KEY CONCEPT

17.2 Electromagnetic waves have many uses.

BEFORE, you learned

- EM waves transfer energy through fields
- EM waves have measurable properties
- EM waves interact with matter

NOW, you will learn

- How EM waves differ from one another
- How different types of EM waves are used

VOCABULARY

electromagnetic spectrum p. 560
radio waves p. 562
microwaves p. 563
visible light p. 564
infrared light p. 564
ultraviolet light p. 565
x-rays p. 566
gamma rays p. 566

EXPLORE Radio Waves

How can you make radio waves?

PROCEDURE

1. Tape one end of one length of wire to one end of the battery. Tape one end of the second wire to the other end of the battery.
2. Wrap the loose end of one of the wires tightly around the handle of the fork.
3. Turn on the radio to the AM band and move the selector past all stations until you reach static.
4. Hold the fork close to the radio. Gently pull the free end of wire across the fork's prongs.

MATERIALS

- two 25 cm lengths of copper wire
- C or D battery
- electrical tape
- metal fork
- portable radio

WHAT DO YOU THINK?

- What happens when you stroke the prongs with the wire?
- How does changing the position of the dial affect the results?

EM waves have different frequencies.

It might seem hard to believe that the same form of energy browns your toast, brings you broadcast television, and makes the page you are now reading visible. Yet EM waves make each of these events possible. The various types of EM waves differ from each other in their wavelengths and frequencies.

The frequency of an EM wave also determines its characteristics and uses. Higher-frequency EM waves, with more electromagnetic vibrations per second, have more energy. Lower-frequency EM waves, with longer wavelengths, have less energy.

REMINDER

Remember that frequency is the number of waves that pass a given point per second. The shorter the wavelength, the higher the frequency.

The Electromagnetic Spectrum

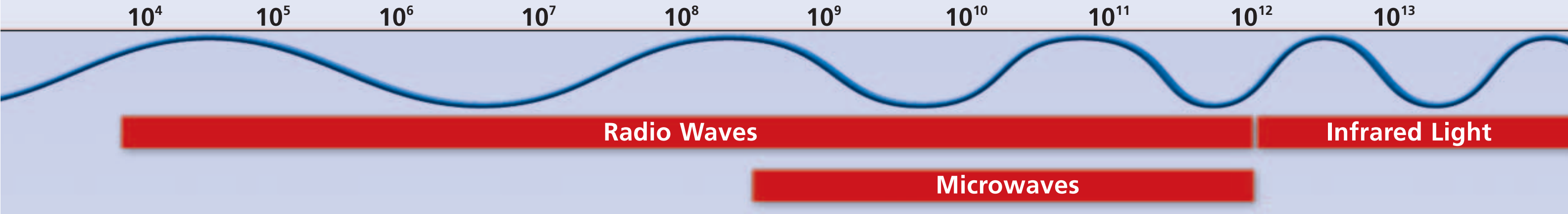
RESOURCE CENTER
CLASSZONE.COM
Learn more about the electromagnetic spectrum.

The range of all EM frequencies is known as the **electromagnetic spectrum** (SPEHK-truhm), or EM spectrum. The spectrum can be represented by a diagram like the one below. On the left are the waves with the longest wavelengths and the lowest frequencies and energies. Toward the right, the wavelengths become shorter, and the frequencies and energies become higher. The diagram also shows different parts of the spectrum: radio waves, microwaves, infrared light, visible light, ultraviolet light, x-rays, and gamma rays.

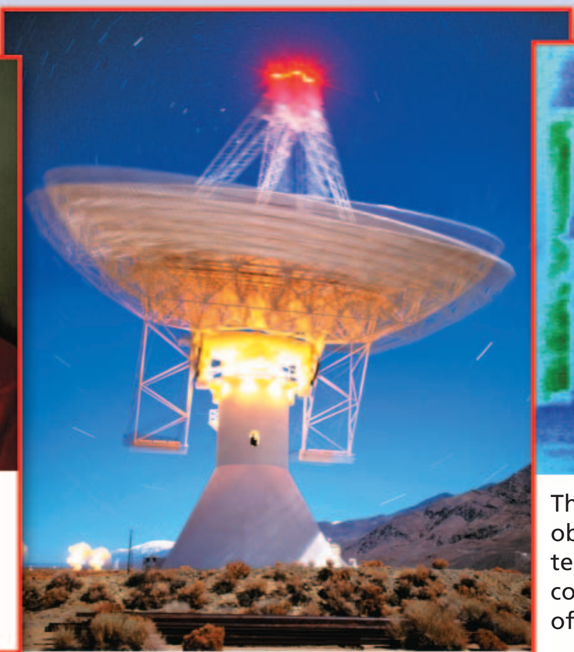
The EM spectrum is a smooth, gradual progression from the lowest frequencies to the highest. Divisions between the different parts of the spectrum are useful, but not exact. As you can see from the diagram below, some of the sections overlap.

The Electromagnetic Spectrum

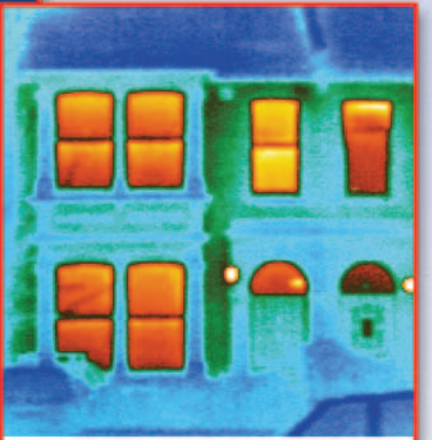
Frequency in Hertz (1 hertz = 1 wavelength/second)



This woman is speaking on the radio. **Radio waves** are used for radio and television broadcasts. They are also used for cordless phones, garage door openers, alarm systems, and baby monitors.



Not all astronomy involves visible light. Telescopes like the one above pick up **microwaves** from space. Microwaves are also used for radar, cell phones, ovens, and satellite communications.



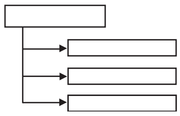
The amount of **infrared light** an object gives off depends on its temperature. Above, different colors indicate different amounts of infrared light.

Measuring EM Waves

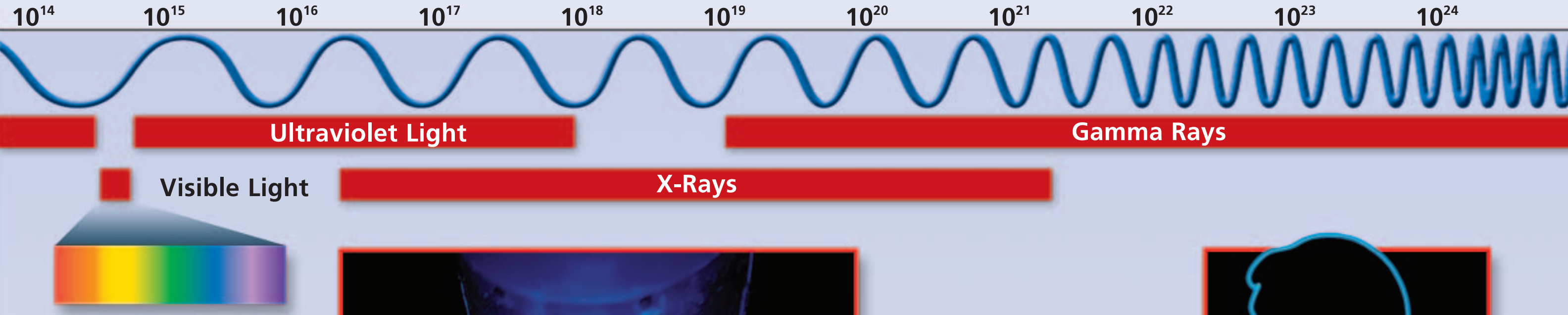
Because all EM waves move at the same speed in a vacuum, the frequency of an EM wave can be determined from its wavelength. EM wavelengths run from about 30 kilometers for the lowest-frequency radio waves to trillionths of a centimeter for gamma rays. EM waves travel so quickly that even those with the largest wavelengths have very high frequencies. For example, a low-energy radio wave with a wavelength of 30 kilometers has a frequency of 10,000 cycles per second.

EM wave frequency is measured in hertz (Hz). One hertz equals one cycle per second. The frequency of the 30-kilometer radio wave mentioned above would be 10,000 Hz. Gamma ray frequencies reach trillions of trillions of hertz.

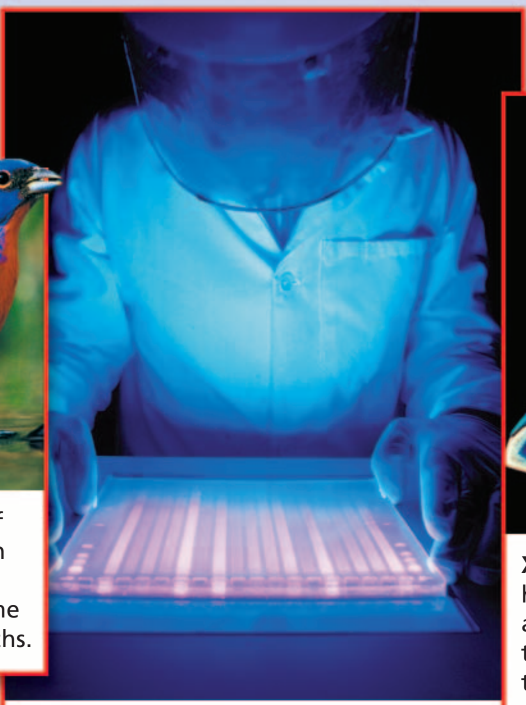
SUPPORTING MAIN IDEAS
Write details that support the main idea that EM waves form a spectrum based on frequency.



CHECK YOUR READING Why is wavelength all you need to know to calculate EM wave frequency in a vacuum?

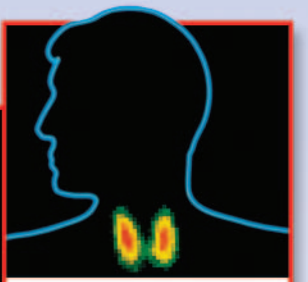


Visible light is the part of the EM spectrum that can be seen with the human eye. This bird's colors come from different wavelengths.



The researcher in this photograph is using **ultraviolet light** in the process of DNA analysis. A chemical in the samples gives off visible pink light when ultraviolet rays are present.

X-rays are useful for showing hard tissues inside the body, such as bones. To make images like the one above, x-ray images have to be displayed using visible light.

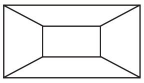


Gamma rays can be used to treat illnesses and to create images like this one of a person's thyroid gland.

Radio waves and microwaves have long wavelengths and low frequencies.

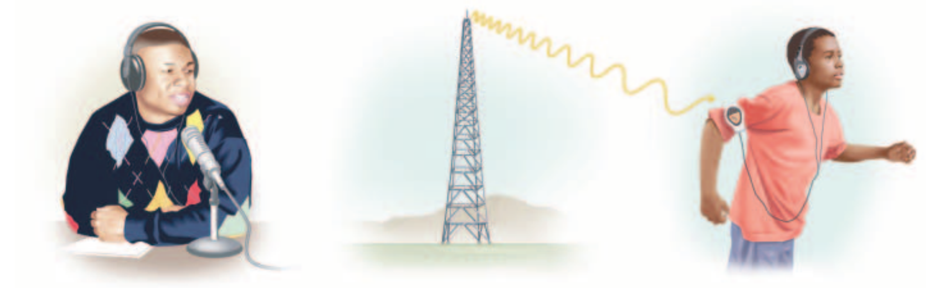
Radio waves are EM waves that have the longest wavelengths, the lowest frequencies, and the lowest energies. Radio waves travel easily through the atmosphere and many materials. People have developed numerous technologies to take advantage of the properties of radio waves.

VOCABULARY
Make a frame game diagram for *radio waves* and the other types of EM waves.



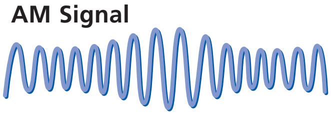
Radio Waves

Radio was the first technology to use EM waves for telecommunication, which is communication over long distances. A radio transmitter converts sound waves into radio waves and broadcasts them in different directions. Radio receivers in many locations pick up the radio waves and convert them back into sound waves.



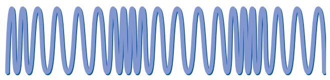
1. Sound waves enter the microphone and are converted into electrical impulses.
2. The electrical impulses are converted into radio waves and broadcast by the transmitter.
3. The radio waves reach a radio receiver and are converted back into sound.

AM Signal



Information is encoded in the signal by varying the radio wave's amplitude.

FM Signal



Information is encoded in the signal by varying the radio wave's frequency.

Different radio stations broadcast radio waves at different frequencies. To pick up a particular station, you have to tune your radio to the frequency for that station. The numbers you see on the radio—such as 670 or 99.5—are frequencies.

Simply transmitting EM waves at a certain frequency is not enough to send music, words, or other meaningful sounds. To do that, the radio transmitter must attach information about the sounds to the radio signal. The transmitter attaches the information by modulating—that is, changing—the waves slightly. Two common ways of modulating radio waves are varying the amplitude of the waves and varying the frequency of the waves. Amplitude modulation is used for AM radio, and frequency modulation is used for FM radio.

You might be surprised to learn that broadcast television also uses radio waves. The picture part of a TV signal is transmitted using an AM signal. The sound part is transmitted using an FM signal.

CHECK YOUR READING What two properties of EM waves are used to attach information to radio signals?

Microwaves

A type of EM waves called microwaves comes next on the EM spectrum. **Microwaves** are EM waves with shorter wavelengths, higher frequencies, and higher energy than other radio waves. Microwaves get their name from the fact that their wavelengths are generally shorter than those of radio waves. Two important technologies that use microwaves are radar and cell phones.

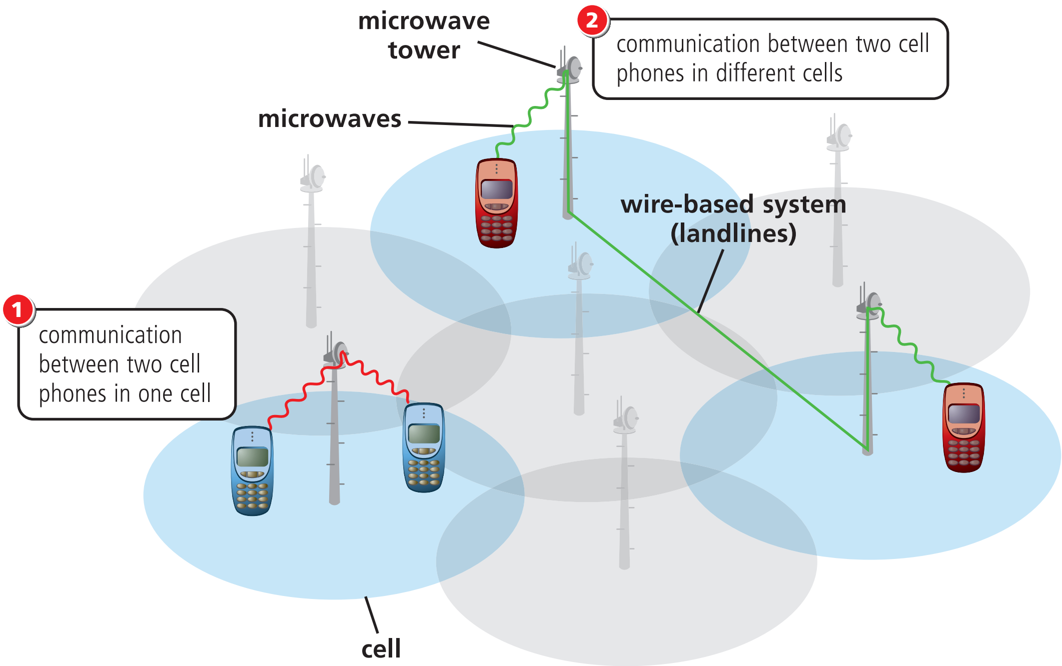
READING TIP

As you read about the different categories of EM waves, refer to the diagram on pages 560 and 561.

Radar The term *radar* stands for "radio detection and ranging." Radar came into wide use during World War II (1939–1945) as a way of detecting aircraft and ships from a distance and estimating their locations. Radar works by transmitting microwaves, receiving reflections of the waves from objects the waves strike, and converting these patterns into visual images on a screen. Today, radar technology is used to control air traffic at airports, analyze weather conditions, and measure the speed of a moving vehicle.

Radar led to the invention of the microwave oven. The discovery that microwaves could be used to cook food was made by accident when microwaves melted a candy bar inside a researcher's pocket.

Cell Phones A cell phone is actually a radio transmitter and receiver that uses microwaves. Cell phones depend on an overlapping network of cells, or areas of land several kilometers in diameter. Each cell has at its center a tower that sends and receives microwave signals. The tower connects cell phones inside the cell to each other or to the regular wire-based telephone system. These two connecting paths are shown below.



Infrared, visible, and ultraviolet light have mid-range wavelengths and frequencies.

Visible light is the part of the EM spectrum that human eyes can see. It lies between 10^{14} Hz and 10^{15} Hz. We perceive the longest wavelengths of visible light as red and the shortest as violet. This narrow band is very small compared with the rest of the spectrum. In fact, visible light is only about 1/100,000 of the complete EM spectrum. The area below visible light and above microwaves is the infrared part of the EM spectrum. Above visible light is the ultraviolet part of the spectrum. You will read more about visible light in the next section.

READING TIP

Infrared means "below red." *Ultraviolet* means "beyond violet."

Infrared Light

The **infrared light** part of the spectrum consists of EM frequencies between microwaves and visible light. Infrared radiation is the type of EM wave most often associated with heat. Waves in this range are sometimes called heat rays. Although you cannot see infrared radiation, you can feel it as warmth coming from the Sun, a fire, or a radiator. Infrared lamps are used to provide warmth in bathrooms and to keep food warm after it is cooked. Infrared rays also help to cook food—for example, in a toaster or over charcoal.

INVESTIGATE The Electromagnetic Spectrum

How can you detect invisible light?

PROCEDURE

1. Find a place that has both bright sunlight and shade, such as a windowsill. Place the white paper in the shade.
2. Using the marker, color the bulbs of the thermometers black. Place one thermometer on the paper. After three minutes, record the temperature.
3. Position the prism so that it shines a bright color spectrum on the white paper. Place the thermometers so that one bulb is in the blue area, one in the red, and one just outside the red, as shown.
4. After five minutes, record the three temperatures.

WHAT DO YOU THINK?

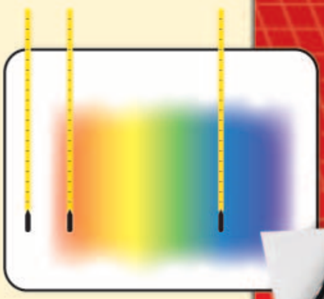
- How did the temperature in the shade compare to the temperature in the light and just outside of it?
- How might you explain the difference?

CHALLENGE How could you modify the experiment to find the hottest location in the infrared range?

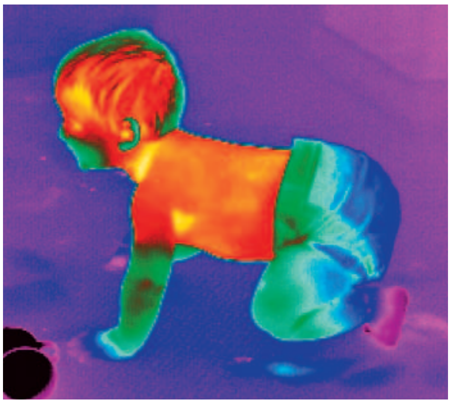
SKILL FOCUS
Drawing conclusions

MATERIALS
- white paper
- black marker
- 3 thermometers
- prism

TIME
30 minutes



Some animals, such as pit viper snakes, can actually see infrared light. Normally, human beings cannot see infrared light. However, infrared scopes and cameras convert infrared radiation into visible wavelengths. They do this by representing different levels of infrared radiation with different colors of visible light. This technology can create useful images of objects based on the objects' temperatures.



In this infrared image, warmer areas appear red and orange, while cooler ones appear blue, green, and purple.

CHECK YOUR READING How do human beings perceive infrared radiation?

Ultraviolet Light

The **ultraviolet light** part of the EM spectrum consists of frequencies above those of visible light and partially below those of x-rays. Because ultraviolet (UV) light has higher frequencies than visible light, it also carries more energy. The waves in this range can damage your skin and eyes. Sunblock and UV-protection sunglasses are designed to filter out these frequencies.

Ultraviolet light has beneficial effects as well. Because it can damage cells, UV light can be used to sterilize medical instruments and food by killing harmful bacteria. In addition, UV light causes skin cells to produce vitamin D, which is essential to good health. Ultraviolet light can also be used to treat skin problems and other medical conditions.

Like infrared light, ultraviolet light is visible to some animals. Bees and other insects can see higher frequencies than people can. They see nectar guides—marks that show where nectar is located—that people cannot see with visible light. The photographs below show how one flower might look to a person and to a bee.

This photograph shows the flower as it appears in visible light.

This photograph shows the flower as it might appear to a bee in ultraviolet light. Bees are able to see nectar guides in the UV range.

X-rays and gamma rays have short wavelengths and high frequencies.

At the opposite end of the EM spectrum from radio waves are x-rays and gamma rays. Both have very high frequencies and energies. **X-rays** have frequencies from about 10^{16} Hz to 10^{21} Hz. **Gamma rays** have frequencies from about 10^{19} Hz to more than 10^{24} Hz. Like other EM waves, x-rays and gamma rays are produced by the Sun and by other stars. People have also developed technologies that use these EM frequencies.


X-rays allow us to see inside the body.

X-rays pass easily through the soft tissues of the body, but many are absorbed by denser matter such as bone. If photographic film is placed behind the body and x-rays are aimed at the film, only the x-rays that pass through the body will expose the film. This makes x-ray images useful for diagnosing bone fractures and finding dense tumors. But too much exposure to x-rays can damage tissue. Even in small doses, repeated exposure to x-rays can cause cancer over time. When you have your teeth x-rayed, you usually wear a vest made out of lead for protection. Lead blocks high-frequency radiation.

Gamma rays have the highest frequencies and energies of any EM waves. Gamma rays are produced by some radioactive substances as well as by the Sun and other stars. Gamma rays can penetrate the soft and the hard tissues of the body, killing normal cells and causing cancer cells to develop. If carefully controlled, this destructive power can be beneficial. Doctors can also use gamma rays to kill cancer cells and fight tumors.

17.2 Review

KEY CONCEPTS

1. What two properties of EM waves change from one end of the EM spectrum to the other?
2. Describe two uses for microwave radiation.
3. How are EM waves used in dentistry and medicine?

CRITICAL THINKING

4. **Infer** Why do you think remote controls for TVs, VCRs, and stereos use infrared light rather than ultraviolet light?
5. **Apply** For a camera to make images of where heat is escaping from a building in winter, what type of EM wave would it need to record?

CHALLENGE

6. **Synthesize** When a person in a car is talking on a cell phone, and the car moves from one cell to another, the conversation continues without interruption. How might this be possible?