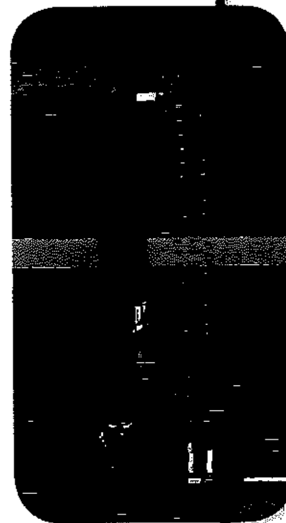
Inquiry MiniLab

15 minutes

How can you make waves with different properties?

Waves traveling through a spring can have different wavelengths and frequencies.



1. Read and complete a lab safety form.
2. Use **tape** to secure one end of a **spring toy** to your desk and the other end to the floor. Tie pieces of **string** to the spring 1/4, 1/2, and 3/4 of the way between the floor and the desk.
3. Pull a few of the lowest coils on the spring toy to the right. Release. Record your observations in your Science Journal.
4. Slowly tap the bottom of the spring toward the right. Repeat, this time doubling your rate of tapping. Record your observations.
5. Push down the bottom 5 cm of the spring toy. Release. Repeat, this time pushing down the bottom 10 cm. Record your observations.

Analyze and Conclude

1. **Compare** the movement of the pieces of string in step 4 and in step 5.
2. **Classify** the types of waves you made in steps 3–5 as transverse or longitudinal.
3. **Key Concept** What do the waves transfer up and down the spring toy?

Properties of Waves

How could you describe water waves at a beach? You might describe properties such as the height or the speed of the wave. When scientists describe waves, they describe the properties of wavelength and frequency.

Wavelength

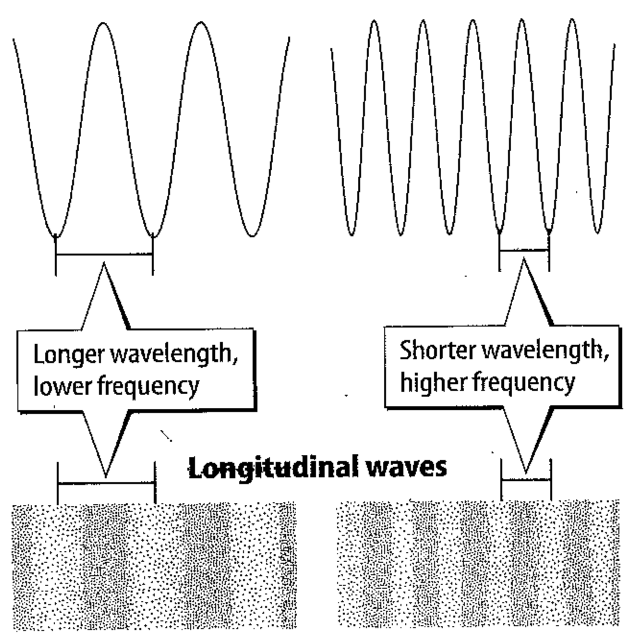
The distance between a point on one wave, such as the crest, and the same point on the next wave is called the wavelength. Different types of waves can have wavelengths that range from thousands of kilometers to less than the size of an atom!

Frequency

The number of wavelengths that pass a point each second is a wave's **frequency.** Frequency is measured in hertz (Hz). One hertz equals one wave per second. As shown in **Figure 7**, the longer the wavelength, the lower the frequency. As the distance between the crests gets shorter, the number of waves passing a point each second increases.

Reading Check What is frequency?

Figure 7 You can describe the wavelength and the frequency of both transverse and longitudinal waves.



Type of Wave	Typical wave speed (m/s)
Ocean wave	25
Sound wave in air	340
Transverse seismic wave (S wave)	1,000 to 8,000
Longitudinal seismic wave (P wave)	1,000 to 14,000
Electromagnetic wave through empty space	300,000,000

Table 2 Wave Speeds

▲ **Table 2** The speed of a wave depends on the type of wave and the medium through which the wave travels.

Wave Speed

A wave's speed depends on the medium, or type of material, through which it travels. Electromagnetic waves always travel through empty space at the same speed, 3×10^8 m/s. That's 300 million meters each second! They travel slower through a medium, or matter, because they must interact with particles. Mechanical waves also travel slower through matter because the waves transfer energy from one particle to another. For example, sound waves travel about one-millionth the speed of light waves. The speed of water waves depends on the strength of the wind that produces them. **Table 2** compares the speeds of different types of waves.

Amplitude and Energy

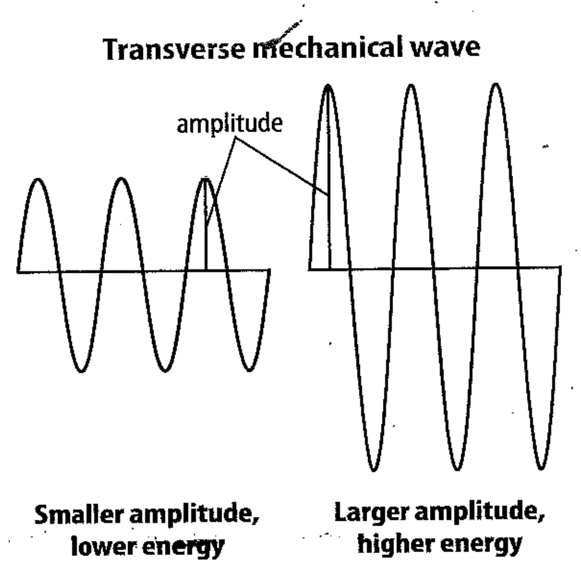
Different waves carry different amounts of energy. Some earthquakes, for example, are catastrophic because they carry so much energy. A shift in Earth's crust can cause particles in the crust to vibrate back and forth very far from their rest positions, producing seismic waves. In January 2010, seismic waves in Haiti transferred enough energy to destroy entire cities.

A wave's **amplitude** *is the maximum distance a wave varies from its rest position.* For mechanical waves, amplitude is the maximum distance the particles of the medium move from their rest positions as a wave passes. The more energy a mechanical wave has, the larger its amplitude. The amplitude of a transverse mechanical wave is shown in **Figure 8.**

Key Concept Check How can you describe waves?

Figure 8 As more energy is used to produce a mechanical wave, particles of a medium vibrate farther from their rest positions. ▶

Amplitude and Energy



Wave Interaction with Matter

You have read that when you knock on a door, longitudinal sound waves transfer the energy of the knock through the door. However, when a person in the next room hears the knock, it is not as loud as the sound on your side of the door. The sound is weaker after it passes through the door because the waves interact with the matter that makes up the door.

Transmission

Some of the sound from your knock passes through the door. The waves transmit, or carry, the energy all the way through the door. The energy then passes into air particles, and the person on the other side hears the knock.

Absorption

Some of the sound is absorbed by the particles that make up the door. Instead of passing through the door, the energy increases the motion of the particles of the wood. The sound energy changes to thermal energy within the door. Therefore, less sound energy passes into the air in the next room.

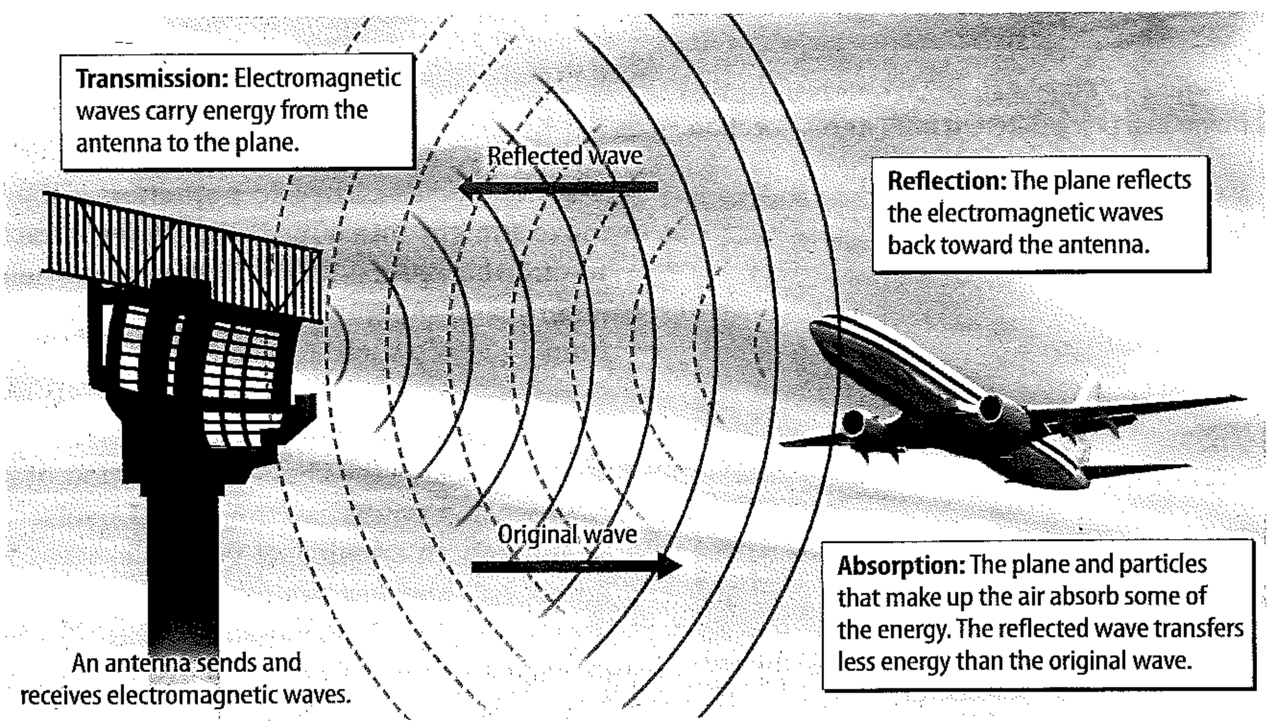
Reflection

Some of the energy you used to knock on the door reflects, or bounces back, into the room you are in. Sound waves in the air transfer sound back to your ears. **Figure 9** shows how the energy of electromagnetic waves can also be transmitted, absorbed, or reflected.

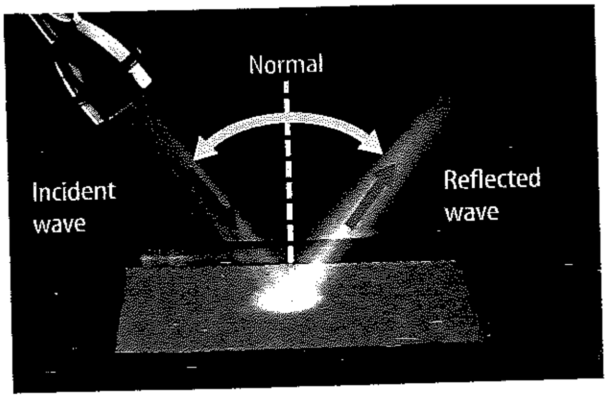
Reading Check What are transmission, absorption, and reflection?

Transmission, Absorption, and Reflection

Figure 9 As waves travel, some of the energy they carry is transmitted, some is absorbed, and some is reflected by the particles in matter.

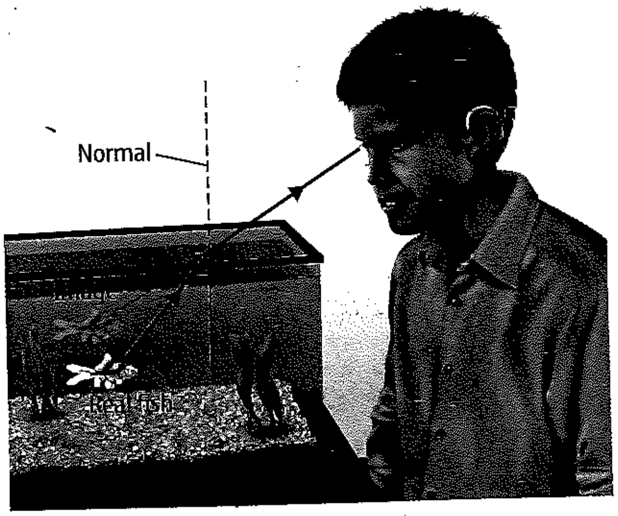


Visual Check Does all of the energy reflected from the plane return to the antenna? Why or why not?



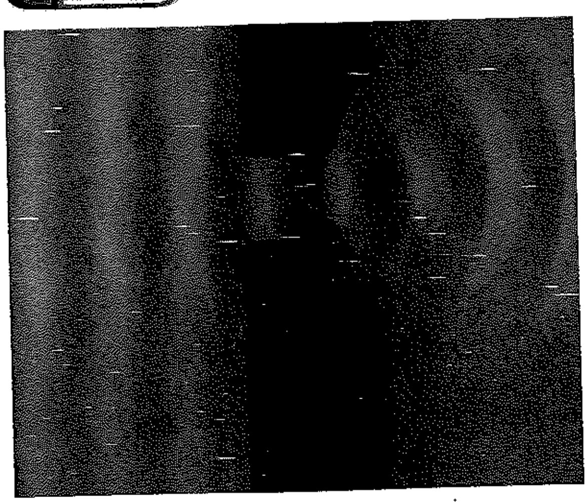
▲ **Figure 10** The law of reflection describes the direction of a reflected wave.

Concepts in Motion **Animation**



▲ **Figure 11** Refraction causes the fish to appear in a place different from its real location.

Review **Personal Tutor**



▲ **Figure 12** Diffraction causes waves to spread around barriers and through openings.

Law of Reflection

You can predict how waves will reflect from a smooth surface. The red arrow in **Figure 10** represents a light wave approaching a surface at an angle. This is called the incident wave. The blue arrow represents the reflected wave. The dotted line perpendicular to the surface at the point where the wave hits the surface is the normal. The law of reflection states that the angle between the incident wave and the normal always equals the angle between the reflected wave and the normal. If the incident angle in **Figure 10** increases, the reflected angle also increases.

Refraction

The change in direction of a wave as it changes speed, moving from one medium into another, is called **refraction.** The image of the fish in **Figure 11** is an example. Light reflects off the fish in all directions. The light speeds up as it moves from water into air. Notice that the light refracts away from the normal, or the line perpendicular to the surface at which the wave moves from one medium to other. This is the light the boy sees. His brain assumes the light traveled in a straight line. The light seems to come from the position of the image. Note that waves only refract if they move at an angle into another medium. They do not refract if they move straight into a medium. Waves refract toward the normal if they slow down when entering a medium and away from the normal if they speed up.

Diffraction

Diffraction is the change in direction of a wave when it travels past the edge of an object or through an opening. If you walk down a school hall and hear sound coming from an open classroom door, the sound waves have diffracted around the corner to your ears. Diffraction is illustrated in **Figure 12.**

Key Concept Check What are some ways in which waves interact with matter?

The Electromagnetic Spectrum

Light is just a one type of electromagnetic wave. There is a wide range of electromagnetic waves that make up the electromagnetic spectrum, shown in **Figure 13.** Besides light, you encounter several other types of electromagnetic waves every day, and they probably play an important role in your life.

Types of Electromagnetic Waves

The electromagnetic spectrum consists of seven main types of waves. These waves range from low-energy, long-wavelength radio waves to very high-energy, short-wavelength gamma rays. Notice the relationship between wavelength, frequency, and energy indicated by the arrows in **Figure 13.** As the wavelength of electromagnetic waves decreases, the wave frequency increases. Low-frequency electromagnetic waves carry low amounts of energy, and high-frequency waves carry high amounts of energy.

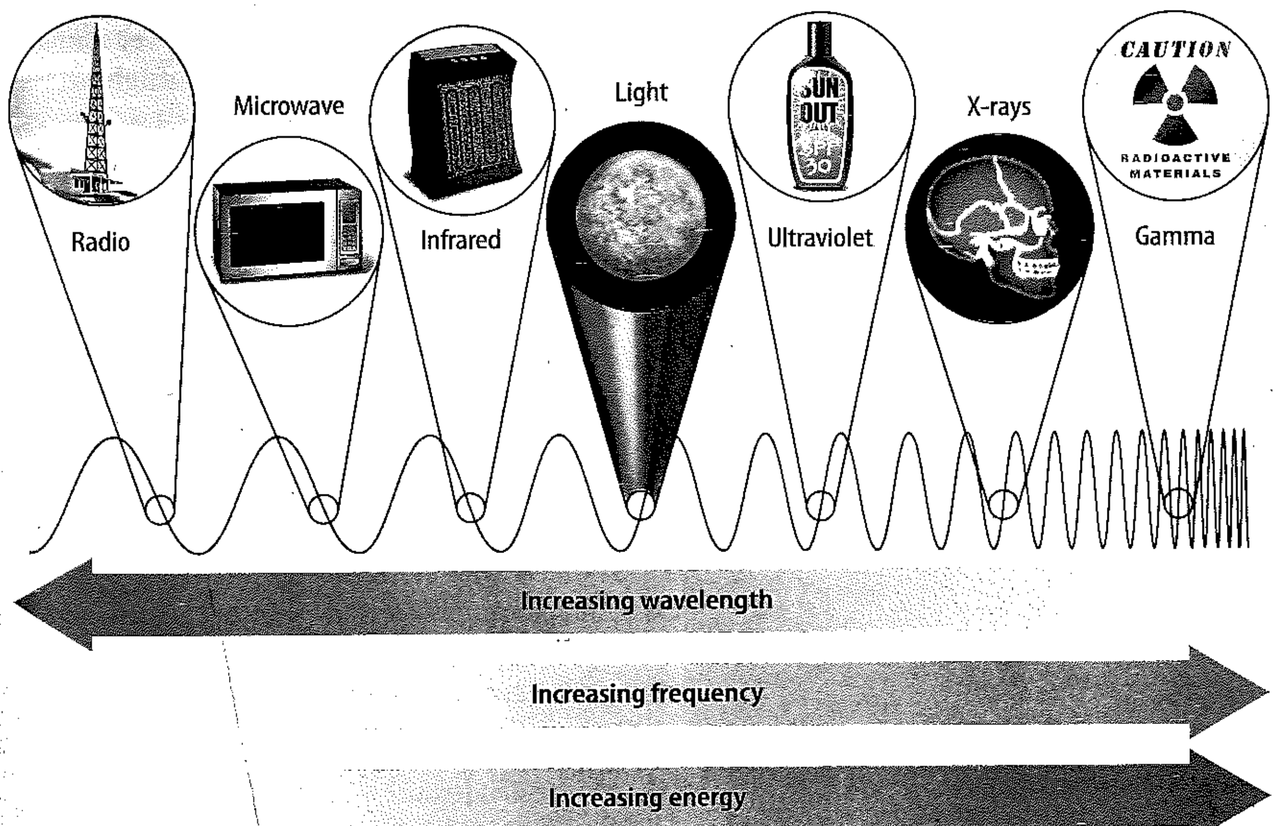
Radio Waves *A low-frequency, low-energy electromagnetic wave that has a wavelength longer than about 30 cm is called a* **radio wave.** Radio waves have the least amount of energy of any electromagnetic wave. On Earth, radio and television transmitters produce radio waves that carry radio and television signals.

Microwaves You might use microwaves to cook your food. Microwaves also carry cell phone signals. Wavelengths of microwaves range from about 1 mm to 30 cm. Microwaves easily pass through smoke, light rain, and clouds, which makes them useful for transmitting information by satellites. Weather radar systems reflect microwaves off rain or storm clouds to detect and calculate the storm's distance and motion. Then, these calculations are used to make weather maps like the one shown on the first page of this chapter.

The Electromagnetic Spectrum

Review Personal Tutor

Figure 13 Electromagnetic waves have different wavelengths, frequencies, and energy.



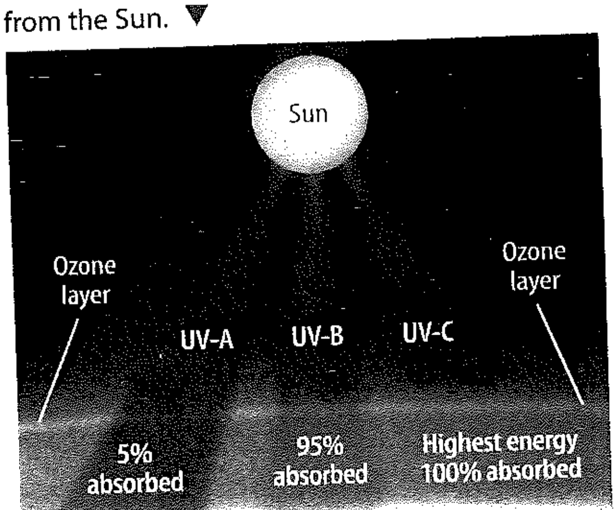
▲ **Figure 14** Infrared waves travel outward in all directions from the campfire.

WORD ORIGIN

infrared
from Latin *infra*, means "below"; and *ruber*, means "red"

ultraviolet
from Latin *ultra*, means "beyond"; and *viola*, means "violet"

Figure 15 The ozone layer protects Earth from the most dangerous ultraviolet waves from the Sun. ▼



Light When you turn on a lamp or stand in sunshine, you probably don't think about waves entering your eyes. However, as you have read, light is a type of electromagnetic wave that the eyes detect. Light includes a range of wavelengths. You will read later in this lesson how this range of wavelengths relates to various properties of light.

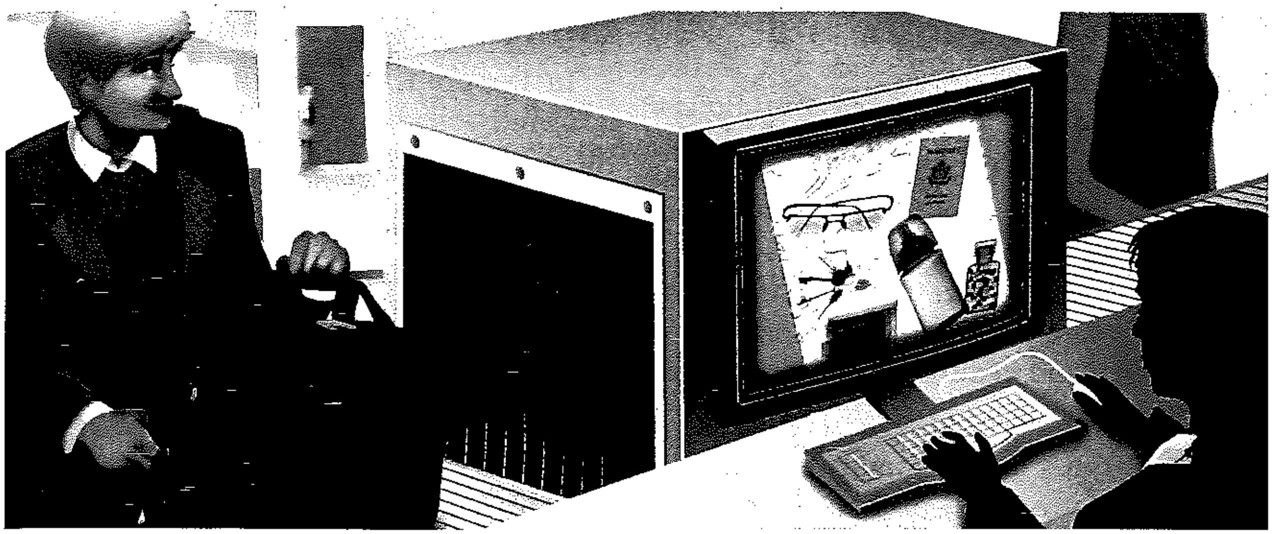
Infrared Waves *An electromagnetic wave with a wavelength shorter than a microwave but longer than light is an* **infrared wave**. When you sit near a heater or a campfire, as in **Figure 14**, infrared waves transfer energy to your skin, and you feel warm. The Sun is Earth's major source of infrared waves. However, vibrating molecules in any type of matter, including your body, emit infrared waves.

✓ **Reading Check** How do infrared waves and microwaves differ?

Ultraviolet Waves *An electromagnetic wave with a slightly shorter wavelength and higher frequency than light is an* **ultraviolet wave**. Electromagnetic waves with shorter wavelengths carry more energy than those with longer wavelengths and, therefore, can be harmful to living things. You might have heard that ultraviolet waves, or UV rays, from the Sun can be dangerous. These waves carry enough energy to cause particles of matter to combine or break apart and form other types of matter. Exposure to high levels of these waves can damage your skin.

Ultraviolet waves from the Sun are sometimes labeled UV-A, UV-B, or UV-C based on their wavelengths. UV-A have the longest wavelengths and the least energy. UV-C are the most dangerous because they have the shortest wavelengths and carry the most energy. As shown in **Figure 15**, the ozone layer in Earth's atmosphere blocks the Sun's most harmful UV rays from reaching Earth.

✓ **Reading Check** Why can ultraviolet waves be dangerous?



▲ **Figure 16** X-rays are useful for security scans because they have enough energy to pass through soft parts of luggage.

Visual Check How do the views of hard parts and soft parts of luggage differ in this X-ray image?

X-rays High-energy electromagnetic waves that have slightly shorter wavelengths and higher frequencies than ultraviolet waves are X-rays. These waves can be very powerful. They have enough energy to pass through skin and muscle, but denser bone can stop them. This makes them useful for taking pictures of the inside of the body. Airport scanners, as in **Figure 16**, sometimes use X-rays to take pictures of the contents of luggage.

Gamma Rays Electromagnetic waves produced by vibrations within the nucleus of an atom are called gamma rays. They have shorter wavelengths and higher frequencies than any other form of electromagnetic wave. Gamma rays carry so much energy that they can penetrate about 10 cm of lead, one of the densest elements. On Earth, gamma rays are produced by radioactive elements and nuclear reactions.

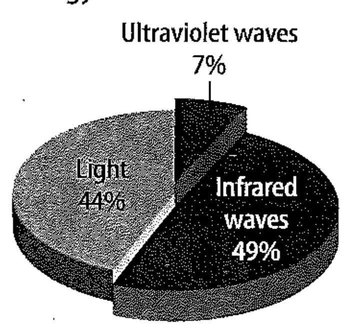
Reading Check Why do you think gamma rays cannot be used for communication in the same way radio waves are used?

Electromagnetic Waves from the Sun

The Sun produces an enormous amount of energy that is carried outward in all directions as electromagnetic waves. Because Earth is so far from the Sun, Earth receives less than one-billionth of the Sun's energy. However, if all the Sun's energy that reaches Earth in a 20-minute period could be transformed to useful energy, it could power the entire Earth for a year!

As shown in **Figure 17**, about 44 percent of the Sun's energy that reaches Earth is carried by light waves, and about 49 percent is carried by infrared waves. About 7 percent is carried by ultraviolet waves. Radio waves, microwaves, X-rays, and gamma rays carry less than 1 percent of the Sun's energy.

Figure 17 Infrared waves, light, and ultraviolet waves carry almost all of the Sun's energy. ▼



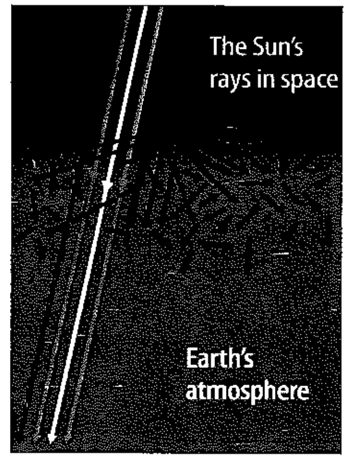
Interaction of Sunlight and Matter

Have you ever wondered why the sky is blue or the Sun is yellow? The interaction of light and matter causes interesting effects such as these when sunlight travels through air.

Scattering of Sunlight

As sunlight moves through Earth's atmosphere, most of the light reaches the ground. However, blue wavelengths are shorter than red wavelengths. The particles that make up the air scatter the shorter blue wavelengths more than they scatter longer wavelengths. The sky appears blue because the blue wavelengths spread out in every direction. They eventually reach the eye from all parts of the sky.

A light source, such as the Sun, that emits all colors of light should appear white. Why does the Sun often appear yellow instead of white? As shown in **Figure 21**, after the blue wavelengths of light scatter, the remaining colors appear yellow.



▲ **Figure 21** The Sun appears yellow because only longer wavelengths of light travel through the air in a straight line.

Reading Check Why is the sky blue? Why is the Sun yellow?

Refraction of Sunlight

Another interesting effect of sunlight occurs because of refraction. Recall that light changes speed as it travels from one medium into another. If light enters a new medium at an angle, the light wave refracts, or changes direction.

As shown in **Figure 22**, the refraction of light can affect the appearance of the setting Sun. The Sun's rays slow down when they enter Earth's atmosphere. The light rays refract toward Earth's surface. The brain assumes the rays that reach your eyes have traveled in a straight line, and the Sun seems to be higher in the sky than it actually is. This refraction causes you to see the Sun even after it has set below Earth's horizon.

FOLDABLES®

Make a vertical two-tab book using the labels shown. Use it to organize your notes on scattering and refraction.

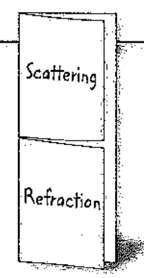
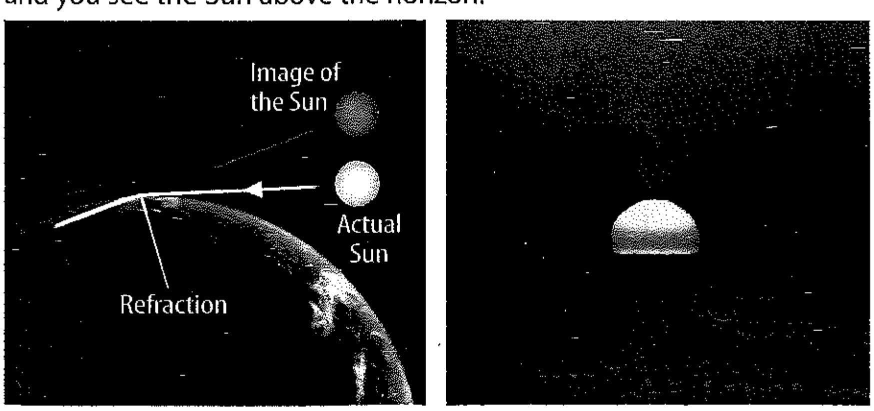


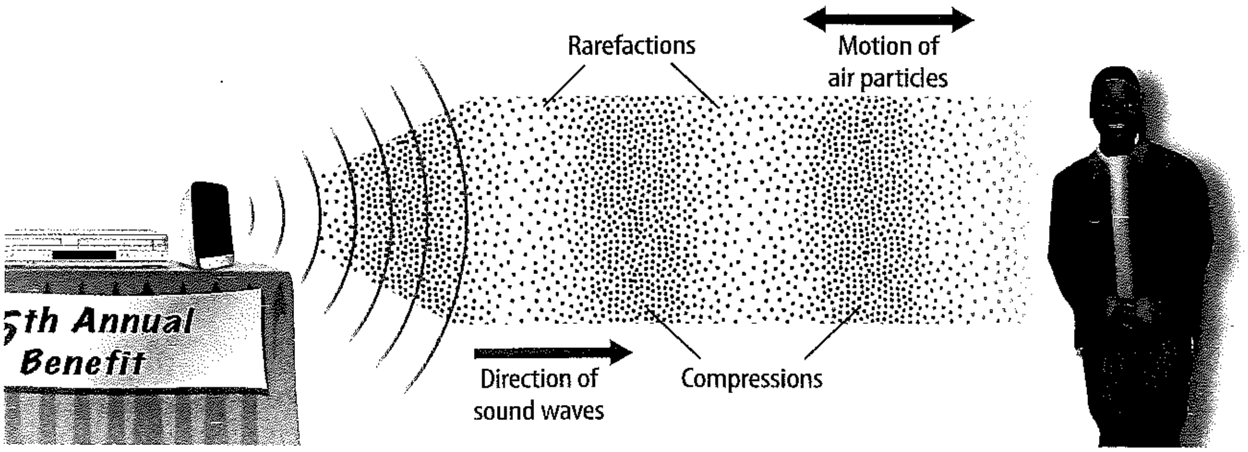
Figure 22 After the Sun actually sets, its light rays refract, and you see the Sun above the horizon.



Sound Waves

Concepts in Motion Animation

Figure 25 A sound wave produces compressions and rarefactions as it passes through matter.



Compressions and Rarefactions

Sound waves usually travel to your ears through air. Air particles are in constant motion. As the particles bounce off objects, they exert a force, or pressure. **Figure 25** shows how sound waves moving through air change the air pressure by causing air particles to move toward and then away from each other.

Suppose you pluck a guitar string. As the string springs back, it pushes air particles forward, forcing them closer together. This increases the air pressure near the string. *A* **compression** *is the region of a longitudinal wave where the particles of the medium are closest together.* As the string vibrates, it moves in the other direction. This leaves behind a region with lower pressure. *A* **rarefaction** *is the region of a longitudinal wave where the particles are farthest apart.*

Reading Check How do compressions and rarefactions differ?

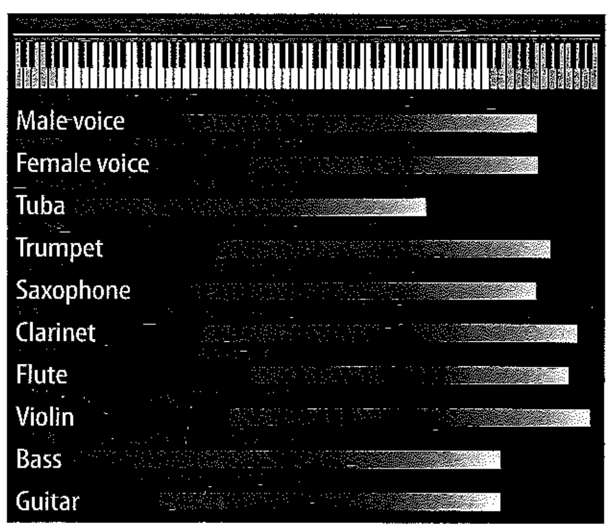
Properties of Sound Waves

A sound wave is described by its wavelength, frequency, amplitude, and speed. These properties of sound waves depend on the compressions and rarefactions of the sound waves.

Wavelength, Frequency, and Pitch

Recall that the wavelength of a wave becomes shorter as the wave's frequency increases. How does the frequency of a sound wave affect what is heard?

The perception of how high or low a sound seems is called **pitch.** The higher the frequency, the higher the pitch of the sound. For example, a female voice generally produces higher-pitched sounds than a male voice. This is because the female voice has a higher range of frequencies. **Figure 26** shows the range of frequencies produced by several instruments and voices.

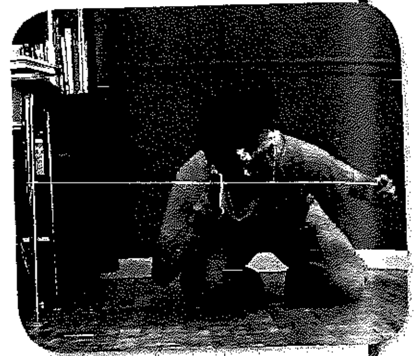


▲ **Figure 26** People and instruments have different ranges of sound frequencies.

Inquiry MiniLab — 10 minutes

Can you make different sounds with string?

A guitar player makes different sounds by holding and plucking the strings in different ways. You can model these sounds.



1. Read and complete a lab safety form.
2. Use **scissors** to cut a piece of **string** 1 m long. Attach one end securely to the leg of a desk.
3. Hold the other end, and stretch the string horizontally. Pluck the string several times, and observe the sound. Record your observations in your Science Journal.
4. Continue holding the string at various locations and plucking it. Notice how the sounds differ. Record your observations.
5. Again, hold the string at different locations. Observe how the sound changes as you pull the string with a greater force and then with a weaker force. Record your observations.

Analyze and Conclude

1. **Interpret** How does pulling the string tighter or changing its length affect the string's sound?
2. **Key Concept** Explain how you changed the frequency, wavelength, pitch, amplitude, and energy of the sound you made with the string.

Science Use v. Common Use

rest position

Science Use position of an undisturbed particle; particles are still in motion here

Common Use the state of something not moving

Amplitude and Energy

You use more energy to shout than to whisper. The more energy you put into your voice, the farther the particles of air move as they vibrate. The distance a vibrating particle moves from its **rest position** is the amplitude. The more energy used to produce the sound wave, the greater the amplitude.

Speed

Sound waves travel much slower than electromagnetic waves. With sound, the transmitted energy must pass from particle to particle. The type of medium and the temperature affect the speed of sound.

Type of Medium Gas particles are far apart and collide less often than particles in a liquid or a solid. As shown in Table 3, a gas takes longer to transfer sound energy between particles.

Temperature Particles move faster and collide more often as the temperature of a gas increases. This increase in the number of collisions transfers more energy in less time. Temperature has the opposite effect on liquids and sounds. As liquids and solids cool, the molecules move closer together. They collide more often and transfer energy faster.

Table 3 The Speed of Sound

Material	Speed (m/s)
Air (0°C)	331
Air (20°C)	343
Water (20°C)	1,481
Water (0°C)	1,500
Seawater (25°C)	1,533
Ice (0°C)	3,500
Iron	5,130
Glass	5,640

Key Concept Check What are some properties of sound waves?

Intensity and Loudness

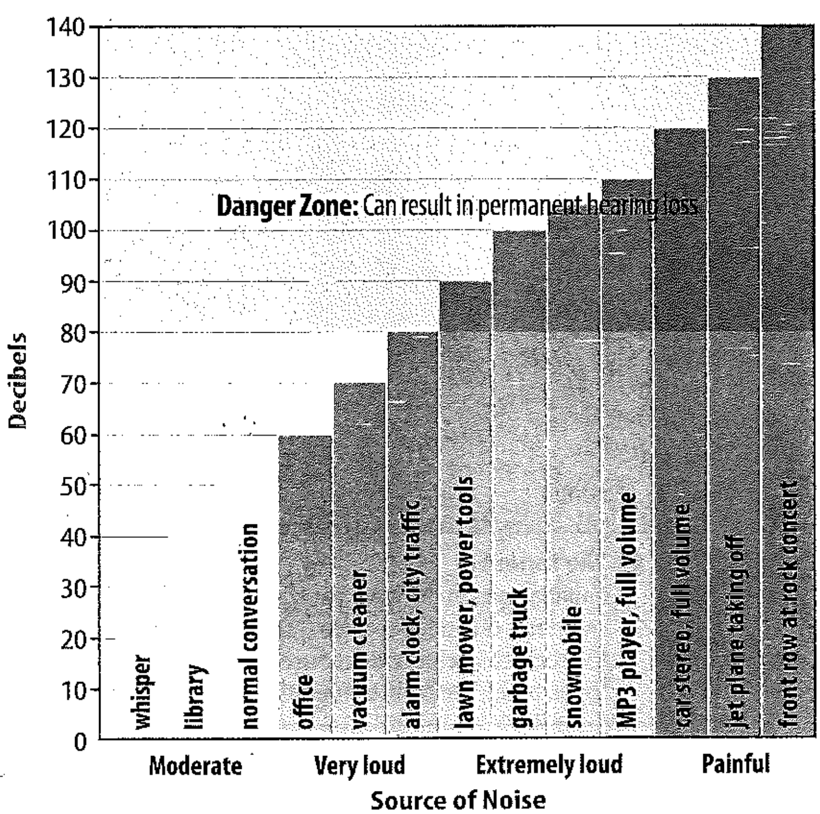
Generally, the greater the amplitude of a sound wave, the louder the sound seems. But what happens if you move away from a sound source? As you move away, the wave's amplitude decreases and the sound seems quieter. This is because as a sound wave moves farther from the source, more and more particles collide, and the energy from the wave spreads out among more particles. Therefore, the farther you move from the source, the less energy present in the same area of space. Recall that the amount of energy that passes through a square meter of space in one second is the intensity of a wave. Loudness is your ear's perception of intensity.

The Decibel Scale

The unit used to measure sound intensity, or loudness, is the **decibel (dB).** The decibel levels of common sounds are shown in **Figure 27.** Each increase of 10 dB causes a sound about twice as loud. As the decibel level goes up, the amount of time you can listen to the sound without risking hearing loss gets shorter and shorter. People who work around loud sounds wear protective hearing devices to prevent hearing loss.

Decibel Levels

Figure 27 The decibel scale helps you understand safe limits of different types of sounds.



Math Skills

Use a Fraction

Because sound energy travels out in all directions from the source, the intensity of the sound decreases as you move away. You can calculate the fraction by which the sound intensity changes. The fraction $= \left(\frac{r_1}{r_2}\right)^2$, where r_1 is the starting distance and r_2 is the ending distance from the source. For example, by what fraction does sound intensity decrease if you move from **3 m** to **6 m** from a source?

1. Replace the variables with given values.
   fraction $= \left(\frac{3}{6}\right)^2$
2. Solve the problem.
   $\left(\frac{3}{6}\right)^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$, so the intensity decreases to $\frac{1}{4}$ of its original value.

Practice

You are standing at a distance of 2 m from a sound source. How does the sound intensity change if you move to a distance of 6 m?

Review

- **Math Practice**
- **Personal Tutor**

Word Origin

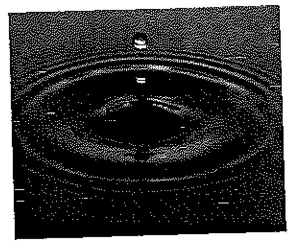
decibel
from Latin *decibus*, means "tenth"

Chapter 4 Study Guide

THE BIG IDEA **Mechanical waves transfer energy from particle to particle in matter. Electromagnetic waves transfer energy through either matter or empty space.**

Key Concepts Summary

Lesson 1: Waves

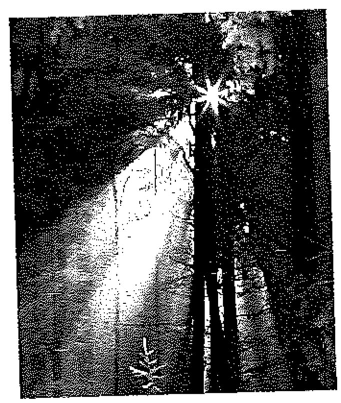


- Waves are disturbances that transfer energy from place to place. A **mechanical wave** forms when a source of energy causes particles of a medium to vibrate. A vibrating electric charge produces an **electromagnetic wave.**
- You can describe wavelength, **frequency,** speed, **amplitude,** and energy of waves.
- Matter can transmit, absorb, or reflect a wave. It also can change a wave's direction by **refraction** or diffraction.

Vocabulary

mechanical wave p. 120
electromagnetic wave p. 120
transverse wave p. 121
longitudinal wave p. 121
frequency p. 123
amplitude p. 124
refraction p. 126

Lesson 2: Light

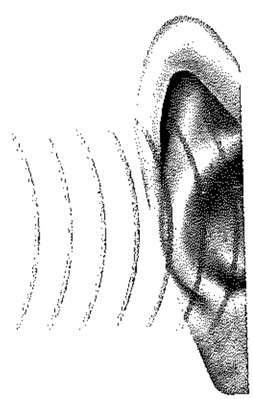


- Light differs from other forms of electromagnetic waves by its frequency, wavelength, and energy. Light is the type of electromagnetic wave that is visible with the human eye.
- Matter can transmit, absorb, and reflect light. These interactions differ in how much light the matter transmits and how it changes the direction of light.
- Cells in the retina of the eyes change light into electric signals that travel to the brain.

Vocabulary

radio wave p. 131
infrared wave p. 132
ultraviolet wave p. 132
transparent p. 134
translucent p. 134
opaque p. 134
intensity p. 136

Lesson 3: Sound



- Sound waves travel through matter as a series of **compressions** and **rarefactions.** The frequency and wavelength of a sound wave determines the **pitch.** Sound waves with greater amplitude sound louder.
- Ears collect and amplify sound and then convert it to signals the brain can interpret.

Vocabulary

compression p. 143
rarefaction p. 143
pitch p. 143
decibel p. 145