Section 1

The Nature of Electromagnetic Waves

Reading Preview

Key Concepts

- What does an electromagnetic wave consist of?
- What models explain the behavior of electromagnetic waves?

Key Terms

- electromagnetic wave
- electromagnetic radiation
- polarized light
- photoelectric effect
- photon

Target Reading Skill

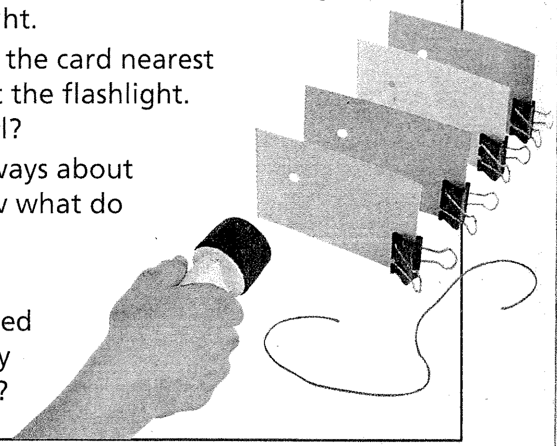
Outlining An outline shows the relationship between major ideas and supporting ideas. As you read, make an outline about electromagnetic waves. Use the red headings for the main topics and the blue headings for the subtopics.

The Nature of Electromagnetic Waves
I. What is an electromagnetic wave?
A. Producing electromagnetic waves
B.
C.
II. Models of electromagnetic waves
A.
B.

Lab zone Discover Activity

How Does a Beam of Light Travel?

1. Punch a hole (about 0.5 cm in diameter) through four large index cards.
2. Use binder clips or modeling clay to stand each card upright so that the long side of the index card is on the tabletop. Space the cards about 10 cm apart, as shown in the photo. To line the holes up in a straight line, run a piece of string through them and pull it tight.
3. Place a flashlight in front of the card nearest you. Shut off all light except the flashlight. What do you see on the wall?
4. Move one of the cards sideways about 3 cm and repeat Step 3. Now what do you see on the wall?

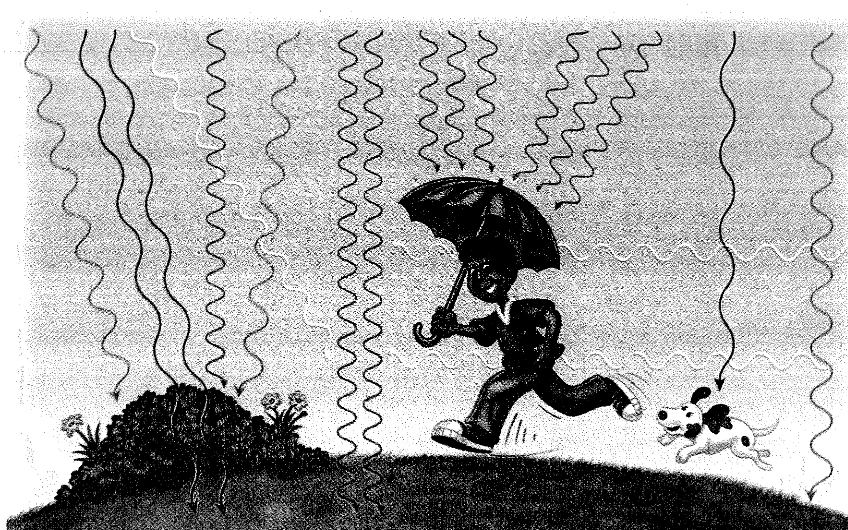


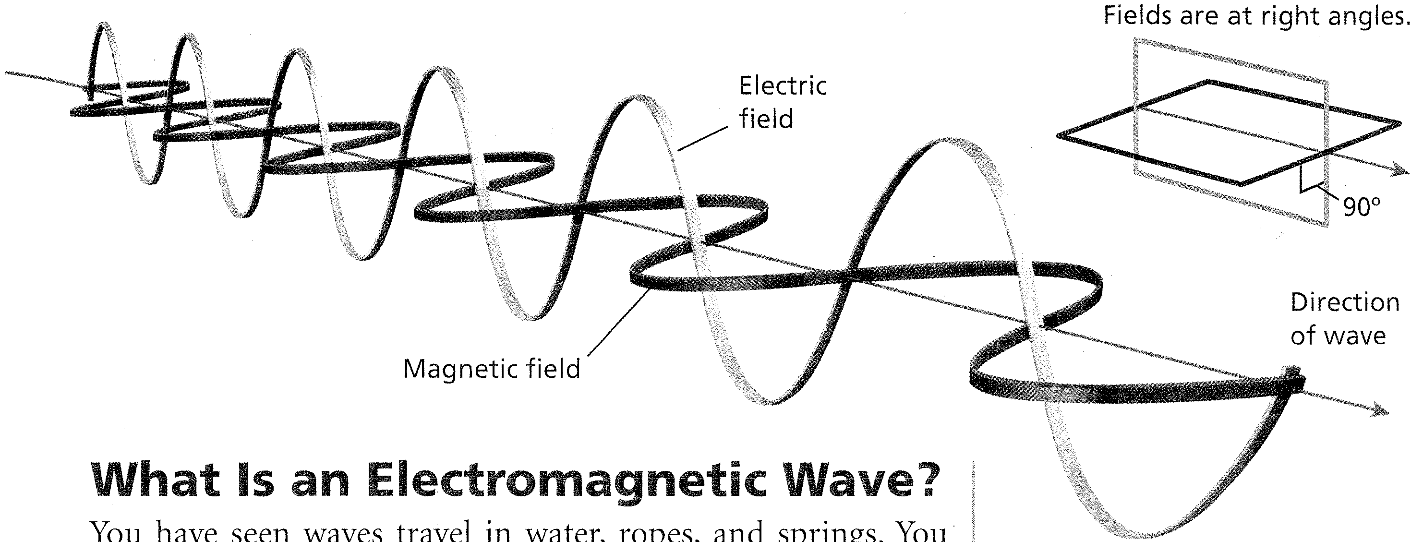
Think It Over

Inferring Explain what happened in Step 4. What does this activity tell you about the path of light?

Have you ever been caught in a rain shower? You run for cover until it passes, so you don't get wet. Believe it or not, you are being "showered" all the time, not by rain but by waves. You cannot see, feel, or hear most of these waves. But as you read this, you are surrounded by radio waves, infrared rays, visible light, ultraviolet rays, and maybe even tiny amounts of X-rays and gamma rays. They are all electromagnetic waves.

Electromagnetic waves ▶





What Is an Electromagnetic Wave?

You have seen waves travel in water, ropes, and springs. You have heard sound waves that travel through air and water. All these waves have two things in common—they transfer energy and they also require a medium through which to travel. But electromagnetic waves can transfer energy without a medium. An **electromagnetic wave** is a transverse wave that transfers electrical and magnetic energy. **An electromagnetic wave consists of vibrating electric and magnetic fields that move through space at the speed of light.**

Producing Electromagnetic Waves Light and all other electromagnetic waves are produced by charged particles. Every charged particle has an electric field surrounding it. The electric field produces electric forces that can push or pull on other charged particles.

When a charged particle moves, it produces a magnetic field. A magnetic field exerts magnetic forces that can act on certain materials. If you place a paper clip near a magnet, for example, the paper clip moves toward the magnet because of the magnetic field surrounding the magnet.

When a charged particle changes its motion, its magnetic field changes. The changing magnetic field causes the electric field to change. When one field vibrates, so does the other. In this way, the two fields constantly cause each other to change. The result is an electromagnetic wave, as shown in Figure 1. Notice that the two fields vibrate at right angles to each other.

Energy The energy that is transfered through space by electromagnetic waves is called **electromagnetic radiation.** Electromagnetic waves do not require a medium, so they can transfer energy through a vacuum, or empty space. This is why you can see the sun and stars—their light reaches Earth through the vacuum of space.

FIGURE 1
Electromagnetic Wave
In an electromagnetic wave, electric and magnetic fields vibrate at right angles to each other. **Classifying** *What type of wave is an electromagnetic wave?*

For: Links on the nature of waves
Visit: www.SciLinks.org
Web Code: scn-1531

Speed All electromagnetic waves travel at the same speed in a vacuum—about 300,000 kilometers per second. This speed is called the speed of light. At this speed, light from the sun takes about 8 minutes to travel the 150 million kilometers to Earth. When light waves travel through a medium such as air, they travel more slowly. But the speed of light waves in air is still about a million times faster than the speed of sound waves in air.

Reading Checkpoint What is the speed of light in a vacuum?

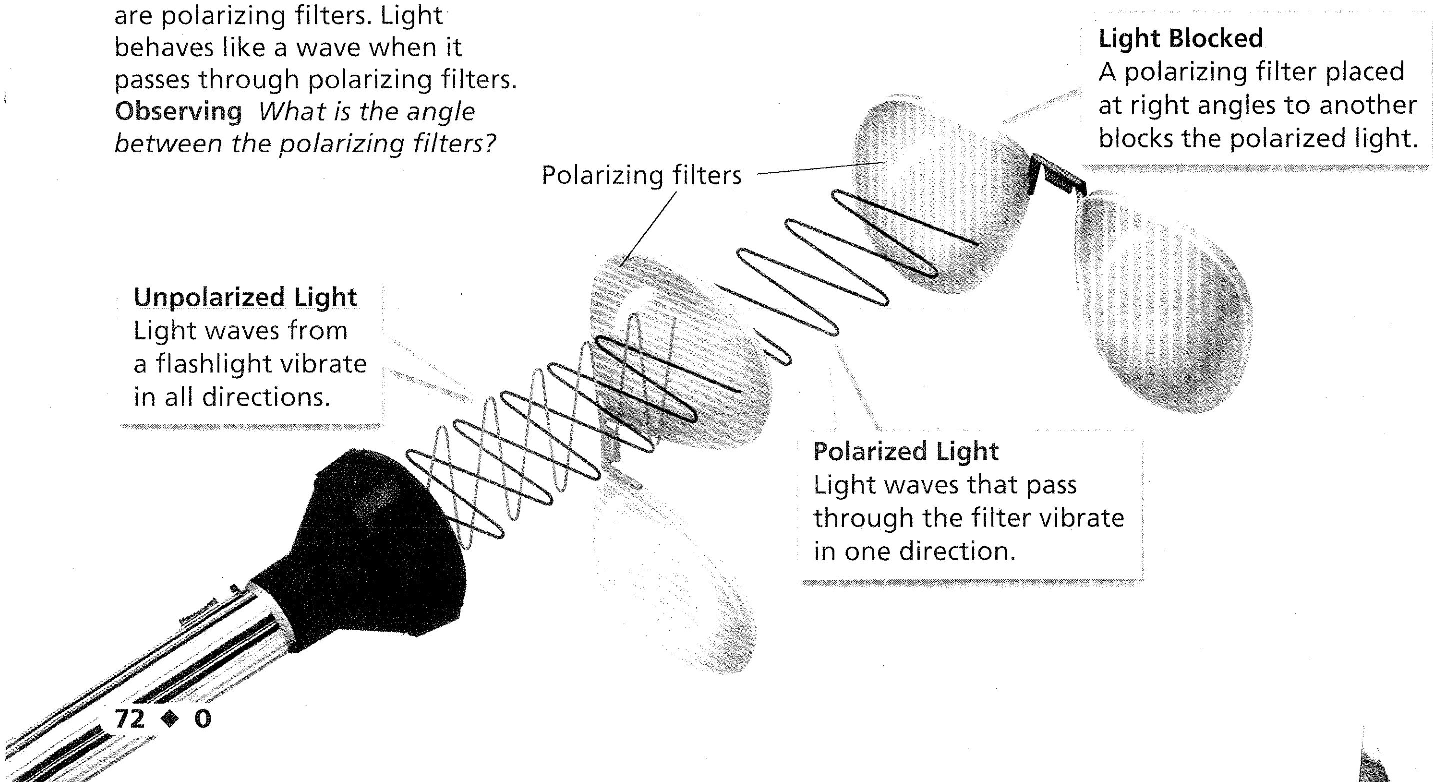
Models of Electromagnetic Waves

Many properties of electromagnetic waves can be explained by a wave model. However, some properties are best explained by a particle model. As you have learned, light is an electromagnetic wave. Both a wave model and a particle model are needed to explain all of the properties of light.

Wave Model of Light The lenses of many sunglasses, like the ones shown in Figure 2, are polarizing filters. Light acts as a wave when it passes through a polarizing filter. Ordinary light has waves that vibrate in all directions—up and down, left and right, and at all other angles. A polarizing filter acts as though it has tiny slits that are aligned in one direction.

Only some light waves pass through a polarizing filter. The light that passes through vibrates in only one direction and is called **polarized light.** No light passes through two polarizing filters that are placed at right angles to each other.

FIGURE 2
Light as a Wave
The lenses of some sunglasses are polarizing filters. Light behaves like a wave when it passes through polarizing filters.
Observing *What is the angle between the polarizing filters?*



To help you understand the wave model of light, think of waves of light as being like transverse waves on a rope. If you shake a rope through a fence with vertical slats, only waves that vibrate up and down will pass through. If you shake the rope side to side, the waves will be blocked. A polarizing filter acts like the slats in a fence. It allows only waves that vibrate in one direction to pass through.

Particle Model of Light Sometimes light behaves like a stream of particles. When a beam of light shines on some substances, it causes tiny particles called electrons to move. The movement of electrons causes an electric current to flow. Sometimes light can even cause an electron to move so much that it is knocked out of the substance. This is called the **photoelectric effect.** The photoelectric effect can be explained only by thinking of light as a stream of tiny packets, or particles, of energy. Each packet of light energy is called a **photon.** Albert Einstein first explained the science behind the photoelectric effect in 1905.

It may be difficult for you to picture light as being particles and waves at the same time. But both models are necessary to explain all the properties of light.

Reading Checkpoint What is a photon?

Lab zone Try This Activity

Waves or Particles?

1. Fill two plastic cups with water. Slowly pour the water from both cups into a sink so the streams of water cross. How do the two streams interfere with each other?
2. Darken a room. Use a slide projector to project a slide on a wall. Shine a flashlight beam across the projector's beam. What is the effect on the projected picture?

Drawing Conclusions Compare the interference of light beams with the interference of water streams. Does this activity support a wave model or a particle model of light? Explain.

Section 1 Assessment

Target Reading Skill Outlining Use the information in your outline about electromagnetic waves to help you answer the questions below.

Reviewing Key Concepts

1. a. **Defining** What is an electromagnetic wave?
   b. **Explaining** How do electromagnetic waves travel?
   c. **Comparing and Contrasting** What is an electric field? What is a magnetic field?
2. a. **Reviewing** What two models explain the properties of electromagnetic waves?
   b. **Describing** Use one of the models of light to describe what happens when light passes through a polarizing filter.
   c. **Relating Cause and Effect** Use one of the models of light to explain what causes the photoelectric effect.

Lab zone At-Home Activity

Polarized Sunglasses On a sunny day, go outside with your family members and compare your sunglasses. Do any have polarizing lenses? If so, which ones? Try rotating sunglasses as you look through them at surfaces that create glare, such as water or glass. Which sunglasses are best designed to reduce glare? **CAUTION:** *Do not look directly at the sun.*

Section 2

Waves of the Electromagnetic Spectrum

Reading Preview

Key Concepts

- How are electromagnetic waves alike, and how are they different?
- What waves make up the electromagnetic spectrum?

Key Terms

- electromagnetic spectrum
- radio waves • microwaves
- radar • infrared rays
- thermogram • visible light
- ultraviolet rays • X-rays
- gamma rays

Target Reading Skill

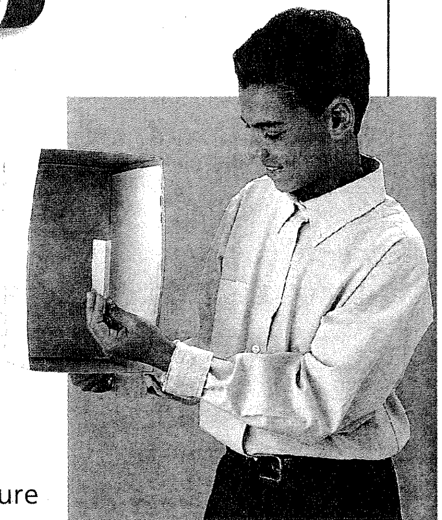
Previewing Visuals Before you read, preview Figure 3. Then write two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

The Electromagnetic Spectrum

Q.	Which electromagnetic waves have the shortest wavelength?
A.	
Q.	

Lab zone Discover Activity

What Is White Light?

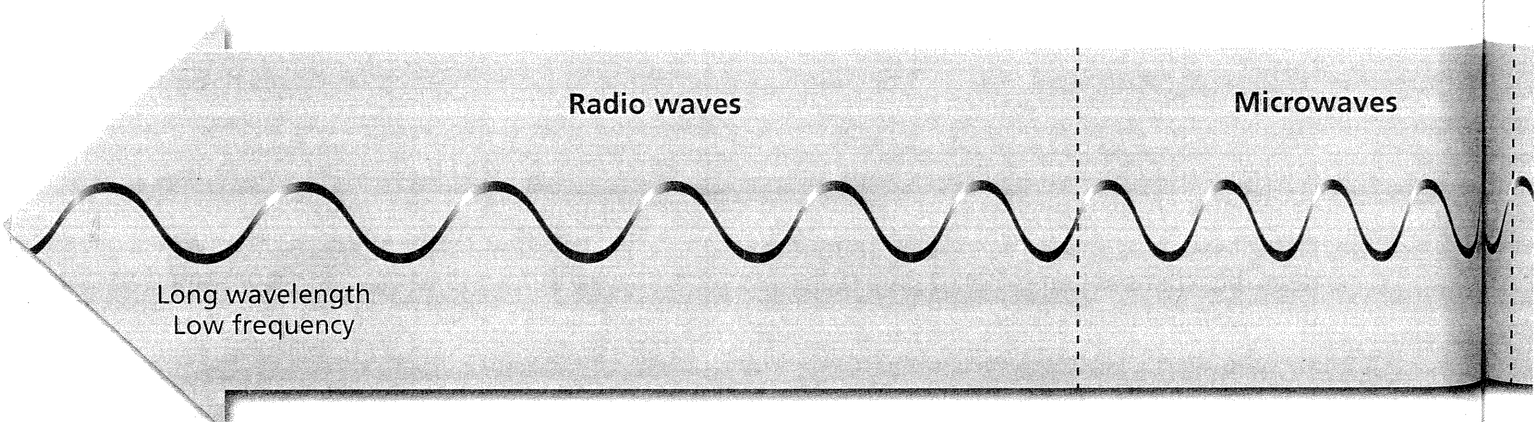


1. Line a cardboard box with white paper. Hold a small triangular prism up to direct sunlight. **CAUTION:** *Do not look directly at the sun.*
2. Rotate the prism until the light coming out of the prism appears on the inside of the box as a wide band of colors. Describe the colors and their order.
3. Using colored pencils, draw a picture of what you see inside the box.

Think It Over

Forming Operational Definitions The term *spectrum* describes a range. How is this term related to what you just observed?

Can you imagine trying to take a photo with a radio? How about trying to tune in a radio station on your flashlight or heat your food with X-rays? Light, radio waves, and X-rays are all electromagnetic waves. But each has properties that make it more useful for some purposes and less useful for others. What makes light different from radio waves and X-rays?



What Is the Electromagnetic Spectrum?

All electromagnetic waves travel at the same speed in a vacuum, but they have different wavelengths and different frequencies. Radiation in the wavelengths that your eyes can see is called visible light. But only a small portion of electromagnetic radiation is visible light. The rest of the wavelengths are invisible. Your radio detects radio waves, which have much longer wavelengths than visible light. X-rays, on the other hand, are waves with much shorter wavelengths than visible light.

Recall how speed, wavelength, and frequency are related:

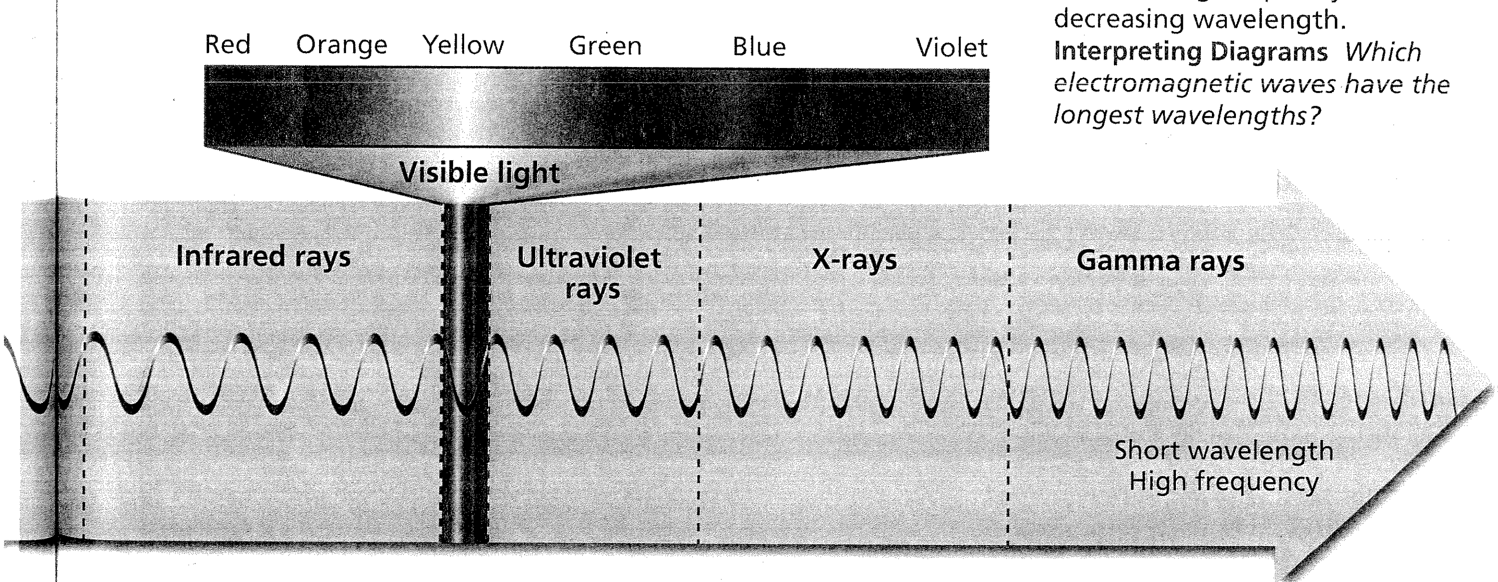
$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

Because the speed of all electromagnetic waves is the same, as the wavelength decreases, the frequency increases. Waves with the longest wavelengths have the lowest frequencies. Waves with the shortest wavelengths have the highest frequencies. The amount of energy carried by an electromagnetic wave increases with frequency. The higher the frequency of a wave, the higher its energy is.

The **electromagnetic spectrum** is the complete range of electromagnetic waves placed in order of increasing frequency. The full spectrum is shown in Figure 3. **The electromagnetic spectrum is made up of radio waves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays.**

Reading Checkpoint What is the electromagnetic spectrum?

FIGURE 3
The Electromagnetic Spectrum
The electromagnetic spectrum shows the range of different electromagnetic waves in order of increasing frequency and decreasing wavelength.
Interpreting Diagrams *Which electromagnetic waves have the longest wavelengths?*



Lab zone **Try This Activity**

Microwave Test

In this activity, you will compare how water, corn oil, and sugar absorb microwaves.

1. Add 25 mL of water to a glass beaker. Record the temperature of the water.
2. Microwave the beaker for 10 seconds and record the water temperature again.
3. Repeat Steps 1 and 2 two more times, using 25 mL of corn oil and 25 mL of sugar.

Drawing Conclusions Compare the temperature change of the three materials. Which material absorbed the most energy from the microwaves?

Radio Waves

Radio waves are the electromagnetic waves with the longest wavelengths and lowest frequencies. They include broadcast waves (for radio and television) and microwaves.

Broadcast Waves Radio waves with longer wavelengths are used in broadcasting. They carry signals for both radio and television programs. A broadcast station sends out radio waves at certain frequencies. Your radio or TV antenna picks up the waves and converts the radio signal into an electrical signal. Inside your radio, the electrical signal is converted to sound. Inside your TV, the signal is converted to sound and pictures.

Microwaves The radio waves with the shortest wavelengths and the highest frequencies are **microwaves.** When you think of microwaves, you probably think of microwave ovens that cook and heat your food. But microwaves have many uses, including cellular phone communication and radar.

Radar stands for **ra**dio **d**etection **a**nd **r**anging. **Radar** is a system that uses reflected radio waves to detect objects and measure their distance and speed. To measure distance, a radar device sends out radio waves that reflect off an object. The time it takes for the reflected waves to return is used to calculate the object's distance. To measure speed, a radar device uses the Doppler effect, which you learned about in an earlier chapter. For example, a police radar gun like the one in Figure 4 sends out radio waves that reflect off a car. Because the car is moving, the frequency of the reflected waves is different from the frequency of the original waves. The difference in frequency is used to calculate the car's speed.

Reading Checkpoint **What does *radar* stand for?**

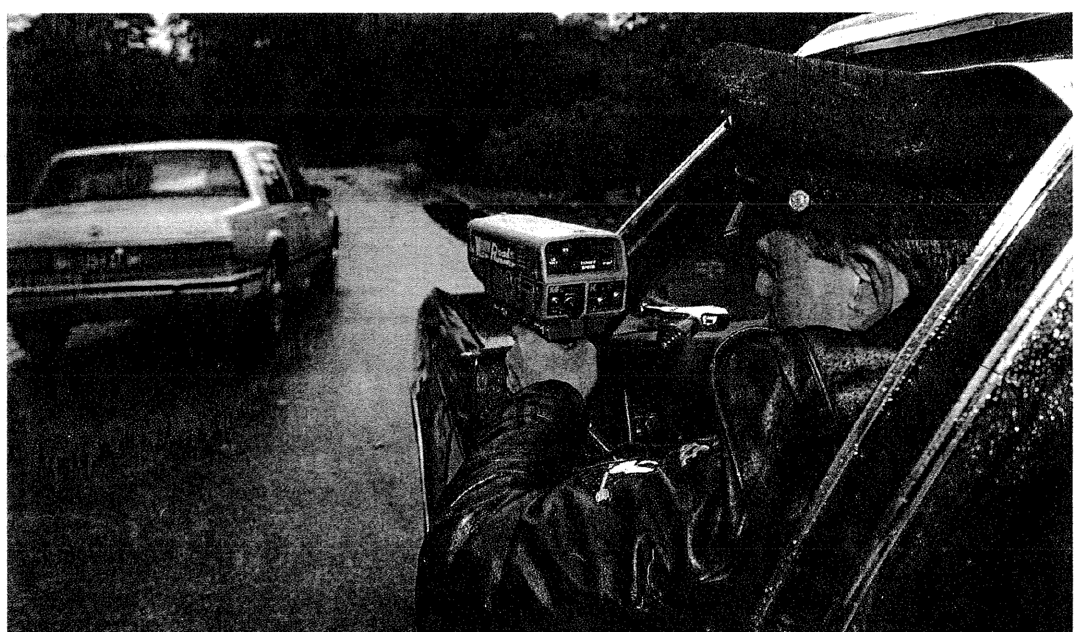


FIGURE 4
Radar Gun
Radio waves and the Doppler effect are used to find the speeds of moving vehicles.

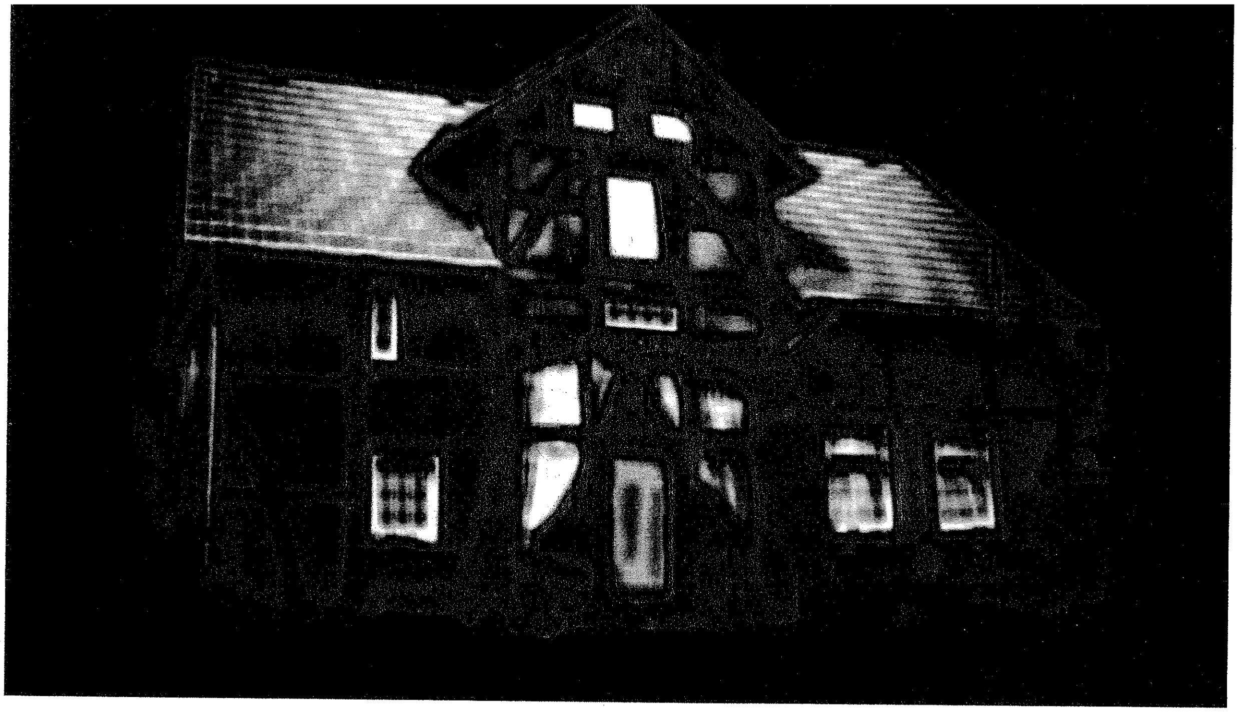


FIGURE 5
Infrared Images
An infrared camera produced this image, called a thermogram. Regions of different temperatures appear in different colors.
Interpreting Photographs *Which areas of the house are warmest (color-coded white)? Which are coolest (color-coded blue)?*

Infrared Rays

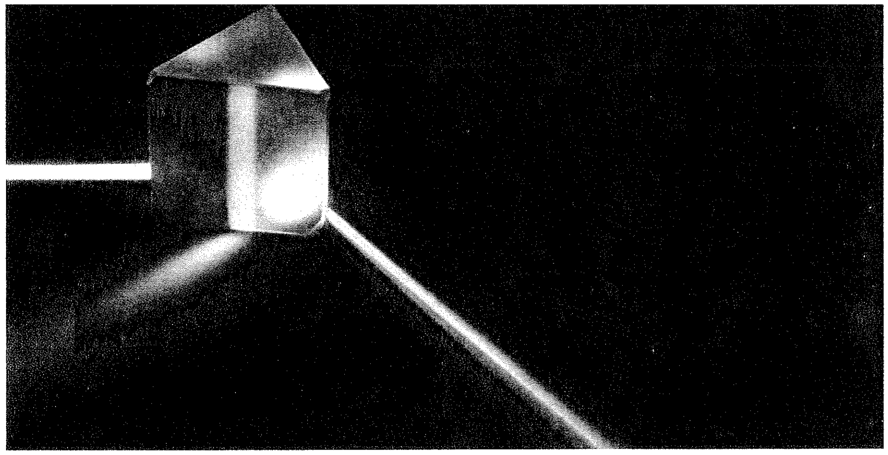
If you turn on a burner on an electric stove, you can feel it warm up before the heating element starts to glow. The invisible heat you feel is infrared radiation, or infrared rays. **Infrared rays** are electromagnetic waves with wavelengths shorter than those of radio waves.

Heat Lamps Infrared rays have a higher frequency than radio waves, so they have more energy than radio waves. Because you can feel the energy of infrared rays as heat, these rays are often called heat rays. Heat lamps have bulbs that give off mostly infrared rays and very little visible light. These lamps are used to keep food warm at a cafeteria counter. Some people use heat lamps to warm up their bathrooms quickly.

Infrared Cameras Most objects give off some infrared rays. Warmer objects give off infrared waves with more energy and higher frequencies than cooler objects. An infrared camera takes pictures using infrared rays instead of light. These pictures are called thermograms. A **thermogram** is an image that shows regions of different temperatures in different colors. Figure 5 shows a thermogram of a house. You can use an infrared camera to see objects in the dark. Firefighters use infrared cameras to locate fire victims inside a dark or smoky building. Satellites in space use infrared cameras to study the growth of plants and the motions of clouds.

Reading Checkpoint **What does an infrared camera use to take pictures?**

FIGURE 6
Refraction in a Prism
When white light passes through a prism, refraction causes the light to separate into its wavelengths.
Observing *Which color of light is refracted the least?*



Visible Light

Electromagnetic waves that you can see are called **visible light.** They make up only a small part of the electromagnetic spectrum. Visible light waves have shorter wavelengths and higher frequencies than infrared rays. Visible light waves with the longest wavelengths appear red in color. As the wavelengths decrease, you can see other colors of light. The shortest wavelengths of visible light appear violet in color.

Visible light that appears white is actually a mixture of many colors. White light from the sun can be separated by a prism into the colors of the visible spectrum—red, orange, yellow, green, blue, and violet. Recall that when waves enter a new medium, the waves bend, or refract. The prism refracts different wavelengths of visible light by different amounts and thereby separates the colors. Red light waves refract the least. Violet light waves refract the most.

Ultraviolet Rays

Electromagnetic waves with wavelengths just shorter than those of visible light are called **ultraviolet rays.** Ultraviolet rays have higher frequencies than visible light, so they carry more energy. The energy of ultraviolet rays is great enough to damage or kill living cells. In fact, ultraviolet lamps are often used to kill bacteria on hospital equipment.

Small doses of ultraviolet rays are useful. For example, ultraviolet rays cause skin cells to produce vitamin D, which is needed for healthy bones and teeth. However, too much exposure to ultraviolet rays is dangerous. Ultraviolet rays can burn your skin, cause skin cancer, and damage your eyes. If you apply sunblock and wear sunglasses that block ultraviolet rays, you can limit the damage caused by ultraviolet rays.

Reading Checkpoint How can ultraviolet rays be useful?

Math Skills

Scientific Notation

Frequencies of waves often are written in scientific notation. A number in scientific notation consists of a number between 1 and 10 that is multiplied by a power of 10. To write 150,000 Hz in scientific notation, move the decimal point left to make a number between 1 and 10:

1.50,000 Hz

In this case, the number is 1.5. The power of 10 is the number of spaces you moved the decimal point. In this case, it moved 5 places, so

$$150{,}000 \text{ Hz} = 1.5 \times 10^5 \text{ Hz}$$

Practice Problem A radio wave has a frequency of 5,000,000 Hz. Write this number in scientific notation.

X-Rays

X-rays are electromagnetic waves with wavelengths just shorter than those of ultraviolet rays. Their frequencies are just a little higher than ultraviolet rays. Because of their high frequencies, X-rays carry more energy than ultraviolet rays and can penetrate most matter. But dense matter, such as bone or lead, absorbs X-rays and does not allow them to pass through. Therefore, X-rays are used to make images of bones inside the body or of teeth, as shown in Figure 7. X-rays pass through skin and soft tissues, causing the photographic film in the X-ray machine to darken when it is developed. The bones, which absorb X-rays, appear as the lighter areas on the film.

Too much exposure to X-rays can cause cancer. If you've ever had a dental X-ray, you'll remember that the dentist gave you a lead apron to wear during the procedure. The lead absorbs X-rays and prevents them from reaching your body.

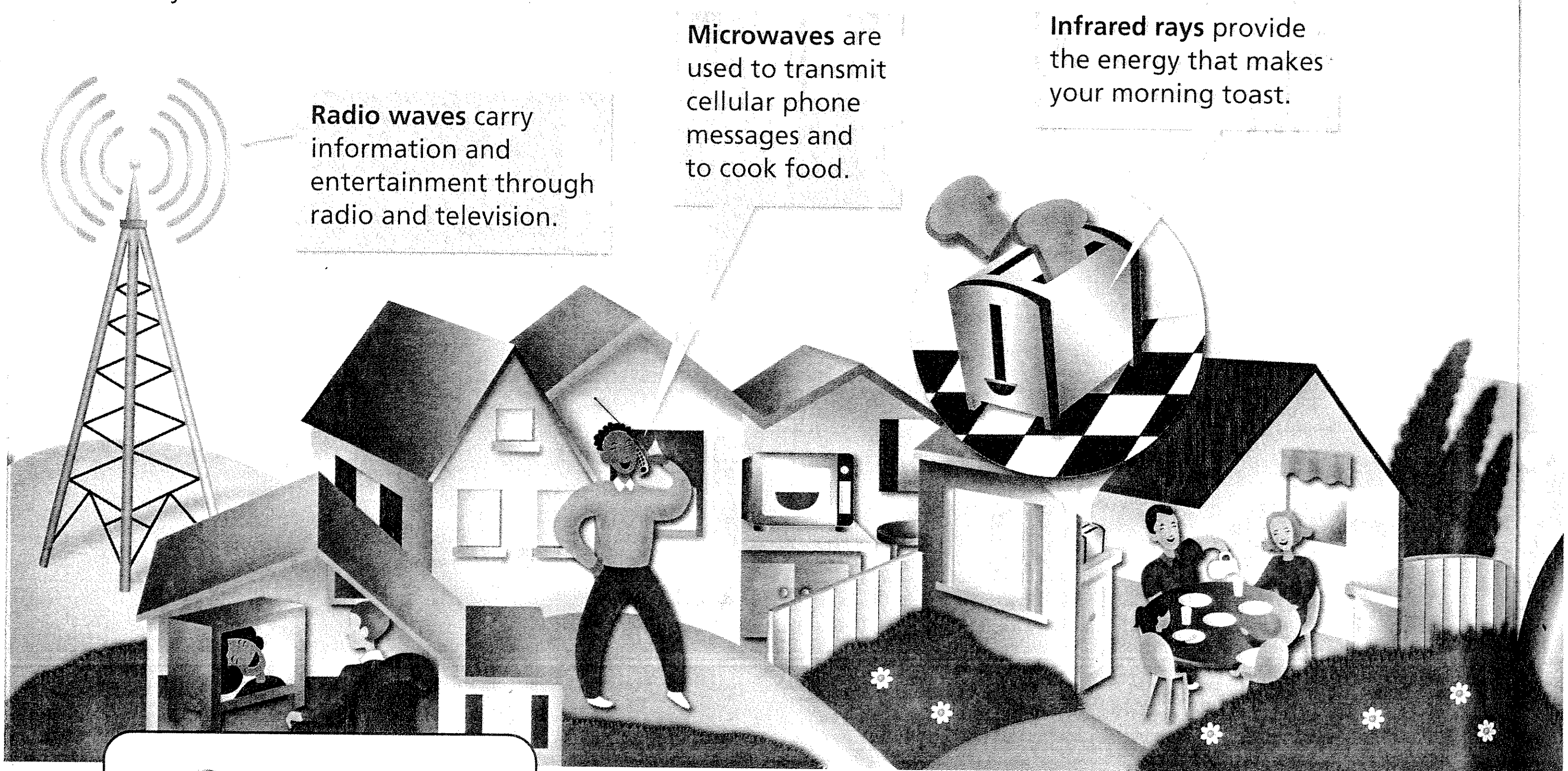
X-rays are sometimes used in industry and engineering. For example, to find out if a steel or concrete structure has tiny cracks, engineers can take an X-ray image of the structure. X-rays will pass through tiny cracks that are invisible to the human eye. Dark areas on the X-ray film show the cracks. This technology is often used to check the quality of joints in oil and gas pipelines.

Reading Checkpoint **What kind of matter blocks X-rays?**

FIGURE 7
Dental X-Ray
X-rays pass through soft parts of the body but are absorbed by teeth. When the photographic plate is developed, the teeth and fillings show up as lighter areas.

FIGURE 8
Electromagnetic Waves

Electromagnetic waves are all around you—in your home, your neighborhood, and your town.



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Gamma Rays

Gamma rays are the electromagnetic waves with the shortest wavelengths and highest frequencies. Because they have the greatest amount of energy, gamma rays are the most penetrating of all the electromagnetic waves.

Some radioactive substances and certain nuclear reactions produce gamma rays. Because of their great penetrating ability, gamma rays have some medical uses. For example, gamma rays can be used to kill cancer cells inside the body. To examine the body's internal structures, a patient can be injected with a fluid that emits gamma rays. Then a gamma-ray detector can form an image of the inside of the body.

Some objects in space give off bursts of gamma rays. The gamma rays are blocked by Earth's atmosphere, so gamma-ray telescopes that detect them must orbit above Earth's atmosphere. Astronomers think that explosions of stars in distant galaxies are one way of producing these gamma rays.

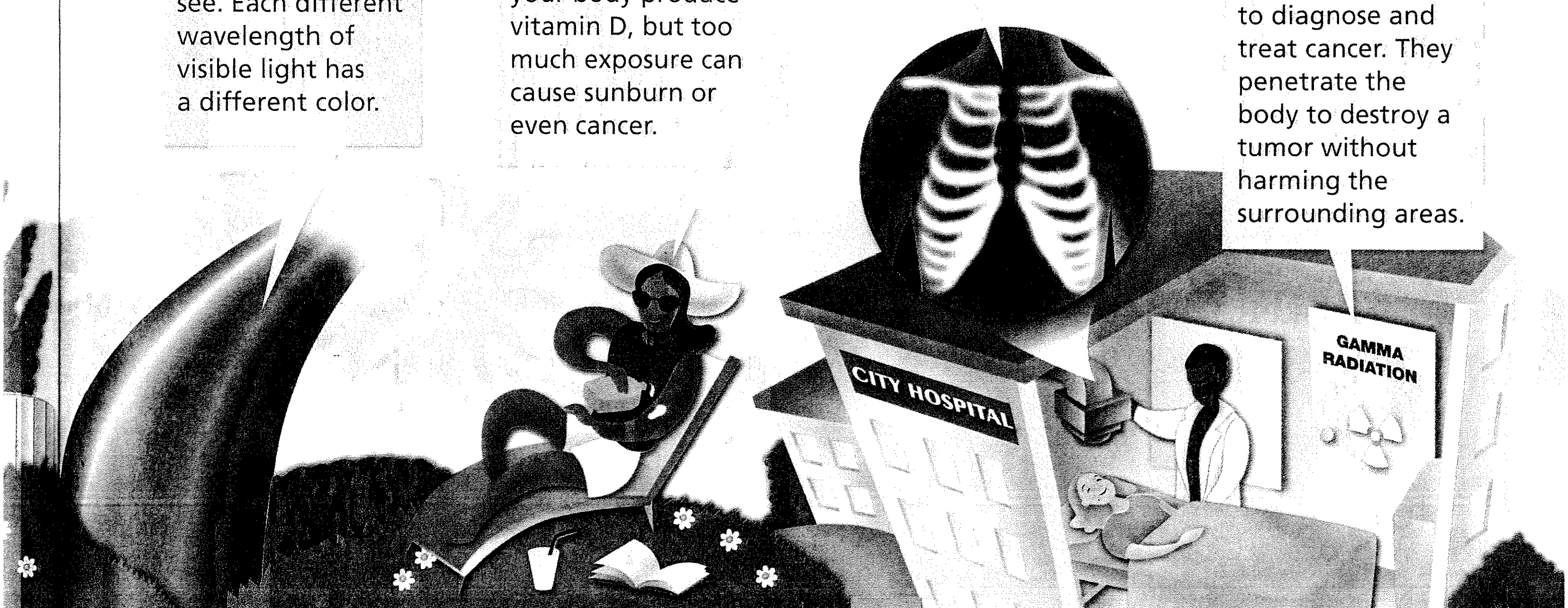
Reading Checkpoint **How are gamma rays produced?**

Visible light is the part of the electromagnetic spectrum you can see. Each different wavelength of visible light has a different color.

Ultraviolet rays, in small quantities, help your body produce vitamin D, but too much exposure can cause sunburn or even cancer.

X-rays are used to see inside the body. They help doctors to diagnose and treat many health problems.

Gamma rays are used in hospitals to diagnose and treat cancer. They penetrate the body to destroy a tumor without harming the surrounding areas.



Section 2 Assessment

Target Reading Skill Previewing Visuals Refer to your questions and answers about Figure 3 to help you answer Question 2 below.

Reviewing Key Concepts

1. a. **Reviewing** What is the mathematical relationship among wavelength, frequency, and speed?
   b. **Summarizing** In what way are all electromagnetic waves the same? In what ways are they different?
   c. **Making Generalizations** As the wavelengths of electromagnetic waves decrease, what happens to their frequencies? To their energies?
2. a. **Listing** List the waves in the electromagnetic spectrum in order from lowest frequency to highest frequency.
   b. **Explaining** Why are some electromagnetic waves harmful to you but others are not?
   c. **Classifying** List one or more types of electromagnetic waves that are useful for each of these purposes: cooking food, communication, seeing inside the body, curing diseases, reading a book, warming your hands.

Math Practice

Scientific Notation

3. An FM radio station broadcasts at a frequency of 9×10^5 Hz. Write the frequency as a number without an exponent.
4. Red light has a frequency of 4×10^{14} Hz. Express the frequency without using an exponent.

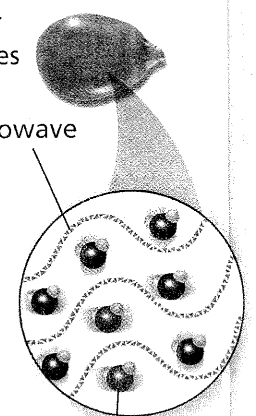
Technology and Society • Tech & Design •

Microwave Ovens

In 1946, as Dr. Percy Spencer worked on a radar device that produced microwaves, a candy bar melted in his pocket. Curious, he put some popcorn kernels near the device—they popped within minutes. Then, he put an egg near the device. It cooked so fast that it exploded. Dr. Spencer had discovered a new way of cooking food quickly. The microwave-oven industry was born.

Making Microwave Popcorn

1. Popcorn kernels are enclosed in a paper bag that microwaves pass through.
2. Microwaves strike water particles in the kernels, causing them to vibrate rapidly and produce heat.
3. The heat turns the water to steam, causing the kernels to explode.



Cooking With Microwaves

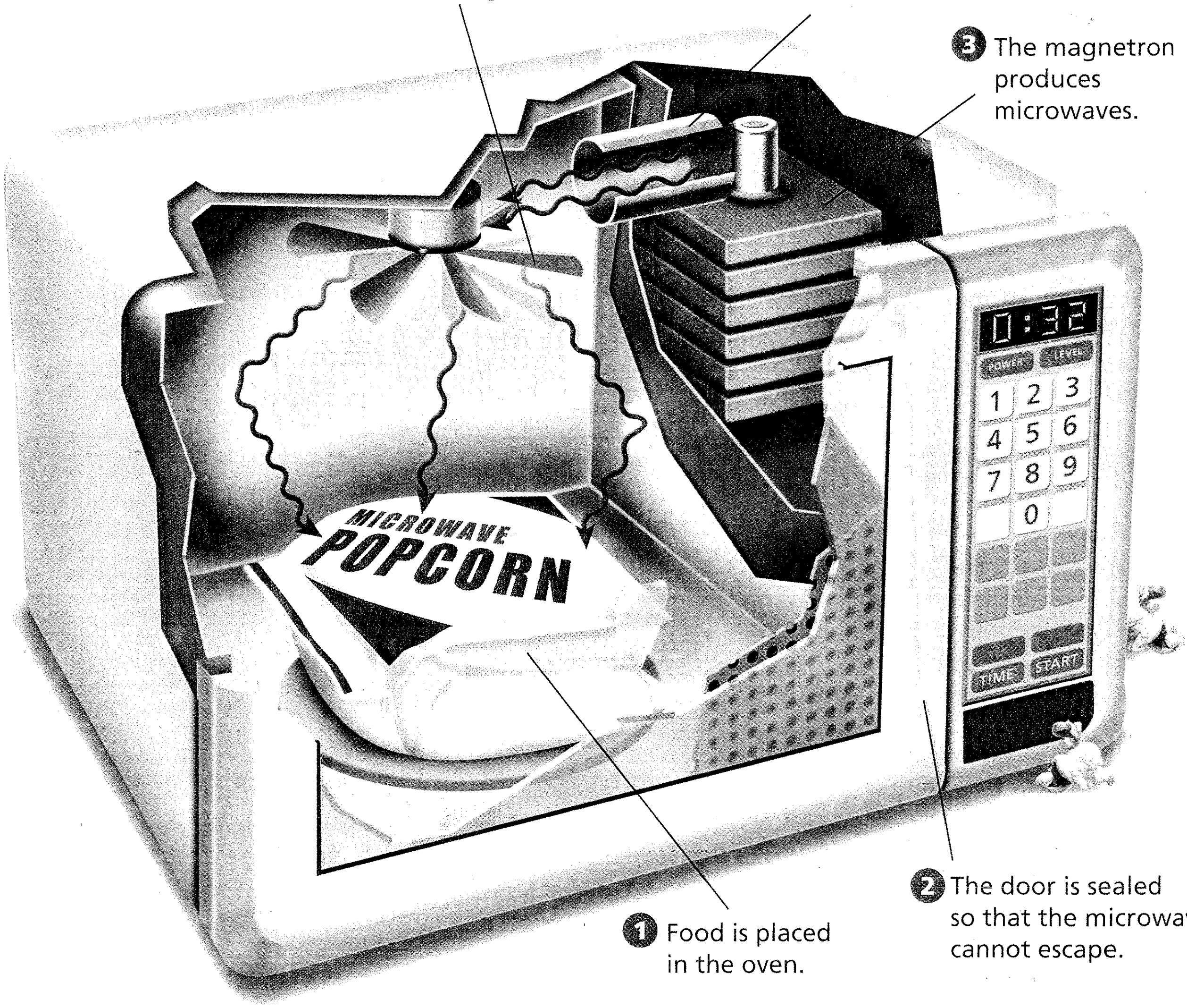
How do microwave ovens cook food? The answer lies in the way microwaves are reflected, transmitted, and absorbed when they strike different types of materials, such as food, metal, and plastic. In a microwave oven, microwaves reflect off the inner metal walls, bouncing around in the cooking chamber. They mostly pass right through food-wrapping materials such as plastic, glass, and paper. But foods absorb microwaves. Within seconds, the energy from the absorbed microwaves causes water and fat particles in the foods to start vibrating rapidly. These vibrations produce the heat that cooks the food.

Faster Cooking, But Is It Safe?

Using microwave ovens has made preparing food faster and easier than using conventional ovens. But, using microwave ovens has drawbacks. Overheating liquids in a microwave oven can cause the liquids to boil over or can cause serious burns. Also, microwave ovens can cook foods unevenly. This can result in foods being undercooked. Health risks can result from not cooking some foods, such as meats and poultry, thoroughly.

How a Microwave Oven Works

A microwave oven produces microwaves and scatters them throughout the oven to reach the food to be cooked.



Weigh the Impact

1. Identify the Need

What advantages do microwave ovens have over conventional ovens?

2. Research

The U.S. Food and Drug Administration (FDA) regulates safety issues for microwave ovens. Research microwave ovens on the Internet to find FDA guidelines about this technology. What safety measures does the FDA recommend?

3. Write

Based on your research, create a poster showing how to use microwave ovens safely. With your teacher's permission, display your poster in the school cafeteria.

Go Online
PHSchool.com

For: More on microwave ovens
Visit: PHSchool.com
Web Code: cgh-5030

Section 3

Producing Visible Light

Reading Preview

Key Concept
- What are the different types of light bulbs?

Key Terms
- illuminated
- luminous
- spectroscope
- incandescent light
- tungsten-halogen bulb
- fluorescent light
- vapor light
- neon light

Target Reading Skill
Comparing and Contrasting
Compare and contrast the five types of light bulbs by completing a table like the one below.

Light Bulbs

Feature	Ordinary Light Bulb	Tungsten-Halogen
Bulb material	Glass	
Hot/Cool		

Lab zone Discover Activity

How Do Light Bulbs Differ?
1. Your teacher will give you one incandescent and one fluorescent light bulb.
2. Examine the bulbs. Record your observations and describe any differences. Draw each type of bulb.
3. How do you think each bulb produces light?

Think It Over
Posing Questions Make a list of five questions you could ask to help you understand how each bulb works.

Look around you. Most of the objects you see are visible because they reflect light from some kind of light source. An object is **illuminated** if you see it by reflected light. The page you are reading, your desk, and the moon are examples of illuminated objects. An object is **luminous** if it gives off its own light. A light bulb, a burning log, and the sun all are examples of luminous objects.

Different types of light bulbs may be used to illuminate the spaces around you. **Common types of light bulbs include incandescent, tungsten-halogen, fluorescent, vapor, and neon lights.** Some light bulbs produce a continuous spectrum of all of the wavelengths of visible light. Others produce only a few wavelengths. You can use an instrument called a **spectroscope** to view the different colors of light produced by a light bulb.

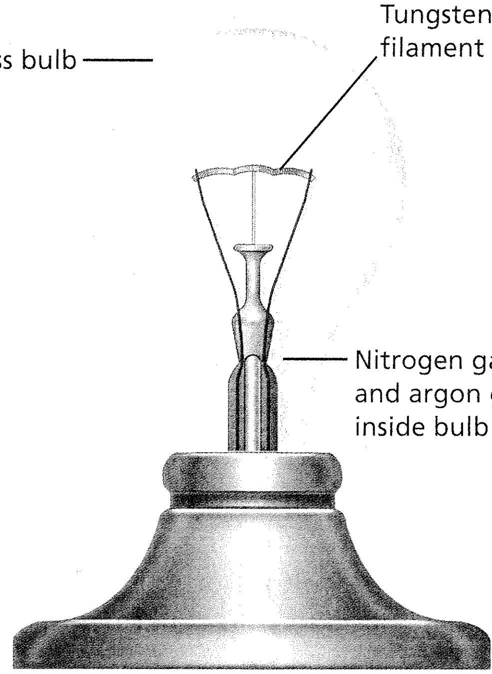
◀ Glassblower working with heated glass

Incandescent Lights
Have you heard the phrase "red hot"? When a glassblower heats glass, it glows and gives off red light. At a higher temperature, it gives off white light and the glass is said to be "white hot." An **incandescent light** (in kun DES unt) is a light bulb that glows when a filament inside it gets white hot. Thomas Edison, the American inventor, patented the first practical incandescent light bulb in 1879.

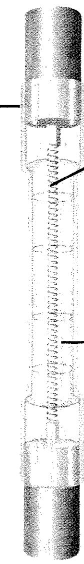
FIGURE 9

Incandescent Lights

A filament glows when electric current passes through it. **Comparing and Contrasting** *How are ordinary light bulbs like tungsten-halogen bulbs? How are they different?*



Ordinary Light Bulb



Tungsten-Halogen Bulb

Ordinary Light Bulbs Look closely at the ordinary light bulb shown in Figure 9. Notice the thin wire called the filament. It is made of a metal called tungsten. When an electric current passes through the filament, it quickly heats up and becomes hot, giving off white light. The filament is enclosed in an airtight glass bulb. Most ordinary light bulbs contain small amounts of nitrogen and argon gases.

Ordinary light bulbs are not efficient. Less than 10 percent of their energy is given off as light. Most of their energy is given off as infrared rays. That's why they get so hot.

Tungsten-Halogen Bulbs A bulb that has a tungsten filament and contains a halogen gas such as iodine or bromine is called a **tungsten-halogen bulb.** The filament of this bulb gets much hotter than in an ordinary light bulb, so the bulb looks whiter.

Tungsten-halogen bulbs are more efficient than ordinary bulbs because they give off more light and use less electrical energy. But they also give off more heat. Because tungsten-halogen bulbs get so hot, they must be kept away from materials that could catch fire.

Reading Checkpoint **What gases are used in tungsten-halogen bulbs?**

Lab zone Skills Activity

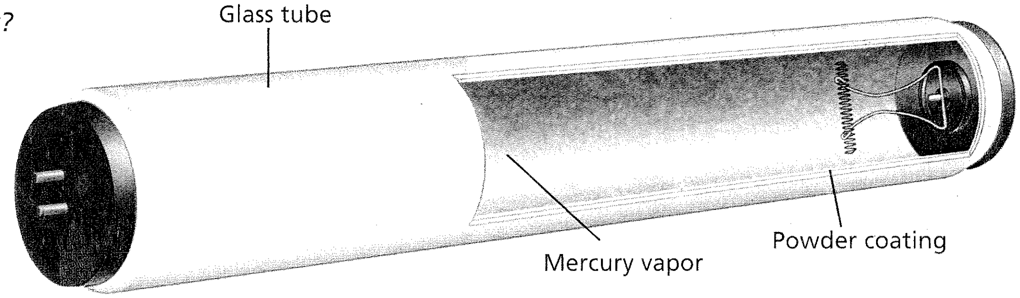
Observing

Use a spectroscope to view light from two sources. **CAUTION:** *Do not view the sun with the spectroscope.*

1. Look through the spectroscope at an ordinary light bulb. Use colored pencils to draw and label what you see.
2. Now, look at a fluorescent light through the spectroscope. Again, draw and label what you see.

How are the colors you see the same? How are they different?

FIGURE 10
Fluorescent Light
A fluorescent light is cool because very little energy is given off as infrared rays. **Inferring** *Why is a fluorescent light efficient?*



Other Light Sources

Incandescent light bulbs are not the only light bulbs you see around you. Some spaces are lit by fluorescent lights. Streets and parking lots may be lit with vapor lights. Neon lights are often used to attract attention to stores and theaters.

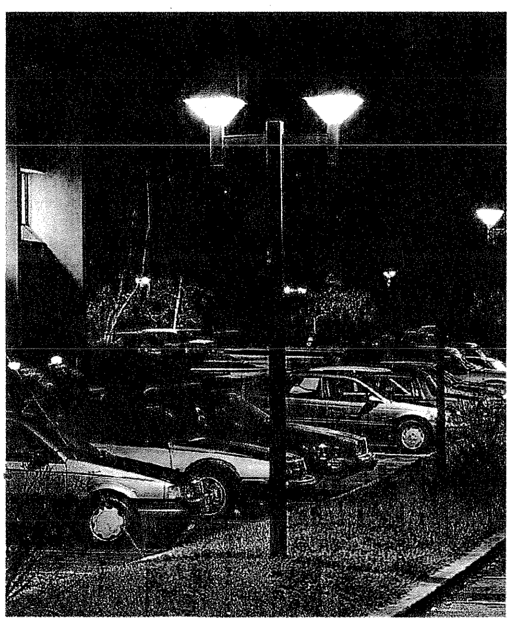
Fluorescent Lights Have you ever noticed long, narrow glass tubes that illuminate schools and stores? These are fluorescent light bulbs. A **fluorescent light** (floo RES unt) is a bulb that contains a gas and is coated on the inside with a powder. When an electric current passes through the bulb, it causes the gas inside to give off ultraviolet rays. When the ultraviolet rays hit the powder in the tube, the powder gives off visible light.

Fluorescent lights give off most of their energy as visible light and only a little energy as infrared rays. Therefore, fluorescent lights do not get as hot as incandescent light bulbs. They also usually last longer than incandescent lights and use less electrical energy for the same brightness. So, fluorescent lights are very efficient.

Vapor Lights A bulb that contains neon or argon gas and a small amount of solid sodium or mercury is a **vapor light.** When an electric current passes through the gas, the gas heats up. The hot gas then heats the sodium or mercury. The heating causes the sodium or mercury to change from a solid into a gas. In a sodium vapor light, the particles of sodium gas glow to give off a yellowish light. A mercury vapor light produces a bluish light.

Both sodium and mercury vapor lights are used for street lighting and parking lots. They require very little electrical energy to give off a great deal of light, so they are quite efficient.

FIGURE 11
Sodium Vapor Lights
Sodium vapor lights give off a yellowish light.



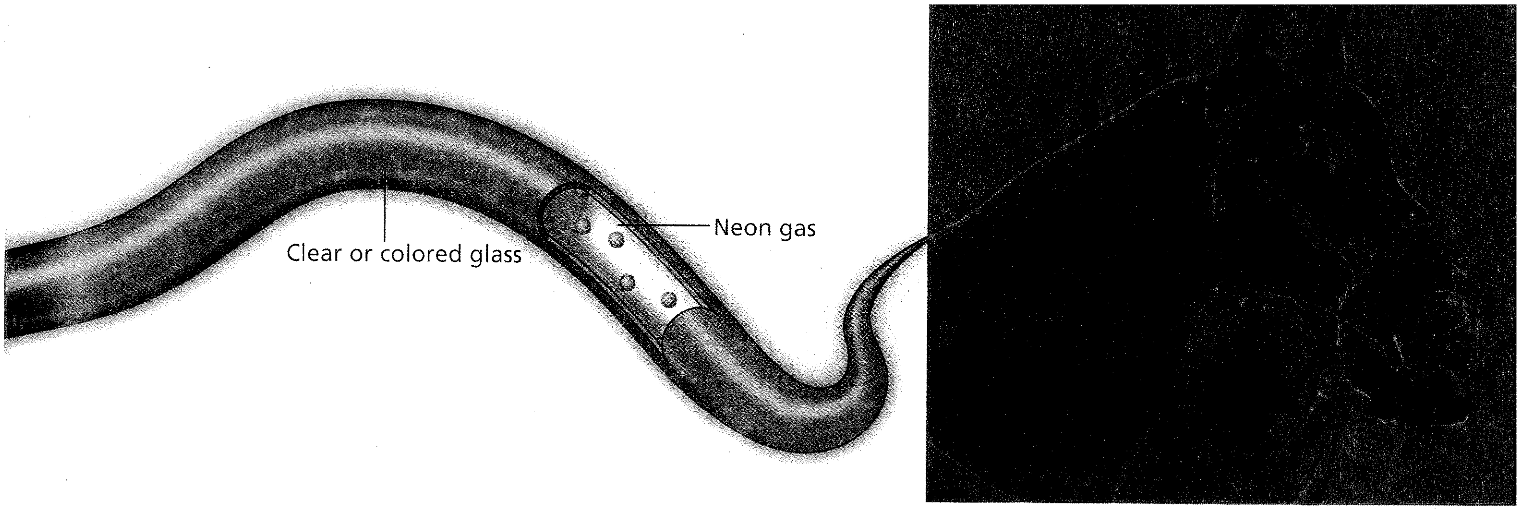


FIGURE 12
Neon Lights
The color of a neon light depends in part on which gas or gases are in the tube.

Neon Lights A **neon light** is a sealed glass tube that contains neon gas. When an electric current passes through the neon, particles of the gas absorb energy. However, the gas particles cannot hold the energy for very long. The energy is released in the form of light. This process is called electric discharge through gases.

A true neon light gives off red light, as shown in Figure 12. But often, lights that contain different gases or a mixture of gases are also called neon lights. Different gases produce different colors of light. For example, both argon gas and mercury vapor produce greenish-blue light. Helium gives pink light. Krypton gives a pale violet light. Sometimes colored glass tubes are used to produce other colors. Neon lights are commonly used for bright, flashy signs.

Reading Checkpoint **What color of light does a neon light give off?**

Section 3 Assessment

Target Reading Skill Comparing and Contrasting Use the information in your table about light bulbs to help you answer Question 1 below.

Reviewing Key Concepts

1. a. **Listing** What are five common types of light bulbs?
   b. **Explaining** How do incandescent light bulbs work?
   c. **Inferring** Lamps that use ordinary light bulbs often have cloth or paper shades. But tungsten-halogen lamps usually have metal shades. Explain.
   d. **Making Generalizations** What gives off light in incandescent light bulbs? What gives off light in other types of light bulbs?

Lab zone At-Home Activity

Buying Light Bulbs Invite family members to visit a hardware store. Ask a salesperson to describe the different kinds of light bulbs available. Read the information about each bulb on the packages. Look for the cost and the expected life of the bulbs. How does this information help you and your family to choose bulbs for different purposes?

Section 4 • Tech & Design •

Wireless Communication

Reading Preview

Key Concepts

- How do radio waves transmit information?
- How do cellular phones work?
- How do communications satellites relay information?

Key Terms

- amplitude modulation
- frequency modulation

Target Reading Skill

Using Prior Knowledge Your prior knowledge is what you know before you read about a topic. Before you read, write what you know about wireless communication in a graphic organizer. As you read, continue to write in what you learn.

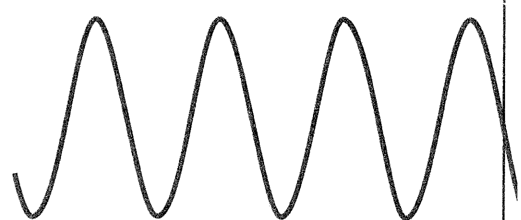
Lab zone Discover Activity

How Can Radio Waves Change?

1. Trace the wave diagram onto a piece of tracing paper. Then transfer the tracing onto a flat piece of latex from a balloon or a glove.
2. Stretch the latex horizontally. How is the stretched wave different from the wave on the tracing paper?
3. Now stretch the latex vertically. How is this wave different from the wave on the tracing paper? How is it different from the wave in Step 2?

Think It Over

Making Models Which stretch changes the wave's amplitude? The wave's frequency?



You race home from school and switch on the TV to catch the final innings of your favorite team's big game. In an instant, you see and hear the game just as if you were sitting in the stands.

Today you can communicate with people far away in just seconds. You can watch a live television broadcast of a soccer game from Europe or listen to a radio report from Africa. How do these radio and television programs reach you?

Radio and Television

Radio waves carry, or transmit, signals for both radio and television programs. The radio waves are produced by charged particles moving back and forth inside transmission antennas. **Transmission antennas send out, or broadcast, radio waves in all directions. Radio waves carry information from the antenna of a broadcasting station to the receiving antenna of your radio or television.** There are two methods of transmitting the signals—amplitude modulation and frequency modulation. Radio stations broadcast using either method. Television stations use both methods—amplitude modulation for pictures and frequency modulation for sound.

FIGURE 13
Miniature Television
Radio waves transmit the signals for this small portable television.

Amplitude Modulation AM stands for amplitude modulation. **Amplitude modulation** is a method of transmitting signals by changing the amplitude of a wave. The information that will become sound, such as speech and music, is coded in changes, or modulations, of a wave's amplitude. The frequency of the wave remains constant, as shown in Figure 14. At a radio broadcasting station, sound is converted into electronic signals. The electronic signals are then converted into a pattern of changes in the amplitude of a radio wave. Your radio receives the wave and converts it back into sound.

AM radio waves have relatively long wavelengths and are easily reflected by Earth's ionosphere. The ionosphere is a region of charged particles high in the atmosphere. The reflected waves bounce back to Earth's surface. Therefore, AM radio stations can broadcast over long distances.

Frequency Modulation FM stands for frequency modulation. **Frequency modulation** is a method of transmitting signals by changing the frequency of a wave. FM signals travel as changes, or modulations, in the frequency of the wave. The amplitude of the wave remains constant.

FM waves have higher frequencies and more energy than AM waves. As shown in Figure 14, they pass through the ionosphere instead of being reflected back to Earth. Thus, FM waves do not travel as far as AM waves. So, if you go on a long car trip with an FM radio station tuned in, you may quickly lose reception of the station. But FM waves are usually received clearly and produce better sound quality than AM waves.

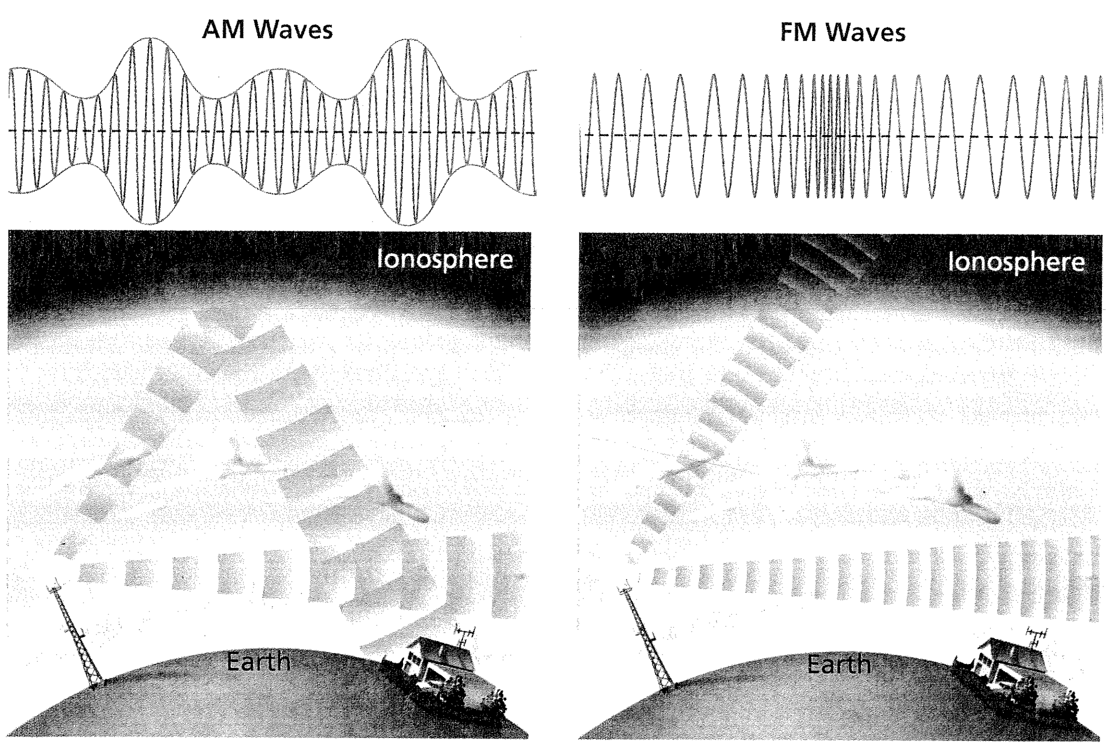


FIGURE 14
AM and FM Radio Waves
In AM transmissions, the amplitude of a radio wave is changed. In FM transmissions, the frequency is changed.
Interpreting Diagrams *What property is constant in the AM wave? In the FM wave?*

Math Analyzing Data

Comparing Frequencies

The table shows the ranges of radio broadcast frequencies used for AM radio, UHF television, FM radio, and VHF television.

1. **Interpreting Data** In the table, what units of measurement are used for frequency?
2. **Interpreting Data** Which type of broadcast shown in the table uses the highest-frequency radio waves? Which uses the lowest-frequency waves?
3. **Calculating** Which type of broadcast uses waves with the shortest wavelength?

Broadcast Frequencies

Type of Broadcast	Frequency Range
AM radio broadcast	535 kHz to 1,605 kHz
VHF television	54 MHz to 216 MHz
FM radio broadcast	88 MHz to 108 MHz
UHF television	470 MHz to 806 MHz

4. **Inferring** A broadcast uses a frequency of 100 MHz. Can you tell from this data if it is a television or a radio program? Explain.

Discovery Channel School

The Electromagnetic Spectrum

Video Preview

▶ Video Field Trip

Video Assessment

The Radio Spectrum In addition to radio and television broadcasts, radio waves are used for many types of communication. For example, taxi drivers, firefighters, and police officers all use radio waves to do their jobs. The Federal Communications Commission, or FCC, assigns different radio frequencies for different uses. Radio stations are allowed to use one part of the radio spectrum. Television stations use other parts. Taxi and police radios are assigned separate sets of frequencies. Because the signals all have different assigned frequencies, they travel without interfering.

You probably have seen these assigned frequencies when you tune a radio. AM radio stations use frequencies measured in kilohertz (kHz), while FM radio stations use frequencies measured in megahertz (MHz). Recall that a hertz is one cycle per second. If something vibrates 1,000 times a second, it has a frequency of 1,000 Hz, or 1 kilohertz (kHz). (The prefix *kilo-* means "one thousand.") If something vibrates 1,000,000 times a second, it has a frequency of 1,000,000 Hz, or 1 megahertz (MHz). (The prefix *mega-* means "one million.")

AM radio stations range from 535 kHz to 1,605 kHz. FM radio stations range between 88 MHz and 108 MHz. A television station uses one of two sets of frequencies: Very High Frequency (VHF) or Ultra High Frequency (UHF). VHF stations range from 54 MHz to 216 MHz, corresponding to Channels 2 through 13 on your television set. UHF channels range from 470 MHz to 806 MHz, corresponding to Channels 14 through 69.

Reading Checkpoint **What does the term *kilohertz* stand for?**

Cellular Phones

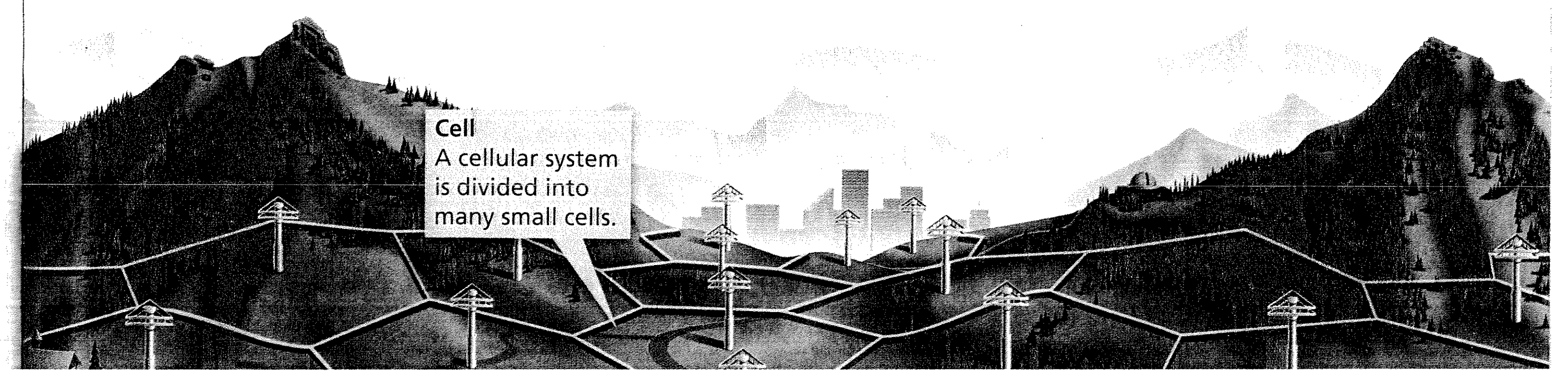
Cellular telephones have become very common, but they only work if they are in or near a cellular system. The cellular system, which is shown in Figure 15, works by dividing regions into many small cells, or geographical areas. Each cell has one or more towers that relay signals to a central hub.

Cellular phones transmit and receive signals using high-frequency microwaves. When you place a call on a cellular phone, the phone sends out microwaves. The microwaves are tagged with a number unique to your phone. A tower picks up the microwaves and transfers the signal to a hub. In turn, the hub channels and transmits the signal to a receiver. The receiver may be another tower or another hub, depending on the distance between the two phones. That tower or hub transmits the signal to the receiving cellular phone. The receiving phone rings when it picks up the microwave signal from a tower or hub. The whole exchange seems to be instantaneous.

In addition to making phone calls, you can also use some cellular phones to page someone, to send text messages, or to get information from the Internet. Some modern cellular phones can even be used as digital cameras.

Reading Checkpoint **What are three ways to communicate with a cellular phone?**

FIGURE 15
Cellular Phone System
In the cellular phone system, cellular phones transmit and receive radio waves that travel to the nearest tower.
Predicting *What happens if a cellular phone is far away from a tower?*



Go Online
SCILINKS NSTA
For: Links on using waves to communicate
Visit: www.SciLinks.org
Web Code: scn-1534

Communications Satellites

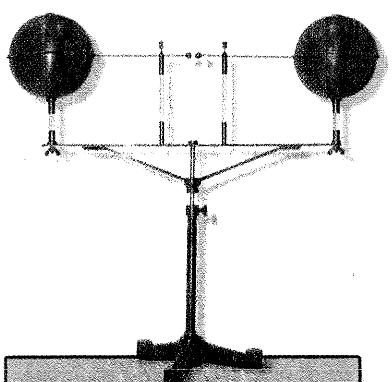
Satellites orbiting Earth are used to send information around the world. Communications satellites work like the receivers and transmitters of a cellular phone system. **Communications satellites receive radio, television, and telephone signals and relay the signals back to receivers on Earth.** Because a satellite can "see" only part of Earth at any given time, more than one satellite is needed for any given purpose.

Satellite Phone Systems Several companies have developed satellite phone systems. The radio waves from one phone are sent up to a communications satellite. The satellite transmits the waves back to the receiving phone on Earth. With this kind of phone, you can call anywhere in the world, but the cost is greater than using a cellular phone.

Science and **History**

Wireless Communication

Since the late 1800s, many developments in communication have turned our world into a global village.



1888
Electromagnetic Waves
German scientist Heinrich Hertz proved that radio waves exist. Hertz demonstrated that the waves could be reflected, refracted, diffracted, and polarized just like light waves.

1895
First Wireless Transmission
Italian engineer and inventor Guglielmo Marconi successfully used radio waves to send a coded wireless signal a distance of more than 2 km.

1901
First Transatlantic Signals
On December 12, the first transatlantic radio signal was sent from Poldhu Cove, Cornwall, England, to Signal Hill, Newfoundland. The coded radio waves traveled more than 3,000 km through the air.

1923 Ship-to-Ship Communication
For the first time, people on one ship could talk to people on another. The signals were sent as electromagnetic waves, received by an antenna, and converted into sound.

1880 1900 1920

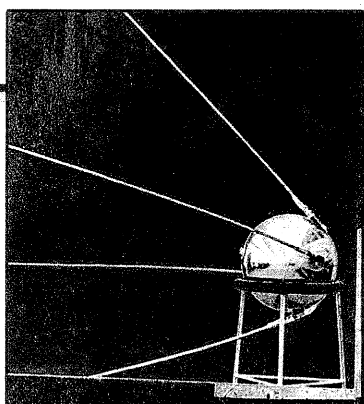
Television Satellites Both television networks and cable companies use communications satellites. First, the television signals are changed into AM and FM waves. These radio waves are sent up to satellites. Then the signals are relayed to local stations around the world.

Some people have their own antennas to receive signals for television programs directly from satellites. Many of the antennas are dish-shaped, so they are known as satellite dishes. Older satellite dishes were very large, more than 2 meters in diameter. But newer dishes are much smaller because the signals from satellites have become more powerful.

Television signals from satellites often are scrambled to make sure that only people who pay for the programs can use the signal. Customers need a decoding box to unscramble the signals.

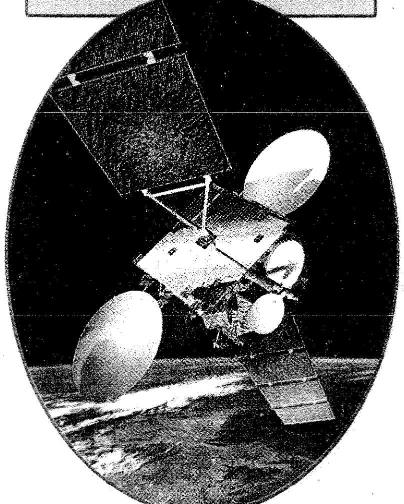
Writing in Science

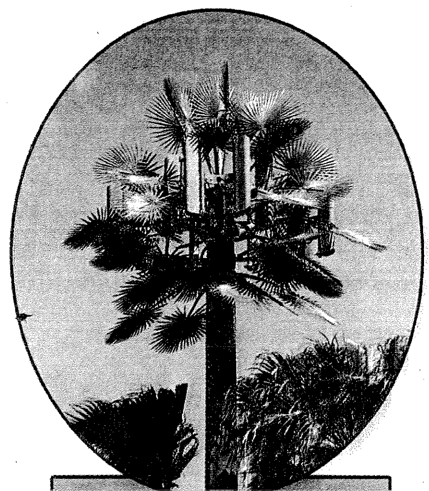
Research and Write Use library or Internet resources to find out more about Guglielmo Marconi. Imagine that you were hired as his assistant. Write a short letter to a friend that describes your new job.



1957 *Sputnik I*
On October 4, the Soviet Union became the first country to successfully launch an artificial satellite into orbit. This development led to a new era in communications. Since then, more than 5,000 artificial satellites have been placed in orbit.

1963 Geosynchronous Orbit
Communications satellites are launched into orbits at altitudes of about 35,000 km. At this altitude, a satellite orbits Earth at the same rate as Earth rotates.





1979 Cellular Phone Network
In Japan, the world's first cellular phone network allowed people to make wireless phone calls. Today, cellular phone towers like the one above are common.

1960 1980 2000

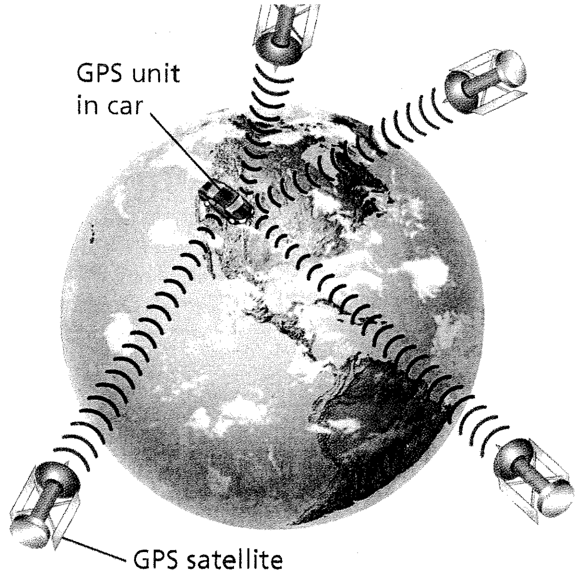


FIGURE 16
Global Positioning System
In the Global Positioning System (GPS), signals from four satellites are used to pinpoint a location on Earth.

Global Positioning System The Global Positioning System (GPS) is a system of navigation originally designed for the military. Now many other people use the system. GPS uses a network of satellites that broadcast radio signals to Earth. These signals carry information that tells you your exact location on Earth's surface, or even in the air. Anybody with a GPS receiver can pick up these signals.

Figure 16 shows how the signals from four GPS satellites are used to determine your position. The signals from three satellites tell you where you are on Earth's surface. The signal from the fourth satellite tells you how far above Earth's surface you are.

Today, GPS receivers are found in airplanes, boats, and cars. In a car, you can type your destination into a computer. The computer uses GPS data to map out your route. A computerized voice might even tell you when to turn right or left.

Reading Checkpoint What does GPS stand for?

Section 4 Assessment

Target Reading Skill **Using Prior Knowledge** Review your graphic organizer and revise it based on what you just learned in this section.

Reviewing Key Concepts

1. a. **Identifying** What type of wave carries signals for radio and television programs?
   b. **Sequencing** Describe the events that bring an AM broadcast into your home.
   c. **Comparing and Contrasting** How are AM waves different from FM waves? How are they the same?
2. a. **Summarizing** How does a cellular telephone work?
   b. **Interpreting Diagrams** A cellular phone transmits a signal to a receiving tower in Figure 15. How is the signal passed on to another cellular phone user?
   c. **Relating Cause and Effect** Your cellular phone transmits a signal at a specific frequency. What will happen if a cellular phone next to you also uses this frequency?
3. a. **Listing** What are three kinds of communications satellites?
   b. **Reviewing** How do communications satellites work?
   c. **Predicting** If your GPS device received signals from only three satellites, what information about your location would you be missing?

Writing in Science

Cause and Effect Paragraph Just before going to sleep one night, you search for an AM station on your radio. To your surprise, you pick up a station coming from a city 1,000 kilometers away. Your older brother tells you it is because of Earth's ionosphere. Write a paragraph explaining your brother's statement. Be sure to describe how the ionosphere affects AM radio transmissions.

Build a Crystal Radio

Problem

Can you build a device that can collect and convert radio signals?

Skills Focus

observing, drawing conclusions, making models

Materials

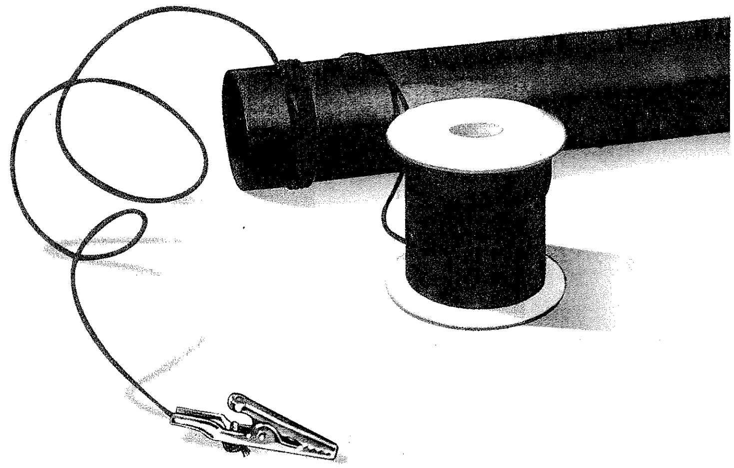
- cardboard tube (paper towel roll)
- 3 pieces of enameled or insulated wire, 1 about 30 m long, and 2 about 30 cm long
- wirestrippers or sandpaper
- 2 alligator clips
- scissors
- aluminum foil
- 2 pieces of cardboard (sizes can range from 12.5 cm × 20 cm to 30 cm × 48 cm)
- masking tape
- crystal diode
- earphone
- 2 pieces of insulated copper antenna wire, 1 about 30 m long, and 1 about 0.5 m long

Procedure

PART 1 Wind the Radio Coil

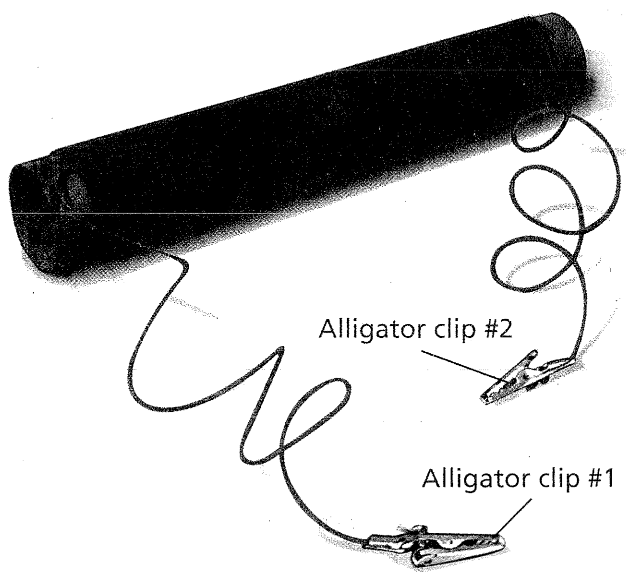
(*Hint*: All ends of the insulated wires need to be stripped to bare metal. If the wire is enameled, you need to sandpaper the ends.)

1. Carefully punch two holes approximately 2.5 cm apart in each end of a cardboard tube. The holes should be just large enough to thread the insulated wire through.
2. Feed one end of the 30-m piece of insulated wire through one set of holes. Leave a 50-cm lead at that end. Attach alligator clip #1 to this lead. See Figure 1.



▲ **Figure 1** Winding the Coil

3. Wind the wire tightly around the cardboard tube. Make sure the coils are close together but do not overlap one another.
4. Wrap the wire until you come to the end of the tube. Feed the end of the wire through the other set of holes, leaving a 50-cm lead as before. Attach alligator clip #2 to this lead. See Figure 2.



▲ **Figure 2** The Finished Coil

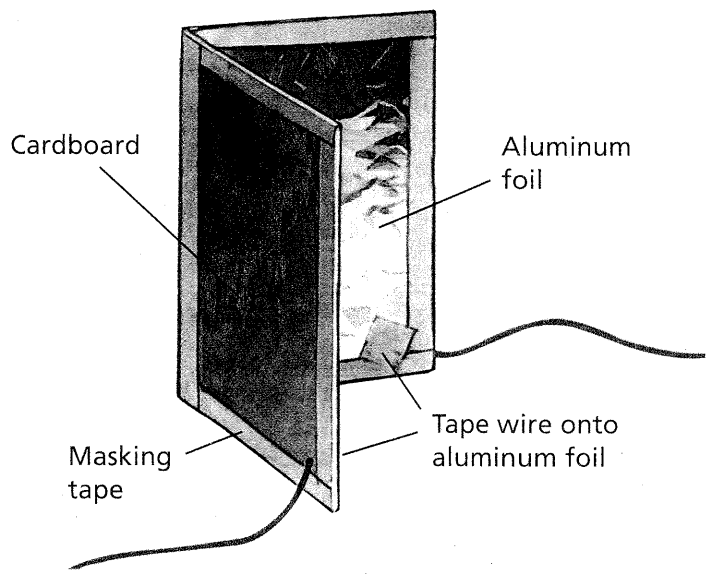
PART 2 Make the Tuning Plates

5. Without wrinkling the aluminum foil, cover one side of each piece of cardboard with the foil. Trim off any excess foil and tape the foil in place.
6. Hold the pieces of cardboard together with the foil facing inward. Tape along one edge to make a hinge. It is important for the foil pieces to be close together but not touching. See Figure 3.

▼ **Figure 3** Taping the Tuning Plates

7. Make a small hole through the cardboard and foil near a corner of one side. Feed one of the short pieces of insulated wire through the hole and tape it onto the foil as shown. Tape the other short piece of insulated wire to the corner of the other side. See Figure 4.

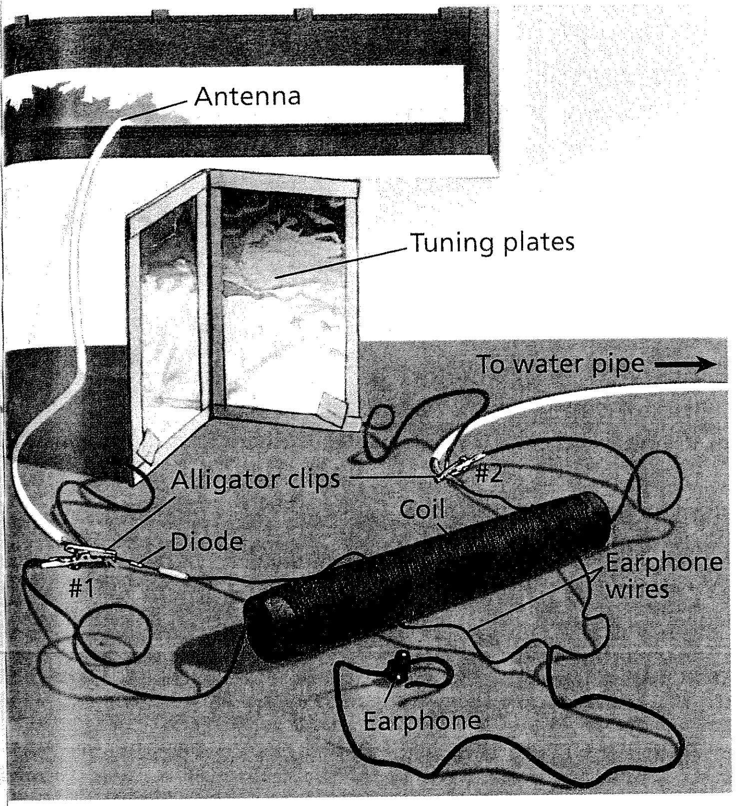
▼ **Figure 4** Connecting the Tuning Plates



8. Connect one end of the wire from the foil to alligator clip #1. Connect the other wire from the foil to alligator clip #2.

PART 3 Prepare the Earphone

9. Handle the diode carefully. Connect one wire from the diode to alligator clip #1. The arrow on the diode should point to the earphone. Tape the other end of the diode wire to one of the earphone wires.
10. Connect the other wire from the earphone to alligator clip #2. See Figure 5.



▲ **Figure 5** **The Completed Radio**

PART 4 Hook Up the Antenna

11. String the long piece of antenna wire along the floor to an outside window. Connect the other end of the wire to alligator clip #1.
12. Connect one end of the shorter piece of antenna wire to a cold-water pipe or faucet. Connect the other end to alligator clip #2. See Figure 5.
13. Put on the earphone and try to locate a station by squeezing the tuning plates slowly until you hear a signal. Some stations will come in when the plates are close together. Other stations will come in when the plates are opened far apart.

Analyze and Conclude

1. **Observing** How many stations can you pick up? Where are these stations located, and which station has the strongest signal? Keep a log of the stations you receive.
2. **Forming Operational Definitions** In your own words, give a definition of "signal strength." How did you compare the signal strengths of different radio stations?
3. **Drawing Conclusions** How does adjusting the tuning plates affect reception of the radio signals?
4. **Making Models** You can improve reception by having a good antenna. How can you improve your antenna?
5. **Communicating** Write a paragraph describing the various parts of the radio and how they are linked together.

Design an Experiment

Use a radio to test signal reception at various times of the day. Do you receive more stations at night or in the morning? Does weather affect reception? *Obtain your teacher's permission before carrying out your investigation.*