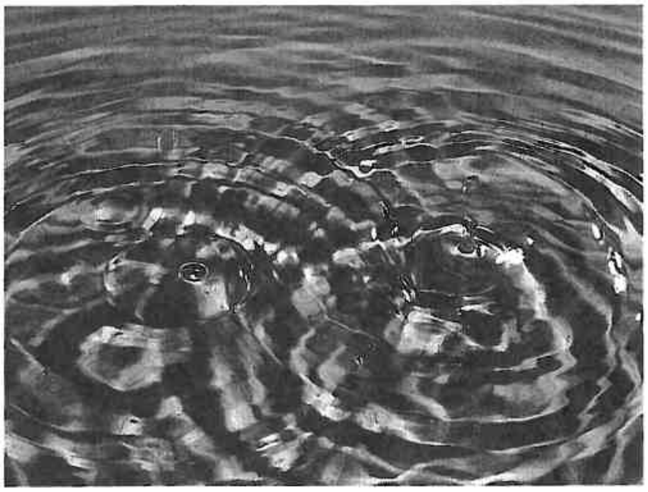


Figure 19

Water waves passing through each other produce interference patterns.

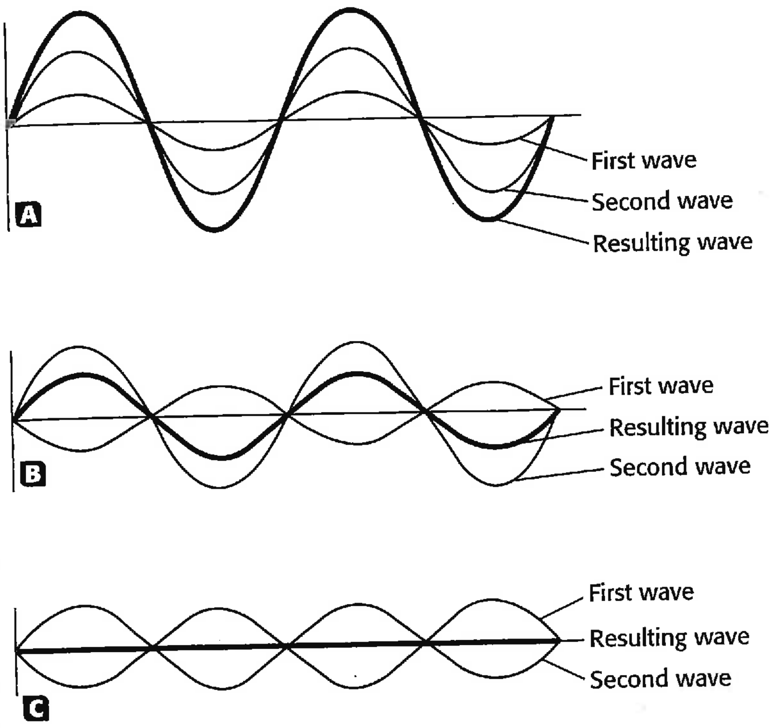


Figure 20

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.

Constructive interference increases amplitude

When the crest of one wave overlaps the crest of another wave, the waves reinforce each other, as shown in ***Figure 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.**

Destructive interference decreases amplitude

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 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 20C.***

PHYSICAL SCIENCE INTERACTIVE TUTOR

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

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

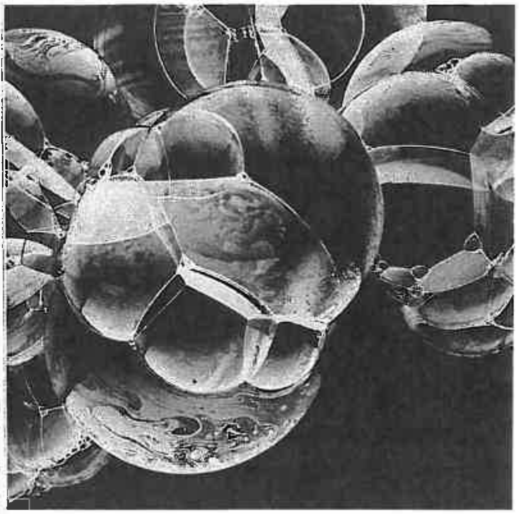


Figure 21
The colorful swirls on a bubble result from the constructive interference of some colors and the destructive interference of other colors.

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 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 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 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.

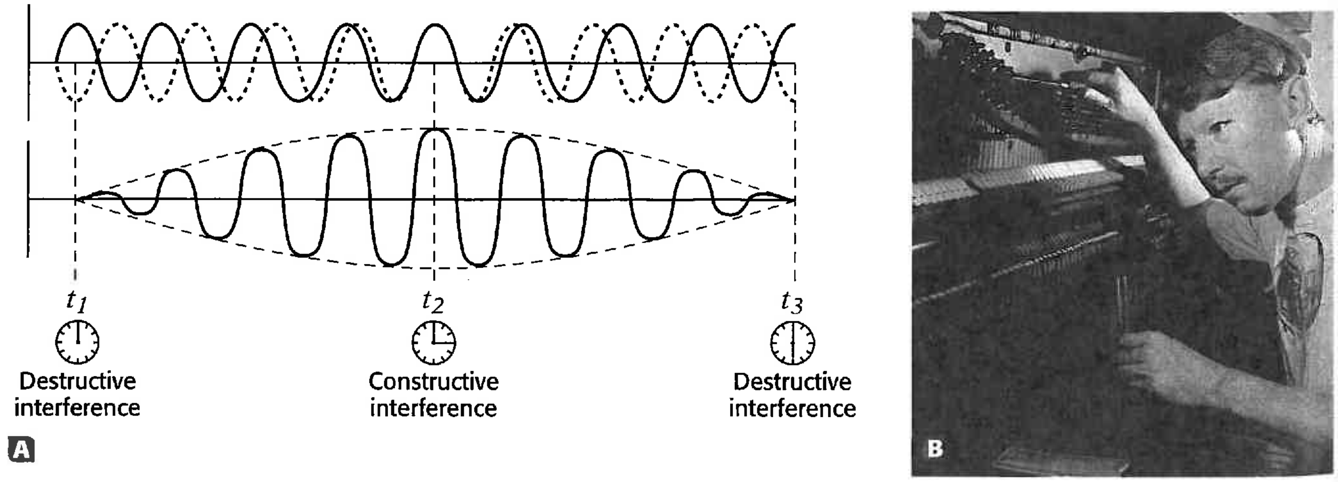


Figure 22B shows a piano tuner tuning a string. Piano tuners listen for beats between a tuning fork of known frequency and a string on a piano. By adjusting the tension in the string, the tuner can change the pitch (frequency) of the string's vibration. When no beats are heard, the string is vibrating 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

Standing waves can form when a wave is reflected at the boundary of a medium. In a standing wave, interference of the original wave with the reflected wave causes the medium to vibrate in a stationary pattern that resembles a loop or a series of loops. Although it appears as if the wave is standing still, in reality waves are traveling in both directions.

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 resulting 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. **WRITING SKILL**

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 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 at the right frequency, 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.

standing wave a pattern of vibration that simulates a wave that is standing still

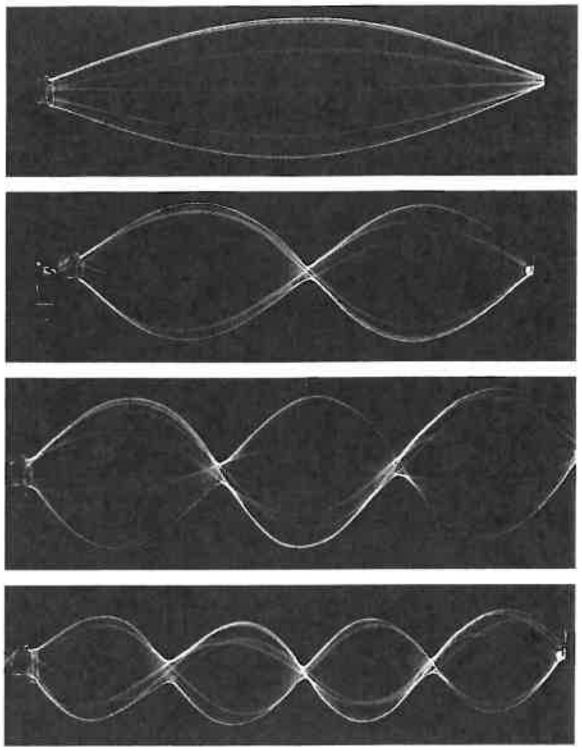


Figure 23

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

Standing waves can have only certain wavelengths

Figure 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. It is even possible for standing waves of more than one wavelength to exist on a string at the same time.

SECTION 3 REVIEW

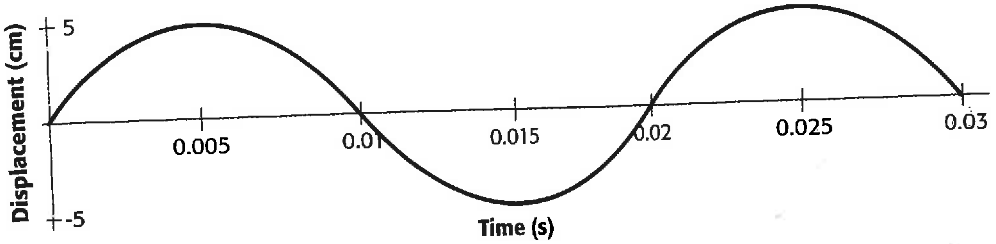
SUMMARY

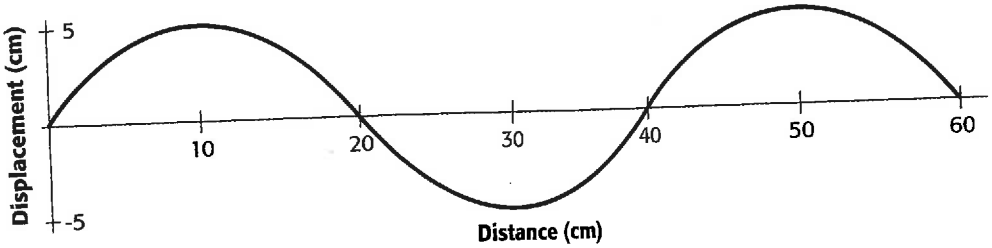
- Waves bouncing off a surface is called reflection.
- Diffraction is the bending of waves as they pass an edge or corner.
- Refraction is the bending of waves as they pass from one medium to another.
- Interference results when two waves exist in the same place and combine to make a single wave.
- Interference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

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 tuned to the same frequency.
8. **Critical Thinking** Determine the longest possible wavelength of a standing wave on a string that is 2 m long.

Graphing Skills

Interpreting Graphs





The graphs above show the behavior of a single transverse wave. Study the graphs, and answer the following questions.

1. What types of graphs are these?
2. What variable is described in the *x*-axis of the first graph? What variable is described in the *x*-axis of the second graph?
3. What information about the wave is indicated by the first graph? What information is indicated by the second graph?
4. Determine from the graphs the period, amplitude, and wavelength of the wave.
5. Using the frequency-period equation, calculate the frequency of the wave. Use the wave speed equation to calculate the speed of the wave.
6. Why are both graphs needed to provide complete information about the wave?
7. Plot the data given in the table to the right. From the graph, calculate the wavelength and amplitude of the wave.

x-axis (cm)	*y*-axis (cm)
0	0.93
0.25	2.43
0.50	3.00
0.75	2.43
1.00	0.93
1.25	–0.93
1.50	–2.43
1.75	–3.00
2.00	–2.43
2.25	–0.93
2.50	0.93
2.75	2.43
3.00	3.00

CHAPTER 14 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found at the end of each section. The key vocabulary terms are listed on the first page of each section.

UNDERSTANDING CONCEPTS

1. A wave is a disturbance that transmits
a. matter.
b. particles.
c. energy.
d. a medium.

2. Electromagnetic waves
a. are transverse waves.
b. require a medium.
c. are mechanical waves.
d. are longitudinal waves.

3. The speed of a wave depends on the
a. medium.
b. frequency.
c. amplitude.
d. wavelength.

4. Waves that need a medium in which to travel are called
a. longitudinal waves.
b. transverse waves.
c. mechanical waves.
d. All of the above.

5. Most waves are caused by
a. velocity.
b. amplitude.
c. a vibration.
d. earthquakes.

6. For which type of waves do particles in the medium vibrate perpendicular to the direction in which the waves are traveling?
a. transverse waves
b. longitudinal waves
c. P waves
d. none of the above

7. A sound wave is an example of
a. an electromagnetic wave.
b. a transverse wave.
c. a longitudinal wave.
d. a surface wave.

8. In an ocean wave, the molecules of water
a. move perpendicular to the direction of wave travel.
b. move parallel to the direction of wave travel.
c. move in circles.
d. don't move at all.

9. Half the vertical distance between the crest and trough of a wave is called the
a. frequency.
b. crest.
c. wavelength.
d. amplitude.

10. The number of waves passing a given point per unit of time is called the
a. frequency.
b. wave speed.
c. wavelength.
d. amplitude.

11. The Doppler effect of a passing siren results from an apparent change in
a. loudness.
b. wave speed.
c. frequency.
d. interference.

12. The combining of waves as they meet is known as
a. a crest.
b. noise.
c. interference.
d. the Doppler effect.

13. Waves bend when they pass through an opening. This is called
a. interference.
b. diffraction.
c. refraction.
d. the Doppler effect.

14. Refraction occurs whenever
a. a wave passes from one medium to another at an angle.
b. two waves interfere with one another.
c. a wave is reflected at a free boundary.
d. standing waves occur.

15. The Greek letter λ is often used to represent a wave's
a. period.
b. wavelength.
c. frequency.
d. amplitude.

USING VOCABULARY

16. How would you describe the *amplitude* of a wave using the words *crest* and *trough*?

17. Explain the difference between waves bending due to *refraction* and *diffraction.*

18. Imagine you are shaking the end of a rope to create a series of waves. What will you observe if you begin shaking the rope more quickly? Use the terms *wave speed, frequency,* and *wavelength* in your answer.

19. Describe the changes in *elastic potential energy* and *kinetic energy* that occur when a mass vibrates on a spring.

20. Use the *kinetic theory* to explain the difference in *wave speed* in solids, liquids, and gases.

21. Why is the reflection of a wave at a *free boundary* different from reflection at a *fixed boundary?*

22. How do *beats* help determine whether two sound waves are of the same *frequency?* Use the terms *constructive interference* and *destructive interference* in your answer.

23. How is an *electromagnetic wave* different from a *mechanical wave?*

24. 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?*

25. Identify each of the following as a distance measurement, a time measurement, or neither.

- **a.** *amplitude*
- **b.** *wavelength*
- **c.** *period*
- **d.** *frequency*
- **e.** *wave speed*

26. Explain the difference between *constructive interference* and *destructive interference.*

27. 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,* and *Doppler effect.*

28. Draw a picture of a *standing wave,* and label a *node* and an *antinode.*

BUILDING MATH SKILLS

29. 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?

30. Wave Speed Ocean waves are hitting a beach at a rate of 2.0 Hz. The distance between wave crests is 1.5 m. Calculate the speed of the waves.

31. Wavelength All electromagnetic waves have the same speed in empty space, 3.00×10^8 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

32. Frequency Microwaves range in wavelength from 1 mm to 30 cm. Calculate their range in frequency. Use 3.00×10^8 m/s as the speed of electromagnetic waves.

33. Wavelength The frequency of radio waves range from about 3.00×10^5 Hz to 3.00×10^7 Hz. What is the range of wavelengths of these waves? Use 3.00×10^8 m/s as the speed of electromagnetic waves.

34. Frequency The note A above middle C on a piano emits a sound wave with wavelength 0.77 m. What is the frequency of the wave? Use 340 m/s as the speed of sound in air.

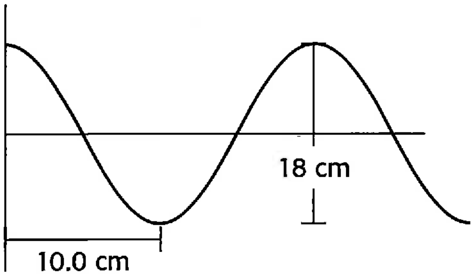
CHAPTER 14 REVIEW

BUILDING GRAPHING SKILLS

35. Graphing Draw a sine curve, and label a crest, a trough, and the amplitude.

36. 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
b. wavelength
c. speed
d. period



THINKING CRITICALLY

37. 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.

38. 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.)

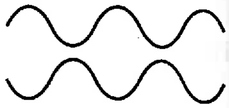
39. Understanding Systems You are standing on a street corner, and you hear a fire truck approaching. Does the pitch of the siren stay constant, increase, or decrease as it approaches you? Explain.

40. 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.

41. Interpreting Graphics Draw the wave that results from interference between the two waves shown below.

a.

b.



42. Understanding Systems An orchestra is playing in a huge outdoor amphitheater, and thousands of listeners are sitting 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? Explain what might happen if the signal were not delayed at all.

43. Applying Knowledge Dolphins use sound waves to detect other organisms close by. How can a dolphin use the Doppler effect to determine whether an organism is moving towards it? (**Hint:** the sound waves dolphins use can reflect off objects in the water and create an echo.)

DEVELOPING LIFE/WORK SKILLS

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

45. 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

46. **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? Do you believe that the manufacturer is correct in its statement?

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

48. **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.

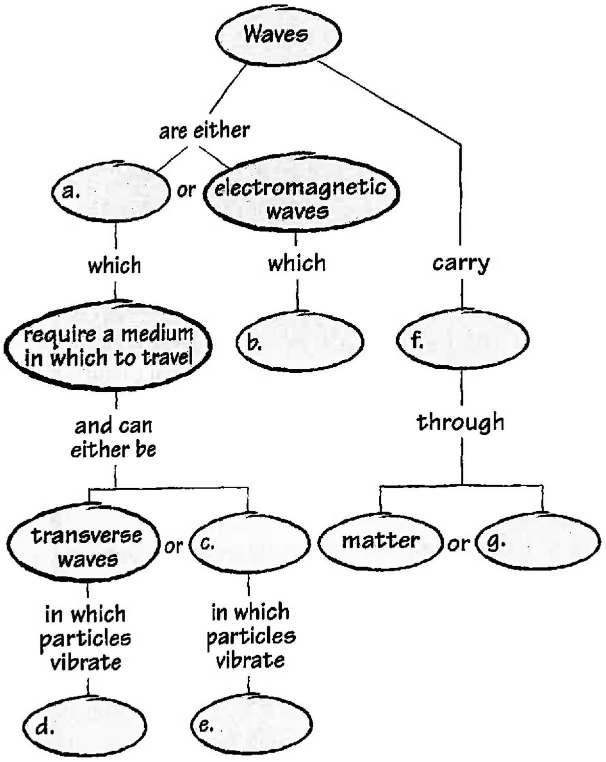
INTEGRATING CONCEPTS

49. **Connection to Space Science** The Doppler effect occurs for light waves as well as for sound waves. Research some of the ways in which the Doppler effect has helped astronomers understand the motion of distant galaxies and other objects in deep space.

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

51. **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.

52. **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.



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Skills Practice Lab

Modeling Transverse Waves

Introduction

When a transverse wave model is created with a sand pendulum, what wave characteristics can you measure?

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.
- **USING SCIENTIFIC METHODS** ***Form a hypothesis*** about how changes to the experiment may change the amplitude and wavelength.
- ***Calculate*** frequency and wave speed using your measurements.

Materials

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

▶ Procedure

Making Sine Curves with a Sand Pendulum

1. Review the discussion in Section 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 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)	Twice average amplitude (m)
Curve 1			
Curve 2			
Curve 3			

8. 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."
9. 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 "Twice average amplitude."

Designing Your Experiment

10. With your lab partners, form a hypothesis about how to make two additional sine curve traces, one with a different average wavelength than the first trace and one with a different average amplitude.
11. 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

12. 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.
13. After each trace, return the sand to the cup and roll the paper back up.

▶ Analysis

1. 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.
2. For each curve, use the wave speed equation to calculate average frequency.

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

▶ Conclusions

3. 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?
4. What factor did you change to alter the average amplitude? Did your plan work?