UNIT

2 Optics

Telescopes in observatories have lenses and mirrors that can focus light from the depths of space.

Key Ideas

4 **Many properties of light can be understood using a wave model of light.**

4.1 The Nature of Light
4.2 Properties of Waves
4.3 Properties of Visible Light
4.4 Light and the Electromagnetic Spectrum

5 **The law of reflection allows mirrors to form images.**

5.1 The Ray Model of Light
5.2 Images in Plane Mirrors
5.3 Images in Curved Mirrors

6 **Lenses refract light to form images.**

6.1 Concave and Convex Lenses
6.2 Human Vision
6.3 Extending Human Vision

Getting Started

An aerobatic team produces colourful vapor trails.

High-performance jets fly low in front of a crowd. The jets are at high speed and in tight formation, moving at 300 km/h and holding steady at a separation of just 3 m from wing tip to wing tip. On a radio command, each pilot squeezes a trigger, releasing the billowing clouds of red, white, and green. The spectators see the sky filled with brightly coloured clouds. A thunderous roar rips through the air as the jets scream by. As the jets move off, the clouds begin to mix and break up.

A performance like an air show depends on many things, including the effective use of light. The pilots produced the coloured clouds at the same instant using radio transmissions to communicate. Radio communication, colours, cameras, binoculars, eyeglasses, and our own human vision system all depend on predictable properties of light.

Ancient societies used light energy from fire and sunlight. In our modern society, we also use laser light, radio waves, infrared light, and other forms of light energy. In this unit, you will learn about how we see and use visible light as well as invisible kinds of radiation. You will learn about optics the branch of physics that studies the properties of light and vision.


A laser light show can dazzle an audience.

internet connect

Four main types of light sources are incandescence, electrical discharge, fluorescence, and phosphorescence. Find out how each of these processes produces light. Start your search at **www.discoveringscience8.ca**.

Word Connect

Light comes from the Greek word *leukos*, which means "white", and later from German word, *leuhtjan*, which means "to shine. "

Light is Energy

Find Out ACTIVITY

Solar calculators use light from a source such as a lamp in the room or the Sun to operate without batteries. In this activity, you can observe evidence that light is a form of energy.

Materials

- calculator with solar panel that does not use batteries

What to Do

1. Enter some numbers into the calculator and then block any light from getting to the solar panel. Note the result.
2. Uncover the panel and look again at the display. Note the result.

What Did You Find Out?

1. What happened to the display when light was prevented from reaching the solar panel?
2. Was the calculator able to retain the numbers that were entered before the solar panel was covered? Explain.
3. How would you explain to a younger student how this experiment does or does not show that light is energy?

Chapter 4

Many properties of light can be understood using a wave model of light.

Imagine standing at the edge of a lake. The lake is calm and flat. It acts like a mirror, reflecting the far shore and the mountains beyond. Suddenly a fish jumps. You hear a splash, and circles of water waves radiate out from where the fish re-entered. These waves carry the energy that the fish transferred to the water surface by its jump. The size of the waves and the amount of energy they carry give you information about the size of the fish and how far out of the water it jumped. Light is also a wave that carries energy a long way, as it travels from its source, such as a flashlight or a star. All waves, including water waves and light waves, share many common characteristics.

What You Will Learn

In this chapter, you will
- **provide** examples of early light technologies
- **recognize** that waves carry energy
- **describe** ways in which water waves can explain properties of light
- **explain** why a prism separates white light into different colours
- **describe** properties and uses of electromagnetic waves

Why It Is Important

You can see and hear the world around you because of the energy carried by waves. Waves with different properties can be used in different ways. Electromagnetic waves can be used to make different kinds of images of the world around us.

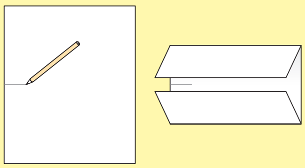
Skills You Will Use

In this chapter, you will
- **observe** how light can be separated into colours
- **model** the properties of light
- **communicate** using diagrams and colours

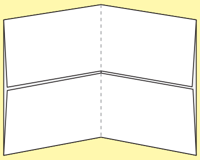
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 4.

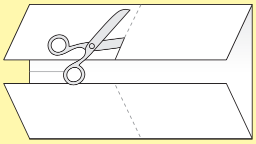
STEP 1 **Draw** a mark at the midpoint of a sheet of paper along the side edge. Then **fold** the top and bottom edges in to touch the midpoint. (If you are using notebook paper, use the centre of the middle hole to mark the midpoint.)



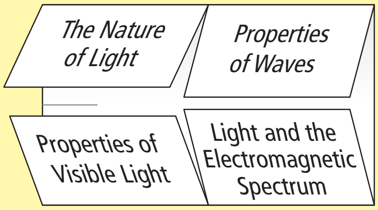
STEP 2 **Fold** in half from side to side.



STEP 3 **Open** and cut along the inside fold lines to form four tabs.



STEP 4 **Label** each tab as shown.



Read and Write As you read the chapter, record notes under the appropriate tabs.

4.1 The Nature of Light

Early philosophers believed that light was made of particles. Before they understood the nature of light, scientists and technologists made lenses and built microscopes and telescopes. As they experimented more with light, some scientists began to believe that light was actually a wave, while other scientists continued to believe that light was made of particles. During the 1800s, scientists demonstrated the wave nature of light and found that the speed of light is 3×10^8 m/s in a vacuum.

Key Terms

Pythagoras
microscope
telescope

What is light? People have been asking this question and trying to find answers for thousands of years. Early philosophers understood that there was a connection between light and vision. One of the first people to attempt to explain how light made it possible to see was **Pythagoras**, a Greek philosopher who was born around 580 B.C.E. Pythagoras believed that beams of light were made up of tiny particles as shown in Figure 4.1. When these beams of light came from objects and reached the eye, they carried information about the object to the eye. Other Greek philosophers believed that the eye sent out fibres, or threads of light, allowing the eye to "touch" or sense an object and gather information from it. For hundreds of years, people accepted these ideas because they seemed to explain all observations about the way light behaved.

Did You Know?

Ibn al-Haytham was a scientist born in Mesopotamia (now known as Iraq) in 965 C.E. He performed controlled experiments to test his ideas about light. He showed that light from sources such as the Sun and candles was reflected by other objects. He also described how the eye receives light and forms an image. It was hundreds of years before European scientists made similar discoveries.

Figure 4.1 Pythagoras thought that beams of light were made up of tiny particles. The eye could detect these particles and see the object.

Early Technologies Involving Light

By 1000 C.E., scientists still had a lot to learn about the properties of light, but people began to understand how to manipulate light to improve vision. People noticed that objects observed through a curved piece of glass (known today as a lens) appeared larger than they actually were. The first known lens that was designed to magnify print on a page was called a reading stone (Figure 4.2). It was a section of a glass sphere with one flat side. When it was placed on the page of a book, the words on the page appeared larger and were easier to read.

Eventually, a few people learned how to make lenses. A magnifying lens was put in a circular frame with a handle, similar to small magnifying glasses that are common now. In the late 1200s, in Italy, someone attached two magnifying glasses together at the handle so they could sit on a person's nose. These connected magnifying glasses became the first known spectacles or eyeglasses. A replica of these glasses is shown in Figure 4.3.

Explore More

You can make a "reading stone" out of gelatin desert. Follow the recipe on a box of lemon gelatin desert. Use round measuring spoons as molds for some of the gelatin. When the gelatin is firm, put the bottom of the spoon in a little warm water to loosen it. Then invert it onto some clear plastic. Holding it by the plastic, sit it on a printed page. Read the print through the gelatin. How does the gelatin affect the print on the page?

Figure 4.2 Nearly everyone older than 40 to 50 years old has trouble reading without glasses. Before the 1200s, a reading stone was the only way that older people could magnify the print enough to read it.

Figure 4.3 The frames of these first spectacles were made of bone, metal, or even leather.

In the late 1500s, a Dutch father and son, Zaccharias and Hans Janssen, experimented with the lenses and learned how to magnify objects even more. They made tubes that would slide inside each other and they put lenses on the ends of the tubes. By experimenting with different lenses and moving the tubes in and out, they discovered that they could make small objects look very large. They had invented the first compound **microscope**.

Figure 4.4 The first compound microscope was just two tubes with lenses in the ends.

One of their microscopes is shown in Figure 4.4. Anton van Leeuwenhoek is famous for building microscopes and discovering many tiny living organisms in a drop of water. He discovered that he could increase the magnifying power of a lense by increasing its curvature. One of the microscopes that Leeuwenhoek used is shown in Figure 4.5.

Figure 4.5 This probably does not look like a microscope but Leeuwenhoek discovered many "wee beasties" with it. The sample was placed on the point of the screw and Leeuwenhoek looked through a lens that was on the other side of the opening.

Figure 4.6 Galileo built and used this telescope in the early 1600s.

Galileo, an Italian scientist and philosopher, heard about many experiments with lenses. Soon he made his own lenses, which he used to build a **telescope** to magnify objects in space. (Figure 4.6). He continued to improve his telescopes and, using them, he discovered four of Jupiter's moons.

Reading Check

1. How did the early Greeks describe light?
2. Describe the first object that was used to help people read small print.
3. What did Leeuwenhoek learn to do to increase the magnifying power of lenses?
4. Who built and used the first telescope?
5. (a) Give one example of a technology that was developed before the science was understood.
   (b) Give one example of a technology that made other scientific discoveries possible.

Speed of Light

Scientists believed that determining the speed of light would help them understand the nature of light. What is the speed of light? It would be easy to assume that light travels instantaneously. After all, when you turn on a light, you see it instantly. Many early scientists also thought that light travelled instantaneously.

Galileo is believed to be the first person to try to measure the speed of light. In 1638, Galileo proposed that he and an assistant would stand on hilltops about one kilometre apart, holding lanterns (Figure 4.8). He would uncover his lantern first. As soon as his assistant saw the light, he would uncover his lantern. Galileo would measure the time between the moment that he uncovered his lantern and the moment he saw the light from his assistant's lantern. When he carried out the experiment, however, he was unable to calculate the speed of light from his results.

Figure 4.8 Galileo tried to measure the speed of light using lanterns. Why was he unsuccessful?

Particles or Waves of Light?

From the 1200s through the 1500s, scientists made great progress in using lenses and light to see things never seen before. However, they still did not fully understand the properties of light. Most philosophers and scientists continued to believe that light was made of streams of particles. In the 1600s, as scientists began to study light more carefully, they realized that some properties of light could not be possible if light was a stream of particles. For example, if light was made of particles that travelled only in straight lines, how could it bend around corners or spread out as it passed through narrow openings? Some scientists began to believe that light actually travelled like waves. In the early 1800s, an English scientist named Thomas Young and a French scientist named Augustin Fresnel both provided evidence that light did, indeed, behave like a wave (Figure 4.7).

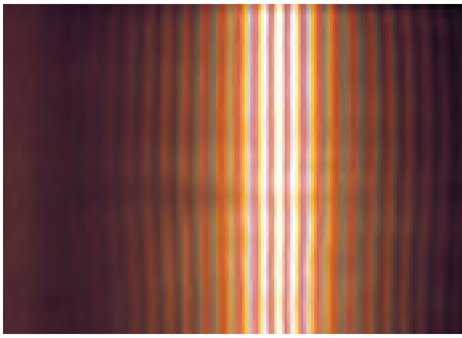


Figure 4.7 Thomas Young found that light spread out into this pattern when it passed through two narrow slits. If light was a stream of particles, what would he have seen?

The first person to measure the speed of light very accurately was Albert Michelson. Michelson used a strong light source, an eight-sided rotating mirror, and another large mirror about 35 km away from his measuring equipment (Figure 4.9). By using the distance the light had travelled and the speed at which his mirrored wheel was spinning, he was able to calculate the speed of light. He continued to improve his equipment and repeat his measurements over the course of several years, arriving at a final measurement of 299 796 km/s.

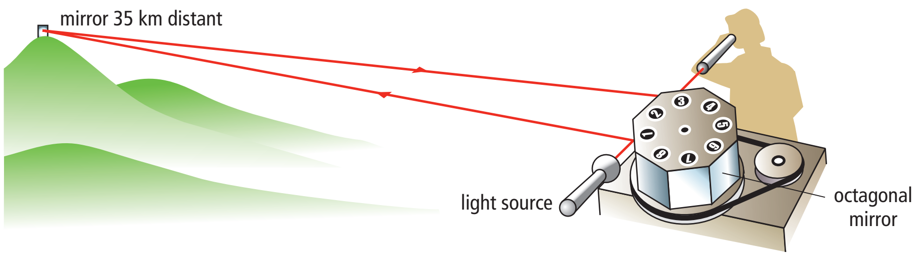


Figure 4.9 Michelson shone a light on a rotating mirror, which reflected to a large mirror about 35 km away. The returning beam of light reflected off another face of the rotating mirror into the eye of the observer. By precisely measuring the speed of the rotating mirror and the distance to the distant mirror, Michelson calculated the speed of light.

Although you know the speed of light, it is still difficult to develop a sense of how fast it really is. Consider this. If light could bend and travel around Earth, it would circle Earth seven and a half times in one second.

How does the speed of sound compare with the speed of light? The speed of sound in dry air at 20°C is 343 m/s (1235 km/h). This is much slower than the speed of light. It would take 32 h for sound to travel around Earth once.

The difference between the speeds of light and sound allows you to estimate the distance from where you are standing to the point of a lightning strike. A lightning strike causes a roar of thunder; both happen at the same time. However, you see the lightning before you hear the thunder. If you measured the time between seeing the lightning and hearing the thunder, you could multiply that by the speed of sound to estimate the distance. For example, if three seconds passed between seeing the lightning and hearing the thunder, then the lightning strike must have been approximately 3 × 343 m/s or about 1000 m (1 km) away.

Did You Know?

The universe is so big that the light you see coming from some stars left those stars more than one hundred thousand years ago. The light has been travelling through space ever since. So, when you see a star, you are looking into the past because you are seeing what happened thousands of years ago.

Reading Check

1. What made scientists think that light behaved like a wave, rather than a stream of particles?
2. Why was Galileo's attempt to measure the speed of light unsuccessful?
3. Who was the first person to accurately measure the speed of light?
4. How does the speed of light compare to the speed of sound?

Check Your Understanding

Checking Concepts

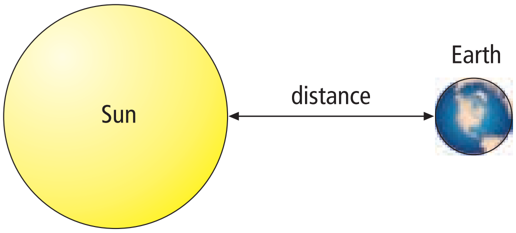
1. What ideas did early Greek philosophers have about how light brought information to the eyes?
2. What is a reading stone? How was a reading stone used?
3. How were the first spectacles (glasses) made?
4. How did Leeuwenhoek improve the magnification of the microscope?
5. How did ideas about light change after the 1500s, as more experiments were performed?
6. How was Galileo involved in the study of light?
7. What is the speed of light?
8. How could you determine how far away a lightning strike is?

Understanding Key Ideas

9. Explain how it was possible for people to make lenses and build telescopes and microscopes when they did not understand the nature of light.
10. Why was it extremely difficult to measure the speed of light?
11. Compare Leeuwenhoek's microscope to modern microscopes.
12. Explain how Galileo intended to calculate the speed of light. Why was he unsuccessful?
13. When astronauts first landed on the Moon, they carefully placed a panel of mirrors on its surface. Scientists on Earth can aim a laser at the moon and observe the beam being reflected back. How can they use this observation to calculate the distance between the Earth and the Moon?

Pause and Reflect

The speed of light is 3×10^8 m/s. If it takes 8 minutes for light to get to Earth from the Sun, how far away is the Sun?



4.2 Properties of Waves

Waves transfer energy through matter or space. Amplitude is the height of a wave crest or depth of a wave trough, as measured from its rest position. A wavelength is the distance over which the wave repeats. As the wavelength decreases, the frequency increases. Waves can differ in how much energy they carry and in how fast they travel.

Key Terms

amplitude
compression wave
crest
energy
force
frequency
hertz
medium
transverse wave
trough
wave
wavelength

A surfer bobs in the ocean waiting for the perfect wave (Figure 4.10), microwaves warm up your leftover pizza, and sound waves from your CD player bring music to your ears. These and other types of waves have many properties in common.

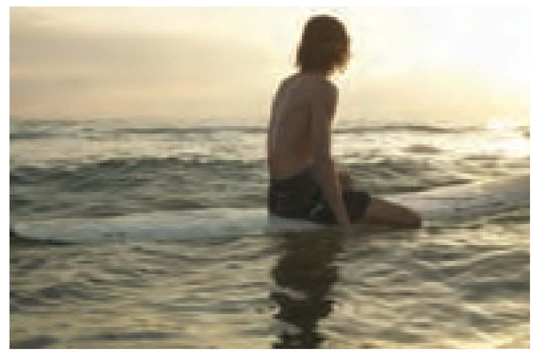


Figure 4.10 Waiting for a wave. A wave transfers energy through matter or space.

4-2A Watching Water Waves

Find Out ACTIVITY

You do not need to visit the ocean to make waves. In this activity, you can make waves right in your classroom.

Materials

- pie plate or wide pan
- water
- pencil

What to Do

1. Fill a pie plate or other wide pan with water about 2 cm deep.
2. Lightly tap the bottom of a pencil once in the middle of the surface of the water. Observe the waves that form.
3. Lightly tap your pencil once per second on the surface of the water. Observe the spacing of the water waves.
4. Increase the rate of your tapping. Observe the spacing of the water waves.
5. Clean up and put away the equipment you have used.

What Did You Find Out?

1. In what direction did the waves travel when you tapped the water lightly with your pencil?
2. How did the spacing of the water waves change when the rate of tapping increased?

Features of a Wave

A **wave** is a disturbance or movement that transfers energy through matter or space, without causing any permanent displacement. Sound waves disturb the air and transfer energy through it. Ocean waves disturb the water and transfer energy through it. **Energy** is the capacity to apply a force over a distance. A **force** is a push or pull on an object.

To visualize the features of a wave, examine Figure 4.11. The dotted line shows the equilibrium or rest position. The rest position is the level of the water when there are no waves. Notice the labels in the illustration. A **crest** is the highest point in a wave. A **trough** is the lowest point in a wave.

Did You Know?

Sound waves can be used to make an image of an unborn child during an ultrasound procedure. Sound waves can also be used for cleaning lenses and other optical equipment, dental instruments, and surgical instruments.

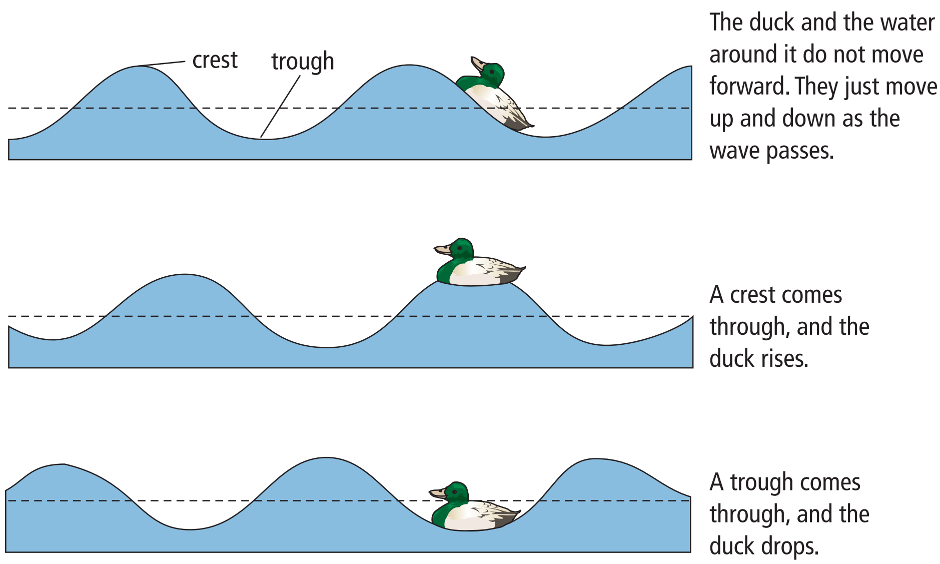


Figure 4.11 The wave is moving from left to right.

Wavelength

The **wavelength** is the distance from crest to crest or from trough to trough. You can also think of a wavelength as the distance covered by one complete crest plus one complete trough (see Figure 4.12). Wavelength is measured in metres.

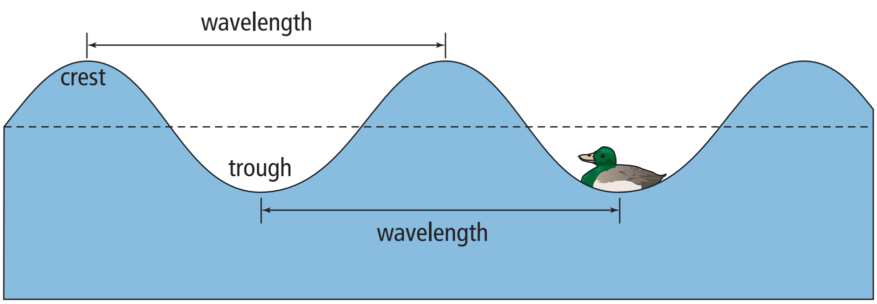


Figure 4.12 A wavelength is the distance over which the wave repeats.

Amplitude

If a breeze picks up on the lake where the duck is sitting, the height of the waves can increase. This means that the duck floats higher and lower as the crests rise and the troughs deepen. When the crests are high and the troughs are low, we say the wave has a larger amplitude. The **amplitude** is the height of a wave crest or depth of a wave trough, as measured from its rest position (see Figure 4.13).

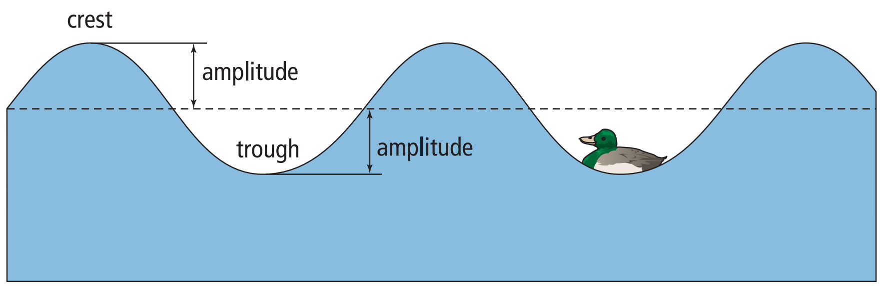


Figure 4.13 The amplitude of the wave crest equals the amplitude of the wave trough.

The amplitude is related to the amount of energy carried by the wave. The larger the amplitude, the greater the energy transported. A light wave that has a large amplitude carries more energy and is very bright. A dim light has a lower amplitude and carries less energy. The next time you lower the brightness of a light using a dimmer switch, think of the switch as a light wave amplitude adjuster.

internet connect

With sound waves, frequency is related to musical pitch. Find out more about the frequencies of musical notes. Start your search at **www.discoveringscience8.ca.**

Frequency

As the wavelength decreases, the duck and the water move up and down more frequently. Every cycle of bobbing up and down is called an oscillation or a vibration. **Frequency** is the number of repetitive motions, or oscillations, that occur in a given time. Frequency is usually measured in **hertz** (Hz), or cycles per second. In our example, it is the number of times per second the duck bobs from crest to crest. For example, if two wave crests were to pass under the duck every second, then the duck is said to be vibrating or oscillating at a frequency of 2 Hz.

Suggested Activity

Find Out Activity 4-2B on page 142
Find Out Activity 4-2C on page 143

When the duck is sitting in water waves with short wavelengths, it will bob and down frequently. When the duck is sitting in waves with long wavelengths, it will bob up and down less frequently. The shorter the wavelength, the greater the frequency (see Figure 4.14). When one value increases as the other decreases, scientists call this an *inverse relationship*.

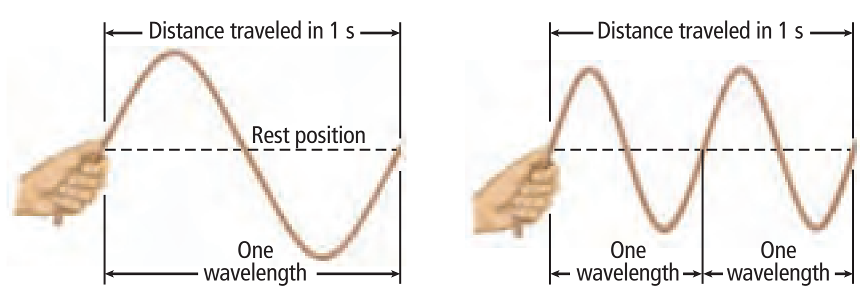


Figure 4.14 The wavelength of a wave decreases as the frequency increases. All waves share this property.

A Water Wave Moves Energy, Not Water

A water wave does not carry water along with it. Only the energy carried by the water wave moves forward (see Figure 4.15). Many important types of waves share this property—they carry energy without transporting matter. Think of being out in the middle of a lake and bobbing straight up and down as the wave passes underneath. Only the energy in the wave moves forward toward the shore. You do not move forward and neither does the water. Once the waves have passed, the water returns to its original, or rest, position.

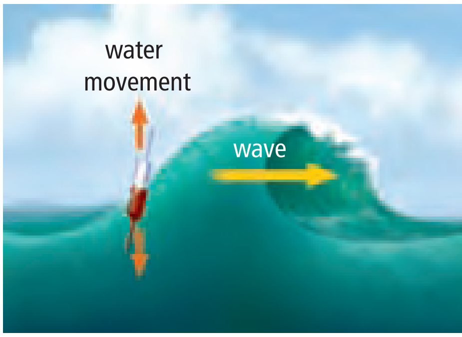


Figure 4.15 The energy carried by the wave moves forward. The water moves up and down.

Two Types of Waves

Waves can differ in how much energy they carry and in how fast they travel. Waves also have other characteristics that make them different from each other.

Sound waves travel through the air to reach your ears. Ocean waves move through water to reach the shore. In both cases, the matter the waves travel through is called a **medium**. The medium can be a solid, liquid, or gas, or a combination of these. For sound waves, the medium is air, and for ocean waves the medium is water. The two types of waves that travel through a medium are transverse waves and compression waves.

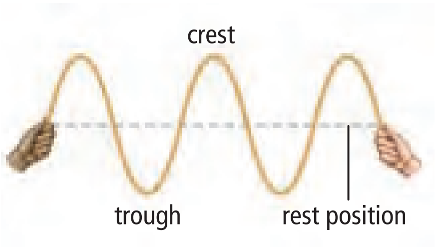


Figure 4.16 A transverse wave travels horizontally along the rope, and the rope moves up and down.

Transverse waves

In a **transverse wave**, matter in the medium moves up and down perpendicular to the direction that the wave travels (see Figure 4.16). When you shake one end of a rope while your friend holds the other end, you are making transverse waves. The wave and its energy travel from you to your friend as the rope moves up and down.

Compression waves

Sound waves are compression waves. In a **compression wave**, matter in the medium moves back and forth along the same direction that the wave travels. You can model compression waves with a coiled spring with a piece of string tied on a coil (see Figure 4.17). Squeeze several coils together at one end of the spring. Then let go of the coils, still holding onto the other end of the spring. A wave will travel along the spring. As the wave moves, it looks as if the whole coil spring is moving toward one end. The string moves back and forth as the wave passes, and then stops moving after the wave has passed. The wave carries energy, but not matter, forward along the spring.

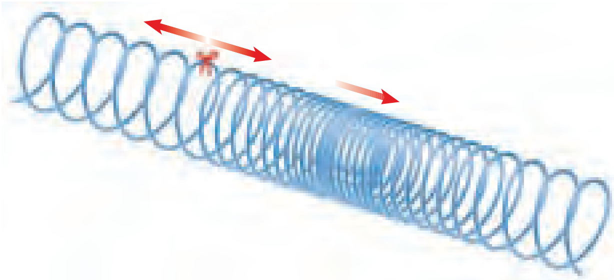


Figure 4.17 A compression wave travels horizontally along the spring, and the coils in the spring move back and forth horizontally.

Explore More

Traffic waves are a form of traffic jam on highways that can occur when cars are more densely packed in some places and less densely packed in others. A traffic wave can move through a lane of cars causing the whole lane to slow down. Find out what causes these waves and what can be done to prevent them. Start your search at **www.discoveringscience8.ca**.

Suggested Activity

Conduct an Investigation 4-2D on page 144

Water waves and seismic (earthquake) waves are a combination of transverse and compression waves. Seismic waves can travel through Earth and along Earth's surface. When objects on Earth's surface absorb some of the energy carried by seismic waves, the objects move and shake.

Not all waves need a medium to travel through. Some waves, such as visible light waves and radio waves, can travel through space where there is no material.

Reading Check

1. What is the difference between a crest and a trough?
2. What are three ways to measure wavelength?
3. What property of a wave is measured in hertz?
4. How are the wavelength and frequency of a wave related?
5. What is the difference between a transverse wave and a compression wave?

4-2B Frequency Formula

Think About It

Examples of frequency exist all around you. In this activity, you can calculate frequency by using the number of cycles, the time, and an equation.

What to Do

1. Use the following equation to calculate frequency (in hertz) for each of the examples below. Remember that frequency is equal to the number of cycles (*i.e.*, swings, revolutions, flashes, or beats) per second. The first example is done for you.
   (a) pendulum: 24 swings in 6 s
   frequency = cycles/s
   = 24 swings/6 s
   = 4 Hz
   (b) merry-go-round: 12 revolutions per 2 min
   (c) flashing red light at an intersection: 30 flashes in 0.5 min
   (d) heart rate: 18 beats per 20 s
   (e) car drive shaft: 2000 rpm (revolutions per min)

What Did You Find Out?

1. In order to calculate frequency measured in hertz, what must be done with the time unit before dividing?

4-2C Catch a Waveform

Find Out ACTIVITY

A waveform is a visual record of waves. In this activity, you will make a waveform using the motion of a vibrating metre stick.

Materials

- felt pen
- metre stick
- C clamp
- cardboard or manila card stock
- masking tape

What to Do

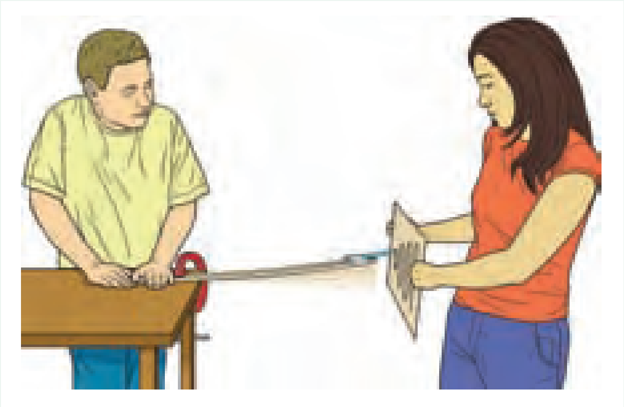
1. Tape the felt pen to the end of the metre stick.

Part 1

2. Clamp the metre stick to a desk with 40 cm of the metre stick (and the pen) extending out from the desk. Hold the end firmly in place on the desk.
3. Gently press down on the metre stick and let it go so that it can vibrate gently.
4. Have a partner hold the cardboard and walk slowly next to the vibrating pen. The waveform should be recorded on the cardboard. Make sure that several waves are recorded. You may need to practise this several times to get it right. Your partner can follow a masking tape line on the floor in front of the desk to make it easier to walk in a straight line.

Part 2

5. Make a new waveform on a new piece of cardboard by repeating steps 3 and 4. This time, increase the length that the metre stick extends out from the desk to 60 cm.
6. Label each waveform with crest, trough, and wavelength.
7. Clean up and put away the equipment you have used.



Part 1, step 4

What Did You Find Out?

1. What did you observe about the sound of the metre stick vibrating?
2. Measure the distance between two adjacent crests on each waveform. Which trial produced waves with the longest wavelengths?
3. Which trial produced the most vibrations?
4. As the wavelength increases, what happens to the frequency?
5. What is the relationship between wavelength and frequency?
6. Is it possible for the wave with the greatest wavelength to also have the greatest frequency? Explain.

4-2D Wire Waves

SkillCheck
- Observing
- Classifying
- Communicating
- Modeling

Safety

- Do not let go of the spring when it is stretched out.
- The end of the spring might be sharp.

Materials

- coiled metal spring or Slinky®
- piece of masking tape or string

A coiled metal spring can be stretched along the floor and moved back and forth to generate waves. A side to side movement of one end of the spring will produce a transverse wave.

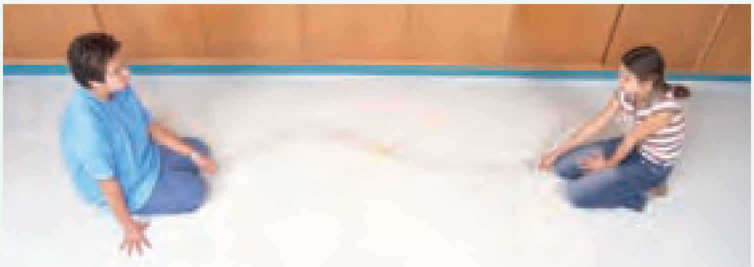
Question

How can a coiled metal spring be used to investigate amplitude, wavelength, and frequency?

Step 1 Attach tape or string to the spring.

Step 2 Carefully stretch the spring out on the floor.

Inquiry Focus



Step 3 Hold each end of the spring firmly.

Procedure

1. Work with a partner. Attach a piece of tape or string at about the halfway mark of the spring.
2. Stretch the spring out on the floor, with you and your partner each holding an end. Be very careful not to overstretch the spring, as it is easily damaged. Also, be careful not to allow the spring to get knotted up. Always keep the spring on the floor when generating waves.
3. Hold one end of the spring firmly in place as your partner moves the other end slowly from side to side. Observe and draw a diagram of the wave that results. Label it "low frequency wave," and indicate its wavelength. Use arrows to show the directions in which the marked coil moves. Note whether you feel a side-to-side force as you hold the spring firmly in place.
4. Repeat step 3 but have your partner move the end of the spring quickly from side to side to provide a higher frequency. There will be more places on the spring that do not move very much, and other places that move a lot. What has happened to the frequency? Observe and draw a diagram of the resulting wave. Indicate the wavelength. Label this diagram.
5. Try to do the following:
   (a) Increase the amplitude of the wave.
   (b) Make a low frequency, high amplitude wave.
   (c) Make a high frequency, high amplitude wave.
   (d) Make a low frequency and low amplitude wave.

Draw and label a diagram for each of your results.

Analyze

1. How did the wavelength in the spring change as it moved from side to side more quickly?
2. How did the marked coil move in each of your waves?
3. (a) How are the frequency and amplitude of a wave related?
   (b) Can a low frequency wave sometimes have a large amplitude, and sometimes have a small amplitude? Explain.

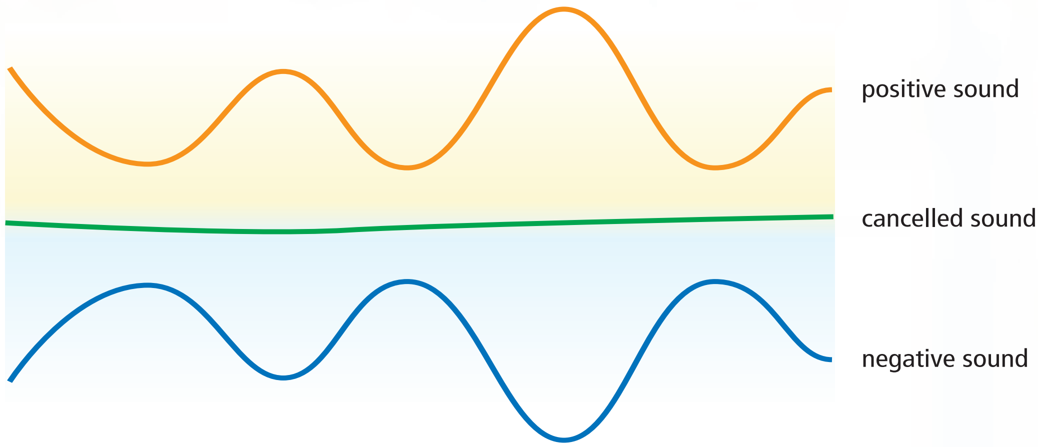
Conclude and Apply

1. (a) Draw a diagram to illustrate:
      (i) a wave with a high frequency, a short wavelength, and a large amplitude
      (ii) a wave with a low frequency, a long wavelength, and a small amplitude
   (b) Use labels to show crests, troughs, wavelength, and amplitude on both diagrams you drew in (a).
2. The amount of energy transferred by the spring changes with frequency, and also with wavelength.
   (a) What happens to the amount of energy transferred through the spring as the frequency increases?
   (b) What happens to the amount of energy transferred through the spring as the wavelength increases?

Wild, Weird, Wonderful

www Science

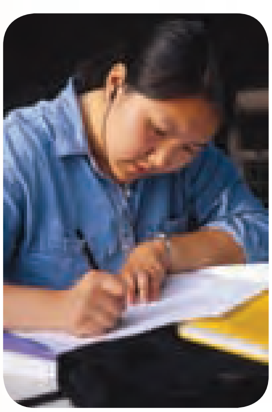
Noise-Cancellation Headphones



The positive and negative sound waves cancel each other in noise-cancellation headphones.

Have you ever tried to listen to music on a noisy bus? Earphone plugs help to keep out the background noise, while larger headphones have foam pads that help block noise. Noise-cancellation headphones, also called noise-reduction headphones, use properties of sound waves to reduce noise by cancelling out unwanted waves. Noise-cancellation headphones work best against constant noise, such as the sounds of a school cafeteria or an aircraft engine.

Sound is carried by a series of high and low pressure waves that move from the source of the sound to your eardrum. The changing pressures cause your eardrum to vibrate. Sound waves have a particular shape that is determined by their wavelength and amplitude. The wavelength determines the pitch of the sound and the amplitude determines how loud the sound is.



Noise-cancellation headphones have tiny microphones mounted into the headsets that detect the background noise. The background noise is called the positive sound, because it is the sound that is normally heard. A digital signal processor analyzes the shape of the positive sound wave and then generates another sound wave that has the exact opposite shape. This cancellation wave is called the negative sound. The negative sound is then amplified and played through the headphones. The positive and negative sound waves combine and effectively cancel each other out.

Some people use noise-cancellation headphones simply to listen to silence. Others use them to listen to music. Using noise-cancellation allows you to listen to music at a lower volume than you would otherwise be able to.

Noise cancellation does not remove all sounds that you might hear—which is a good thing, because you want to be able to hear the approach of the school bus you are waiting for!

Check Your Understanding

Checking Concepts

1. Draw a wave with a wavelength of 4 cm and an amplitude of 1 cm. Label the crest, the trough, the amplitude, and the wavelength.
2. (a) A buzzer vibrates 900 times in 1 s. What is its frequency?
   (b) A guitar string vibrates 880 times in 2 s. What is its frequency?
   (c) A ball bounces on the floor 10 times in 50 s. What is its frequency?
3. (a) Draw a transverse wave and a compression wave.
   (b) Give an example of each type of wave.
4. A speedboat zips by on a lake and sends a series of waves toward a dock. The frequency of the waves is 0.5 Hz. How many wave crests will pass by the dock in 8 s?

Understanding Key Concepts

5. You can make a wave by shaking the end of a long rope up and down.
   (a) Explain how you would shake the end of the rope to make the wavelength shorter.
   (b) State two different ways you could shake the rope to increase the energy carried by the wave.
6. Explain why water waves travelling under a raft do not move the raft horizontally.
7. A wave in the open ocean between the Northern Peninsula of the island of Newfoundland and the coast of Labrador has an amplitude of 15 m in a large storm. The wavelength is 100 m.
   (a) How high will the crest of the wave be above a boat that is in the trough?
   (b) If the wave travels at a speed of 10 km per hour, how often will a wave pass under the boat?
8. A student performs a frequency experiment on three different pendulums and obtains the following results:

Pendulum	Number of Swings	Time to Complete All the Swings (s)
A	32	8 s
B	72	9 s
C	210	1 min 20 s

   (a) Calculate the frequency of each pendulum in Hz.
   (b) Rank the pendulums from lowest to highest frequency.
9. A female soprano sings at a higher frequency (higher pitch) than a male baritone.
   (a) Which singer is producing waves of longer wavelength? Explain your answer.
   (b) If both singers sing at an equal volume, which singer is sending more energy out through his or her voice? Or are they both sending out the same energy? Explain your answer.

Pause and Reflect

Write a paragraph or develop a table to explain how a wave with a length of 6 cm and a frequency of two waves per second changes when the frequency is changed to four waves per second.

4.3 Properties of Visible Light

Light is a form of energy that you can detect with your eyes. Visible light is a mixture of all the colours of the rainbow. A prism refracts light, separating the colours. A second prism can recombine the colours to form white light. Different colours of light are carried by light waves that have different wavelengths. An object looks blue in sunlight because it reflects blue and absorbs colours other than blue from the sunlight.

Key Terms

reflection
refraction
spectrum
visible light
wave model of light

After a rainstorm you might step outside to a dazzling display of colour in the sky (see Figure 4.18). There might be a huge arc of colours curving through the sky in front of you.

Figure 4.18 When the sunlight is behind you and the air is full of water droplets, you may be lucky enough to see a spectacular rainbow.

4-3A Rainbows of Light

Find Out ACTIVITY

The ability to see colour depends on the cells in your eyes that are sensitive to different wavelengths of light. In this activity, you will observe the colours of the light produced by a flashlight.

Materials

- flashlight
- glass prism
- water
- dishwashing liquid

What to Do

1. In a darkened room, shine a flashlight through a glass prism. Project the resulting colours onto a white wall or ceiling. What colours do you see?
2. In a darkened room, shine a flashlight over the surface of water with dishwashing liquid bubbles in it. What do you see?
3. Clean up and put away the equipment you have used.

What Did You Find Out?

1. How did your observations in each case differ? Explain where you think the colours came from.

Wave Model of Light

Scientists have developed a model of light by looking at how light behaves, and then trying to explain what they see. As you learned in earlier science studies, a *model* is a way of representing something in order to understand it better and to make predictions. As you learned in Section 4.1, scientists discovered evidence during the 1800s to suggest that light could behave as a wave. This evidence supports an explanation of light behaviour called the **wave model of light**. In this model, light is a type of wave that travels through empty space and transfers energy from one place to another, such as from the Sun to Earth. In the simplest terms, **visible light** is a wave that you can see.

Refraction of Light

What occurs when a light wave passes from one material to another—from air into water for example? If the light wave is travelling at an angle and the speed that light travels is different in the two materials, the wave will be bent, or refracted. **Refraction** is the bending or changing direction of a wave as it passes from one material to another.

White light, such as sunlight, is made up of waves having different wavelengths and frequencies. If a light wave is refracted, such as by passing through a prism (see Figure 4.19), the different wavelengths bend by different amounts. Because the longer wavelengths are refracted less than the shorter wavelengths, different colours are separated when they emerge from the prism.

Figure 4.19 A prism refracts light into different colours.

Did You Know?

The fastest known form of energy in our universe is a light wave travelling through space. The speed of light is approximately 300 000 km/s. The distance 300 000 km is equal to about seven times the distance around Earth.

Did You Know?

The order of the colours in the visible spectrum, ROY G BIV, never changes. That's because violet light refracts the most while red refracts the least. What do you think is the order of colours by order of refraction?

Colours of the Rainbow

Does the light leaving the prism in Figure 4.19 remind you of a rainbow? Like prisms, water droplets also refract light (see Figure 4.20). In a rainbow, the human eye can distinguish a range of colours that are often described as falling into seven broad categories. In order of decreasing wavelength, and increasing frequency, these colours are red, orange, yellow, green, blue, indigo, and violet. This range of colours or frequencies of visible light is called the visible **spectrum** (see Figure 4.21). The seven colours most easily seen in a rainbow are sometimes abbreviated in the form of a person's name: ROY G BIV (**R**ed, **O**range, **Y**ellow, **G**reen, **B**lue, **I**ndigo, **V**iolet).

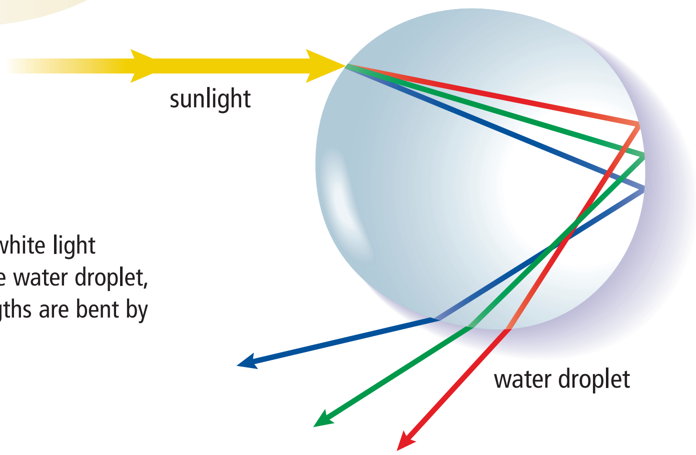
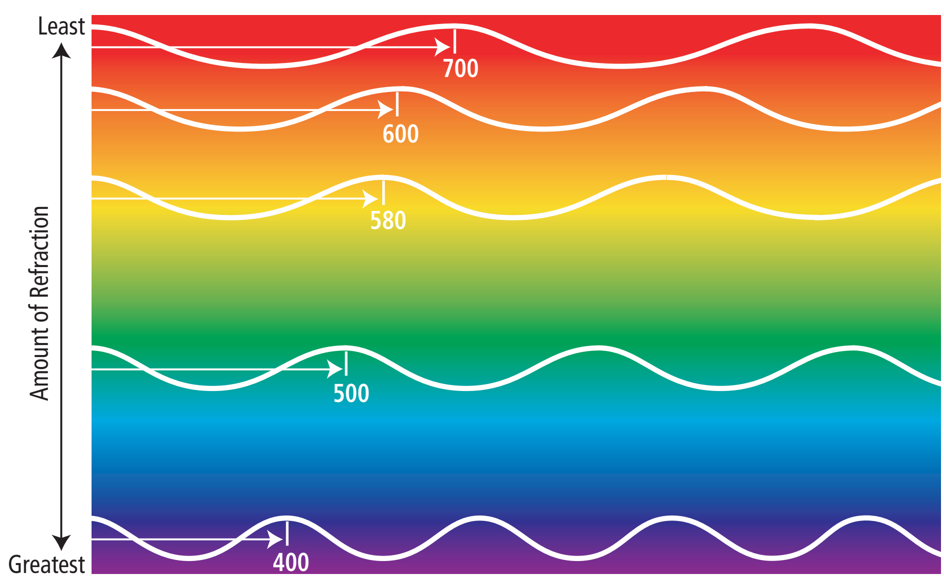


Figure 4.20 As white light passes through the water droplet, different wavelengths are bent by different amounts.

Figure 4.21 The visible spectrum is made up of different colours, each having its own wavelength. Red has the longest wavelength, about 700 nanometres (nm), while violet has the shortest, about 400 nm.



Did You Know?

The wavelength of light is measured in nanometres (nm). A nanometre is one-billionth of a metre. To picture just how small this is, consider that a single human hair is 50 000 to 80 000 nm wide. If 1 nm was approximately the diameter of a quarter, a centimetre would stretch from St. John's to Gander!

Reading Check

1. How does a prism separate light into different colours?
2. Which colour has the longest wavelength?
3. Which colour has the shortest wavelength?
4. Which colour has the highest frequency?
5. Which colour has the lowest frequency?

Producing the Visible Spectrum

Figure 4.22 Sir Isaac Newton

At one time, people believed that colour was something added to light. When white light struck a green leaf, people believed that the leaf was adding green to the light. Is colour picked up when light strikes a coloured object? Or does light itself contain colour? In the 17th century, English scientist Sir Isaac Newton (see Figure 4.22) conducted a famous experiment in search of the answer to these questions.

Newton placed a prism so that a thin beam of white light could pass through it. When white light travelled through the prism, he saw bands of colour emerge. He observed that each band of colour was refracted at a different angle. Newton concluded that the prism was not the source of the colours. The different colours must have been present already in the white light.

He proved his theory by using prisms to recombine the colours into white light (Figure 4.23). In this way, Newton showed that colour was a property of visible light. He proposed that white light such as sunlight is the result of mixing together all the different colours of light.

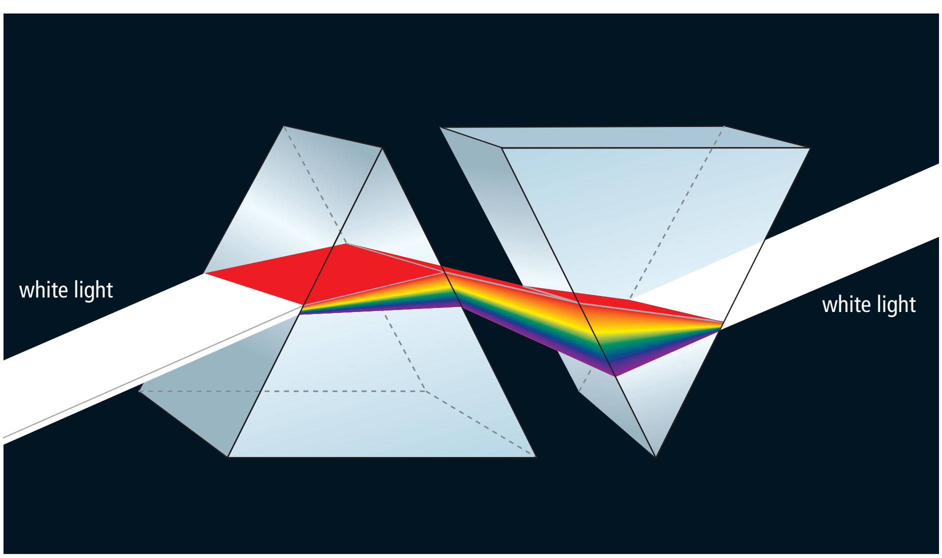


Figure 4.23 A prism causes white light to split into a spectrum. If the refracted light is passed through a second prism, the colours are recombined, producing white light again.

Did You Know?

The Sun's maximum output is in the red to yellow part of the visible spectrum. Plants have evolved to make maximum use of these wavelengths. Various kinds of chlorophyll, the pigments that capture sunlight during photosynthesis, absorb red and yellow pigments especially well.

Colour and Reflection

Reflection occurs when a light wave strikes an object and bounces off. When sunlight strikes coloured clothing, some colours are reflected while other colours are absorbed (Figure 4.24). Only the reflected colours can be seen.

Figure 4.24 Yellow cloth reflects yellow and absorbs other colours. Red cloth reflects red and absorbs other colours.

internet connect

Only three numbers are needed to specify every colour that can be produced on a computer screen. People who create web pages sometimes specify colours this way. For more information go to **www.discoveringscience8.ca**.

Why does a bright red shirt look black when it is placed in a dark room? The answer is that since a shirt does not produce its own light, but merely reflects the light in the room, the shirt appears to be black when there is no source of light.

Only three colours of light, such as red, green, and blue, are needed to produce all the colours of the rainbow. The colours red, green, and blue are sometimes called the additive primary colours. They are called additive colours because adding all three together in the proper amounts will make white light, as shown in Figure 4.25A. The light of two additive primary colours will produce a secondary colour. The three secondary colours are yellow, cyan, and magenta (see Figure 4.25B).

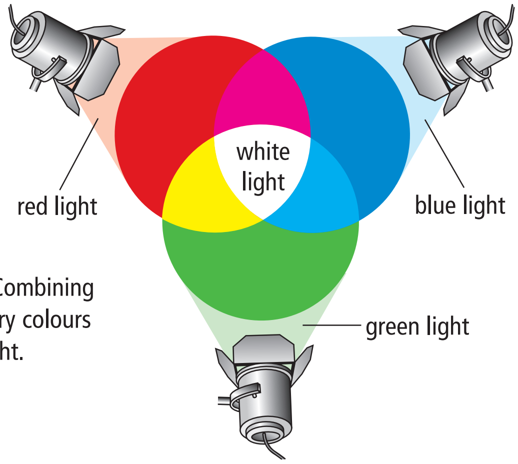


Figure 4.25(A) Combining the additive primary colours produces white light.

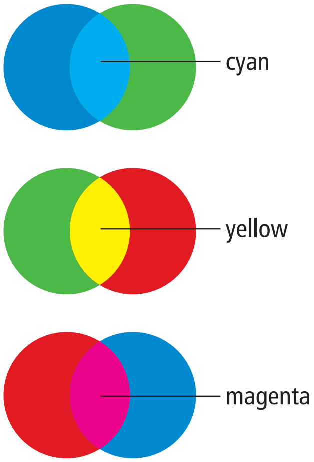


Figure 4.25(B) Each secondary colour is created by combining two of the primary additive colours.

Figure 4.26 When light waves reflect from the ridges on a CD, the light waves can add together to make some colours brighter. Light waves can also cancel each other, removing some colours.

Explore More

It takes three colours of light to produce white light, but they do not have to be the primary colours. For example, the secondary colours of yellow, magenta, and cyan, could do the same job. Red, green, and blue (RGB) are usually used in computer monitors, while cyan, magenta, yellow, and black (CMYK) are usually used in printers. Find out why these colour systems are used. Visit **www.discoveringscience8.ca.**

Reading Check

1. Why did Newton conclude that the prism was not the source of colours?
2. How could you use primary colours to produce secondary colours?
3. Why does a green shirt look green?
4. Why does a blue hat look black when it is in a dark room?

4-3B Colour Your Rainbow

Find Out ACTIVITY

In this activity, you will create a rainbow using a bright light source and a CD. Then you can "colour your rainbow" as you observe it through different coloured filters.

Materials

- CD
- coloured filters
- coloured pencils or felt pens
- white light source

What to Do

1. Hold a CD up to a light and adjust it until you can see a rainbow of colours. Keep in mind that different individuals see colours differently.
2. Select a red coloured filter. Hold it between your eye and the CD. Then try holding the filter between the CD and the light source. Use coloured pencils or felt pens to draw what you see in colour.
3. Repeat with several different coloured filters.

What Did You Find Out?

1. Compare your findings with your classmates' findings.
2. Write a short paragraph that answers the following questions:
   (a) Which colours do you see when you look at the rainbow made from white light? (Remember, you might see more or fewer colours than a classmate.)
   (b) What is the effect on the appearance of the rainbow when a red filter is held in front of it?
   (c) Does it make any difference whether the filter is held between the CD and your eye or between the CD and the light source? Explain.
   (d) What does a coloured filter do to the light coming from the light source?

Career Connect

Concert Lighting Designer

Garry Waldie

It is pitch black when you hear the first notes of that hit song. Suddenly the lights come up and your favourite band is in the spotlight. Garry Waldie has designed, programmed, and run thousands of light shows at concerts. He has worked with Justin Timberlake, Metallica, John Mellencamp, Christina Aguilera, P. Diddy, and many more.

Q. How did you become a lighting designer?

A. As a kid, I was always going to the theatre. I managed to get on tour after working with some local acts. Then I got to do the lighting for the opening act. Eventually I worked up to lighting the main act, and today I do about 200 shows a year.

Q. Why is lighting important to a concert?

A. It sets the mood and enhances the whole show.

Q. How do you create a light show?

A. First I listen to the material and come up with a concept for each song. I pitch the concept to the band and find out what else will be happening at the same time, such as live-feed video. Once the concept is firm, we videotape the band doing the songs. We work through the night programming the lights so they give the songs the right feel. We can usually program two to four songs per night. Today you need a lot of programming skills so you can use computer-aided design programs such as AutoCAD to design the light show. You also need to understand how the lights and lenses work.

Q. What do you need to know about lenses and prisms to be able to design a light show?

A. These days we usually use automated lights that have all the different lenses and prisms integrated into one unit. The lenses spread the beam size to make it cover a larger or smaller area. Prisms break up the patterns that we put in the lights. These "gobo patterns" can be anything from a simple spiral to the name of a band or hockey team.

An example of gobo patterns

Questions

1. How are the lights for a concert controlled?
2. Why does the designer need to understand different lenses and prisms?
3. Why would a computer-aided design program be good to learn if you wanted to become a lighting designer?

Check Your Understanding

Checking Concepts

1. You can understand some properties of light by using the wave model.
   (a) What is a model in science?
   (b) What is light, as described by the wave model?
2. Which has a longer wavelength, red light or green light?
3. Which colour refracts more in a prism, yellow or blue?
4. Explain how a prism is able to break sunlight up into its component colours.
5. Contrast refraction and reflection.
6. (a) What is the minimum number of coloured lights needed to produce all possible colours, including white?
   (b) List some colours that will work together to produce white light.
7. What do the letters B and V stand for in the acronym ROY G BIV?

Understanding Key Ideas

8. A light beam that is composed of red and green light is passed through a red-coloured filter.
   (a) What is the colour of light that passes through the filter?
   (b) What colour is absorbed by the filter?
9. Explain how a shirt can look green even though the light falling on it contains red, blue, and green.
10. Why do you think you are most likely to see a rainbow after a rainstorm?
11. Make a concept map that links wavelength, frequency, amplitude, brightness, and colour.
12. (a) A certain electromagnetic wave has a wavelength of 200 nm. Is this wave visible to humans? Explain your answer.
    (b) A micrometre (μm) is one millionth of a metre. State the wavelength of the wave
    (i) in micrometres
    (ii) in millimetres
    (iii) in metres
13. Suppose that a device is built that converts colour into sound. For example, if this device detects the colour yellow, it will produce the tone equivalent to middle C on the piano. If it detects blue, then it will produce the same tone one octave higher in pitch (C above middle C).
    (a) How will the sound for red light compare with the two tones mentioned above?
    (b) How will green, orange, and violet compare?

Pause and Reflect

Some green paints are green because the pigment is made out of chemicals that reflect green light. Other green paints are made by blending two or more non-green pigments such as blue and yellow. Why do you think that many artists prefer to blend their own green paints rather than use ready-made green paints?

4.4 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
- radiant energy
- 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 4.27). 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 4.27 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.

4-4A 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 4.28. **Electromagnetic radiation** is the transmission of energy in the form of waves that extend from the longest radio waves to the shortest gamma rays.

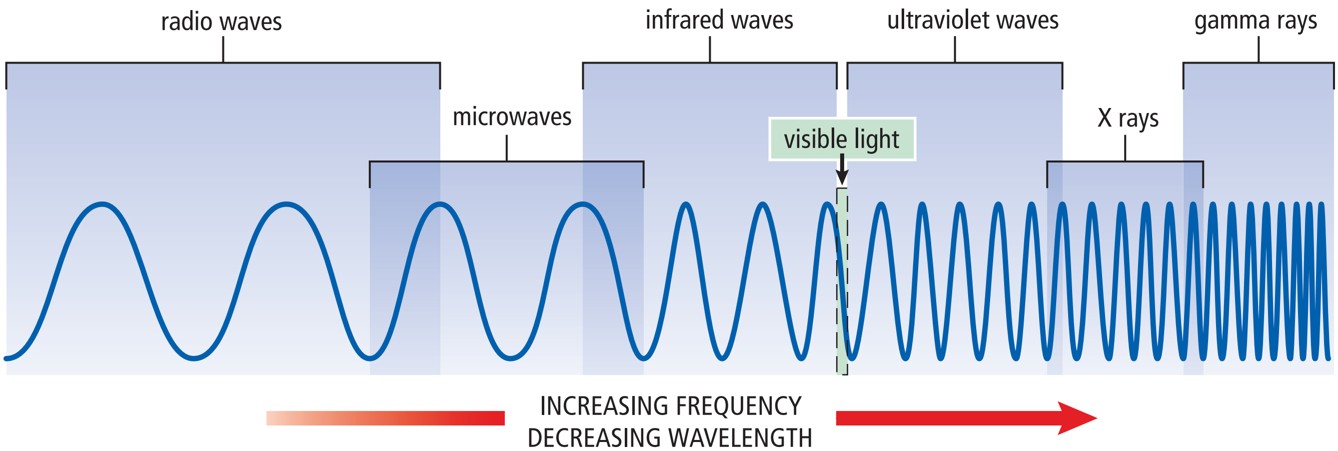


Figure 4.28 Electromagnetic waves are described by different names depending on their frequency and wavelength.

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.

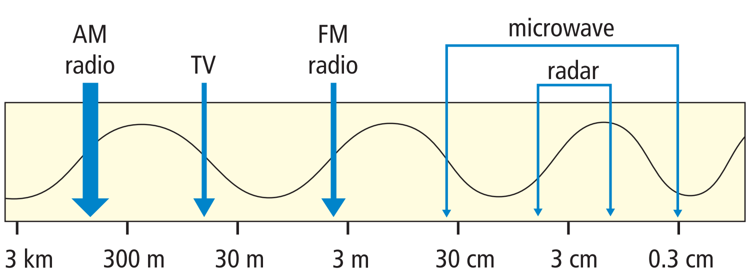


Figure 4.29 Radio wave region of the electromagnetic spectrum

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 4.29). 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 4.30A). 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 4.30B).

Figure 4.30(A) Magnetic resonance imaging technology uses radio waves as an alternative to imaging with X rays.

Figure 4.30(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 4.31). 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.

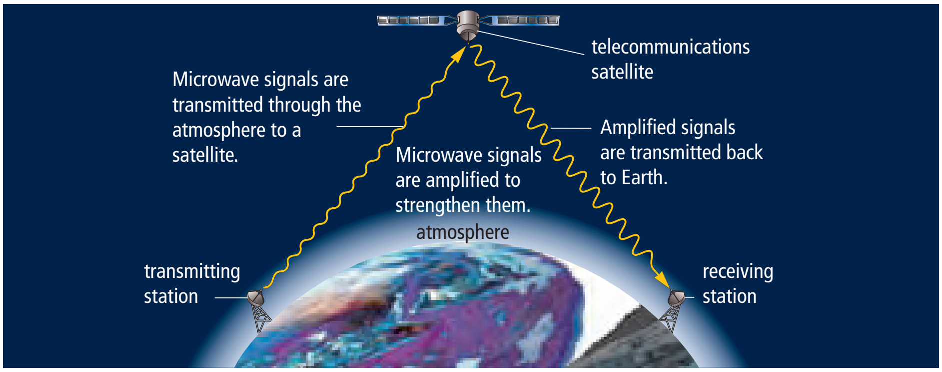


Figure 4.31 Signals sent by satellites can travel vast distances. One satellite can replace many ground relay stations. (This illustration is not drawn to scale.)

Word Connect

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

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 4.32), watercraft, and spacecraft.

Figure 4.32 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 4.33). 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 4.34) help to protect lives and save property.

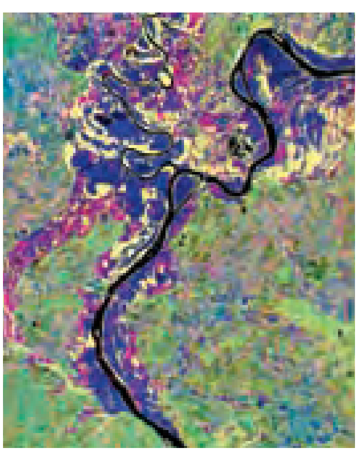


Figure 4.34 A RADARSAT image of flooded areas

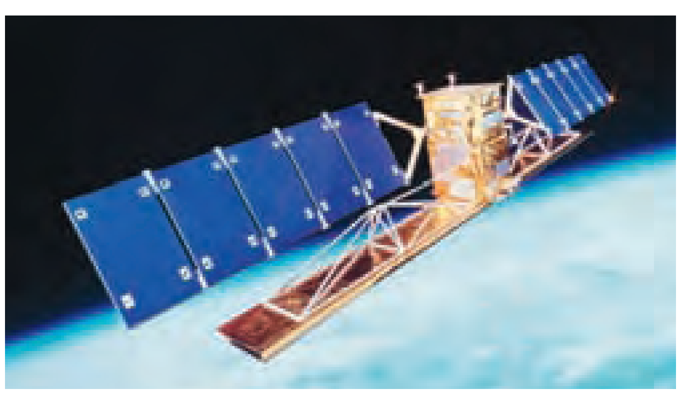


Figure 4.33 RADARSAT takes pictures of Earth's surface using radar.

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 4.35, 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 4.36).

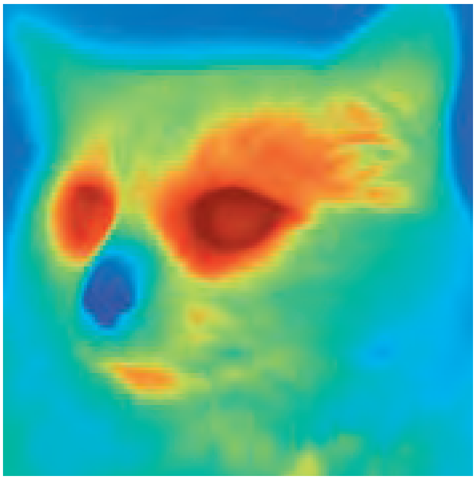


Figure 4.35 An infrared camera and film detect differences in temperature and assign false colours to different brightnesses. The result is information that we could not get from a visible light photograph.

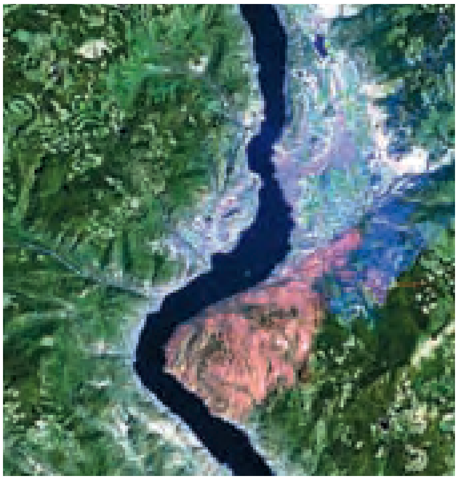


Figure 4.36 A LANDSAT image of areas burned by fires.

Word Connect

Infrared means below red.

Did You Know?

You may have seen outdoor lights on a house that come on automatically when someone comes to the door. These lights have motion sensors that detect infrared radiation. The circuits inside the sensors are designed to detect sudden changes in the amount of infrared radiation that is reaching the sensor. When they detect a sudden change, it is interpreted as motion. Some home safety systems also use infrared motion sensors inside the home.

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 4-4B on page 165

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 4.37). However, an overexposure to ultraviolet radiation can result in sunburns and skin cancers, and damage to the surface of the eye.

Figure 4.37 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.

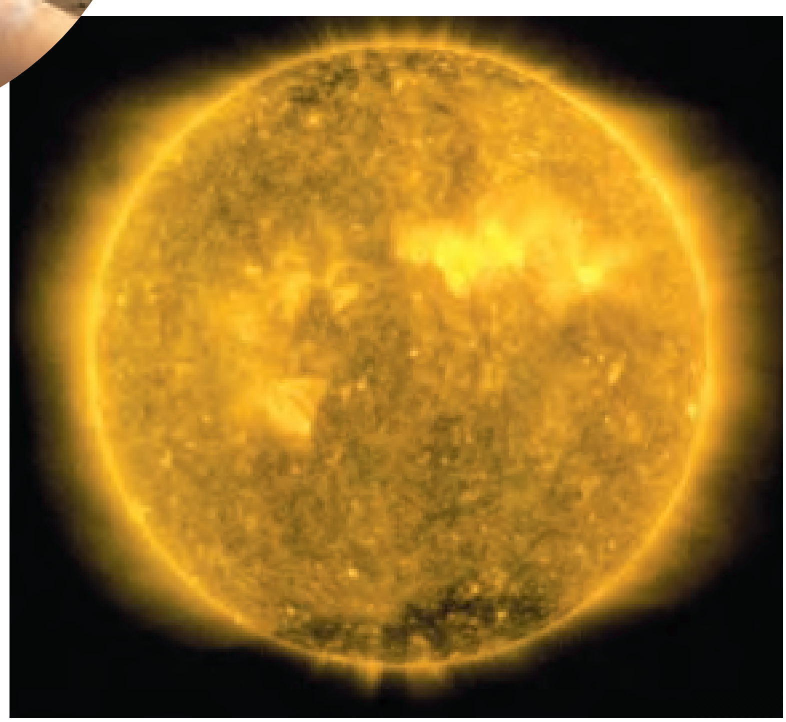


Figure 4.37 Earth's atmosphere absorbs some of the ultraviolet radiation emitted by the Sun.

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.discoveringscience8.ca.**

Other uses for UV waves

Fluorescent materials absorb ultraviolet waves and emit the energy as visible light. As shown in Figure 4.38, 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 4.38 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 an X-ray photograph of his wife's left hand, similar to the one in Figure 4.39. Her wedding ring was visible as a dark lump. Today, X rays are commonly used to photograph teeth and bones. (see Figure 4.40).

Suggested Activity

Find Out Activity 4-4C on page 165

Figure 4.39 X rays pass easily through tissue such as skin and muscle. However, X rays are absorbed by bone.

Figure 4.40 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.discoveringscience8.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 4.41).

Figure 4.41 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?

4-4B 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.

4-4C 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

Is Electromagnetic Radiation Helpful or Harmful?

Electromagnetic radiation is used in a wide range of technologies. It has applications in medicine, telecommunications, scientific research, and even entertainment. All of these applications are possible because electromagnetic waves carry energy. However, the more energy they carry, the greater the possibility that they can cause harm to the human body. So, are electromagnetic waves actually helpful or harmful?

The answer is both. As wave frequency increases, so does the energy carried by the wave. Waves in the high-frequency ultraviolet range and above have enough energy to actually break chemical bonds. This means that they can cause damage to chemical compounds within our cells. For this reason, X rays, and gamma rays are often used in medical treatments. Their ability to cause damage is actually useful when their targets are diseased cells.

X rays are extremely important tools in medicine. They make it possible for doctors to diagnose a variety of illnesses and injuries. However, X rays can also cause cancer and other damage to body tissues. Many years ago, people did not know that X rays were harmful. X ray machines were used in shoe stores in order to visualize a customer's foot and give a better-fitting shoe. Today, X rays are used more carefully, and exposure is limited to very low amounts to reduce the risk of cell damage.

These X-ray machines were common in shoe stores in the 1950s. Children liked to use them because they could wiggle their toes and see their bones move.

Ultraviolet waves can damage our eyes and skin if we spend too much time in the Sun. However, they are also used in medicine to treat newborn infants who have severe jaundice. Jaundice is a yellowing of the skin caused by too much of a substance called bilirubin in the blood. In severe cases, it can cause damage to brain cells. Ultraviolet radiation on the skin converts the bilirubin into a substance that can be eliminated in the urine.

Jaundice is not unusual for newborns. If it does not go away by itself, however, it can harm the baby. In such cases, newborns receive ultraviolet therapy.

Radio waves play a huge role in our daily lives. They carry signals to our cell phones, radios, televisions, and even computers, through wireless Internet connections. Because we are constantly exposed to so many of these signals, some people are concerned that, over many years, they could have a negative impact on our health. However, scientists have not found evidence to support this claim.

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?

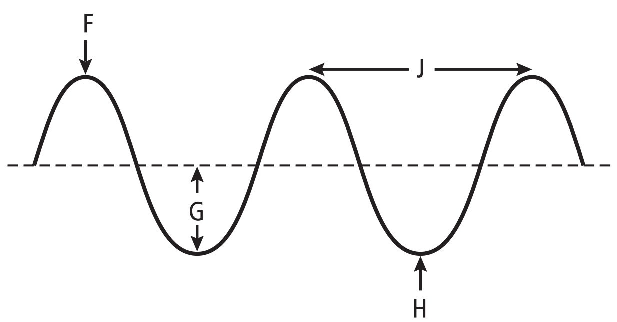
Prepare Your Own Summary

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. Use the following headings to organize your notes:

1. Early Ideas About Light
2. Features of Waves
3. The Visible Spectrum
4. Reflection and Refraction
5. Benefits and Risks of Using Electromagnetic Radiation

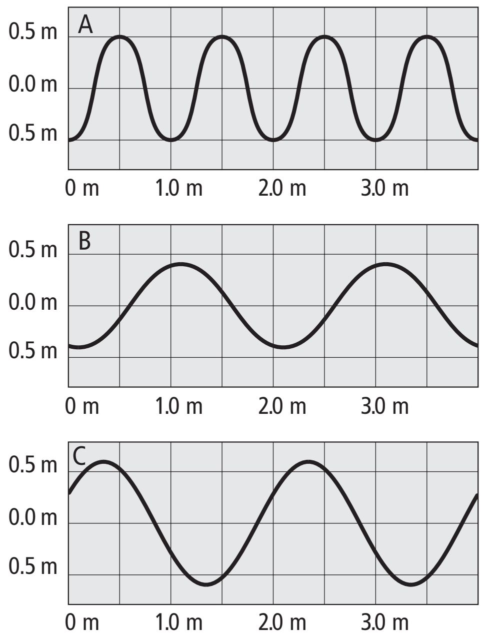
Checking Concepts

1. Who was Pythagoras and what were his ideas about light?
2. Describe one early technology that involved lenses.
3. Who provided evidence for the wave theory of light?
4. Name each of the following for the diagram below:
   (a) F
   (b) G
   (c) H
   (d) J



5. What is the relationship between wavelength and frequency?
6. Give examples of two ways in which light waves are similar to sound waves.
7. 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.
8. (a) What similarities do the waves of all colours of light share?
   (b) How do waves of different colours of light differ?
9. What unit is used for measuring frequency?
10. Describe the difference between wavelength and wave amplitude.

Use the diagram below to answer questions 11, 12, and 13.



11. (a) What is the amplitude of Wave A?
    (b) What is the wavelength of Wave A?
12. (a) What is the amplitude of Wave B?
    (b) What is the wavelength of Wave B?
13. (a) What is the amplitude of Wave C?
    (b) What is the wavelength of Wave C?

14. White light contains many colours. How is it that a shirt can appear to be blue when it is being lit with white light?
15. 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.
16. Describe how radio waves can be used to form an image of a human brain.

Understanding Key Ideas

17. When early philosophers and scientists attempted to describe the nature of light, they always included vision in their ideas. Why do you think they always linked light to the eyes?
18. Do lightning and thunder occur at the same time? Are they detected by your senses at the same time? Explain.
19. What properties do light waves and the waves in a fishpond share?
20. 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?
21. Explain why it is not possible to increase a wave's wavelength and frequency at the same time.
22. Make a table that compares and contrasts infrared waves, visible light, and X rays.
23. 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?
24. 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?