chapter 1 Waves

section 1 What are waves?

Before You Read

Describe what comes to mind when you think of waves.

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What You'll Learn

- how waves, energy, and matter are related
- the difference between transverse waves and compressional waves

Read to Learn

Study Coach

Create a Quiz As you read this section, write quiz questions based on what you have learned. After you write the quiz questions, answer them.

What is a wave?

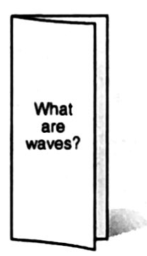
Imagine that you are floating on an air mattress in a swimming pool and someone jumps into the pool near you. You and your air mattress bob up and down after the splash. What happened? Energy from the person jumping in made your air mattress move. But the person did not touch your air mattress. The energy from the person jumping in moved through the water in waves. **Waves** are regular disturbances that carry energy without carrying matter. The waves disturbed, or changed the motion of, your air mattress.

What do waves do?

Water waves carry energy. Sound waves also carry energy. Have you ever felt a clap of thunder? If so, you felt the energy in a sound wave. You also move energy when you throw a ball. But, there is a difference between a moving ball and a wave. A ball is made of matter. When you throw a ball, you move matter as well as energy. A wave moves only energy.

FOLDABLES™

A Identify Make the following Foldable from a sheet of notebook paper to help you organize information about waves.



A Model for Waves

How can a wave move energy without moving matter? Imagine several people standing in a line. Each person passes a ball to the next person. The ball moved, but the people did not. Think of the ball as the energy in a wave and the people as the molecules that move the energy.

Think it Over

1. **Recognize** Write two examples of a mechanical wave.

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Picture This

2. **Draw and Label** In the figure, draw a circle around each crest in the wave. Then, use a different color of pen or pencil to draw a square around each trough.

Mechanical Waves

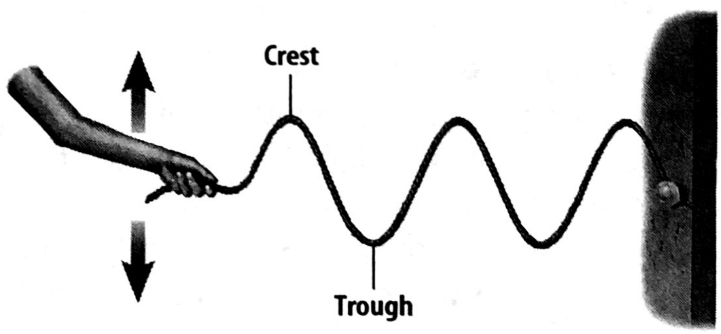
In the model of the wave, the ball (energy) could not be moved if the people (molecules) were not there. The same thing happens when a rock is thrown into a pond. Waves form where the rock hits the water. The molecules in the water bump into each other and pass the energy in the waves. The energy of a water wave cannot be moved or transferred if there are no water molecules.

Waves that use matter to move or transfer energy are **mechanical waves**. Water waves are mechanical waves. The matter that a mechanical wave travels through is called a medium. In a water wave, the medium is water. Solids, liquids, and gases are also mediums. For example, sound waves can travel through air, water, solids, and other gases. Without one of these mediums, there would be no sound waves. There is no air in outer space, so sound waves cannot travel in space.

What are transverse waves?

One kind of mechanical wave is a transverse wave. Transverse means to pass through, across, or over. In a **transverse wave**, the energy of the wave makes the medium move up and down or back and forth at right angles to the direction the wave moves. Think of a long rope stretched out on the ground. If you shake one end of the rope up and down, you make a wave that seems to slide along the rope, like the wave shown in the figure.

Transverse Wave



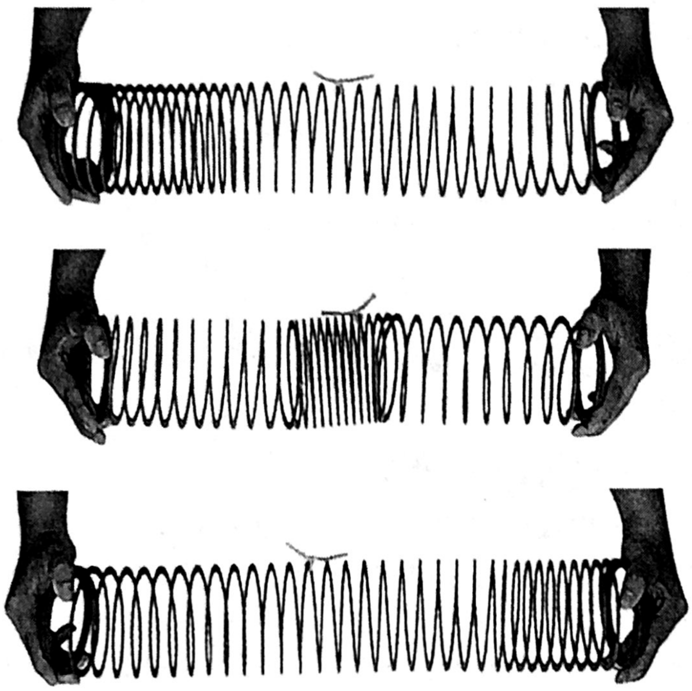
It might seem that the rope is moving away from you, but only the wave is moving away from your hand. The energy of the wave travels through the rope. But the matter in the rope does not move. Look at the figure. You can see that the wave has peaks and valleys that are spaced apart at even and regular distances. The high points of transverse waves are called crests. The low points are called troughs.

What are compressional waves?

Mechanical waves can be either transverse or compressional. Compress means to press or squeeze together. In a **compressional wave**, matter in the medium moves forward and backward along the same direction that the wave travels.

An example of a compressional wave made with a coiled spring is shown in the figure. A string is tied to the spring to show how the wave moves. Some coils on one end are compressed and then let go. As the wave begins, the coils near the end are close together. The other coils are far apart. The wave travels along the spring.

Compressional Wave



The coils and string move only as the wave passes them. Then, they go back to where they were. Compressional waves carry only energy forward along the spring. 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? Hold your fingers against your throat while you hum. You can feel your vocal cords vibrating, or moving back and forth very quickly. You can also feel vibrations when you touch a stereo speaker while it is playing. All waves are made by something that is vibrating. ☑

Picture This

3. **Describe** Look at the figures. Describe the coils of the spring when the wave passes through them. Are they close together or far apart?

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Reading Check

4. **Identify** What kind of waves are sound waves?

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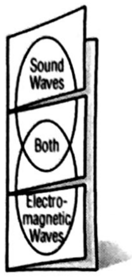
FOLDABLES™

B Compare and Contrast Make the following Foldable to compare and contrast the characteristics of sound waves and electromagnetic waves.



Picture This

5. **Identify** Look at the figure. What do the dots above the drum represent?

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✔ Reading Check

6. **Classify** What is radiant energy?

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Making Sound Waves

A vibrating object causes the air molecules around it to vibrate. Look at the figure. When the drum is hit, the drumhead vibrates up and down. When the drumhead moves up, the air molecules next to it are pushed closer, or compressed, together. The group of compressed molecules is called a compression. The compression moves away from the drumhead.

When the drumhead moves down, the air molecules near it have more room and can spread apart. This group of molecules is a rarefaction. Rarefaction means something that has become less dense. The rarefaction also moves away from the drumhead. As the drumhead vibrates up and down, it makes a series of compressions and rarefactions in the air molecules that make up a sound wave.

Electromagnetic Waves

Electromagnetic (ih lek troh mag NEH tik) **waves** are waves that can travel through space where there is no matter. There are different kinds of electromagnetic waves, such as radio waves, infrared waves, visible light waves, ultraviolet waves, X rays, and gamma rays. These waves can travel in matter or in space. For example, radio waves from TV and radio stations travel through air. They can be reflected from a satellite in space. Then, they travel through air and the walls of your house to your TV or radio.

How does the Sun emit light and heat?

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. Visible light waves make it possible for you to see. Some of the Sun's radiant energy is carried by ultraviolet waves. These are the waves that can cause sunburn. ✔

● After You Read

Mini Glossary

compressional wave: a type of mechanical wave in which matter in the medium moves forward and backward along the same direction that the wave travels

electromagnetic waves: waves that can travel through space where there is no matter

mechanical waves: waves that use matter to move energy

transverse wave: a type of mechanical wave in which the energy of the wave makes the medium move up and down or back and forth at right angles to the direction the wave travels

waves: regular disturbances that carry energy without carrying matter

1. Read the key terms and definitions in the Mini Glossary above. Write a sentence using the term *mechanical wave* on the lines below.

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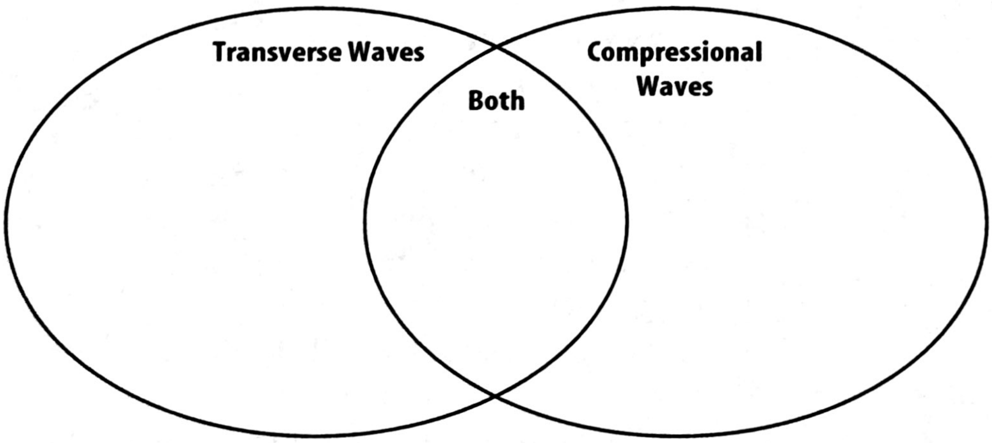
2. Use the Venn diagram to compare and contrast transverse and compressional waves. Arrange the characteristics of the waves according to whether they are true for transverse waves, compressional waves, or both.



3. How did the examples of the rope and the spring toy help you understand the difference between transverse and compressional waves?

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End of Section

chapter 1 Waves

section 2 Wave Properties

What You'll Learn

- about the frequency and the wavelength of a wave
- why waves travel at different speeds

Before You Read

Think about waves in an ocean and waves in a pond. How would you describe each kind of wave?

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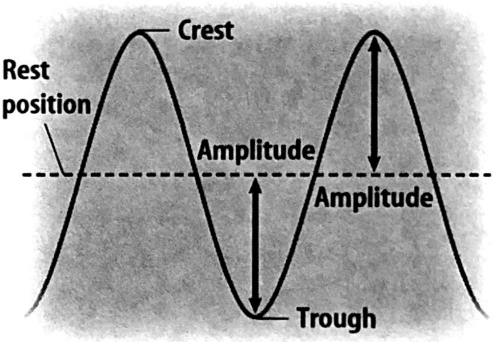
Mark the Text

Underline Terms As you read this section, underline each property of a wave. Then, highlight information about each property in a different color.

Read to Learn

Amplitude

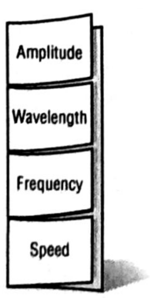


To describe a water wave, you might say how high the wave rises above, or falls below, a certain level. This distance is called the wave's amplitude. The <u>**amplitude**</u> of a transverse wave is one-half the distance between a crest and a trough, as shown in the figure.

In a compressional wave, the amplitude depends on how close together the particles of the medium are. The amplitude is greater when the particles of the medium are squeezed closer together in each compression and spread farther apart in each rarefaction.

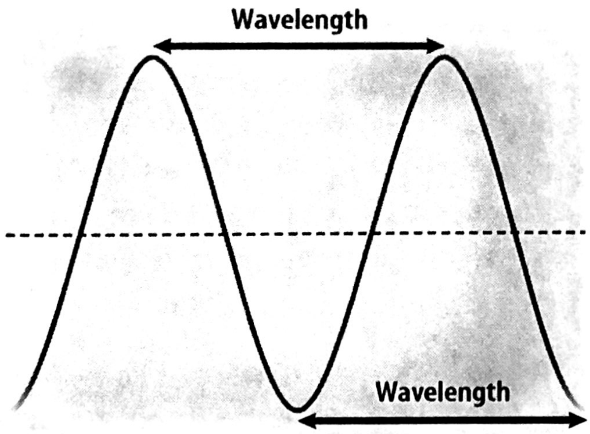
FOLDABLES™

C Organize Information Make the following Foldable to help you organize information about the different properties of waves.

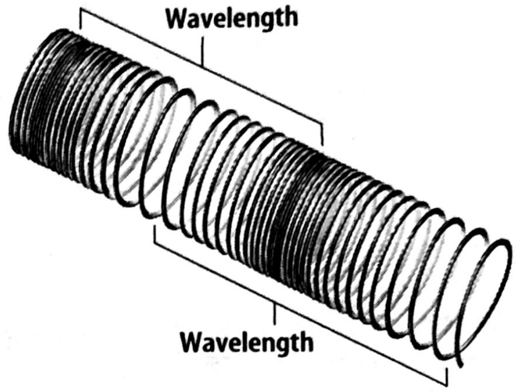


How are amplitude and energy related?

A wave's amplitude is related to the energy that the wave carries. For example, electromagnetic waves of bright light carry more energy and have greater amplitudes than electromagnetic waves of dim light. Loud sound waves carry more energy and have greater amplitudes than soft sound waves. A very loud sound can carry enough energy to damage your hearing.



Transverse Wave



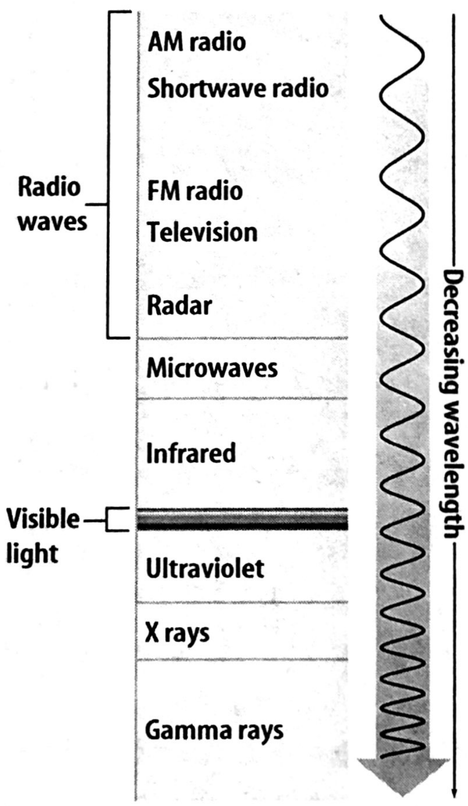
Compressional Wave

Wavelength

You also can describe a wave by its wavelength. Look at the figure above. 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.

The wavelengths of electromagnetic waves can vary from extremely short to longer than a kilometer. X rays and gamma rays have wavelengths that are smaller than the diameter of an atom.

This range of wavelengths is called the electromagnetic spectrum. The figure at the right shows the names given to different parts of the electromagnetic spectrum. Visible light, or light you can see, is only a small part of the electromagnetic spectrum. The wavelength of visible light gives light its color. For example, red light waves have longer wavelengths than green light waves.



Picture This

1. **Describe** Look at the figure of the transverse wave. Compare the wavelengths between two crests to the wavelength between two troughs. Describe what you find.

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Picture This

2. **Use Graphs** Which of the following has the greatest wavelength?
   - **a.** microwaves
   - **b.** X rays
   - **c.** AM radio waves
   - **d.** FM radio waves

Frequency

The **frequency** of a wave is the number of wavelengths that pass a given point in 1 s. Frequency is measured in hertz (Hz). Hertz are the number of wavelengths per second. So, 1 Hz means one wavelength per second. Remember that waves are made by something that vibrates. The faster the vibration is, the higher the frequency is of the wave. ☑

Reading Check

3. **Summarize** Write the correct words to complete the sentence on the lines below.

   Waves that vibrate fast have ___a.___ frequencies. Waves that vibrate slowly have ___b.___ frequencies.

   a. ____________________

   b. ____________________

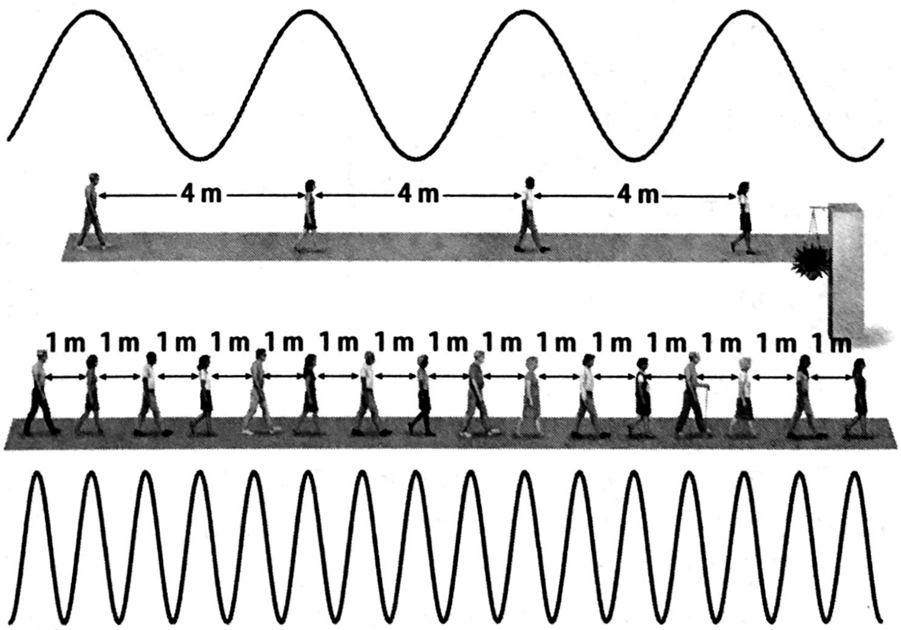
How can you model frequency?

You can use a model to help you understand frequency. If two waves travel with the same speed, their frequency and wavelength are related. Look at the figure below. Imagine people on two moving sidewalks next to each other. One sidewalk has four people on it. They are spaced 4 m apart. The other sidewalk has 16 people on it. They are spaced 1 m apart.

Imagine both sidewalks are moving at the same speed. The sidewalks move toward a pillar. On which sidewalk will more people go past the pillar? The sidewalk with 16 people on it has a shorter distance between people. Four people on this sidewalk will pass the pillar for every one person on the other sidewalk.

Picture This

4. **Use Models** On the bottom sidewalk, circle groups of four people each. Then draw a line from each group of four people to one person on the top sidewalk.



Applying Math

5. **Calculate** If three people on the top sidewalk pass the pillar, how many people on the bottom sidewalk will have passed the pillar?

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How are frequency and wavelength related?

Suppose that each person on the sidewalks represents the crest of a transverse wave. The movement of the people on the first sidewalk is like a wave with a 4 m wavelength. For the second sidewalk, the wavelength would be 1 m.

The sidewalk with the longer, 4 m, wavelength carries a person past the pillar less frequently. Longer wavelengths have lower frequencies. On the second sidewalk, people pass the pillar more frequently. There, the wavelength is shorter—only 1 m. Shorter wavelengths have higher frequencies. This is true for all waves that travel at the same speed. As the frequency of a wave increases, its wavelength decreases.

What makes different colors and pitches?

The color of a light wave depends on the wavelength or the frequency of the light wave. For example, blue light has a higher frequency and shorter wavelength than red light.

Pitch is how high or how low a sound seems to be. Either the wavelength or the frequency determines the pitch of a sound wave. The pitch and frequency increase from note to note when you sing a musical scale. High-sounding pitches have higher frequencies. As the frequency of sound waves increases, their wavelengths decrease. Lower pitches have lower frequencies. As the frequency of a sound wave decreases, their wavelengths increase. ☑

Wave Speed

You have probably watched a thunderstorm on a hot summer day. You see lightning flash between a dark cloud and the ground. If the thunderstorm is far away, it takes many seconds before you will hear the sound of the thunder that goes with the lightning. 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. You can calculate the speed of any wave using this equation. The Greek letter lambda, λ, represents wavelength.

Wave Speed Equation

wave speed (m/s) = **frequency** (Hz) × **wavelength** (m)

$$v = f\lambda$$

Mechanical waves, such as sound, and electromagnetic waves, such as light, change speed when they travel in different mediums. 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.

Reading Check

6. **Summarize** What determines color and pitch? Circle your answer.
   - a. wavelength
   - b. frequency
   - c. wavelength and frequency
   - d. wavelength or frequency

Applying Math

7. **Use an Equation** What is the speed in m/s of a wave with a frequency of 50 Hz and wavelength of 2 m? Show your work.

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After You Read

Mini Glossary

amplitude: transverse wave—one-half the distance between a crest and a trough; compressional wave—how close together the particles of the medium are

frequency: the number of wavelengths that pass a given point in 1 s

wavelength: transverse wave—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; compressional wave—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

1. Review the terms and their definitions in the Mini Glossary. Explain in your own words how wavelength and frequency are related.

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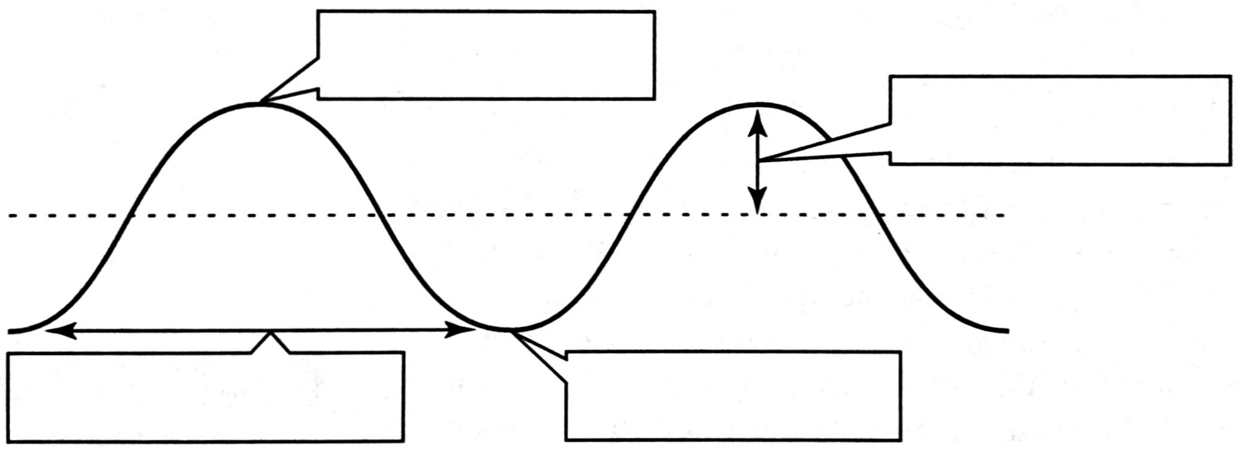
2. Label the parts of the transverse wave in the diagram below.



3. You were asked to underline properties of waves and highlight information about them. How did this help you understand and learn about properties of waves?

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End of Section

Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about properties of waves.

chapter 1 Waves

section 3 Wave Behavior

Before You Read

Have you ever shouted and heard an echo? On the lines below, write about what you think causes an echo.

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What You'll Learn

- how waves can reflect
- how waves change direction
- how waves can bend around barriers

Read to Learn

Mark the Text

Identify Details Highlight each question head. Then use another color to highlight the answer to each question.

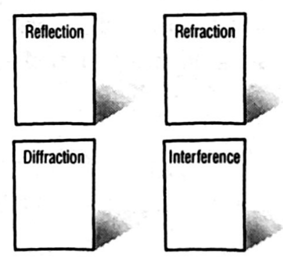
Reflection

You can see yourself in a mirror because waves of light are reflected. Reflect means to throw back. **Reflection** happens when a wave hits an object or surface and bounces off. Light waves from the Sun or a lightbulb bounce off of your face. The light waves hit the mirror and reflect back to your eyes. So you see your reflection in the mirror.

You can see your reflection in the smooth surface of a pond, too. But, if the water has ripples or waves, it is harder to see your reflection. You cannot see a sharp image when light reflects from an uneven surface like ripples on the water. This is because the reflected light goes in many different directions.

FOLDABLES™

D Organize Information Use four quarter-sheets of paper to take notes about reflection, refraction, diffraction, and interference as you read.



Refraction

A wave changes direction when it reflects from a surface. Waves can also change direction in another way. Have you ever tried to grab a sinking object in a swimming pool, but missed it? You were probably sure you grabbed right where it was. But, the light waves from the object changed direction when they moved from the water to the air. The bending of a wave as it moves from one medium to another is **refraction**.

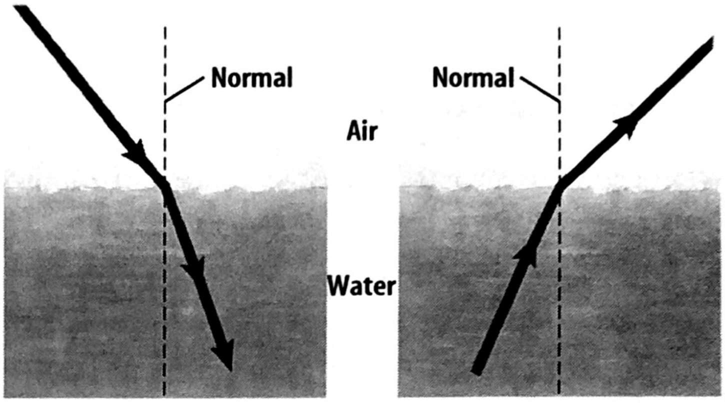
How are refraction and wave speed related?

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 happens when the speed of a wave changes as it moves from one medium to another.

Picture This

1. **Display** In the water of the first figure, draw an arrow from the light ray to the normal that shows how the light ray bends toward the normal.

   In the air of the second figure, draw an arrow from the normal to the light ray to show how the light ray bends away from the normal.



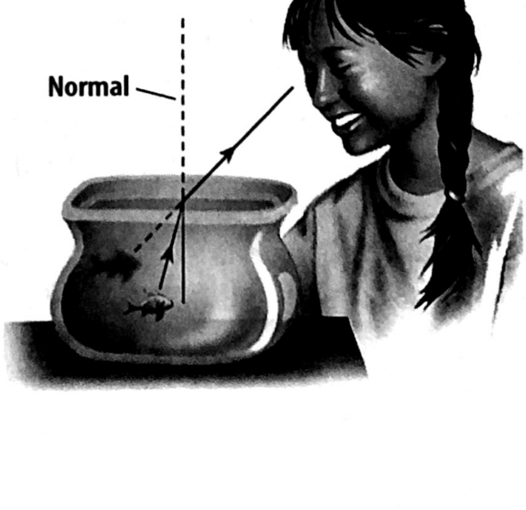
Wave Speed The figures above show how a light wave bends when it passes from air to water and water to air. A line that is perpendicular to the water's surface is called the normal. A light ray slows down and bends toward the normal when it passes from air into water. A light ray speeds up and bends away from the normal when it passes from water into air. If the speed of the wave changes a lot between mediums, the direction of the wave will change a lot too.

Refraction The figure below shows refraction of a fish in a fishbowl. Refraction makes the fish appear to be closer to the surface. It also appears farther away from you than it really is. Light rays reflected from the fish are bent away from the normal as they pass from water to air. Your brain assumes that light rays always travel in straight lines. So, the light rays seem to be coming from a fish that is closer to the surface.

Picture This

2. **Use an Illustration** In the figure, trace the line that shows how the light would travel if light rays did not travel at different speeds in water and air.

Refraction



How does refraction make color?

Recall that different wavelengths make different colors. You can separate the colors in sunlight using a prism. A prism is an object or medium used to break light into its different wavelengths. Light is refracted twice when it passes through a prism—once it when it enters and once when it leaves. Since each color has a different wavelength, each color is refracted by a different amount. The colors of light are separated when they leave the prism. Violet light has the shortest wavelength. It is refracted, or bent, the most. Red light has the longest wavelength. It is refracted the least.

Think it Over

3. **Explain** why the color violet is refracted the most.

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How are the colors of a rainbow made?

Each raindrop is a tiny prism. Light rays refract when they enter and again when they leave a raindrop. The colors refract at different angles because they have different wavelengths. The wavelengths separate into all the colors you can see. 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? Sound waves bend as they pass through an open doorway. This is why you can hear the music. This bending is caused by diffraction. **Diffraction** is the bending of waves around a barrier. ☑

Reading Check

4. **Define** What is diffraction?

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Light waves can diffract, too. But, they cannot diffract as much as sound waves. You can hear the band playing music when you are down the hall, but you cannot see the musicians until you actually look inside the band room door.

How are diffraction and wavelength related?

The wavelengths of light are much shorter than the opening of the band room door. This is why the light waves do not diffract as much as the sound waves do when they pass through the door. Light waves have wavelengths that are very short—between about 400 and 700 billionths of a meter. The doorway is about 1 m wide. The wavelengths of sound waves you can hear can be as long as 10 m. Sound waves are much closer in measurement to the opening of the door. A wave diffracts more when its wavelength is similar to the size of the barrier or opening.

Think it Over

5. **Communicate** A garage door is 3 m wide. Which sound waves will diffract most easily when they pass through the door—ones with a wavelength of 2 m or ones with a wavelength of 0.2 m?

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Can water waves diffract?

Imagine water waves in the ocean. What happens when the waves hit a barrier like an island? They go around the island. If the wavelength of the water waves is close to the size and spacing between the islands, the water waves diffract around the islands and keep moving. If the islands are bigger than the wavelength of the water waves, the water waves diffract less.

What happens when waves meet?

Suppose you throw two pebbles into a still pond. Waves spread out from where each pebble hits the water. When two waves meet, will they hit each other and change direction? No, they pass right through each other and keep moving. ☑

Reading Check

6. **Infer** What happens when two waves meet?

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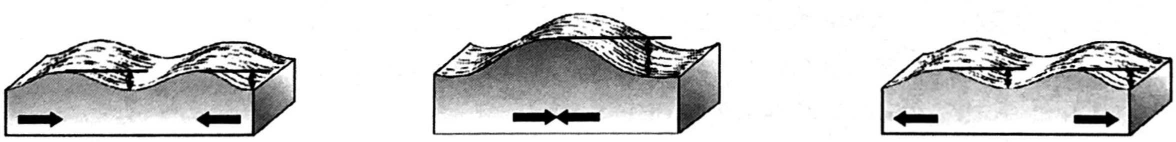
How do waves interfere with each other?

What happens when two waves overlap? The two waves add together, or combine, and make a new wave. The ability of two waves to combine and make a new wave when they overlap is **interference.** There are two kinds of interference—constructive and destructive as shown in the figure.

Constructive Interference In constructive interference, the crest of one wave overlaps the crest of another wave. They form a larger wave with greater amplitude. Then the original waves pass through each other and keep traveling as they were before.

Constructive Interference

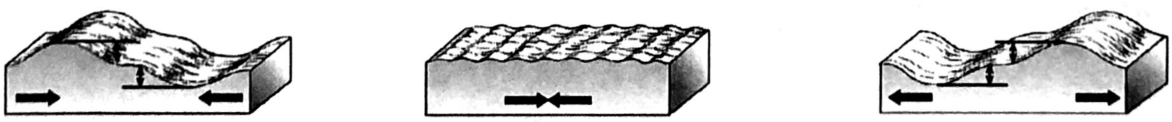


Picture This

7. **Conclude** Look at the figure of destructive interference. When can two waves cancel each other out?

Destructive Interference In destructive interference, the crest of one wave overlaps the trough of another. The amplitudes of the waves combine to make a wave with a smaller amplitude. If the waves have equal amplitudes, they will cancel each other out while the waves overlap. Then the original waves pass through each other and keep traveling as they were before.

Destructive Interference



How are particles and waves different?

Diffraction When light travels through a small opening, it spreads out in all directions on the other side of the opening. What would happen if particles were sent through the small opening? They would not spread out. They would keep going in a straight line. Diffraction, or spreading, happens only with waves.

Interference Interference does not happen with particles, either. When waves meet, they interfere and then keep going. If particles meet, either they hit each other and scatter, or miss each other. Interference and diffraction both are properties of waves but not particles. ☑

How can noise be reduced?

A lawn mower and a chain saw make loud noises. These loud noises can damage hearing.

Ear Protectors That Absorb Noise Loud sounds have waves with larger amplitudes than softer sounds. Loud sound waves carry more energy than softer sound waves. You have cells in your ears that vibrate and send signals to your brain. Energy from loud sound waves can damage these cells and can cause you to lose your hearing. Ear protectors can help prevent loss of hearing. The protectors absorb, or take in, some of the energy from sound waves. The ear is protected because less sound energy reaches it.

Ear Protectors That Interfere With Noise Pilots of small planes have a similar problem. The airplane's engine makes a lot of noise. But, pilots cannot wear ear protectors to shut out all of the engine's noise. If they did, they would not be able to hear instructions from air-traffic controllers.

Instead, pilots wear special ear protectors. These ear protectors have electronic circuits. The circuits detect noise from the airplane. Then they make sound frequencies that destructively interfere with the noise. Remember that destructive interference makes a smaller wave. The frequencies interfere only with the engine's noise. Pilots can still hear the air-traffic controllers. So, destructive interference can be helpful.

Reading Check

8. **Determine** What two properties do waves have that particles do not have?

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Think it Over

9. **Explain** How do the ear protectors some pilots wear work?

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After You Read

Mini Glossary

diffraction: the bending of waves around a barrier

interference: the ability of two waves to combine and make a new wave when they overlap

reflection: occurs when a wave hits an object or surface and bounces off

refraction: the bending of a wave as it moves from one medium to another

1. Review the terms and their definitions in the Mini Glossary. Write one or two sentences describing how refraction can make a rainbow.

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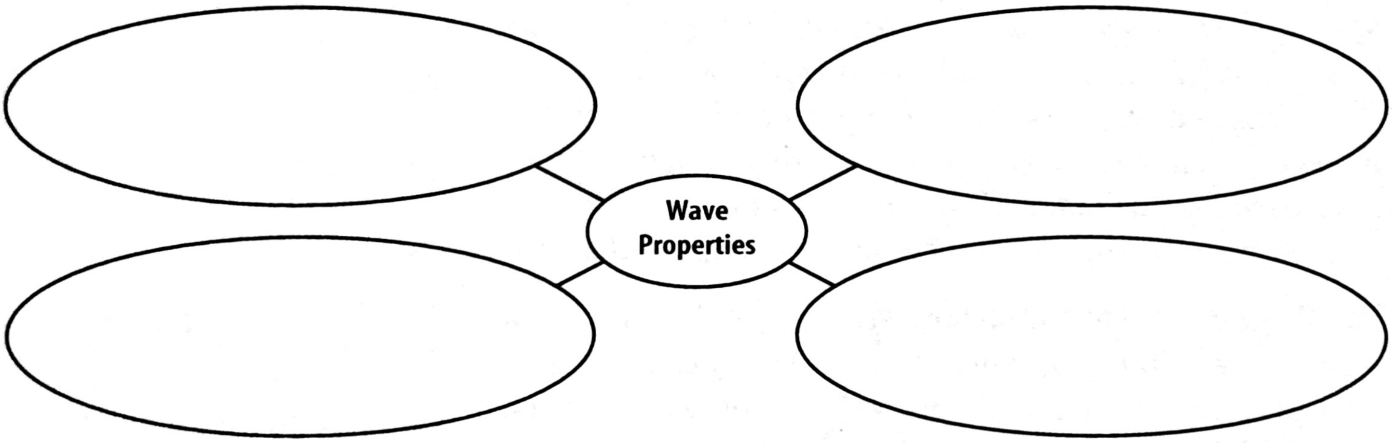
2. In the graphic organizer below, name the four different wave properties. Give an example of each.



3. You were asked to highlight each question head and the answer to each question as you read this section. Name another strategy that would help you learn the properties of wave.

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End of Section

Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about wave behavior.

chapter 2 Sound

section 1 What is sound?

Before You Read

Write down two sounds that you like to hear and two sounds that you do not like to hear. Why are some sounds pleasant and others not?

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What You'll Learn

- what the characteristics of sound waves are
- how sound travels
- what the Doppler effect is

Read to Learn

Sound and Vibration

Think of all the sounds you have heard today. You may have heard the sound of your alarm clock, people talking, or locker doors slamming. All sounds have one thing in common. Every sound is made by something that vibrates.

What are sound waves?

How does an object that is vibrating make sound? When you speak, vocal cords in your throat vibrate. The vibrations make sound waves that travel through the air to other people's ears. Their brain understands the sound waves and they hear your voice.

A wave carries energy from one place to another. A wave does not move matter from one place to another. An object that is vibrating in air makes a sound wave. The vibrating object causes air molecules to move back and forth. These air molecules bump into other air molecules nearby and make them move back and forth, too. This happens again and again. In this way, energy is transferred from one place to another as a sound wave.

Mark the Text

Identify Characteristics As you read this section, highlight the sentences that describe characteristics of sound waves.

What type of wave is a sound wave?

A sound wave is a compressional wave. Have you ever played with a coiled spring toy? When you hold both ends of the spring and someone squeezes together the coils at one end, a wave moves along the spring. You can see the coils of the spring move together and then apart as the compressional wave moves along the spring. The coils move back and forth as the compressional wave moves past them but the toy stays in the same place. ☑

✔ Reading Check

1. **Describe** What type of wave is a sound wave?

____

In a compressional wave, the material the wave passes through moves back and forth along the same direction that the wave moves. In the toy, the coils of the spring move back and forth along the same direction the wave is moving as energy is transferred. In a sound wave, air molecules move back and forth along the same direction the sound wave is moving.

How are sound waves made?

Look at the tuning fork on the left in the figure below. When the end moves outward into the air, it pushes the air molecules together. This makes an area where the air molecules are closer together, or more dense. This area of higher density is called a compression.

When the end of the tuning fork moves inward, the air molecules next to it spread farther apart. This area of lower density is called a rarefaction. You can see a rarefaction on the right in the figure below.

As the tuning fork vibrates, it forms a series of compressions and rarefactions. The compressions and rarefactions move away from the tuning fork as the molecules bump into other molecules. Energy is transferred from one molecule to the next as the compressions and rarefactions move away from the tuning fork.

Picture This

2. **Compare and Contrast** In the figures, how do the molecules in the rarefaction differ from the molecules in the compression?

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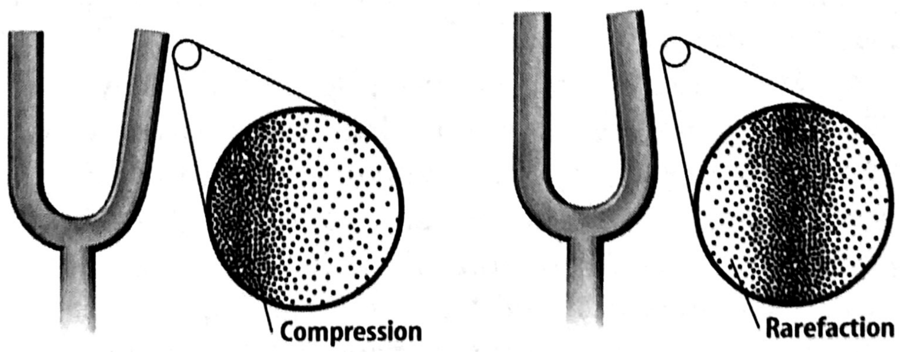
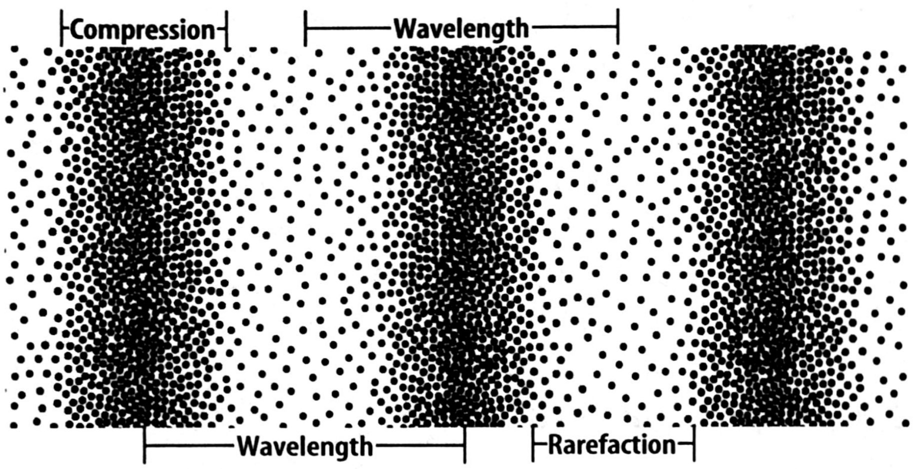


Sound Wave



Picture This

3. Determine How many compressions can be seen in the wave in the figure?

____

What is a wavelength?

Like other waves, a sound wave can be described by its wavelength and frequency. Look at the figure above. It shows the wavelength of a compressional wave. The wavelength is the distance from one compression to the next or from one rarefaction to the next.

What is frequency?

The frequency of a sound wave is the number of compressions or rarefactions that pass by a certain point in one second. The faster an object vibrates, the higher the frequency of the sound wave it forms.

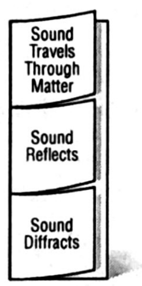
The Speed of Sound

Sound waves can travel through other materials in the same way they travel through air. But, sound waves travel at different speeds through different materials.

As a sound wave travels through a material, molecules in that material bump into each other. Molecules in a solid are closer together than they are in a liquid or a gas. That means they do not have to travel far before they bump into nearby molecules. Sound travels fastest in solids because the molecules are closest together. Sound usually travels slowest through gases because the molecules are farthest apart. For example, sound travels through air at 343 m/s. Sound travels through water at 1,483 m/s, and through glass at 5,640 m/s.

FOLDABLES™

A Organize Information Make the following Foldable to help you organize information about sound. Give examples under each tab.



Does temperature change the speed of sound?

Sound travels faster through a material when that material is at a higher temperature. The molecules of a material move faster as the material heats up. The faster the molecules move, the more often they bump into each other. The more times the molecules hit each other, the faster sound travels through the material. For example, the speed of sound in air at 0°C is 331 m/s. When the air warms to 20°C, sound travels through it at 343 m/s.

Applying Math

4. Calculate How much faster does sound travel through air at 20°C than through air at 0°C?

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Amplitude and Loudness

What's the difference between loud sounds and quiet sounds? Play a radio loudly, then play it quietly. You will hear the same instruments and voices, but something is different. The difference is that loud sound waves usually carry more energy than soft sound waves do. **Loudness** is a person's understanding of how much energy a sound wave carries.

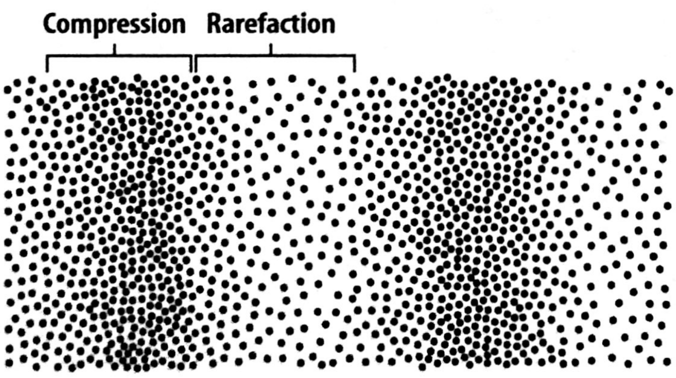
How are amplitude and energy related?

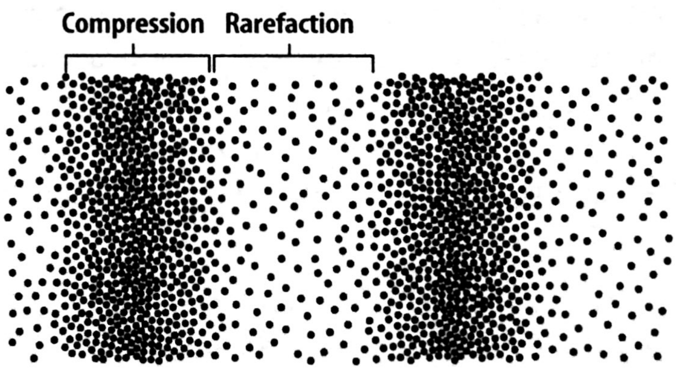
The amount of energy a wave carries depends on its amplitude. The amplitude of a sound wave shows how spread out the molecules are in the compressions and rarefactions of the wave.

Compare the two sound waves in the figure below. In the sound wave on the right, the molecules are closer together in the compressions and farther apart in the rarefactions than in the wave on the left. This wave has a higher amplitude. The vibrating object that made the wave on the right transferred more energy to move the particles closer together or spread them farther apart. Sound waves with greater amplitude carry more energy and sound louder. Sound waves with smaller amplitude carry less energy and sound quieter.

Picture This

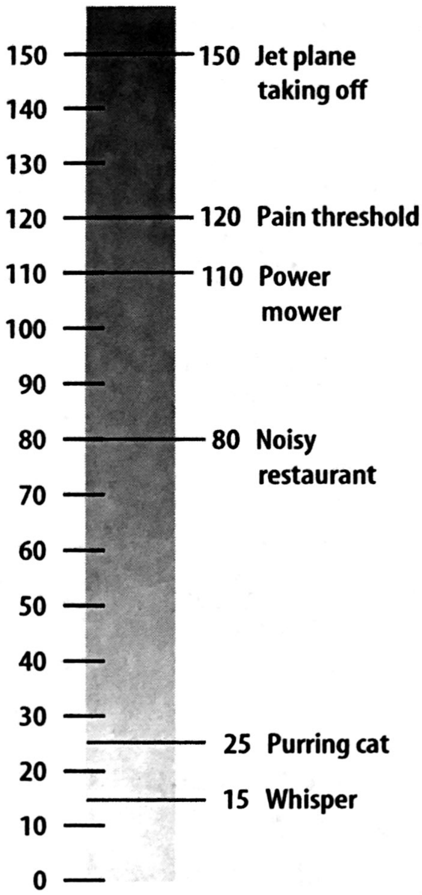
5. Infer Circle the sound wave that will sound louder.





How is the energy of a sound wave measured?

How loud a sound seems is different for each person. But, the energy carried by sound waves can be measured by a scale called the decibel (dB) scale. The figure to the right shows the decibel scale. An increase of 10 dB means the energy carried by a sound has increased ten times. But, an increase of 20 dB means that the sound carries 100 times more energy.



Decibel Scale

Hearing Damage Hearing damage begins to happen at sound levels of about 85 dB. The amount of damage depends on the frequencies of the sound and how long a person is exposed to the sound. Some music concerts produce sound levels as high as 120 dB. The energy carried by these sound waves is about 30 billion times greater than the energy carried by sound waves made by whispering.

Frequency and Pitch

The **pitch** of a sound is how high or how low it sounds. A flute makes a high-pitched sound. A tuba makes a low-pitched sound. The pitch of a sound depends on the frequency of the sound. The higher the pitch is, the higher the frequency is. For example, a sound wave with a frequency of 440 hertz (Hz) has a higher pitch than a sound wave with a frequency of 220 Hz.

What frequencies can be heard?

You can hear sound waves with frequencies between about 20 Hz and 20,000 Hz. Some animals can hear sounds with even higher or lower frequencies. Dogs can hear frequencies up to almost 50,000 Hz. Dolphins and bats can hear frequencies as high as 150,000 Hz.

Picture This

6. **Use Diagrams** How many decibels is the sound level of a purring cat?

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Think it Over

7. **Think Critically** Explain why going to some music concerts could damage your hearing.

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Think it Over

8. **Infer** Which sound wave has a higher pitch, a wave with a frequency of 100 Hz or a wave with a frequency of 500 Hz?

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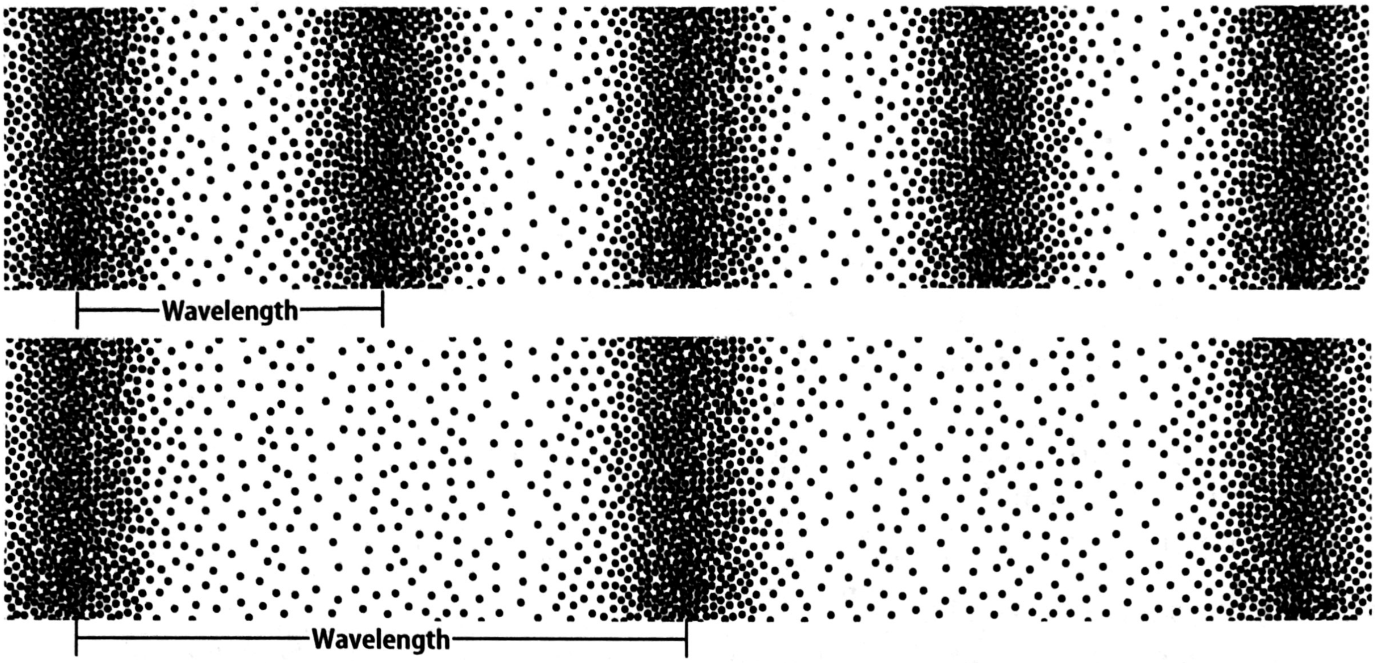
Frequency and Wavelength



Picture This

9. Interpret Scientific Diagrams Circle the sound wave that has the higher pitch.

Reading Check

10. Identify Who has shorter vocal cords, a child or an adult?

____

How are frequency and wavelength related to pitch?

Recall that frequency and wavelength are related. If two sound waves travel at the same speed, the wave with the shorter wavelength has the higher frequency. Look at the sound waves in the figure. The wavelength of the upper wave is shorter. So, more compressions and rarefactions will go past a certain point every second than for the wave at the bottom of the figure. This means the upper sound wave has a higher frequency than the lower sound wave. It also means that the upper wave is higher in pitch. Sound waves with a higher pitch have shorter wavelengths than those with a lower pitch.

Why do some human voices sound higher than others?

When you make a sound, you breathe out past your vocal cords and your vocal cords vibrate. Not everyone's vocal cords are the same length and thickness. Shorter, thinner vocal cords vibrate at higher frequencies than longer or thicker ones. Children have shorter, thinner vocal cords because their vocal cords are still growing. So, most children's voices sound higher than adults' voices. Muscles in the throat can stretch the vocal cords tighter. People can change the pitch of their voices by controlling these muscles. ☑

Echoes

Sound waves reflect off hard surfaces just like a water wave bounces off rocks at the beach. An **echo** is a reflected sound wave. The amount of time it takes an echo to return to where the sound wave was first made depends on how far away the reflecting surface is.

Sonar systems use reflected sound waves to find the location and shape of objects under water. A pulse of sound is sent toward the ocean floor. The wave reflects off the ocean floor and back to a receiver. By measuring the length of time it took the echo to return, the distance to the ocean floor can be measured. Sonar can be used to map the ocean floor, locate submarines, schools of fish, and other objects under water. ☑

What is echolocation?

Some animals use echoes to tell their location and to hunt. This is called echolocation. Bats give off high-pitched squeaks, then listen for the echoes. The type of echo a bat hears tells it exactly where an insect is. Dolphins also use echolocation to help navigate or find their way and to locate objects in the ocean. People who have vision problems might use echolocation to estimate the size and shape of a room.

The Doppler Effect

Have you listened to an ambulance siren as the ambulance sped toward you, then passed you? The pitch gets higher as the ambulance moves toward you. It gets lower as the ambulance moves away from you. The **Doppler effect** is the change in frequency of a sound wave when the source of a sound moves compared to the listener.

The Doppler effect occurs if the source of the sound is moving or if the listener is moving. Suppose you drive past a factory as its whistle blows. As you move toward the factory, the whistle will sound higher pitched. As you move closer, you meet each sound wave a little earlier than you would if you were not moving. You hear more wavelengths per second, so the whistle sounds higher in pitch. As you move away from the factory, each sound wave takes a little longer to reach you. You hear fewer wavelengths per second. So, the whistle sounds lower in pitch.

Reading Check

11. **Explain** What does sonar measure to find the depth of the ocean floor?

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Think it Over

12. **Determine** Which sound would have a higher pitch, a sound moving toward you or a sound moving away from you?

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Reading Check

13. **Describe** What does a radar gun use to find the speed of an object?

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Radio Waves Radar guns can measure the speed of cars and baseball pitches by using the Doppler effect. A radar gun sends out a radio wave instead of a sound wave. The radio wave reflects off a moving object. The frequency of the radio wave changes depending on the speed of the moving object and whether the object is moving toward the radar gun or away from it. The radar gun uses the change in the frequency of the reflected wave to find the speed of the object. ☑

Diffraction of Sound Waves

A sound wave diffracts when it bends around an object in its path or when it spreads out after passing through a small opening. The amount a wave diffracts depends on whether the wavelength is bigger or smaller than the object or opening. A wave barely diffracts if its wavelength is much smaller than the object or opening. As the size of the wavelength becomes closer to the size of the object or opening, the amount of diffraction increases.

You can hear the diffraction of sound waves if you go to the band room while the band is practicing. If you stand in the open doorway, you will hear the band normally. If you stand around the corner from the band room, you will hear the tubas and other low-pitched instruments better than the high-pitched instruments.

The low-pitched instruments make sound waves with longer wavelengths than the high-pitched instruments. The long wavelengths are closer to the size of the door opening than the shorter wavelengths made by the high-pitched instruments. The longer wavelengths diffract more. So, you hear them even when you are not standing in the doorway. In the same way, the lower frequencies in the human voice allows you to hear someone talking even when the person is around the corner.

Think it Over

14. **Evaluate** Which instrument are you more likely to hear if you are standing around the corner from the band room, a trombone or a flute?

____

Using Sound Waves

Sound waves can be used to treat some health problems. A process called ultrasound uses sound waves with high frequencies. Ultrasound can be used to make an image of the inside of the body. Ultrasound can be used to see how a fetus is developing and to study the heart. Ultrasound along with the Doppler effect can be used to determine if a heart is working properly.

● After You Read

Mini Glossary

Doppler effect: the change in frequency of a sound wave when the source of a sound moves compared to the listener

echo: a reflected sound wave

loudness: a person's understanding of how much energy a sound wave carries

pitch: how high or how low a sound is

1. Review the terms and their definitions in the Mini Glossary. Write one or two sentences that describe how animals use echoes.

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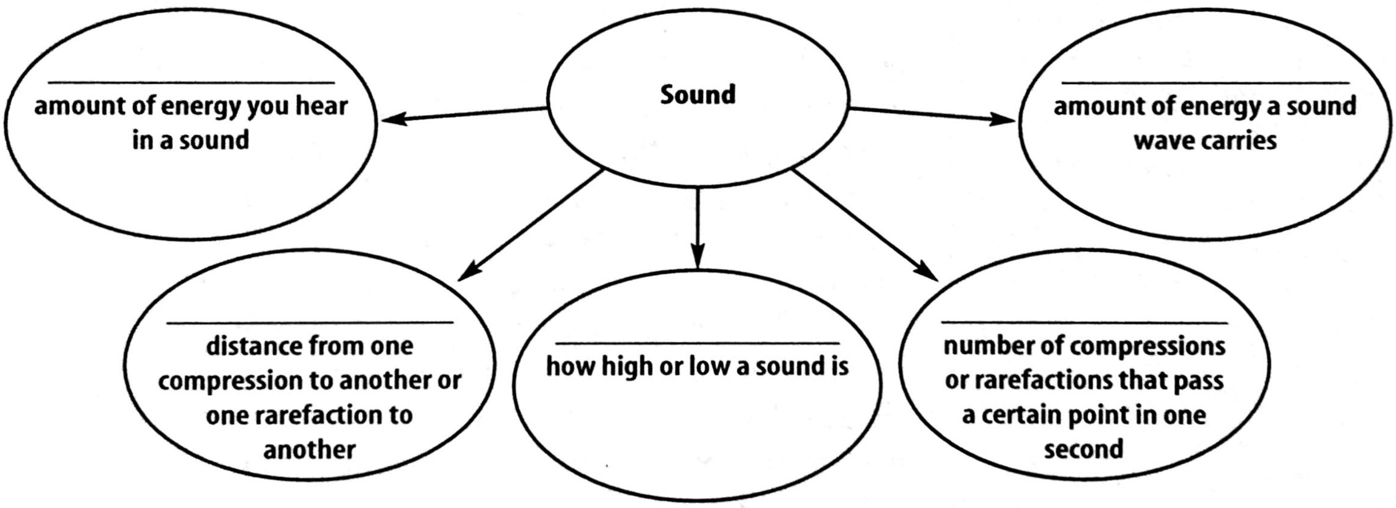
2. Place each characteristic of sound in the correct space on the concept map below.

wavelength **frequency** **loudness** **amplitude** **pitch**



3. You were asked to highlight the sentences that describe characteristics of sound waves. How did this help you learn the content of the section?

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Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about sound.

End of Section

chapter 2 Sound

section 2 Music

What You'll Learn

- the difference between music and noise
- how instruments produce music
- how you hear

Before You Read

What is your favorite song? What do you like about it?

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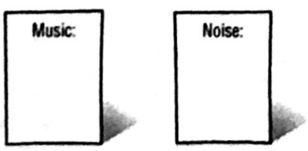
Mark the Text

Locate Information As you read this section, highlight the main ideas about stringed instruments in one color. Highlight the main ideas about percussion instruments in another color. Highlight the main ideas about brass and woodwind instruments in a third color.

FOLDABLES™

B Compare and Contrast Make the following Foldable to help you understand the differences between music and noise. Include examples of each.

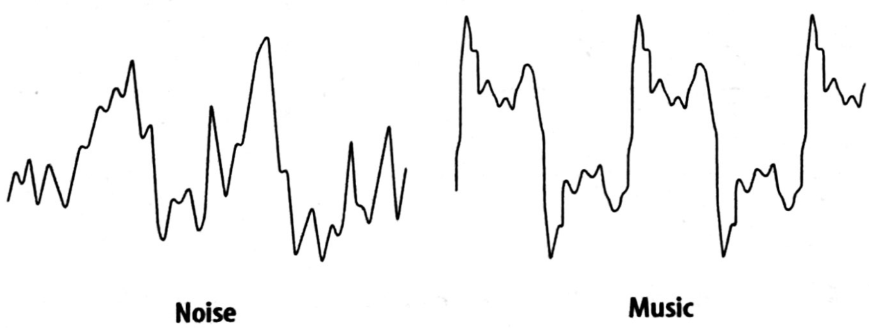


Read to Learn

What is music?

Turn on the radio to your favorite station and you hear music. Drop a plate on the kitchen floor and you hear noise. Music and noise are both groups of sounds. Why do humans hear some sounds as music and others as noise?

The answer is that music and noise have different patterns of sound. **Music** is a group of sounds put together on purpose to make a regular pattern. Look at the figure below. The wave pattern on the left shows noise. It has no regular pattern. The wave on the right shows the wave pattern of a piece of music. Notice that the pattern repeats itself. The sounds that make up music usually have a regular pattern of pitches, or notes. Some natural sounds also have regular patterns. That is why sounds like rain on a roof or birds singing may sound musical to some people.



How is music made?

Music is made by vibrations. Your vocal cords vibrate when you sing. When you play a guitar, the strings vibrate. When you beat a drum, the drumhead vibrates. ☑

Tap a bell with a hard object and the bell makes a sound. Tap another bell that has a different size or shape and you will hear a different sound. The bells sound different because each bell vibrates at different frequencies.

The frequencies at which a bell vibrates depend on the bell's shape and the material it is made from. The certain frequencies at which an object vibrates are called its **natural frequencies**.

How are natural frequencies used in music?

When an object is struck or plucked, it vibrates at one or more natural frequencies. The natural frequencies of any object depend on its size, shape, and the material it is made from. Musical instruments use the natural frequencies of strings, drumheads, and air inside pipes to produce different musical notes. ☑

What is resonance?

Sometimes sound waves can make an object vibrate. When a tuning fork is struck, it vibrates at its natural frequency and produces a sound wave. The sound wave has the same frequency as the natural frequency of the tuning fork.

Suppose you have two tuning forks that have the same natural frequency. You strike one tuning fork. The sound waves it makes strike the other tuning fork. These sound waves cause the tuning fork that was not struck to absorb energy and vibrate. This is an example of resonance. **Resonance** happens when an object is made to vibrate at its natural frequencies by absorbing energy from a sound wave or another object vibrating at these frequencies.

How do musical instruments use resonance?

Musical instruments use resonance to make their sounds louder. If a vibrating tuning fork is placed against a table, the sound waves made by the tuning fork may make the table resonate, or vibrate at the same frequency. The vibrations of the tuning fork and the table combine. This makes the sound louder.

☑ Reading Check

1. **Explain** how music is made.

____

____

☑ Reading Check

2. **List** the three things the natural frequencies of an object depend on.

____

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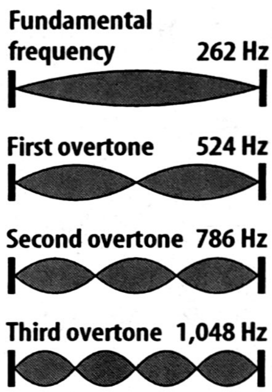
Overtones

The same note played on different instruments sounds different even though it has the same pitch. Why? A tuning fork produces a single frequency called a pure tone. Musical instruments do not produce pure tones. Most objects vibrate at more than one natural frequency, so they produce sound waves of more than one frequency.

If you play one note on a guitar, the pitch you hear is the lowest frequency produced by the vibrating string. The **fundamental frequency** is the lowest frequency produced by a vibrating object. The string also vibrates at higher frequencies. **Overtones** are the frequencies higher than an instrument's fundamental frequency. The figure below shows that overtones are multiples of the fundamental frequency. The different overtones produced by each musical instrument make them sound different from each other.



Think it Over

3. **Think Critically** Why does a note played on a piano sound different than the same note played on a guitar?

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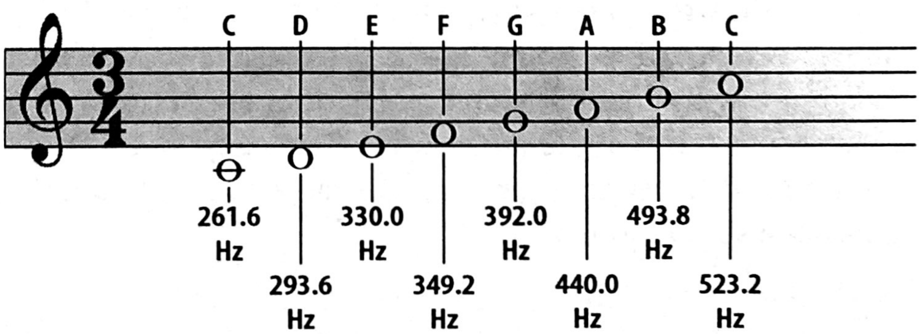
Musical Scales

A musical instrument produces musical sounds. The sounds often are part of a musical scale that is a series of notes with certain frequencies. The figure below shows a sequence of notes from a musical scale. Notice that the frequency of the eighth note in the scale is twice that of the first note. The frequency doubles every eight notes.



Applying Math

4. **Calculate** the frequency of the next C note in the sequence shown in the figure.

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Stringed Instruments

A piano, a violin, and a guitar are all stringed instruments. Stringed instruments produce music by making strings vibrate. Piano strings are struck. A bow is slid across violin strings. Guitar strings are plucked.

Strings for these instruments often are made of wire. The pitch of a note depends on the length of the string, the thickness of the string, and how tight the string is. Shorter, narrower, or tighter strings produce higher pitches. For example, a thinner guitar string produces a higher pitch than a thicker string.

How do stringed instruments use resonance?

A vibrating string usually produces a soft sound. To make the sound louder, most stringed instruments have a hollow space that contains air. This space is called a resonator. The resonator absorbs energy from the vibrating strings. Then, it begins to vibrate at its natural frequencies. ☑

For example, the body of a guitar is a resonator. It makes the vibrating strings sound louder. When a guitar is played, the strings vibrate. The vibrating strings make the guitar's body and the air inside it resonate. The vibrating guitar strings sound louder, just as the vibrating tuning fork that was placed against a table sounded louder.

✔ Reading Check

5. **Explain** What makes the sound of stringed instruments louder?

____

Percussion

You have to strike a percussion instrument to make a sound. Drums are percussion instruments. When you strike a drumhead, it vibrates. The vibrating drumhead is attached to a hollow chamber filled with air. The chamber resonates and makes the sound louder.

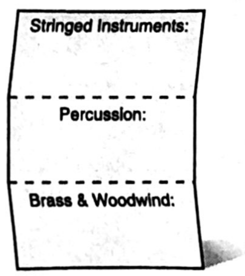
Can you change the pitch of a drum?

Some drums have a fixed pitch, but some can be tuned to play different notes. If the drumhead is tightened, the natural frequency of the drumhead is increased. The pitches produced by the drum get higher. A steel drum plays different notes in the scale when you hit different areas in the drum.

A xylophone is another percussion instrument. It is made of wood or metal bars of different lengths. You strike these bars when you play a xylophone. The longer the bar is, the lower the note it produces when it is struck.

FOLDABLES™

C Classify Make the following Foldable to organize musical instruments into groups. Give examples of instruments and how they make music.



Brass and Woodwinds

Brass and woodwind instruments, like those in the figure below, are made of one or more pipes of different lengths. The pipes can be straight or twisted. The pipes contain columns of air. The columns of air have different natural frequencies. Music is made when the air in an instrument vibrates at different frequencies. ☑

Reading Check

6. **Identify** What vibrates inside the pipes of a brass instrument?

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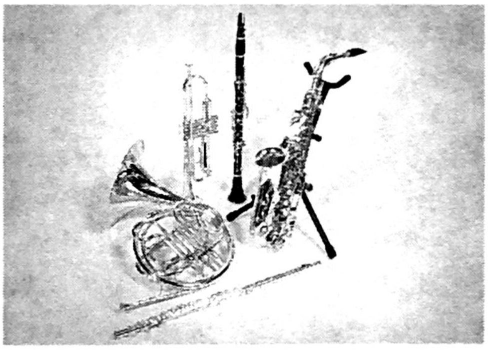


There are different ways to make the air column vibrate. To play a brass instrument like a trumpet, a musician vibrates the lips and blows into the mouthpiece. The air column vibrates and a note sounds on the trumpet.

Some woodwind instruments, like clarinets, saxophones, and oboes, use one or two reeds to make sounds. The reeds vibrate when the musician blows on them. This makes the air column vibrate and you hear a note. Flutes also are woodwind instruments. To play the flute, a musician blows across a small opening in the instrument to make the air column vibrate.

How do you change pitch in woodwinds?

To change a note played on a woodwind, a musician changes the length of the vibrating air column. If the length of the vibrating air column is made shorter, the pitch of the sound goes higher. Musicians change the length of the vibrating column of air by closing and opening finger holes along the instrument.

Think it Over

7. **Infer** If you made the column of air in a woodwind instrument longer, what would happen to the pitch?

____

____

How is pitch changed in brass instruments?

Musicians playing a brass instrument can blow harder to change the pitch of a sound. Blowing harder makes the air column resonate at a higher natural frequency. This makes the pitch higher. Another way to change the pitch is by pressing valves that change the length of the tube.

Beats

Interference happens when two waves overlap and combine to make a new wave. The new wave can have a different frequency, wavelength, and amplitude than the two original waves.

Suppose two notes close in frequency are played at the same time. The two notes interfere to make a new sound. The new sound gets louder and softer several times each second. If you were listening to the sound, you would hear a series of beats as the sound got louder and softer. The number of beats you would hear each second is called the beat frequency. The beat frequency is equal to the difference in the frequencies of the two notes.

Suppose the frequency of the first note is 329 Hz and the frequency of the second note is 332 Hz. The beat frequency is the difference in these two frequencies, or 332 Hz − 329 Hz. The beat frequency is 3 Hz. That means you would hear the sound get louder and softer three times each second. In other words, you would hear three beats each second.

What are beats used for?

In music, beats are used to help tune instruments. To tune a piano, a piano tuner might hit a tuning fork that vibrates at a certain frequency. The piano tuner then hits the key on the piano that makes a note of the same frequency. Beats are heard if the pitch of the note from the piano is different from the pitch of the tuning fork. When the piano string is tuned correctly, the beats disappear.

Reverberation

You have learned that sound reflects off hard surfaces. If you stand in an empty gym and speak in a loud voice, the sound of your voice will be reflected back and forth several times. The sound of your voice will bounce off the floor, walls, and ceiling. It will reverberate. Repeated echoes of sound are called **reverberation**. ☑

In the gym, reverberation makes the sound of your voice stay for awhile before the sound dies out. Some reverberation makes voices and music sound lively. Not enough reverberation makes sounds flat and lifeless. But sometimes, reverberation can produce a confusing mess of noise. This happens when too many sounds stay for too long.

Applying Math

8. **Calculate** What is the beat frequency between a note with a frequency of 293 Hz and a note with a frequency of 295 Hz?

____

✔ Reading Check

9. **Describe** What do you hear when you hear repeated echoes of sound?

____

How is reverberation controlled?

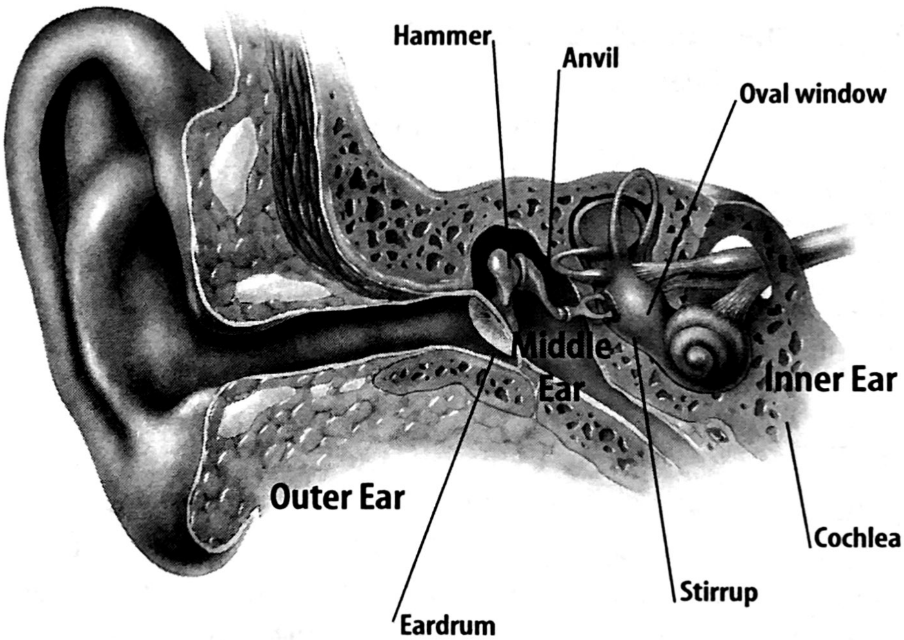
Concert halls and theaters are designed to produce just the right amount of reverberation. Sometimes the walls, floors, and ceiling are covered with soft materials. This reduces echoes. Sometimes special panels are put on walls or hung from the ceiling. These panels are designed to reflect sound toward the audience.

The Ear

You hear sounds with your ears. Your ear is an organ that can hear sounds of many different frequencies. It can hear sounds from about 20 Hz to 20,000 Hz. Your ear can also hear very loud sounds and very soft sounds. The softest sounds you can hear have about one trillionth the amount of energy as the loudest sounds you can hear. The figure below shows a human ear. It has three parts—the outer ear, the middle ear, and the inner ear.

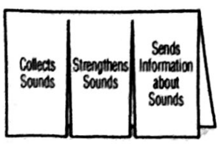
Picture This

10. Identify Highlight the ear canal in the figure.



FOLDABLES™

D Make Drawings Make the following Foldable to show how the ear works. Draw the parts of the ear under the tabs. Label each part.



What does the outer ear do?

Your outer ear collects sound waves. Then, it directs the sound waves into the ear canal. Look at the figure again. Notice that the outer ear looks something like a funnel. This shape helps it collect the sound waves.

How do animals collect sounds?

Some animals use their ears to find food or to keep away from danger. These animals often have large outer ears. A barn owl uses its ears to hunt for food at night. Its outer ears are not made of flesh. The feathers on the owl's face help direct the sound to its ears. Sea mammals hear very well even though their outer ears are small holes.

What does the middle ear do?

When sound waves reach the middle ear, they make the eardrum vibrate. The **eardrum** is a thin skin-like structure, or membrane, that stretches across the ear canal like a drumhead. When the eardrum vibrates, it makes the three small bones next to it vibrate. These bones are connected to each other. They are called the hammer, the anvil, and the stirrup. These bones make the vibrations stronger. ☑

Reading Check

11. **Identify** What vibrates when sound waves reach the middle ear?

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What does the inner ear do?

The stirrup vibrates another membrane. This membrane is called the oval window. The inner ear begins at the oval window. The inner ear is filled with fluid. The fluid vibrates when the vibrations from the middle ear reach the inner ear. When the fluid vibrates, it makes special hair-tipped cells inside the cochlea vibrate.

Different sounds vibrate these cells in different ways. The cells send signals with information about the sound's frequency and strength. The cells also send information about how long a sound lasts. The signals travel to the brain along the auditory nerve. They go to the part of the brain that is responsible for hearing.

Hearing Loss

Some diseases can damage your ears. Loud sounds also can damage your ears. If you listen to loud sounds for long periods of time, the sounds can damage the hair cells in the cochlea. These hair cells may die if they are damaged. You cannot grow new hair cells. When the hair cells die, some of your hearing is lost. ☑

As people get older, they can lose their hearing. Some hair cells and nerves in the ear stop working properly. About 30 percent of people older than 65 have some hearing loss due to aging.

Reading Check

12. **Explain** why listening to loud sounds for a long time can damage your hearing.

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● After You Read

Mini Glossary

eardrum: a very thin layer of skin that stretches across the ear canal like a drumhead

fundamental frequency: the lowest frequency made by a vibrating object

music: a group of sounds put together on purpose to make a regular pattern

natural frequencies: the certain frequencies at which an object vibrates

overtones: the frequencies higher than an instrument's fundamental frequency

resonance: happens when an object is made to vibrate at its natural frequencies by absorbing energy from a sound wave or another object vibrating at these same frequencies

reverberation: repeated echoes of sound

1. Review the terms and their definitions in the Mini Glossary. Use the terms *music* and *eardrum* in a sentence together.

____

____

____

2. Write the letter of the statement in Column 2 that best matches the term in Column 1.

Column 1	Column 2
______ **1.** music	**a.** used by musical instruments to make their sounds louder
______ **2.** musical scale	**b.** part of the ear that collects sounds
______ **3.** outer ear	**c.** percussion instrument
______ **4.** resonance	**d.** organized sound
______ **5.** xylophone	**e.** a series of notes
______ **6.** hair cells	**f.** send signals about a sound to the brain

3. How could you show a younger student what reverberation is?

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End of Section

Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about music.

chapter 3 Electromagnetic Waves

section 1 The Nature of Electromagnetic Waves

Before You Read

What do you think of when you hear the word *wave*?

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What You'll Learn

- how electromagnetic waves are made
- what electromagnetic waves are like

Read to Learn

Waves in Space

When you are at the beach, you may enjoy swimming or surfing in the ocean waves. Did you know that you are also enjoying another type of wave when you are at the beach? You can feel the warmth of the Sun on your skin. You can see its brightness with your eyes. The energy from the Sun that you can feel and see comes to you in the form of waves. These waves are a lot like those that bring you TV and cell phone signals. These are the same type of waves that a dentist uses to take X rays.

How is energy moved by waves?

A wave moves or transfers energy from one place to another without transferring matter. How do waves transfer energy? Waves, like water or sound waves, transfer energy by making particles of matter move. Energy passes from particle to particle when the particles bump into each other. Waves that use matter to transfer energy are called mechanical waves.

The space between the Sun and Earth is almost empty. How can the Sun's energy reach Earth if there is no matter to transfer the energy? A different type of wave called an electromagnetic wave is what carries energy from the Sun to Earth. An **electromagnetic wave** is a wave of charged particles that can travel through empty space or through matter.

Mark the Text

Underline New Ideas Look for words or sentences that you do not understand. Underline them. When you finish reading, ask a classmate or your teacher to help you understand the things you underlined.

Forces and Fields

Electromagnetic waves are made of two parts—an electric field and a magnetic field. These fields are force fields. A force field is what lets one object put forces on another object without the objects touching. Earth is surrounded by a force field called the gravitational field. This field exerts or puts the force of gravity on all objects that have mass. ☑

How does Earth's force field work? When you throw a ball into the air, it always falls back to Earth. That is because the force of gravity pulls down on the ball. Gravity pulls on the ball when it is still in your hand. It pulls on the ball when it is flying through the air. Earth's gravitational field even goes out into space. Earth's gravitational field is what keeps the Moon orbiting Earth.

✔ Reading Check

1. **Explain** What does a force field do?

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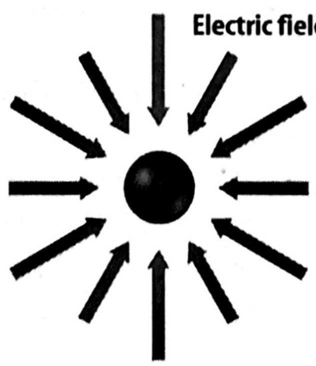
What are magnetic fields?

Have you ever played with magnets? You may know they come together, or attract each other, without touching. They also push each other apart, or repel, without touching. Two magnets put forces on each other without touching because they are surrounded by a force field called a magnetic field. Remember how a gravitational field exerts a force on anything with mass? A magnetic field exerts a force on another magnet or magnetic materials. Magnetic fields cause other magnets to line up along the direction of the magnetic field.

What are electric fields?

Remember that atoms contain protons, neutrons, and electrons. Protons and electrons have a property called electric charge. Protons have a positive electric charge. Electrons have a negative electric charge.

A particle with electric charge is surrounded by an electric field, just like a magnet is surrounded by a magnetic field. The figure shows a charged particle. The arrows show the force put on the particle by the electric field.



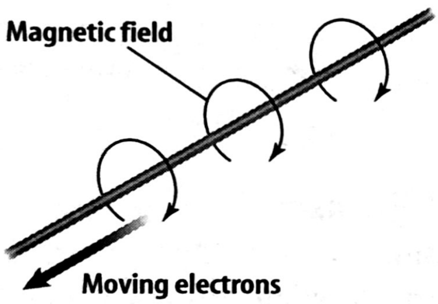
Picture This

2. **Identify** Which of these could be the charged particle in the figure?
   - **a.** a neutron
   - **b.** a wave
   - **c.** a field
   - **d.** an electron

Making Electromagnetic Waves

An electromagnetic wave is made of electric and magnetic fields. How is this kind of wave produced? Think about a wave on a rope. You can make a wave on a rope by shaking one end of the rope up and down. An electromagnetic wave is produced when charged particles, such as electrons, move back and forth or vibrate.

You know that a charged particle is surrounded by an electric field. But, a charged particle that is moving also is surrounded by a magnetic field. For example, electrons flow in a wire that carries an electric current. Because of this, the wire is surrounded by a magnetic field as shown in the figure below. So, a moving charged particle is surrounded by an electric field and a magnetic field.

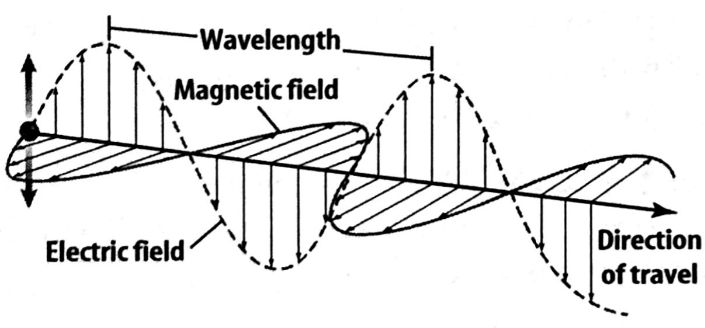


Picture This

3. Identify Highlight the direction the electrons are moving in the figure. Use another color to highlight the magnetic field.

How are electromagnetic waves produced?

When you shake a rope up and down, you make a wave that moves away from your hand. When a charged particle vibrates up and down, it makes changing electric and magnetic fields that move away from the vibrating charge in many directions. These changing fields form an electromagnetic wave. The figure below shows how electric and magnetic fields change as they move along one direction.



Picture This

4. Interpret Data What fields produce electromagnetic waves?

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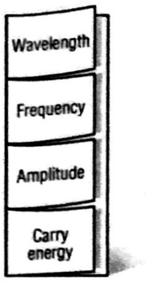
FOLDABLES™

A Organize Information Make the following Foldable to help you organize information about electromagnetic waves.



Picture This

5. **Label** a crest and a trough on the wave in the figure.

✔ Reading Check

6. **Describe** What causes a charged particle to move when it is struck by an electromagnetic wave?

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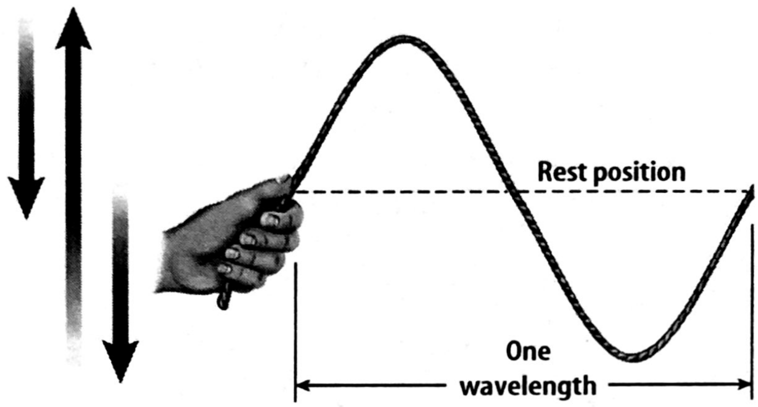
____

Properties of Electromagnetic Waves

Like all waves, an electromagnetic wave has a wavelength and a frequency. You can make a wave on a rope when you move your hand up and down while holding the rope. Look at the figure. Frequency is how many times you move the rope up and back down in 1 s. Wavelength is the distance from one crest to the next or from one trough to the next.



Wavelength and Frequency An electromagnetic wave is made by a vibrating charged particle. When the charged particle makes one complete vibration, one wavelength is made. Look at the figure on the previous page. The frequency of an electromagnetic wave is the number of wavelengths that pass by a point in 1 s. This is the same as the number of times the charged particle makes one complete vibration in 1 s.

Energy The energy carried by an electromagnetic wave is **radiant energy**. What happens if an electromagnetic wave hits a charged particle? The electric field part of the wave exerts a force on the particle and causes it to move. Some of the radiant energy carried by the wave is transferred into the energy of motion of the particle. ✔

How much energy an electromagnetic wave carries depends on its frequency. The higher the frequency of an electromagnetic wave, the more energy it has.

The Speed of Light All electromagnetic waves travel through space at the same speed, about 300,000 km/s. This speed sometimes is called the speed of light.

● After You Read

Mini Glossary

electromagnetic wave: a wave of moving charged particles that can travel through empty space or through matter

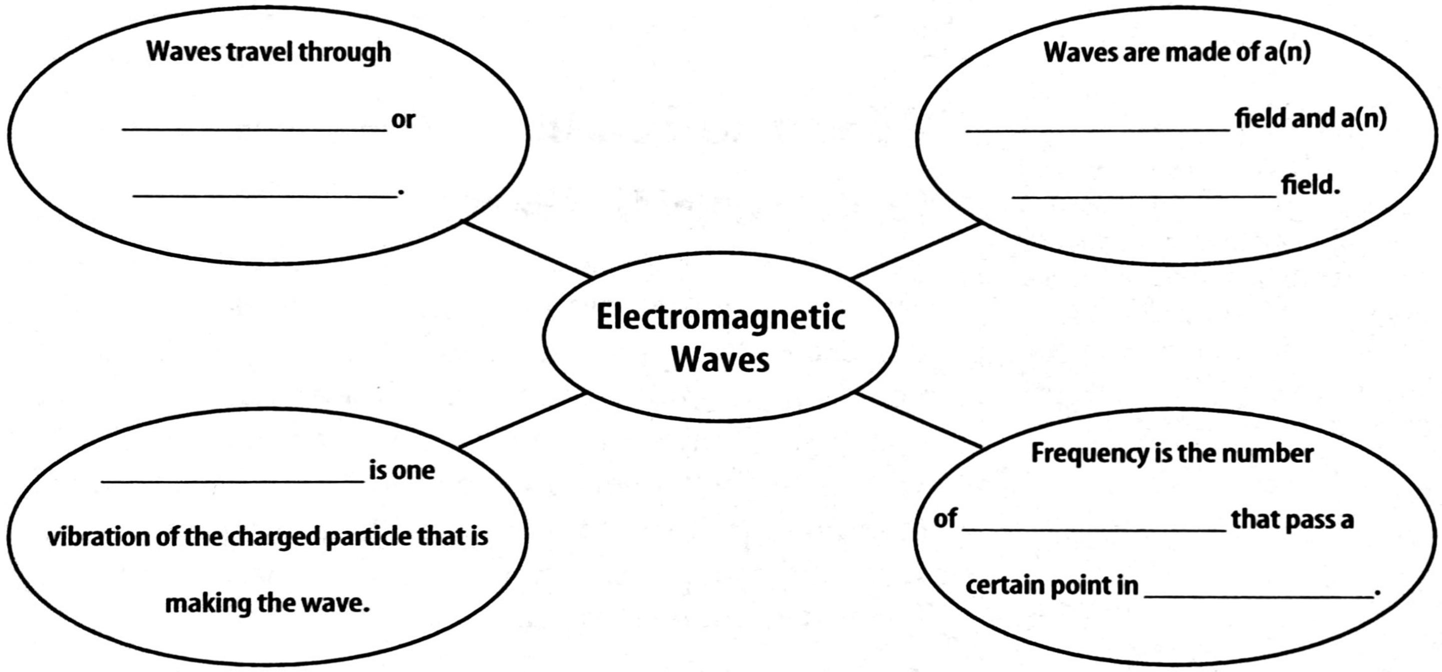
radiant energy: the energy carried by an electromagnetic wave

1. Review the terms and their definitions in the Mini Glossary. Use the terms *radiant energy* and *electromagnetic wave* to describe why you can feel the warmth of the Sun.

____

____

2. Fill in the blanks in the concept map below to describe electromagnetic waves.



3. At the beginning of the section, you were asked to underline words or sentences that you did not understand. How did this help you learn the material?

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Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about the nature of electromagnetic waves.

End of Section

chapter 3 Electromagnetic Waves

section 2 The Electromagnetic Spectrum

What You'll Learn

- the differences among kinds of electromagnetic waves
- uses for different kinds of electromagnetic waves

Before You Read

What happens when you stay in the sun too long without sunscreen? Why do you think this happens?

____

____

Study Coach

Make Flash Cards For each paragraph you read, think of a question your teacher might ask on a test. Write the question on one side of a flash card. Then, write the answer to the question on the other side. Quiz yourself until you know the answers.

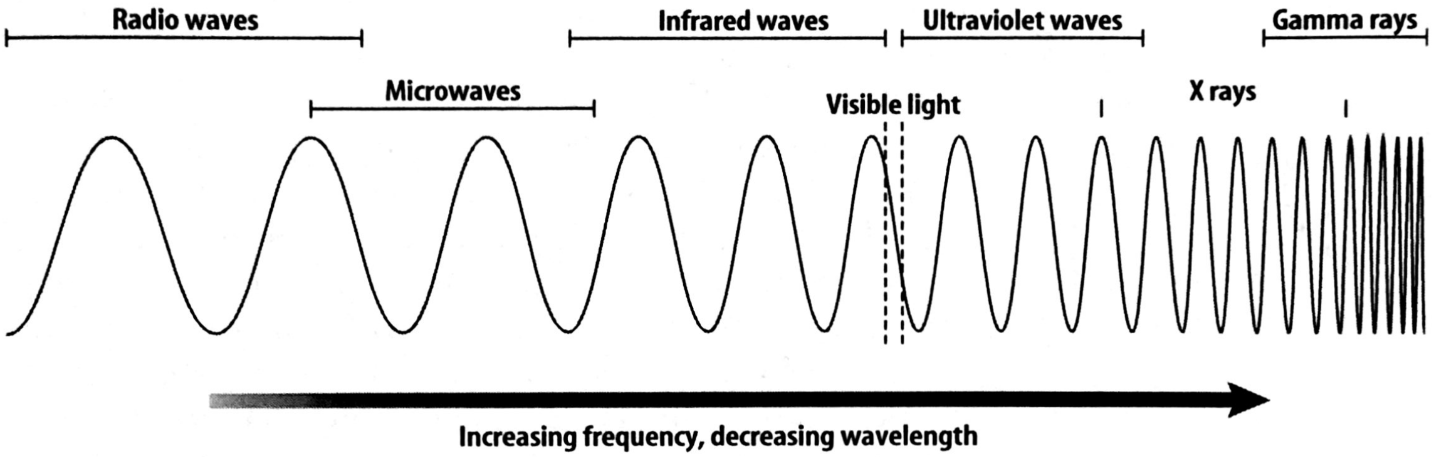
Read to Learn

Electromagnetic Waves

The room you are sitting in is filled with electromagnetic waves. These waves have many different wavelengths and frequencies. You cannot see many of these waves. TV and radio stations send electromagnetic waves that are invisible. They pass through walls and windows. These waves have wavelengths from about 1 m to over 500 m. Light waves are electromagnetic waves that you can see. They have wavelengths more than a million times shorter than those broadcast by radio stations.

How are electromagnetic waves grouped?

The **electromagnetic spectrum** is the wide range of electromagnetic waves with different wavelengths and frequencies. The electromagnetic spectrum is divided into different parts. Look at the figure at the top of the next page. It shows the electromagnetic spectrum and the names of the different waves that make up different parts of the spectrum. Even though electromagnetic waves have different names, they all travel at the same speed in empty space—the speed of light. Remember that for waves that travel at the same speed, the frequency increases as the wavelength decreases. So, as the frequency of electromagnetic waves increases, their wavelength decreases.



Radio Waves

Electromagnetic waves with wavelengths longer than about 0.3 m are called radio waves. **Radio waves** have the lowest frequencies of all the electromagnetic waves. They also carry the least energy. Television signals and AM and FM radio signals are types of radio waves. Like all electromagnetic waves, radio waves are produced by moving charged particles. One way to make radio waves is to make electrons vibrate in a piece of metal. This piece of metal is called an antenna. The moving electrons in an antenna cause radio waves to move outward from the antenna. By changing how fast the electrons in the antenna vibrate, radio waves of different frequencies can be made.

How are radio waves received?

Radio waves can cause electrons in another antenna to vibrate. Vibrating electrons in a receiving antenna form an alternating electric current. This current can be used to produce a picture on a TV screen and sound from a loudspeaker. Changing the frequency of the waves changes the alternating current in the receiving antenna. This produces the different pictures and sounds you hear on your TV. ☑

What are microwaves?

Radio waves with wavelengths from about 0.3 m to 0.001 m are called microwaves. Microwaves have a higher frequency and shorter wavelength than the waves used in your home radio. Cellular and portable phones use microwaves.

Microwave ovens use microwaves to heat food. The microwaves cause water molecules in food to vibrate. As the molecules vibrate faster, the food becomes warmer.

Picture This

1. **Interpret** What type of electromagnetic waves have the shortest wavelength?

____

✔ Reading Check

2. **Describe** What happens when radio waves cause electrons in an antenna to vibrate?

____

____

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What is radar?

Some animals, like bats, use echolocation. In echolocation, sound waves are sent out and bounce off objects. The reflected sound waves help determine the size and location of objects. Radar uses electromagnetic waves to detect objects in this way. Radar stands for RAdio Detecting And Ranging. Radar was first used in World War II to find enemy aircraft.

A radar station sends out radio waves that bounce off objects such as aircraft. Electronic equipment receives the reflected signals. The equipment measures the time it takes for the waves to return. Because the speed of the radio waves is known, the distance to the airplane can be found from the measured time. Electromagnetic waves travel so fast that this process takes less than one second. ☑

✔ Reading Check

3. Identify What is known about radio waves that helps measure distance?

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Infrared Waves

Have you ever stood close to a fireplace to warm up? It does not take long to feel the heat from the glowing fire. You can also warm up by standing next to a hot object that is not glowing. The heat you feel is from electromagnetic waves called infrared waves. **Infrared waves** are electromagnetic waves with wavelengths between about one thousandth and 0.7 millionths of a meter.

All objects send out electromagnetic waves. In any material, the atoms and molecules are always moving. The electrons in the atoms and molecules also vibrate and send out electromagnetic waves. Most electromagnetic waves given off by an object at room temperature are infrared waves. They have wavelengths of about 0.000 01 m, or one hundred thousandth of a meter.

Infrared detectors can detect infrared waves from objects that are warmer or cooler than their surroundings. Forests are usually cooler than their surroundings. Infrared detectors on satellites can be used to map forests, water, rock, and soil. Some types of night vision devices use infrared detectors. They make it possible for objects to be seen in nearly total darkness.

Think it Over

4. Infer Why are pit vipers able to hunt at night?

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How do animals use infrared waves?

Some animals can detect infrared rays. Snakes called pit vipers have a pit between the nostril and the eye that detects infrared waves. These pits help them hunt at night by detecting the infrared waves their prey gives off.

Visible Light

Have you ever wondered why some hot objects glow? As an object gets warmer, its atoms and electrons vibrate faster and faster. The vibrating electrons produce electromagnetic waves with higher frequencies and shorter wavelengths. The object might glow if the temperature is high enough. Some of the electromagnetic waves the object gives off, or emits, can be seen. Electromagnetic waves you can see with your eyes are called **visible light**. ☑

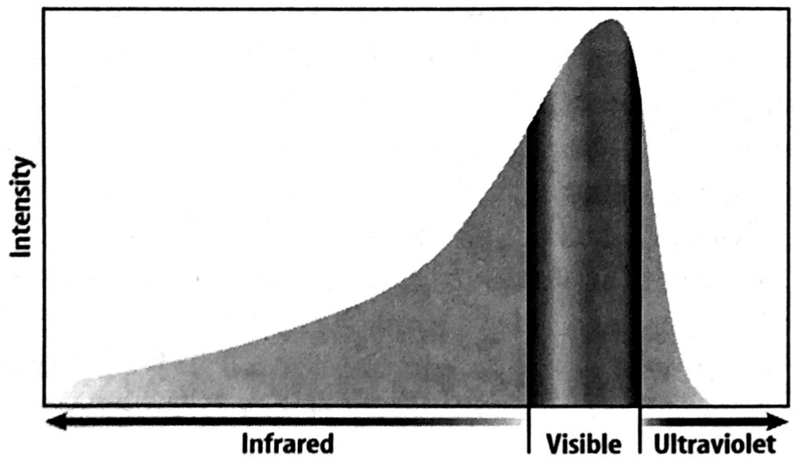
Visible light has wavelengths between about 0.7 and 0.4 millionths of a meter. The different colors you see are electromagnetic waves with different wavelengths. Red light has the longest wavelength. Blue light has the shortest wavelength. Most objects you see do not give off visible light. They reflect visible light from another source, such as the Sun or a lightbulb.

Ultraviolet Radiation

Ultraviolet radiation is higher in frequency than visible light and has even shorter wavelengths—between 0.4 millionths and about 10 billionths of a meter. Ultraviolet radiation also carries more energy. The radiant energy carried by an ultraviolet wave can damage or kill the molecules that make up living cells.

The figure below shows the intensity, or strength, of the electromagnetic waves from the sun. Most of the Sun's waves are infrared waves and visible light. But, too much exposure to the Sun's ultraviolet waves can cause sunburn. Exposure to these waves over a long period of time can cause the skin to age and might cause skin cancer. To protect your skin from ultraviolet waves, wear sunscreen and do not stay in the Sun too long.

Electromagnetic Waves from the Sun



Reading Check

5. **Describe** Why do some hot objects glow?

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Picture This

6. **Identify** Most of the electromagnetic waves emitted by the Sun are what type?

____

Is ultraviolet radiation helpful?

Your body uses ultraviolet radiation from the Sun to produce vitamin D. A few minutes of sunlight each day is enough to produce all the vitamin D your body needs. Human skin tans as protection against too much ultraviolet radiation. But, a tan can be a sign that the skin has received too much ultraviolet radiation.

Because ultraviolet radiation can kill cells, it is used to disinfect objects such as surgical instruments and goggles.

What is the ozone layer?

Ozone is a molecule that contains three oxygen atoms. It is formed high in Earth's atmosphere. The ozone layer absorbs most of the ultraviolet radiation from the Sun before it reaches Earth's surface.

Chemical compounds called CFCs can react with ozone molecules and break them apart. CFCs are used in some air conditioners and refrigerators. There is evidence that CFCs in the atmosphere reduce the ozone over Antarctica at certain times of the year. This reduction is known as the ozone hole. To prevent this, CFCs are being used less.

The atmosphere also absorbs other types of electromagnetic radiation. It absorbs higher energy waves like X rays and gamma rays. Radio waves, light waves, and some infrared waves can pass through the atmosphere.

Think it Over

7. Draw Conclusions Why is the ozone layer important to life on Earth?

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X Rays and Gamma Rays

Ultraviolet rays can go through, or penetrate, the top layer of your skin. **X rays** have an even higher frequency than ultraviolet rays and enough energy to go right through skin and muscle. A shield made out of a dense metal such as lead is needed to stop X rays.

Gamma rays have the highest frequency and carry the most energy. Gamma rays are the hardest to stop. They are produced by changes in the nuclei of atoms. In nuclear fusion, protons and neutrons bond together. In nuclear fission, protons and neutrons break apart. In both of these reactions, huge amounts of energy are released. Some of this energy is released as gamma rays.

The energy of X rays and gamma rays is much greater than ultraviolet rays. Like ultraviolet radiation, too much X-ray or gamma radiation can hurt or kill cells. This means that even small amounts of exposure can cause damage.

Think it Over

8. Explain Why do gamma rays have more energy than other forms of electromagnetic energy?

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How are X rays used?

Have you ever had an X ray? If so, you know that doctors can use X rays to see inside your body. X rays can pass through the less dense tissues of skin and muscle. X rays strike a film and leave shadow images of bones and denser tissues. Doctors use X-ray images to find injuries and diseases such as broken bones and cancer. A CT scanner uses X rays to produce images of the human body as if it had been sliced like a loaf of bread.

Like ultraviolet waves, X rays can be harmful to cells and tissue. One or two X rays are not harmful. However, a large number of X rays could be harmful to your body. X-ray machine operators usually stand behind shields to protect themselves. A patient who gets an X ray usually wears a lead apron or shield to protect the body parts that are not receiving the X ray.

How are gamma rays used?

Even though gamma rays are dangerous to living organisms, they have some helpful uses, just like X rays do. A beam of gamma rays can be used to kill cancerous tumors. Gamma rays can also kill disease-causing bacteria in food. More than 1,000 Americans die each year from *Salmonella* bacteria in poultry and *E. coli* bacteria in meat. Gamma radiation has been used since 1963 to kill bacteria in food. However, this method is not often used in the food industry.

Astronomy with Different Wavelengths

Astronomers use more than visible light to study objects in space. Some objects that produce no visible light can be found through X rays, infrared waves, or radio waves that they give off. Scientists use instruments that can detect many types of electromagnetic radiation to study these objects.

Recall that Earth's atmosphere blocks X rays, gamma rays, most ultraviolet rays, and some infrared rays. To study these types of radiation from space, scientists have to get above Earth's atmosphere. Satellites have been built for this. Three of these sattelites are the Extreme Ultraviolet Explorer (EUVE), the Chandra X-Ray Observatory, and the Infrared Space Observatory (ISO). ☑

Think it Over

9. Draw Conclusions Why do doctors use X rays only when necessary?

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Reading Check

10. Describe How are astronomers able to study X rays and gamma rays given off by objects in space?

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After You Read

Mini Glossary

electromagnetic spectrum: the wide range of electromagnetic waves with different wavelengths and frequencies

gamma rays: electromagnetic waves that have the highest frequency and carry the most energy

infrared waves: electromagnetic waves with wavelengths between about one thousandth and 0.7 millionths of a meter

radio waves: electromagnetic waves that have the lowest frequencies and carry the least energy

ultraviolet radiation: electromagnetic waves that are higher in frequency than visible light and have even shorter wavelengths—between 0.4 millionths and about 10 billionths of a meter

visible light: electromagnetic waves that you can see with your eyes

X rays: electromagnetic waves that have an even higher frequency than ultraviolet rays and enough energy to go right through skin and muscle

1. Review the terms and their definitions in the Mini Glossary. What are the two types of electromagnetic radiation that humans can sense?

____

2. In the table below, place the six types of electromagnetic radiation you learned about in this section in order from longest wavelength to shortest wavelength.

Types of Electromagnetic Radiation

3. Which type of harmful electromagnetic radiation are you exposed to most often? How can you protect yourself from too much exposure?

____

____

End of Section

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chapter 3

Electromagnetic Waves

section 3 Using Electromagnetic Waves

Before You Read

When was the last time you listened to the radio or watched TV? How often do you do these things each week?

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What You'll Learn

- the different ways of using electromagnetic waves to communicate
- the differences between AM and FM radio signals

Read to Learn

Telecommunications

You use electromagnetic waves each time you talk on the telephone, listen to the radio, watch TV, or do research on the Internet. Today you can talk to someone far away or send an email almost instantly. Communicating with electromagnetic waves is called telecommunications.

Using Radio Waves

Radio waves are used to send and receive information over long distances. Using radio waves to communicate has several advantages. Radio waves pass through walls and windows easily. They are not harmful to people like X rays and ultraviolet waves are. So, most telecommunication devices like radios, TVs, and telephones use radio waves to send and receive sounds and images.

How does radio transmission work?

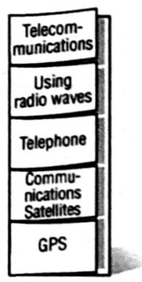
Radio and TV stations are given a frequency at which they broadcast radio waves. **Carrier waves** are the radio waves broadcast by a station at its assigned frequency. To receive the station's signals, you tune your radio or TV to the frequency of the station's carrier waves. The amplitude or frequency of the carrier wave is changed to send information.

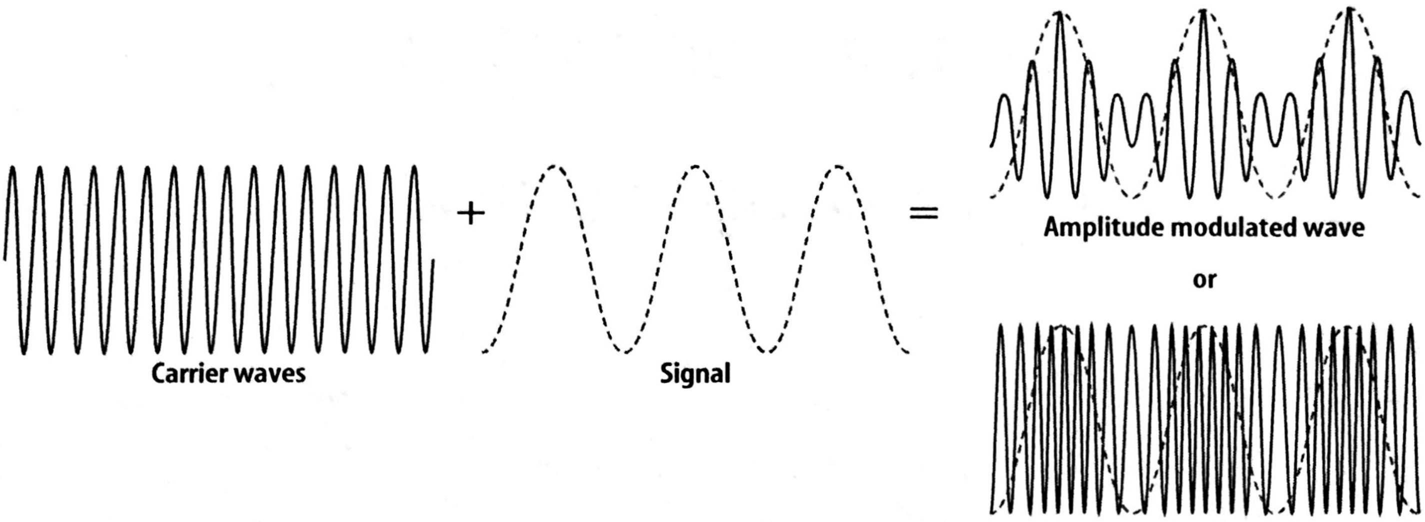
Study Coach

Identify the Main Point As you read, write down the main point under each heading in the text.

FOLDABLES™

B Organize Information Make the following Foldable to organize information about using electromagnetic waves.





Picture This

1. **Explain** Look at the figure above. How does the carrier wave change in an AM wave?

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✔ Reading Check

2. **Describe** What part of the carrier wave is changed in FM transmission?

____

What is amplitude modulation?

The letters *AM* in AM radio stand for amplitude modulation. In amplitude modulation, the amplitude of the carrier wave is changed to send information. The original sound is changed into an electrical signal. The electrical signal is used to vary the amplitude of the carrier wave. You can see an example in the figure above. The frequency of the carrier wave does not change—only the amplitude changes. In the receiver, the varying amplitude of the carrier waves produces an electric signal. The radio's loudspeaker uses the signal to produce the original sound.

What is frequency modulation?

FM stands for frequency modulation. FM radio works much the same way as AM radio. The difference is the frequency of the carrier wave is changed instead of the amplitude. You can see this in the figure at the top of the page. The FM receiver uses the varying frequency of the carrier wave to produce an electric signal. The radio's speaker converts the electric signal into sound waves. ☑

Telephones

Telephones change a sound wave into an electric signal. The signal travels through a wire to the telephone switching system. The electric signals may be sent through wires or changed to radio or microwave signals and sent through the air. The electric signal may also be changed to a light wave to be sent through fiber-optic cables. At the receiving end, the signal is changed back to sound waves.

How do wireless phones and pagers work?

Many phones do not use wires to send signals. Some use radio waves. Cordless phones change the electrical signal from the microphone of a telephone into a radio signal. The signal is sent to the base station of the telephone. The phone changes the electrical signals into sound waves. If you are receiving a call on a cordless telephone, the base station sends electrical signals to the phone. The phone changes the signals into sound waves. Cellular phones work the same way. But they work over distances of many kilometers. The base station uses a large antenna. The antenna communicates with the cell phone and with other base stations.

Pagers also use base stations. When you dial a pager, the signal is sent to a base station. The base station sends an electromagnetic signal to the pager. The pager receives the signal and beeps or vibrates to indicate that someone has called. You can also send information to a pager if you have a touch-tone phone. The pager receives and displays information such as your phone number.

Communications Satellites

How can radio signals be sent to the other side of the world? Radio signals cannot travel directly through Earth. Instead, radio signals are sent to satellites. The satellites can communicate with other satellites or with ground stations. Some satellites are designed to move at the same speed as Earth, so they are above the same place on Earth at all times. This is called geosynchronous (jee oh SIHN kroh nus) orbit.

The Global Positioning System

The **Global Positioning System**, or GPS, is a system of ground stations, satellites, and receivers that is used to locate objects on Earth. A GPS receiver measures the time it takes radio waves to travel from several satellites to the receiver. The receiver uses this information to find its latitude, longitude, and elevation. Handheld GPS receivers can give a location within a few hundred meters. Some GPS units are used to measure the movements of Earth's crust. They can measure the movement to within a few centimeters. ☑

Think it Over

3. **Explain** When you are using a wireless phone, you are really using a radio. Explain.

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Reading Check

4. **Identify** What is the purpose of the Global Positioning System?
   a. to locate satellites in space
   b. to locate objects on Earth
   c. to locate radios on Earth
   d. to communicate with other parts of Earth

After You Read

Mini Glossary

carrier waves: the radio waves broadcast by a station at its assigned frequency

Global Positioning System (GPS): a system of ground stations, satellites, and receivers that is used to locate objects on Earth

1. Review the terms and their definitions in the Mini Glossary. Write a sentence explaining how the carrier wave is changed in frequency modulation.

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2. In the space provided, give three examples of telecommunication devices that use radio waves. Then, describe how the device uses radio waves.

Example	Use of Radio Waves

3. Which form of telecommunication do you use most often? Explain.

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End of Section

Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about using electromagnetic waves.

chapter 4 Light, Mirrors, and Lenses

section 1 Properties of Light

Before You Read

When someone says the word *light,* what do you think of?

____

____

What You'll Learn
- about light waves
- how light behaves
- why objects have color

Read to Learn

What is light?

What happens when you drop a rock on the smooth surface of a pond? The rock makes a wave. You can see the wave spread out in a circle. A wave is a disturbance that carries energy through matter or space. The matter in this case is water. The energy comes from the rock hitting the water. As the ripples spread out, they carry some of the energy.

Light is another type of wave that carries energy. A light source is something that gives off light. Light bulbs and the Sun are light sources. Light sources give off light waves into space like the ripples in a pond. While ripples from a rock spread out only on the surface of a pond, light waves spread out in all directions from a light source.

Sometimes it is easier to think of light as a ray. A **light ray** is a narrow beam of light that travels in a straight line. A light source gives off many light rays that travel away from the source in all directions. ✔

How does light travel through space?

Waves on a pond need a material to travel through. The material through which a wave travels is a **medium**. Light is an electromagnetic wave. Electromagnetic waves can travel through empty space. They do not need a medium in which to travel. They also can travel through materials such as air, water, and glass.

Mark the Text

Highlight Highlight the words and phrases that you do not understand. When you finish reading, ask another student or your teacher to help you understand the things you highlighted.

✔ Reading Check

1. **Describe** How does a light ray travel?

____

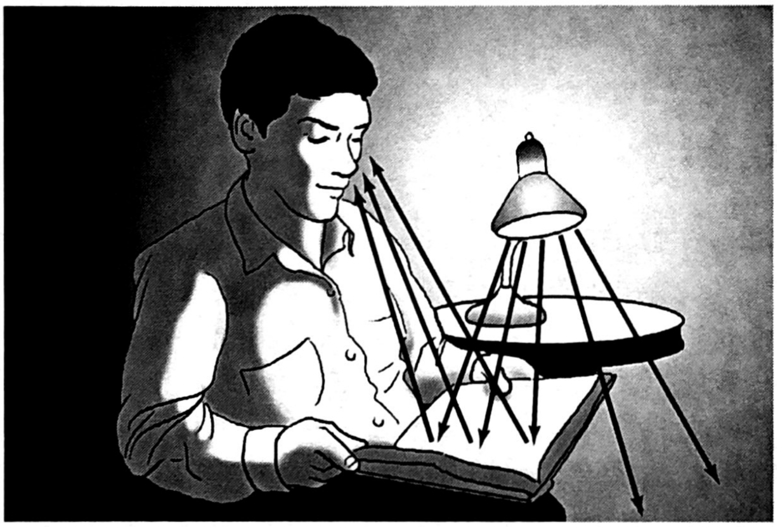
____

Light and Matter

What can you see in a dark room with no windows or lights? You cannot see anything until you turn on the lights or open the door to let in light from outside the room. Most objects around you are not light sources. For these objects to be seen, light from a light source bounces off the objects and into your eyes. The figure below shows how this works. The process of light hitting an object and bouncing off is called reflection. You can read the words on this page because of reflection. Light from a source reflects from the page and into your eyes. But, not all light rays reflected from the page go to your eyes. Light rays reflect in many directions.

Picture This

2. Identify Circle the light source in the figure.



What are opaque, translucent, and transparent objects?

Three things can happen to light waves that strike an object. Some of the waves are absorbed by the object, some are reflected by it, and some might pass through it. What happens to light when it strikes an object depends on what material the object is made of.

Materials that let no light pass through them are opaque (oh PAYK). You cannot see other objects through opaque materials. Materials that let almost all light pass through them are transparent. You can see other objects clearly through transparent materials. Examples of transparent materials are clear glass and clear plastic. Materials that let only some light pass through them are translucent (trans LEW sent). You can see objects through translucent materials, but not clearly. Waxed paper and frosted glass are translucent materials. ☑

Reading Check

3. Describe Which of the following best describes an object that you can see clearly through? Circle your answer.

a. opaque
b. transparent
c. translucent
d. opaque and translucent

Color

Light from the Sun looks white. But, it is really a mixture of colors. Each color of light is a light wave with a different wavelength. Red light waves have the longest wavelengths. Violet light waves have the shortest wavelengths. When white light passes through a prism, the light separates into different colors. When light waves from all the colors enter your eye at the same time, your brain sees the mixture as white.

Why do objects have color?

Why does grass look green and a rose look red? When white light hits an object that is not transparent, the object absorbs some of the light waves. The other light waves are reflected. If an object reflects red light waves and absorbs all the other waves, it looks red. If an object reflects only blue waves, it looks blue. An object that looks white reflects all of the light waves that strike it. Objects that look black absorb all light waves. ☑

What are the primary light colors?

White light is made up of red, orange, yellow, green, blue and violet light. But, there are many more colors. Humans can see thousands of colors, including brown, pink, and purple.

You can make almost any color light by mixing different amounts of red, green, and blue light. Red, green, and blue are known as primary light colors. Mix all three primary light colors together and you get white light. Mix red and green light to get yellow light. You see yellow because that is how your brain interprets the mixture of red and green. To your brain, a mixture of red and green light waves looks the same as yellow light made by a prism.

What are primary pigment colors?

Materials that are used to change the color of objects, like paint, are called pigments. Mixing pigments together forms colors in a different way than mixing colored light does.

The color of the pigment you see is the color of the light waves that are reflected from it. But, the primary pigment colors are not red, blue, and green. They are yellow, magenta, and cyan (SI an). The primary colors for light and pigments are different, but related. Yellow pigment absorbs blue light and reflects red and green light. Magenta pigment absorbs green light and reflects red and blue light. Cyan pigment absorbs red light and reflects blue and green light.

Reading Check

4. **Explain** What happens to light waves that strike an object that looks white?

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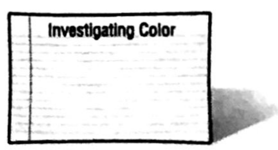
FOLDABLES™

A Organize Information
Use a half-sheet of notebook paper to help you organize information about color.



● After You Read

Mini Glossary

light ray: a narrow beam of light that travels in a straight line

medium: the material through which a wave travels

1. Review the terms and their definitions in the Mini Glossary. Explain the difference between light waves and waves caused by a rock tossed into a pond.

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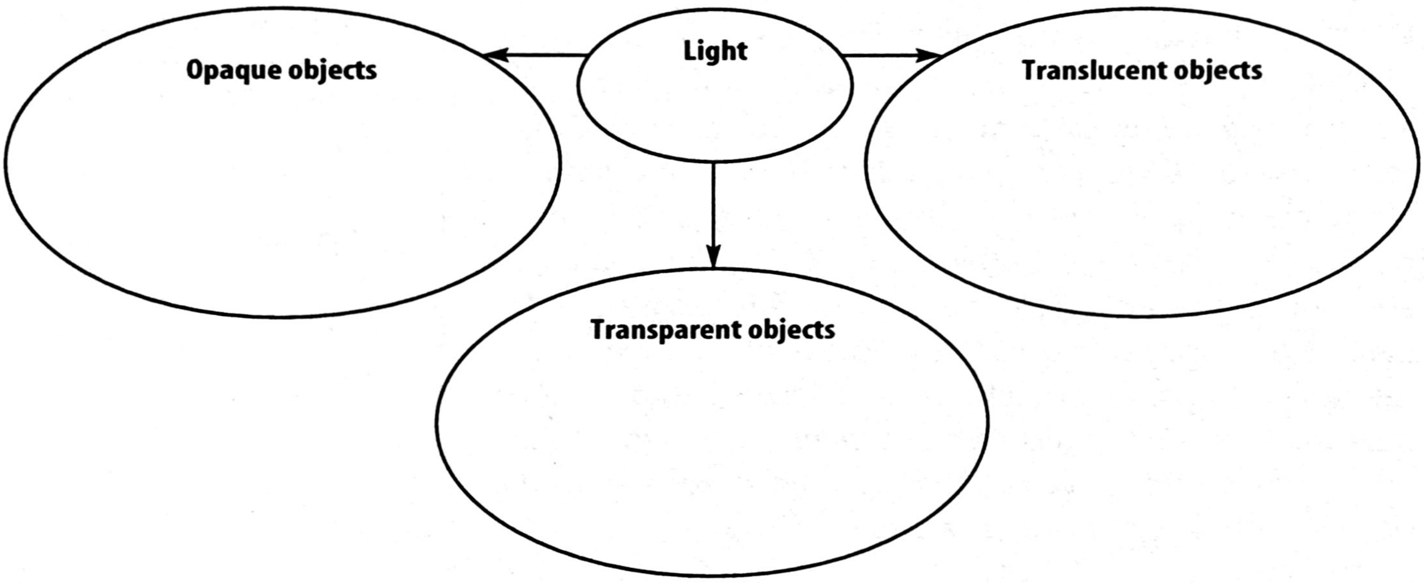
2. Fill in the graphic organizer below to compare and contrast what happens when light hits different types of materials.



3. At the beginning of the section, you were asked to highlight things that you did not understand. How did this help you learn the material?

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End of Section

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chapter 4 Light, Mirrors, and Lenses

section 2 Reflection and Mirrors

Before You Read

On the lines below, describe at least one way that you use a mirror.

____

____

What You'll Learn

- how light is reflected from rough and smooth surfaces.
- how mirrors work
- about concave and convex mirrors

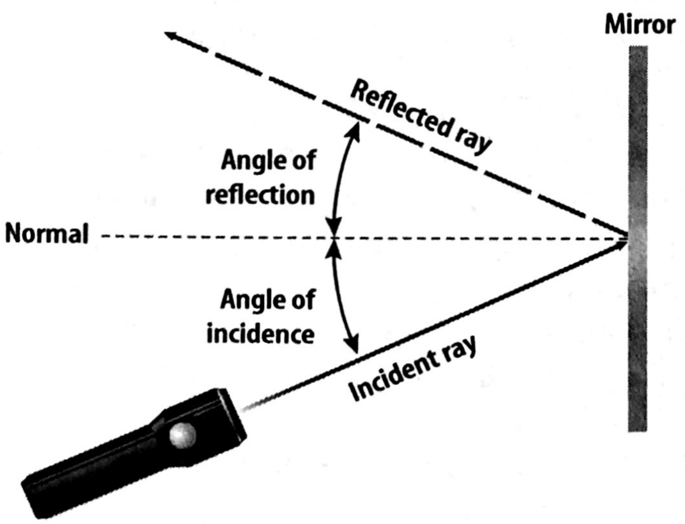
Read to Learn

Study Coach

Outline As you read, make an outline of this section. Use the headings of the section to make your outline. Write down the main points or ideas under each heading.

The Law of Reflection

Have you ever seen your reflection on the surface of a pond? You can see yourself because light reflects from the surface to your eyes. The figure below shows a light ray reflecting from a mirror. The normal is an imaginary line that is perpendicular to the surface where the light ray strikes. The angle between the incoming light ray and the normal is called the angle of incidence. The angle between the reflected light ray and the normal is called the angle of reflection. The **law of reflection** states that the angle of incidence is equal to the angle of reflection.



Picture This

1. **Determine** Look at the angles marked in the figure. If the angle of reflection measures 20 degrees, what is the measure of the angle of incidence?

____

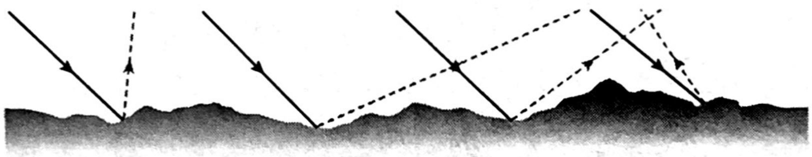
Reflection from Surfaces

Why can you see your reflection in some surfaces but not others? Why does a piece of metal make a better mirror than a piece of paper? Reflection depends on the smoothness of the surfaces.

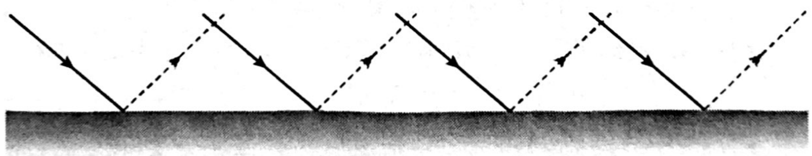
What are the types of reflection?

The surface of a piece of paper may seem smooth. But it is not as smooth as the surface of a mirror. If you look at the surface of the paper under a microscope, you would see how rough it is. Look at the first figure below. A rough surface causes light rays to reflect in many directions. This uneven reflection of light waves from a rough surface is called diffuse reflection.

Diffuse Reflection



Regular Reflection



Picture This

2. Describe the pattern of light rays and reflections in the second figure.

Smooth surfaces, like the one in the second figure, reflect light rays in a more regular way. Reflection from mirrors or other very smooth surfaces is called regular reflection. Light rays that are regularly reflected make the image you see in a mirror. Every light ray that strikes a surface obeys the law of reflection. It does not matter if the surface is rough or smooth.

How is light scattered?

Scattering of light happens when light rays traveling in one direction are made to travel in many different directions. Scattering also happens when light rays strike small particles, like dust. You may have seen dust particles floating in a beam of sunlight. The light rays in the sunbeam scatter in all directions when they strike a dust particle. These scattered light rays enter your eye. The dust particle looks like a bright speck of light to you.

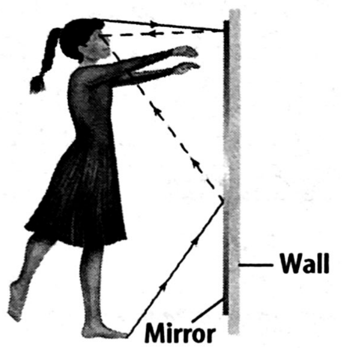
Think it Over

3. Explain What kind of surface causes light waves to scatter?

What is a plane mirror?

A plane mirror has a flat reflecting surface. Your image in a plane mirror looks like it would in a photograph. You and your image in a plane mirror are facing in opposite directions. Your left and right sides switch places on your mirror image. Your image also seems to be coming from behind the mirror.

The figure below shows a person looking into a plane mirror. Light rays from a light source strike each part of the person. These light rays bounce off the person. Some of these light rays strike the mirror and are reflected off the mirror. The figure shows the path of some of these light rays that have been reflected off the person and reflected back to the person's eye by the mirror.

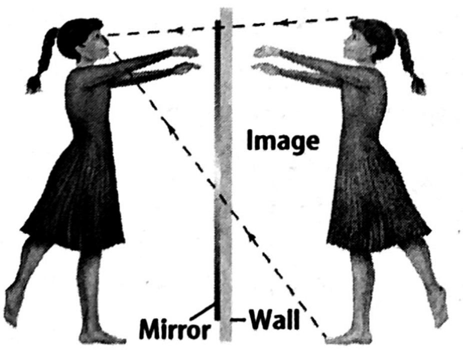


Picture This

4. Highlight Trace the path of the light rays.

How is an image formed in a plane mirror?

The image in a plane mirror seems to be behind the mirror because of the way your brain understands the light rays that enter your eyes. When the light rays bounce off the mirror's surface, your brain thinks they followed the path shown by the dashed lines in the figure below. Your brain thinks light rays travel in straight lines without changing direction. This makes reflected light rays look like they are coming from behind the mirror. The image also looks like it is the same distance behind the mirror as the person is in front of the mirror.



Picture This

5. Explain The dashed line shows where the light waves seem to be coming from. Where are they really coming from?

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Concave and Convex Mirrors

Some mirrors are not flat. A concave mirror has a surface that is curved inward, like the bowl of a spoon. Concave mirrors cause reflected light rays to come together, or converge.

A convex mirror has a surface that curves outward, like the back of a spoon. Convex mirrors cause reflected light rays to spread out, or diverge. Concave and convex mirrors form images that are different from the images that are formed by plane mirrors. To help you remember which is concave and which is convex, think of a concave mirror as caved in. ☑

Reading Check

6. Contrast Explain the difference between concave and convex mirrors.

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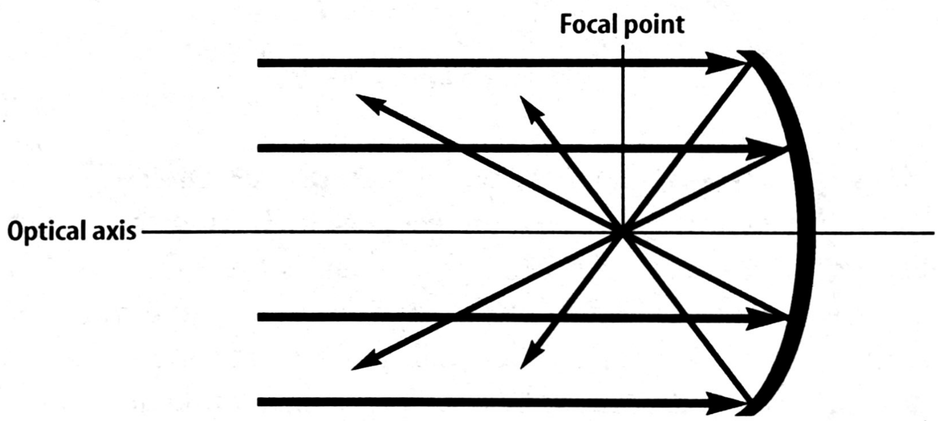
How do concave mirrors form images?

The figure below shows a concave mirror. The optical axis is a straight line drawn perpendicular to the center of the mirror. When light rays travel parallel to the optical axis and strike the mirror, they all reflect through the same point on the optical axis. The point on the optical axis that reflected light rays pass through is the **focal point.** The distance along the optical axis from the focal point to the center of the mirror is the **focal length.**

Picture This

7. Identify Use a highlighter to mark the focal length in the figure.



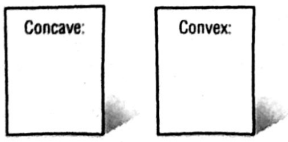
How does the focal point affect an image?

The image formed by a concave mirror depends on where the object is compared to the focal point. If the object is farther from the mirror than the focal point, the image looks upside down, or inverted. The size of this image becomes smaller as the object moves farther away from the mirror. If the object is closer to the mirror than the focal point the image is upright. This image gets smaller as the object moves closer to the mirror.

If a light source is placed at the focal point of a concave mirror, the mirror will produce a beam of light. Flashlights and car headlights use concave mirrors to produce beams of light.

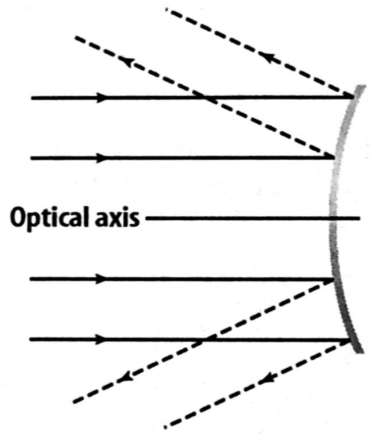
FOLDABLES™

B Compare and Contrast Use two quarter-sheets of notebook paper to help you compare and contrast concave and convex mirrors.

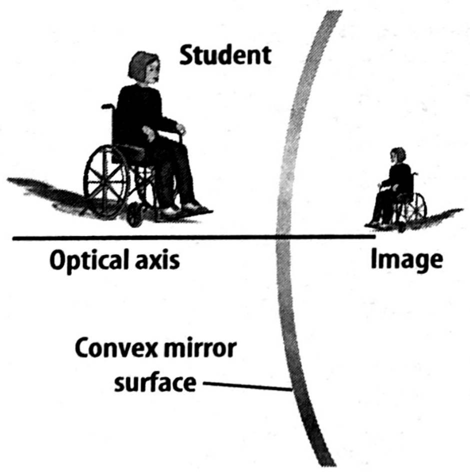


How do convex mirrors form images?

A convex mirror has a reflecting surface that curves outward. Convex mirrors cause light rays to spread out, or diverge, as shown in the figure below.



Images formed by convex mirrors are upright. They also seem to be behind the mirror like images in plane mirrors. But, convex mirrors are different from plane mirrors. As shown in the figure below, the image in a convex mirror is always smaller than the actual object. It does not matter how far away the object is.



How are convex mirrors used?

Since you can see a larger area reflected in a convex mirror than you can in other mirrors convex mirrors often are used as security mirrors in stores. Outside rearview mirrors on cars and trucks also are made from convex mirrors.

Picture This

8. **Explain** Why does a convex mirror not have a focal point?

___

___

___

Picture This

9. **Describe** How does the size of the image formed by a convex mirror compare to the size of the actual object?

___

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● After You Read

Mini Glossary

focal length: the distance along the optical axis from the focal point to the center of the mirror

focal point: the point on the optical axis that reflected light rays pass through

law of reflection: says that the angle of incidence is equal to the angle of reflection

1. Review the terms and their definitions in the Mini Glossary. Use the term *focal point* in a sentence or two to explain when the image in a concave mirror is inverted.

____

____

2. Fill in the table below about the images formed by different types of mirrors.

Type of Mirror	What does the mirror look like?	What kind of image is formed?
Plane		Image is upright.
Concave		If the object is past the focal point, the image is ____________. If the object is between the focal point and the mirror, the image is ____________.
Convex	Curved outward	Images are ____________ and ____________ than the object.

3. What objects in your house are examples of plane, concave, and convex mirrors?

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End of Section

Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about reflection and mirrors.

Light, Mirrors, and Lenses

section 3 Refraction and Lenses

Before You Read

Why do some people wear eyeglasses? What do eyeglasses do?

___

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What You'll Learn
- why light waves change direction
- how concave and convex lenses form images

Read to Learn

Bending of Light Rays

Have you ever looked at a glass of water with a straw in it? Did the water make the straw look like it was bent? Sometimes a penny in the bottom of a cup cannot be seen from the side until water is added. These things happen because light rays bend as they pass from one material to another. What causes light rays to change direction?

What is the speed of light and how does it change?

The speed of light in empty space is about 300 million meters per second (m/s). Light passing through air, water, or glass travels more slowly. This is because atoms that make up these materials slow the light waves down. The table below shows the speed of light in some different materials.

The Speed of Light Through Some Materials

Material	Speed of Light
Air	About 300 million m/s
Water	About 227 million m/s
Glass	About 197 million m/s
Diamond	About 125 million m/s

Study Coach

Identifying the Main Point As you read each paragraph, find the main point or main idea and write it down. When you finish reading, make sure you understand each main idea that you have written.

Applying Math

1. **Calculate** About how much faster is the speed of light through air than through glass?

___

___

___

The Refraction of Light Waves

Suppose you are looking at a straw in a glass of water. Light waves from the part of the straw that is underwater travel through water, glass, and air before they reach your eyes. The speed of light is different in each of these materials.

What happens to a light wave when it travels from one material into another? If the light wave is traveling at an angle to the boundary between the two materials, it changes direction, or bends. This bending happens because the speed of the light wave changes when it passes from one material into the other. The bending of light waves due to a change in speed is called refraction. The greater the change in speed, the more the light wave bends, or refracts. ☑

☑ Reading Check

2. Explain What is refraction?

____

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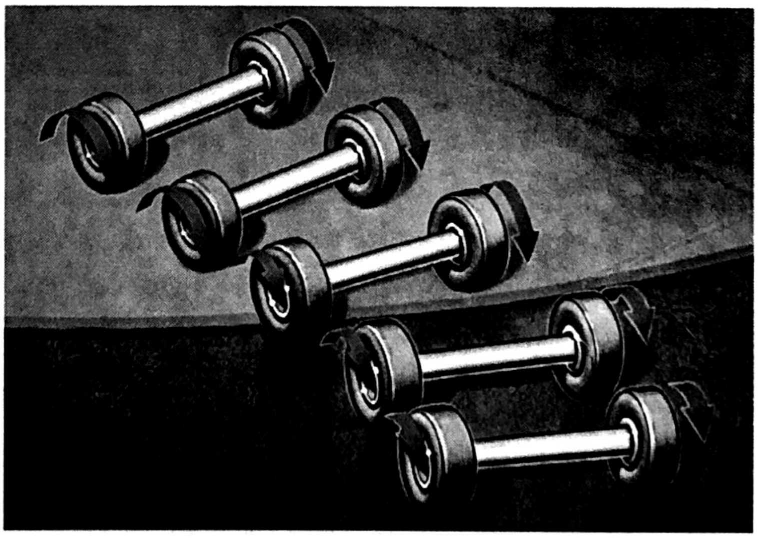
How does light bend?

Why does a change in speed cause a light wave to bend? The figure below shows what happens to the wheels of a car as they move from pavement to mud at an angle. The wheel that enters the mud first slows down a little. The other wheel is still on pavement and is still turning at the original speed. The difference in speed between the two wheels on the axle causes the axle to turn a little bit. This makes the car turn a little bit, too.

Picture This

3. Identify Look at the figure. Find the axle with one wheel in the mud and the other on the pavement. Circle the wheel that is traveling slower.



Now imagine a light wave traveling at an angle from air into water. Like the car wheels, the first part of the wave to enter the water slows down. The rest of the wave travels at the original speed until it enters the water. The light wave bends as long as one part is traveling faster than the rest of the wave.

Convex and Concave Lenses

Do you like to take pictures? Have you ever looked at something far away through binoculars or a telescope? Maybe you have looked at a small insect with a magnifying glass. You can do all of these things because of lenses. A **lens** is a transparent object with at least one curved side that causes light to bend. How much the light bends depends on how curved the sides of the lens are. The more curved the sides of a lens are, the more light will be bent after it enters the lens. ☑

✔ Reading Check

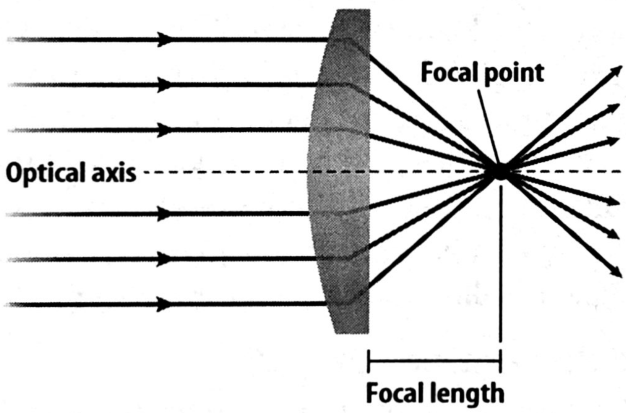
4. Explain What does a lens do?

____

____

How do convex lenses bend light?

A **convex lens** is thicker in the center than it is at the edges. Look at the figure below. In a convex lens, light rays traveling parallel to the optical axis are bent so they pass through the focal point. The more curved the lens is, the closer the focal point is to the lens. This makes the focal length shorter. Convex lenses are sometimes called converging lenses because they cause light waves to meet, or converge.



Picture This

5. Describe What happens to the light rays after they pass through the lens?

____

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____

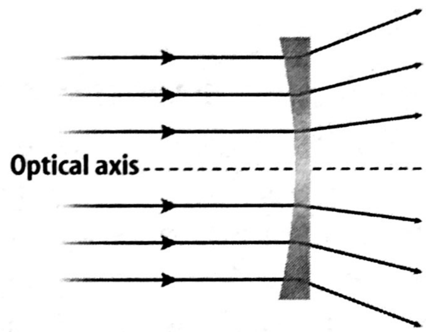
How do magnifying glasses work?

The image formed by a convex lens is like the image formed by a concave mirror. For both, the type of image depends on how far the object is from the mirror or lens. If the object is farther than two focal lengths from the lens, the image seen through the lens is upside down, or inverted. The image also is smaller than the actual object.

If the object is closer to the lens than one focal length, the image is right-side up and larger than the object. A magnifying glass is a convex lens. As long as the magnifying glass is less than one focal length from the object, you can make the image appear larger by moving the magnifying glass away from the object.

How do concave lenses bend light?

A **concave lens** is thicker at the edges than in the middle. A concave lens causes light waves to spread out, or diverge. They are not brought to a focus. The figure below shows how light waves that travel parallel to the optical axis are bent after passing through a concave lens. The image formed by a concave lens is like the image formed by a convex mirror. The image is upright and smaller than the actual object.



Total Internal Reflection

Sometimes you can see your reflection when you look at a glass window. This happens because some light rays reflected from you hit the glass and are reflected back to your eyes. This is an example of partial reflection. In partial reflection, only some of the light waves that strike the window are reflected. But sometimes, all the light waves that strike the boundary between two transparent materials can be reflected. This is called total internal reflection.

What is the critical angle?

To see how total internal reflection works, look at the figure at the top of the next page. Light travels faster in air than in water, so the refracted beam bends away from the normal. As the angle between the incident beam and the normal increases, the refracted beam bends closer to the air-water boundary. At the same time, more of the light is reflected, and less passes into the air.

Total internal reflection occurs when a light beam in water strikes the boundary at the angle with the normal called the critical angle. All the light waves are reflected when an angle is equal to or greater than the critical angle at the air-water boundary. It is as if there were a mirror at the boundary. The size of the critical angle depends on the two materials. The critical angle for an air-water boundary is about 48 degrees. ☑

Picture This

6. Draw Conclusions Which type of mirror forms an image like the image formed by a concave lens?

____

✔ Reading Check

7. Identify What happens to a light beam that strikes the air-water boundary at an angle greater than the critical angle?

____

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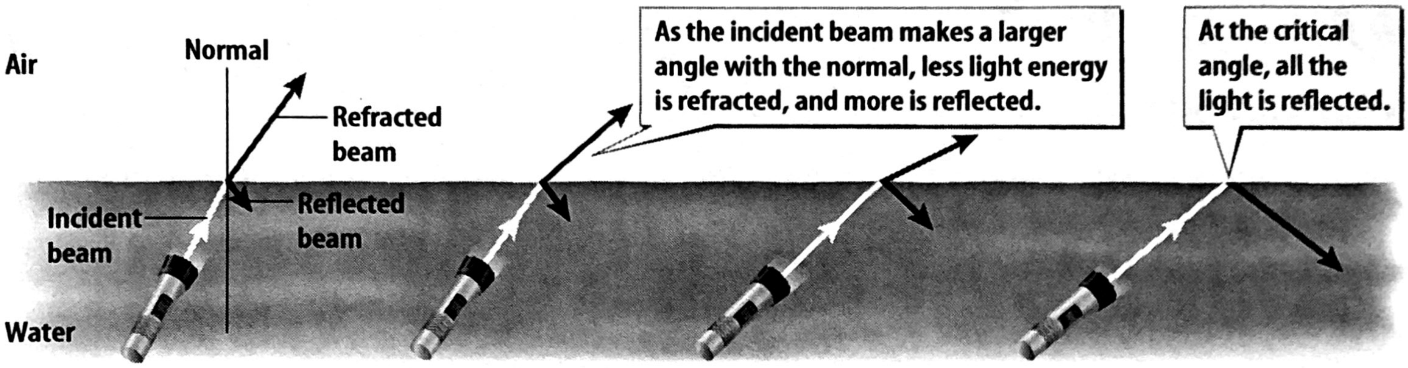
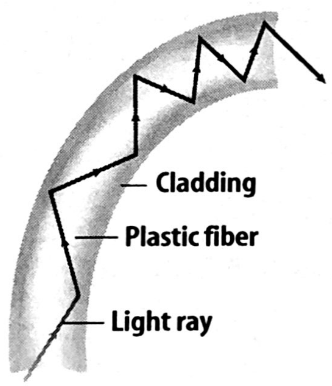


What are optical fibers?

Optical fibers are thin, flexible, transparent fibers. Think of an optical fiber as a light pipe. A light beam can travel for many kilometers through an optical fiber. It loses almost no energy. Even if the fiber is bent, light that goes in one end of the fiber comes out the other end.

Light moves through optical fibers because of total internal reflection. A thin fiber of glass or plastic is covered with a material called cladding. Light travels faster in the cladding than in the fiber. When light strikes the boundary between the fiber and the cladding, total internal reflection happens. The beam of light bounces from boundary to boundary as it travels down the fiber, as shown in the figure below.



How are optical fibers used?

Optical fibers are used in the communications industry. Television programs, computer information, and telephone conversations can be changed into light signals. These signals are sent from place to place through optical fibers. Signals cannot leak from one fiber to another because of total internal reflection. This means the signal stays clear. One optical fiber the thickness of a human hair can carry thousands of phone conversations.

Picture This

8. **Describe** What happens to the light beam at the critical angle?

____

____

Picture This

9. **Identify** Use a highlighter to highlight the path light takes through the optical fiber in the figure.

● After You Read

Mini Glossary

concave lens: a lens that is thicker at the edges than in the middle

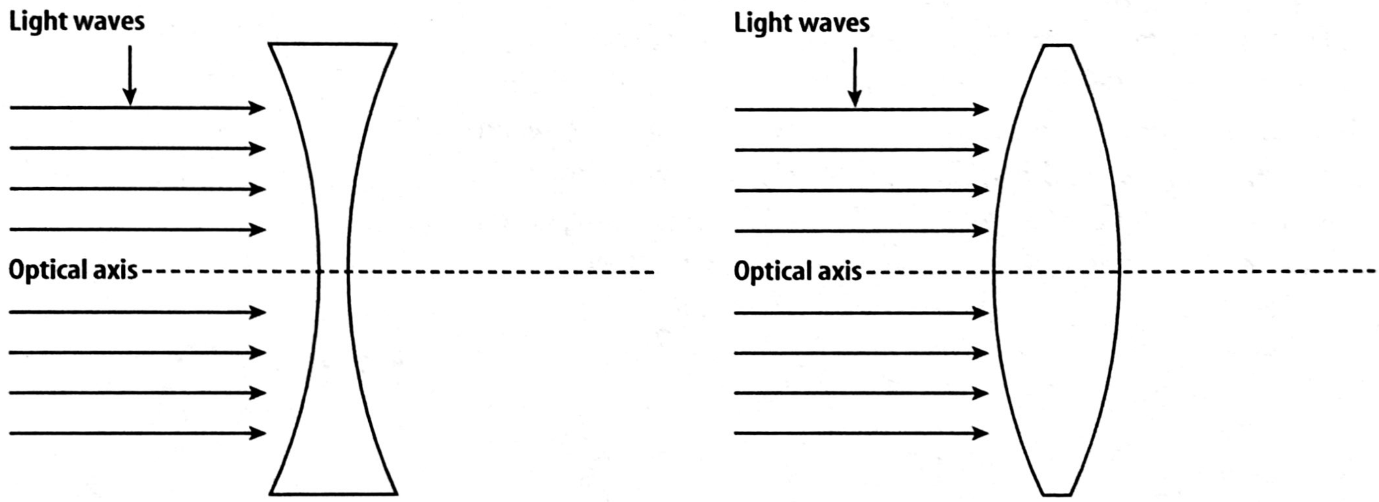
convex lens: a lens that is thicker in the center than it is at the edges

lens: a transparent object with at least one curved side that causes light to bend

1. Review the terms and their definitions in the Mini Glossary. Write a sentence about how concave lenses bend light.

____

2. On the figure below, continue each light wave to show what happens to the light waves after they pass through the lenses.



3. Look carefully at a pair of eyeglasses. Are the lenses concave or convex? How do you know?

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End of Section

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chapter 4 Light, Mirrors, and Lenses

section 4 Using Mirrors and Lenses

Before You Read

List some ways you use mirrors. List some ways you use lenses.

___

___

What You'll Learn

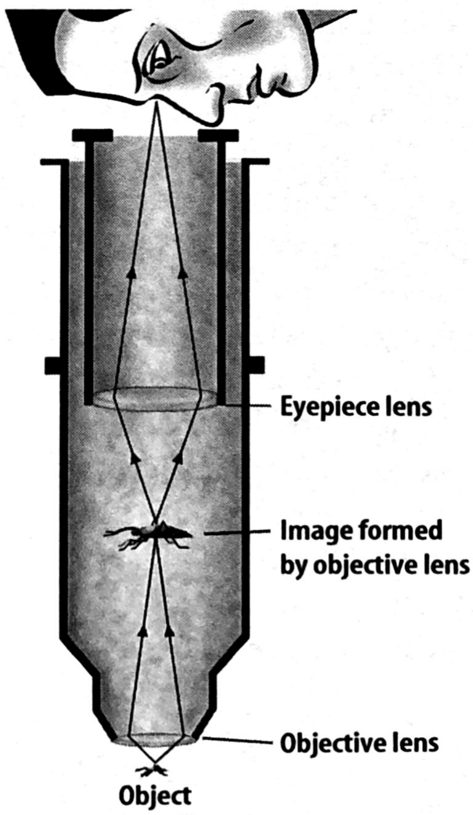
- how microscopes magnify images
- how telescopes work
- how a camera works

Read to Learn

Microscopes

For almost 500 years, lenses have been used to see very small objects. Early microscopes were simple. They had only one lens and magnified less than 100 times. Today, compound microscopes use more than one lens and can magnify objects up to 2,500 times.

The figure shows how a compound microscope forms an image. An object is placed close to a convex lens called the objective lens. This lens produces a larger image inside the microscope. The light rays from the image pass through a second convex lens called the eyepiece lens. The eyepiece lens makes the image larger, or magnifies it. When two lenses are used, a much larger image is formed than with just one lens.

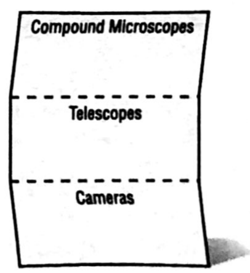


Study Coach

Create a Quiz As you read, write down questions about the things you read. After you finish reading, answer the questions to make sure you understand the material.

FOLDABLES™

C Organize Information Make the following Foldable to help you organize information about microscopes, telescopes, and cameras.



Telescopes

Telescopes are used to look at objects that are far away. The first telescopes were made about the same time as the first microscopes. Much of what we know about the solar system and the distant universe has come from images gathered by telescopes.

What is a refracting telescope?

The simplest **refracting telescope** uses two convex lenses to form an image of a distant object. Just like a compound microscope, light passes through an objective lens and an eyepiece lens. The objective lens forms an image and the eyepiece lens magnifies it.

The main purpose of a telescope is to gather as much light as possible from distant objects. Refractive telescopes use a large objective lens to gather light from distant objects. In a telescope, the larger the lens is, the more light it can gather. When more light enters the telescope, images of faraway objects look brighter, sharper, and more detailed. ☑

Reading Check

1. **Explain** What is the purpose of an objective lens in a refracting telescope?

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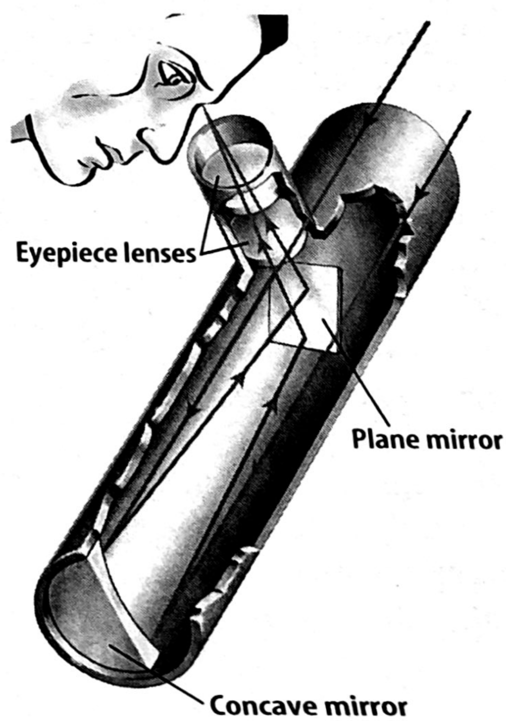
What is a reflecting telescope?

A **reflecting telescope** has a concave mirror instead of a concave objective lens to gather the light from distant objects. As you can see in the figure, the large concave mirror focuses light onto a secondary plane mirror. That mirror directs the light into the eyepiece. The eyepiece magnifies the image.

Because they are easier to make and keep clean, concave mirrors are less expensive than similar-sized objective lenses. Concave mirrors can be supported at their edges and on their backside. They can be made much larger than objective lenses. The largest telescopes in the world are reflecting telescopes.



Reflecting Telescope

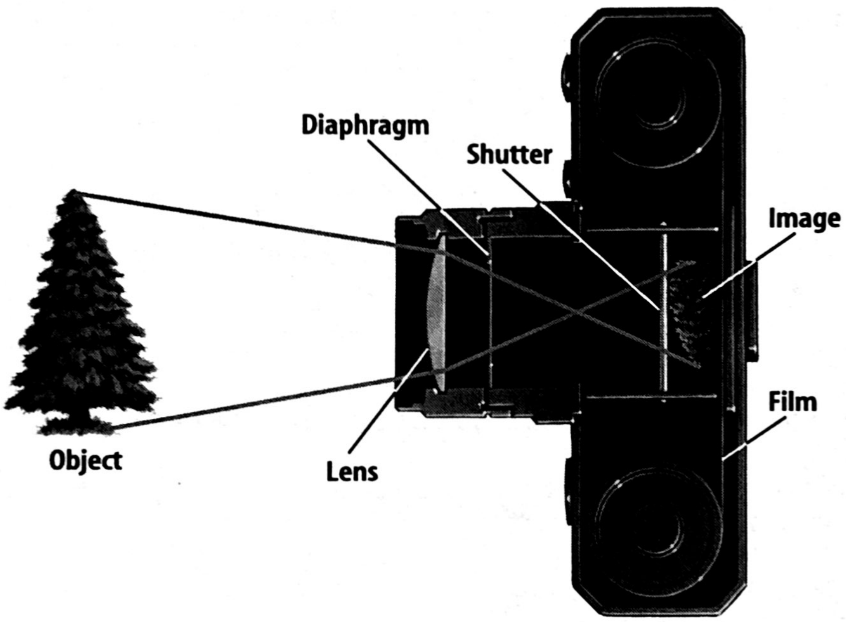
Picture This

2. **Identify** Circle the part of the reflecting telescope that gathers the light.

Cameras

You probably see photographs taken by cameras every day. A camera uses a convex lens to form an image on a piece of film. This is similar to the way the eye focuses an image on the retina. The convex lens has a short focal length. It forms an image that is smaller than the object and upside down, or inverted, on the film.

Look at the camera in the figure. When the shutter is open, the convex lens focuses an image on a piece of film that is sensitive to light. The film contains chemicals that undergo chemical reactions when light hits it. A device called a diaphragm controls how much light reaches the film. The brighter parts of the image affect the film more than the darker parts do.



Picture This

3. **Describe** the image that is formed on the film by the convex lens.

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Lasers

If you shine a flashlight on a wall in a darkened room, you see a spot of light. If you move back from the wall, the light spreads out and becomes less powerful. Laser light is different. The light waves in laser light are all the same wavelength. The crests and troughs of the light waves overlap, so the waves are in phase. Laser light does not spread out like regular light.

A laser can focus a large amount of energy on a very small area, so lasers are used for cutting and welding materials. They also can be used instead of scalpels in surgery. Less powerful lasers are used to read and write to CDs or to scan bar codes.

Think it Over

4. **Explain** Why do the waves of laser light have so much energy?

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● After You Read

Mini Glossary

reflecting telescope: uses a concave mirror to gather light from distant objects

refracting telescope: uses two convex lenses to gather light and form an image of a distant object

1. Review the terms and their definitions in the Mini Glossary. Explain the difference between a reflecting telescope and a refracting telescope.

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2. Fill in the table below to describe how microscopes, telescopes, and cameras work.

Device	Lenses or Mirrors Used	How does it work?
Microscope	two convex mirrors	The two lenses ______________ ______________.
Refracting telescope		The objective lens gathers light and the eyepiece ______________.
Reflecting telescope	one concave mirror and one convex lens	The ______________ gathers the light and the ______________ magnifies it.
Camera		The ______________ focuses a smaller, upside down image on the film.

3. Which device with lenses described in this section do you use most often? Explain.

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End of Section

Science Online Visit **booko.msscience.com** to access your textbook, interactive games, and projects to help you learn more about using mirrors and lenses.