SECTION 2

The Electromagnetic Spectrum

When you look around, you can see things that reflect light to your eyes. But a bee might see the same things differently. Bees can see a kind of light—called ultraviolet light—that you can't see!

What You Will Learn

- Identify how electromagnetic waves differ from each other.
- Describe some uses for radio waves and microwaves.
- List examples of how infrared waves and visible light are important in your life.
- Explain how ultraviolet light, X rays, and gamma rays can be both helpful and harmful.

Vocabulary

electromagnetic spectrum

READING STRATEGY

Mnemonics As you read this section, create a mnemonic device to help you remember the kinds of EM waves.

It might seem odd to call something you can't see *light.* The light you are most familiar with is called *visible light.* Ultraviolet light is similar to visible light. Both are kinds of electromagnetic (EM) waves. In this section, you will learn about many kinds of EM waves, including X rays, radio waves, and microwaves.

Characteristics of EM Waves

All EM waves travel at the same speed in a vacuum—300,000 km/s. How is this possible? The speed of a wave is found by multiplying its wavelength by its frequency. So, EM waves having different wavelengths can travel at the same speed as long as their frequencies are also different. The entire range of EM waves is called the **electromagnetic spectrum.** The electromagnetic spectrum is shown in **Figure 1.** The electromagnetic spectrum is divided into regions according to the length of the waves. There is no sharp division between one kind of wave and the next. Some kinds even have overlapping ranges.

Reading Check **How is the speed of a wave determined?** *(See the Appendix for answers to Reading Checks.)*

Figure 1 The Electromagnetic Spectrum

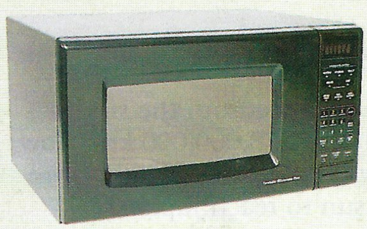
The electromagnetic spectrum is arranged from long to short wavelength or from low to high frequency.

Radio waves

All radio and television stations broadcast radio waves.

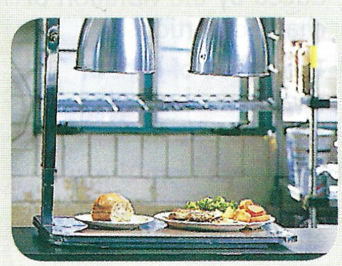
Microwaves

Despite their name, microwaves are not the shortest EM waves.



Infrared

Infrared means "below red."



Radio Waves

Radio waves cover a wide range of waves in the EM spectrum. Radio waves have some of the longest wavelengths and the lowest frequencies of all EM waves. In fact, radio waves are any EM waves that have wavelengths longer than 30 cm. Radio waves are used for broadcasting radio signals.

Broadcasting Radio Signals

Figure 2 shows how radio signals are broadcast. Radio stations encode sound information into radio waves by varying either the waves' amplitude or their frequency. Changing amplitude or frequency is called *modulation* (MAHJ uh LAY shuhn). You probably know that there are AM radio stations and FM radio stations. The abbreviation *AM* stands for "amplitude modulation," and the abbreviation *FM* stands for "frequency modulation."

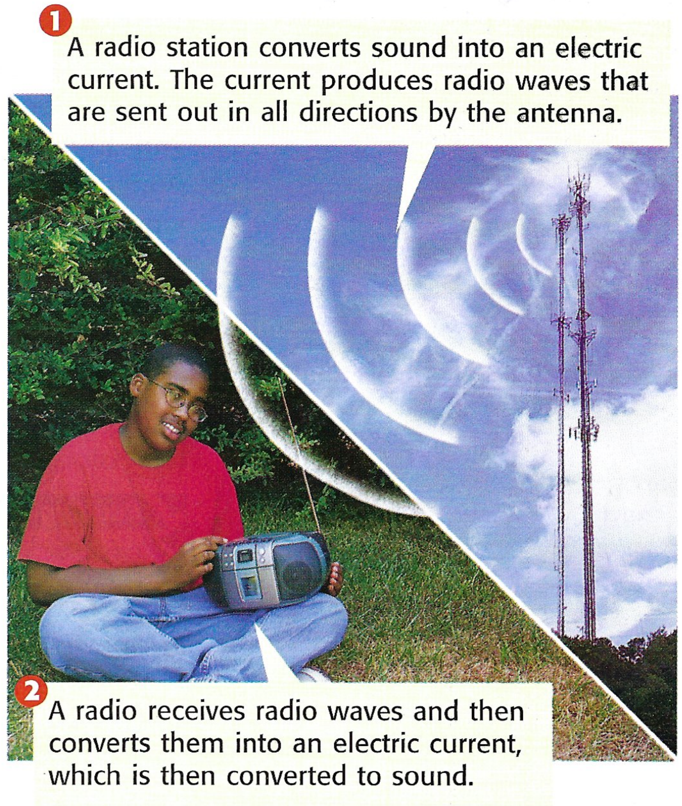
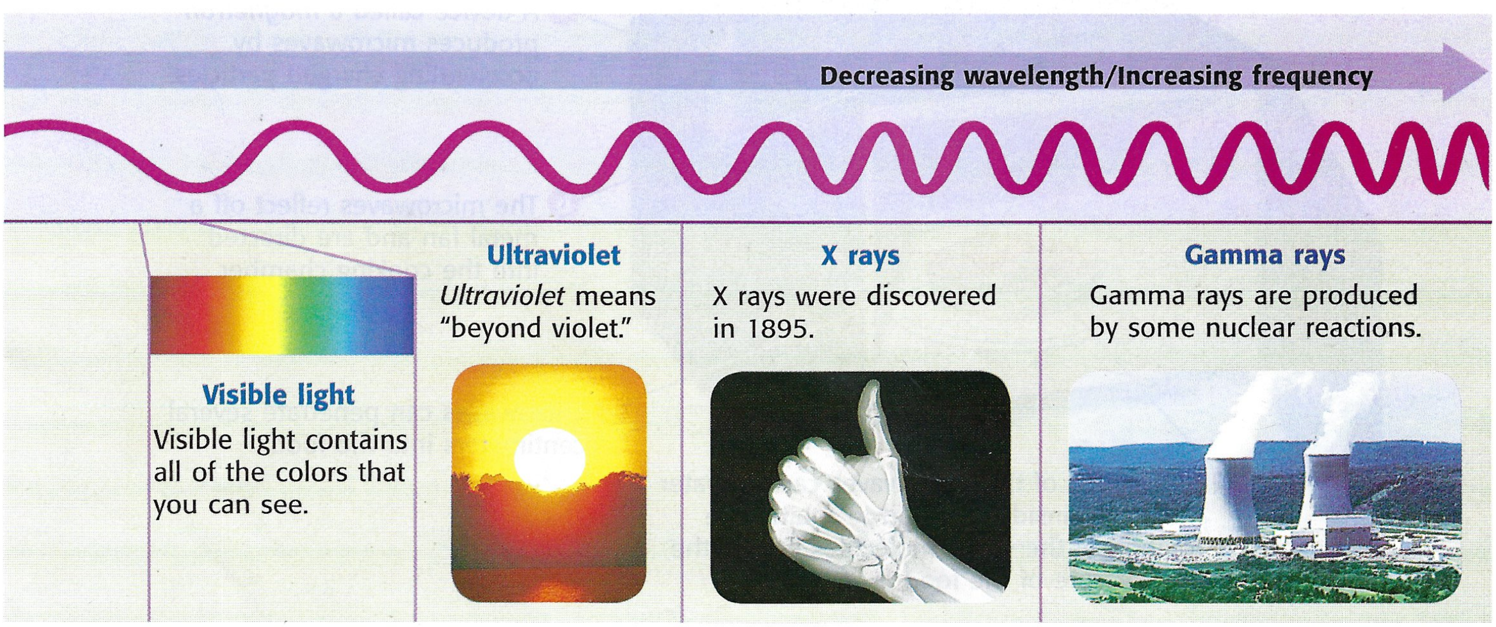


Figure 2 *Radio waves cannot be heard, but they can carry energy that can be converted into sound.*

Comparing AM and FM Radio Waves

AM radio waves are different from FM radio waves. For example, AM radio waves have longer wavelengths than FM radio waves do. And AM radio waves can bounce off the atmosphere and thus can travel farther than FM radio waves. But FM radio waves are less affected by electrical noise than AM radio waves are. So, music broadcast from FM stations sounds better than music broadcast from AM stations.

electromagnetic spectrum all of the frequencies or wavelengths of electromagnetic radiation



Radio Waves and Television

Television signals are also carried by radio waves. Most television stations broadcast radio waves that have shorter wavelengths and higher frequencies than those broadcast by radio stations. Like radio signals, television signals are broadcast using amplitude modulation and frequency modulation. Television stations use frequency-modulated waves to carry sound and amplitude-modulated waves to carry pictures.

Some waves carrying television signals are transmitted to artificial satellites orbiting Earth. The waves are amplified and sent to ground antennas. They then travel through cables to televisions in homes. Cable television works by this process.

Reading Check **Which EM waves can carry television signals?**

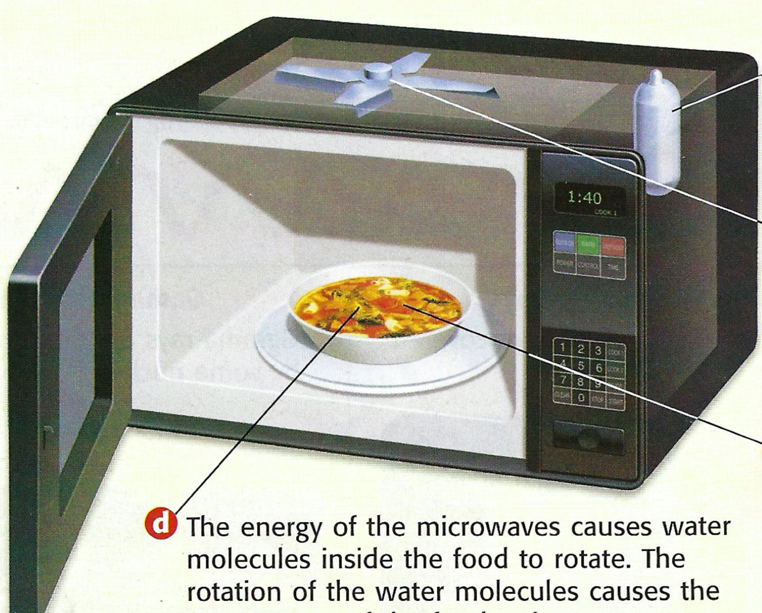
Microwaves

Microwaves have shorter wavelengths and higher frequencies than radio waves do. Microwaves have wavelengths between 1 mm and 30 cm. You are probably familiar with microwaves—they are created in a microwave oven, such as the one shown in **Figure 3.**

Microwaves and Communication

Like radio waves, microwaves are used to send information over long distances. For example, cellular phones send and receive signals using microwaves. And signals sent between Earth and artificial satellites in space are also carried by microwaves.

Figure 3 **How a Microwave Oven Works**



a A device called a *magnetron* produces microwaves by accelerating charged particles.

b The microwaves reflect off a metal fan and are directed into the cooking chamber.

c Microwaves can penetrate several centimeters into the food.

d The energy of the microwaves causes water molecules inside the food to rotate. The rotation of the water molecules causes the temperature of the food to increase.

Figure 4 *Police officers use radar to detect cars going faster than the speed limit.*

Radar

Microwaves are also used in radar. *Radar* (**ra**dio **d**etection **a**nd **r**anging) is used to detect the speed and location of objects. The police officer in **Figure 4** is using radar to check the speed of a car. The radar gun sends out microwaves that reflect off the car and return to the gun. The reflected waves are used to calculate the speed of the car. Radar is also used to watch the movement of airplanes and to help ships navigate at night.

Infrared Waves

Infrared waves have shorter wavelengths and higher frequencies than microwaves do. The wavelengths of infrared waves vary between 700 nanometers and 1 mm. A nanometer (nm) is equal to 0.000000001 m.

On a sunny day, you may be warmed by infrared waves from the sun. Your skin absorbs infrared waves striking your body. The energy of the waves causes the particles in your skin to vibrate more, and you feel an increase in temperature. The sun is not the only source of infrared waves. Almost all things give off infrared waves, including buildings, trees, and you! The amount of infrared waves an object gives off depends on the object's temperature. Warmer objects give off more infrared waves than cooler objects do.

You can't see infrared waves, but some devices can detect infrared waves. For example, infrared binoculars change infrared waves into light you can see. Such binoculars can be used to watch animals at night. **Figure 5** shows a photo taken with film that is sensitive to infrared waves.

Figure 5 *In this photograph, brighter colors indicate higher temperatures.*

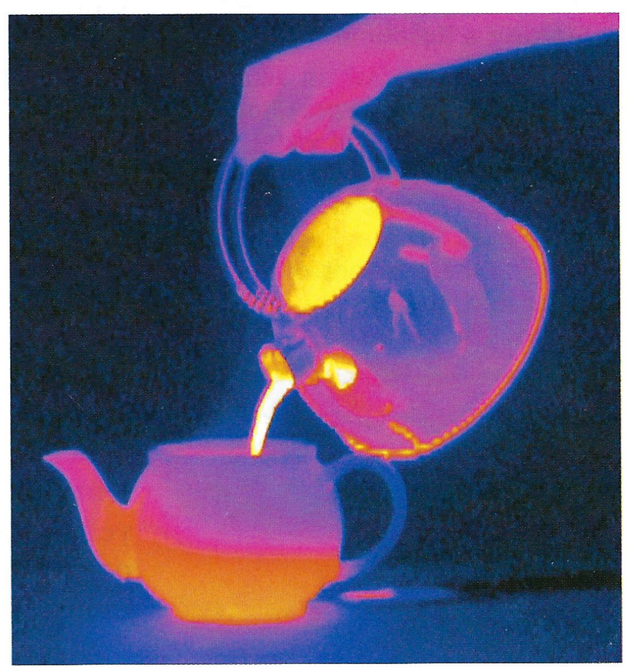


Figure 6 *Water droplets can separate white light into visible light of different wavelengths. As a result, you see all the colors of visible light in a rainbow.*

Visible Light

Visible light is the very narrow range of wavelengths and frequencies in the electromagnetic spectrum that humans can see. Visible light waves have shorter wavelengths and higher frequencies than infrared waves do. Visible light waves have wavelengths between 400 nm and 700 nm.

Visible Light from the Sun

Some of the energy that reaches Earth from the sun is visible light. The visible light from the sun is white light. *White light* is visible light of all wavelengths combined. Light from lamps in your home as well as from the fluorescent bulbs in your school is also white light.

Reading Check What is white light?

Colors of Light

Humans see the different wavelengths of visible light as different colors, as shown in **Figure 6.** The longest wavelengths are seen as red light. The shortest wavelengths are seen as violet light.

The range of colors is called the *visible spectrum.* You can see the visible spectrum in **Figure 7.** When you list the colors, you might use the imaginary name *ROY G. BiV* to help you remember their order. The capital letters in Roy's name represent the first letter of each color of visible light: red, orange, yellow, green, blue, and violet. What about the *i* in Roy's last name? You can think of *i* as standing for the color indigo. Indigo is a dark blue color.

SCHOOL to HOME

Making a Rainbow

On a sunny day, ask an adult to use a hose or a spray bottle to make a mist of water outside. Move around until you see a rainbow in the water mist. Draw a diagram showing the positions of the water mist, the sun, the rainbow, and yourself.

ACTIVITY

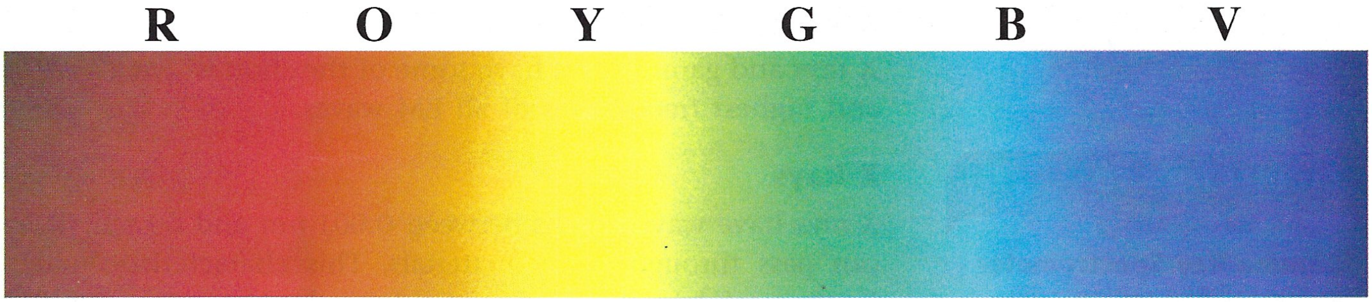


Figure 7 *The visible spectrum contains all colors of light.*

Ultraviolet Light

Ultraviolet light (UV light) is another type of electromagnetic wave produced by the sun. Ultraviolet waves have shorter wavelengths and higher frequencies than visible light does. The wavelengths of ultraviolet light waves vary between 60 nm and 400 nm. Ultraviolet light affects your body in both bad and good ways.

Reading Check **How do ultraviolet light waves compare with visible light waves?**

Bad Effects

On the bad side, too much ultraviolet light can cause sunburn, as you can see in **Figure 8.** Too much ultraviolet light can also cause skin cancer, wrinkles, and damage to the eyes. Luckily, much of the ultraviolet light from the sun does not reach Earth's surface. But you should still protect yourself against the ultraviolet light that does reach you. To do so, you should use sunscreen with a high SPF (**s**un **p**rotection **f**actor). You should also wear sunglasses that block out UV light to protect your eyes. Hats, long-sleeved shirts, and long pants can protect you, too. You need this protection even on overcast days because UV light can travel through clouds.

Figure 8 *Too much exposure to ultraviolet light can lead to a painful sunburn. Using sunscreen will help protect your skin.*

Good Effects

On the good side, ultraviolet waves produced by ultraviolet lamps are used to kill bacteria on food and surgical tools. In addition, small amounts of ultraviolet light are beneficial to your body. When exposed to ultraviolet light, skin cells produce vitamin D. This vitamin allows the intestines to absorb calcium. Without calcium, your teeth and bones would be very weak.

X Rays and Gamma Rays

X rays and gamma rays have some of the shortest wavelengths and highest frequencies of all EM waves.

X Rays

X rays have wavelengths between 0.001 nm and 60 nm. They can pass through many materials. This characteristic makes X rays useful in the medical field, as shown in **Figure 9.** But too much exposure to X rays can also damage or kill living cells. A patient getting an X ray may wear special aprons to protect parts of the body that do not need X-ray exposure. These aprons are lined with lead because X rays cannot pass through lead.

X-ray machines are also used as security devices in airports and other public buildings. The machines allow security officers to see inside bags and other containers without opening the containers.

Reading Check How are patients protected from X rays?

Gamma Rays

Gamma rays are EM waves that have wavelengths shorter than 0.1 nm. They can penetrate most materials very easily. Gamma rays are used to treat some forms of cancer. Doctors focus the rays on tumors inside the body to kill the cancer cells. This treatment often has good effects, but it can have bad side effects because some healthy cells may also be killed.

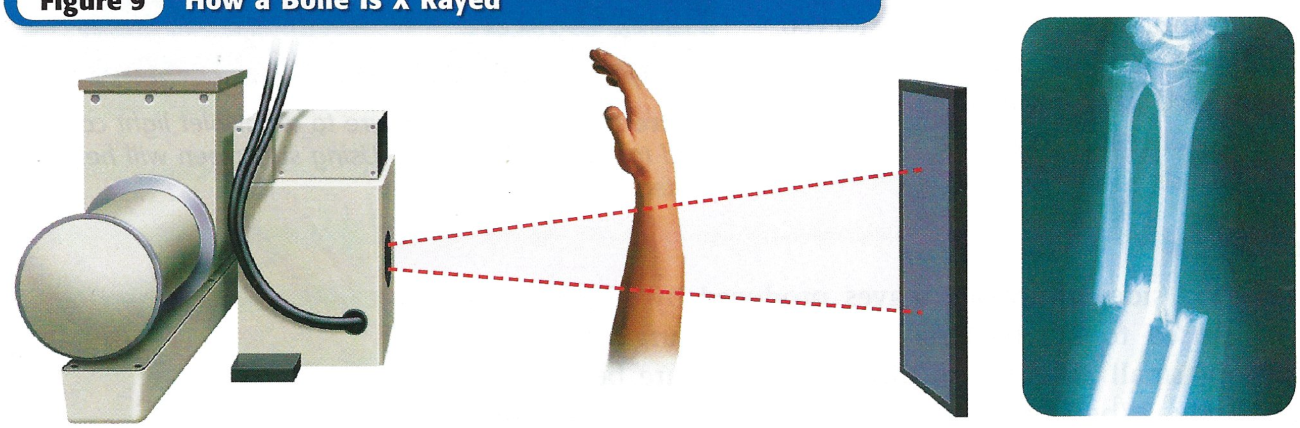
Gamma rays are also used to kill harmful bacteria in foods, such as meat and fresh fruits. The gamma rays do not harm the treated food and do not stay in the food. So, food that has been treated with gamma rays is safe for you to eat.

CONNECTION TO Astronomy

Gamma Ray Spectrometer In 2001, NASA put an artificial satellite called the *2001 Mars Odyssey* in orbit around Mars. The *Odyssey* is carrying a gamma ray spectrometer. A *spectrometer* is a device used to detect certain kinds of EM waves. The gamma ray spectrometer on the *Odyssey* was used to look for water and several chemical elements on Mars. Scientists hope to use this information to learn about the geology of Mars. Research the characteristics of Mars and Earth. In your **science journal,** make a chart comparing Mars and Earth.

ACTIVITY

Figure 9 How a Bone Is X Rayed



1. X rays travel easily through skin and muscle but are absorbed by bones.
2. The X rays that are not absorbed strike the film.
3. Bright areas appear on the film where X rays are absorbed by the bones.

SECTION Review

Summary

- All electromagnetic (EM) waves travel at the speed of light. EM waves differ only by wavelength and frequency.
- The entire range of EM waves is called the *electromagnetic spectrum*.
- Radio waves are used for communication.
- Microwaves are used in cooking and in radar.
- The absorption of infrared waves is felt as an increase in temperature.
- Visible light is the narrow range of wavelengths that humans can see. Different wavelengths are seen as different colors.
- Ultraviolet light is useful for killing bacteria and for producing vitamin D in the body. Overexposure to ultraviolet light can cause health problems.
- X rays and gamma rays are EM waves that are often used in medicine. Overexposure to these kinds of rays can damage or kill living cells.

Using Key Terms

1. In your own words, write a definition for the term *electromagnetic spectrum*.

Understanding Key Ideas

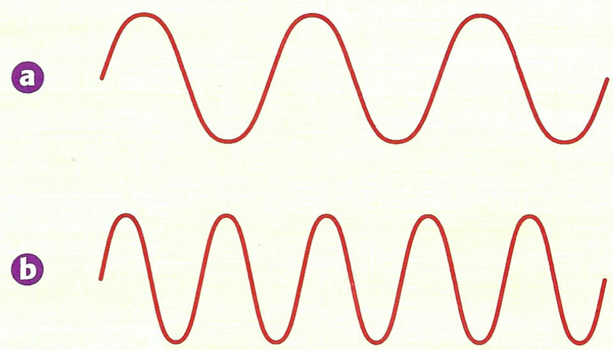
2. Which of the following electromagnetic waves are produced by the sun?
   - **a.** infrared waves
   - **b.** visible light
   - **c.** ultraviolet light
   - **d.** All of the above
3. How do the different kinds of EM waves differ from each other?
4. Describe two ways of transmitting information using radio waves.
5. Explain why ultraviolet light, X rays, and gamma rays can be both helpful and harmful.
6. What are two common uses for microwaves?
7. What is white light? What are two sources of white light?
8. What is the visible spectrum?

Critical Thinking

9. **Applying Concepts** Describe how three different kinds of electromagnetic waves have been useful to you today.
10. **Making Comparisons** Compare the wavelengths of infrared waves, ultraviolet light, and visible light.

Interpreting Graphics

The waves in the diagram below represent two different kinds of EM waves. Use the diagram below to answer the questions that follow.



11. Which wave has the longest wavelength?
12. Suppose that one of the waves represents a microwave and one of the waves represents a radio wave. Which wave represents the microwave?