18.2 The Electromagnetic Spectrum

Reading Focus

Key Concepts

- What waves are included in the electromagnetic spectrum?
- How is each type of electromagnetic wave used?

Vocabulary

- electromagnetic spectrum
- amplitude modulation
- frequency modulation
- thermograms

Reading Strategy

Summarizing Copy the chart below and add four more rows to complete the table for the electromagnetic spectrum. After you reac, list at least two uses for each kind of wave.

Type of Waves	Uses	
Radio Waves	Communications	a. ?
Infrared Rays	b. ?	Keeping food warm

How do you investigate something that is invisible? First you have to suspect that it exists. Then you have to figure out a way to detect what is invisible and collect data about it. Such was the way the German-born astronomer William Herschel (1738–1822) discovered infrared radiation.

The Waves of the Spectrum

In England in 1800, with a technique discovered earlier, Herschel used a prism to separate the wavelengths present in sunlight. He produced a band of colors: red, orange, yellow, green, blue, and violet. He wondered if the temperature of each color of light was different from the temperature of the other colors of light. As you can see in Figure 8, Herschel placed thermometers at various places along the color band and measured the temperatures. Herschel observed that the temperature was lower at the blue end and higher toward the red end.

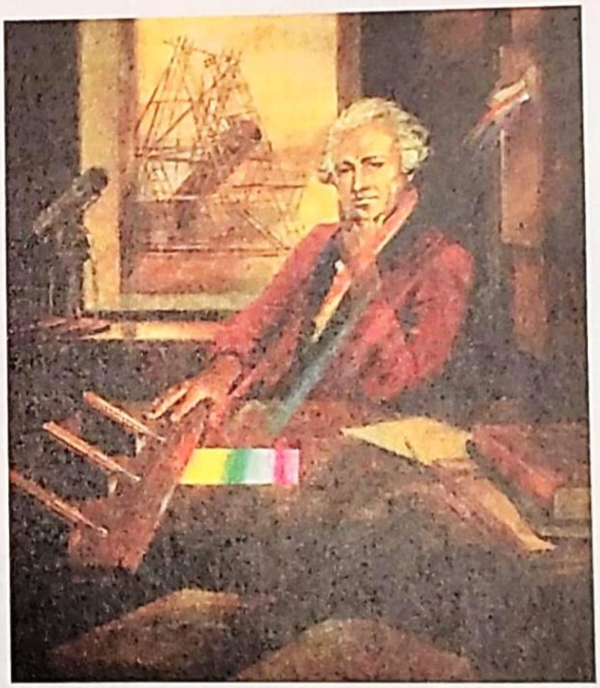

Figure 8 Herschel measured the temperature of different colors of light. The temperature was lowest at the blue end and highest at the red end. Curiosity led Herschel to discover evidence of radiation past the red end of the band of visible light.

This discovery made Herschel pose a new question: Would the temperature increase even more beyond the red end, in an area that showed no color? He measured the temperature just beyond the red end of the color band. This area recorded an even higher temperature than the red area. Herschel concluded there must be invisible radiation beyond the red end of the color band.

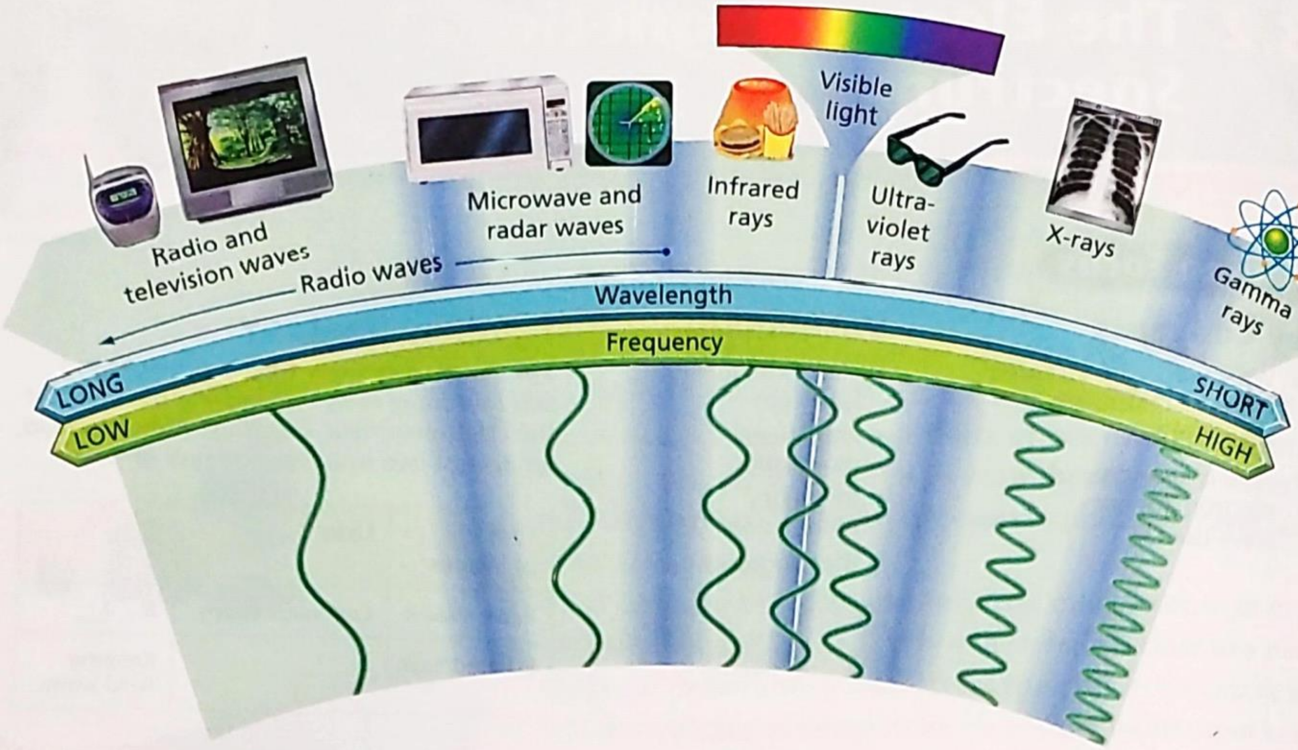

Figure 9 The electromagnetic spectrum consists of radio waves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays.
Interpreting Diagrams ***Which waves of the electromagnetic spectrum have the longest wavelengths?***

Today, radiation beyond the red end of the color band is called infrared radiation. Herschel experimented with infrared radiation and found it had many of the same properties as visible light. With these experiments, Herschel opened the door to the study of invisible types of electromagnetic radiation.

The full range of frequencies of electromagnetic radiation is called the **electromagnetic spectrum.** Figure 9 shows the spectrum of electromagnetic radiation in order of increasing frequency from left to right. Visible light is the only part of the electromagnetic spectrum that you can see, but it is just a small part. **The electromagnetic spectrum includes radio waves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays.** Each kind of wave is characterized by a range of wavelengths and frequencies. All of these waves have many useful applications.

Reading Checkpoint *What is the full range of frequencies of electromagnetic radiation called?*

Radio Waves

Radio waves have the longest wavelengths in the electromagnetic spectrum, from 1 millimeter to as much as thousands of kilometers or longer. Because they are the longest waves, radio waves also have the lowest frequencies in the spectrum—300,000 megahertz (MHz) or less. **Radio waves are used in radio and television technologies, as well as in microwave ovens and radar.**

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Radio In a radio studio such as the one in Figure 10, music and voices that have been changed into electronic signals are coded onto radio waves and then broadcast. There are two ways that radio stations code and transmit information on radio waves. Both ways are based on a wave of constant frequency and amplitude. To code the information onto this wave so that it can be broadcast, one of two characteristics of the wave must be varied, or modulated.

In **amplitude modulation,** the amplitude of the wave is varied. The frequency remains the same. AM radio stations broadcast by amplitude modulation. In **frequency modulation,** the frequency of the wave is varied. The amplitude remains the same. FM stations broadcast by frequency modulation. Whichever way the radio wave is transmitted, your radio receives it, decodes it, and changes it back into sound waves you can hear.

Have you ever traveled a long distance in a car and "lost" a station on the radio? A station is lost when its signal becomes too weak to detect. An FM radio station is more likely to be lost than an AM station because FM radio signals do not travel as far as AM signals along Earth's curved surface. AM radio stations use frequencies between 535 kilohertz and 1605 kilohertz. FM stations use frequencies between 88 megahertz and 108 megahertz. Particles in Earth's upper atmosphere reflect the lower-frequency AM radio waves much better than the higher-frequency FM radio waves. The reflection helps transmit AM signals farther.

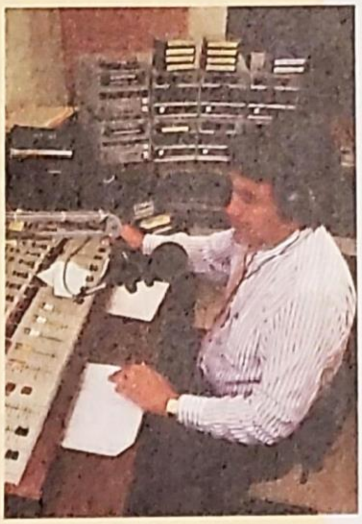
Television Radio waves also carry signals for television programming. The process is like transmitting radio signals. But one difference is that the radio waves carry information for pictures as well as for sound. Once they have been broadcast, the signals are received by an antenna, and sent to the TV set.

Location and weather can affect the reception of television signals by an antenna. For that reason, many people prefer to receive television signals that have been transmitted by satellite. With this type of transmission, TV broadcasts are sent to satellites, which then retransmit the signals back to Earth.

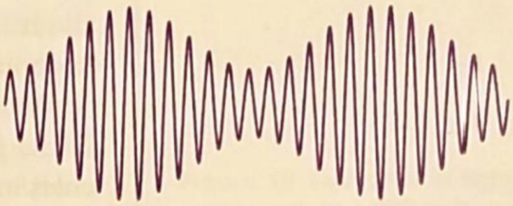
If you have a satellite dish, you can receive the signals directly. If not, a cable service can receive the signals and resend them to your home.

Radio Broadcasting

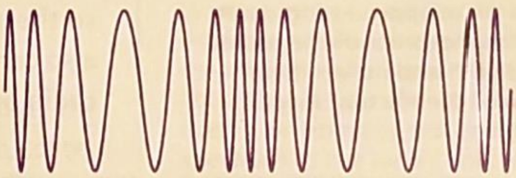
Figure 10 The announcer's voice and the music on CD leave the radio studio as electronic signals. Those signals are used to produce a wave with either a varying amplitude or a varying frequency.
A AM waves have a varying amplitude.
B FM waves have a varying frequency.

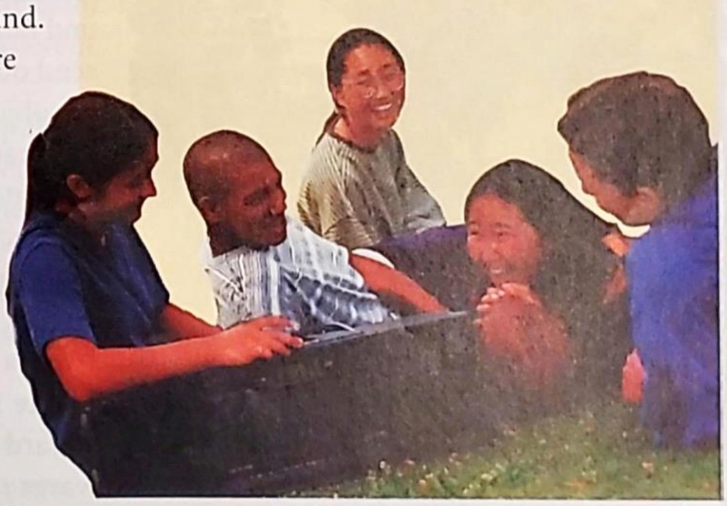


A Amplitude modulation



B Frequency modulation

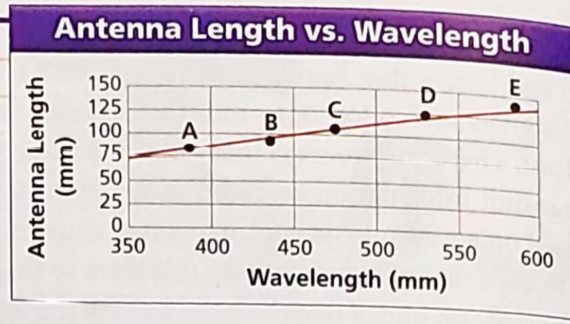




Data Analysis

How Long Does an Antenna Need to Be?

Have you ever noticed how the lengths of antennas vary from quite short (cell phones) to very long (radio transmitters)? The length of an antenna depends in part on the length of the waves it transmits. Each letter in the graph (A–E) represents an antenna of a different length. The graph shows the wavelengths that can be transmitted by antennas of a few different lengths.



1. **Calculating** What is the frequency of the wave that antenna B transmits? (*Hint:* Assume the wave travels at the speed of light.)
2. **Drawing Conclusions** What relationship is there between antenna length and wavelength?
3. **Inferring** At an outdoor concert, a singer is using a wireless microphone with antenna C. Speakers broadcast her performance. Now and then the speakers also broadcast an employee taking an order at a fast food restaurant nearby. What is the approximate wavelength of the transmissions from the restaurant? How do you know?
4. **Predicting** If you used a microphone that transmitted waves at 600 MHz, approximately how long would its antenna need to be?

Microwaves The shortest-wavelength radio waves are called microwaves. Microwaves have wavelengths from about 1 meter to about 1 millimeter. Their frequencies vary from about 300 megahertz to about 300,000 megahertz.

Microwaves cook and reheat food. When water or fat molecules in the food absorb microwaves, the thermal energy of these molecules increases. But microwaves generally penetrate foods only a few centimeters, so heating occurs only near the surface of the food. That is why instructions tell you to let the food stand for a few minutes—so thermal energy can reach the center by conduction. Microwaves also carry cell phone conversations. The process works much like the radio broadcast.

Figure 11 A speed-monitoring trailer uses radar to measure the speed of an approaching car. It reminds motorists of the posted speed limit and makes them aware of their actual speed.

Radar The word *radar* is an acronym for *ra*dio *d*etection *a*nd *r*anging. Radar technology uses a radio transmitter to send out short bursts of radio waves. The waves reflect off the objects they encounter, and bounce back toward where they came from. The returning waves are then picked up and interpreted by a radio receiver.

Recall that the Doppler effect is an apparent change in the frequency of a wave. The Doppler effect can be used to find the speed of a moving car. Radio waves are sent from a stationary source, such as the radar trailer in Figure 11, toward a moving car. The faster a car is moving toward the source, the higher is the frequency of the radio waves returning to the source.

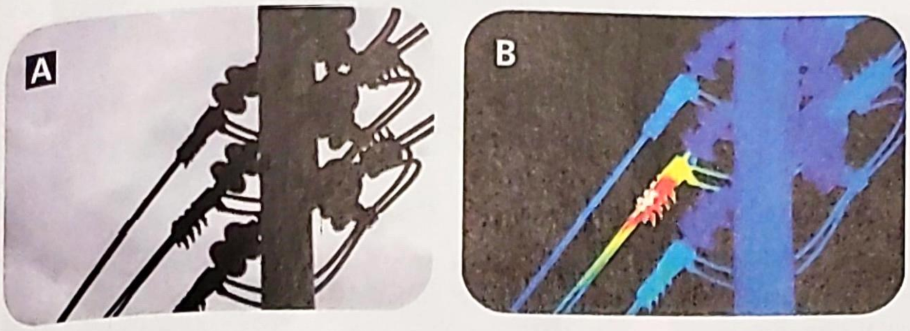


Figure 12 A thermogram can be used to diagnose problems in a utility line. **A** When viewed in visible light the wires all look the same. **B** The colors in the thermogram image show that the electric current in the center wire is not flowing as it should.

Infrared Rays

Infrared rays have higher frequencies than radio waves and lower frequencies than red light. Infrared wavelengths vary from about 1 millimeter to about 750 nanometers. (A nanometer is 10^{-9} meters, or one millionth of a millimeter.) **Infrared rays are used as a source of heat and to discover areas of heat differences.**

You cannot see infrared radiation, but your skin senses it as warmth. Reptile habitats at zoos are often kept warm with infrared lamps. Restaurants use infrared lamps to keep foods served buffet-style at a safe temperature for consumption.

Warmer objects give off more infrared radiation than cooler objects. A device called a thermograph uses infrared sensors to create thermograms. **Thermograms** (THUR moh gramz) are color-coded pictures that show variations in temperature. They are used to find places where a building loses heat to the environment. Thermograms can also locate problems in the path of electric current, as shown in Figure 12.

The human body is usually warmer than its surroundings. After a natural disaster such as an earthquake, search-and-rescue teams use infrared cameras to locate victims quickly—even underground.

Visible Light

The visible part of the electromagnetic spectrum is light that the human eye can see. Each wavelength in the visible spectrum corresponds to a specific frequency and has a particular color. Figure 13 shows the wavelength and frequency ranges of different colors of light in a vacuum.

People use visible light to see, to help keep them safe, and to communicate with one another. Light enables people to read. It is what makes flowers, boxes, signs, and all other objects visible. Automobiles have headlights and taillights that make night driving safer. Traffic lights communicate information to drivers about what is expected of them—to stop, for example, when the light is red.

Reading Checkpoint *What is the visible part of the electromagnetic spectrum?*

Figure 13 Each color of light corresponds to a different range of wavelengths. The wavelengths of visible light are quite small. Wavelengths of red light, for example, are about one hundredth the thickness of a human hair.
Using Tables *As the wavelength decreases from the red end of the spectrum to the violet end, what happens to the frequency?*

The Visible Spectrum

Color	Wavelength (nm)	Frequency ($\times 10^{14}$ Hz)
Red	610–750	4.9–4.0
Orange	590–610	5.1–4.9
Yellow	570–590	5.3–5.1
Green	500–570	6.0–5.3
Blue	450–500	6.7–6.0
Violet	400–450	7.5–6.7

Quick Lab

Evaluating Sunscreen

Procedure

1. Insert a black paper strip inside each of two plastic petri dishes to cover the sides. Place six ultraviolet-detecting beads in each dish. Cover each dish with its lid.
2. On one of the lids, spread a thin layer of sunscreen.
3. Place the dishes in direct sunlight. Record the time it takes for the beads in each dish to change color.

Analyze and Conclude

1. **Comparing and Contrasting** Compare the times the beads in the two dishes took to change color.
2. **Using Models** Explain how this lab models the use of sunscreen. What does the color change of the beads represent?
3. **Predicting** How might a sunscreen with a higher SPF (sun protection factor) affect the time needed for the beads to change color?

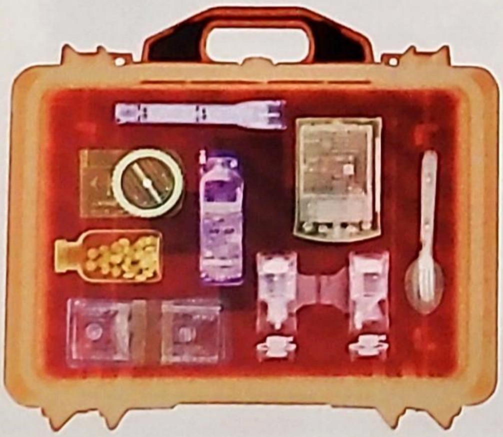
Ultraviolet Rays

The wavelengths of ultraviolet rays vary from about 400 nanometers to about 4 nanometers. Ultraviolet radiation has higher frequencies than violet light. **Ultraviolet rays have applications in health and medicine, and in agriculture.**

In moderation, exposure to ultraviolet rays helps your skin produce vitamin D. Vitamin D helps the body absorb calcium from foods to produce healthy bones and teeth. Excessive exposure can cause sunburn, wrinkles, and eventually skin cancer. It can also damage your eyes.

Ultraviolet rays are used to kill microorganisms. In heating and cooling systems of large buildings, ultraviolet rays disinfect the air that flows through the systems. In winter, plant nurseries use ultraviolet lights to help plants grow.

Figure 14 Airport security screeners use X-rays to search baggage for potentially dangerous objects.
Inferring *Why are there dark areas in this X-ray image?*



X-Rays

X-rays have very short wavelengths, from about 12 nanometers to about 0.005 nanometers. They have higher frequencies than ultraviolet rays. X-rays have high energy and can penetrate matter that light cannot. **X-rays are used in medicine, industry, and transportation to make pictures of the inside of solid objects.**

Your teeth and bones absorb X-rays. X-ray photographs show softer tissue as dark, highly exposed areas. Bones and teeth appear white. Too much exposure to X-rays can kill or damage living tissue.

The lids on aluminum cans are sometimes inspected with X-rays to make sure they are sealed properly. X-rays can be used to identify the contents of entire truck trailers. Packages and suitcases, such as the one in Figure 14, are X-rayed in search of dangerous contents.

Reading Checkpoint *What are X-rays used for?*

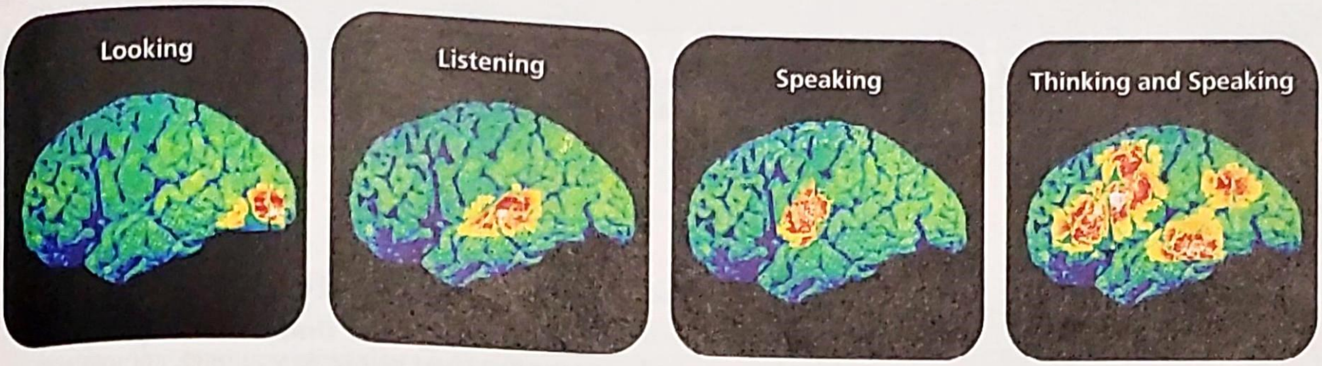


Figure 15 Gamma rays emitted by radioactive tracers in the brain are used to produce color-coded images. Areas of high activity show up in red. These images show where the brain is active when the patient is (from left to right) looking at something, listening, speaking, and thinking and speaking. The more involved the task, the more parts of the brain are activated.

Gamma Rays

Gamma rays have the shortest wavelengths in the electromagnetic spectrum, about 0.005 nanometer or less. They have the highest frequencies and therefore the most energy and the greatest penetrating ability of all the electromagnetic waves. Exposure to tiny amounts of gamma rays are tolerable, but overexposure can be deadly. **Gamma rays are used in the medical field to kill cancer cells and make pictures of the brain, and in industrial situations as an inspection tool.**

Gamma rays are used in radiation therapy to kill cancer cells without harming nearby healthy cells. Gamma rays are also used to make pictures of the human brain, with different levels of brain activity represented by different colors. Four brain scans are shown in Figure 15.

Pipelines are checked with machines that travel on the inside of a pipe, taking gamma ray pictures along the entire length. Technicians examine the pictures for rusting, cracks, or other signs of damage.

Section 18.2 Assessment

Reviewing Concepts

1. List the kinds of waves included in the electromagnetic spectrum, from longest to shortest wavelength.
2. Name three uses for each type of wave.
3. How is radar used to determine the speed of a car?
4. How can X-rays make pictures of the inside of solid objects?

Critical Thinking

5. **Comparing and Contrasting** How are AM radio waves similar to FM radio waves? How are they different?
6. **Classifying** What type of electromagnetic wave are microwaves and radar?
7. **Predicting** Which do you think will penetrate farther into a block of lead, X-rays or gamma rays? Explain your reasoning.

Writing in Science

Explanatory Writing Write one paragraph each about three different kinds of electromagnetic waves that you will encounter today. Use a single characteristic, such as wavelength or frequency, to describe each wave. Explain how life might be different without each kind of wave.