4.3 Light and the Electromagnetic Spectrum

A rainbow, or visible spectrum, is a tiny portion of a much larger spectrum of radiation called the electromagnetic spectrum. Radio waves and infrared radiation have longer wavelengths, lower frequencies, and less energy than visible light. Ultraviolet light, X rays, and gamma rays all have shorter wavelengths, higher frequencies, and more energy than visible light. Each region of the invisible spectrum has special properties that make it useful in some sort of imaging technology.

Key Terms

electromagnetic radiation
gamma rays
infrared waves
microwaves
radio waves
ultraviolet waves
X rays

No matter where you are, you are surrounded by invisible waves. Even though you cannot feel them, some of these waves are travelling right through your body.

Imagine that you are at the park on a summer day (Figure 4 19). You lather sunscreen on your skin to prevent a sunburn from the Sun's invisible waves. Someone plays music from a radio, while another person calls a friend on a cellphone. After you return home you use invisible rays when you finish your homework on your computer with its wireless Internet connection, and then prepare popcorn in a microwave oven to eat while you watch television.

Figure 4.19 Invisible waves allow us to communicate using cellphones and wireless Internet connections.

Did You Know?

There are two types of sunscreen. Physical sunscreens protect the skin by reflecting the ultraviolet waves. Chemical sunscreens protect the skin by absorbing the ultraviolet waves.

4-7 Seeing the Invisible

Find Out ACTIVITY

Sunscreen containers are labelled with a Sun protection factor (SPF) number that represents how much longer than usual you can stay in the sunlight without burning. A "black light" produces UV light as well as some visible light. In this activity, you will observe evidence that tonic water absorbs UV light and then radiates that energy as visible light.

Safety

- Do not look directly at the black light.

Materials

- beaker
- tonic water
- black light
- SPF 30 sunscreen
- Canadian currency bill

What to Do

Part 1

1. Fill a beaker with tonic water and shine a black light on it. What do you notice about the appearance of the tonic water?
2. Coat the outside of the beaker with SPF 30 sunscreen. Shine the black light through the wall of the beaker. What do you notice about the appearance of the tonic water?

Part 2

1. Shine a black light on a Canadian currency bill. You may be very surprised by the UV feature built into it. Stores and banks use black lights to check for counterfeit bills.
2. Rub some sunscreen onto the bill, and observe the results.
3. Clean up and put away the equipment you have used.

What Did You Find Out?

1. Compare the appearance of the tonic water under normal light with its appearance under a black light.
2. (a) How did the appearance of the tonic water change when the beaker was covered with sunscreen?

   (b) Explain the reason for this change.
3. What would you expect to observe if you coated the outside of the beaker with a tanning lotion that did not include sunscreen?
4. Would a colour photocopy of a currency bill be affected the same way under black light as an authentic bill? Explain.

Beyond Visible Light

The Sun is the most important source of light on Earth. However, there is far more to sunshine than meets the eye!

Light spreads out, or radiates, from the Sun and other stars in all directions, like the spokes of a bicycle wheel. Energy, such as light, that travels by radiation is often called **radiant energy**. In addition to the visible energy that we call light, the Sun also radiates invisible energy. The light we see is just a tiny band of a much broader spectrum of energy.

Electromagnetic Radiation

Water waves can be used to represent how light moves through space. However, in many ways, light is a different kind of wave from those that travel through water. In a water wave, water particles vibrate up and down as the wave passes through the water. In a light wave, electrical and magnetic fields vibrate. As a result, light is classified as electromagnetic radiation. Visible light energy and all the invisible forms of radiant energy exist on the electromagnetic spectrum, as shown in Figure 4.20. **Electromagnetic radiation** is the transmission of energy in the form of waves that extend from the longest radio waves to the shortest gamma rays.

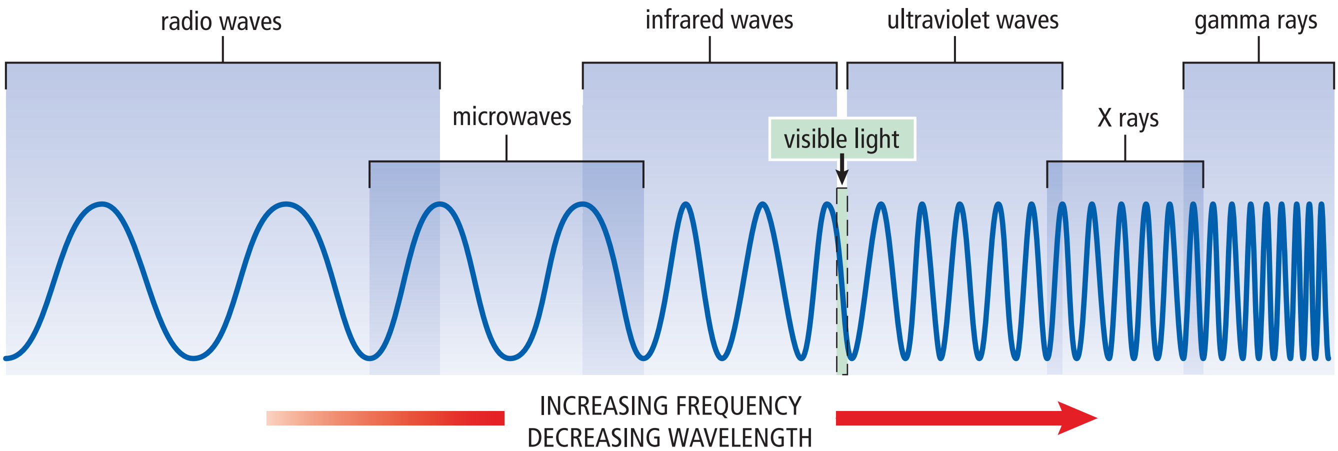


Figure 4.20 Electromagnetic waves are described by different names depending on their frequency and wavelength.

Wavelengths Longer than Visible Light

The electromagnetic waves that we can detect with our eyes are a small portion of the entire electromagnetic spectrum. However, various devices have been developed to detect other frequencies. For example, the antenna of your radio detects radio waves. Radio waves and infrared waves have longer wavelengths and are lower frequency than visible light.

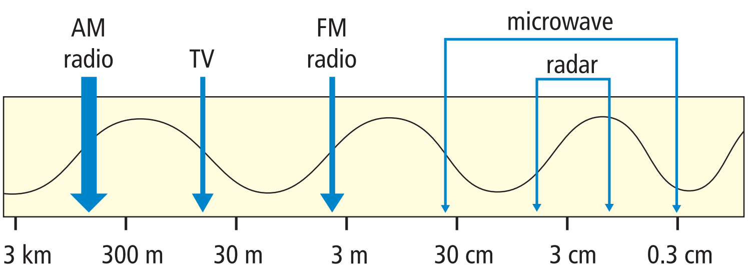


Figure 4.21 Radio wave region of the electromagnetic spectrum

Radio Waves

Radio waves are a type of electromagnetic radiation that have the longest wavelength and lowest energy and frequency compared to all other types. Different wavelengths of radio waves have different uses, such as radio and television broadcasting (see Figure 4.21). Microwaves and radar are types of radio waves.

Some of the longest radio waves can help us see inside our bodies and diagnose illnesses without having to do surgery (see Figure 4.22A). In magnetic resonance imaging (MRI), a patient lies in a large cylinder that is equipped with a powerful magnet, a radio wave emitter, and a radio wave detector. Particles in the bones and soft tissues behave like tiny magnets and can be lined up. When the MRI machine causes the orientation of the particles to flip, they produce radio waves. The released energy is detected by the radio receiver and used to create a map of the different tissues (Figure 4.22B).

Figure 4.22(A) Magnetic resonance imaging technology uses radio waves as an alternative to imaging with X rays.

Figure 4.22(B) An MRI scan of the brain

Microwaves

Microwaves have the shortest wavelength and the highest frequency of all the radio waves. Microwave ovens use a specific wavelength (or frequency) of microwave that is strongly absorbed by water particles. When the water particles in the food absorb microwaves, they begin to vibrate quickly and become hot. Only foods that contain water particles can be heated using microwaves.

Microwave frequencies are also used in telecommunications (see Figure 4.23). Microwaves can be transmitted to telecommunications satellites that orbit Earth. The satellites receive microwave signals, strengthen them, and retransmit them to a new location. Some radio telescopes are directed not at Earth, but toward distant planets and galaxies. Scientists study radio waves to learn more about the composition, motion, and structure of these distant objects.

Did You Know?

The waves created by a jumping fish give us information about the fish that made them. The energy, wavelength, and frequency of radio waves from distant objects in space give us information about the objects that made them.

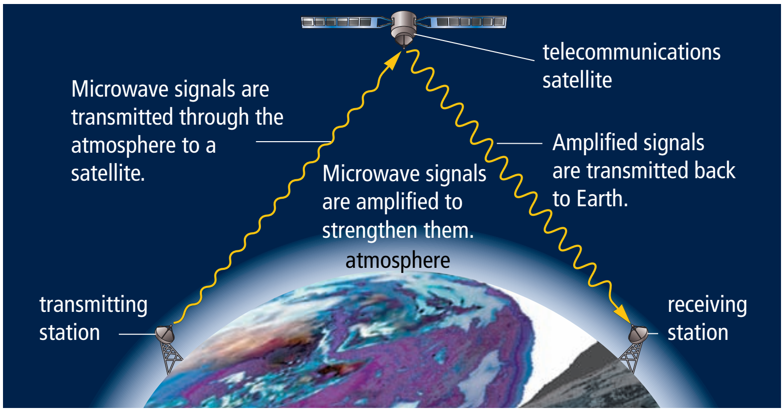


Figure 4.23 Signals sent by satellites can travel vast distances. One satellite can replace many ground relay stations. (This illustration is not drawn to scale.)

Radar

Shorter wavelength microwaves are used in remote sensing, such as radar. In this case, microwaves are beamed out through the air. The waves that reflect from an object can show the location and speed of the object. Radar is used for tracking the movement of automobiles, aircraft (see Figure 4.24), watercraft, and spacecraft.

Word Connect

"Radar" stands for **ra**dio **d**etecting **a**nd **r**anging.

Figure 4.24 Air traffic controllers use radar to guide airplanes during takeoffs and landings.

Radar is also used in weather forecasting. Raindrops, snow crystals, and other objects in the air reflect radio waves. Weather radar devices, such as Doppler radar, electronically convert the reflected radio waves into pictures that show the location and intensity of precipitation and the speed of the wind.

RADARSAT is a Canadian satellite that sweeps the ground below with radio waves (see Figure 4.25). These radio waves can penetrate haze, fog, clouds, and rain. When RADARSAT is over the ocean, it reflects information about ice floes that can imperil shipping. RADARSAT can also monitor oil spills so that workers can identify where environmental damage might occur. When over land, RADARSAT gathers data about the geographical features of Earth's surface that can be used to locate possible sites for oil, natural gas, and minerals. RADARSAT images of floods (see Figure 4.26) help to protect lives and save property.

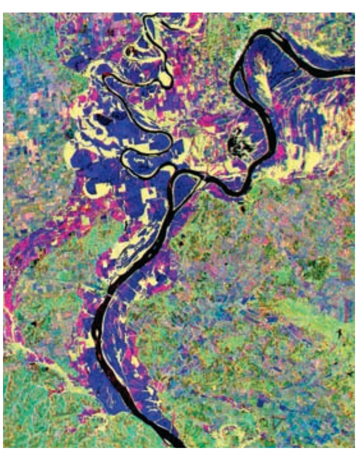


Figure 4.26 A RADARSAT image of flooded areas

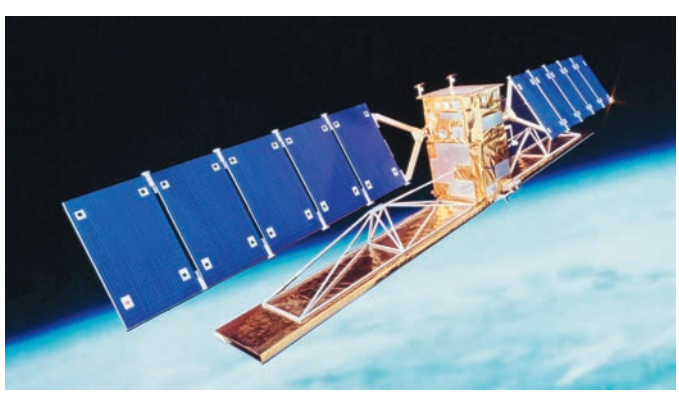


Figure 4.25 RADARSAT takes pictures of Earth's surface using radar.

Infrared Waves

Infrared waves are a type of electromagnetic radiation that, relative to light, has a longer wavelength and lower energy and frequency. You use infrared waves every day. A remote control emits infrared waves to control a television set. A computer uses infrared waves to read CD-ROMs. Infrared radiation is also referred to as heat radiation. In fact, every object emits some infrared waves because all objects contain some heat energy. Warmer objects emit more infrared waves than cooler objects. Longer infrared waves are used in heat lamps to keep food warm in fast food restaurants.

In the infrared image shown in Figure 4.27, the warmest parts of the cat are the most orange. The cat's nose is cool because of evaporation. Infrared images are used at some airports to determine whether passengers arriving from other countries have a fever. A fever means they may carry an infectious disease.

Canadian observation satellites such as LANDSAT use infrared devices to observe the extent of various crops or forests and monitor damage caused by insects, disease, and fire (see Figure 4.28).

Word Connect

Infrared means below red.

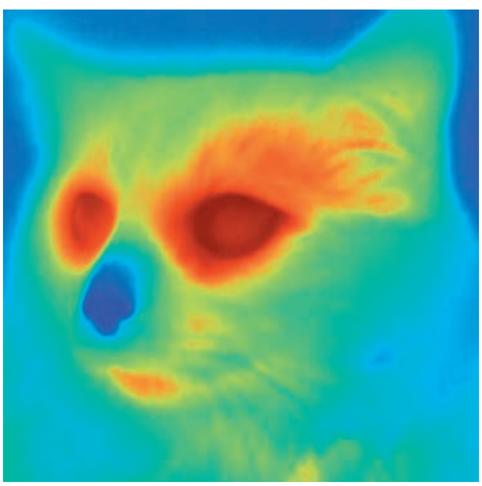


Figure 4.27 An infrared camera and film detect differences in temperature and assign false colours to different brightnesses. The result is information that we could not get from a visible light photograph.

Figure 4.28 A LANDSAT image of areas burned by fires, Kelowna, 2003

Reading Check

1. Where is visible light found on the electromagnetic spectrum?
2. Which type of electromagnetic radiation has the longest wavelength?
3. Why does an empty plate not heat up in the microwave?
4. What are two uses of radar?
5. What is another term for heat radiation?

Suggested Activity

Find Out Activity 4-8 on page 161

Word Connect

Ultraviolet means above violet.

Wavelengths Shorter than Visible Light

Wavelengths that are shorter than visible light carry more energy than the electromagnetic waves in the visible region. These shorter wavelength, higher frequency waves include ultraviolet waves, X rays, and gamma rays.

Ultraviolet Waves

Just beyond the violet end of the visible region of the electromagnetic spectrum are the ultraviolet waves. **Ultraviolet waves** are a type of electromagnetic radiation that, relative to light, has a shorter wavelength and higher energy and frequency. This radiation is very energetic. Ultraviolet radiation striking your skin enables your body to make vitamin D, which you need for healthy bones and teeth (see Figure 4.29). However, an overexposure to ultraviolet radiation can result in sunburns and skin cancers, and damage to the surface of the eye.

Figure 4.29A You can prevent damage to your skin from ultraviolet radiation by wearing sunscreen and covering up exposed skin. Sunglasses that block ultraviolet radiation can help protect your eyes.

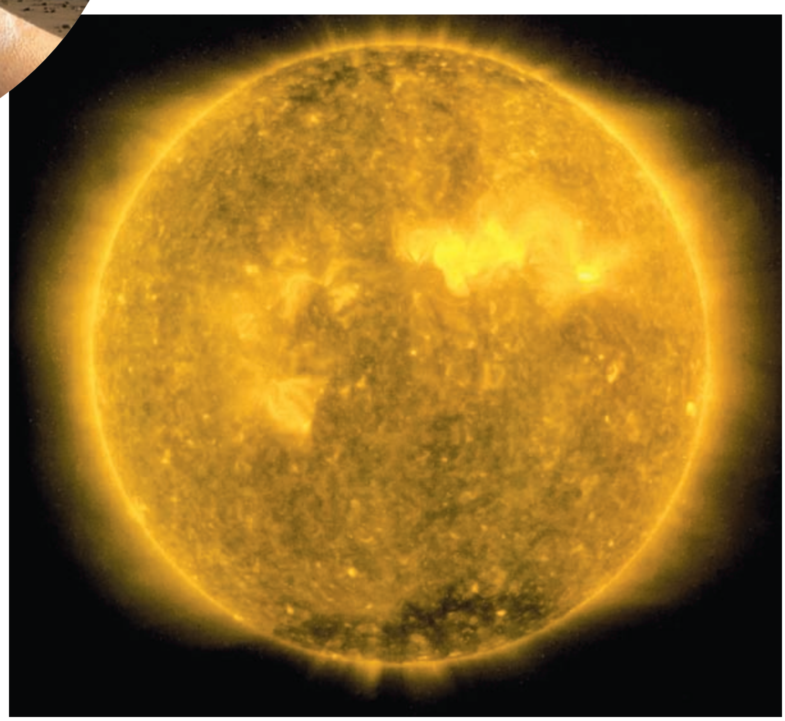


Figure 4.29B Earth's atmosphere absorbs some of the ultraviolet radiation emitted by the Sun.

internet connect

Light from the Sun is produced by nuclear fusion of hydrogen particles. This process releases an enormous amount of energy. Find out more about nuclear fusion and temperatures in the Sun. Start your search at **www.bcscience8.ca.**

Other uses for UV waves

Fluorescent materials absorb ultraviolet waves and emit the energy as visible light. As shown in Figure 4.30, police detectives sometimes use fluorescent powder to study fingerprints when solving crimes. Another useful property of ultraviolet waves is their ability to kill bacteria in food, water, and medical supplies.

Figure 4.30 The detective is shining ultraviolet light on fingerprints dusted with fluorescent powder.

Did You Know?

The ink from highlighter pens is very bright because it reflects visible light and absorbs a small amount of UV radiation. The ink then radiates the UV light as visible light. Manufacturers put chemicals into laundry soap to make white clothing appear brighter in daylight. The chemicals in the detergent respond to UV light in the same way as the highlighter pigments.

X Rays

X rays are a type of electromagnetic radiation that have a much shorter wavelength and higher energy and frequency than ultraviolet waves. Wilhelm Roentgen, a German physicist, discovered X rays in 1895. A week later he made this X-ray photograph of his wife's left hand (Figure 4.31). Her wedding ring is visible as a dark lump. Today, X rays are commonly used to photograph teeth and bones. (see Figure 4.32).

Suggested Activity

Find Out Activity 4-9 on page 161

Figure 4.31 X rays pass easily through tissue such as skin and muscle. However, X rays are absorbed by bone.

Figure 4.32 X rays are commonly used to locate a break in a bone, such as this forearm fracture.

Explore More

In certain situations, doctors will perform a CT scan on a patient instead of a traditional X ray. Find out more about CT scans. For example, what kind of radiation is used in a CT scan? How can it be used to generate a 3-D image of a person? Start your search at **www.bcscience8.ca.**

Other uses for X rays

Doctors and dentists use low doses of X rays to form images of internal organs, bones, and teeth. People who work with X rays protect themselves from harmful radiation by leaving the room while the equipment is being used. When a dentist takes an X ray of your teeth, he or she places a shielding pad on your body to protect you. You may have noticed airport security personnel using X-ray screening devices to examine the contents of luggage. X rays can also be used to inspect for cracks inside high performance jet engines without taking the engine apart, and to photograph the inside of machines (see Figure 4.33).

Figure 4.33 An X-ray photograph of a clock

Gamma Rays

Gamma rays are the highest energy and frequency and shortest wavelength portion of the electromagnetic spectrum. Gamma rays result from nuclear reactions and are produced by the hottest regions of the universe. Focussed bursts of gamma rays are used in radiation therapy to kill cancer cells.

Did You Know?

Gamma ray explosions in distant galaxies can release more energy in 10 s than our Sun will emit in its entire 10 billion–year lifetime.

Reading Check

1. What are three wavelengths that are shorter than visible light?
2. What are three uses of ultraviolet waves?
3. What can result from overexposure to ultraviolet waves?
4. What are three uses of X rays?
5. What can gamma rays be used for?

4-8 Reflection in the Infrared

Find Out ACTIVITY

Visible light reflects off mirrors and white pieces of paper. In this activity, you will observe evidence about what kinds of materials reflect infrared light.

Materials

- television set with remote control
- variety of materials such as cardboard, aluminum foil, paper, glass, cloth, mirror
- freezer

What to Do

1. Point the remote control away from the television and press the button until you find a direction in which the remote does not turn on the television. Then use a mirror or piece of cardboard to try to reflect the infrared beam back to the television.
2. Test a variety of your materials to determine their effectiveness in reflecting infrared light. Record your results.
3. Cool some of the same materials in a freezer for about 5 min. Then repeat step 2 of the test.

What Did You Find Out?

1. (a) What kinds of objects reflected the infrared beam?
   (b) What kinds did not?
2. What effect did cooling have on an object's ability to reflect an infrared beam?
3. Based on your results, would a block of ice be able to reflect an infrared beam? Explain your answer.

4-9 Sunscreen Circles

Find Out ACTIVITY

In this activity, you will model how sunscreen protects the skin from UV radiation.

Materials

- paper
- yellow felt pen
- yellow highlighter
- vegetable oil
- SPF 30 sunscreen
- black light

What to Do

1. Make a table to record your observations. Give your table a title.
2. Use a yellow felt pen to shade in three circles about 2 cm in diameter on white paper. Label the circles "felt pen."
3. Make three similar circles in different places on the same paper using a yellow highlighter. Label the circles "highlighter."
4. Cover one "felt pen" circle and one "highlighter" circle with oil.
5. Use SPF 30 sunscreen to cover one of the remaining "felt pen" circles and one of the remaining "highlighter" circles. Leave the last two circles untreated.
6. Shine all of the circles with black light and observe. Record your observations.

What Did You Find Out?

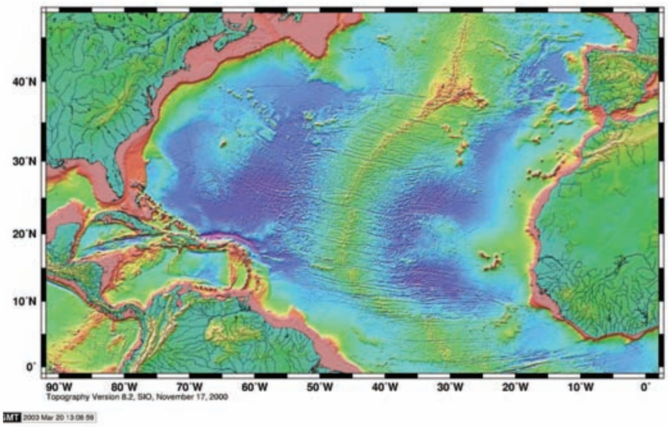
1. What happened to the colours of the six circles when you shone a black light on them?
2. Compare the circles made with the yellow highlighter. How are they different?
3. Why were two circles left untreated?
4. Why was oil used on two of the circles?
5. Why were both a regular felt pen and a highlighter pen used in this experiment?

Wild, Weird, Wonderful

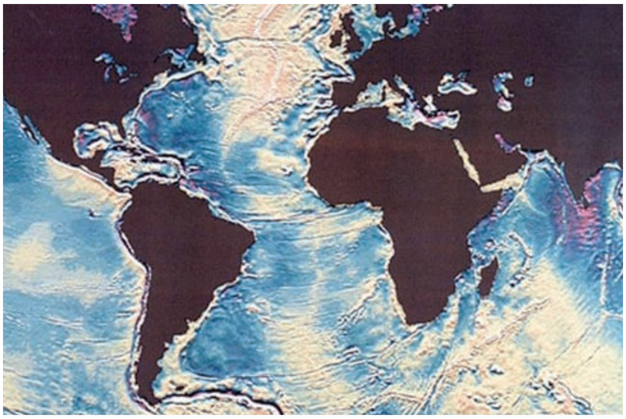
www Science

Using Satellites to Map the Ocean Floor

The top picture below is an image of the bottom of the North Atlantic Ocean. Notice the Mid-Atlantic Ridge, which runs from north to south down the centre of the Atlantic. Also clearly visible are several great fractures in the floor of the ocean that run from east to west. One fracture runs right across the centre of the North Atlantic and several other fractures run between South America and Africa.



An image of the ocean floor made by combining sonar and satellite data



A satellite radar image of the ocean floor

How is such an image generated? Sonar measurements are often used to find the depths of oceans. However, making sonar measurements means making many trips across an ocean with research vessels.

Another way to examine the oceans is with remote sensing. Remote sensing involves detecting features on Earth using satellite imaging. The second image was produced using radar technology. However, radar cannot penetrate water. So how can an image of the bottom of an ocean be produced if the radar cannot reach the bottom of the ocean? In fact, the second image is NOT an image of the floor of the ocean. It is an image of the surface of the ocean.

How can the surface of the ocean reveal the features of the ocean floor? A radar device mounted on a satellite bounces radar waves off the surface of the ocean and measures the distance to the surface of the water with an error of less than 1 cm. All oceans have small surface waves, so an average sea level is calculated. The bumps and valleys in the average sea level correlate to bumps and valleys in the ocean floor. Why?

The answer is gravity. Usually, we do not think about or feel the gravitational pull of a mountain as we drive by it in a car. These effects can only be measured with special equipment. However, in the ocean, a large seamount has enough gravitational pull to draw water toward it, making the sea level higher by up to 1 m near the sea mount. The gravitational pull of the rock in the ocean floor affects the sea level just like the gravitational pull of the Moon causes tides. Ocean trenches have the opposite effect, letting the sea level drop. The result is an image on the surface of the ocean that matches the topography of the ocean floor.

Check Your Understanding

Checking Concepts

1. (a) List all types of electromagnetic radiation that have wavelengths longer than those of visible light.
   (b) Name one use for each of the waves in (a).
2. (a) List all types of electromagnetic radiation that have wavelengths shorter than those of visible light.
   (b) Name one use for each of the waves in (a).
3. Why should you use sunscreen and a hat when you are out in the Sun?
4. (a) What is meant by the term radiant energy?
   (b) What is an example of radiant energy?
5. How can radar be used to help predict weather?
6. List five common uses of X rays.
7. How are radio waves used in an MRI to make an image of a person's internal tissues?
8. A mug of water is heated in a microwave oven. Explain why the water gets hotter than the mug.

Understanding Key Ideas

9. Describe why you can see visible light waves, but not other electromagnetic waves.
10. Name the kind of electromagnetic radiation likely to be used in each of the following technologies.
    (a) TV broadcast signals
    (b) detecting a broken arm
    (c) examining the inside of a weld in a steel oil pipe
    (d) lamp used to warm a baby chick
    (e) measuring the speed of a passing car
    (f) communicating between an aircraft and a control tower
    (g) cellphone
11. (a) What is a beneficial effect of human exposure to ultraviolet rays?
    (b) What is a harmful effect of human exposure to ultraviolet rays?
12. An oncologist is a physician who studies and treats cancer.
    (a) What portion of the invisible spectrum would an oncologist be likely to use to try to kill cancer cells in a patient?
    (b) How does the oncologist kill cancer cells but not healthy cells?

Pause and Reflect

What kind of information about a house could be revealed by examining the house using infrared photography?

Chapter Review

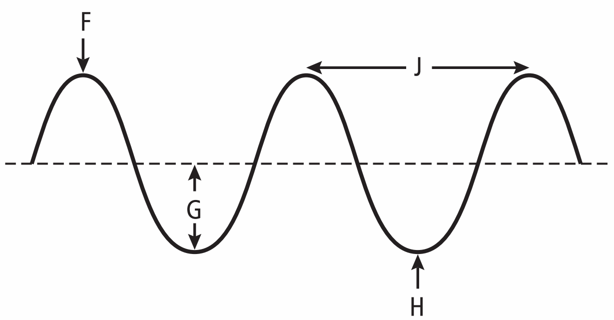
Prepare Your Own Summary

In this chapter, you investigated how a wave model of light can help you understand the properties of light. Create your own summary of key ideas from this chapter. You may want to include graphic organizers or illustrations with your notes. (See Science Skill 10 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Features of Waves
2. Prisms
3. The Visible Spectrum
4. Wavelengths Longer than Visible Light
5. Wavelengths Shorter than Visible Light

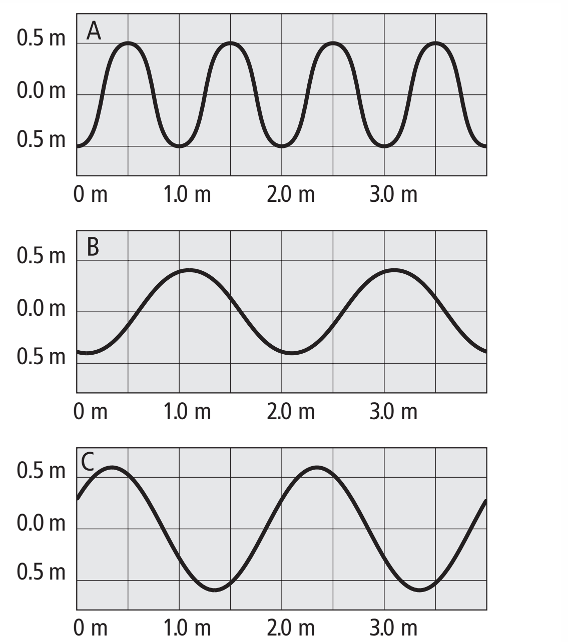
Checking Concepts

1. Name each of the following for the diagram below:
   (a) F
   (b) G
   (c) H
   (d) J



2. What is the relationship between wavelength and frequency?
3. Give examples of two ways in which light waves are similar to sound waves.
4. Describe how you would measure the length of a water wave made by tapping the end of a pencil through the surface of a bowl of water.
5. (a) What similarities do the waves of all colours of light share?
   (b) How do waves of different colours of light differ?
6. What unit is used for measuring frequency?
7. Describe the difference between wavelength and wave amplitude.

   Use the diagram below to answer 8, 9, and 10.



8. (a) What is the amplitude of Wave A?
   (b) What is the wavelength of Wave A?
9. (a) What is the amplitude of Wave B?
   (b) What is the wavelength of Wave B?
10. (a) What is the amplitude of Wave C?
    (b) What is the wavelength of Wave C?

11. White light contains many colours. How is it that a shirt can appear to be blue when it is being lit with white light?
12. List five regions of the invisible electromagnetic spectrum. For each region, state whether the electromagnetic waves are longer or shorter than that of visible light.
13. Describe how radio waves can be used to form an image of a human brain.

Understanding Key Ideas

14. What properties do light waves and the waves in a fishpond share?
15. Suppose a series of waves passes under a dock.
    (a) What is the frequency of the waves if 14 crests pass the dock in 7 s?
    (b) What is the frequency of the waves if 30 crests pass the dock in 5 s?
    (c) What is the frequency of the waves if one half of a wave passes the dock in 10 s?
    (d) Sketch waves (a), (b), and (c) in which each wave has a wavelength of 2 cm and an amplitude of 4 cm. Label your diagrams.
16. Explain why it is not possible to increase a wave's wavelength and frequency at the same time.
17. Make a table that compares and contrasts infrared waves, visible light, and X rays.
18. Mei Lin holds a DVD up to a bright light and sees a visible spectrum reflected off its surface.
    (a) State the part of the spectrum that she sees that has the longest wavelength.
    (b) State the part of the spectrum that she sees that has the highest frequency.
    (c) If Mei Lin were to remove the middle colours of the spectrum and recombine the two colours at the outside edge, what colour would she see?
19. When X-ray devices first became common, about 50 years ago, many shoe stores installed X-ray scanners. Customers would try on new shoes and then stand on the scanner. They could see the bones of their feet inside their new shoes to see if the shoes fit. Explain why this practice was quickly abandoned.

Pause and Reflect

Suppose you were to design a treatment for cancer using electromagnetic radiation. What kind of radiation would you choose, and why would you choose it? How might you use it to kill cancer cells?