Lesson 1

Reading Guide

Key Concepts
ESSENTIAL QUESTIONS

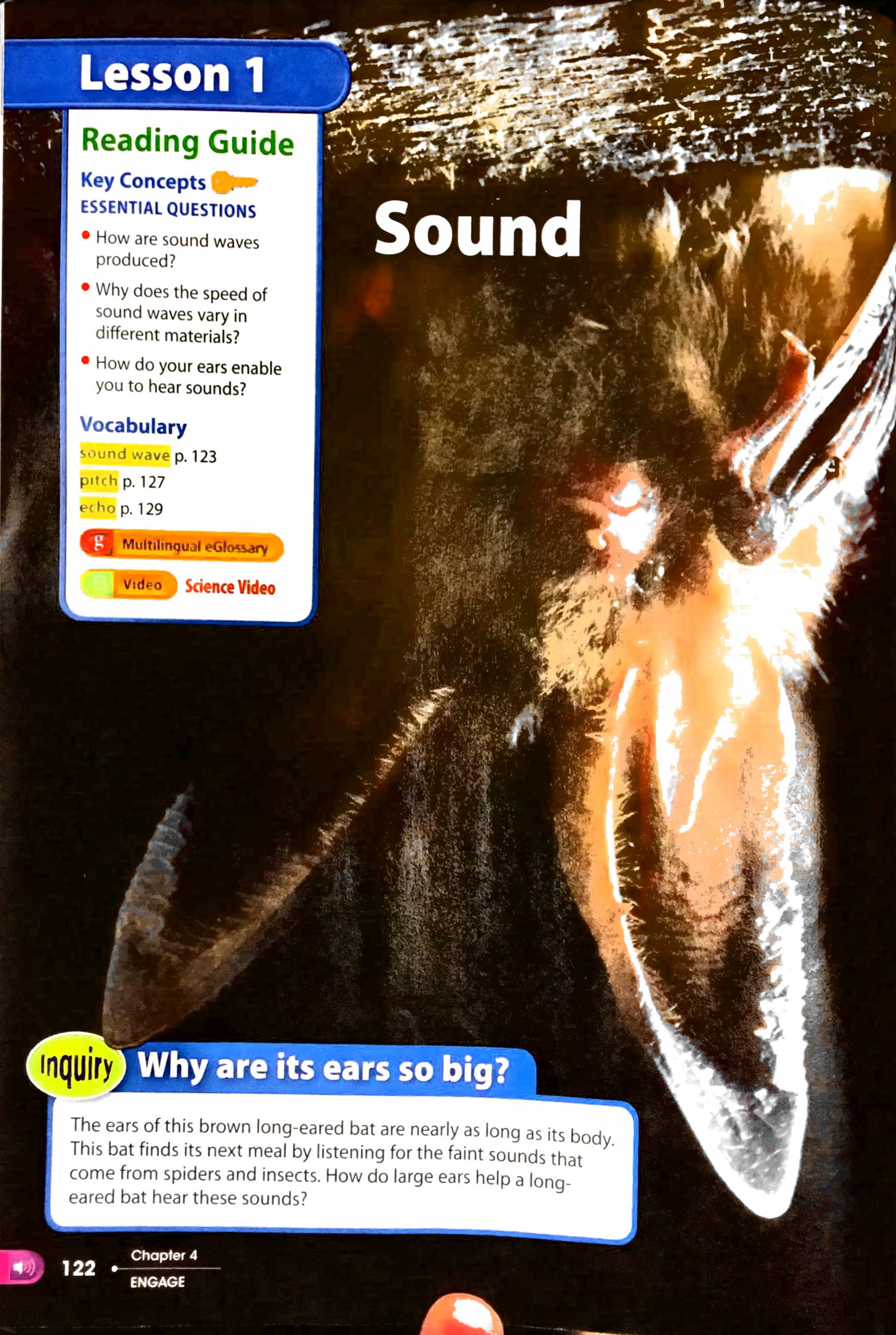
- How are sound waves produced?
- Why does the speed of sound waves vary in different materials?
- How do your ears enable you to hear sounds?

Vocabulary
sound wave p. 123
pitch p. 127
echo p. 129

Multilingual eGlossary

Video Science Video

Sound



Inquiry Why are its ears so big?

The ears of this brown long-eared bat are nearly as long as its body. This bat finds its next meal by listening for the faint sounds that come from spiders and insects. How do large ears help a long-eared bat hear these sounds?

inquiry **Launch Lab** 15 minutes

How is sound produced?

When an object vibrates, it produces sound. How does the sound produced depend on how the object vibrates?

1. Read and complete a lab safety form.
2. Place a **ruler** on a table so it extends over the table edge. Hold the ruler firmly on the table with one hand.
3. With the other hand, lightly bend the protruding end of the ruler down and then release it. Observe the ruler's motion and note the sound it produces.
4. Move the ruler back 2 cm so there is less of it extending over the edge of the table. Repeat step 3.

Think About This

1. How did the vibration rate and the sound change as the length of the ruler over the side of the table decreased?
2. **Key Concept** Were the sound and the ruler's vibration rate related? Explain.

What is sound?

Have you ever walked down a busy city street and noticed all the sounds? You might hear many sounds every day, such as the music from an MP3 player, as shown in **Figure 1.** All sounds have one thing in common. The sounds travel from one place to another as sound waves. *A* **sound wave** *is a* ***longitudinal wave*** *that can travel only through matter.*

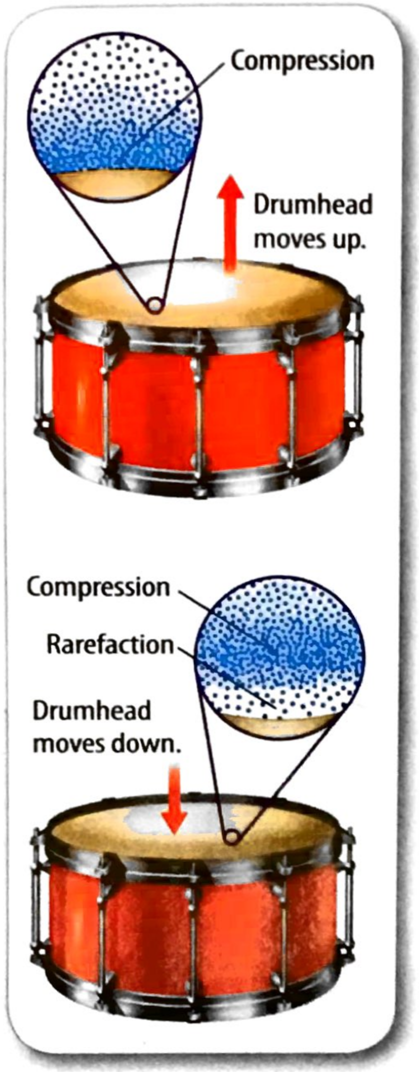
Sound waves can travel only through matter—solids, liquids, and gases. The sounds you might hear now are traveling through air—a mixture of solids and gases. You might have dived underwater and heard someone call to you. Then the sound waves traveled through a liquid. Sound waves travel through a solid when you knock on a door. As you will read, vibrating objects produce sound waves.

All sounds might have something else in common, too. Vibrating objects produce sound waves. For example, when you knock on a door, you produce sound waves by making the door vibrate. How do vibrating objects make sound waves?

REVIEW VOCABULARY

longitudinal wave
a wave in which particles in a material move along the same direction that the wave travels

Figure 1 Earbuds produce sound waves that travel into the listener's ears.



▲ **Figure 2** Vibrations of the drumhead produce sound waves.

Vibrations and Sound

Objects such as doors or drums vibrate when you hit them. For example, when you hit a drum, the drumhead moves up and down, or vibrates, as shown in **Figure 2**. These vibrations produce sound waves by moving molecules in air.

Compressions and Rarefactions

As the drumhead moves up, it pushes the molecules in the air above it closer together. The region where molecules are closer together is a compression, as shown in **Figure 2**. When the drumhead moves down, it produces a rarefaction. This is a region where molecules are farther apart. As the drumhead vibrates down and up, it produces a series of rarefactions and compressions that travels away from the drumhead. This series of rarefactions and compressions is a sound wave.

The vibrating drumhead causes molecules in the air to move closer together and then farther apart. The molecules in air move back and forth in the same direction that the sound wave travels. As a result, a sound wave is a longitudinal wave.

Key Concept Check How do vibrating objects produce sound waves?

Wavelength and Frequency

A sound wave can be described by its wavelength and frequency. Wavelength is the distance between a point on a wave and the nearest point just like it, as shown in **Figure 3**. A sound wave's frequency is the number of wavelengths that pass a given point in one second. Recall that the SI unit of frequency is hertz (Hz). The faster an object vibrates, the higher the frequency of the sound wave produced.

Figure 3 Wavelength is the distance between one compression and the next compression or the distance between a rarefaction and the next rarefaction. ▼

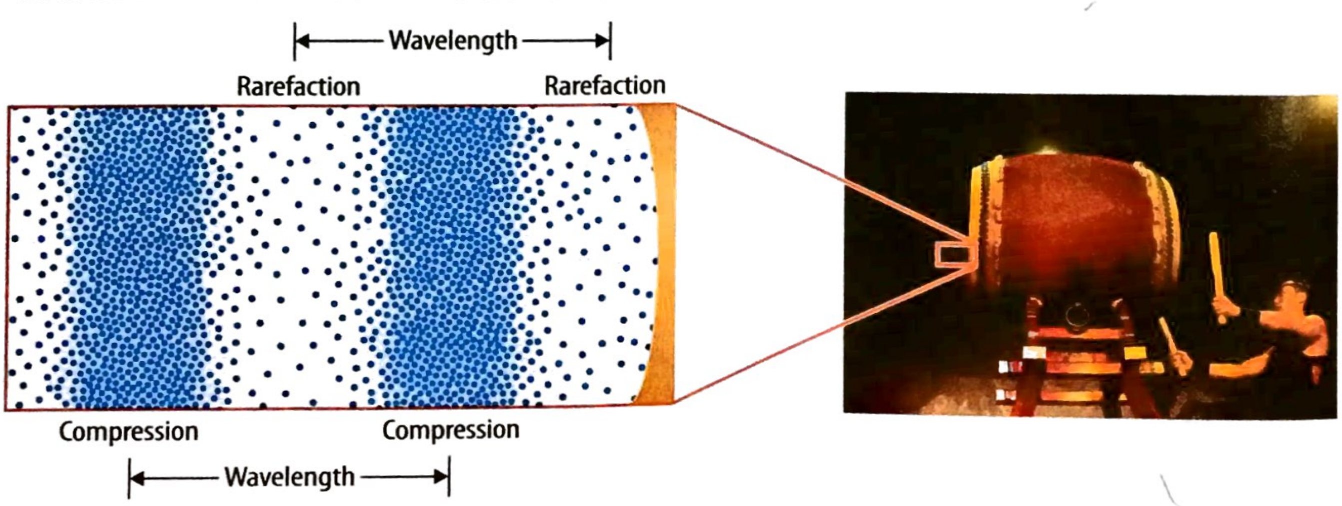


Table 1 The Speed of Sound Waves in Different Materials

Gases (0°C)		Liquids (25°C)		Solids	
Material	Speed (m/s)	Material	Speed (m/s)	Material	Speed (m/s)
Carbon dioxide	259	Ethanol	1,207	Brick	3,480
Dry Air	331	Mercury	1,450	Ice	3,850
Water vapor	405	Water	1,500	Aluminum	6,420
Helium	965	Glycerine	1,904	Diamond	17,500

Table 1 Sound waves travel at different speeds in different materials. Sound waves usually travel fastest in solids and slowest in gases.

Concepts in Motion **Interactive Table**

Speeds of Sound Waves

Sound waves traveling through air cause the sounds you might hear every day. Like all types of waves, the speed of a sound wave depends on the material in which it travels.

Sound in Gases, Liquids, and Solids

Table 1 lists the speeds of sound waves in different materials. A sound wave's speed increases when the material's density increases. Solids and liquids are usually more dense than gases.

In addition, a sound wave's speed increases when the strengths of the forces between the particles—atoms or molecules—in the material increase. These forces are usually strongest in solids and weakest in gases. Overall, sound waves usually travel faster in solids than in liquids or gases.

Key Concept Check Why is the speed of sound waves faster in solids than in liquids or gases?

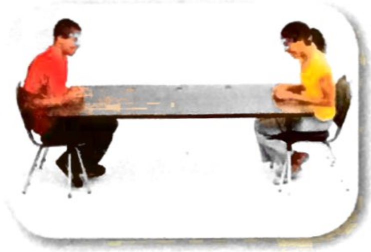
Temperature and Sound Waves

The temperature of a material also affects the speed of a sound wave. The speed of a sound wave in a material increases as the temperature of the material increases. For example, the speed of a sound wave in dry air increases from 331 m/s to 343 m/s as the air temperature increases from 0°C to 20°C. A sound wave in air travels faster on a warm, summer day than on a cold, winter day.

Inquiry MiniLab **20 minutes**

Can you model a sound wave?

A wave on a coiled spring toy is similar to a sound wave.



1. Read and complete a lab safety form.
2. Set a long **coiled spring toy** on a flat surface. Tie three small pieces of **yarn** on three different coils, dividing the spring into four equal sections. Stretch the spring about 2 m between you and a partner.
3. Squeeze together about one-fourth of the coils and hold the end of the spring with the other hand. While holding the end of the spring tightly, release the group of coils. Observe the wave.

Analyze and Conclude

1. **Draw** three sketches of the spring in your Science Journal, showing how the wave traveled through the spring. Label the compressions and rarefactions.
2. **Key Concept** Explain how the wave on the spring is similar to a sound wave.

Math Skills

Use a Simple Equation

Speed (s) is equal to the distance (d) something travels divided by the time (t) it takes to cover that distance:

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

You can use this equation to calculate the speed of sound waves. For example, if a sound wave travels a distance of 662 meters in 2 seconds in air, its speed is:

$$s = \frac{d}{t} = \frac{662 \text{ m}}{2 \text{ s}} = 331 \text{ m/s}$$

Practice

How fast is a sound wave traveling if it travels 5,000 m in 5 s?

Review

- Math Practice
- Personal Tutor

The Human Ear

When you think about your ears, you probably only think about the structure on each side of your head. However, there is more to your ears than those structures. The human ear has three parts—the outer ear, the middle ear, and the inner ear, as shown in **Figure 4.**

1 The Outer Ear

The outer ear collects sound waves. The structure on each side of your head is part of the outer ear. The ear canal is also part of the outer ear, as shown in **Figure 4.** The visible part of the outer ear funnels sound waves into the ear canal. The ear canal channels sound waves into the middle ear.

2 The Middle Ear

The middle ear amplifies sound waves. As shown in **Figure 4,** the middle ear includes the eardrum and three tiny bones. The eardrum is a thin membrane that stretches across the ear canal. The three tiny bones are called the hammer, the anvil, and the stirrup. A sound wave hitting the eardrum causes it to vibrate. The vibrations travel to the three bones, which amplify the sound.

3 The Inner Ear

The inner ear converts vibrations to nerve signals that travel to the brain. The inner ear consists of a small, fluid-filled chamber called the cochlea (KOH klee uh). Tiny hairlike cells line the inside of the cochlea. As a sound wave travels into the cochlea, it causes some hair cells to vibrate. The movements of these hair cells produce nerve signals that travel to the brain.

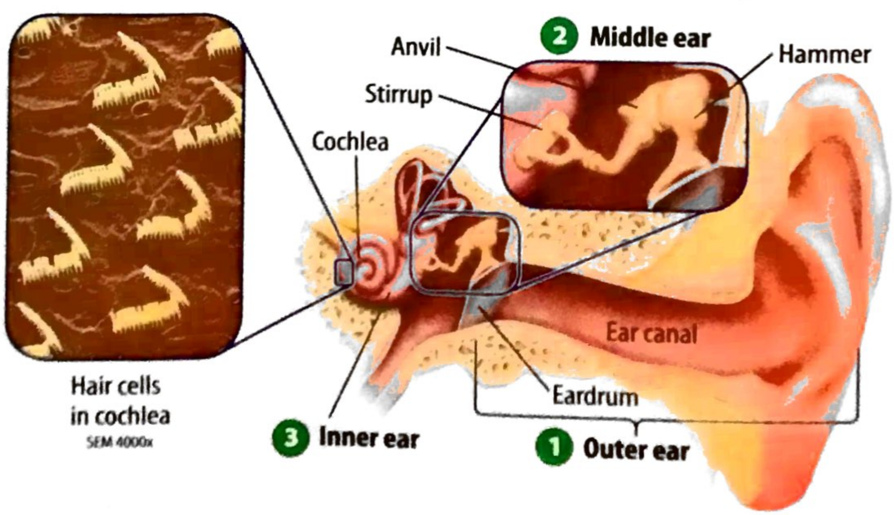
Key Concept Check What is the function of each of the three parts of the ear?

Structure of the Ear

Concepts in Motion Animation

Figure 4 The human ear has three parts. The outer ear collects sound waves, the middle ear amplifies these waves, and the inner ear converts them to nerve signals.

Visual Check Which parts of the ear are considered the middle ear?



Frequencies and the Human Ear

As you can see in **Table 2,** humans hear sounds with frequencies between about 20 and 20,000 Hz. Some mammals can hear sounds with frequencies greater than 100,000 Hz.

Table 2 Frequencies Different Mammals Can Hear

Creature	Frequency Range (Hz)
Human	20–20,000
Dog	67–45,000
Cat	45–64,000
Bat	2,000–110,000
Beluga whale	1,000–123,000
Porpoise	75–150,000

▲ **Table 2** Different mammals can hear sound waves over different ranges of frequencies.

Sound and Pitch

Have you ever played a guitar? A guitar has strings with different thicknesses. If you pluck a thick string, you hear a low note. If you pluck a thin string, you hear a higher note. The sound a thick string makes has a lower pitch than the sound a thin string makes. *The* pitch *of a sound is the perception of how high or low a sound seems.* A sound wave with a higher frequency has a higher pitch. A sound wave with a lower frequency has a lower pitch.

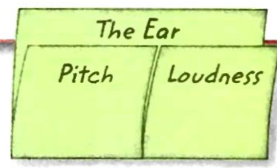
Reading Check How does the pitch of a sound wave depend on the frequency of the sound wave?

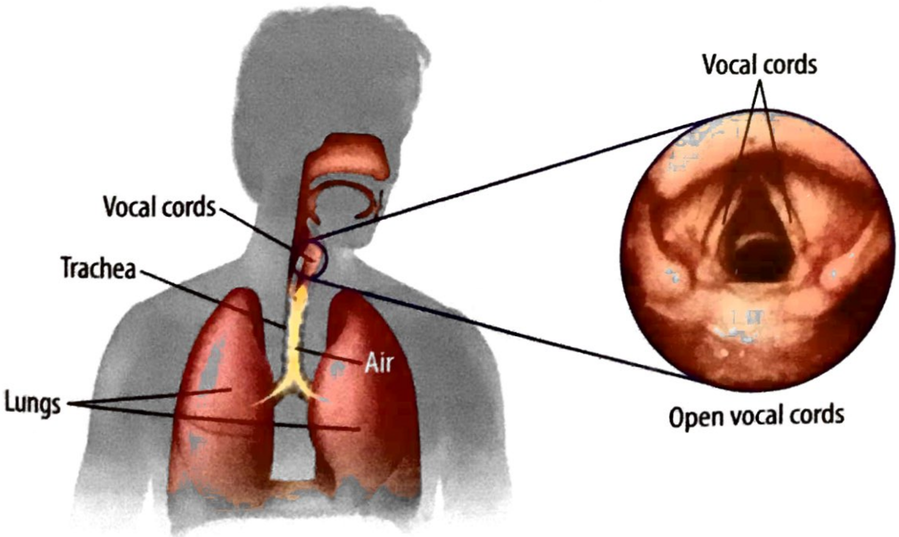
You can produce sounds of different pitches by using your vocal cords. The vocal cords, shown in **Figure 5,** are two membranes in your neck above your windpipe, or trachea (TRAY kee uh). When you speak, you force air from your lungs through the space between the vocal cords. This causes the vocal cords to vibrate, creating sound waves you and other people hear as your voice.

Muscles connected to your vocal cords enable you to change the pitch of your voice. When these muscles contract, they pull on your vocal cords. This stretches the vocal cords and they become longer and thinner. The pitch of your voice is then higher, just as a thinner guitar string has a higher pitch than a thicker guitar string. When these muscles relax, the vocal cords become shorter and thicker and the pitch of your voice becomes lower.

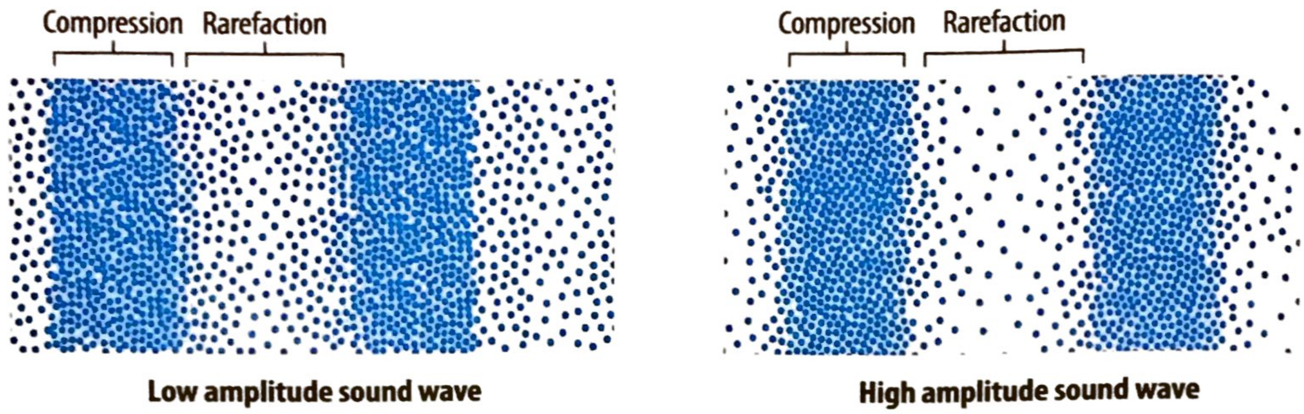
FOLDABLES®

Make a two-tab concept map book. Label it as shown. Use it to organize information about pitch and loudness.





◀ **Figure 5** The vocal cords vibrate by opening and closing when air is forced through them. These vibrations produce the sounds of the human voice.



▲ **Figure 6** The amplitude of a sound wave depends on how close together or far apart the particles are in the compressions and rarefactions.

Visual Check How do distances between particles differ in high- and low-amplitude sound waves?

Concepts in Motion

Animation

Sound and Loudness

Why is a shout louder than a whisper? Loudness is the human sensation of how much energy a sound wave carries. Sound waves produced by shouting carry more energy than sound waves produced by whispering. As a result, a shout sounds louder than a whisper.

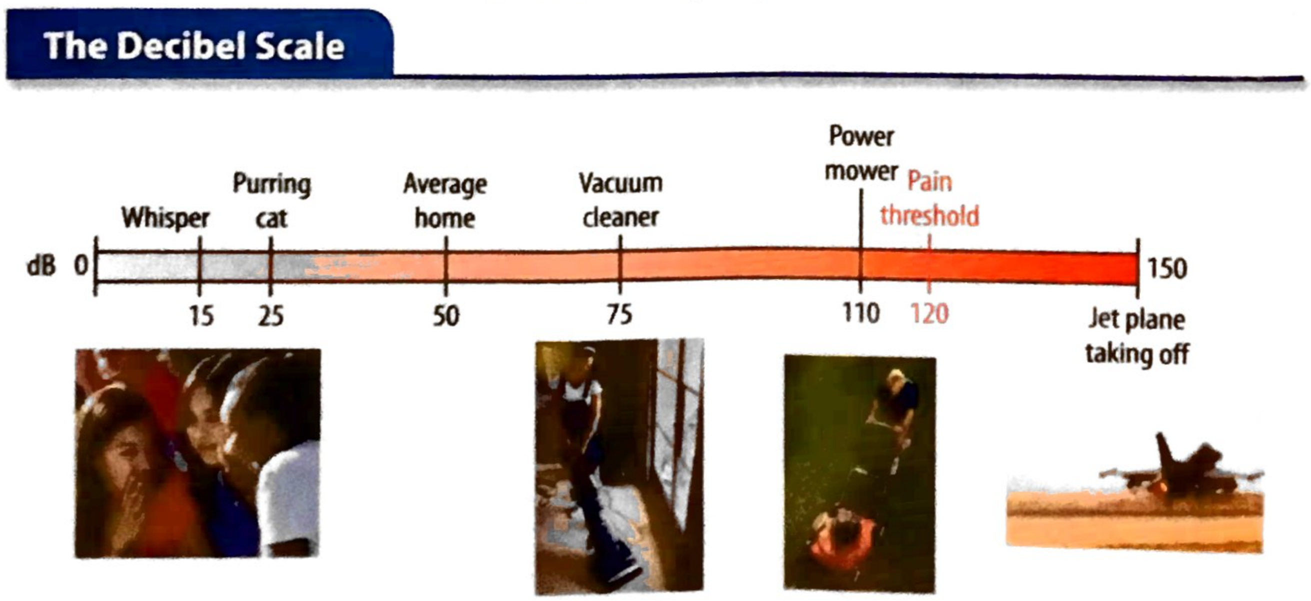
Amplitude and Energy

The amplitude of a wave depends on the amount of energy that the wave carries. The more energy a wave has, the greater the amplitude. **Figure 6** shows the difference between a high-amplitude sound wave and a low-amplitude sound wave. High-amplitude sound waves have particles that are closer together in the compressions and farther apart in the rarefactions.

The Decibel Scale

The decibel scale, shown in **Figure 7**, is one way to compare the loudness of sounds. On this scale, the softest sound a person can hear is about 0 decibels (dB), and a jet plane taking off is at about 150 dB. Normal conversation is at about 50 dB. A sound wave that is 10 dB higher than another sound wave carries 10 times more energy. However, people hear the higher-energy sound wave as being only twice as loud.

Figure 7 The loudness of sounds can be compared on the decibel scale. ▼



Lesson 2

Light

Reading Guide

Key Concepts
ESSENTIAL QUESTIONS

- How are light waves different from sound waves?
- How do waves in the electromagnetic spectrum differ?
- What happens to light waves when they interact with matter?

Vocabulary
light source p. 135
light ray p. 135
transparent p. 136
translucent p. 136
opaque p. 136

Multilingual eGlossary

Video
- BrainPOP®
- Science Video
- What's Science Got to do With It?

Inquiry Are both men real?

No, the man on the right is a hologram. A hologram is a type of image that seems to be three-dimensional. Light from a laser is reflected from the person and is used to create the life-like image. What are light waves and how do they interact with matter?

Inquiry Launch Lab

15 minutes

What happens when light waves pass through water?

Do light waves always travel in a straight line? What happens to light waves when they travel through water?

1. Read and complete a lab safety form.
2. Add **distilled water** to a **500-mL beaker** until it is two-thirds full.
3. Use **scissors** to cut a thin slit in a sheet of **paper.** **Tape** the paper over the lens of a **flashlight.**
4. Turn on the flashlight and tilt it slightly downward so the light beam is visible on the tabletop. Place the water-filled beaker in the light beam. Record your observations in your Science Journal.

Think About This

Key Concept Compare the direction of the light beam before it entered the water to after it left the water.

What is light?

As you read these words, you are probably looking at a page in a book. You might also see the desk on which the book is resting as well as the light from a lamp. What do your eyes detect when you see something?

Your eyes sense light waves. You see books and desks when light waves reflect off these objects and enter your eyes. Some objects, like a candle flame and a lightbulb that is lit, also emit light waves. You see a candle flame or a glowing lightbulb because the light waves they emit enter your eyes.

Light—An Electromagnetic Wave

Light is a type of wave called an electromagnetic wave. Like sound waves, electromagnetic waves can travel through matter. But they can also travel through a vacuum, where no matter is present. For example, light can travel through the space between Earth and the Sun.

Light travels through a vacuum at a speed of about 300,000 km/s. However, light waves slow down when they travel through matter. The speed of light in some different materials is listed in **Table 3.** Light waves travel much faster than sound waves. For example, in air the speed of light is about 900,000 times faster than the speed of sound.

Key Concept Check How are light waves different from sound waves?

Table 3 Light waves travel fastest in empty space. When light waves travel in matter, they move fastest in gases and slowest in solids.

Table 3 Speed of Light Waves in Some Materials

Material	Wave Speed (km/s)
Vacuum	300,000
Air	299,920
Water	225,100
Glass	193,000

The Electromagnetic Spectrum

Review | Personal Tutor

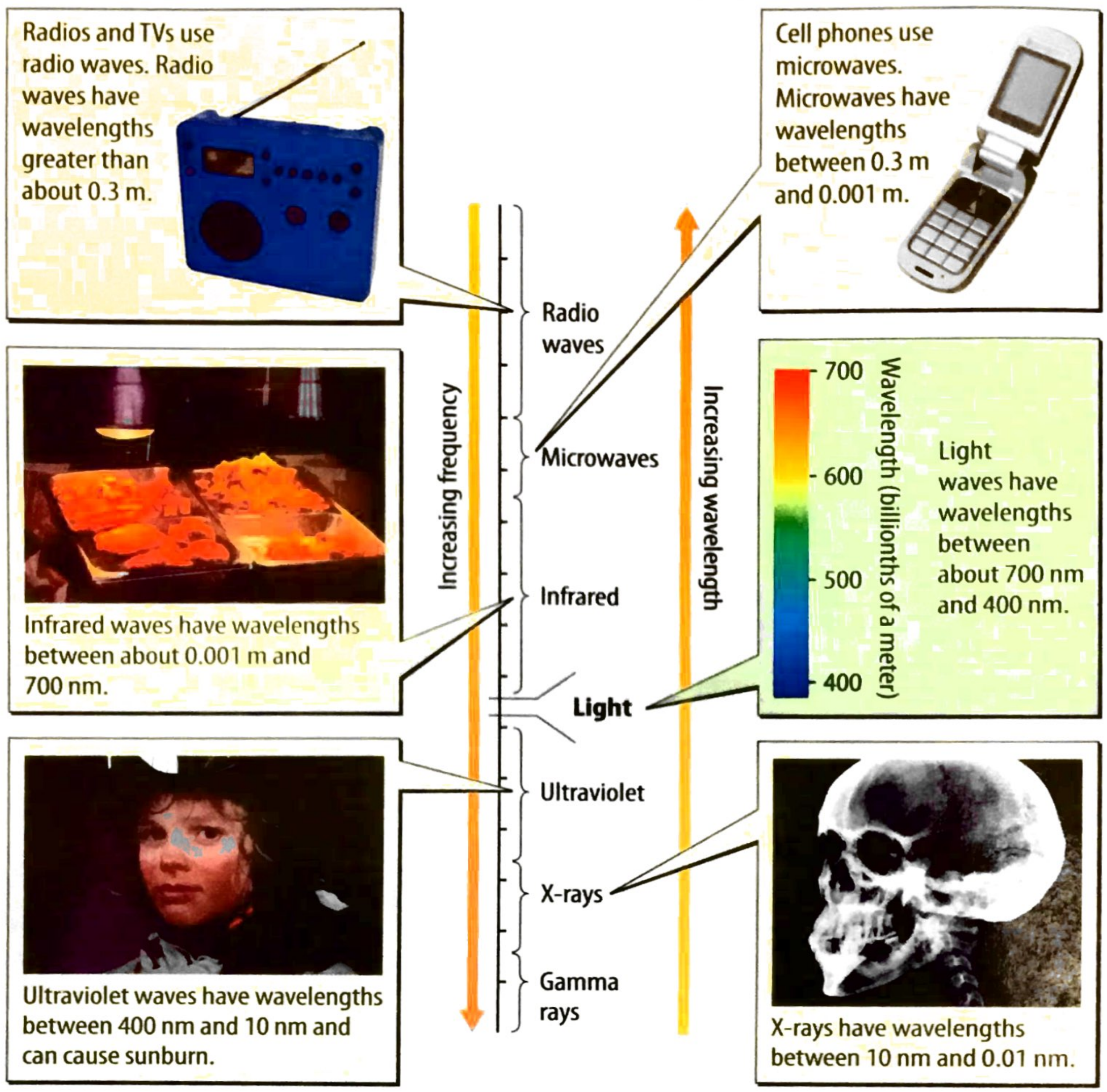


Figure 10 Electromagnetic waves are classified according to their wavelength or frequency. Visible light waves are part of the electromagnetic spectrum.

Visual Check Which type of electromagnetic waves have the longest wavelengths?

The Electromagnetic Spectrum

Besides visible light waves, there are other types of electromagnetic waves, such as X-rays and radio waves. Scientists classify electromagnetic waves into groups based on their wavelengths, as shown in **Figure 10.** The entire range of electromagnetic waves is called the electromagnetic spectrum.

Key Concept Check How are waves in the electromagnetic spectrum different?

Light waves are only a small part of the electromagnetic spectrum. The wavelengths of light waves are so short they are usually measured in nanometers (nm). One nanometer equals one-billionth of a meter. The wavelengths of light waves are from about 700 nm to about 400 nm. This is about one-hundredth the width of a human hair. You see different colors when different wavelengths of light waves enter your eyes.

Light-Emitting Objects

Think about walking into a dark room and turning on a light. The lightbulb produces light waves that travel away from the bulb in all directions, as shown in **Figure 11.** *A* light source *is something that emits light.* In order to emit light, the lightbulb transforms electric energy into light energy. Other examples of light sources are the Sun and burning candles. The Sun transforms nuclear energy into light energy. Burning candles transform chemical energy into light energy. Light sources convert other forms of energy into light energy.

Light Rays

As you just read, light waves spread out in all directions from a light source. You also can think of light in terms of light rays. *A* light ray *is a narrow beam of light that travels in a straight line.* The arrows in **Figure 11** represent some of the light rays moving away from the light source. Unless light rays come in contact with a surface or pass through a different material, they travel in straight lines.

Reading Check What is a light ray?

Light Reflection

Suppose you are in a dark room. Do you see anything? Now you turn on a light. What do you see now? Light sources emit light. But other objects, like books, reflect light. In order to see an object that is not a light source, light waves must reflect from an object and enter your eyes.

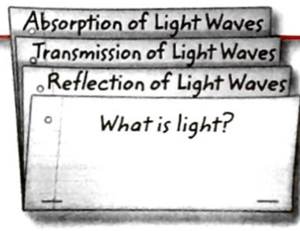
Seeing Objects

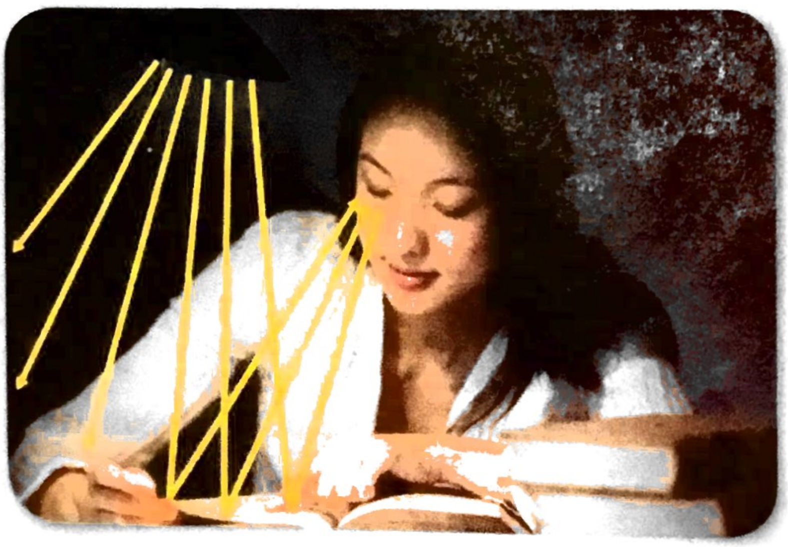
When you see a light source, light rays travel directly from the light source into your eye. Light rays also reflect off objects, as shown in **Figure 12.** Light rays reflect from an object in many directions. Some of the light rays that reflect from an object enter your eye, enabling you to see the object.

▲ **Figure 11** Light travels in all directions away from its source.

FOLDABLES

Make a layered book from two sheets of paper. Use it to summarize information about light and how light waves interact with matter.





◀ **Figure 12** Some light waves from a light source reach the page and reflect off it. The girl sees the page when some of the reflected light enters her eyes.

Figure 13 The butterfly's wing, the frosted glass, and the curtains interact with light waves differently.

Transparent

Translucent

Opaque

WORD ORIGIN

opaque
from Latin *opacus*, means "shady, dark"

The Interaction of Light and Matter

Like all waves, when light waves interact with matter they can be transmitted, absorbed, or reflected.

- Reflection occurs when light waves come in contact with the surface of a material and bounce off.
- Transmission occurs when light waves travel through a material.
- Absorption occurs when interactions with a material convert light energy into other forms such as thermal energy.

In many materials, reflection, transmission, and absorption occur at the same time. For example, the tinted glass of an office building reflects some light, transmits some light, and absorbs some light.

Key Concept Check What can happen to light waves when they interact with matter?

Depending on how they interact with light, materials can be classified as transparent, translucent, or opaque, as shown in **Figure 13.** *A material is* transparent *if it allows almost all light that strikes it to pass through and forms a clear image. A material is* translucent *if it allows most of the light that strikes it to pass but forms a blurry image. A material is* opaque *if light does not pass through it.* An opaque material, such as light-blocking cloth curtains, does not transmit light.

The Reflection of Light Waves

Figure 14 shows what happens when a surface reflects light waves. All waves, including light waves, obey the law of reflection. According to the law of reflection, the angle of incidence always equals the angle of reflection. In **Figure 14,** the line perpendicular to a surface is called the normal. The angle between the normal and the incoming light ray is the angle of incidence. The angle between the reflected light ray and the normal is the angle of reflection.

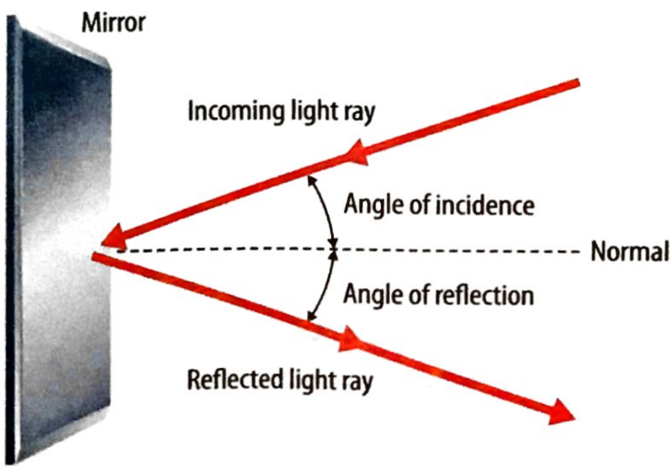
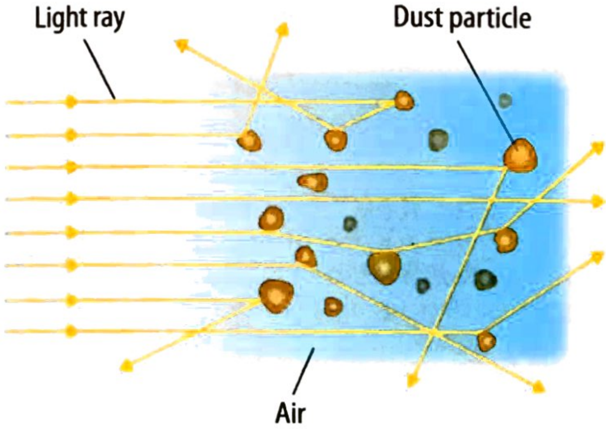


Figure 14 When a surface reflects a light ray, the angle of incidence equals the angle of reflection.

Visual Check How will the angle of reflection change if the angle of incidence increases?

Figure 15 Particles of dust floating in the air scatter light rays in a sunbeam. When light rays strike these particles, light rays reflect in many different directions. ▼



Scattering

When a beam of sunlight shines through a window, you might notice tiny particles of dust. You see the dust particles because they reflect light waves. As **Figure 15** shows, dust particles reflect light waves in many different directions because they have different shapes. This is an example of scattering. Scattering occurs when light waves traveling in one direction are made to travel in many directions. The dust particles scatter the light waves in the sunbeam.

The Refraction of Light Waves

Like all types of waves, light waves can change direction when they travel from one material to another. The light beam in **Figure 16** changes direction as it goes from the air into the glass and from the glass into the air. A wave that changes direction as it travels from one material into another is refracting.

Recall that light waves travel at different speeds in different materials. Refraction occurs when a wave changes speed. The greater the change in speed, the more the light wave refracts or changes direction.

Reading Check When does refraction occur?

Inquiry MiniLab 15 minutes

Can you see a light beam in water?

Scattering by water droplets in air enables you to see a car's headlight beams on a foggy day or night. What could enable you to see a light beam traveling in water?

1. Read and complete a lab safety form.
2. Add **distilled water** to a **clear glass jar** until it is two-thirds full.
3. Shine the light from a **flashlight** through the water and record your observations in your Science Journal.
4. Add a few drops of **milk** to the water and swirl the jar to mix the milk and water. Repeat step 3.

Analyze and Conclude

1. **Compare** the appearance of the light beams in steps 3 and 4.
2. **Key Concept** Hypothesize how the milk enabled the light beam to be visible in the milk-water mixture.

▲ **Figure 16** The red beam of light slows down as it enters the glass rectangle. It speeds up as it leaves the rectangle and enters the air.

The Colors of Objects

The objects you see around you are different colors. A banana is mostly yellow, but a rose might be red. Why is a banana a different color from a rose? Bananas and roses do not give off, or emit, light. Instead, they reflect light. The colors of an object depend on the wavelengths of the light waves it reflects.

Reflection of Light and Color

When light waves of different wavelengths interact with an object, the object absorbs some light waves and reflects others. The wavelengths of light waves absorbed and reflected depend on the materials from which the object is made.

For example, **Figure 23** shows that the rose is red because the petals of the rose reflect light waves with certain wavelengths. When these light waves enter your eye, they cause the cone cells in your retina to send certain nerve signals to your brain. These signals cause you to see the rose as red.

A banana reflects different wavelengths of light than a rose. These different wavelengths cause cone cells in the retina to send different signals to your brain. These signals cause you to see the banana as yellow instead of red.

You might think that light waves have colors. Color, however, is a sensation produced by your brain when light waves enter your eyes. Light waves have no color as they travel from an object to your eyes.

Key Concept Check Why do you experience the sensation of color?

The Color of Objects that Emit Light

Some objects such as the Sun, lightbulbs, and neon lights emit light. The color of an object that emits light depends on the wavelengths of the light waves it emits. For example, a red neon light emits light waves with wavelengths that you see as red.

The rose reflects light waves with wavelengths that you see as red. It absorbs all other wavelengths of light.

The banana reflects light waves with wavelengths that you see as yellow. It absorbs all other wavelengths of light.

Figure 23 The color of an object depends on the wavelengths of the light waves the object reflects.

Concepts in Motion Animation