

The BIG Idea

Waves transfer energy from place to place without transferring matter.

SECTION 1
What are waves?

Main Idea Waves can carry energy through matter or through empty space.

SECTION 2
Wave Properties

Main Idea Waves can be described by their amplitude, wavelength, and frequency.

SECTION 3
Wave Behavior

Main Idea Waves can change direction at the boundary between different materials.

Waves

A large photograph of a windsurfer riding a wave. The windsurfer is in the foreground, wearing a yellow life vest and red shorts, holding a large, colorful sail with pink, yellow, and blue sections. The sail is partially submerged in the water. In the background, two other windsurfers are visible, one with a pink and blue sail and another with a yellow and pink sail. The ocean is a vibrant blue-green color with white foam from the waves.

Catch A Wave

On a breezy day in Maui, Hawaii, windsurfers ride the ocean waves. Waves carry energy. You can see the ocean waves in this picture, but there are other waves you cannot see, such as microwaves, radio waves, and sound waves.

Science Journal Write a paragraph about some places where you have seen water waves.

Start-Up Activities



Waves and Energy

It's a beautiful autumn day. You are sitting by a pond in a park. Music from a school marching band is carried to your ears by waves. A fish jumps, making waves that spread past a leaf that fell from a tree, causing the leaf to move. In the following lab, you'll observe how waves carry energy that can cause objects to move.

1. Add water to a large, clear, plastic plate to a depth of about 1 cm.
2. Use a dropper to release a single drop of water onto the water's surface. Repeat.
3. Float a cork or straw on the water.
4. When the water is still, repeat step 2 from a height of 10 cm, then again from 20 cm.
5. **Think Critically** In your Science Journal, record your observations. How did the motion of the cork depend on the height of the dropper?



Preview this chapter's content and activities at booko.msscience.com

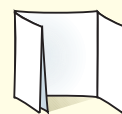
FOLDABLES™ Study Organizer

Waves Make the following Foldable to compare and contrast the characteristics of transverse and compressional waves.

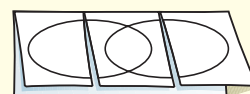
- STEP 1** Fold one sheet of paper lengthwise.



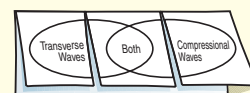
- STEP 2** Fold into thirds.



- STEP 3** Unfold and draw overlapping ovals. Cut the top sheet along the folds.



- STEP 4** Label the ovals as shown.



Construct a Venn Diagram As you read the chapter, list the characteristics unique to transverse waves under the left tab, those unique to compressional waves under the right tab, and those characteristics common to both under the middle tab.

Get Ready to Read

New Vocabulary

1 Learn It! What should you do if you find a word you don't know or understand? Here are some suggested strategies:

1. Use context clues (from the sentence or the paragraph) to help you define it.
2. Look for prefixes, suffixes, or root words that you already know.
3. Write it down and ask for help with the meaning.
4. Guess at its meaning.
5. Look it up in the glossary or a dictionary.

2 Practice It! Look at the word *rarefaction* in the following passage. See how context clues can help you understand its meaning.

Context Clue
Rarefactions are groups of molecules.

Context Clue
Rarefactions move away from a vibrating object.

Context Clue
Rarefactions are parts of a sound wave.

When the drumhead moves downward, the molecules near it have more room and can spread farther apart. This group of molecules that are farther apart is a rarefaction. The rarefaction also moves away from the drumhead. As the drumhead vibrates up and down, it forms a series of compressions and rarefactions that move away and spread out in all directions this series of compressions and rarefactions is a sound wave.

— from page 11

3 Apply It! Make a vocabulary bookmark with a strip of paper. As you read, keep track of words you do not know or want to learn more about.

Reading Tip

Read a paragraph containing a vocabulary word from beginning to end. Then go back to determine the meaning of the word.

Target Your Reading

Use this to focus on the main ideas as you read the chapter.

- 1 Before you read** the chapter, respond to the statements below on your worksheet or on a numbered sheet of paper.
 - Write an **A** if you **agree** with the statement.
 - Write a **D** if you **disagree** with the statement.
- 2 After you read** the chapter, look back to this page to see if you've changed your mind about any of the statements.
 - If any of your answers changed, explain why.
 - Change any false statements into true statements.
 - Use your revised statements as a study guide.

| Before You Read A or D | Statement | After You Read A or D |
|---------------------------|--|--------------------------|
| | 1 There can be no sound in outer space. | |
| | 2 Light waves are mechanical waves that can travel only through matter. | |
| | 3 Waves are produced by something that vibrates. | |
| | 4 In air, sound waves travel faster than light waves. | |
| | 5 The pitch of a sound wave depends on the frequency of the wave. | |
| | 6 The only difference between microwaves and light waves is that microwaves have longer wavelengths. | |
| | 7 A wave moves in a straight line, even if the speed of the wave changes. | |
| | 8 Higher-pitched sounds bend more as they pass through an open door than lower-pitched sounds do. | |
| | 9 When two waves overlap, they always cancel each other. | |


Print out a worksheet
of this page at
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What are waves?


as you read

What You'll Learn

- **Explain** the relationship among waves, energy, and matter.
- **Describe** the difference between transverse waves and compressional waves.

Why It's Important

Waves enable you to see and hear the world around you.

 **Review Vocabulary**
energy: the ability to cause change

New Vocabulary

- wave
- mechanical wave
- transverse wave
- compressional wave
- electromagnetic wave

What is a wave?

When you are relaxing on an air mattress in a pool and someone does a cannonball dive off the diving board, you suddenly find yourself bobbing up and down. You can make something move by giving it a push or pull, but the person jumping didn't touch your air mattress. How did the energy from the dive travel through the water and move your air mattress? The up-and-down motion was caused by the peaks and valleys of the ripples that moved from where the splash occurred. These peaks and valleys make up water waves.

Waves Carry Energy Rhythmic disturbances that carry energy without carrying matter are called **waves**. Water waves are shown in **Figure 1**. You can see the energy of the wave from a speedboat traveling outward, but the water only moves up and down. If you've ever felt a clap of thunder, you know that sound waves can carry large amounts of energy. You also transfer energy when you throw something to a friend, as in **Figure 1**. However, there is a difference between a moving ball and a wave. A ball is made of matter, and when it is thrown, the matter moves from one place to another. So, unlike the wave, throwing a ball involves the transport of matter as well as energy.

Figure 1 Water waves and a moving ball both transfer energy from one place to another.



Water waves produced by a boat travel outward, but matter does not move along with the waves.



When the ball is thrown, energy is transferred as matter moves from place to place.



As the students pass the ball, the students' positions do not change—only the position of the ball changes.

A Model for Waves

How does a wave carry energy without transporting matter? Imagine a line of people, as shown in **Figure 2**. The first person in line passes a ball to the second person, who passes the ball to the next person, and so on. Passing a ball down a line of people is a model for how waves can transport energy without transporting matter. Even though the ball has traveled, the people in line have not moved. In this model, you can think of the ball as representing energy. What do the people in line represent?

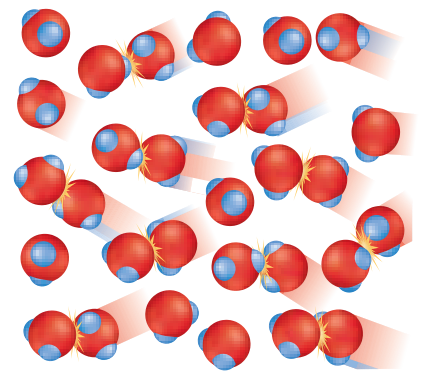
Think about the ripples on the surface of a pond. The energy carried by the ripples travels through the water. The water is made up of water molecules. It is the individual molecules of water that pass the wave energy, just as the people. The water molecules transport the energy in a water wave by colliding with the molecules around them, as shown in **Figure 2**.

 **Reading Check** *What is carried by waves?*

Mechanical Waves

In the wave model, the ball could not be transferred if the line of people didn't exist. The energy of a water wave could not be transferred if no water molecules existed. These types of waves, which use matter to transfer energy, are called **mechanical waves**. The matter through which a mechanical wave travels is called a medium. For ripples on a pond, the medium is the water.

A mechanical wave travels as energy is transferred from particle to particle in the medium. For example, a sound wave is a mechanical wave that can travel through air, as well as solids, liquids, and other gases. Without a medium such as air, there would be no sound waves. In outer space sound waves can't travel because there is no air.



In a water wave, water molecules bump each other and pass energy from molecule to molecule.

Figure 2 A wave transports energy without transporting matter from place to place.

Describe other models that could be used to represent a mechanical wave.

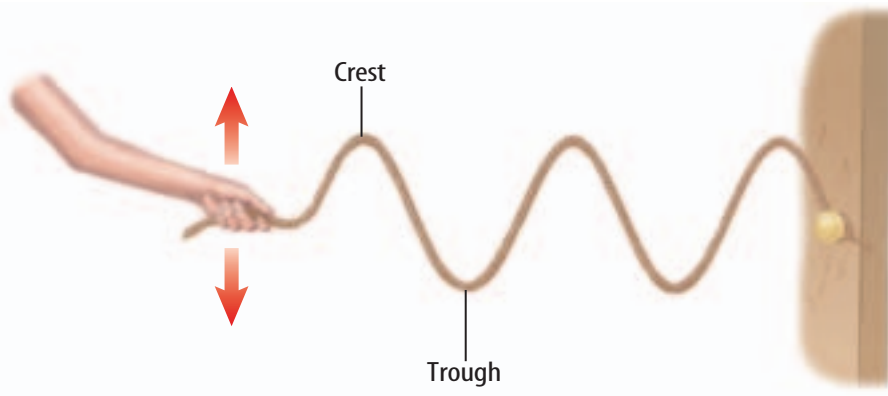


Figure 3 The high points on the wave are called crests and the low points are called troughs.

Transverse Waves In a mechanical **transverse wave**, the wave energy causes the matter in the medium to move up and down or back and forth at right angles to the direction the wave travels. You can make a model of a transverse wave. Stretch a long rope out on the ground.

Hold one end in your hand. Now shake the end in your hand back and forth. As you shake the rope, you create a wave that seems to slide along the rope.

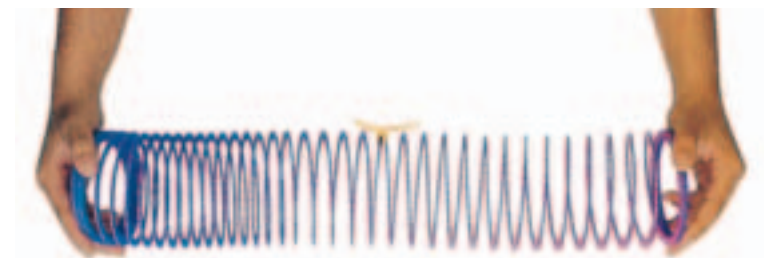
When you first started shaking the rope, it might have appeared that the rope itself was moving away from you. But it was only the wave that was moving away from your hand. The wave energy moves through the rope, but the matter in the rope doesn't travel. You can see that the wave has peaks and valleys at regular intervals. As shown in **Figure 3**, the high points of transverse waves are called crests. The low points are called troughs.

Reading Check

What are the highest points of transverse waves called?

Figure 4 A compressional wave can travel through a coiled spring toy.

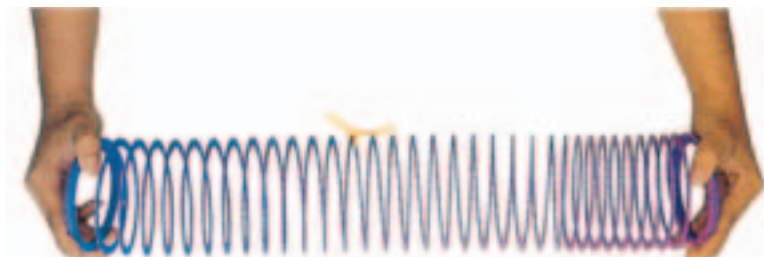
As the wave motion begins, the coils on the left are close together and the other coils are far apart.



The wave, seen in the squeezed and stretched coils, travels along the spring.



The string and coils did not travel with the wave. Each coil moved forward and then back to its original position.



Compressional Waves Mechanical waves can be either transverse or compressional. In a **compressional wave**, matter in the medium moves forward and backward along the same direction that the wave travels. You can make a compressional wave by squeezing together and releasing several coils of a coiled spring toy, as shown in **Figure 4**.

The coils move only as the wave passes and then return to their original positions. So, like transverse waves, compressional waves carry only energy forward along the spring. In this example, the spring is the medium the wave moves through, but the spring does not move along with the wave.

Sound Waves Sound waves are compressional waves. How do you make sound waves when you talk or sing? If you hold your fingers against your throat while you hum, you can feel vibrations. These vibrations are the movements of your vocal cords. If you touch a stereo speaker while it's playing, you can feel it vibrating, too. All waves are produced by something that is vibrating.

Making Sound Waves

How do vibrating objects make sound waves? Look at the drum shown in **Figure 5**. When you hit the drumhead it starts vibrating up and down. As the drumhead moves upward, the molecules next to it are pushed closer together. This group of molecules that are closer together is a compression. As the compression is formed, it moves away from the drumhead, just as the squeezed coils move along the coiled spring toy in **Figure 4**.

When the drumhead moves downward, the molecules near it have more room and can spread farther apart. This group of molecules that are farther apart is a rarefaction. The rarefaction also moves away from the drumhead. As the drumhead vibrates up and down, it forms a series of compressions and rarefactions that move away and spread out in all directions. This series of compressions and rarefactions is a sound wave.

Comparing Sounds

Procedure

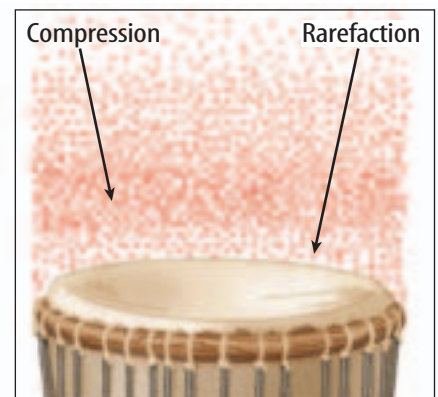
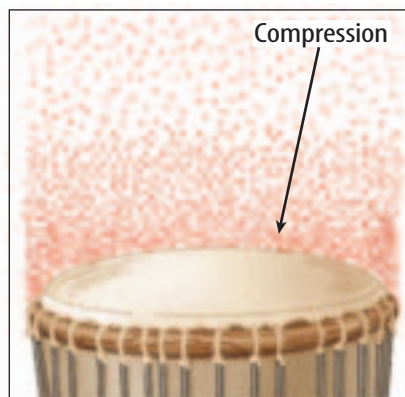
1. Hold a **wooden ruler** firmly on the edge of your **desk** so that most of it extends off the edge of the desk.
2. Pluck the free end of the ruler so that it vibrates up and down. Use gentle motion at first, then pluck with more energy.
3. Repeat step 2, moving the ruler about 1 cm further onto the desk each time until only about 5 cm extend off the edge.

Analysis

1. Compare the loudness of the sounds that are made by plucking the ruler in different ways.
2. Describe the differences in the sound as the end of the ruler extended farther from the desk.

Figure 5 A vibrating drumhead makes compressions and rarefactions in the air.

Describe how compressions and rarefactions are different.





Global Positioning Systems

Maybe you've used a global positioning system (GPS) receiver to determine your location while driving, boating, or hiking. Earth-orbiting satellites send electromagnetic radio waves that transmit their exact locations and times of transmission. The GPS receiver uses information from four of these satellites to determine your location to within about 16 m.

Electromagnetic Waves

Waves that can travel through space where there is no matter are **electromagnetic waves**. There are different types of electromagnetic waves, including radio waves, infrared waves, visible light waves, ultraviolet waves, X rays, and gamma rays. These waves can travel in matter or in space. Radio waves from TV and radio stations travel through air, and may be reflected from a satellite in space. They then travel through air, through the walls of your house, and to your TV or radio.

Radiant Energy from the Sun The Sun emits electromagnetic waves that travel through space and reach Earth. The energy carried by electromagnetic waves is called radiant energy. Almost 92 percent of the radiant energy that reaches Earth from the Sun is carried by infrared and visible light waves. Infrared waves make you feel warm when you sit in sunlight, and visible light waves enable you to see. A small amount of the radiant energy that reaches Earth is carried by ultraviolet waves. These are the waves that can cause sunburn if you are exposed to sunlight for too long.

section 1 review

Summary

What is a wave?

- Waves transfer energy, but do not transfer matter.

Mechanical Waves

- Mechanical waves require a medium in which to travel.
- When a transverse wave travels, particles of the medium move at right angles to the direction the wave is traveling.
- When a compressional wave travels, particles of the medium move back and forth along the same direction the wave is traveling.
- Sound is a compressional wave.

Electromagnetic Waves

- Electromagnetic waves can travel through empty space.
- The Sun emits different types of electromagnetic waves, including infrared, visible light, and ultraviolet waves.

Self Check

1. **Describe** the movement of a floating object on a pond when struck by a wave.
2. **Explain** why a sound wave can't travel from a satellite to Earth.
3. **Compare and contrast** a transverse wave and a compressional wave. How are they similar and different?
4. **Compare and contrast** a mechanical wave and an electromagnetic wave.
5. **Think Critically** How is it possible for a sound wave to transmit energy but not matter?

Applying Skills

6. **Concept Map** Create a concept map that shows the relationships among the following: *waves, mechanical waves, electromagnetic waves, compressional waves, and transverse waves*.
7. **Use a Word Processor** Use word-processing software to write short descriptions of the waves you encounter during a typical day.

Wave Properties

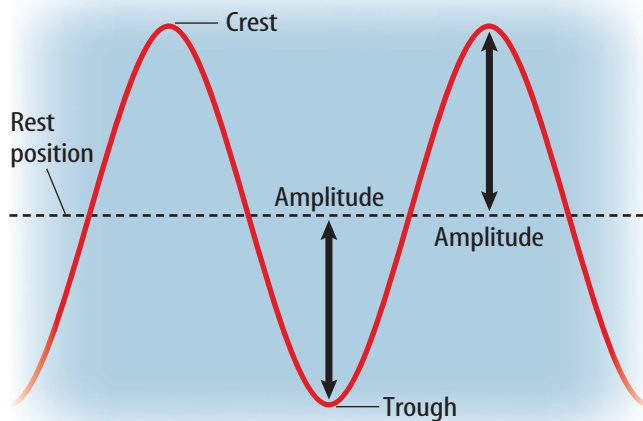
Steven Starr/Stock Boston

Amplitude

Can you describe a wave? For a water wave, one way might be to tell how high the wave rises above, or falls below, the normal level. This distance is called the wave's amplitude. The **amplitude** of a transverse wave is one-half the distance between a crest and a trough, as shown in **Figure 6**. In a compressional wave, the amplitude is greater when the particles of the medium are squeezed closer together in each compression and spread farther apart in each rarefaction.

Amplitude and Energy A wave's amplitude is related to the energy that the wave carries. For example, the electromagnetic waves that make up bright light have greater amplitudes than the waves that make up dim light. Waves of bright light carry more energy than the waves that make up dim light. In a similar way, loud sound waves have greater amplitudes than soft sound waves. Loud sounds carry more energy than soft sounds. If a sound is loud enough, it can carry enough energy to damage your hearing.

When a hurricane strikes a coastal area, the resulting water waves carry enough energy to damage almost anything that stands in their path. The large waves caused by a hurricane carry more energy than the small waves or ripples on a pond.



The amplitude of a transverse wave is a measure of how high the crests are or how deep the troughs are.

as you read

What You'll Learn

- **Describe** the relationship between the frequency and wavelength of a wave.
- **Explain** why waves travel at different speeds.

Why It's Important

The properties of a wave determine whether the wave is useful or dangerous.

Review Vocabulary
speed: the distance traveled divided by the time needed to travel the distance

New Vocabulary

- amplitude
- wavelength
- frequency

Figure 6 The energy carried by a wave increases as its amplitude increases.

A water wave of large amplitude carried the energy that caused this damage.



For transverse waves, wavelength is the distance from crest to crest or trough to trough.

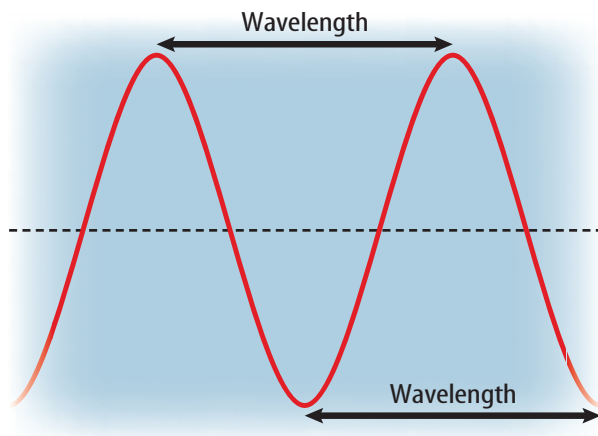


Figure 7 A transverse or a compressional wave has a wavelength.

For compressional waves, wavelength is the distance from compression to compression or rarefaction to rarefaction.

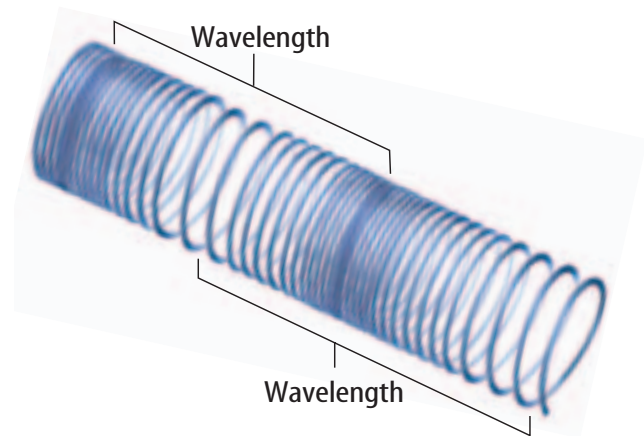
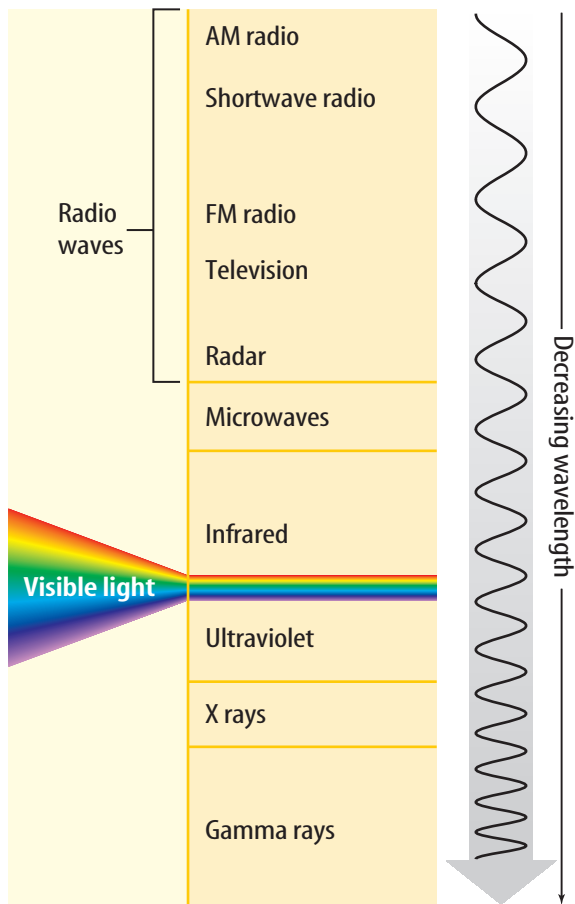


Figure 8 The wavelengths and frequencies of electromagnetic waves vary.



The devastating effect that a wave with large amplitude can have is seen in the aftermath of tsunamis. Tsunamis are huge sea waves that are caused by under-water earthquakes along faults on the seafloor. The movement of the seafloor along a fault produces the wave. As the wave moves toward shallow water and slows down, the amplitude of the wave grows. The tremendous amounts of energy tsunamis carry cause great damage when they move ashore.

Wavelength

Another way to describe a wave is by its wavelength. **Figure 7** shows the wavelength of a transverse wave and a compressional wave. For a transverse wave, **wavelength** is the distance from the top of one crest to the top of the next crest, or from the bottom of one trough to the bottom of the next trough. For a compressional wave, the wavelength is the distance between the center of one compression and the center of the next compression, or from the center of one rarefaction to the center of the next rarefaction.

Electromagnetic waves have wavelengths that range from kilometers, for radio waves, to less than the diameter of an atom, for X rays and gamma rays. This range is called the electromagnetic spectrum. **Figure 8** shows the names given to different parts of the electromagnetic spectrum. Visible light is only a small part of the electromagnetic spectrum. It is the wavelength of visible light waves that determines their color. For example, the wavelength of red light waves is longer than the wavelength of green light waves.

Frequency

The **frequency** of a wave is the number of wavelengths that pass a given point in 1 s. The unit of frequency is the number of wavelengths per second, or hertz (Hz). Recall that waves are produced by something that vibrates. The faster the vibration is, the higher the frequency is of the wave that is produced.

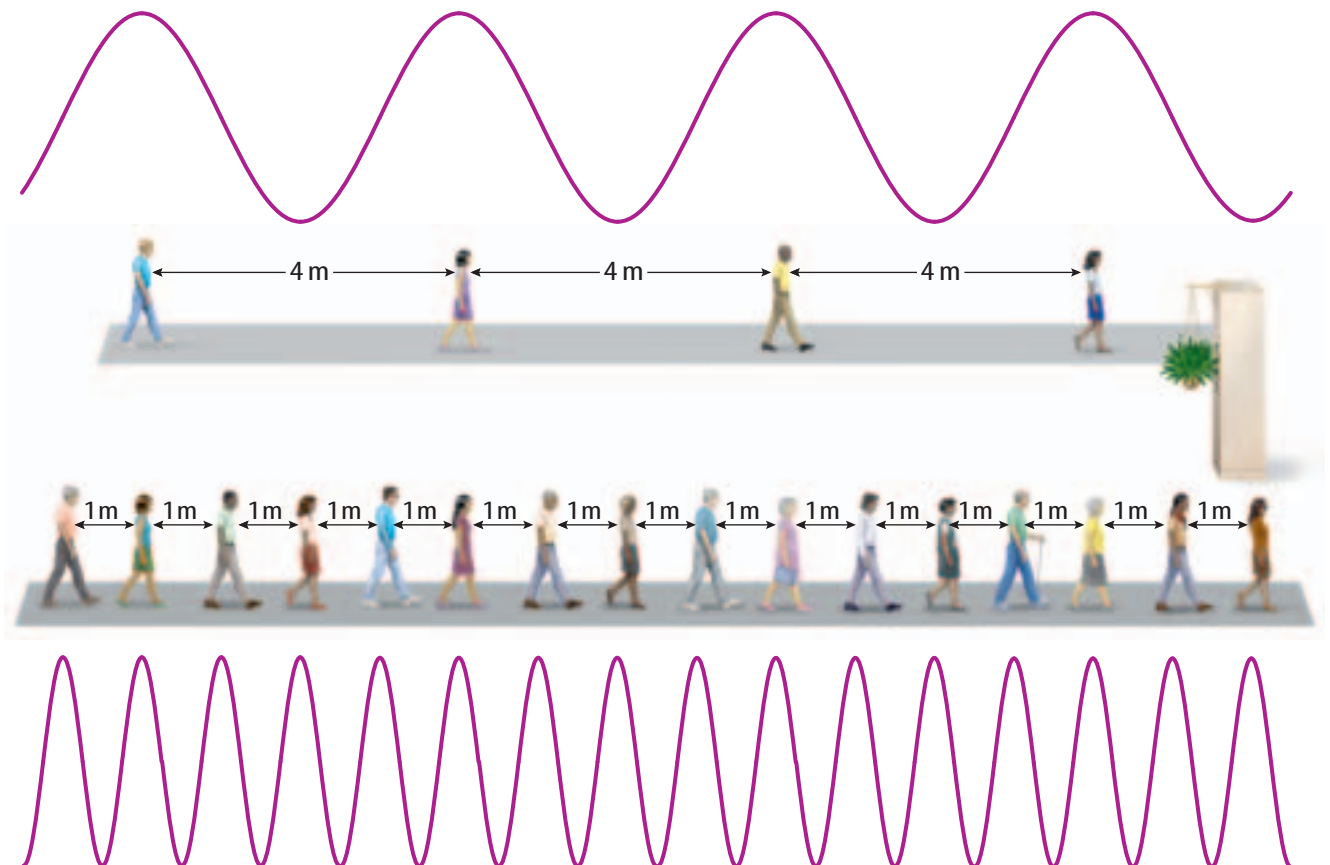
Reading Check How is the frequency of a wave measured?

A Sidewalk Model For waves that travel with the same speed, frequency and wavelength are related. To model this relationship, imagine people on two parallel moving sidewalks in an airport, as shown in **Figure 9**. One sidewalk has four travelers spaced 4 m apart. The other sidewalk has 16 travelers spaced 1 m apart.

Now imagine that both sidewalks are moving at the same speed and approaching a pillar between them. On which sidewalk will more people go past the pillar? On the sidewalk with the shorter distance between people, four people will pass the pillar for each one person on the other sidewalk. When four people pass the pillar on the first sidewalk, 16 people pass the pillar on the second sidewalk.

Figure 9 When people are farther apart on a moving sidewalk, fewer people pass the pillar every minute.

Infer how the number of people passing the pillar each minute would change if the sidewalk moved slower.





Ultrasonic Waves Sound waves with ultra-high frequencies cannot be heard by the human ear, but they are used by medical professionals in several ways. They are used to perform echocardiograms of the heart, produce ultrasound images of internal organs, break up blockages in arteries, and sterilize surgical instruments. Describe how the wavelengths of these sound waves compare to sound waves you can hear.

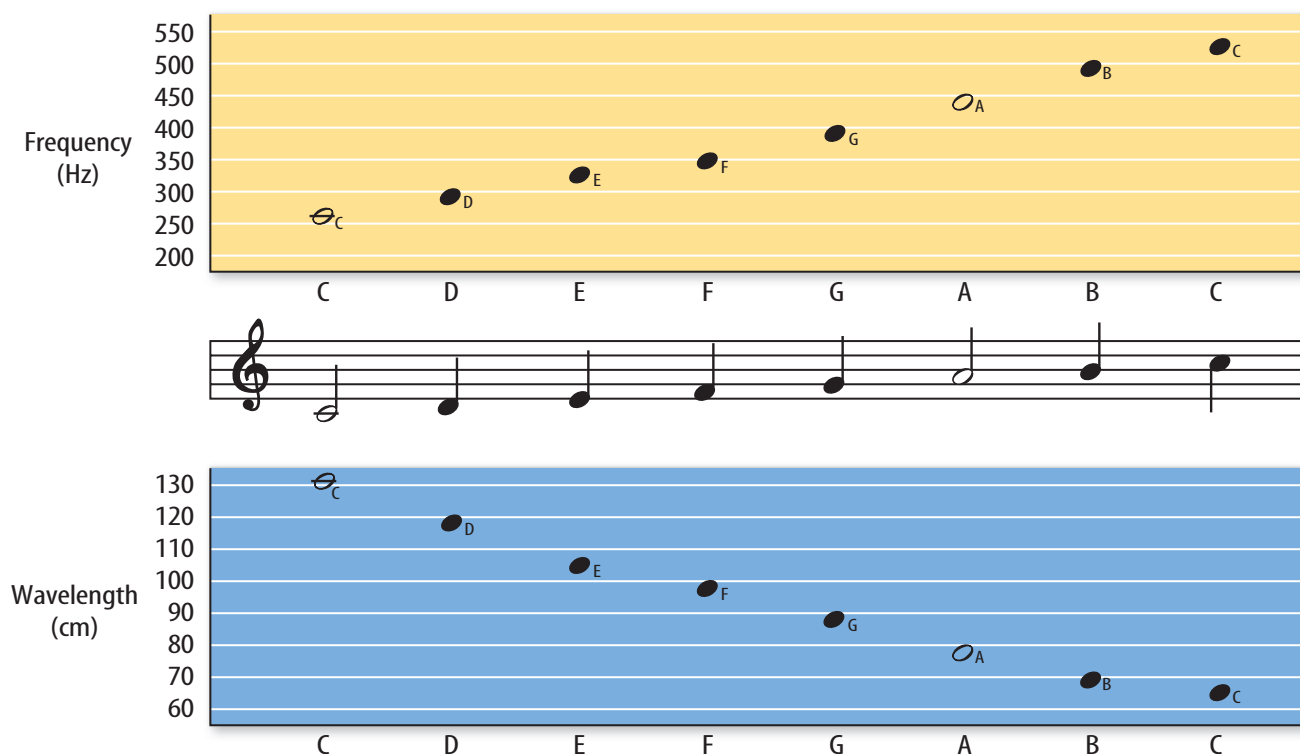
Figure 10 The frequency of the notes on a musical scale increases as the notes get higher in pitch, but the wavelength of the notes decreases.

Frequency and Wavelength Suppose that each person in **Figure 9** represents the crest of a wave. Then the movement of people on the first sidewalk is like a wave with a wavelength of 4 m. For the second sidewalk, the wavelength would be 1 m. On the first sidewalk, where the wavelength is longer, the people pass the pillar *less* frequently. Smaller frequencies result in longer wavelengths. On the second sidewalk, where the wavelength is shorter, the people pass the pillar *more* frequently. Higher frequencies result in shorter wavelengths. This is true for all waves that travel at the same speed. As the frequency of a wave increases, its wavelength decreases.

Reading Check How are frequency and wavelength related?

Color and Pitch Because frequency and wavelength are related, either the wavelength or frequency of a light wave determines the color of the light. For example, blue light has a larger frequency and shorter wavelength than red light.

Either the wavelength or frequency determines the pitch of a sound wave. Pitch is how high or low a sound seems to be. When you sing a musical scale, the pitch and frequency increase from note to note. Wavelength and frequency are also related for sound waves traveling in air. As the frequency of sound waves increases, their wavelength decreases. **Figure 10** shows how the frequency and wavelength change for notes on a musical scale.



Wave Speed

You've probably watched a distant thunderstorm approach on a hot summer day. You see a bolt of lightning flash between a dark cloud and the ground. If the thunderstorm is many kilometers away, several seconds will pass between when you see the lightning and when you hear the thunder. This happens because light travels much faster in air than sound does. Light travels through air at about 300 million m/s. Sound travels through air at about 340 m/s. The speed of any wave can be calculated from this equation:

Wave Speed Equation

$$\text{wave speed (in m/s)} = \text{frequency (in Hz)} \times \text{wavelength (m)}$$
$$v = f\lambda$$

In this equation, the wavelength is represented by the symbol λ , which is the Greek letter lambda.

When mechanical waves, such as sound, and electromagnetic waves, such as light, travel in different materials, they change speed. Mechanical waves usually travel fastest in solids, and slowest in gases. Electromagnetic waves travel fastest in gases and slowest in solids. For example, the speed of light is about 30 percent faster in air than in water.



Topic: Wave Speed

Visit booko.msscience.com for Web links to information about wave speed in different materials.

Activity Make a chart showing the speed of light in different materials.

section 2 review

Summary

Amplitude

- In a transverse wave, the amplitude is one-half the distance between a crest and a trough.
- The larger the amplitude, the greater the energy carried by the wave.

Wavelength

- For a transverse wave, wavelength is the distance from crest to crest, or from trough to trough.
- For a compressional wave, wavelength is the distance from compression to compression, or from rarefaction to rarefaction.

Frequency

- The frequency of a wave is the number of wavelengths that pass a given point in 1 s.
- For waves that travel at the same speed, as the frequency of the wave increases, its wavelength decreases.

Self Check

1. **Describe** how the frequency of a wave changes as its wavelength changes.
2. **Explain** why a sound wave with a large amplitude is more likely to damage your hearing than one with a small amplitude.
3. **State** what accounts for the time difference between seeing and hearing a fireworks display.
4. **Explain** why the statement "The speed of light is 300 million m/s" is not always correct.
5. **Think Critically** Explain the differences between the waves that make up bright, green light and dim, red light.

Applying Math

6. **Calculate Wave Speed** Find the speed of a wave with a wavelength of 5 m and a frequency of 68 Hz.
7. **Calculate Wavelength** Find the wavelength of a sound wave traveling in water with a speed of 1,470 m/s, and a frequency of 2,340 Hz.

Waves on a Spring



Waves are rhythmic disturbances that carry energy through matter or space. Studying waves can help you understand how the Sun's energy reaches Earth and sounds travel through the air.

Real-World Question

What are some of the properties of transverse and compressional waves on a coiled spring?

Goals

- **Create** transverse and compressional waves on a coiled spring toy.
- **Investigate** wave properties such as speed and amplitude.

Materials

long, coiled spring toy
colored yarn (5 cm)
meterstick
stopwatch

Safety Precautions

WARNING: Avoid overstretching or tangling the spring to prevent injury or damage.

Procedure

1. Prepare a data table such as the one shown.

Wave Data

| | |
|--|-----------------------------------|
| Length of stretched spring toy | Do not write in this book. |
| Average time for a wave to travel from end to end—step 4 | |
| Average time for a wave to travel from end to end—step 5 | |

2. Work in pairs or groups and clear a place on an uncarpeted floor about 6 m × 2 m.

3. Stretch the springs between two people to the length suggested by your teacher. Measure the length.
4. Create a wave with a quick, sideways snap of the wrist. Time several waves as they travel the length of the spring. Record the average time in your data table.
5. Repeat step 4 using waves that have slightly larger amplitudes.
6. Squeeze together about 20 of the coils. Observe what happens to the unsqueezed coils. Release the coils and observe.
7. Quickly push the spring toward your partner, then pull it back.
8. Tie the yarn to a coil near the middle of the spring. Repeat step 7, observing the string.
9. **Calculate** and compare the speeds of the waves in steps 4 and 5.

Conclude and Apply

1. **Classify** the wave pulses you created in each step as compressional or transverse.
2. **Classify** the unsqueezed coils in step 6 as a compression or a rarefaction.
3. **Compare and contrast** the motion of the yarn in step 8 with the motion of the wave.

Communicating Your Data

Write a summary paragraph of how this lab demonstrated any of the vocabulary words from the first two sections of the chapter. **For more help, refer to the Science Skill Handbook.**

Wave Behavior

Reflection

What causes the echo when you yell across an empty gymnasium or down a long, empty hallway? Why can you see your face when you look in a mirror? The echo of your voice and the face you see in the mirror are caused by wave reflection.

Reflection occurs when a wave strikes an object or surface and bounces off. An echo is reflected sound. Sound reflects from all surfaces. Your echo bounces off the walls, floor, ceiling, furniture, and people. You see your face in a mirror or a still pond, as shown in **Figure 11**, because of reflection. Light waves produced by a source of light such as the Sun or a lightbulb bounce off your face, strike the mirror, and reflect back to your eyes.

When a surface is smooth and even the reflected image is clear and sharp. However, **Figure 11** shows that when light reflects from an uneven or rough surface, you can't see a sharp image because the reflected light scatters in many different directions.

Reading Check *What causes reflection?*



The smooth surface of a still pond enables you to see a sharp, clear image of yourself.



If the surface of the pond is rough and uneven, your reflected image is no longer clear and sharp.

as you read

What You'll Learn

- **Explain** how waves can reflect from some surfaces.
- **Explain** how waves change direction when they move from one material into another.
- **Describe** how waves are able to bend around barriers.

Why It's Important

The reflection of waves enables you to see objects around you.

Review Vocabulary

echo: the repetition of a sound caused by the reflection of sound waves

New Vocabulary

- reflection
- refraction
- diffraction
- interference

Figure 11 The image formed by reflection depends on the smoothness of the surface.

Mini LAB

Observing How Light Refracts

Procedure

1. Fill a large, opaque drinking glass or cup with water.
2. Place a white soda straw in the water at an angle.
3. Looking directly down into the cup from above, observe the straw where it meets the water.
4. Placing yourself so that the straw angles to your left or right, slowly back away about 1 m. Observe the straw as it appears above, at, and below the surface of the water.

Analysis

1. Describe the straw's appearance from above.
2. Compare the straw's appearance above and below the water's surface in step 4.

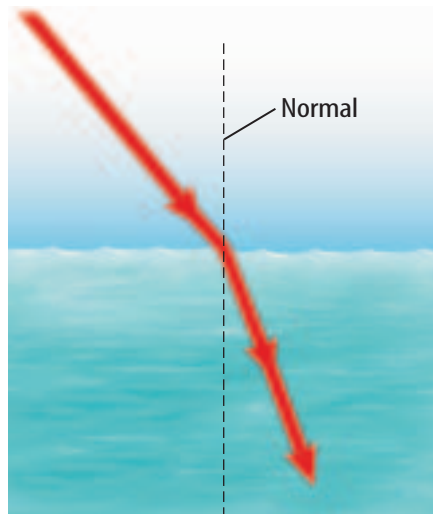


Refraction

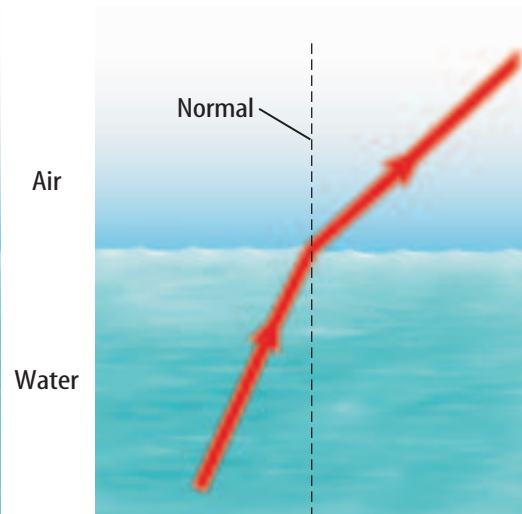
A wave changes direction when it reflects from a surface. Waves also can change direction in another way. Perhaps you have tried to grab a sinking object when you are in a swimming pool, only to come up empty-handed. Yet you were sure you grabbed right where you saw the object. You missed grabbing the object because the light rays from the object changed direction as they passed from the water into the air. The bending of a wave as it moves from one medium into another is called **refraction**.

Refraction and Wave Speed Remember that the speed of a wave can be different in different materials. For example, light waves travel faster in air than in water. Refraction occurs when the speed of a wave changes as it passes from one substance to another, as shown in **Figure 12**. A line that is perpendicular to the water's surface is called the normal. When a light ray passes from air into water, it slows down and bends toward the normal. When the ray passes from water into air, it speeds up and bends away from the normal. The larger the change in speed of the light wave is, the larger the change in direction is.

You notice refraction when you look down into a fishbowl. Refraction makes the fish appear to be closer to the surface and farther away from you than it really is, as shown in **Figure 13**. Light rays reflected from the fish are bent away from the normal as they pass from water to air. Your brain interprets the light that enters your eyes by assuming that light rays always travel in straight lines. As a result, the light rays seem to be coming from a fish that is closer to the surface.



As the light ray passes from air to water, it bends toward the normal.



As the light ray passes from water to air, it bends away from the normal.

Figure 12 A wave is refracted when it changes speed.

Explain how the direction of the light ray changes if it doesn't change speed.

Color from Refraction Sunlight contains light of various wavelengths. When sunlight passes through a prism, refraction occurs twice: once when sunlight enters the prism and again when it leaves the prism and returns to the air. Violet light has the shortest wavelength and is bent the most. Red light has the longest wavelength and is bent the least. Each color has a different wavelength and is refracted a different amount. As a result, the colors of sunlight are separated when they emerge from the prism.

Figure 14 shows how refraction produces a rainbow when light waves from the Sun pass into and out of water droplets. The colors you see in a rainbow are in order of decreasing wavelength: red, orange, yellow, green, blue, indigo, and violet.

Diffraction

Why can you hear music from the band room when you are down the hall? You can hear the music because the sound waves bend as they pass through an open doorway. This bending isn't caused by refraction. Instead, the bending is caused by diffraction. **Diffraction** is the bending of waves around a barrier.

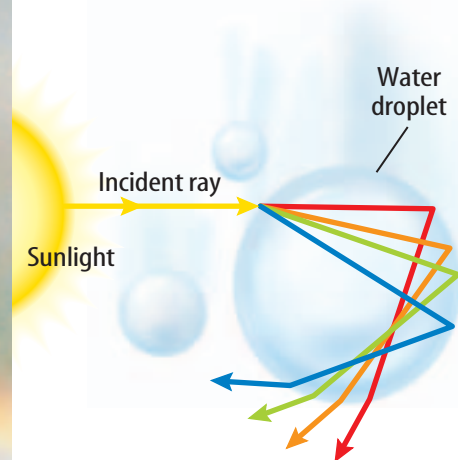
Light waves can diffract, too. You can hear your friends in the band room but you can't see them until you reach the open door. Therefore, you know that light waves do not diffract as much as sound waves do. Light waves do bend around the edges of an open door. However, for an opening as wide as a door, the amount the light bends is extremely small. As a result, the diffraction of light is far too small to allow you to see around a corner.



Figure 13 When you look at the goldfish in the water, the fish is in a different position than it appears.

Infer how the location of the fish would change if light traveled faster in water than in air.

Figure 14 Light rays refract as they enter and leave each water droplet. Each color refracts at different angles because of their different wavelengths, so they separate into the colors of the visible spectrum.



Diffraction and Wavelength The reason that light waves don't diffract much when they pass through an open door is that the wavelengths of visible light are much smaller than the width of the door. Light waves have wavelengths between about 400 and 700 billionths of a meter, while the width of doorway is about one meter. Sound waves that you can hear have wavelengths between a few millimeters and about 10 m. They bend more easily around the corners of an open door. A wave is diffracted more when its wavelength is similar in size to the barrier or opening.



Reading Check

Under what conditions would more diffraction of a wave occur?

Diffraction of Water Waves Perhaps you have noticed water waves bending around barriers. For example, when water waves strike obstacles such as the islands shown in **Figure 15**, they don't stop moving. Here the size and spacing of the islands is not too different from the wavelength of the water waves. So the water waves bend around the islands, and keep on moving. They also spread out after they pass through openings between the islands. If the islands were much larger than the water wavelength, less diffraction would occur.

What happens when waves meet?

Suppose you throw two pebbles into a still pond. Ripples spread from the impact of each pebble and travel toward each other. What happens when two of these ripples meet? Do they collide like billiard balls and change direction? Waves behave differently from billiard balls when they meet. Waves pass right through each other and continue moving.

Figure 15 Water waves bend or diffract around these islands. More diffraction occurs when the object is closer in size to the wavelength.



Wave Interference While two waves overlap a new wave is formed by adding the two waves together. The ability of two waves to combine and form a new wave when they overlap is called **interference**. After they overlap, the individual waves continue to travel on in their original form.

The different ways waves can interfere are shown in **Figure 16** on the next page. Sometimes when the waves meet, the crest of one wave overlaps the crest of another wave. This is called constructive interference. The amplitudes of these combining waves add together to make a larger wave while they overlap. Destructive interference occurs when the crest of one wave overlaps the trough of another wave. Then, the amplitudes of the two waves combine to make a wave with a smaller amplitude. If the two waves have equal amplitudes and meet crest to trough, they cancel each other while the waves overlap.

Waves and Particles Like waves of water, when light travels through a small opening, such as a narrow slit, the light spreads out in all directions on the other side of the slit. If small particles, instead of waves, were sent through the slit, they would continue in a straight line without spreading. The spreading, or diffraction, is only a property of waves. Interference also doesn't occur with particles. If waves meet, they reinforce or cancel each other, then travel on. If particles approach each other, they either collide and scatter or miss each other completely. Interference, like diffraction, is a property of waves.



Topic: Interference

Visit booko.msscience.com for Web links to information about wave interference.

Activity Write a paragraph about three kinds of interference you found in your research.

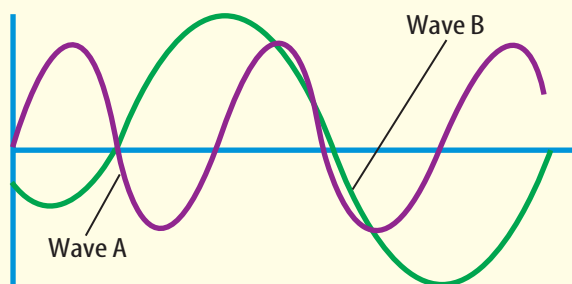
Applying Science

Can you create destructive interference?

Your brother is vacuuming and you can't hear the television. Is it possible to diminish the sound of the vacuum so you can hear the TV? Can you eliminate some sound waves and keep the sounds you do want to hear?

Identifying the Problem

It is possible to create a wave that will destructively interfere with one wave, but will not destructively interfere with another wave. The graph shows two waves with different wavelengths.



Solving the Problem

1. Create the graph of a wave that will eliminate wave A but not wave B.
2. Create the graph of a wave that would amplify wave A.

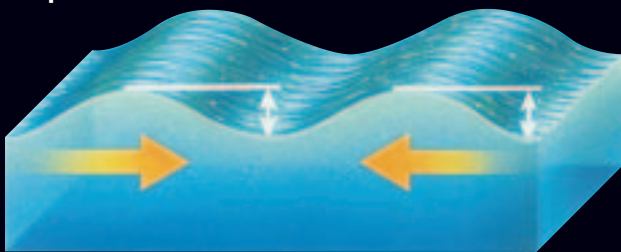
Figure 16

Whether they are ripples on a pond or huge ocean swells, when water waves meet they can combine to form new waves in a process called interference. As shown below, wave interference can be constructive or destructive.



Constructive Interference

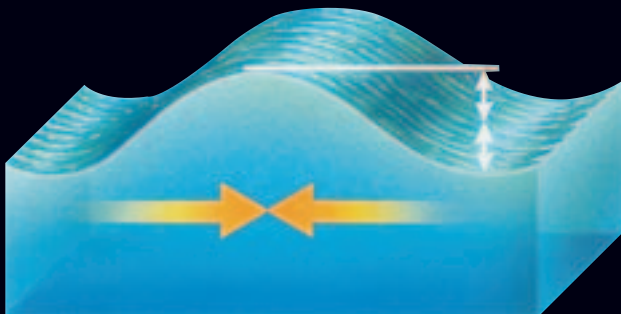
In constructive interference, a wave with greater amplitude is formed.



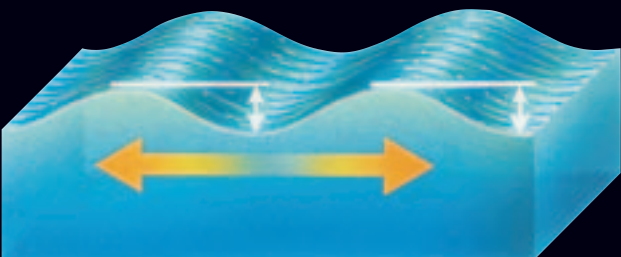
A

B

The crests of two waves—A and B—approach each other.



The two waves form a wave with a greater amplitude while the crests of both waves overlap.



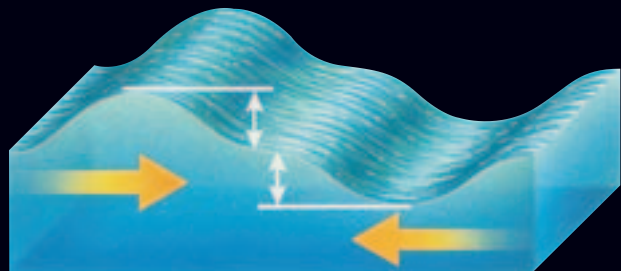
B

A

The original waves pass through each other and go on as they started.

Destructive Interference

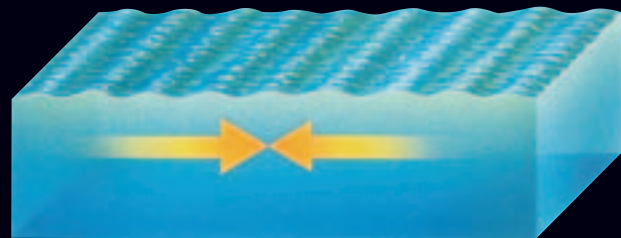
In destructive interference, a wave with a smaller amplitude is formed.



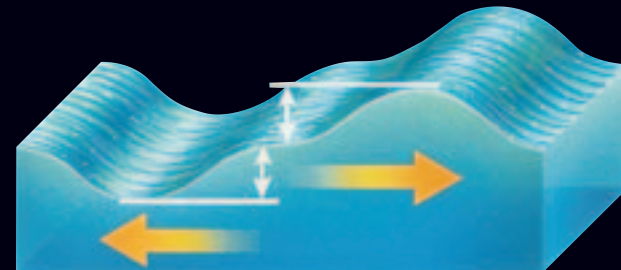
A

B

The crest of one wave approaches the trough of another.



If the two waves have equal amplitude, they momentarily cancel when they meet.



B

A

The original waves pass through each other and go on as they started.

Reducing Noise You might have seen someone use a power lawn mower or a chain saw. In the past, many people who performed these tasks damaged their hearing because of the loud noises produced by these machines.

Loud sounds have waves with larger amplitudes and carry more energy than softer sounds. The energy carried by loud sounds can damage cells in the ear that vibrate and transmit signals to the brain. Damage to the ear from loud sounds can be prevented by reducing the energy that reaches the ear. Ear protectors contain materials that absorb some of the energy carried by sound waves, so that less sound energy reaches the ear.

Pilots of small planes have a more complicated problem. If they shut out all the noise of the plane's motor, the pilots wouldn't be able to hear instructions from air-traffic controllers. To solve this problem, ear protectors have been developed, as shown in **Figure 17**, that have electronic circuits. These circuits detect noise from the aircraft and produce sound frequencies that destructively interfere with the noise. They do not interfere with human voices, so people can hear normal conversation. Destructive interference can be a benefit.



Figure 17 Some airplane pilots use special ear protectors that cancel out engine noise but don't block human voices.

section 3 review

Summary

Reflection

- Reflected sound waves can produce echoes.
- Reflected light rays produce images in a mirror.

Refraction

- The bending of waves as they pass from one medium to another is refraction.
- Refraction occurs when the wave's speed changes.
- A prism separates sunlight into the colors of the visible spectrum.

Diffraction and Interference

- The bending of waves around barriers is diffraction.
- Interference occurs when waves combine to form a new wave while they overlap.
- Destructive interference can reduce noise.

Self Check

1. **Explain** why you don't see your reflection in a building made of rough, white stone.
2. **Explain** how you are able to hear the siren of an ambulance on the other side of a building.
3. **Describe** the behavior of light that enables magnifying lenses and contact lenses to bend light rays.
4. **Define** the term *diffraction*. How does the amount of diffraction depend on wavelength?
5. **Think Critically** Why don't light rays that stream through an open window into a darkened room spread evenly through the entire room?

Applying Skills

6. **Compare and Contrast** When light rays pass from water into a certain type of glass, the rays refract toward the normal. Compare and contrast the speed of light in water and in the glass.

WAVE SPEED

Goals

- **Measure** the speed of a wave within a coiled spring toy.
- **Predict** whether the speed you measured will be different in other types of coiled spring toys.

Possible Materials

long, coiled spring toy
meterstick
stopwatch
tape

**clock with a second hand*

**Alternate materials*

Safety Precautions



Real-World Question

When an earthquake occurs, it produces waves that are recorded at points all over the world by instruments called seismographs. By comparing the data that they collected from these seismographs, scientists discovered that the interior of Earth must be made of layers of different materials. These data showed that the waves traveled at different speeds as they passed through different parts of Earth's interior. How can the speed of a wave be measured?

Form a Hypothesis

In some materials, waves travel too fast for their speeds to be measured directly. Think about what you know about the relationships among the frequency, wavelength, and speed of a wave in a medium. Make a hypothesis about how you can use this relationship to measure the speed of a wave within a medium. Explain why you think the experiment will support your hypothesis.

Test Your Hypothesis

Make a Plan

1. Make a data table in your Science Journal like the one shown.
2. In your Science Journal, write a detailed description of the coiled spring toy you are going to use. Be sure to include its mass and diameter, the width of a coil, and what it is made of.
3. **Decide** as a group how you will measure the frequency and length of waves in the spring toy. What are your variables? Which variables must be controlled? What variable do you want to measure?



Using Scientific Methods

- Repeat your experiment three times.

Follow Your Plan

- Make sure your teacher approves your plan before you start.
- Carry out the experiment.
- While you are doing the experiment, record your observations and measurements in your data table.

| Wave Data | | | |
|------------------------------------|-----------------------------------|---------|---------|
| | Trial 1 | Trial 2 | Trial 3 |
| Length spring was stretched (m) | | | |
| Number of crests | | | |
| Wavelength (m) | Do not write in this book. | | |
| # of vibrations timed | | | |
| # of seconds vibrations were timed | | | |
| Wave speed (m/s) | | | |

Analyze Your Data

- Calculate** the frequency of the waves by dividing the number of vibrations you timed by the number of seconds you timed them. Record your results in your data table.
- Use the following formula to calculate the speed of a wave in each trial.

$$\text{wavelength} \times \text{frequency} = \text{wave speed}$$
- Average the wave speeds from your trials to determine the average speed of a wave in your coiled spring toy.

Conclude and Apply

- Infer** which variables affected the wave speed in spring toys the most. Which variables affected the speed the least? Was your hypothesis supported?
- Analyze** what factors caused the wave speed measured in each trial to be different.



Communicating Your Data

Post a description of your coiled spring toy and the results of your experiment on a bulletin board in your classroom. **Compare and contrast** your results with other students in your class.

Waves, Waves, and More Waves

Did you know...

... **Radio waves from space were discovered** in 1932 by Karl G. Jansky, an American engineer. His discovery led to the creation of radio astronomy, a field that explores parts of the universe that can't be seen with telescopes.



... **The highest recorded ocean wave** was 34 meters high, which is comparable to the height of a ten-story building. This super wave was seen in the North Pacific Ocean and recorded by the crew of the naval ship *USS Ramapo* in 1933.

Applying Math A tsunami formed by an earthquake on the ocean floor travels at 900 km/h. How long will it take the tsunami to travel 4,500 km?



... **Waves let dolphins see with their ears!** A dolphin sends out ultrasonic pulses, or clicks, at rates of 800 pulses per second. These sound waves are reflected back to the dolphin after they hit an obstacle or a meal. This process is called echolocation.

Graph It

Go to booko.msscience.com/science_stats to learn about discoveries by radio astronomers. Make a time line showing some of these discoveries.

Reviewing Main Ideas

Section 1 What are waves?

1. Waves are rhythmic disturbances that carry energy but not matter.
2. Mechanical waves can travel only through matter. Electromagnetic waves can travel through matter and space.
3. In a mechanical transverse wave, matter in the medium moves back and forth at right angles to the direction the wave travels.
4. In a compressional wave, matter in the medium moves forward and backward in the same direction as the wave.

Section 2 Wave Properties

1. The amplitude of a transverse wave is the distance between the rest position and a crest or a trough.
2. The energy carried by a wave increases as the amplitude increases.

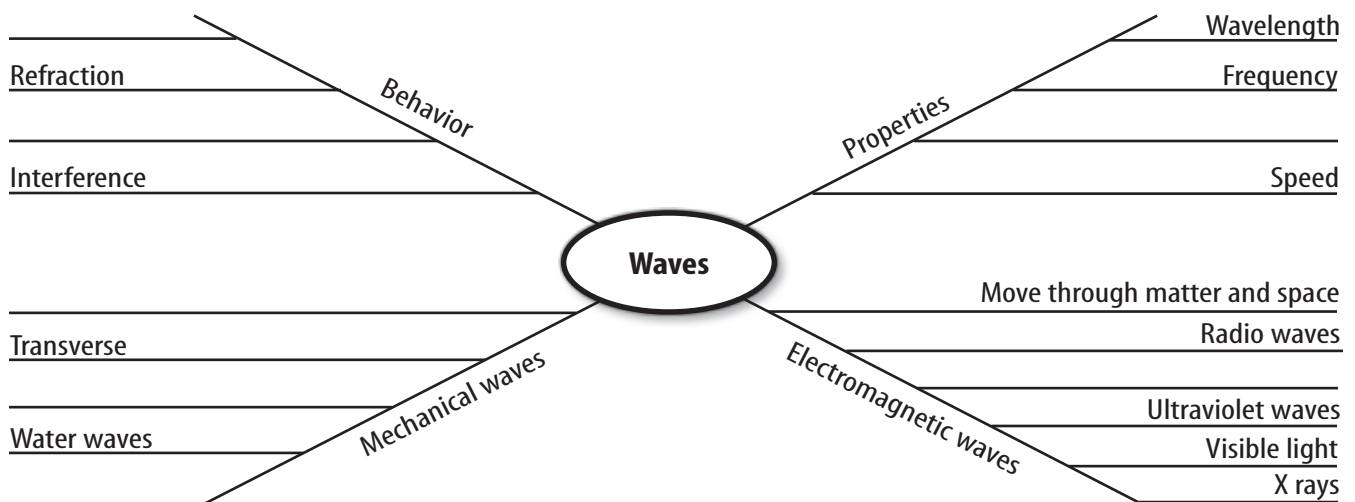
3. Wavelength is the distance between neighboring crests or neighboring troughs.
4. The frequency of a wave is the number of wavelengths that pass a given point in 1 s.
5. Waves travel through different materials at different speeds.

Section 3 Wave Behavior

1. Reflection occurs when a wave strikes an object or surface and bounces off.
2. The bending of a wave as it moves from one medium into another is called refraction. A wave changes direction, or refracts, when the speed of the wave changes.
3. The bending of waves around a barrier is called diffraction.
4. Interference occurs when two or more waves combine and form a new wave while they overlap.

Visualizing Main Ideas

Copy and complete the following spider map about waves.



Using Vocabulary

amplitude p.13

compressional
wave p.11

diffraction p.21

electromagnetic
wave p.12

frequency p.15

interference p.23

mechanical wave p.9

reflection p.19

refraction p.20

transverse wave p.10

wave p.8

wavelength p.14

Fill in the blanks with the correct word or words.

- _____ is the change in direction of a wave going from one medium to another.
- The type of wave that has rarefactions is a _____.
- The distance between two adjacent crests of a transverse wave is the _____.
- The more energy a wave carries, the greater its _____ is.
- A(n) _____ can travel through space without a medium.

Checking Concepts

Choose the word or phrase that best answers the question.

- What is the material through which mechanical waves travel?
 - charged particles
 - space
 - a vacuum
 - a medium
- What is carried from particle to particle in a water wave?
 - speed
 - amplitude
 - energy
 - matter
- What are the lowest points on a transverse wave called?
 - crests
 - troughs
 - compressions
 - rarefactions

- What determines the pitch of a sound wave?

A) amplitude C) speed
B) frequency D) refraction

- What is the distance between adjacent wave compressions?

A) one wavelength
B) 1 km
C) 1 m/s
D) 1 Hz

- What occurs when a wave strikes an object or surface and bounces off?

A) diffraction
B) refraction
C) a transverse wave
D) reflection

- What is the name for a change in the direction of a wave when it passes from one medium into another?

A) refraction C) reflection
B) interference D) diffraction

Use the figure below to answer question 13.



- What type of wave is a sound wave?

A) transverse
B) electromagnetic
C) compressional
D) refracted

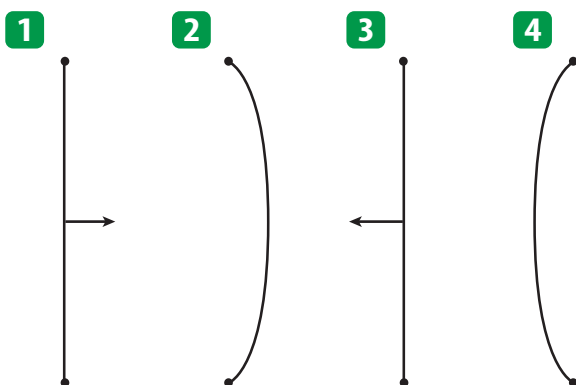
- What color light has the shortest wavelength and the highest frequency?

A) red C) Orange
B) green D) Blue

Thinking Critically

15. **Explain** what kind of wave—transverse or compressional—is produced when an engine bumps into a string of coupled railroad cars on a track.
16. **Infer** Is it possible for an electromagnetic wave to travel through a vacuum? Through matter? Explain your answers.
17. **Draw a Conclusion** Why does the frequency of a wave decrease as the wavelength increases?
18. **Explain** why you don't see your reflected image when you look at a white, rough surface?
19. **Infer** If a cannon fires at a great distance from you, why do you see the flash before you hear the sound?
20. **Form a Hypothesis** Form a hypothesis that can explain this observation. Waves A and B travel away from Earth through Earth's atmosphere. Wave A continues on into space, but wave B does not.

Use the figure below to answer question 21.



21. **Explain** how the object shown above causes compressions and rarefactions as it vibrates in air.

22. **Explain** why you can hear a person talking even if you can't see them.
23. **Compare and Contrast** AM radio waves have wavelengths between about 200 m and 600 m, and FM radio waves have wavelengths of about 3 m. Why can AM radio signals often be heard behind buildings and mountains but FM radio signals cannot?
24. **Infer** how the wavelength of a wave would change if the speed of the wave increased, but the frequency remained the same.
25. **Explain** You are motionless on a rubber raft in the middle of a pool. A friend sitting on the edge of the pool tries to make the float move to the other edge of the pool by slapping the water every second to form a wave. Explain whether the wave produced will cause you to move to the edge of the pool.

Performance Activities

26. **Make Flashcards** Work with a partner to make flashcards for the bold-faced terms in the chapter. Illustrate each term on the front of the cards. Write the term and its definition on the back of the card. Use the cards to review the terms with another team.

Applying Math

Use the following equation to answer questions 27–29.

$$\text{wave speed} = \text{wavelength} \times \text{frequency}$$

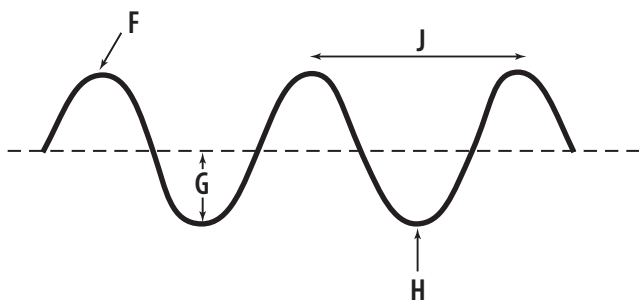
27. **Wave Speed** If a wave pool generates waves with a wavelength of 3.2 m and a frequency of 0.60 Hz, how fast are the waves moving?
28. **Frequency** An earthquake wave travels at 5000 m/s and has a wavelength of 417 m. What is its frequency?
29. **Wavelength** A wave travels at a velocity of 4 m/s. It has a frequency of 3.5 Hz. What is the wavelength of the wave?

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. What do waves carry as they move?
- | | |
|-----------|-------------------------|
| A. matter | C. matter and energy |
| B. energy | D. particles and energy |

Use the figure below to answer questions 2 and 3.



2. What property of the wave is shown at F?
- | | |
|---------------|-----------|
| A. amplitude | C. crest |
| B. wavelength | D. trough |
3. What property of the wave is shown at J?
- | | |
|---------------|-----------|
| A. amplitude | C. crest |
| B. wavelength | D. trough |
4. What kind of wave does NOT need a medium through which to travel?
- | | |
|---------------|--------------|
| A. mechanical | C. light |
| B. sound | D. refracted |
5. What happens as a sound wave's energy decreases?
- | |
|------------------------------|
| A. Wave frequency decreases. |
| B. Wavelength decreases. |
| C. Amplitude decreases. |
| D. Wave speed decreases. |
6. What unit is used to measure frequency?
- | | |
|------------------|-------------|
| A. meters | C. decibels |
| B. meters/second | D. hertz |
7. What properties of a light wave determines its color?
- | | |
|---------------|-----------------|
| A. wavelength | C. speed |
| B. amplitude | D. interference |

8. When two waves overlap and interfere constructively, what does the resulting wave have?

- | |
|--------------------------|
| A. a greater amplitude |
| B. less energy |
| C. a change in frequency |
| D. a lower amplitude |

9. What happens when light travels from air into glass?

- | |
|--------------------------------------|
| A. It speeds up. |
| B. It slows down. |
| C. It travels at 300,000 km/s. |
| D. It travels at the speed of sound. |

Use the figure below to answer questions 10 and 11.



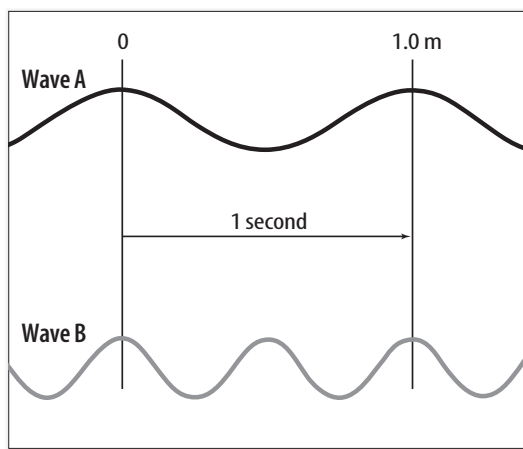
10. What behavior of light waves lets you see a sharp, clear image of yourself?
- | | |
|----------------|-----------------|
| A. refraction | C. reflection |
| B. diffraction | D. interference |
11. Why can't you see a clear image of yourself if the water's surface is rough?
- | |
|---|
| A. The light bounces off the surface in only one direction. |
| B. The light scatters in many different directions. |
| C. There is no light shining on the water's surface. |
| D. The light changes speed when it strikes the water. |

Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

12. An earthquake in the middle of the Indian Ocean produces a tsunami that hits an island. Is the water that hits the island the same water that was above the place where the earthquake occurred? Explain.

Use the figure below to answer questions 13 and 14.



13. Compare the wavelengths and frequencies of the two waves shown.
14. If both waves are traveling through the same medium, how do their speeds compare? Explain.
15. Suppose you make waves in a pond by dipping your hand in the water with a frequency of 1 Hz. How could you make waves of a longer wavelength? How could you increase the amplitude of the waves?
16. How are all electromagnetic waves alike? How do they differ from one another?

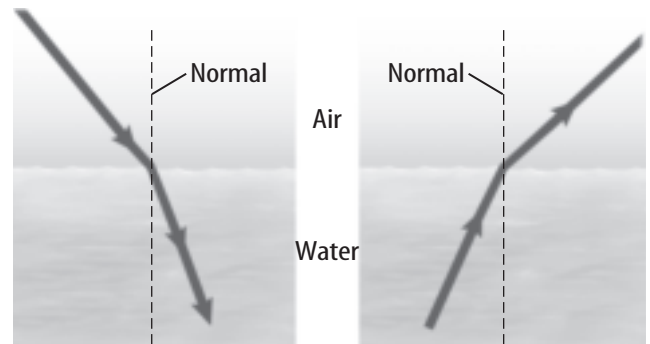
Test-Taking Tip

Take Your Time Stay focused during the test and don't rush, even if you notice that other students are finishing the test early.

Part 3 Open Ended

Record your answers on a sheet of paper.

Use the figure below to answer questions 17 and 18.



17. Why does the light ray bend toward the normal when it passes from air into water, but bend away from the normal as it passes from water into air?
18. A boy has caught a fish on his fishing line. He reels the fish in near the boat. How could the refraction of light waves affect him as he tries to net the fish while it is still in the water?
19. In a science fiction movie, a spaceship explodes. The people in a nearby spaceship see and hear the explosion. Is this realistic? Explain.
20. The speed of light in warm air is greater than its speed in cold air. The air just above a highway is warmer than the air a little higher. Will the light moving parallel to the highway be bent up or down? Explain.
21. You are standing outside a classroom with an open door. You know your friends are in the room because you can hear them talking. Explain why you can hear them talking but cannot see them.
22. How does the size of an obstacle affect the diffraction of a wave?