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.

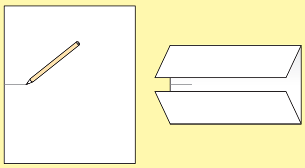
Skills You Will Use

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

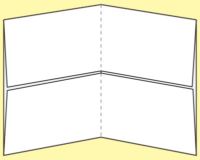
FOLDABLES™
Reading & Study Skills

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

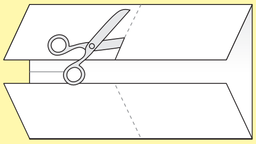
STEP 1 **Draw** a mark at the midpoint of a sheet of paper along the side edge. Then **fold** the top and bottom edges in to touch the midpoint. (If you are using notebook paper, use the centre of the middle hole to mark the midpoint.)



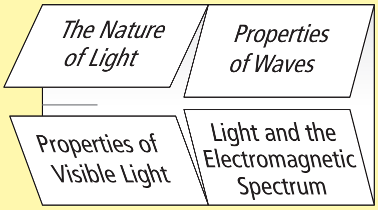
STEP 2 **Fold** in half from side to side.



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

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.

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.

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).

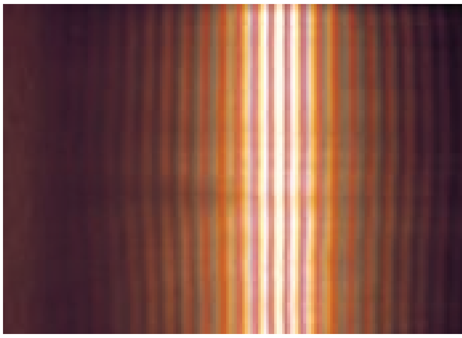


Figure 4.7 Thomas Young found that light spread out into this pattern when it passed through two narrow slits. If light was a stream of particles, what would he have seen?

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.

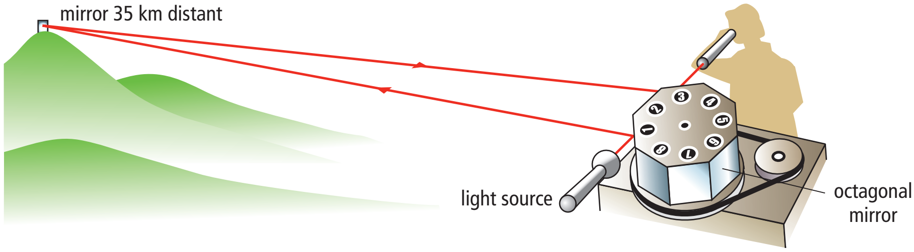


Figure 4.9 Michelson shone a light on a rotating mirror, which reflected to a large mirror about 35 km away. The returning beam of light reflected off another face of the rotating mirror into the eye of the observer. By precisely measuring the speed of the rotating mirror and the distance to the distant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

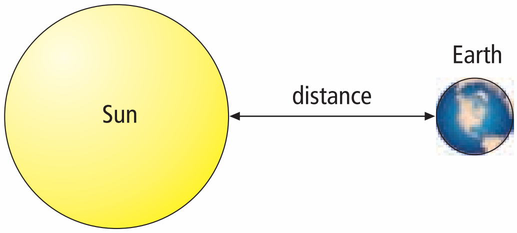
1. What ideas did early Greek philosophers have about how light brought information to the eyes?
2. What is a reading stone? How was a reading stone used?
3. How were the first spectacles (glasses) made?
4. How did Leeuwenhoek improve the magnification of the microscope?
5. How did ideas about light 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.

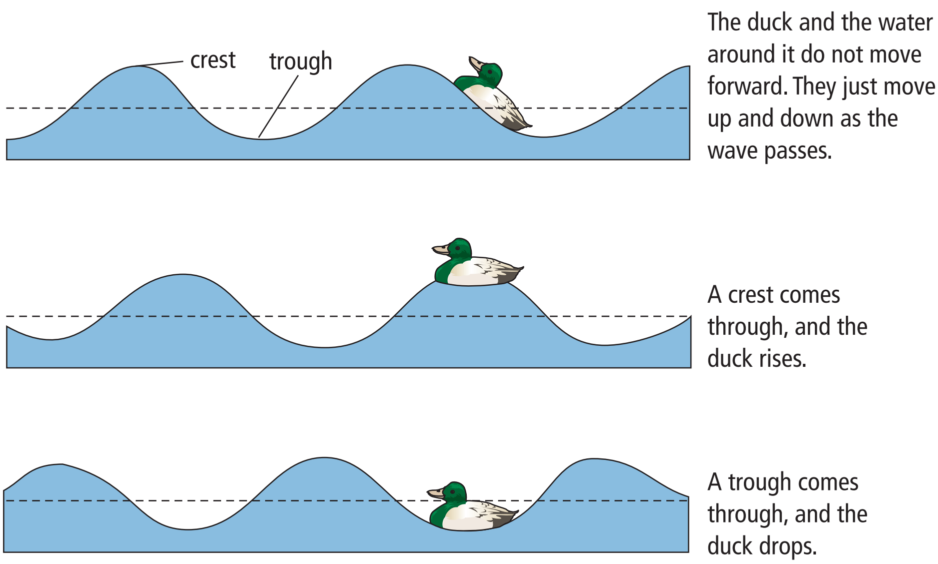


Figure 4.11 The wave is moving from left to right.

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.

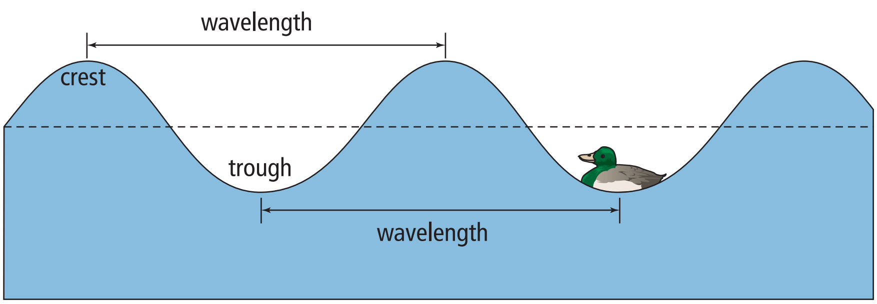


Figure 4.12 A wavelength is the distance over which the wave repeats.

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).

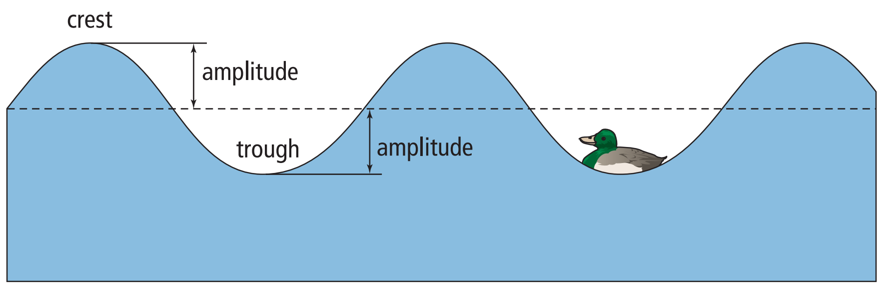


Figure 4.13 The amplitude of the wave crest equals the amplitude of the wave trough.

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.

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*.

Suggested Activity

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

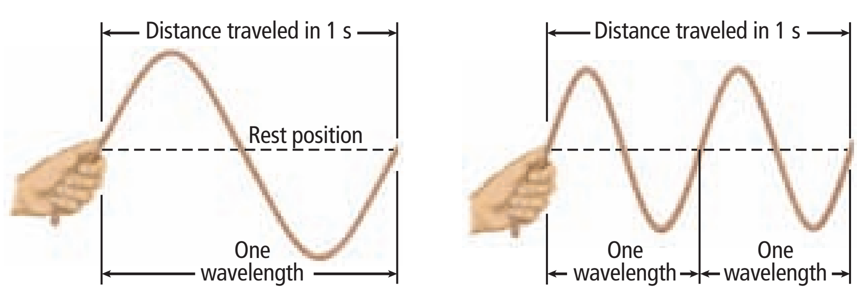


Figure 4.14 The wavelength of a wave decreases as the frequency increases. All waves share this property.

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.

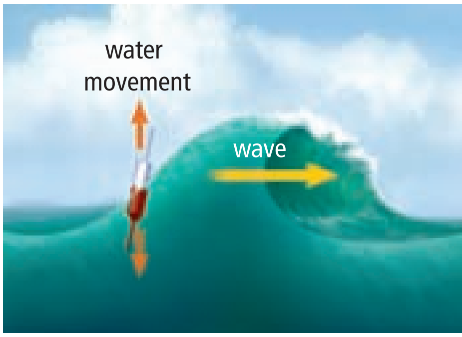


Figure 4.15 The energy carried by the wave moves forward. The water moves up and down.

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.

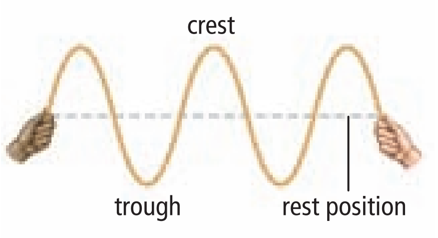


Figure 4.16 A transverse wave travels horizontally along the rope, and the rope moves up and down.

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.

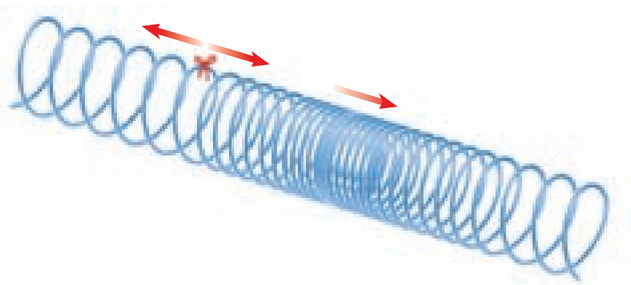


Figure 4.17 A compression wave travels horizontally along the spring, and the coils in the spring move back and forth horizontally.

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.

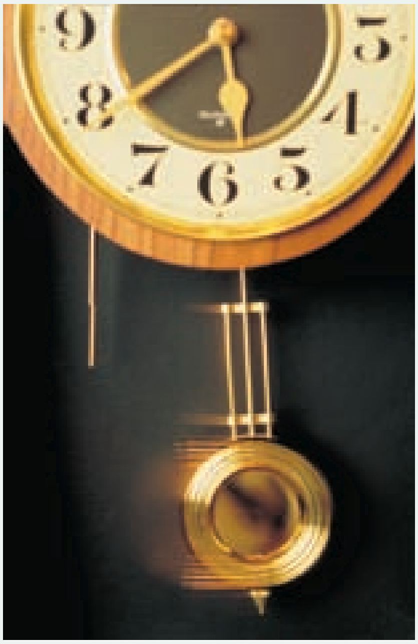
Reading Check

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

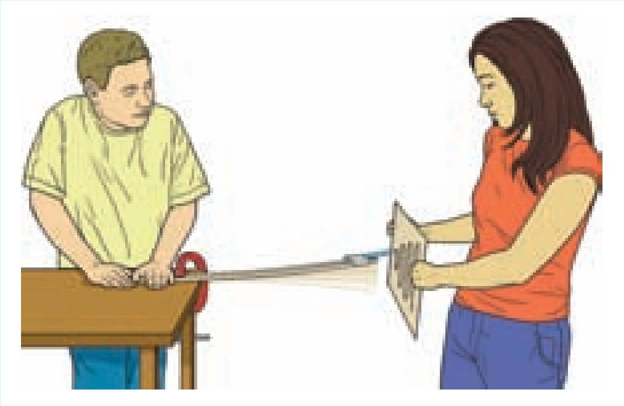
1. Tape the felt pen to the end of the metre stick.

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

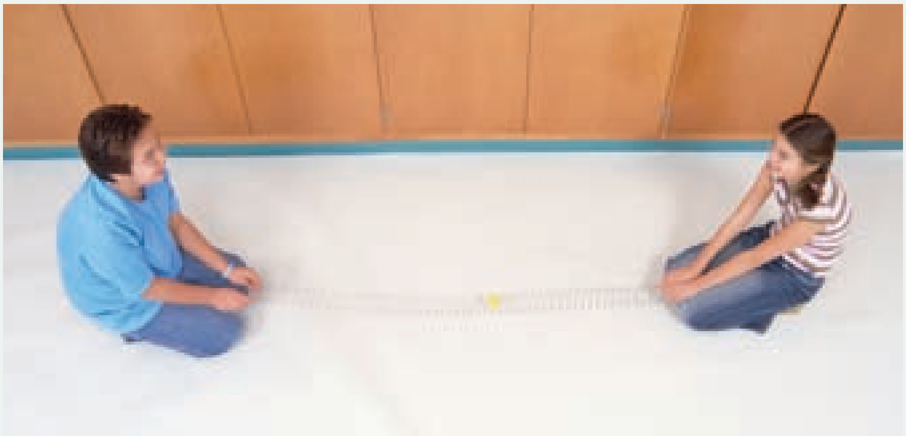
- coiled metal spring or Slinky®
- piece of masking tape or string

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.

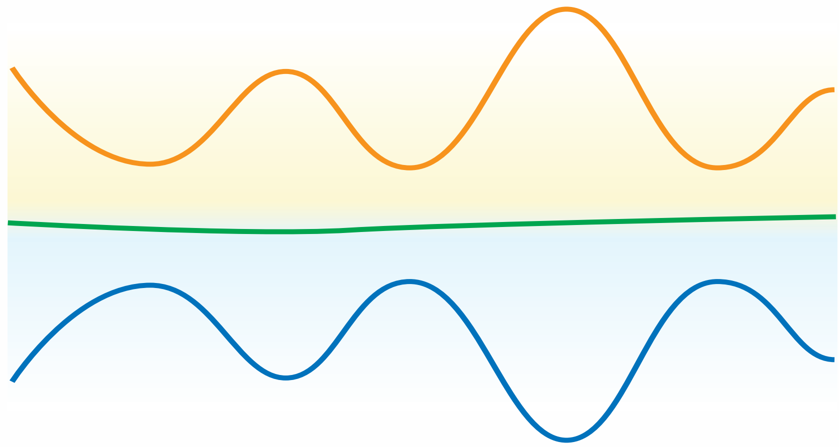
Conclude and Apply

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

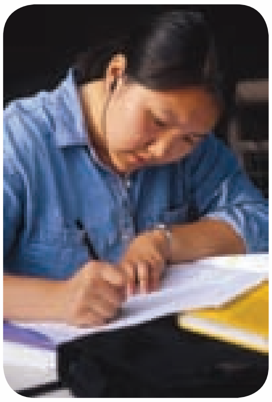
Noise-Cancellation Headphones



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.

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).

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?

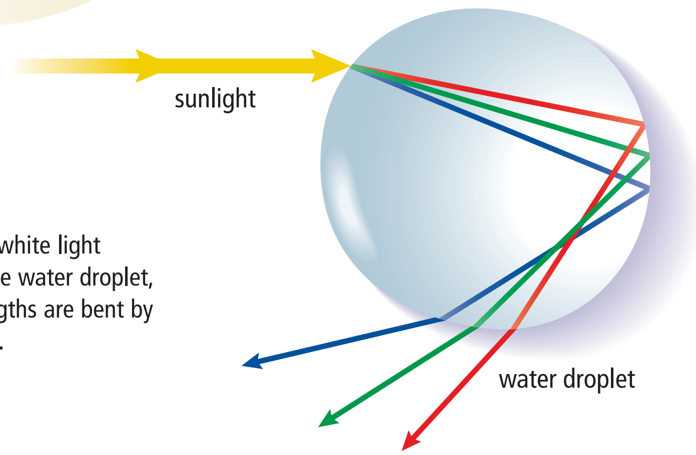
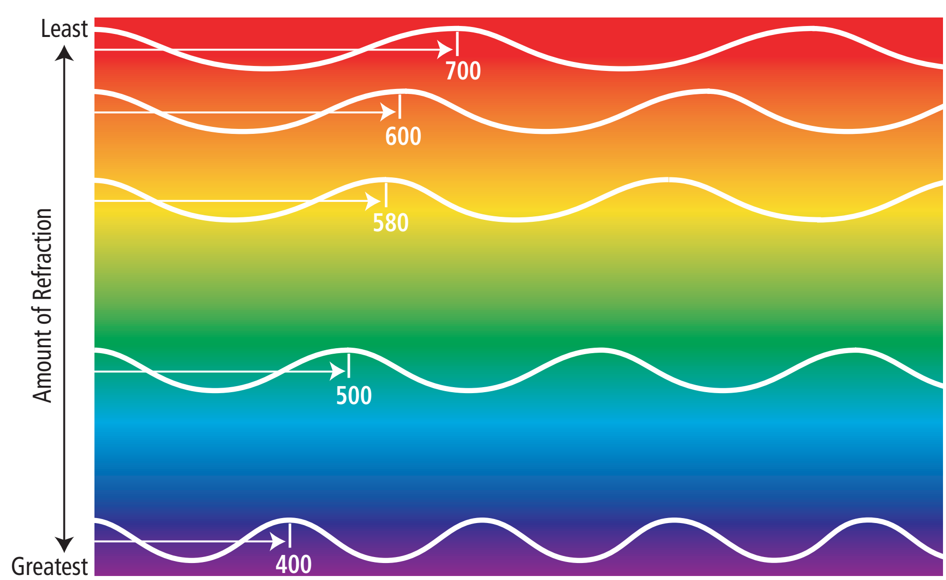


Figure 4.20 As white light passes through the water droplet, different wavelengths are bent by different amounts.

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

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.

Figure 4.22 Sir Isaac Newton

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.

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.

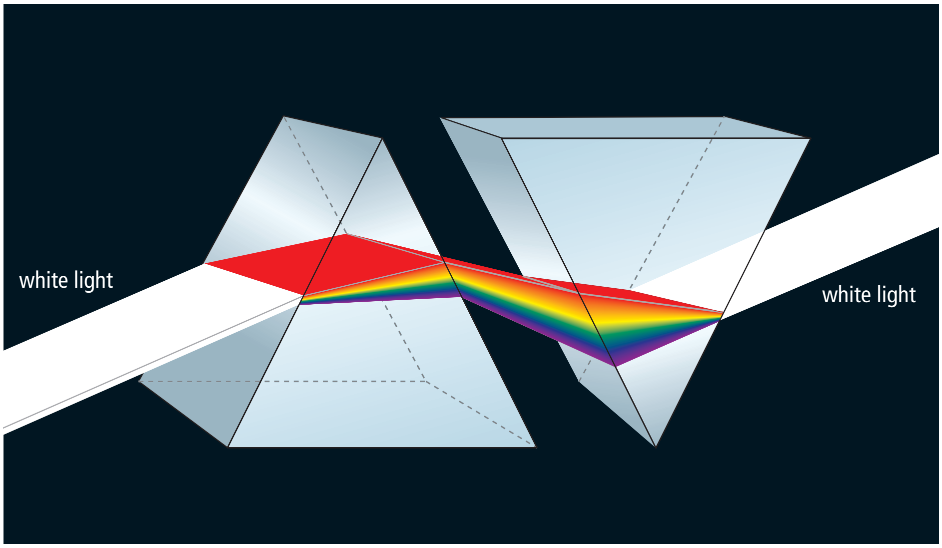


Figure 4.23 A prism causes white light to split into a spectrum. If the refracted light is passed through a second prism, the colours are recombined, producing white light again.

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).

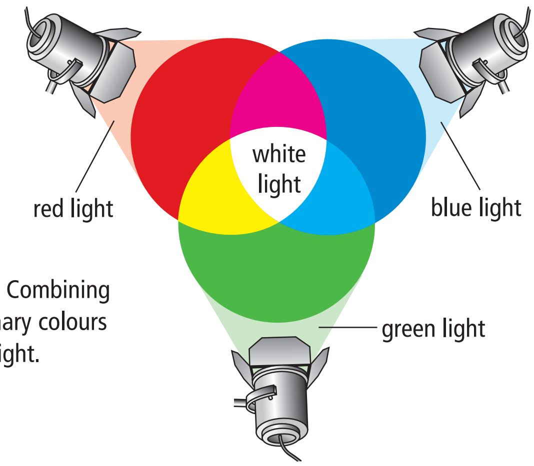


Figure 4.25(A) Combining the additive primary colours produces white light.

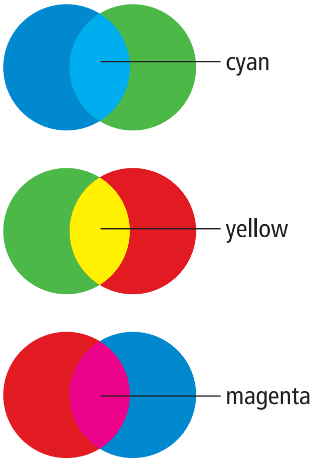


Figure 4.25(B) Each secondary colour is created by combining two of the primary additive colours.

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.

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.

Figure 4.27 Invisible waves allow us to communicate using cellphones and wireless Internet connections.

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.

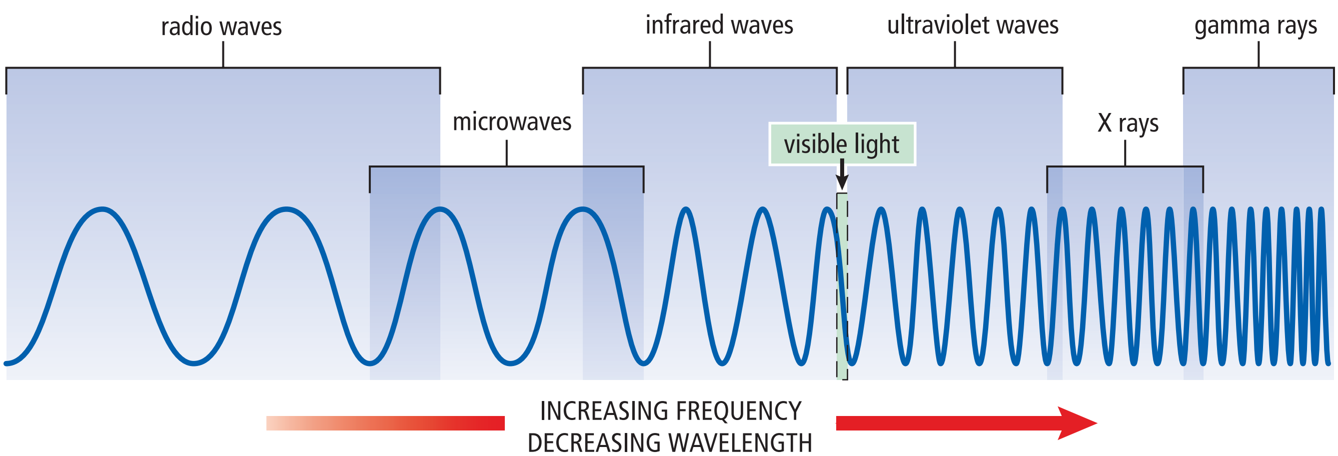


Figure 4.28 Electromagnetic waves are described by different names depending on their frequency and wavelength.

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.

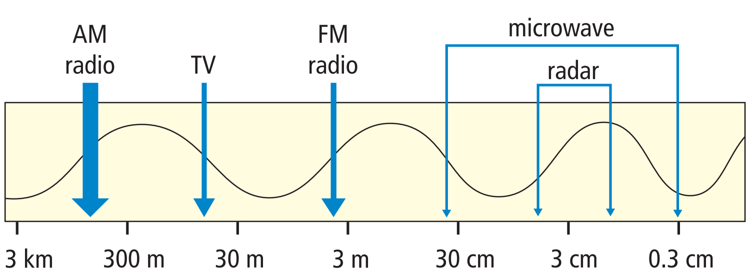


Figure 4.29 Radio wave region of the electromagnetic spectrum

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.

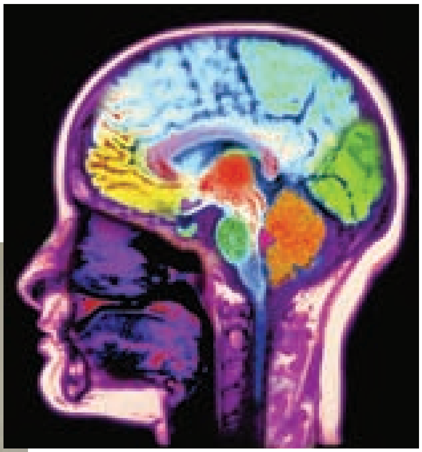


Figure 4.30(B) An MRI scan of the brain

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.

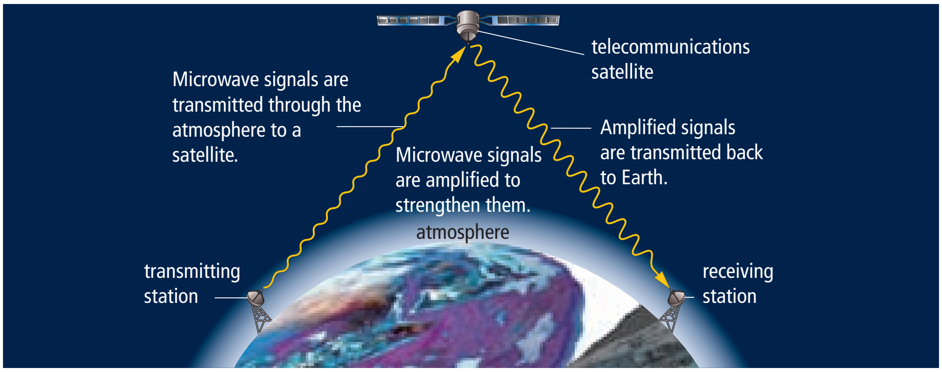


Figure 4.31 Signals sent by satellites can travel vast distances. One satellite can replace many ground relay stations. (This illustration is not drawn to scale.)

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

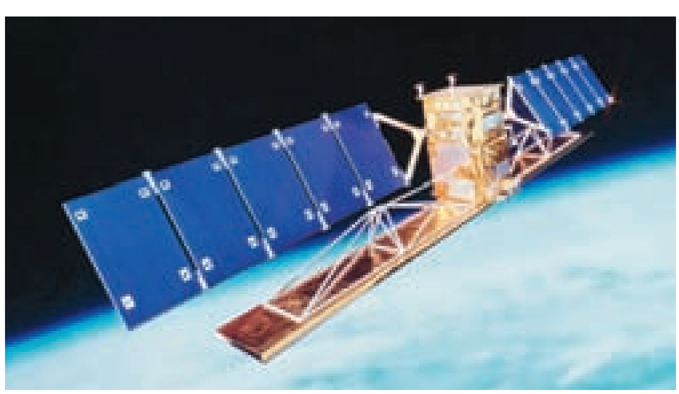


Figure 4.33 RADARSAT takes pictures of Earth's surface using radar.

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).

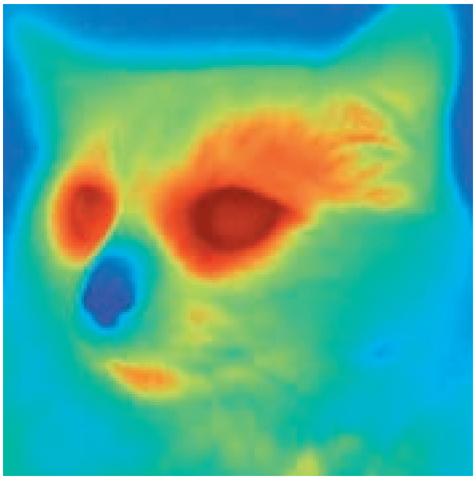


Figure 4.35 An infrared camera and film detect differences in temperature and assign false colours to different brightnesses. The result is information that we could not get from a visible light photograph.

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.

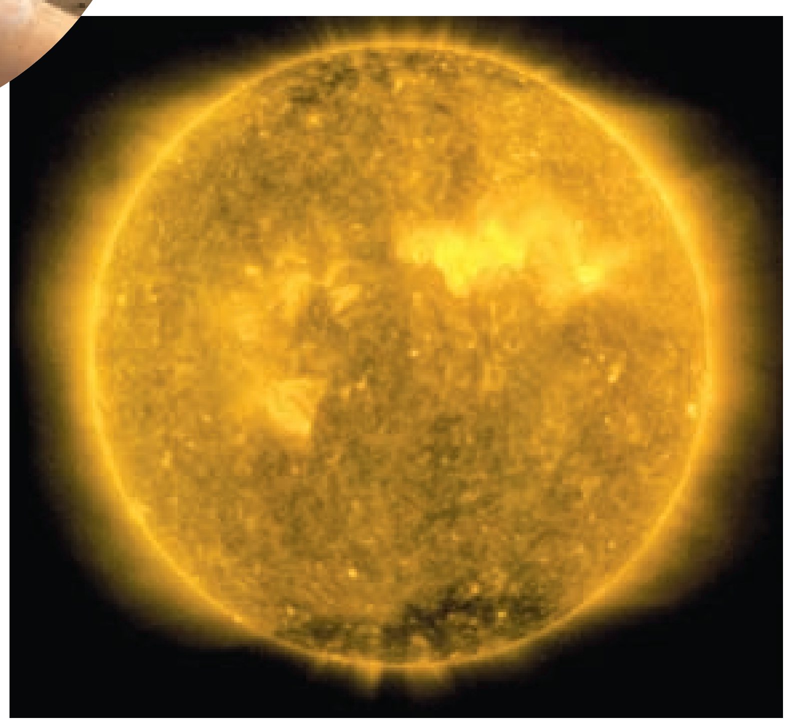


Figure 4.37 Earth's atmosphere absorbs some of the ultraviolet radiation emitted by the Sun.

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.

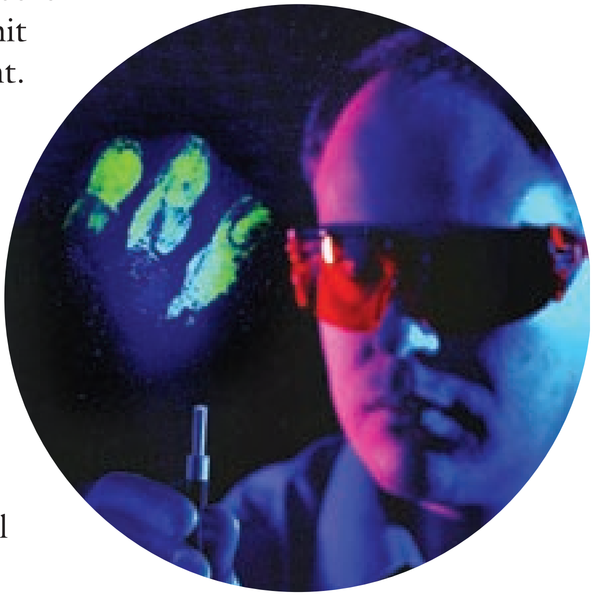


Figure 4.38 The detective is shining ultraviolet light on fingerprints dusted with fluorescent powder.

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.

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?

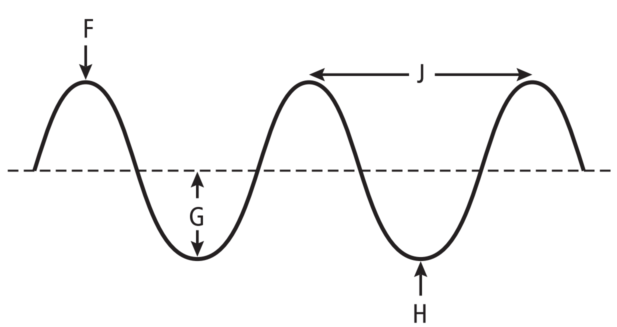
Prepare Your Own Summary

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

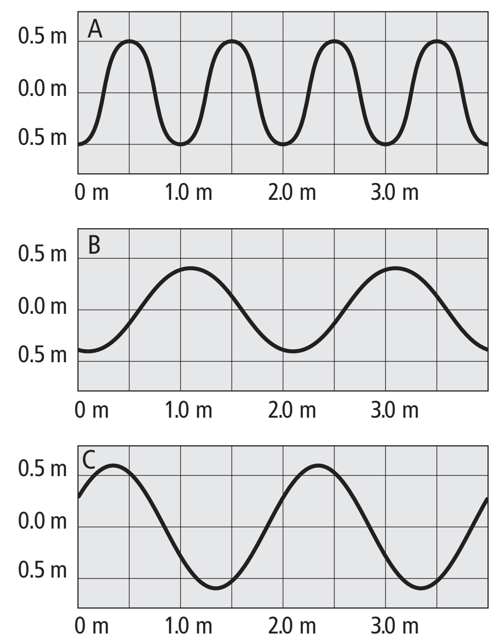
Checking Concepts

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?

The law of reflection allows mirrors to form images.

Nearly all surfaces reflect light. Some surfaces, such as the surface of this lake, reflect light in a way that creates an almost perfect image of the surroundings. People often refer to such a lake as a "glassy lake" because the surface is so smooth and still, like glass. Water must be very smooth and still in order to reflect light in a way that produces an image. However, the pages of this book are smooth and still but you cannot see a reflection of your face when you look at the pages. What is the difference between the surface of still water or of a mirror and the surface of these pages in the way that they reflect light? In this chapter, you will learn about the law of reflection and how to use the law to make predictions about whether an image will form and how it will appear.

What You Will Learn

In this chapter, you will
- **explain** the law of reflection
- **explain** the difference between specular and diffuse reflection
- **define** terms used to create and describe ray diagrams for plane, concave, and convex mirrors
- **describe** the characteristics of images including size, orientation, and whether they are real or virtual

Why It Is Important

You use mirrors every day. When you drive, it is important to understand the images you see in the rearview mirrors in the car. Many instruments contain mirrors. The law of reflection applies to many processes in addition to the formation of images in mirrors.

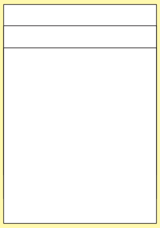
Skills You Will Use

In this chapter, you will
- **draw** ray diagrams for plane, concave, and convex mirrors
- **interpret** ray diagrams to predict the characteristics of images in plane, concave, and convex mirrors
- **use** mirrors effectively to investigate the characteristics of images formed

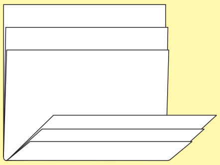
FOLDABLES™ Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 5.

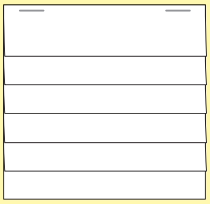
STEP 1 **Collect** 3 sheets of letter-sized paper and layer them about 2.5 cm apart vertically. (Hint: from the tip of your index finger to your first knuckle is about 2.5 cm.) Keep the edges level.



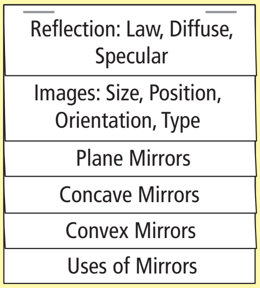
STEP 2 **Fold** up the bottom edges of the paper to form 6 tabs.



STEP 3 **Fold** the papers and crease well to hold the tabs in place. **Staple** along the fold.



STEP 4 **Label** the tabs as shown. (Note: the first tab will be larger than shown here.)



Summarize As you read the chapter, summarize what you learn under the appropriate tabs.

5.1 The Ray Model of Light

The ray model of light can be used to understand how light moves in straight lines, reflects off mirrors, and refracts through lenses. Materials can be classified as opaque, translucent, and transparent depending on their ability to block, obscure, or transmit light. Mirrors reflect light rays according to the law of reflection, which states that the angle of incidence equals the angle of reflection. Refraction occurs when light rays pass between two materials of different density. When this happens, the direction and speed of a light ray change in a predictable way.

Key Terms

angle of incidence
angle of reflection
angle of refraction
diffuse reflection
incident ray
law of reflection
normal
opaque
particle model of light
ray diagram
ray model of light
rectilinear propagation
reflected ray
refracted ray
specular reflection
translucent
transparent

Sir Isaac Newton believed that light is a stream of fast-moving, unimaginably tiny particles. For example, a lantern flame was thought to release tiny particles of light, which travelled in a perfectly straight line until they entered an eye, where they were absorbed to make an image. This model came to be called the **particle model of light**, and parts of the model are still in use today.

However, light also has properties that are best described using waves, such as the use of wavelength and frequency to account for the different colours of light. You studied the wave model of light in Chapter 4. The particle model and the wave model correctly describe some properties of light, but neither one describes all of light's properties.

For the study of optics, especially when looking at the behaviour of light when it reflects off mirrors (see Figure 5.1) and passes through lenses, it is very helpful to use a simplified model called the **ray model of light**. In the ray model, light is simply represented as a straight line, or ray, that shows the direction the light wave is travelling (see Figure 5.2).

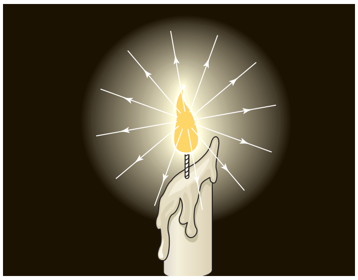


Figure 5.2 A ray is an imaginary line showing the direction in which light is travelling.

Figure 5.1 In order for you to see such a clear image in the mirror, reflected light must follow a very precise pattern.

5-1A Absorb, Reflect, Transmit

Find Out ACTIVITY

When light strikes an object, the light might be absorbed, reflected, and/or transmitted. In this activity, you will classify a variety of objects based on their ability to transmit light.

Materials

- variety of objects, such as a block of wood; thin and thick blocks of wax; prisms of tinted, frosted, and clear glass or Plexiglas; petri dishes of water; milk

What to Do

1. Create a table listing those materials that mostly absorb light (opaque), mostly transmit light but obscure the image (translucent), or mostly transmit light and allow the image to pass through (transparent).
2. Place various objects on an overhead projector. Classify the objects based on your observations.

What Did You Find Out?

1. Based on the objects you have classified as "mostly absorb light," how would you define opaque?
2. Distinguish between the terms "translucent" and "transparent."

Light and Matter

One use for the ray model is to help in understanding what happens when light energy reaches different materials. Imagine you are looking around your darkened room at night (see Figure 5.3). After your eyes adjust to the darkness, you begin to recognize some familiar objects. You know that some of the objects are brightly coloured, but they look grey or black in the dim light. You can no longer tell the difference between an orange shirt and a green shirt. What you see depends on the amount of light in the room and the colour of the objects. The type of matter in an object determines the amount of light it absorbs, reflects, and transmits.

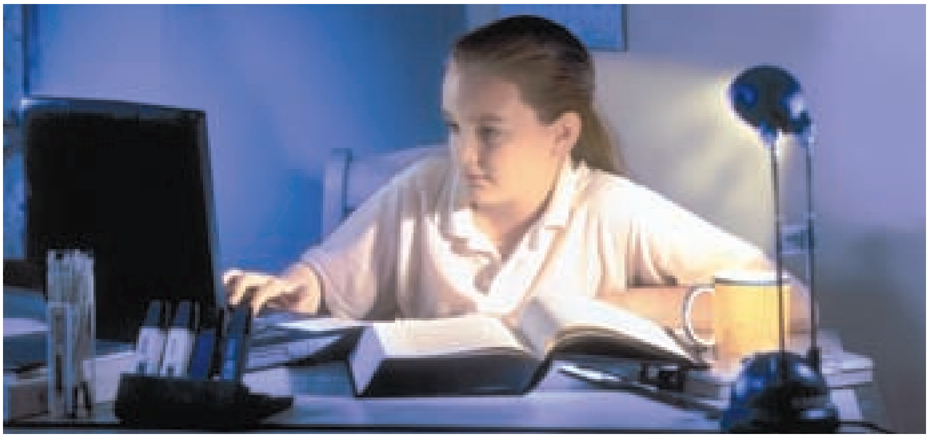
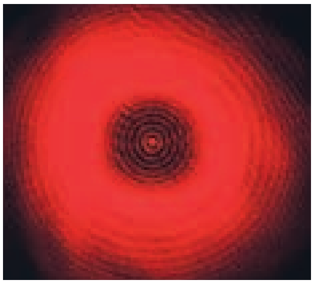


Figure 5.3 In order for you to see an object, it must reflect some light back to your eyes.

Did You Know?

Light can bend around corners! When a water wave hits the end of a breakwater, some part of the wave curves around behind it. All waves go around edges a little bit, and so does light. For this reason no shadow can be perfectly sharp. For example, if a laser light is shone on a coin, the shadow of the coin will be visibly fuzzy, as in the picture below.



A. Transparent

B. Translucent

C. Opaque

Figure 5.4 These candleholders have different light-transmitting properties.

Transparent

Some materials will transmit light, which means that all light can get through them without being completely absorbed. When light passes through clear materials, the rays continue along their path. We say these materials are transparent. A **transparent** material allows light to pass through it freely. Only a small amount of light is absorbed and reflected. Objects can be clearly seen through transparent materials, such as the candle in the transparent candleholder in Figure 5.4A. Air, water, and window glass are all examples of transparent materials.

Translucent

A ray diagram can show the difference between a transparent material and a translucent material (see Figure 5.5). In a **translucent** material, such as frosted glass or a lampshade, most light rays get through, but are scattered in all directions. Translucent materials, like the candleholder in Figure 5.4B, do not allow objects to be seen distinctly. Translucent glass is often used in bathroom windows to let in light without losing privacy.

Opaque

An **opaque** material prevents any light from passing through it. For example, the material in the candleholder in Figure 5.4C only absorbs and reflects light—no light passes through it.

internet connect

You may have seen a one-way mirror (sometimes called a two-way mirror). If you stand on the brightly lit side of the mirror you see your own reflection. If you stand on the darker side of the mirror you can see through it, like a transparent window. Find out how it is possible to see through one way but not both ways. Go to **www.discoveringscience8.ca.**

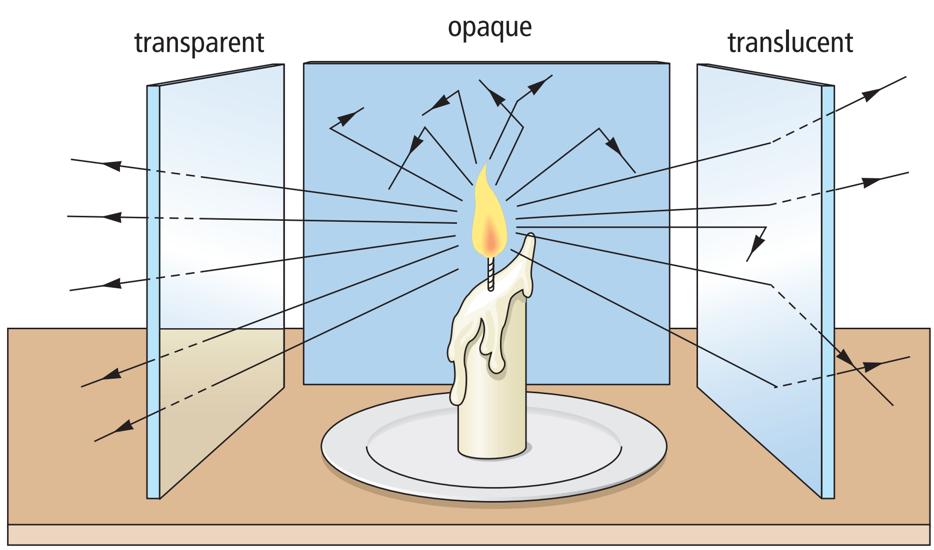


Figure 5.5 Light travels in straight lines until it strikes something.

Shadows

Shadows tell you about one of the most important properties of light: light travels in straight lines. This is known as **rectilinear propagation**. It is true as long as light stays in the same medium, or substance. This property allows you to make predictions about shadows and images using ray diagrams. For example, when you are walking away from the Sun during sunset, your shadow becomes much longer than you are tall (see Figure 5.6). In the ray diagram, your body casts a shadow because it blocks the light rays striking you. The light rays on either side of you continue in a straight line until they hit the ground. Figure 5.7 shows how a ray diagram can be used to show how the size of shadows is related to the distance of the object from the light source.

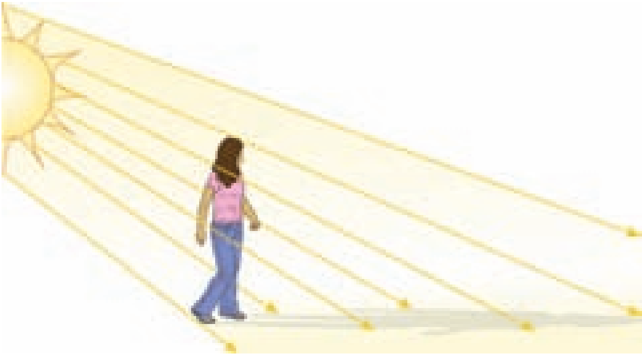


Figure 5.6 Ray diagrams can show how shadows are cast.

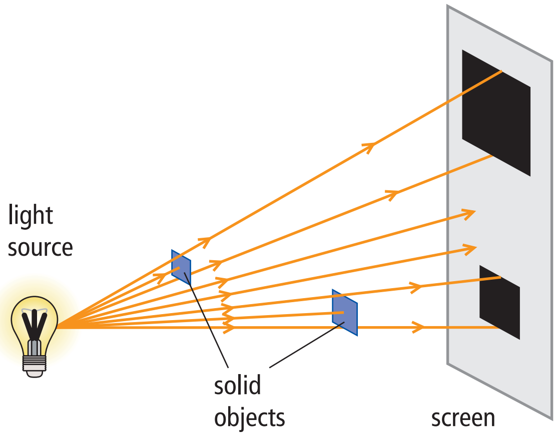


Figure 5.7A A ray diagram shows how the distance from the light source affects the size of the shadow that an object makes. The smaller object casts the larger shadow because it is closer to the light source.

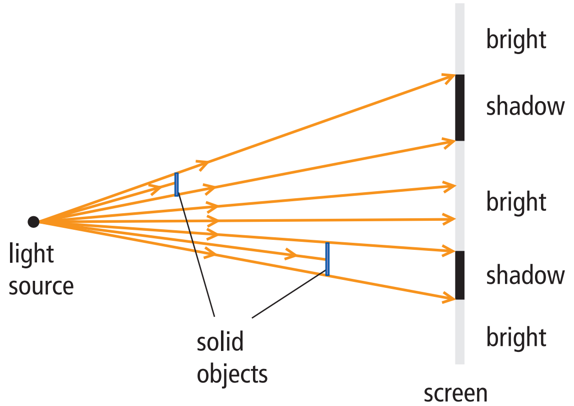


Figure 5.7B To make ray diagrams easier to draw and to visualize, you usually draw them as though you were looking at the objects from the side. You can represent the light source with a dot.

Reading Check

1. What are three uses for the ray model?
2. How is an opaque material different from a translucent material?
3. Is a glass of water with red food colouring in it translucent or transparent? Explain.
4. What is the relationship between the size of the shadow and the distance of the object from the light source?

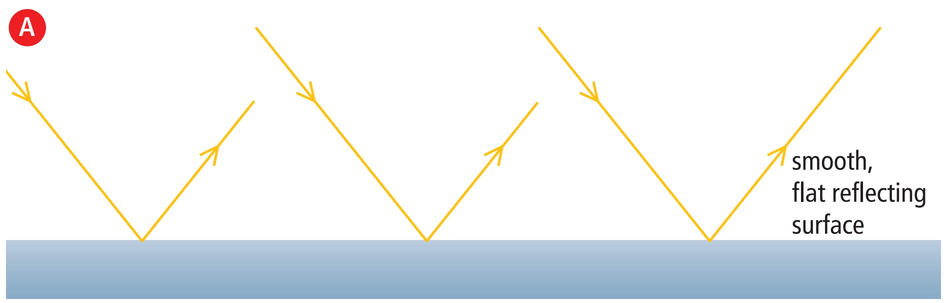
Suggested Activity

Find Out Activity 5-1C on page 183

Light Can Be Reflected

This book uses black letters printed on white paper. The black ink is opaque because all the light falling on the ink is absorbed. But the white paper reflects all of the light that falls on it. Does that mean the white paper is a mirror? If so, why can you not see your reflection in the white parts of the page?

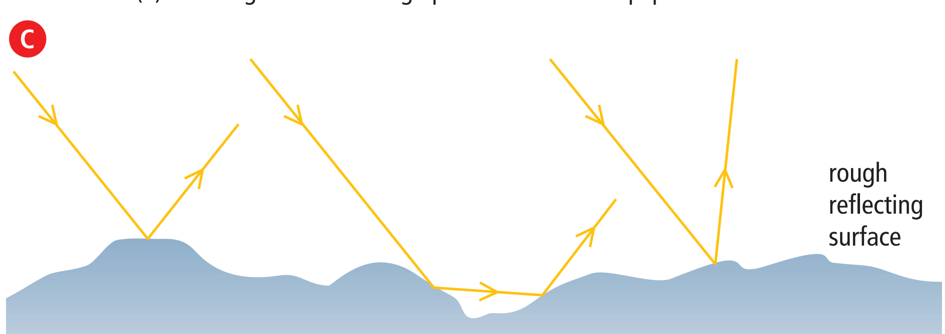
In fact, there are two different types of reflection. Reflection from a mirror-like surface, which produces an image of the surroundings, is called **specular reflection**. Reflection from a rough surface, which does not produce a clear image but instead allows you to see what is on the surface, is called **diffuse reflection**. To act as a mirror, a surface needs to be smooth compared to the wavelength of the light striking the surface (see Figure 5.8A). Even though a piece of paper may feel smooth, a photograph taken through a microscope reveals that the surface is actually not very smooth at all (see Figure 5.8B). The ray diagram shows that the light rays bounce off randomly at all angles, giving the paper the appearance of being translucent (see Figure 5.8C).



(A) Specular reflection: Smooth surfaces reflect all light uniformly.

B

(B) Scanning electron micrograph of the surface of paper



(C) Diffuse reflection: Rough surfaces appear to reflect light randomly.

Figure 5.8

Diffuse reflection helps to allow you to read the print on this page. To understand how, examine Figure 5.9. The black ink in the print absorbs most of the incoming light. The white paper produces diffuse reflection and reflected rays go out in all directions. You can see the reflected light from all of the white parts of the page will reach your eyes but no light will reach your eyes from the print because the black print does not reflect any light. Imagine how a page would look if the paper was as smooth as a mirror. You would see your own reflection behind the print and it would be extremely difficult to read it.

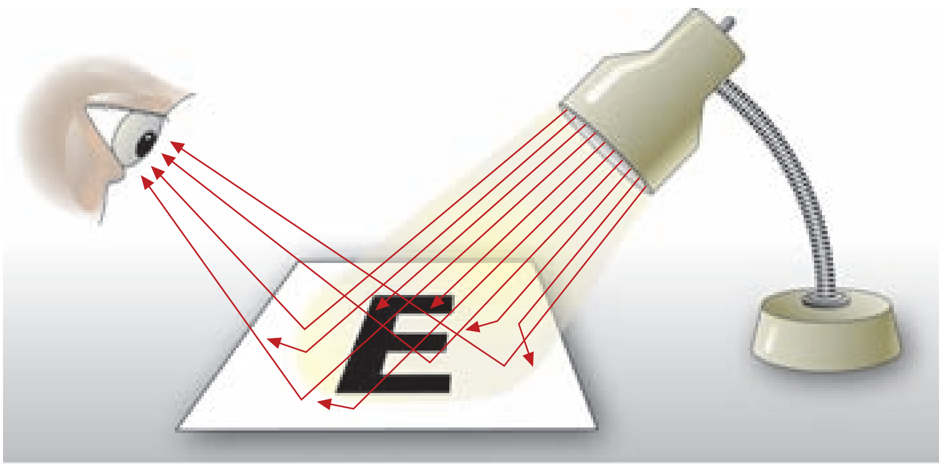


Figure 5.9 The black print ink on the page absorbs all of the light that hits it. No light from the black areas reaches your eyes. Diffuse reflection from all of the rest of the page reaches your eyes, allowing you to see the uneven surface of the paper.

As you learned in Chapter 4, you see colour when an object absorbs only part of the visible light spectrum. Some wavelengths of light are absorbed, and the rest are reflected. If the print on a page is not black but instead is a colour such as blue, the print will absorb all colours except blue. Only the blue light is reflected from the print. Therefore, only blue light reaches your eyes from the print but white light reaches your eyes from the rest of the page.

Reading Check

1. Explain the difference between specular and diffuse reflection.
2. Describe the type of surface that is responsible for diffuse reflection.
3. Draw a diagram to show how an eye sees a green "T" on a white page.

Did You Know?

Objects that bounce off a surface sometimes behave like waves that are reflected from a surface. For example, suppose you throw a bounce pass while playing basketball. The angle between the ball's direction and the normal to the floor is the same before and after it bounces.

The Law of Reflection

How does light reflect off a mirror? It is helpful to think about how a light ray is similar to a water wave bouncing off a solid barrier. Imagine a great rock wall rising high out of the water. If waves strike such a barrier head on, the waves will bounce straight back in the reverse direction. However, if a wave strikes the barrier from an angle, then it will also bounce off at an angle—at precisely the same angle as the incoming wave that struck the barrier.

Ray diagrams, like the one in Figure 5.10, use straight lines to illustrate the path of light rays. The incoming ray is called the **incident ray**. The ray that bounces off the barrier is called the **reflected ray**. Notice in Figure 5.10 that a dotted line has been drawn at right angles to the solid barrier. This line is called the **normal**. The normal is an imaginary line that is perpendicular to the barrier. It is used to help explain how waves reflect.

The angle formed by the incident beam and the normal is the **angle of incidence**, labelled *i*. The angle formed by the reflected beam and the normal is the **angle of reflection**, labelled *r*. Notice that the angle is always measured from the normal line to the ray, not from the mirror to the ray. Observations for all types of surfaces have shown, without exception, that the angle of reflection is the same as the angle of incidence. Therefore, this observation is considered to be a law. You can state the **law of reflection** as "the angle of reflection equals the angle of incidence." For example, if the angle of incidence, *i*, is 60° then the angle of reflection, *r*, will be 60°.

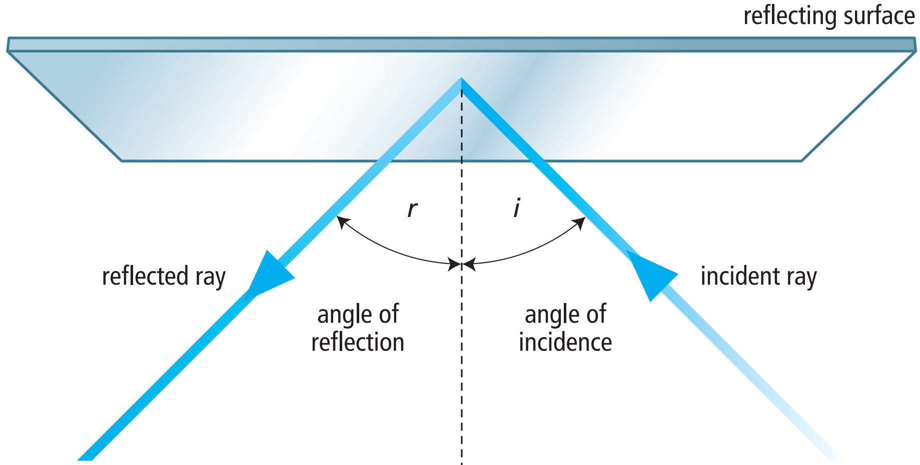


Figure 5.10 Light reflected from any surface follows the law of reflection.

Light Can Be Refracted

You learned in Chapter 4 that refraction is the bending of a wave, such as light, when it travels from one medium (material) to another. Figure 5.11 shows you how light bends as it travels from air to water.

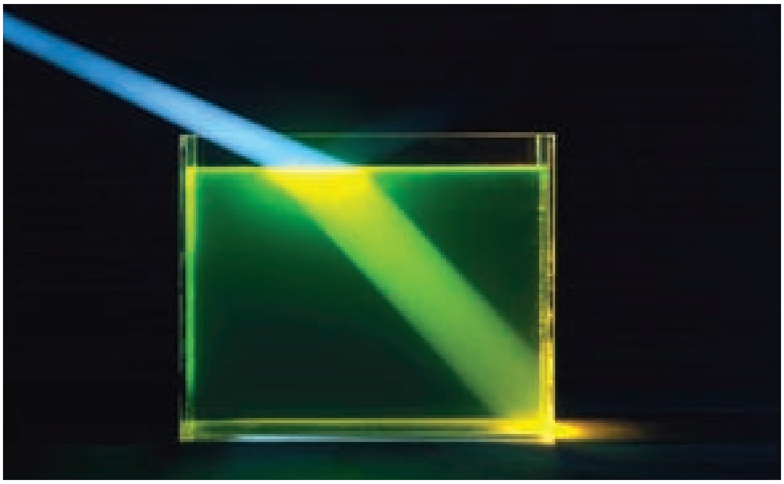


Figure 5.11 You can see the beam of light in air because there are dust particles in the air that scatter the light. You can see the beam of light in the water because there is a substance in the water that fluoresces. (To fluoresce means to give off more visible light than is absorbed.) These "tricks" help you see the beam of light as it bends when it travels from air to water.

Waves bend because the speed of the waves changes when travelling from one medium to another. But why does a change in speed cause a change in the direction of a wave?

To visualize what happens when the crest of a wave reaches the surface between two media, imagine each wave crest as a row of students in a marching band. In Figure 5.12, you see the band marching from an area of firm ground to an area of mud. The mud is so sticky that the students cannot march as fast. As each student in the band reaches the mud, he or she slows down. The slower students "pull" the line back and cause a bend in the line. As a result, the direction in which the entire row is marching, changes. The larger red arrow shows the direction in which the band, as a whole, is moving. This is just what happens to a wave when it crosses the surface from air into water.

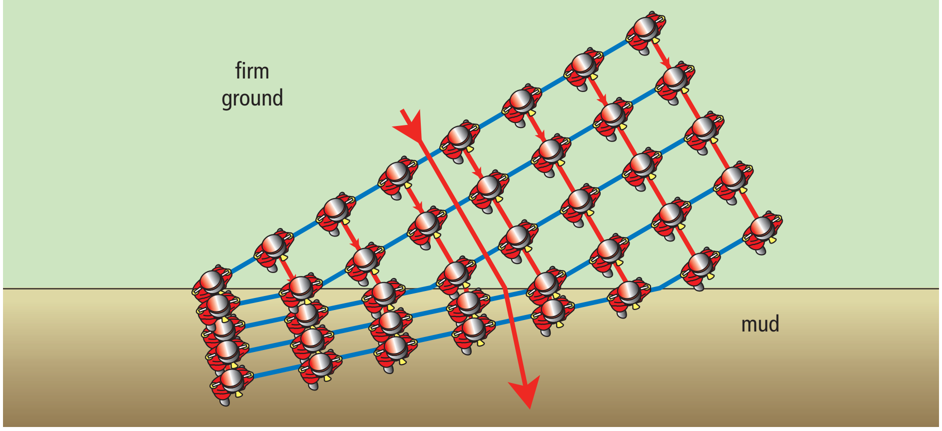


Figure 5.12 Each row of students represents the crest of a wave. When one end of the wave front slows down, the direction of the wave changes.

Word Connect

The word *media* is the plural for medium.

Explore More

As a class, simulate the marching band in Figure 5.12. Draw a line on the ground or put a piece of masking tape on the floor. Line up like a marching band. March toward the line so that the rows of students are at an angle with the line. As each student reaches the line, he or she should take steps that are half the size of the steps taken before reaching the line.

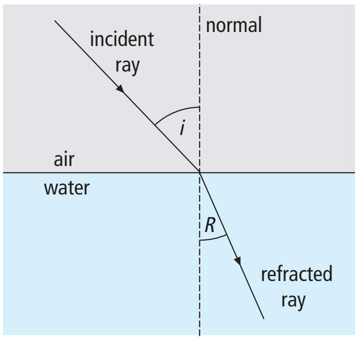


Figure 5.13 The terms, incident ray, normal, and angle of incidence all have the same meaning in refraction that they had in reflection. The new terms are "refracted ray" and "angle of refraction."

Describing Refraction

Now that you understand why a change in the speed of a wave, such as light, causes refraction, you can use rays to describe the direction of the wave. Most of the terms used to describe refraction are the same or similar to the terms used with reflection (Figure 5.13). The incident ray and angle of incidence are defined just as they are in reflection. This time, the normal is perpendicular to the surface between the two media and it extends through both media. As you can see in the figure, the **refracted ray** is in the second medium and is travelling in a different direction than the incident ray. The angle labelled "*R*" is the **angle of refraction**. Note that a capital, or uppercase, *R* is used for refraction whereas a small, or lowercase, *r* is used for reflection.

5-1B Observing Refraction

Find Out ACTIVITY

You can observe refraction by using a ray box and a solid block of a transparent material.

What You Will Need

- block of glass or transparent plastic
- ray box
- ruler
- protractor
- piece of white paper

What to Do

1. Place the block of glass (or plastic) flat on the table. To practice using the materials, shine the light from the ray box into the side of the block. Follow the light ray through the block and then out of the far side. Change the angle of the block in relation to the incident beam of light from the ray box and, for each angle, observe the path of the light ray.
2. Set the glass block in one place on a large piece of white paper that you can use to trace the path of the light rays. With reference to the point where the light enters the glass block, draw and label the incident ray, the refracted ray, the normal, the angle of incidence, and the angle of refraction.
3. Continue the diagram showing the light ray as it passes out of the other side of the block. Draw and label the incident ray, the refracted ray, the normal, the angle of incidence, and the angle of refraction. **Hint:** The refracted ray from the first surface (entering the block) becomes the incident ray for the second surface (leaving the block).

What Did You Find Out?

1. (a) Does the light ray passing through the glass block change direction at the surface of the block or somewhere in the middle?

   (b) How do you know the answer to part (a)?
2. (a) Does the light ray entering the block bend toward or away from the normal?

   (b) Does the light ray leaving the block bend toward or away from the normal?

   (c) What can you infer from your answers to parts (a) and (b) about the speed of light through the glass (or plastic) and through air?
3. Compare the direction in which the light ray is travelling after it leaves the block with the direction of the ray before it entered the block.

Reading Check

1. What is the relationship between the crest of a wave and the direction of the wave?
2. Why does the direction of a ray of light change when the light travels from one medium to another medium having a different density?
3. Define "angle of refraction."

The Direction of the Refracted Ray

You saw in the model of the marching band that when the marchers slowed down, their direction turned toward the normal. In general, when the speed of a wave slows down in the second medium, the direction of the wave is bent toward the normal. Is there a way that you can predict whether a wave will slow down or speed up when going from the first to the second medium?

The density of the material determines the speed of light in that medium. In general, light travels more slowly in a more dense medium than in a less dense medium. Therefore, when light travels from a less dense to a more dense medium, the ray bends toward the normal. When light travels from a more dense medium to a less dense medium, the ray bends away from the normal. These points are summarized in Figure 5.14.

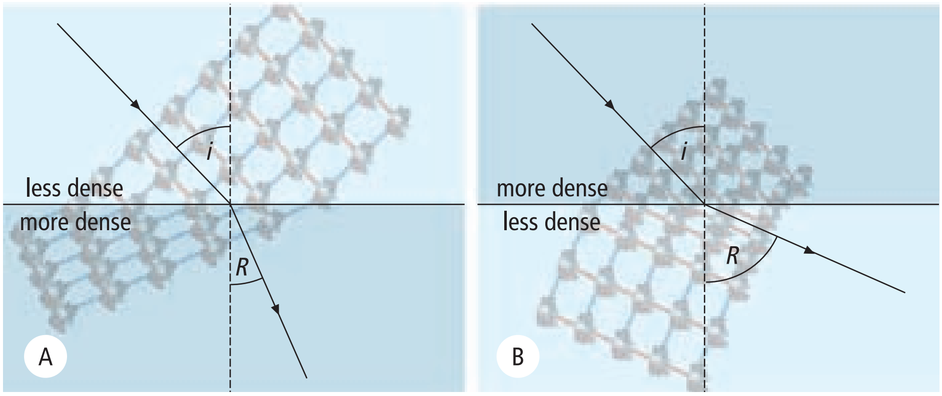


Figure 5.14 The direction in which a refracted ray travels depends on whether the second medium is more dense or less dense than the first medium. In A, the light is slowing down as it enters the denser medium, just as the marching band is slowing down as they march into the mud. In B, the light is speeding up as it exits the denser medium, just as the marchers are speeding up as they march out of the mud.

Refraction Effects

When you see an object, your brain assumes that the light coming from the object traveled to your eyes in straight lines. However, if the light from the object passed through two different media before it reached your eye, the light did not travel in a straight line. As a result, the object is not where your brain thinks it is.

Suggested Activity

Investigation 5-1D on page 184.

Figure 5.15 You know that the pencil is straight yet it looks bent and broken. The pencil is not bent but the light rays are.

You can see this effect if you look at a pencil that is sticking out of a glass of water (Figure 5.15). The light from the top portion of the pencil travels in a straight line to your eye. The light from the bottom portion bends as it exits the water. Your brain has trouble determining the correct position of the underwater portion, so the pencil appears to be broken at the water level.

To understand how your brain sees an underwater object, examine Figure 5.16. The solid line from the fish shows the actual path of the light. It bends at the surface of the water before reaching your eye. The dotted line shows how your brain thinks the light is travelling. Your brain thinks that the fish is located at the "apparent position."

Knowing that a fish underwater is not where it appears to be makes you wonder how fishing birds are able to catch fish without difficulty. Figure 5.17 shows a pelican diving for a fish. The pelican saw the fish while flying high above the water and started a dive. It will hit the water forcefully and continue into water and catch the fish. The pelican has developed a method of knowing where the fish really is.

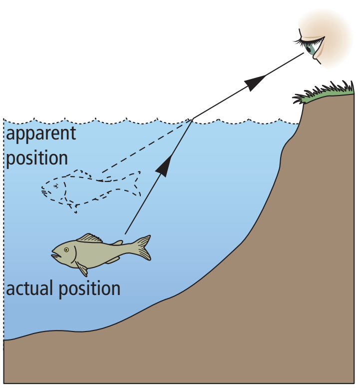


Figure 5.16 Objects under water are never where they appear to be. Water never looks as deep as it really is.

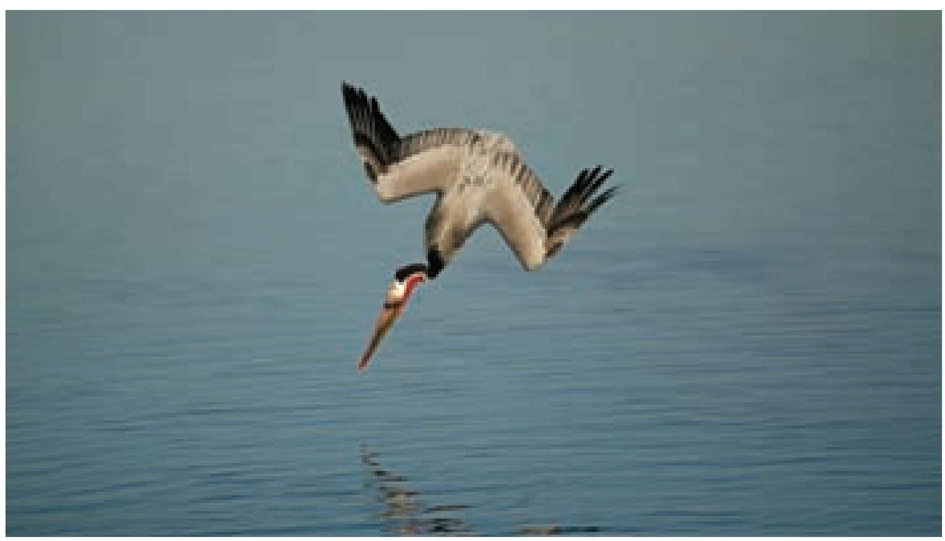


Figure 5.17 Fishing birds dive under water to catch their meal.

internet connect

The mirages that you sometimes see on the road on a very hot day are also caused by the refraction of the Sun's rays. Learn more about mirages on the Internet. Start your search at **www.discoveringscience8.ca**.

Reading Check

1. If a ray of light passes from a more dense medium into a less dense medium, which way will the refracted ray bend in relation to the normal?
2. Imagine that you are standing beside a wishing well. There are many coins on the bottom of the well. Do the coins look like they are below or above their actual position?

5-1C When Light Reflects

Find Out ACTIVITY

In this activity, you will observe whether light reflects off liquid surfaces according to the same principles as when it reflects off a solid mirror surface.

Materials

- clear plastic cup
- water
- paper
- ruler
- wooden pencil

What to Do

1. Fill the cup about three quarters full of water. Place the cup on a level surface.
2. Observe the surface of the water. Move your head around until you can see a reflection of the lights overhead, or a reflection of a window.
3. Make a simple ray diagram to record the direction in which light travels before it reaches your eye. Show and label the positions of the light source, the surface of the water, and your eye. This drawing should show the situation as someone would observe it from the side.
4. Move the cup of water to the edge of the desk or table. Wait until the water stops jiggling. Crouch down so that you can look up at the bottom of the water's surface.
5. Slide a pencil across the desk toward the cup and your eye. Move the pencil along the desk surface until you can see a reflection of the pencil in the lower surface of the water.
6. Make a simple ray diagram to record the path of the light from the pencil to your eye.
7. Look at the reflection of the pencil as you did in step 5, but now gently tap on the rim of the glass. Record your observations.
8. Wipe up any spills. Clean up and put away the equipment you have used.

What Did You Find Out?

1. (a) In steps 4 and 5, what happened to some of the light that struck the lower flat surface between the air and water?
   (b) What common device depends on this behaviour of light?
2. (a) In step 7, what change occurred in the surface of the water when you tapped on the glass?
   (b) What happened to the reflection of the pencil?
3. During reflection, what happens to the direction in which light travels?
4. Does light reflect off liquid surfaces according to the same principles as when it reflects off a solid mirror surface? Explain your answer.

Slide a pencil across the desk toward the cup.

5-1D Follow That Refracted Ray! Core Lab

SkillCheck
- Hypothesizing
- Designing
- Measuring
- Analyzing

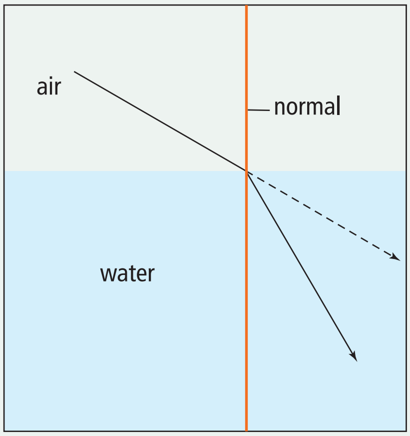
Materials
- ray box
- sheet of white paper
- transparent plastic, watertight tray (box top from greeting cards, candles, etc.)
- ruler
- protractor
- water
- vegetable oil
- rubbing alcohol

You will work in small groups and design this investigation. You will study the refraction of light in two different substances. When you studied reflection, you discovered that there was a pattern. The angle of reflection is equal to the angle of incidence.

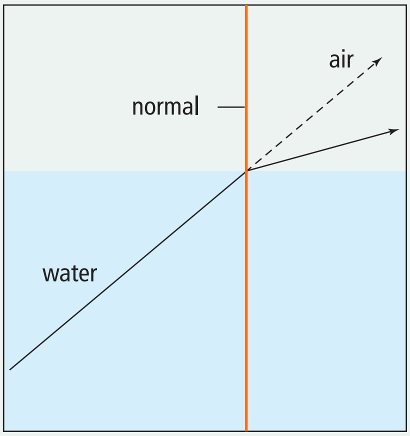
Question
Is there a pattern that describes the path of light during refraction?

Hypothesis
Make a hypothesis about the path of the refracted ray and then test it.

Procedure
1. With your group, design a procedure that will allow you to observe and then trace the paths of light rays entering and leaving a transparent, watertight tray.
2. Write a brief description of the procedure you plan to follow. Have your teacher approve your procedure.
3. Prepare actual-size diagrams on which you can record your observations.
4. Each of your diagrams should show the following:
   (a) the path of a light ray going from the air, through the empty tray, and back into the air through the opposite side of the tray, for at least three different angles of incidence
   (b) the path of the same incident rays when there is water in the tray
   (c) the paths of light rays that travel through i) vegetable oil and ii) rubbing alcohol, for the same incident rays you used in parts (a) and (b)
5. Wipe up any spills and wash your hands after this investigation.



A Light slows down and refracts toward the normal as it passes from air into water.



B Light speeds up and bends away from the normal as it passes from water into air.

Analyze

1. On your diagrams, draw the normal at each point where a light ray travels from one medium into another. If necessary, you can refer to the diagrams above.
2. Measure and record the size of each angle on your diagrams. Record the angles using the symbols, *i* and *R*.

Conclude and Apply

3. Does light bend toward or away from the normal when it travels from air into another medium such as water? Did your results support your hypothesis? Did other groups get similar results using their procedures?
4. What happens to the size of the angle of refraction when the angle of incidence increases?
5. What happens to the size of the angle of refraction when a liquid other than water is used and the angle of incidence is the same?
6. Do light rays move toward or away from the normal when they travel from a medium such as water into air?
7. Is there an angle of incidence for which there is no change in the direction of the light? Draw a diagram for this situation for light travelling through a rectangular shape.
8. Write a statement that answers the "Question" at the beginning of the investigation.

Science Math connect

How Big Is Earth?

What is the circumference of Earth? Today you might use the Internet to find the answer. But 2250 years ago, you could have asked a man named Eratosthenes of Alexandria, Egypt. He had just figured it out for himself, and was the first person to do so. Eratosthenes was a mathematician, a geographer, and the director of the great library of Alexandria, the greatest centre of knowledge of the ancient world.

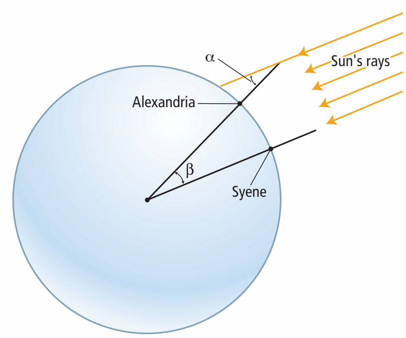
Eratosthenes was a Greek mathematician, born in North Africa in 276 B.C.E.

How did Eratosthenes measure the circumference of Earth? He used a light ray experiment and some geometry. Eratosthenes knew that if you looked down a well in the southern city of Syene at noon on the longest day of the year, you could see a reflection of the Sun. This meant that at that moment the Sun was directly overhead, and that flagpoles, for example, did not cast a shadow.

At his more northerly home, in Alexandria, at exactly the same time, you could not see to the bottom of a well, and flagpoles did cast a shadow. Eratosthenes measured some angles and drew a diagram and found something startling. In geometry, it is known that when two parallel lines are crossed by a third line, some of the angles that are formed are equal. In particular, the alternate interior angles are equal.

How is this information useful? Flagpoles in both Alexandria and Syene point directly to the centre of Earth. They meet at an angle: an alternate interior angle. The other alternate interior angle is found by looking at the light ray that passes the top of the flag pole in Alexandria and forms the shadow on the ground.

This is the angle that Eratosthenes measured. He found the angle to be 7.2°. Since a complete circle is 360°, the two cities were 7.2 ÷ 360 apart, or about a 50th of the distance around Earth. The distance from Syene to Alexandria was about 800 km. The circumference of Earth must therefore be 50 times longer, or 40 000 km. We know that Earth's circumference varies between about 40 008 km and 40 075 km depending on where it is measured. Eratosthenes got the right answer, to within 1 percent—an amazing feat!



The alternate interior angle passes the top of the flag pole and forms the shadow on the ground.

Questions

1. If flagpoles in Syene and Alexandria both point directly to the centre of Earth, why are the flagpoles not parallel?
2. Why is the angle formed by the flagpoles and the centre of Earth the same as the angle formed by a ray of sunlight and the flagpole in Alexandria?
3. If the distance between Syene and Alexandria had been 500 km, with the same alternate interior angle, what would be Earth's circumference?

Check Your Understanding

Checking Concepts

1. Compare and contrast the following terms:
   (a) translucent, transparent
   (b) transmit, absorb
   (c) reflect, refract
2. The angle of incidence of a light ray is 43°. What is the angle of reflection?
3. Light slows down as it moves from air into water. Explain how this causes the direction of a light ray to change.
4. Why can you see your reflection in a smooth piece of aluminum foil, but not in a crumpled ball of foil?
5. If you look at a shiny object and see your reflection in it, are you experiencing specular reflection or diffuse reflection? Explain.

Understanding Key Ideas

6. Explain how shadows demonstrate rectilinear propagation.
7. (a) What is meant by the term "normal" in a ray diagram that represents reflection?
   (b) Does the meaning of normal change when representing refraction? Explain.
8. Why does a pencil that is sticking out of a glass of water look bent? Draw a diagram to support your explanation.

9. (a) Draw a line representing a flat mirror. Then add a normal line perpendicular to the mirror. Draw a light ray approaching and then touching the mirror at the same place as the normal line. Complete the ray diagram showing the ray's reflection.
   (b) Label the incident ray, normal, reflected ray, angle of incidence, and angle of reflection.
10. A semi-transparent mirror will both reflect and refract an incident light ray. Draw a straight line representing the surface of a glass mirror. Show a light ray striking the surface of the mirror at a slightly downward angle. The ray splits into a reflected ray, which bounces back, and a refracted ray, which is transmitted through the glass. When drawing your sketch, make sure to use the laws of reflection. The refracted ray will bend toward the normal since glass is denser than air.
11. Why is it desirable that the pages of a book be rough rather than smooth and glossy?

Pause and Reflect

In Chapter 4, you studied forms of electromagnetic radiation, such as X rays and gamma rays. Do you think these invisible forms of radiation have the property of reflection? Support your answer.

5.2 Images in Plane Mirrors

All mirrors reflect light according to the law of reflection. Plane mirrors form an image that is upright and appears to be as far behind the mirror as the object is in front of it. The image is the same size as the object. Images in plane mirrors are virtual images.

Key Terms

extended rays
image
image distance
inverted
object distance
plane mirror
upright
virtual image

You can see your reflection as you glance into a calm pool of water or walk past a shop window. When you "see yourself", in a reflection, you are actually seeing a likeness of yourself called an **image**. Most of the time, you probably look for your image in a flat, smooth mirror called a **plane mirror**.

5-2A Reflections of Reflections — Find Out ACTIVITY

In this activity, you will find out how many reflections you can see in two plane mirrors.

Materials

- 2 plane mirrors
- protractor
- masking tape
- paper clip

Safety

- Handle glass mirrors and bent paper clips carefully.

Count the images in each mirror.

What to Do

1. Create a table to record your data. Give your table a title.
2. Lay one mirror on top of the other with the mirror surfaces inward. Tape them together so they will open and close. Use tape to label them "L" (left) and "R (right)."
3. Stand the mirrors up on a sheet of paper. Using a protractor, close the mirrors to an angle of 72°.
4. Bend one leg of a paper clip up 90° and place it close to the front of the R mirror.
5. Count the number of images of the clip you see in the R and L mirrors. Record these numbers in your data table.
6. Hold the R mirror still. Slowly open the L mirror to 90°. Count and record the images of the paper clip in each mirror.
7. Hold the R mirror still. Slowly open the L mirror to 120°. Count and record the images of the paper clip in each mirror.

What Did You Find Out?

1. What is the relationship between the number of reflections and the angle between the two mirrors?
2. How could you use two mirrors to see a reflection of the back of your head?

Plane Mirrors

How do reflected rays form an image that we can see in a mirror? Study Figure 5.18 to answer this question. When light shines on an object such as a blueberry, the light reflects off all points on the blueberry in all directions. In Figure 5.18, just a few of the rays that reflect off one point on the blueberry are shown. All of the rays from the blueberry that strike the mirror reflect according to the law of reflection. The rays that reach your eye appear to be coming from a point behind the mirror. The same process occurs for every point on the blueberry. The brain is trained to assume that light rays travel in straight lines. Therefore, your brain interprets the pattern of light that reaches your eye as an image of a blueberry behind the mirror. To find out where the brain believes the blueberry to be, extend the rays that reach the person's eye backward to a point behind the mirror. These **extended rays** are shown by the dotted lines in the figure. When you extend more than one ray, the lines will meet at a point behind the mirror. This is the point where the image is located. You could carry out the same process for several points on the blueberry to find out exactly where the entire image of the blueberry is located.

The image of the blueberry is called a **virtual image**, since the light rays that reach the eye only *appear* to be coming from the object. The reflected rays don't actually meet; only the extended rays meet at the object. When an object's image lies behind the mirror, the image is virtual.

Suggested Activity

Investigation 5-2B on page 192

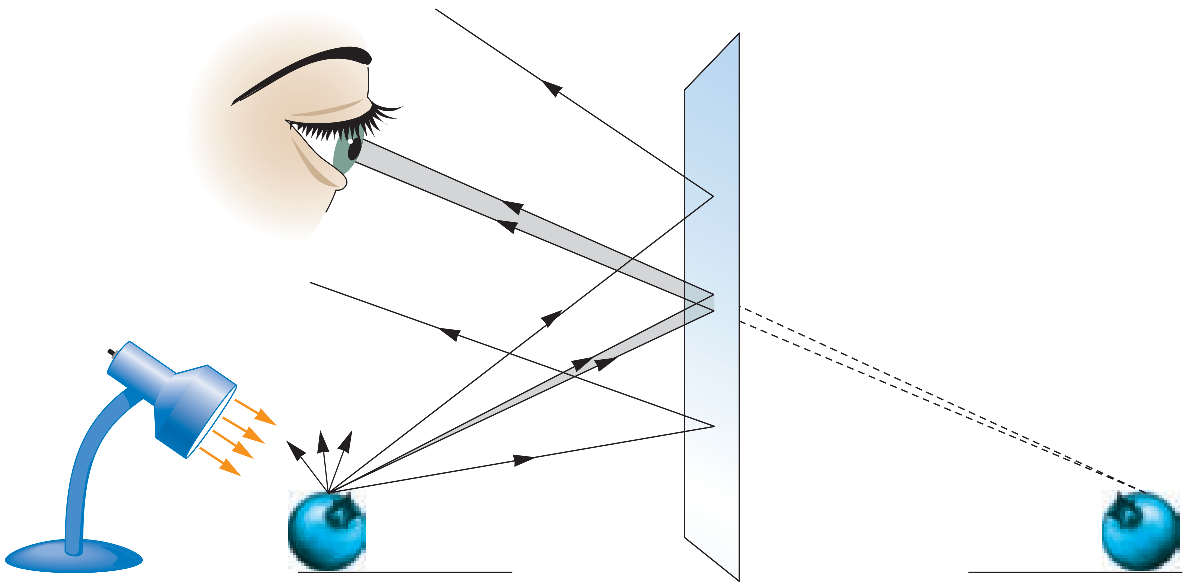


Figure 5.18 Only a small fraction of the light reflecting from an object enters the eye of the observer.

Suggested Activitiy

Investigation 5-2C on page 196

Predicting Image Characteristics

We can use mirrors for many applications if we know certain things about the images they produce. In fact, we can predict certain characteristics of an image by asking four questions:
How does the image size compare to the object size?
How does the image distance compare to the object distance?
Is the image **upright** (right-side-up) or **inverted** (upside-down)?
Is the image virtual?

If you measure the length of an object and its image in a plane mirror, you will find that they are the same size. Next, measure the distance from the object to the mirror. This is called the **object distance**. Then, measure the distance from the image to the mirror. (You can do this by placing a ruler between the object and the mirror.) This is called the **image distance**. You will find that an image in a plane mirror is the same distance from the mirror as is the object. Next, note that an image in a plane mirror is the same orientation as the object. If the object is upright, the image is also upright. Finally, note that the image is behind the mirror. No light rays actually meet at the image, so the image must be virtual.

The following points summarize the characteristics of images in plane mirrors:

- Image size is equal to object size.
- Image distance is equal to object distance.
- The image is upright. (Its orientation is the same as that of the object.)
- The image is virtual.

You will notice another interesting feature of images in plane mirrors if you raise your left hand in front of a mirror. In the image, your right hand appears to be raised. All images in a mirror are reversed, right to left and left to right, compared to the objects being reflected (Figure 5.19).

Figure 5.19 When you look at writing in a mirror, it is extremely difficult to read because it looks like it is written backwards.

Did You Know?

You can summarize the features of an image by remembering the word SPOT:
Size
Position (distance from the mirror)
Orientation (upright or inverted)
Type (virtual?)
For any type of mirror, the image SPOT will tell you the key characteristics of the image produced.

Using Plane Mirrors

When you think of plane mirrors, you probably think first of a bathroom mirror which you might often use to comb your hair. Figure 5.20 shows many different uses for plane mirrors.

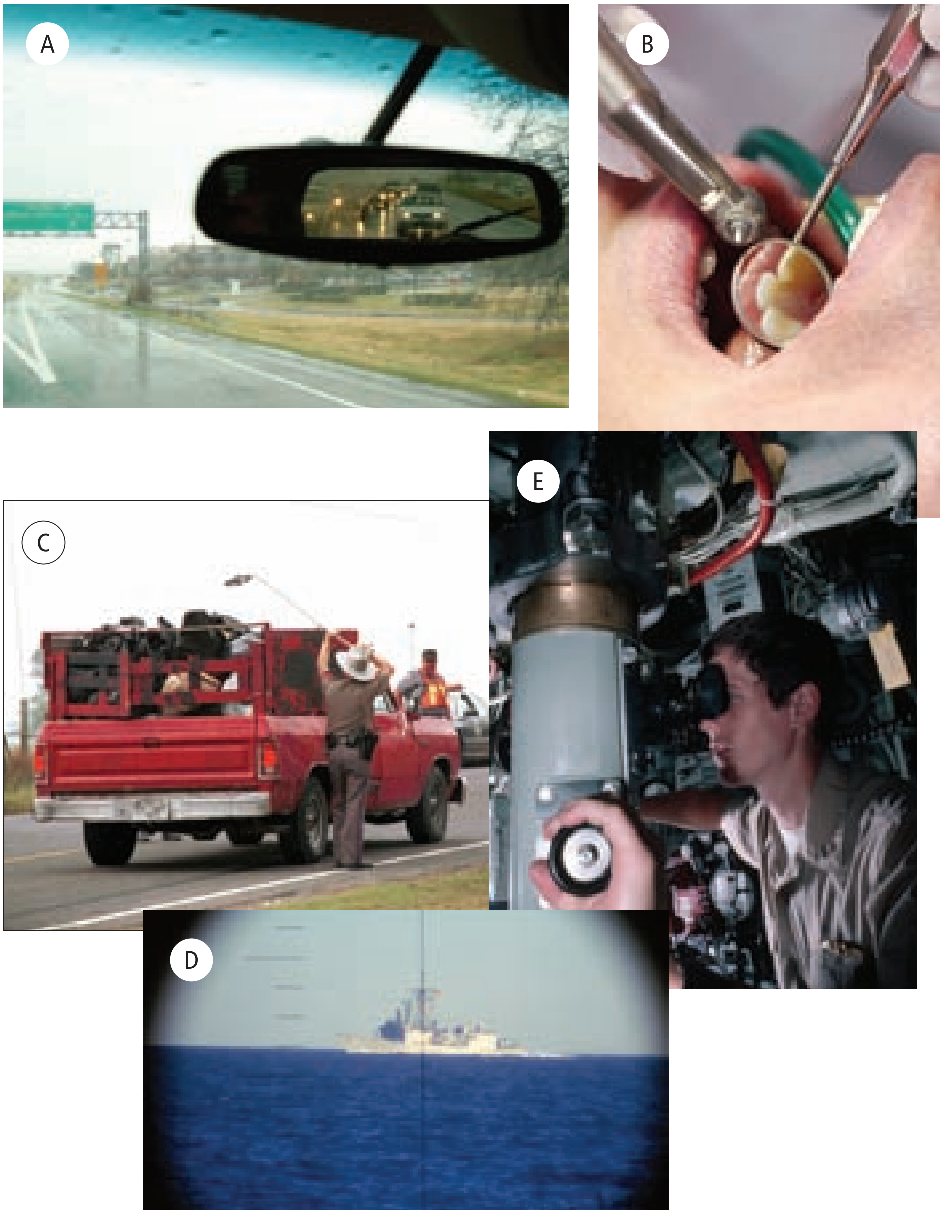


Figure 5.20 Some mirrors are just for convenience. However, many mirrors have a very important function. (A) A driver needs a rear view mirror to see what is behind the car without turning all the way around. (B) The dentist needs a dental mirror to see the inside of your teeth in order to find cavities or other problems. (C) Truck inspectors need a vehicle inspection mirror to see if anything that doesn't belong on the truck is on it. (D) Submarine captains need a small tube containing mirrors, called a periscope, to see if there are any ships nearby. (E) The sailor inside the submarine can see the reflected image of a nearby ship in the periscope, but people in the ship cannot see the submarine.

Reading Check

1. Why does your brain see an image behind a plane mirror?
2. What is a virtual image?
3. How would you describe an image in a plane mirror?

5-2B Demonstrating the Law of Reflection *Core Lab*

SkillCheck

- Observing
- Measuring
- Classifying
- Evaluating Information

Safety

- The edges of the mirror may be sharp. Be careful not to cut yourself.

Materials

- ray box
- small plane mirror (about 5 cm by 15 cm) with support stand
- small object with a pointed end such as a short pencil or a nail (the object should be shorter than the mirror)
- protractor
- ruler
- pencil
- sheet of blank paper (letter size)

When you look in a mirror, light reflects off your face in all directions. Some of this light reflects off the mirror into your eyes. This light must follow a consistent pattern because you always see the same image of your face in a mirror.

In this activity, you will be guided through the process of making a ray diagram. When your diagram is complete, you will analyze the relationship between incident and reflected rays. You will use these data to demonstrate the law of reflection..

Question

How does light behave when it reflects off a flat surface?

Hypothesis

What is the relationship between the angle of incidence and the angle of reflection? Make a hypothesis and test it.

Procedure

1. Near the middle of the blank sheet of paper, draw a straight line to represent the reflecting surface of the plane mirror. (This is usually the back surface of the mirror because the front surface is a sheet of protective glass.) Label the line "plane mirror."

2. Lay the small object on the paper. Place it about 5–10 cm in front of the line representing the plane mirror. Trace the shape of the object. Label the pointed end "P" and the blunt end "O."
3. Remove the object. Draw two different straight lines from point P to the line labelled "plane mirror." On each line, draw an arrowhead pointing toward the mirror. These lines represent the paths of two incident light rays that travel from the object to the mirror.

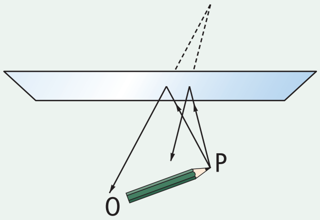
4. Carefully place the mirror in its stand on the sheet of paper. Make sure the mirror's reflecting surface is exactly along the line you drew in step 1.

Inquiry Focus

5. Use the ray box to shine a thin beam of light along one of the incident rays that you drew from point P. Mark the reflected ray with a series of dots along the path of the reflected light.
6. Remove the mirror and the ray box. Locate the reflected ray by drawing a line through the dots and ending at the mirror. On this line draw an arrowhead pointing away from the mirror to indicate that this is a reflected ray.
7. At the point where the incident ray and its corresponding reflected ray meet the mirror, draw a line at 90° to the mirror. Label this line the "normal."
8. Measure and record the angle of incidence (the angle between the normal and the incident ray).
9. Measure and record the angle of reflection (the angle between the normal and the reflected ray).
10. Repeat steps 4 to 9 for the second incident ray from point P.
11. If time permits, repeat steps 3 to 9 for point O.
12. Place the mirror and the object back on the sheet of paper. Observe the image of the object and the reflected rays that you drew. From what point do the reflected rays seem to come?

Analyze

1. You drew two rays from point P to the mirror. If you had enough time, how many rays could you have drawn between point P and the mirror? (You do not need to draw them all, just think about them and answer the question.)
2. How does the angle of reflection compare to the angle of incidence?
3. Extend each reflected ray behind the mirror, using a dotted line. Label the point where these two dotted lines meet as P. This is the location of the image of point P. Measure the perpendicular distance between:
   (a) point P (the object) and the mirror
   (b) point P (the image) and the mirror
   How do these distances compare?



Conclude and Apply

1. From your data, describe the pattern relating the angle of incidence and the angle of reflection. Does this pattern agree with your hypothesis? Explain.
2. You were able to draw the incident ray, the reflected ray, and the normal all on the surface of a flat piece of paper. What name is given to a flat surface? Make up a statement that describes this relationship mathematically.
3. Based on your measurements, how does the distance from the image to the mirror compare with the distance from the object to the mirror?

Core Lab

5-2C Applying the Law of Reflection

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

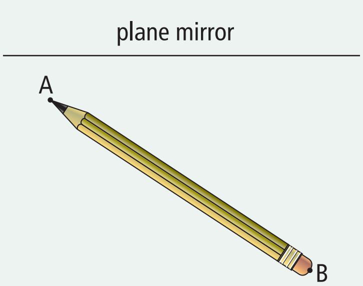
- Predicting
- Observing
- Analyzing
- Communicating

Safety

- The edges of the mirror might be sharp. Be careful not to cut yourself.

Materials

- ray box
- small plane mirror with support stand
- protractor
- ruler
- pencil
- sheet of blank paper



In this investigation, you will use a ray diagram and the law of reflection to make predictions about an image, and then test your predictions with a ray box.

Question

How accurately will you be able to predict the position of the image by using a ray diagram?

Procedure

1. Near the centre of a blank piece of paper, draw a straight line to represent the surface of a plane mirror.
2. About 10 cm from the line, place an object such as a small pencil. Label one end of the pencil A and label the other end B as shown in the diagram. Trace the object.
3. Remove the object. Make a ray diagram and draw an image by extending the reflected rays behind the mirror until they meet.
4. Place the plane mirror in its stand on the sheet of paper. Be sure that the reflecting surface is exactly on the line for the mirror.
5. With the ray box, shine a thin beam of light along each of the incident rays. Compare the reflected ray produced by using the ray box and mirror with the predicted reflected ray if actual reflected ray was not close to your predicted reflected ray, sketch the location of the actual reflected ray.
6. Replace the object on the paper in its outline. Examine the image in the mirror and compare it to the image that you drew. Does your drawing seem to agree with the image in the mirror?

Analyze

1. How many of the rays that you drew were close to the actual reflected rays that you saw when using the ray box?
2. How well do you think the image that you drew corresponded to the image that you saw in the mirror?

Conclude and Apply

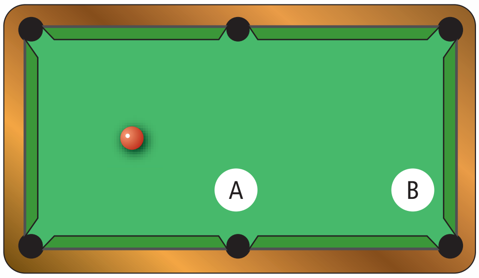
3. Provide an explanation for why predicted reflected light rays may NOT be close to the actual reflected rays.
4. What could you do differently to draw a ray diagram more accurately?

Checking Concepts

1. When you view an object in a plane mirror, light rays carry an image to your eye.
   a) Where do the light rays appear to be coming from?
   b) Where are the light rays actually coming from?
2. Draw a ray diagram of an object in a plane mirror and use the law of reflection to predict the image. Draw and label the normal. Measure and label the angles of incidence and reflection.
3. How is the image produced by a plane mirror different from the object it reflects?
4. List the relationships between an object and its image as seen in a plane mirror.
5. Give at least three examples of uses for plane mirrors.

Understanding Key Ideas

6. The following diagram represents a pool table with a billiard ball sitting on it. When a billiard ball hits the side of the table, it bounces off according to the law of reflection. Copy the drawing on a piece of paper. Sketch the path that the ball would have to take in order to bounce off the opposite side of the table and then land in pocket A. Sketch the path that the ball would have to take in order to bounce off the opposite side of the table and then land in pocket B. Hint: If the side of the table where the ball hits is like a mirror, where is the image of the pocket you want the ball to go in? Why might you aim at that image?



7. If you can see another person's face in a mirror, what must that person see in the same mirror? Explain.

Pause and Reflect

If you look at the front of an ambulance, you will see that the word "AMBULANCE" is written backwards as shown in the photograph. Why do you think that the word is written this way?

5.3 Images in Curved Mirrors

A concave mirror has a reflective surface that curves inward. Images in concave mirrors can be real or virtual, upright or inverted, and larger or smaller than the object, depending on the location of the object relative to the focal point of the mirror. A convex mirror has a reflective surface that curves outward. Images in convex mirrors are virtual, upright, and smaller than the object. You can use ray diagrams to predict the characteristics of the image in a concave or convex mirror.

Key Terms

concave mirror
convex mirror
focal point
principal axis
real image
vertex

Figure 5.21 Did you realize that the reflective surface of this mirror is curved? The centre of the mirror comes out further than the edges. This type of mirror is often used for outside rear view mirrors on the passenger side of vehicles. If you run your fingers across the mirror, you will notice that the surface feels flat. Why might this be?

In Section 5.21, you learned that, in plane mirrors, the distance from the mirror to the image is equal to the distance from the mirror to the object. The warning that appears on the mirror in Figure 5.21 suggests that this is not true for curved mirrors. How does a curved mirror change the image? How can you predict the properties of images in mirrors such as this one? In this section, you will learn how to describe and predict the formation of images in curved mirrors.

5-3A Reflection from a Spoon

Find Out ACTIVITY

You can learn a lot about curved mirrors by using a simple kitchen spoon.

Materials

- kitchen spoon with two shiny, reflective surfaces

What to Do

1. Hold the inside of the spoon up in front of your face. Look at the image of your face.
2. Bring the spoon as close to your face as you can and still see your image. Describe the characteristics of your image in the spoon.
3. Slowly move the spoon away from your face and observe any changes in your image as the spoon gets farther away. If you can still see your image when the spoon is at arms length, have someone else hold the spoon and move it farther away. Describe any changes in the image of your face.
4. Turn the spoon around and look at the bottom of the spoon. Examine the image of your face in the spoon.
5. Move the spoon from close to your face to far away and observe any changes in the image of your face that you see in the spoon. Describe the changes that you observe.

What Did You Find Out?

1. How does the image of your face in the inside of the spoon differ from your image in a plane mirror?
2. How does the image of your face in the bottom of the spoon differ from your image in a plane mirror?

Concave Mirrors

Have you ever looked at yourself in a shaving mirror or a makeup mirror? If you held the mirror close to your face, you probably noticed that the image of your face was very large. If you looked at the mirror from a distance, though, you would have seen that the image of your face looked very small—and upside-down! How could one mirror produce such different images?

Shaving and makeup mirrors are examples of **concave mirrors**. Concave mirrors have a reflecting surface that curves inward like the inside of a bowl or sphere. The curved surface of the mirror reflects light in a unique way, creating an image that differs from the object being reflected (Figure 5.22).

Figure 5.22 A concave mirror produces an image that has different characteristics from the object it reflects.

Explore More

Use a ray box to determine the focal points of several different concave mirrors.

Focal Point of a Concave Mirror

Like plane mirrors, curved mirrors reflect light according to the law of reflection. Because concave mirrors are curved inward, however, they reflect light rays in a special way: reflected light rays travel toward each other, or converge.

To see this effect, first draw a line normal to the centre of the mirror. This line is called the **principal axis**. The principal axis meets the mirror at a point called the **vertex** (V). If you then draw rays of light approaching the mirror parallel to the principal axis, you will see that all of the reflected rays intersect at one point (Figure 5.23). This is called the **focal point** (F) of the mirror.

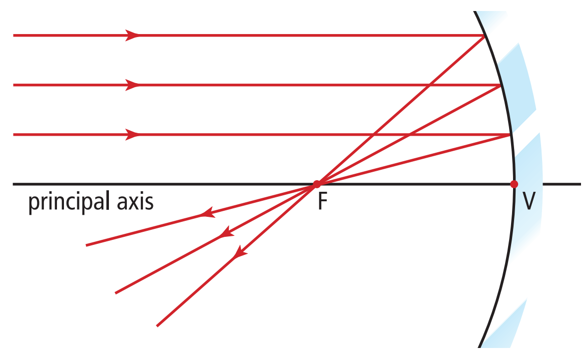


Figure 5.23 The principal axis is normal to the centre of the concave mirror. Rays that are parallel to this axis will all reflect through the focal point.

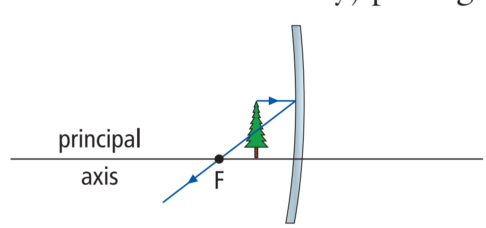
Ray Diagrams for Concave Mirrors

You used ray diagrams to predict the images created by plane mirrors. In the same way, drawing a ray diagram will allow you to predict the features of the image produced by a concave mirror. The ray diagram shows you where the top of the image and the bottom of the image will be. While many rays travel from the object to the mirror, these two points tell you everything you need to know about the image: its size, position, orientation, and type.

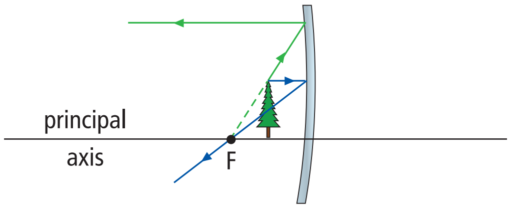
Finding the position of the bottom of the image is easy if you place the object on the principal axis, which is normal to the mirror. A light ray travelling from the bottom of the object to the mirror will reflect directly backward, so the bottom of the image will also sit on the principal axis.

To find the location of the top of the image, you need to draw three rays from the top of the object:

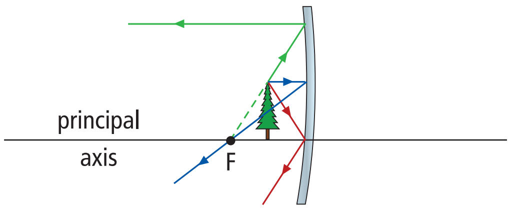
1. Draw a ray parallel to the principal axis, with the reflected ray (or an extension of the reflected ray) passing through the focal point.



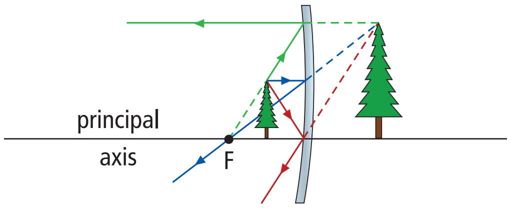
2. Draw a ray or an extended ray through the focal point, with the reflected ray parallel to the principal axis. (If the object lies between the focal point and the mirror, you will have to extend the ray backward to the focal point.)



3. Draw a ray travelling to the vertex and reflecting at the same angle.



(Remember that for all of these rays, the law of reflection will be true.)
The top of the image is located at the point where these three rays meet. If the object is between the focal point and the mirror, you will need to extend the rays behind the mirror to find where they meet to form an image.



Predicting Image Characteristics Using Ray Diagrams

How is it possible for a concave mirror to create different images depending on the distance of your face from the mirror (Figure 5.24)? If you draw ray diagrams for objects in different positions, you will see that the characteristics of an image in a concave mirror depend on the distance between the mirror and the object being reflected.

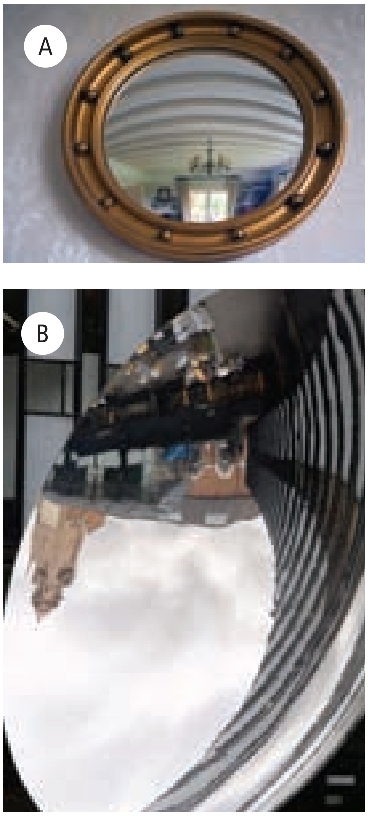


Figure 5.24 Both of these mirrors are concave mirrors. Why is one image upside down and the other right side up?

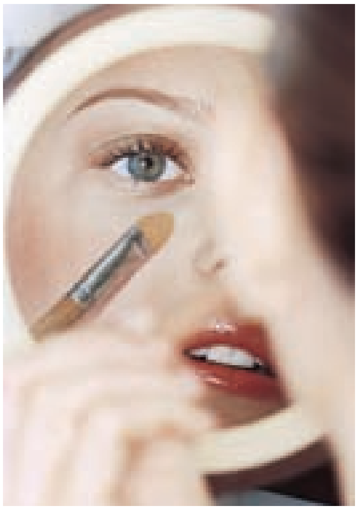


Figure 5.25 When the object is located between the focal point and the concave mirror, the image is larger than the object. Therefore, concave mirrors are often used as magnifying makeup mirrors.

Object Between the Focal Point and the Mirror

Recall that if you hold a makeup mirror very close to your face, your image will appear very large (Figure 5.25). By drawing the three rays from the top of the object, you can predict the image. Look at the ray diagram in Figure 5.26 to see how this image is produced.

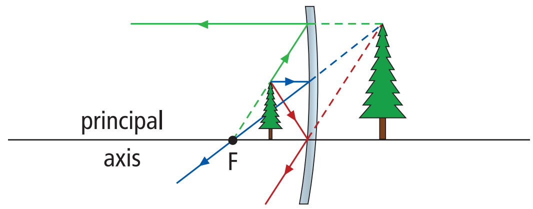


Figure 5.26 Ray diagram for an object between F and V

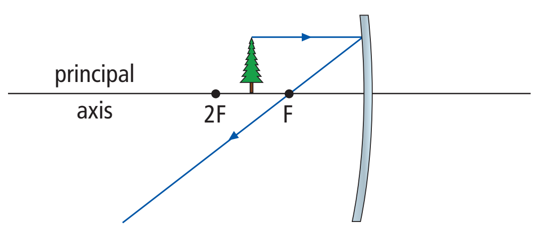
For a concave mirror, when an object is between the focal point and the mirror, the image has the following characteristics:

- The image is larger than the object.
- The image distance is larger than the object distance.
- The image is upright.
- The image is virtual.

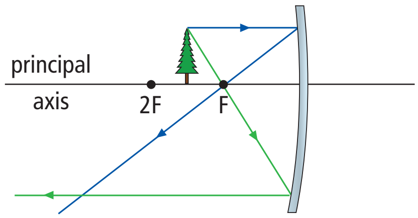
Object Between the Focal Point and Two Times the Focal Point

As you move a makeup mirror away from your face, your image will become inverted. Draw the three rays from the top of the object to find out why:

1. Draw a ray parallel to the principal axis, with the reflected ray passing through the focal point.



2. Draw a ray through the focal point, with the reflected ray parallel to the principal axis.



3. Draw a ray travelling to the vertex, where the principal axis meets the mirror.

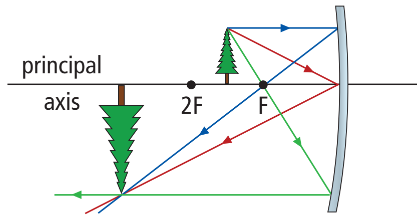


Figure 5.27 Ray diagram for an object between F and 2F

For a concave mirror, when an object is between the focal point and a distance twice that of the focal point, the image has the following characteristics:

- The image is larger than the object.
- The image distance is larger than the object distance.
- The image is inverted.
- The image is real.

Did You Know?

Notice the similarities in the three rays used to determine an image in Figures 5.26 and 5.27. You will apply the three-ray technique to determine images throughout this unit.

Real Images

What is a real image? A **real image** is formed when reflected rays (NOT extended rays) meet. Recall that the virtual images you saw were behind the mirror. A real image is located in front of the mirror. You will notice that what you see in the mirror is somewhat distorted. You need a screen to view a real image. If you held a screen at the position of the real image, you would see a clear, identifiable image on the screen. This is not true for a virtual image.

Object beyond Two Times the Focal Point

What happens as you move a makeup mirror farther from your face? By drawing the three rays from the top of the object, you can predict the image. Look at the ray diagram in Figure 5.28 to see how this image is produced.

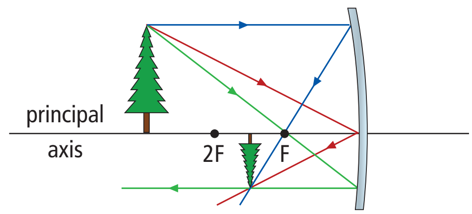


Figure 5.28 Ray diagram for an object beyond 2F

For a concave mirror, when an object is beyond a distance twice that of the focal point, the image has the following characteristics:

- The image is smaller than the object.
- The image distance is smaller than the object distance.
- The image is inverted.
- The image is real.

Now you know how the same mirror can form either an upright image or an inverted image, and an image that is either larger or smaller than the object being reflected. You know how to predict the image, no matter where the object is. It is this important skill that allows people to put concave mirrors to use in a variety of ways.

internet connect

There are many simulations on the internet that show you mirrors, objects, ray diagrams, and images. Go to the website below and follow the directions to see where to go next.
www.discoveringscience8.ca

Reading Check

1. Describe how your approach to drawing the three rays from the top of an object differs depending on where the object is located.
2. What is the difference between a virtual image and a real image?
3. Make a table outlining the image SPOT features for an object between F and V, between F and 2F, and beyond 2F.
4. Use the three rays to draw a ray diagram for an object located at a distance exactly two times the focal point. Describe the characteristics of the image.

Suggested Activity

Conduct an Investigation 5-3B on page 207.

Using Concave Mirrors

Concave mirrors have many uses. If a bright light is placed at the focal point, then all of its light rays that bounce off the mirror are reflected parallel to each other (Figure 5.29A). This makes an intense beam of light. Spotlights, flashlights, overhead projectors, car headlights, and lighthouses use this kind of mirror (Figure 5.29B). The largest telescopes all use concave mirrors to collect light because the mirror concentrates the light so effectively.

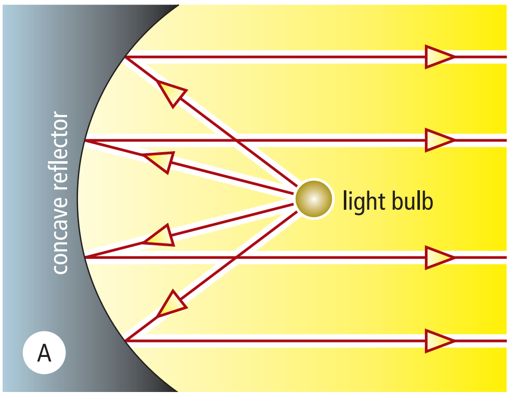


Figure 5.29 (A) A concave reflector collects the light coming from the bulb and directs it forward as parallel rays or headlight. This provides a bright beam of light directed in front. (B) a flashlight.

Did You Know?

Sound reflects off hard surfaces according to the law of reflection. Bird watchers use this fact to capture bird sounds. They use a hard concave surface with a microphone at the focal point. All of the sound that comes from the direction in which they are aiming the reflector will be reflected toward the microphone. They record the sound on a tape recorder.

Satellite dishes that receive television signals are curved dishes that reflect the microwaves coming from satellites. The parallel beams of microwaves coming from the satellite are reflected to a detector that is located at the focal point of the dish (see Figure 5.30). The signal is brought to the receiver inside the house by a cable. The receiver converts the microwave signals into television pictures and sound.

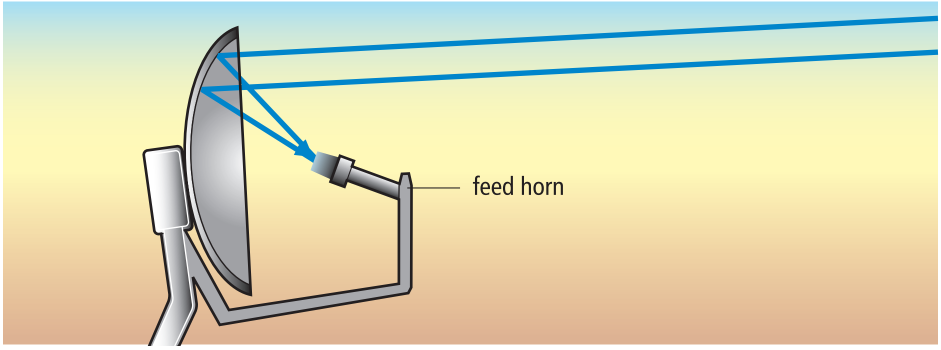


Figure 5.30 Microwave signals from a satellite orbiting Earth arrive at a satellite dish as parallel rays. The dish is curved to reflect all of the signals to the microwave detector that is located at the focal point of the curved dish.

Figure 5.31 Why do the images in this mirror look distorted?

Convex Mirrors

You have probably seen mirrors like the one in Figure 5.31 in convenience stores. A store employee can see nearly everything in the store in the mirror. The images in the mirror, however, are quite distorted due to the shape of the mirror. Can you see how the centre of the mirror sticks out? A mirror that is curved outward, like the outside of a bowl or sphere, is called a **convex mirror**.

Focal Point of a Convex Mirror

The curved surface of a convex mirror causes light rays to travel away from each other, or diverge.

To see this effect, first draw the principal axis for the mirror. Just as with concave mirrors, the principal axis is normal to the centre of the mirror. If you then draw rays of light approaching the mirror parallel to the principal axis, you will see that all of the rays are reflected away from each other (Figure 5.32). They will never meet. However, if you extend the rays behind the mirror, the extended rays will intersect at the focal point, F. The focal point for a convex mirror is behind the mirror.

Explore More

Use a ray box to determine the focal points of several convex mirrors.

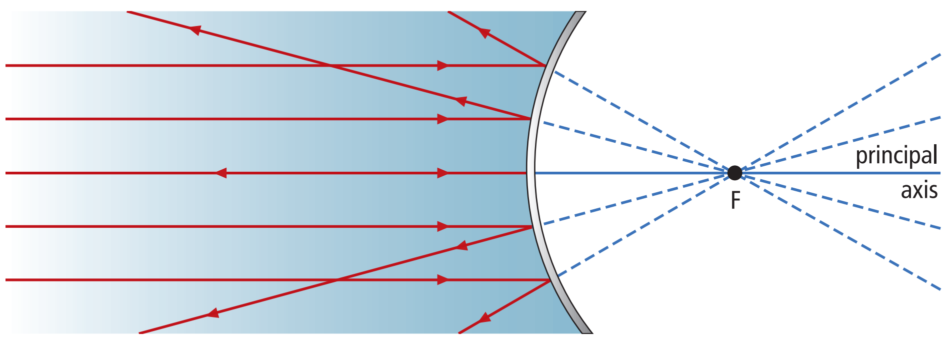
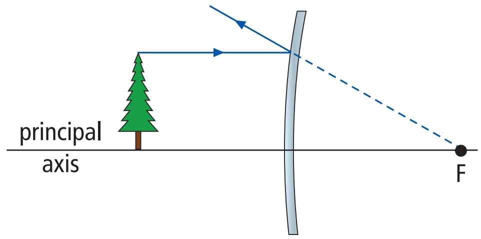


Figure 5.32 The focal point for a convex mirror is always behind the mirror. Nevertheless, you can use it to draw ray diagrams.

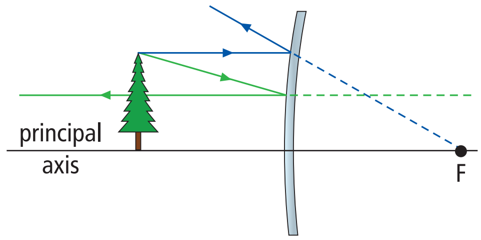
Ray Diagrams for Convex Mirrors

Drawing ray diagrams for convex mirrors is very similar to drawing ray diagrams for concave mirrors. By placing the bottom of the object on the principal axis, you know that the bottom of the image will also lie on the principal axis. If you draw three rays from the top of the object, you will be able to predict the image. Remember that all rays will obey the law of reflection. The three rays are the same as the ones you drew in ray diagrams for concave mirrors:

1. Draw a ray parallel to the principal axis, reflecting such that its extension will pass through the focal point.



2. Draw a ray that is extended through the focal point, with the reflected ray parallel to the principal axis.



3. Draw a ray travelling to the vertex and reflecting at the same angle. Extend the reflected ray to intersect the first two rays.

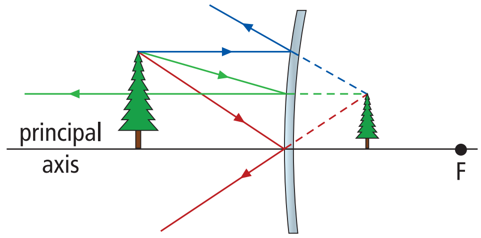


Figure 5.33 Ray diagram for an object in a convex mirror

The three extended rays intersect at the top of the image.

Predicting the Image Characteristics in a Convex Mirror

Drawing a ray diagram allowed you to predict the image of an object in a convex mirror. The diagram also allows you to see the features of the image.

For a convex mirror, the image has the following characteristics:

- The image is smaller than the object.
- The image distance is smaller than the object distance.
- The image is upright.
- The image is virtual.

Using Convex Mirrors

Convex mirrors are very useful because they produce an image that is smaller than the object being reflected. Why is this characteristic important? More objects can be seen in a convex mirror than in a plane mirror of the same size. Convex security mirrors make it possible to monitor a large area from a single location. Convex mirrors can also widen the view of traffic that can be seen in rear-view or side-view mirrors in automobiles, large trucks, and school buses (Figure 5.34A). They are often placed at sharp corners in buildings, or even on roads, to allow people to see hazards that would normally be out of view around the corner.

Some streetlights use convex reflector mirrors for a different reason: they reflect light rays away from each other. This casts light out over a large area. A disco ball also makes use of this property (Figure 5.34B).

Figure 5.34 Convex mirrors allow drivers to view a large area around their vehicles (A). They also cast light out in many directions (B).

Reading Check

1. How does the focal point of a convex mirror differ from that of a concave mirror?
2. If the rays of light that reflect from a convex mirror never meet, how can you use the three rays in a ray diagram to find the image?
3. Do the characteristics of an image in a convex mirror depend on the distance of the object from the mirror? Draw two ray diagrams to illustrate this.

5-3B Real and Virtual Images

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck
- Observing
- Analyzing
- Measuring
- Drawing

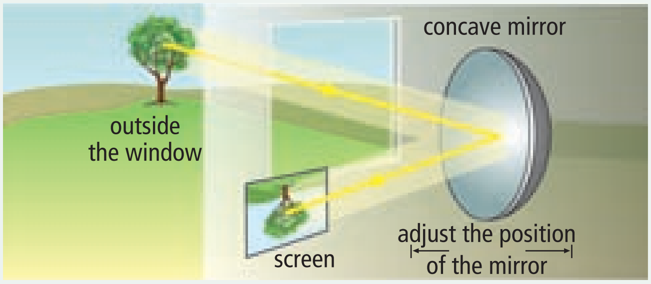
Safety
- The edges of the mirror might be sharp. Be careful not to cut yourself.
- Be careful not to drop any mirrors.

Materials
- 3 concave mirrors with different curvatures
- 1 flat mirror
- 1 convex mirror
- white cardboard for screen
- room with a window

Some mirrors can reflect light so that it forms an image on a screen. Other types of mirrors cannot. In this investigation, you will test several mirrors to demonstrate which can and which cannot form images on a screen.

Question
What type of mirror can create an image on a screen?

Procedure
1. Stand several metres from a window. Hold any concave mirror in your hand so that faces the window.
2. A partner will stand about a metre in front of and facing you. Your partner will hold the white cardboard facing you and your mirror.
3. Move the mirror until it reflects the light from the window onto the screen as shown in the diagram. Move the mirror closer to or farther from the screen to focus an object outside the window on the screen.



4. Observe and record what you see on the screen. Include the size and orientation of the image on the screen. Also include whether the mirror has the greatest, least, or in-between curvature compared to the other two mirrors.
5. Repeat steps 1 through 4 with the other two concave mirrors.
6. Try to repeat the experiment with the flat mirror and the convex mirror.

Analyze
1. Which mirrors could project an image onto the screen?
2. Compare the size of the images on the screen with the curvature of the mirrors that formed the images.

Conclude and Apply
3. Which mirrors formed real images? Which mirrors formed virtual images? Explain how your observations led you to your answers.
4. Which of the concave mirrors produced the largest image? Did that mirror have the greatest or the smallest curvature?
5. Sketch ray diagrams that can explain why the different curvatures of the concave mirrors created images of different sizes.

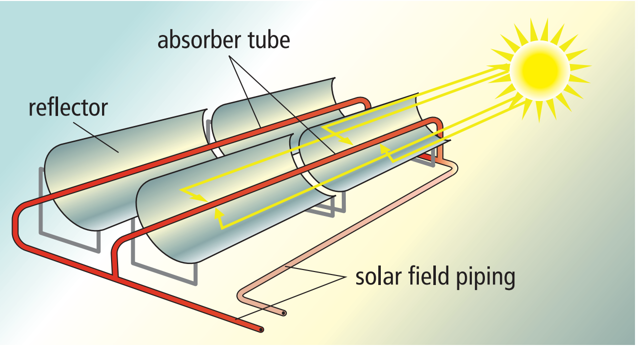
Science Watch

Curved Surfaces Collect Solar Energy

The Sun transmits tremendous amounts of radiant energy to Earth every day. If humans could trap just a small fraction of the Sun's radiant energy, all energy needs could be met. As well, very few environmental problems would result from the use of solar energy. However, the Sun's energy is spread out over such large areas that it is difficult to trap large amounts of this energy. Engineers have designed a few systems using curved reflecting surfaces to focus large amounts of radiant energy onto a small area.

One of the first examples of using curved surfaces to focus radiant energy from the Sun is shown below. This "solar furnace" was built in Odeillo Font-Romeux, France. Sixty-three flat mirrors reflect sunlight onto the large curved mirror which then focusses the light on to a small container in the tower. The material in the container could reach temperatures as high as 3000°C. The heat could be used to generate electrical energy or for manufacturing purposes.

Another method for collecting solar radiation involves using curved trays or troughs. The troughs rotate so they are facing the Sun all day long to collect as much energy as possible. Long pipes are built along the focal lines. Oil runs through these pipes as all of the Sun's rays are reflected toward them. The oil becomes hot enough to be used to boil water. The steam is then used to run generators that produce electrical energy. The diagram above and on the right shows you how all of the sunlight that hits the curved trays is reflected to the central pipes. The second photograph shows some workers standing beside the trays so you can see how large the trays are. The last photograph shows you how many trays have been built in one location.



Questions

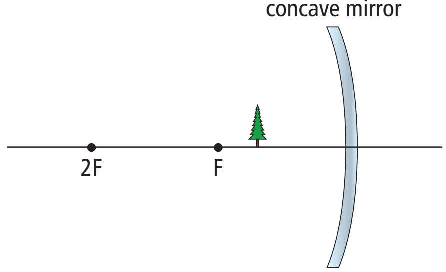
1. Explain why curved reflective surfaces are better than flat surfaces for collecting radiant solar energy.
2. Why do you think that shiny metal surfaces are used for the curved troughs instead of glass mirrors?

Check Your Understanding

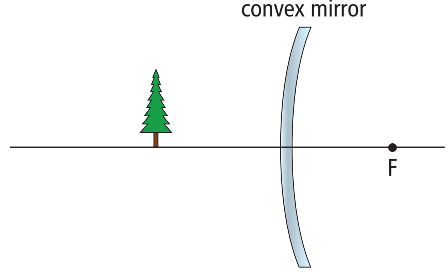
Checking Concepts

1. What are the three rays that allow you to predict an image in a curved mirror?
2. Explain how you would find the focal point of a concave mirror.
3. Sketch a diagram of a concave mirror and include the principal axis and the focal point.
4. For both of the situations below, you can use the three-ray technique to determine the image. Will the process you use to draw each of the three rays be exactly the same for (a) and (b)? If not, how will the process differ at each step?

(a)



(b)



5. Name one way in which concave mirrors are commonly used.
6. How does a convex mirror differ from a concave mirror with respect to the appearances of the mirrors?
7. Can a convex mirror form a real image? a virtual image? Use ray diagrams to support your answers.
8. Describe one common use for convex mirrors.

Understanding Key Ideas

9. Would an object placed exactly at the focal point of a concave mirror produce an image? Use a ray diagram to explain. (Hint: Can you draw the three rays from the top of the object?)
10. Draw two ray diagrams, one for an object in front of a concave mirror and one for a convex mirror. Describe the image characteristics for each drawing.
11. Why is it important to draw a principal axis and place the bottom of the object on the axis when drawing ray diagrams for concave and convex mirrors?
12. Make a sketch that shows how you would find the focal point of a convex mirror.

Pause and Reflect

Examine the passenger-side rear view mirror in Figure 5.21 on page 196. What type of mirror, flat, concave, or convex, is used in these mirrors? The warning says that the objects in the mirror are closer than they appear. Why do you think that motor vehicle manufacturers would use such a mirror considering the fact that it makes it look like objects behind the vehicle are farther away than they really are?

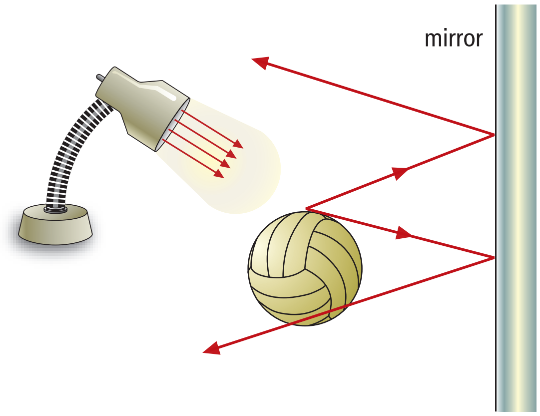
Prepare Your Own Summary

In this chapter, you learned about the law of reflection and about plane, concave, and convex mirrors. You learned how to draw ray diagrams for curved mirrors and to describe the images formed in these mirrors. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. Use the following headings to organize your notes.

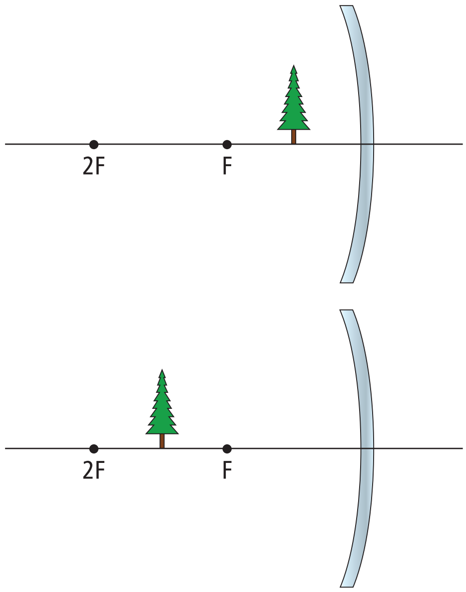
1. Law of Reflection
2. Specular and Diffuse Reflection
3. Refraction of Light
4. Plane, Concave, and Convex Mirrors
5. Ray Diagrams
6. Uses of Mirrors

Checking Concepts

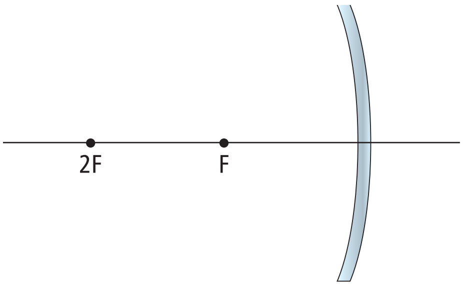
1. (a) Make a drawing of a flat reflecting surface with an incident ray, a normal, and a reflected ray.
   (b) Use your diagram to explain the law of reflection.
2. Explain the difference between specular reflection and diffuse reflection. Which type of reflection allows you to see an image of yourself in a mirror?
3. Explain how reflected light allows you to read the words on this page.
4. In the diagram above and on the right, a lamp is shining light on a volley ball. Light is reflected off all parts of the ball. Two rays that reflect from one point on the ball are shown hitting a plane mirror and reflecting from it. Sketch a similar diagram and use it to show how you would find the image of the same point on the volley ball.



5. Examine the sketch you made for question 4. Is the image real or virtual? Explain.
6. Copy the following drawings in your notebook.
   (a) Complete ray diagrams for both drawings.
   (b) Use your ray diagrams to show and explain how a concave mirror can form upright images and inverted images.
   (c) For each image, state whether it is real or virtual.



7. Why are concave mirrors often used for makeup mirrors or shaving mirrors?
8. How does the image in a shaving mirror change as you move the mirror from arm's length in toward your face?
9. Copy the diagram below into your notebook. Place an object on the principal axis in a location that will form an image that is real, inverted, and smaller than the object. Complete the ray diagram to demonstrate that the image is real, inverted, and smaller than the object. (You might have to try more than once.)



10. Explain how you would make a convex mirror from a piece of a shiny sphere.
11. (a) Draw a horizontal line and a convex mirror passing through the centre of the horizontal line.
    (b) Label the horizontal line "principal axis."
    (c) Label the vertical line "convex mirror."
    (d) Place an object on the left side of the convex mirror.
    (e) Mark the focal point on the principal axis in the correct position for a convex mirror.
    (f) Complete the ray diagram.
    (g) State whether the image is real or virtual, upright or inverted, and whether it is larger or smaller than the object.

Understanding Key Ideas

12. Explain how the law of reflection can account for both specular reflection and diffuse reflection.
13. Explain how you can use a screen to determine whether an image is real or virtual.
14. How does placing the bottom of an object on the principal axis make it easier to locate an image in a ray diagram?
15. Why is the flashlight bulb placed at the focal point of the curved reflector in a flashlight?

Pause and Reflect

Have you ever used two mirrors at angles with each other so you could see the side or back of your head like the girl in this picture? Explain the meaning of the following sentence that describes what happens with two such mirrors.

"The image of the girl in one mirror becomes the object for the second mirror."

Chapter 6

Lenses refract light to form images.

Most of you have probably heard about starting a fire with a magnifying glass like the boy in this photograph is doing. Imagine, however, that you are on a camping trip in the early spring. Someone forgot to bring matches and you have nothing to use to start a fire. You probably did not bring a magnifying glass. However, there is some clear ice at the edge of the lake. Could you start a fire with a piece of ice? You could if you understood how lenses are shaped and how to use them. If you knew how to shape the ice into a lens, you could use it to focus the Sun's rays onto some dry grass and start a fire. In this chapter, you will learn about lenses and how they focus light. You will also explore the role of lenses in human vision and optical technologies.

What You Will Learn

In this chapter, you will
- **classify** concave and convex lenses
- **explain** how refraction of light by lenses can affect images of objects
- **explain** how optical devices magnify objects
- **explain** how human vision works
- **investigate** ways to correct and enhance human vision

Why It Is Important

Nearly every day, you use something that contains a lens or lenses. You might wear corrective lenses or use a camera to take pictures. Understanding refraction and lenses will help you understand how cameras, telescopes, and microscopes work. When you understand how an instrument works, you can make better use of it.

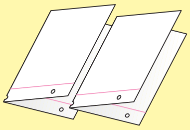
Skills You Will Use

In this chapter, you will
- **predict** the direction of refracted rays of light
- **draw** ray diagrams for concave and convex lenses
- **design** and **build** a simple telescope or microscope

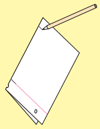
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 6.

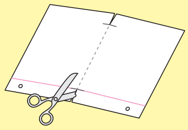
STEP 1 **Fold** two sheets of notebook paper in half along the short axis.



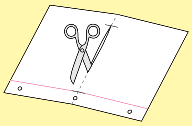
STEP 2 **Mark** both folds 2.5 cm from the outer edges. (On notebook paper, the margins are marked 2.5 cm from the outer edges.)



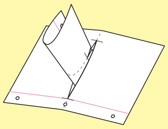
STEP 3 On one of the folded sheets, **cut** from the top and bottom edge to the marked spot on both sides.



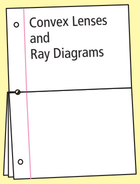
STEP 4 On the second folded sheet, start at one of the marked spots and **cut** the fold between the marks.



STEP 5 **Roll** the first sheet of paper into a long tube, place it through the large opening cut in the second sheet, and **open** the tube so that the folds of the first and second sheet align.



STEP 6 **Fold** the connected sheets in half along the original fold line to form an 8 page book. At the top of each full page, write one of the following.
Convex Lenses and Ray Diagrams
Concave Lenses and Ray Diagrams
Lenses and Human Vision
Modern Optical Technologies



Read and Write As you read this chapter, fill your journal with notes and diagrams on the appropriate page.

6.1 Concave and Convex Lenses

A lens is piece of transparent material that can bend, or refract, light rays to help form a well-focussed image. Lenses have two focal points, one on each side of the lens. Convex lenses are thicker in the middle than at the edge and they cause light rays to converge, or move toward each other. Convex lenses are often used as magnifying glasses because the image of an object that is within twice the focal length from the lens will be larger than the object. Concave lenses are thinner in the middle than at the edge and they cause light rays to spread out, or diverge. Images produced by concave lenses are always smaller than their objects.

Key Terms

concave lens
convex lens
focal length
lens
optical centre

A **lens** is a curved piece of transparent material, such as glass or plastic, that refracts light in a predictable way. Lenses come in a wide variety of sizes and shapes and are made of different types of materials. For example, in Figure 6.1, you see a camera with a very large lens and another camera with a very small lens. These lenses are made of glass. The last picture in the figure is of someone inserting a contact lens. This lens is made of a soft plastic. Regardless of the type of material or the size of the lens, they all work on the same basic principle—the refraction of light.

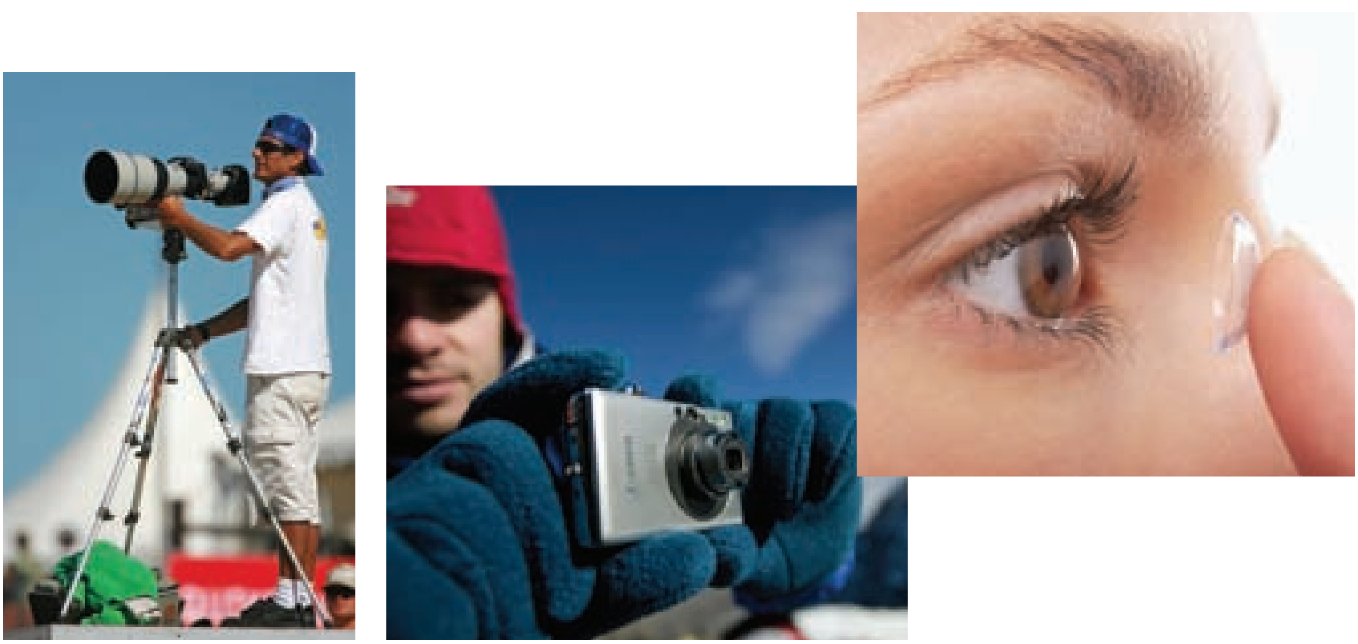


Figure 6.1 Cameras come with many sizes and types of lenses. Some lenses are for distant objects and some are for close up objects. A large lens collects more light so the photographer can take pictures without extra lighting. Contact lenses correct a person's vision.

6-1A Lenses and Light Rays

Find Out ACTIVITY

When a light ray passes through a lens, it refracts twice—once when the ray passes into the lens and once when the ray passes out of the lens. What is the overall effect of a light ray passing through a lens?

Materials

- ray box
- concave lens
- printed page
- convex lens

What to Do

1. Shine the ray box at a concave lens. Observe how the rays are affected. Make a sketch of your observations.
2. Look through the concave lens at some printed text. Observe the appearance of the print. Make a sketch of your observations.
3. Shine the ray box at a convex lens. Observe how the rays are affected. Make a sketch of your observations.
4. Look through the convex lens at some printed text. Observe the appearance of the print. Make a sketch of your observations.

What Did You Find Out?

1. Compare what you observed about the appearance of the text with each of the two lenses.
2. Which type of lens would be best used as a magnifying glass? Explain why.
3. What might the other kind of lens be used for?

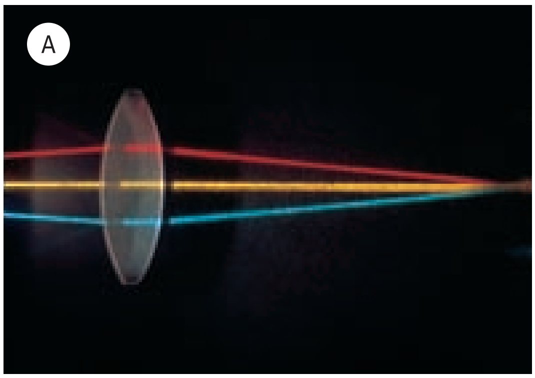
Refraction of Light Through Lenses

You know that light bends when it passes from one medium to another. What happens when a light ray passes into a medium such as glass or plastic and then passes out of that medium on the opposite side? This is what happens when you are looking at an object through a lens (Figure 6.2).

The curved surfaces on lenses are named in the same way as curved surfaces on mirrors. When the centre of the lens bulges out, it is called convex. When the centre of the lens is caved in, it is called concave.

Figure 6.2 A curved lens changes the appearance of objects on the other side.

A **convex lens** causes light rays to bend toward each other, or converge (Figure 6.3). A **concave lens** causes light rays to bend away from each other, or diverge (Figure 6.4). To understand why this happens, remember what you learned about refraction in Chapter 5. As light rays travel from a less dense medium, such as air, into a more dense medium, such as glass or plastic, they bend toward the normal. As the rays exit the other side of the lens, travelling from a more dense to a less dense medium, they bend away from the normal.



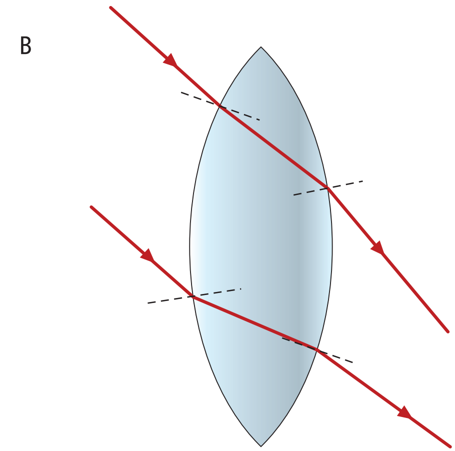
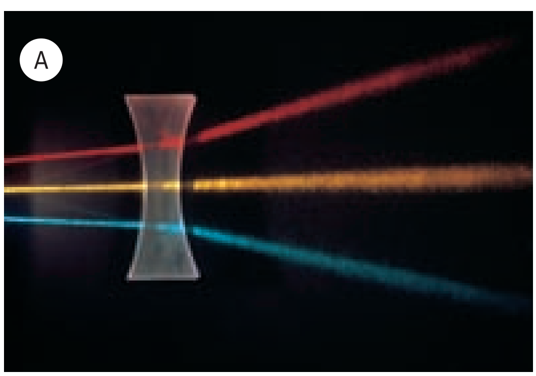


Figure 6.3 (A) Light rays converge when they pass through a convex lens. (B) Rays bend toward the normal (shown by dotted lines) as they enter the lens, and away from the normal as they exit the lens.



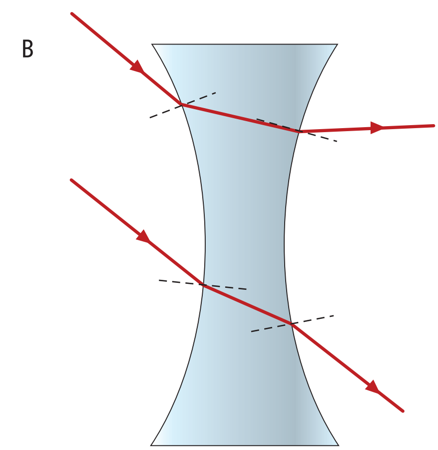


Figure 6.4 (A) Light rays diverge when they pass through a concave lens. (B) Rays bend toward the normal (shown by dotted lines) as they enter the lens, and away from the normal as they exit the lens.

Reading Check

1. Sketch a convex lens and a concave lens.
2. Explain why two parallel rays bend at different angles when they pass from air into a concave lens.
3. What type of lens can make parallel rays spread apart?

Convex Lenses

If you completed Find Out Activity 6-1A, you probably discovered that convex lenses can act as magnifying lenses. They are often found in magnifying glasses such as the one in Figure 6.5. You will be able to demonstrate how convex lenses can magnify an object when you learn to draw ray diagrams for convex lenses.

Many of the terms that you learned while studying mirrors are also applied to lenses. Convex lenses have a focal point where light rays meet after passing through the lens. The **focal length** of the lens is the distance from the centre of the lens to the focal point (Figure 6.6).

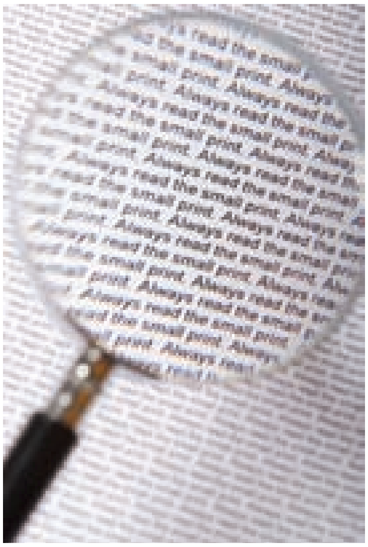


Figure 6.5 The lenses in magnifying glasses are convex lenses.

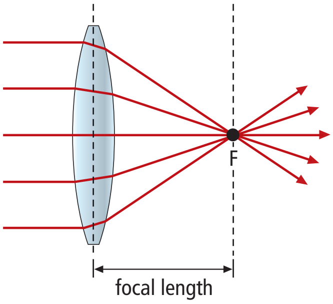


Figure 6.6 The focal point (F) of a convex lens is the point at which parallel rays meet after passing through the lens. The distance between the centre of the lens and the focal point is called the focal length.

Each lens has its own focal length, which is determined by the curvature of the lens. As shown in Figure 6.6, lenses with greater curvature have shorter focal lengths. Recall from Chapter 4 that, centuries ago, Anton van Leeuwenhoek experimented with lens curvature. What did he discover about the relationship between lens curvature and magnifying power?

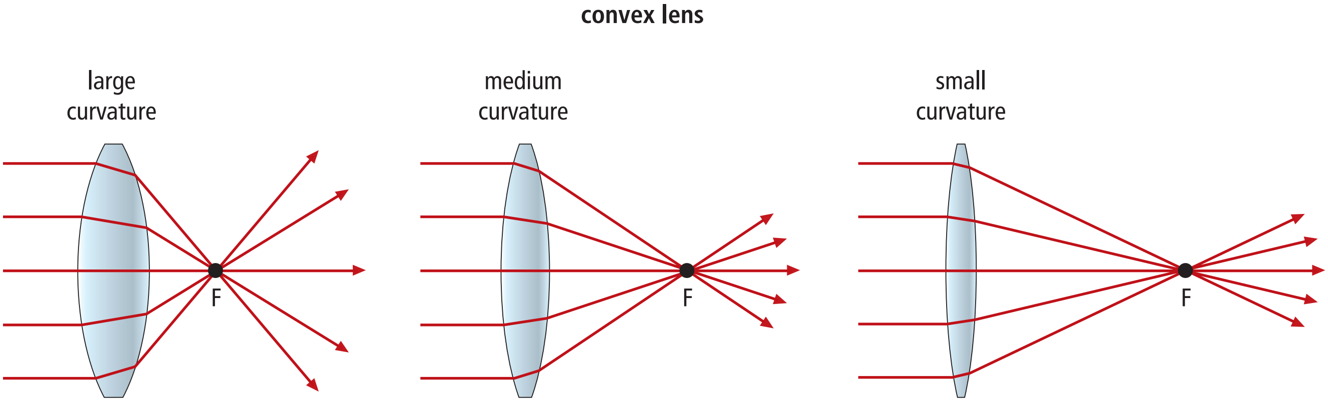


Figure 6.7 The amount of curvature on a convex lens determines how much the lens bends the light passing through it. This also determines the focal length of the lens.

Unlike mirrors, you can shine light on either side of a lens. As a result, a lens has a focal point on both sides. When you draw ray diagrams for lenses, you will put a focal point on each side of the lens as shown in Figure 6.8. Note that the line through the centre of the lens is called the principal axis. The point where the principal axis intersects the centre of the lens is known as the **optical centre** (O).

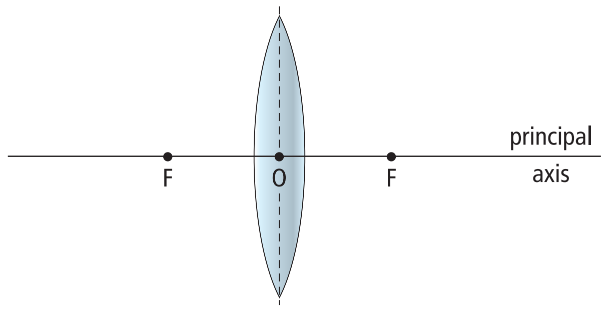


Figure 6.8 All lenses have two focal points—one on each side of the lens. They are always the same distance from the lens.

6-1B The Focal Length of a Convex Lens

Find Out ACTIVITY

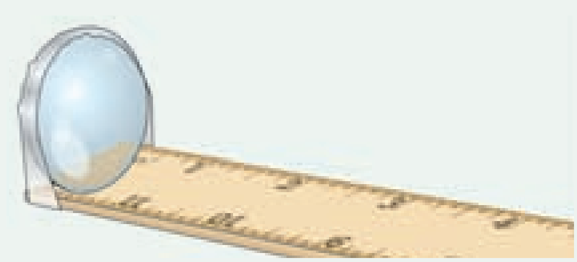
You can use the Sun to find the focal length of a convex lens.

Materials

- convex lens
- ruler
- masking tape
- stiff white paper

What to Do

1. Tape the lens near the end of a ruler as shown.



2. Go to a window where there is direct sunlight. Hold the lens and ruler up so the sunlight is coming directly through the lens. **Caution: Do not look directly at the Sun through the lens.**
3. Hold the piece of stiff white paper behind the lens and move it back and forth along the ruler until you get the smallest possible point of sunlight on the paper.
4. Observe and record the distance between the lens and the paper.

What Did You Find Out?

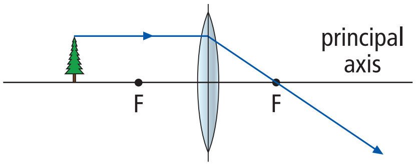
1. What was the distance between the lens and paper when the spot of sunlight was as small as possible?
2. How do you know that the distance that you measured is the focal length of the lens?
3. If you turned the lens around, would your results be the same or different? Why?

Drawing Ray Diagrams for Convex Lenses

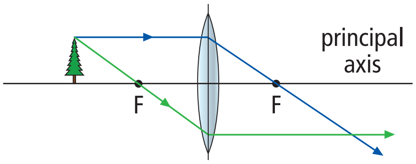
You might think that, when drawing a ray diagram for lenses, you would have to draw refracted rays for each surface of the lens. However, this is not necessary. If you examine the incident and final refracted rays, the process can be simplified. You draw diagrams for lenses as though rays refract only at the centre of the lens rather than at both surfaces.

To draw ray diagrams for lenses, you follow the same basic steps that you followed for curved mirrors. If you place the bottom of the object on the principal axis, the bottom of the image will sit on the principal axis. Drawing three rays from the top of the object will allow you to predict the location of the top of the image:

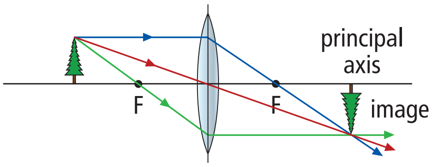
1. Draw a ray parallel to the principal axis. It will refract, passing through the focal point on the opposite side of the lens. (Draw the ray so that it begins to refract at the centre of the lens.)



2. Draw a ray that passes through the near focal point (on the same side of the lens as the object). This ray will refract at the centre of the lens and then run parallel to the principal axis.



3. Draw a ray that travels through the optical centre. No refraction takes place, so the ray will travel straight through.



The top of the image is located at the point where these three rays meet.

Did You Know?

Don't forget that the rays from the bottom of the object pass straight through the lens with no refraction. This is why we know that the bottom of the image will be on the principal axis.

Suggested Activity

Find Out Activity 6-1C on page 224
Conduct an Investigation 6-1D on page 225

Predicting Image Characteristics Using Ray Diagrams

You have seen that convex lenses can act as magnifying glasses. Do convex lenses always magnify the object? You can predict the image characteristics—size, position, orientation, and type—by drawing ray diagrams. All you need to do is position the image in a location and repeat the three-ray process (see page 219). Depending on where the object is located, you may get a very different image. Ray diagrams for some locations are shown in Figure 6.9, below.

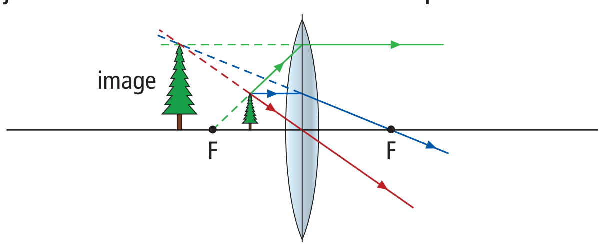
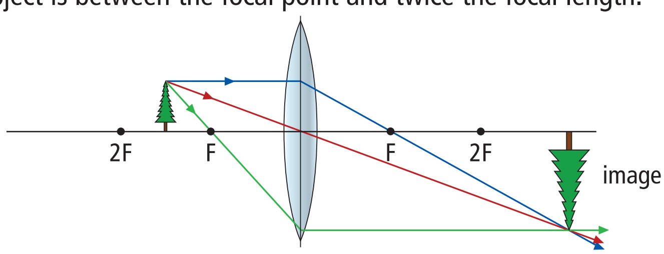
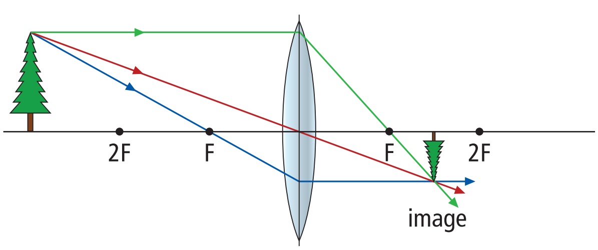
Ray Diagram	Characteristics of Image
The object is between the lens and the focal point. 	• larger than object • farther from lens than object • upright • virtual
The object is between the focal point and twice the focal length. 	• larger than object • farther from lens than object • inverted • real
The object is more than twice as far from the lens as the focal point. 	• smaller than object • closer to lens than object • inverted • real

Figure 6.9 Study each diagram and be sure that you understand how each ray was drawn. Notice that in the first diagram, the refracted rays do not meet. You must extend these rays backward from the lens to find the location of the image.

Figure 6.9 shows that the characteristics of an image in a convex lens depend on the distance of the object from the lens. When the object is between the focal point and the lens, the image is magnified. This is the situation that you saw in Figure 6.5 on page 217, in which the lens was being used as a magnifying glass. When the object is between the focal point and twice the distance to the lens as the focal point, the image is magnified but it is inverted. When the object is farther from the lens than twice the distance to the focal point, the image is smaller than the object and it is inverted.

Notice in Figure 6.9 that when the object is between the focal point and the convex lens, the image is virtual. A virtual image is formed when the refracted rays do not actually meet—only the extended rays meet. A virtual image is located on the same side of the lens as the object, while a real image is located on the opposite side of the lens.

internet connect

There are many simulations of lenses on the Internet. To find one and observe objects and images in many different cases, go to **www.discoveringscience8.ca** to find out where to go next.

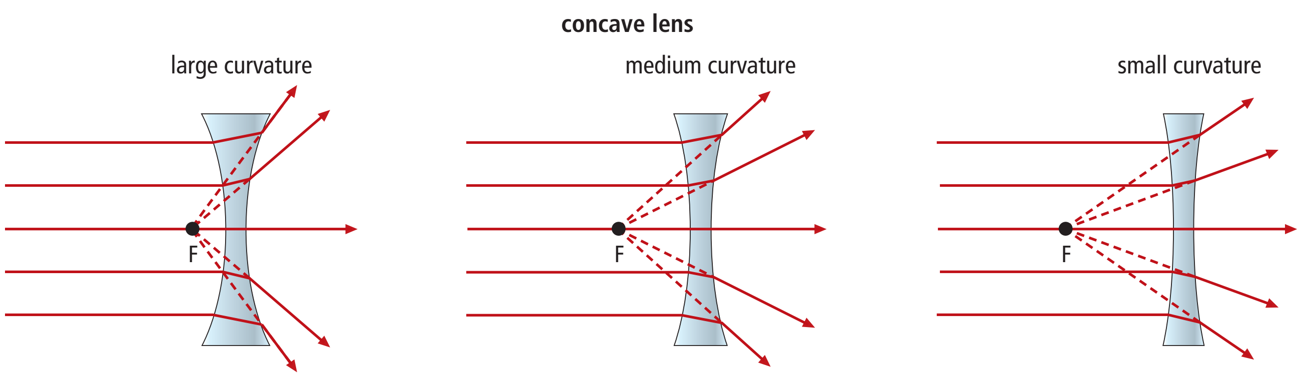
Reading Check

1. Explain how you would find the focal point of a convex lens.
2. Explain how the curvature of a convex lens affects the location of the focal point.
3. Why do lenses have two focal points?
4. Draw a ray diagram for an object that is exactly two focal lengths from a convex mirror. Predict the image characteristics.

Concave Lenses

You saw in Figure 6.4 on page 216, that when parallel light passes through a concave lens, the rays spread out. How do you define the focal point for a concave lens if the refracted rays do not meet? The method for finding the focal point for a concave lens is similar to the method that you used for a convex mirror. After drawing the refracted rays, you extend the rays backward as dotted lines (Figure 6.10). The focal point is the point at which the dotted lines meet. Similar to convex lenses, each concave lens has its own focal length, which is determined by the curvature of the lens. As shown in Figure 6.10, lenses with greater curvature have shorter focal lengths.

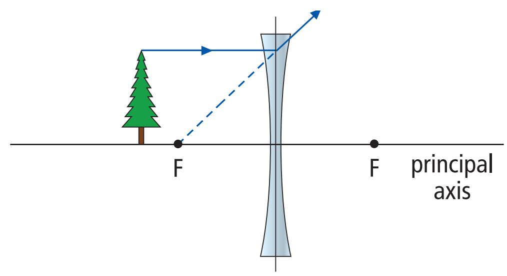
Figure 6.10 The curvature of a concave lens determines the location of the focal point.



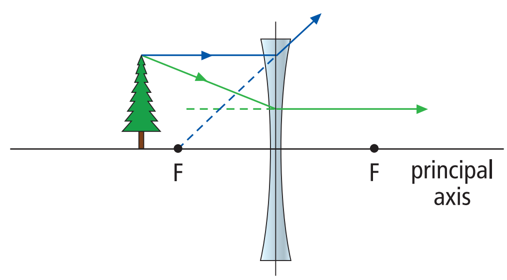
Drawing Ray Diagrams for Concave Lenses

Concave lenses, like convex lenses, have two focal points, one on each side of the lens and the same distance from the lens. Drawing ray diagrams for concave lenses is very similar to drawing ray diagrams for convex lenses. By placing the bottom of the object on the principal axis, you know that the bottom of the image will also lie on the principal axis. If you draw three rays from the top of the object, you will be able to predict the image. The three rays are the same as the ones you have drawn in ray diagrams for curved mirrors and convex lenses, but you will need to extend the rays back toward the object to find the image.

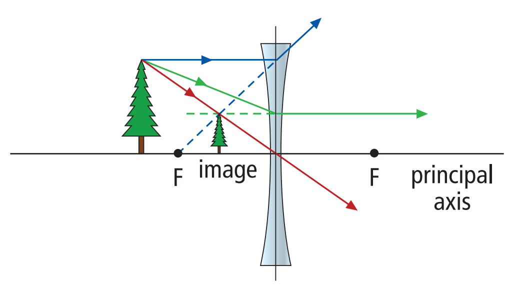
1. Draw a ray parallel to the principal axis. It will refract such that the extension of the refracted ray will pass through the focal point on the same side of the lens as the object.



2. Draw a ray toward the focal point on the opposite side of the lens. This ray will refract parallel to the principal axis. Extend the refracted ray back toward the object.



3. Draw a ray that travels through the optical centre. No refraction takes place, so the ray will travel straight through.



The top of the image is located at the point where two extended rays and one real ray meet.

Image Characteristics for Concave Lenses

Just as you did with convex lenses, you can repeat the three-ray process with concave lenses to determine the images for objects in different positions (Figure 6.11). Recall that the characteristics of an image produced by a convex lens changed depending on the position of the object. Concave lenses produce images that have a lot in common, regardless of the object's position. In all cases, the image formed by a concave lens has the following characteristics:

- The image is smaller than the object.
- The image distance is smaller than the object distance.
- The image is upright.
- The image is virtual.

As the object moves farther from the lens, the image becomes smaller. An example of an image seen through a concave lens is shown in Figure 6.12.

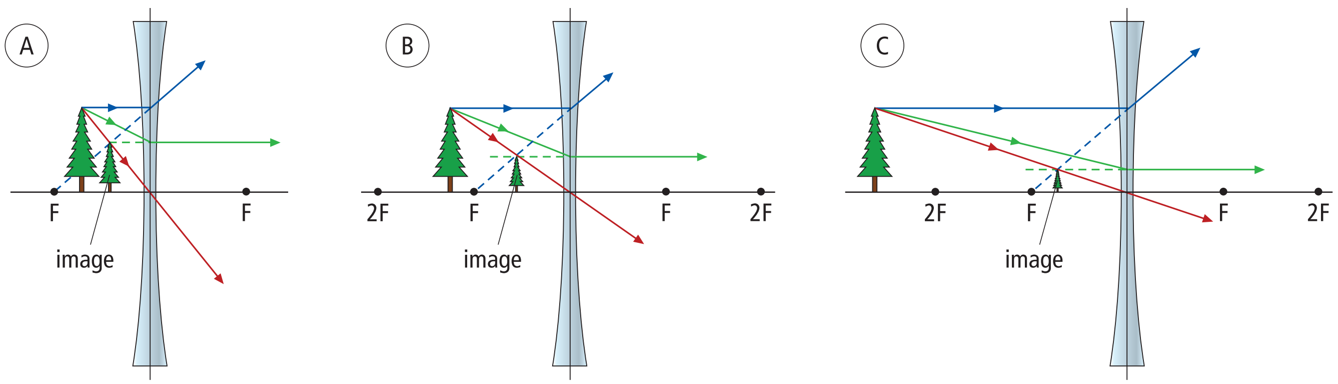


Figure 6.11 The only differences between images created by a concave lens when objects are in different locations are the size of the image and its distance from the concave lens. The images are all upright and virtual.

Reading Check

1. Explain how you would find the focal point of a concave lens.
2. How does the curvature of a concave lens affect the location of the focal point?
3. Draw the figure below. Use three rays to find the image. Describe the characteristics of the image, including size, orientation, distance from lens relative to the object, and whether the image is real or virtual.

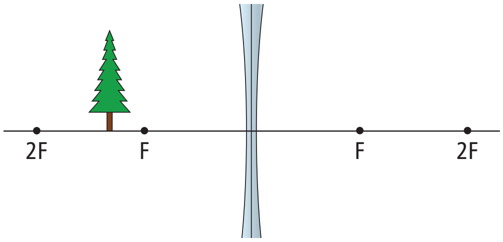


Figure 6.12 A concave lens never produces an image that is as large as or larger than the object.

6-1C Make a Model of a Projector

Find Out ACTIVITY

In this activity, you will examine how an image is affected when seen through a beaker full of water. You will also use a lens to project the image of a light filament onto a screen. A light filament is the twisted wire inside a light bulb.

Safety

- Make sure the electrical cord does not get wet.
- Be careful not to burn yourself with the light bulb.

Materials

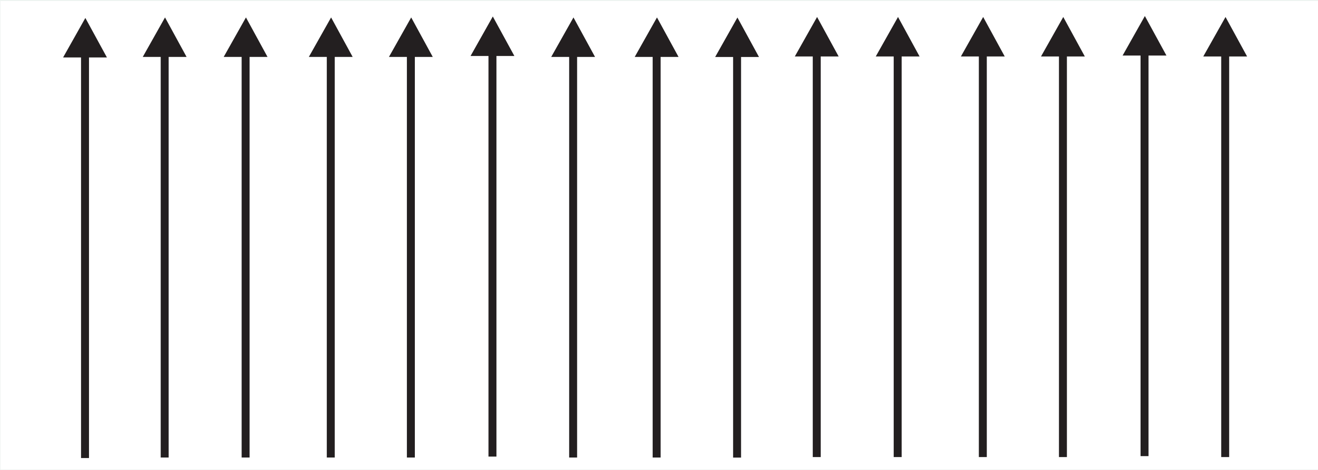
- sheet of paper
- felt pen
- beaker
- water
- convex lens
- unfrosted light bulb

What to Do

1. Draw a series of arrows on a sheet of paper, as shown, and then view the arrows through a beaker full of water. Move the paper left and right and then compare this to the movement of arrows seen through the beaker.
2. Darken the room and turn the light bulb on. Hold the convex lens between the unfrosted light bulb and a plain piece of paper.
3. Move the lens back and forth between the light bulb and the piece of paper. Keep adjusting the distance until you see a sharp image of the filament. Note the size of the image compared to the actual size of the filament.

What Did You Find Out?

1. In step 1:
   (a) How did the orientation of the projected image of the arrows compare with the actual arrows side to side, and up and down?
   (b) How did the projected image of the arrows compare with the actual arrows in terms of size?
2. In step 3:
   (a) How did the orientation of the projected image of the filament compare with the actual filament side to side, and up and down?
   (b) How did the projected image of the filament compare with the actual filament in terms of size?
3. How is the beaker of water like a double convex lens?



6-1D Pinhole Camera

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Classifying
- Modelling
- Explaining systems

Safety

- Never look directly at the Sun with any camera, including the one constructed in this activity.

Materials

- 2 tubes of different diameters (from wrapping paper, paper towels, aluminum foil or plastic wrap) or make 2 tubes using tape and paper
- adhesive tape (with frosty appearance, not clear)
- scissors
- aluminum foil
- pushpin

A tiny hole can act like a lens.

Question

Can a pinhole camera be used to make an image of a bright object such as a light filament or a television screen?

Procedure

1. Obtain two tubes of different diameters so one can slide inside the other.
2. Completely cover one end of the smaller diameter tube with adhesive tape by placing overlapping strips of tape together. The tape is the screen that the image will be projected on.
3. Completely cover one end of the larger diameter tube with aluminum foil and use tape to hold it in place. Use a pushpin to poke a hole in the foil. The hole in the foil acts like a lens.
4. Slide the smaller tube into the larger tube, keeping the tape screen and the aluminum foil on the same side. Begin by sliding the tape right up against the foil.
5. You have just made a camera! Point your camera at a bright object such as a bare light bulb or a television that is turned on. CAUTION: Never look directly at the Sun through any camera, including this one.
6. Slide the smaller tube away from the foil until the image comes into focus. A darkened room may be helpful for this. Is the image in the same orientation as the object or is it inverted?
7. Rotate the camera as you view an image. Does the image rotate with the camera?
8. Clean up and put away the equipment you have used.

Analyze

1. How would the letter d appear if viewed through your camera?
2. Explain, using a ray diagram, why the image formed in the camera is inverted.

Conclude and Apply

1. Passing through a forest on a bright day, you notice that on the ground, right under some leaves, there are many tiny images of the Sun. Explain how these images form.

Wild, Weird, Wonderful

www Science

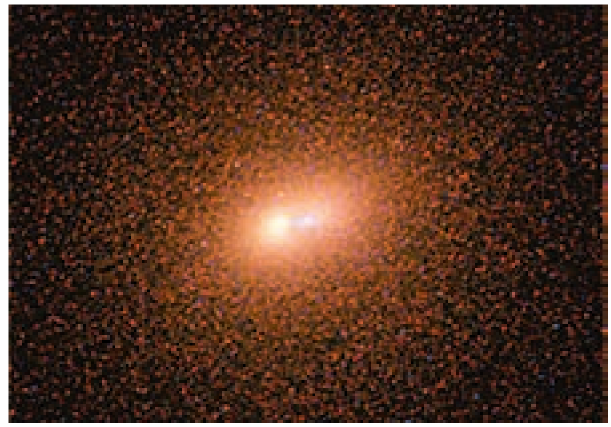
Gravitational Lenses

Imagine that there is a region deep in space that you would like to explore with your telescope, but the distance is just too great to see anything. What if you discovered that halfway between you and the object there was a huge magnifying glass that focussed the light from the distant object right at Earth?

All objects have mass, and where there is mass there is gravity. Gravity not only holds you to Earth and keeps the Moon from flying out of its orbit, it also attracts light. The effect is small for small objects like humans, planets, and individual stars. But gravity can refract light rays passing by a galaxy by a huge amount. When gravity causes many light rays to come together at one point, then we have a lens—a gravitational lens.

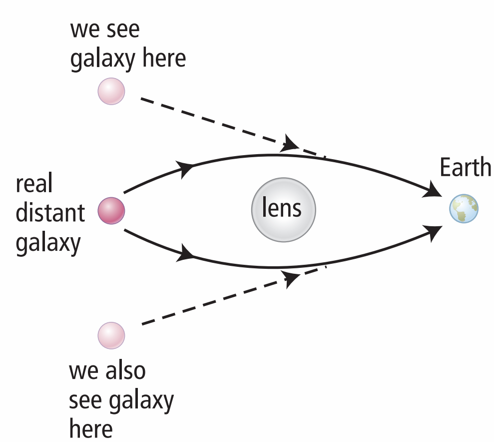
The photograph at the bottom left shows an Einstein ring. The gravitational lens is the bright galaxy in the centre. The blue ring is the distorted image of another galaxy that is on the far side of the lens. The lens is actually in front of the distant blue-coloured galaxy. Light from the blue galaxy passes on all sides of the lens and is pulled together again as it arrives at Earth.

An Einstein ring



A white galaxy

The photograph above shows what appear to be two smaller white galaxies on either side of the lens. Actually, it is one galaxy that is as far behind the lens as we are in front of it. It may seem strange that we get two images, but some light travels above the lens and other light from the same source travels below the lens. The light from the white galaxy has been travelling through space for a very long time. It took two billion years to reach the lens, and another two billion years to reach Earth.

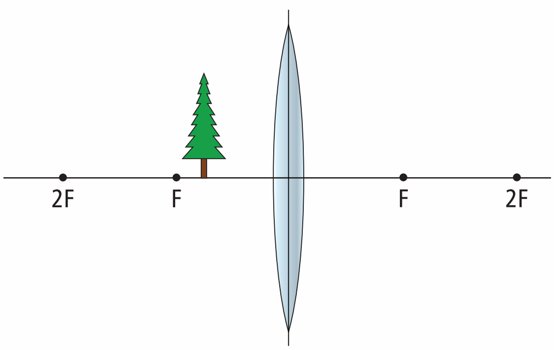


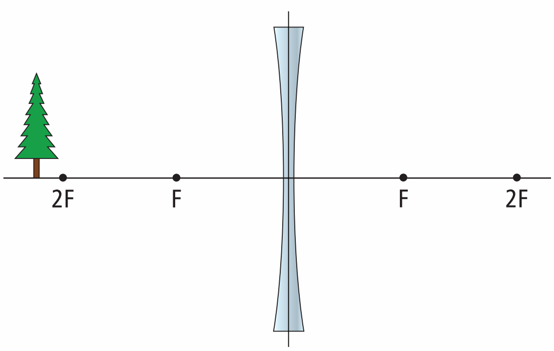
What appears to be two galaxies is actually only one galaxy.

Check Your Understanding

Checking Concepts

1. Make a sketch of the cross section of a convex lens and of a concave lens.
2. What happens to parallel light rays when they pass through a concave lens?
3. Why do lenses have two focal points?
4. Would you use a concave lens or a convex lens for a magnifying glass? Explain why.
5. How does the curvature of a convex lens affect its focal point?
6. Copy the following diagrams. For each diagram, complete a ray diagram, using three rays, to find the image. Describe the characteristics of each of the images, including size, orientation, distance from lens relative to the object, and whether the image is real or virtual.



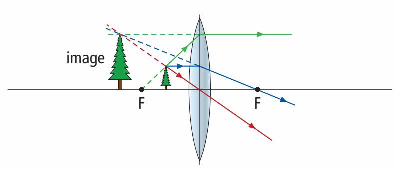


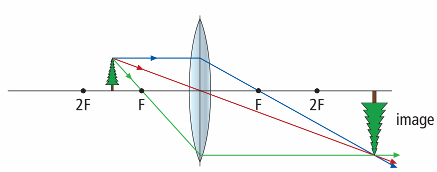
Understanding Key Ideas

7. Does a concave lens affect light more like a concave mirror or a convex mirror? Explain your answer.
8. Describe each of the three rays that you use to make a ray diagram for a convex lens. Explain how you know where the refracted ray will go.
9. Under what conditions will a convex lens not give you a magnified image of the object?
10. On which side of a concave lens do you find the image? Is it on the same side as the object or on the side of the lens opposite the object?

Pause and Reflect

If the image of an object between F and 2F of a convex lens is real and inverted, and the image of an object between the lens and F of the same lens is upright and virtual, what do you think would happen if the object was exactly on the focal point, F? Draw a ray diagram to support your answer.





6.2 Human Vision

The cornea-lens-retina system focusses light at the back of the eye. Special cells in the retina called rod cells and cone cells convert light into electrical signals that are sent to the brain. Light does not always fall on the retina in perfect focus. Near-sightedness results when the eye cannot form a sharp image of distant objects. Near-sightedness can be corrected by placing a concave lens in front of the eye. Far-sightedness results when the lens of the eye cannot form a sharp image of nearby objects. Far-sightedness can be corrected by placing a convex lens in front of the eye.

Key Terms

astigmatism
blindness
blind spot
colour blindness
cone cells
cornea
far-sighted
iris
near-sighted
night blindness
optic nerve
pupil
retina
rod cells
sclera
snow blindness

Your eyes allow you to read the text on this page, to see colourful illustrations, and to focus on moving objects. How is all of this possible? In fact, you have already learned three important facts about light that will help you understand how human vision works:

1. Light travels in straight lines.
2. Light bends as it travels from one medium to another of different density.
3. A lens can be used to focus light by bending it in a specific way.

This knowledge will help you understand how the specialized structure of the human eye allows you to see.

6-2A Changing Colours — Find Out ACTIVITY

In this activity, you can observe how your colour vision adapts to changing lighting conditions.

What to Do

1. Look at the image of the flag of Canada, which is printed in a greenish tint. Stare at the image of the flag for 25 s, making sure not to move your eyes around.
2. Immediately switch your gaze to a white space on the page, and wait a few seconds. What do you see? Achieving this effect may take a few tries.

What Did You Find Out?

1. (a) What did you see when you stared at the white page?
   (b) Why do you think you saw this?
2. How might this adaptability of your colour vision help you as you walk through a forest in bright sunlight and at twilight?

Flag of Canada

How Light Enters the Eye

Light enters your eye through the **pupil** (see Figure 6.13). The pupil is an opening that appears dark because light passes through it without reflecting back. The iris is the coloured circle of muscle surrounding the pupil. The **iris** is the structure we refer to when we speak about the colour of someone's eyes being grey, brown, blue, or hazel. The iris controls the amount of light entering the eye. In dim light, the iris dilates, or expands, the pupil to allow more light to enter (see Figure 6.14A). In bright light, the iris contracts the pupil to reduce the amount of light entering the eye (see Figure 6.14B).

Covering the iris and pupil is a transparent tissue called the **cornea**. The cornea is made of cells that are transparent enough to let light pass through, yet tough enough to hold the eye together. Surrounding the cornea is an opaque tissue called the **sclera**. We see the sclera as the white region surrounding the iris.

Behind the pupil is a flexible convex lens. The light rays pass through the lens and are focussed on a screen at the back of the eye called the **retina**, where an image is formed. Special light-sensitive cells in the retina detect the image. Other cells in the retina convert the light rays into electrical signals that are sent to the brain through a thick nerve called the **optic nerve**.

Did You Know?

The human eye is more sensitive to green light than to any other colour. If you look at a green light and a red light of the same intensity, the green light appears to be brighter.

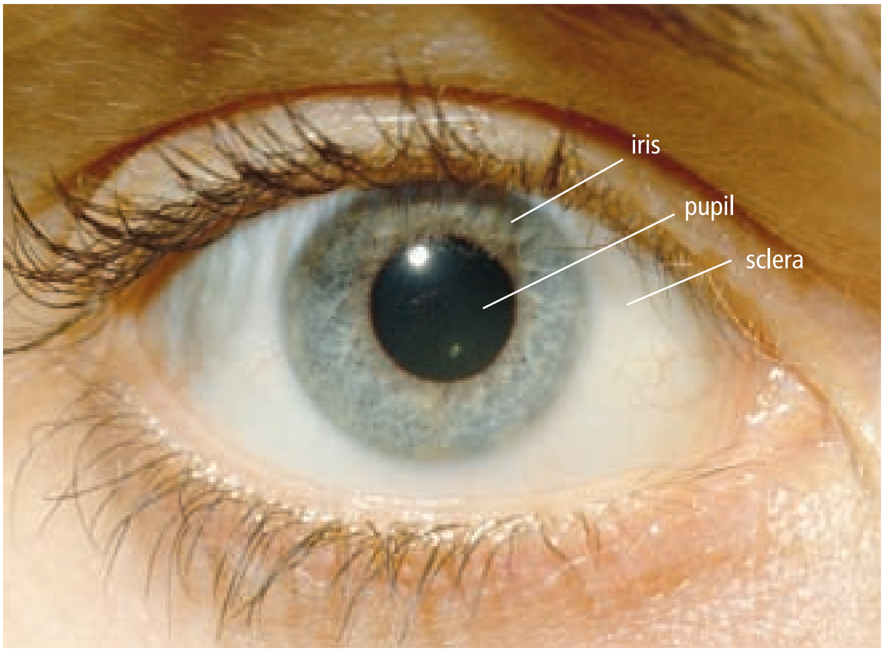


Figure 6.13 Light enters the eye through a transparent opening called the pupil.

Figure 6.14A A dilated pupil

Figure 6.14B A contracted pupil

Word Connect

The term "cornea" comes from the Latin word for horn, the front part of an animal's head. The cornea is the most forward part of the eye.

The Cornea-Lens-Retina System

Light rays pass through a focussing system involving the cornea, the lens, and spaces in the eye filled with a watery fluid (see Figure 6.15). The fluid between the lens and the cornea supports both the cornea and the lens, and provides nutrients to the cornea, which does not have any blood vessels. The fluid behind the lens gives shape to the eye and supports the lens.

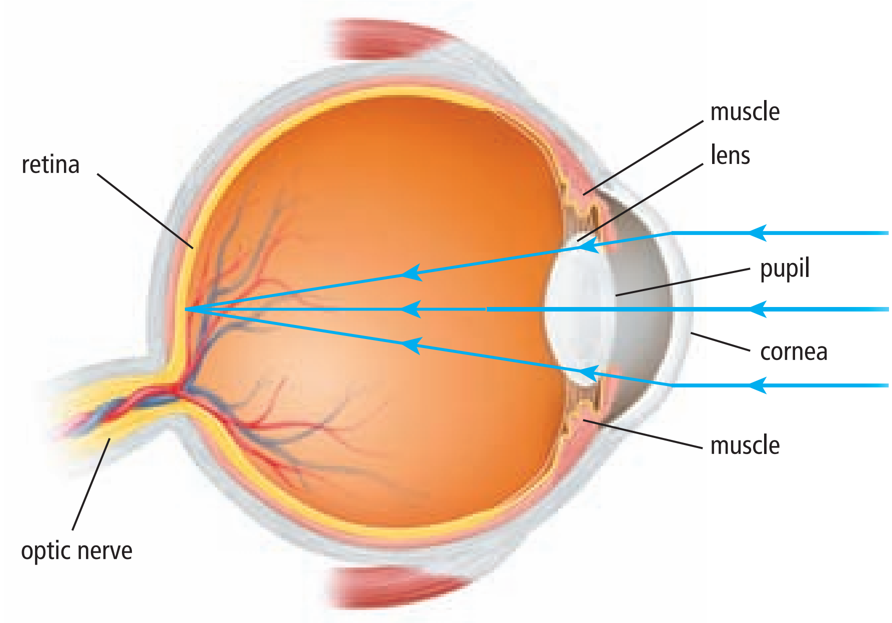


Figure 6.15 The eye in cross section

Light rays begin to be focussed as soon as they pass into the cornea. The cornea refracts incoming light rays so that they converge toward the retina. The cornea provides most of the focussing done by our eyes. The lens does the remaining focussing. This may be a surprise to you because we usually think of the lens as doing the focussing. Perhaps it is because we do not notice the amount of focussing done by the cornea that we tend not to think about its function in forming the image.

The lens has the ability to fine-tune our focus by automatically changing its shape. When certain muscles in the eye contract, there is less tension on the lens, allowing the lens to become thicker. A thicker lens can focus on near objects. When you look at distant objects, these same muscles relax, increasing tension on the lens and making it thinner. You can feel your eyes working hard to focus if you hold a finger up very close and try to see it clearly.

Did You Know?

In some species of animals, such as the octopus, the lens and the retina can move closer together.

Forming an image

All the light rays that enter the eye from one spot on the base of an object come together again in one place at the top of the retina. Similarly, all the light rays that enter the eye from a spot at the top of an object come together at one place at the bottom of the retina. As shown in Figure 6.16 the image formed by the lens is inverted. However, you do not have to stand on your head to see upright. Your brain interprets the image as being upright.

Suggested Activity

Conduct an Investigation 6-2D, on page 238

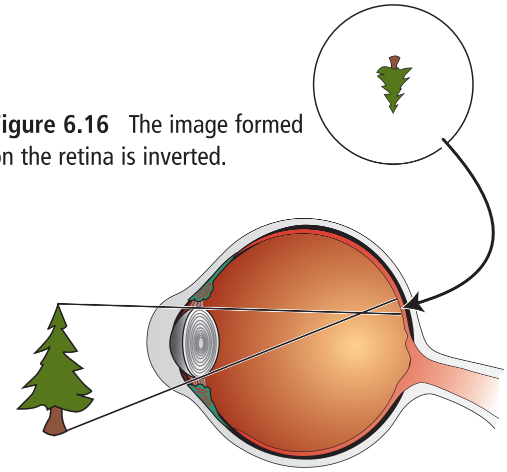


Figure 6.16 The image formed on the retina is inverted.

Blind Spot

The area where the optic nerve enters the retina does not have any light-sensing cells. This area is known as the **blind spot**. You can easily demonstrate the presence of your blind spot by following the steps outlined in Figure 6.17. Note that each eye sees what the other misses because the blind spots are not in the same place.

● X

Figure 6.17 To locate your blind spot, hold this book at arm's length. Cover your right eye with your hand. Stare at the X while you move the book slowly toward yourself. The dot should disappear and then reappear as its image moves onto your blind spot and then off again.

internet connect

An optical or visual illusion tricks the eye and brain into perceiving something unlike what actually exists. Check out examples of optical illusions and find out what they reveal about the way we see. Start your search at **www.discoveringscience8.ca.**

Reading Check

1. What happens to light rays after they enter the eye through the pupil?
2. Where does most of the focussing in the eye occur?
3. How does the lens change to focus on objects that are close?
4. How does the lens change to focus on objects that are distant?
5. Why is the image of an object inverted when it strikes the retina?

Black-and-White Vision and Colour Vision

Once the light rays are focussed correctly on the retina, the cells that absorb the light begin their job. Some cells in your retina specialize in detecting low levels of light. Other cells detect bright light. The cells in your retina that absorb light come in two basic shapes: longer cylindrical ones called rod cells and rounder ones called cone cells (see Figure 6.18).

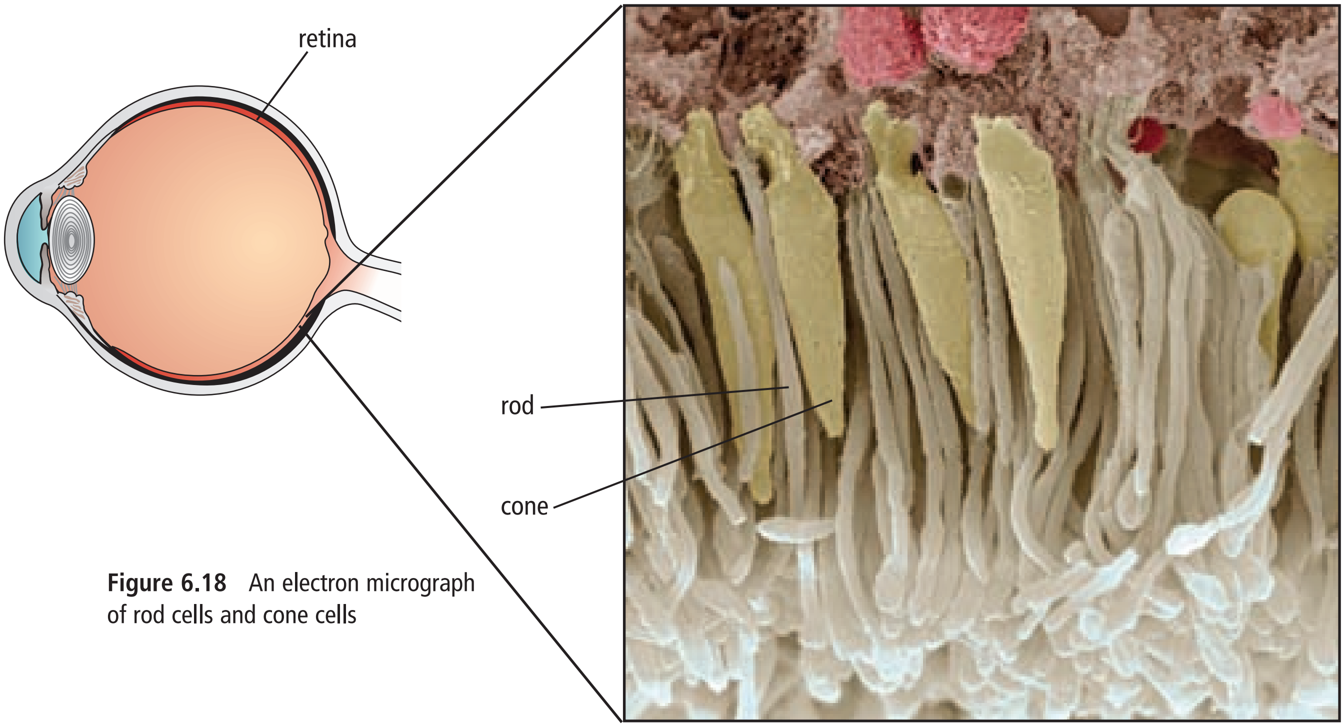


Figure 6.18 An electron micrograph of rod cells and cone cells

Rod cells—shapes, movement, and shades of grey

Rod cells can absorb almost any colour of light, but they absorb green light particularly well. Even so, our brain does not use any of the signals from rod cells to determine colour—just shades of light and dark. This is called our black-and-white vision system, and in low-light conditions it helps us see shapes and movement.

Did You Know?

We sometimes forget we see in black and white at night because we know what the colours should be.

Cone cells—seeing the rainbow

Cone cells allow us to detect colour. We have three kinds of cone cells, each possessing a slightly different kind of pigment. Recall that by using only red, green, and blue it is possible to see all the colours of the rainbow. If our brain receives an equal amount of all three colours, then we see the object as white. The human brain can combine and balance the different colour signals that it receives. This is why the white page of a book can appear white to us under varying amounts of daylight.

What Colours Do Rod and Cone Cells Detect?

In Part 1 of this activity, you will use the information in a table to answer questions about rod cells and cone cells. In Part 2 of this activity, you will use the information in a graph to determine which colours rod cells and cone cells detect.

What to Do

Part 1

1. Use the table below to help you answer the questions that follow. Pigment is the colouring matter in a cellular tissue.

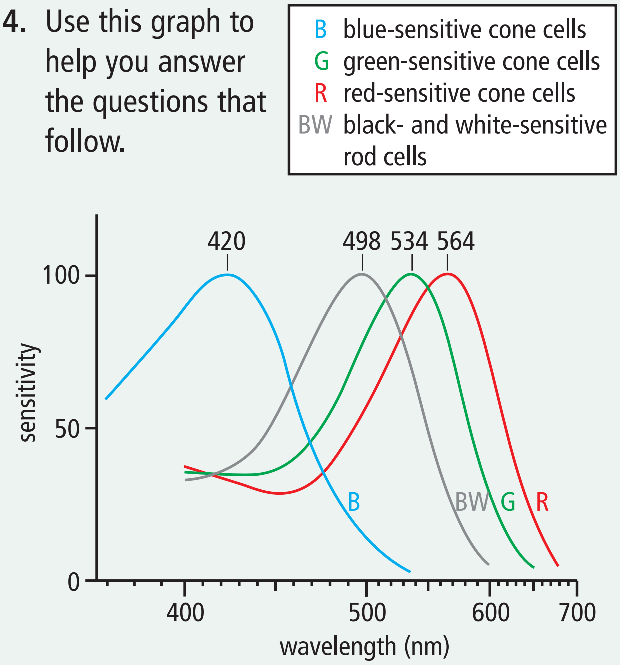
Functions of Rod Cells and Cone Cells

Rod Cells	Cone Cells
Used for night vision	Used for bright illumination vision
Very light sensitive	Not very light sensitive
One type of light-sensitive pigment	Three types of light-sensitive pigment
Have more pigment than cones, so can detect images in low light conditions	Have less pigment than rods, so require more light to detect images
Slow response to light	Fast response to light
Smaller than cone cells	Larger than rod cells
About 100 million in the human eye	About 6 million in the human eye
Mostly found on the outer edges of the retina	Mostly found in the centre of the retina

2. Why are rod cells more useful for night vision?
3. Why are cone cells more useful for colour vision?

Part 2

4. Use this graph to help you answer the questions that follow.



A graph of the ability of cone cells and rod cells to absorb light of differing wavelengths

5. Consider the line labelled "R," for red-sensitive cone cells.
   (a) At what wavelength, in nanometres, are these cells most effective at detecting light?
   (b) What colour does the wavelength in (a) correspond to?
   (c) Which colour are the red-sensitive cells able to detect more easily—green or red?
   (d) Suggest a reason why these cells are called red-sensitive cells even though they can detect many other colours as well.
6. (a) At what wavelength do the black- and white-sensitive rod cells absorb light most efficiently?
   (b) What colour does the wavelength (a) correspond to?
7. Examine the graph and explain why humans are able to detect faint amounts of green light.

Correcting Focus Problems

Most people have trouble focussing clearly at some time in their lives. As children grow, especially in their teen years, the shape of their eye changes. The change of shape can affect their ability to focus and may require the temporary use of eyeglasses. As adults age, the flexibility of the eyes' lenses often decreases, making it harder to focus on nearby objects.

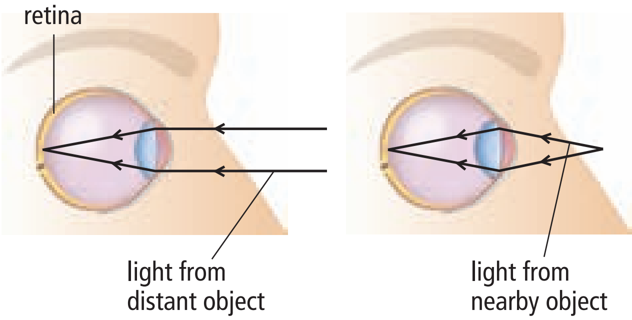
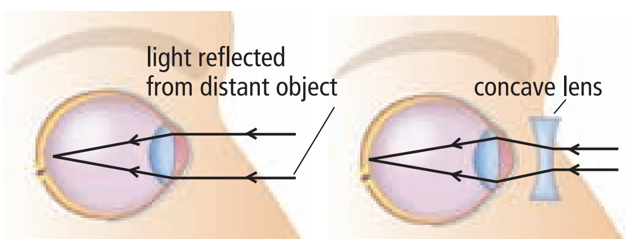


Figure 6.19 How the lens in a normal human eye focusses light rays onto the retina

Normal vision

When light rays from a distant object enter the eye, the rays are nearly parallel (Figure 6.19). The lens, which is convex, causes the rays to converge at the retina, producing a sharp image. Light rays from a nearby object are diverging when they enter the eye, so muscles in the eye cause the lens to change shape, making the lens thicker. This gives the lens a greater ability to converge the light rays to form a clear image.



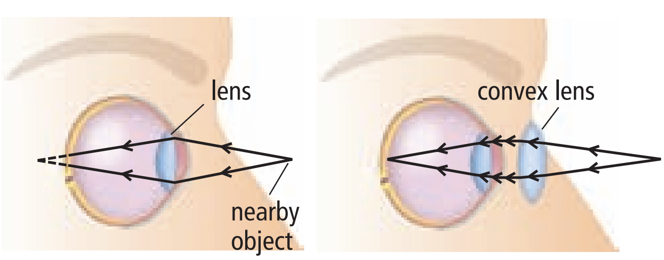
Near-sighted vision: image falls short of retina (eye has longer shape than normal eye)

Vision corrected with concave lens: lens allows image to fall on retina

Figure 6.20 How a concave lens in eyeglasses corrects near-sightedness

Correcting near-sighted vision

People who can see nearby objects clearly but who cannot bring distant objects into focus are **near-sighted** (Figure 6.20). This condition occurs because the lens converges the light rays to form an image in front of the retina. By the time the light rays actually strike the retina they have begun to spread out again, causing the person to see a fuzzy image. A concave lens is used to diverge the parallel rays slightly so that the image forms farther back, on the retina.



Far-sighted vision: image falls behind retina (eye has shorter shape than normal eye)

Vision corrected with convex lens: lens allows image to fall on retina

Figure 6.21 How a convex lens in eyeglasses corrects far-sightedness

Correcting far-sighted vision

Some people can see distant objects clearly but find that nearby objects remain fuzzy no matter how hard they try to focus on them, a condition known as **far-sighted** vision (Figure 6.21). Light rays from distant objects are nearly parallel, and require less refraction to converge them than light from nearby objects. However, light rays from nearby objects are diverging as they enter the eye. A convex lens is needed for the light rays to come into focus exactly on the retina.

Correcting astigmatism

Some people need vision correction because their cornea has a distorted shape, a condition known as **astigmatism**. A normal cornea is shaped spherically, like a soccer ball, while an astigmatic eye has an irregularly-shaped cornea. This condition causes an image to focus on more than one point on the retina, resulting in blurred vision (see Figure 6.22). Astigmatism can be corrected using eyeglasses or contact lenses (see Figure 6.23) or with laser surgery to reshape the cornea.

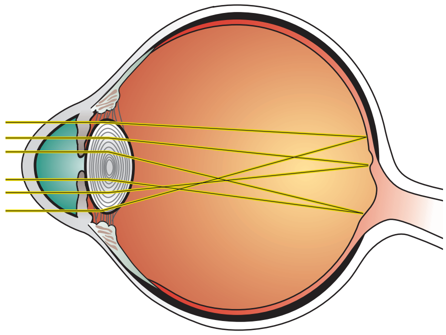


Figure 6.22 In astigmatism, the shape of the cornea causes the image to focus on more than one point of the retina.

Figure 6.23 Contact lenses are small plastic lenses that float on the cornea. Almost any correction that can be made using prescription eyeglasses can also be made using contact lenses.

Blindness

Blindness can be any vision impairment that keeps people from doing important life activities such as riding a bike, reading, or recognizing their friends through sight. In very rare cases, a blind person may not be able to detect any light whatsoever. Most people who are legally blind can perceive some light or even have a limited amount of vision.

In some types of blindness a person can see only a tiny part of the middle of a whole scene. Other people who are blind have the opposite situation: they can see on the edges of their vision, but not directly ahead. Others can detect light and darkness, but no amount of visual aids can help them to see clearly.

In developing countries, blindness is most often a result of disease or malnutrition. Children in poorer communities are more likely to be affected by blindness caused by disease than are children in more affluent communities. Of the approximately 40 million people who are blind in the world today, about 80 percent could have some or all of their sight restored through treatment. However, many people in developing countries cannot afford even basic vision aids such as eyeglasses.

Suggested Activity

Think About It 6-2C on page 237

Figure 6.24 Inuit snow goggles of caribou antler.

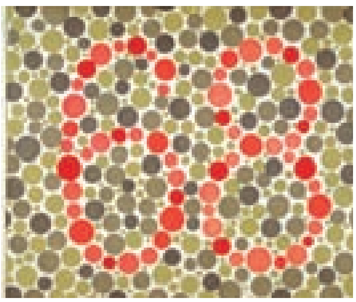


Figure 6.25 Those who do not have red-green colour vision deficiency should see the number 68 here.

Other Types of Blindness

Snow blindness is a painful condition of temporary partial or complete blindness caused by overexposure to the glare of sunlight, such as on snow fields at high altitudes. Treatment includes resting the eyes in a dark room for several days to allow the inflammation to decrease. The Inuit traditionally wore goggles with thin slits to help prevent snow blindness (see Figure 6.24).

Night blindness is a condition in which it is difficult or impossible to see in dim light. The most common cause is the rod cells losing their ability to respond to light. A person might be born with night blindness, or it could develop due to injury or malnutrition.

Colour blindness is the ability to see only in shades of grey, and occurs in about one person in every 40 000. Colour blindness is usually considered a disability, but there are situations in which a person who is colour-blind has an advantage over a person who sees colour. For example, a person who is colour-blind may find it easier to pick out an object from a confusing background.

Although colour blindness is rare, colour vision deficiency is quite common, occurring in about 8 percent of males and 1 percent of females. Colour vision deficiency is an inability to distinguish certain colours. There are many kinds of colour vision deficiency because one, two, or all three kinds of cone cells may be involved. The most common kind of colour vision deficiency involves the inability to tell red and green apart. For many affected people, both colours appear to be shades of yellow. A simple test for colour vision deficiency is shown in Figure 6.25.

Explore More

There are many kinds of vision problems related to focussing, colour perception, and size of field. Other vision problems involve high pressure in the eye, degeneration of parts of the eye or optic nerve, detachment of the retina, or hardening of the lens. Find out more about vision problems. Start your search at **www.discoveringscience8.ca.**

Reading Check

1. What can cause focussing problems as children grow? As adults age?
2. Explain why a person who is near-sighted can see a close object clearly, but not a distant one.
3. Explain why a person who is far-sighted can see a distant object clearly, but not a close one.
4. How does an irregularly-shaped cornea cause astigmatism?
5. What are three examples of what a person who is blind might be able to see?
6. Why are children in developing countries at a greater risk of becoming blind?
7. How can snow blindness be prevented?

6-2C Being Blind

In this activity, you will learn about the life of a blind student.

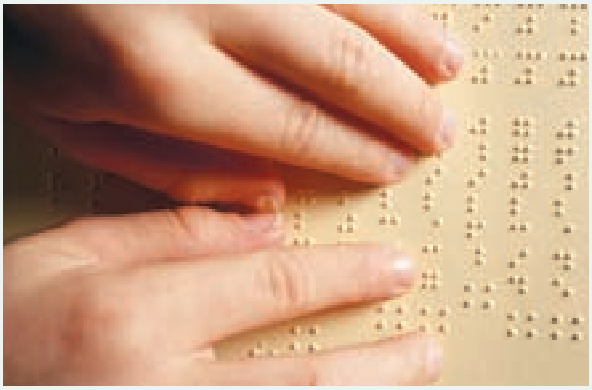
What to Do

1. Read the letter and answer the questions that follow.

Hello, my name is Sean, and I am blind. Although I was born blind, I have learned how to understand the world around me. I can read Braille and I really love reading books in the same way sighted kids learn how to enjoy reading print. The only difference is that I read with my fingers instead of my eyes.

I also enjoy listening to "talking books" on my iPod®. You might think it strange, but I talk about "reading" books, even though I read through my fingers or listen through my ears. I like to do all the things people with sight like to do, like playing with my dog, going swimming, listening to music, or just hanging out with my friends.

I go to school with kids who can see. My favourite subjects are math and English. I use a computer with a Braille keyboard and voice output, so I can check what I have done. The best part of school is the friends I have made. They help me "see" things I cannot see, and I help them with things that are not so visible.



The Braille alphabet allows a blind person to read by touch.

A Braille keyboard

What Did You Find Out?

1. (a) Based on Sean's writing, or on friendships you have with people who are blind or visually impaired, do you think you should use expressions when you talk to them like, "See you later" or "Did you watch the TV show last night?" Explain your answer.
   (b) What about expressions like "The book is over there" or "Come here"? Explain your answer.
2. How could you help a student who is visually impaired who was new to your classroom?
3. How could your classroom be improved to make it easier for a student who is visually impaired to learn?

6-2D Dissecting a Sheep Eye

SkillCheck

- Observing
- Classifying
- Communicating
- Explaining systems

Safety

- The sheep eye is raw meat. Make sure you wash your hands with soap after completing the dissection to ensure that all bacteria have been washed off.
- Keep your hands away from your eyes and mouth when handling the sheep eye.
- Ensure that all of the animal parts are cleaned up and discarded according to your teacher's instructions.
- Sharp edges can cut. Be careful with scissors and prods.

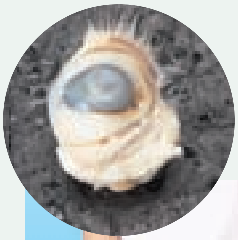
Materials

- preserved sheep eye
- scissors
- prod
- dissection tray
- protective gloves
- paper towel
- plastic disposal bag
- 10 percent bleach solution
- Wear protective gloves. Follow your teacher's instructions for removing and disposing of them.

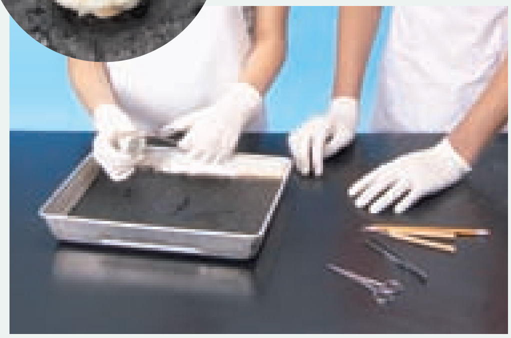
A sheep eye and a human eye have many things in common—as well as a few important differences. Examining a sheep eye will help you better understand how your own eyes function.

Question

How does a sheep eye function?



Exterior view of a sheep eye



Trim away fat and muscle.

Procedure

1. Put on your gloves. Examine the outside of the sheep eye. Notice that it is covered in a layer of fat and muscle. The fat is yellow tissue, and the muscle may appear grey.
   - The fat protects the eye, while the muscle helps the eye to move in its socket. A sheep eye has four large muscles to move the eye up, down, left, and right.
   - Humans have six muscles, which allow us to roll our eyes.
2. Use scissors to trim away the excess fat and muscle.
3. Look at the front of the eye and note the outer layer, called the cornea. The cornea is clear in the living eye, but may have become cloudy in the preserved eye. The cornea is curved, which means light passing through it is focussed.
4. Examine the rest of the outside of the eye. Note that an opaque layer, the sclera, covers the eye.
   - The sclera has a dark layer that prevents the passage of light into the eye from the side. This keeps out stray light.
   - The optic nerve enters the eye at the back.
5. Use the prod to poke a hole in the eye halfway between the cornea and the optic nerve. Some liquid will come out when you do this. Use scissors to cut all the way around the eye, separating it into front and back halves. Try not to disturb the internal parts of the eye as you cut.

Poke a hole into the sclera so that scissors can be used to cut the eye in half.

6. Separate the eye into two halves. Taking the front half of the eye, try to look through it. It may be possible to see right through the lens and cornea. See if you can read text through the eye. If you can see an image through the eye, note whether it appears upright or upside down.
7. Use the prod again to poke a hole at the junction of the cornea and the sclera. Use the scissors to cut a circle around the cornea in order to remove it.
   - Under the cornea is more jelly-like substance that is liquid in the living eye. The jelly-like substance supports the cornea and helps to give it shape.
   - Under the cornea is the iris, which is a ring of tissue. In a sheep, the iris is oval-shaped. In humans, it is circular. The pupil is seen to be simply a hole in the iris.

Cut a circle around the cornea in order to remove it.

8. Remove the lens from the eye and, using a paper towel, wipe all the jelly from it. The lens will probably be yellow, but it is colourless and clear in the living eye. See if you can see an image through the lens. The lens will be hard, but in the living eye it is soft and can change shape in order to focus.
9. Examine the inside of the back half of the eye. Note where the optic nerve comes into the eye. There are no rod or cone cells here, and this is the sheep's blind spot. Humans have a similar blind spot.
   - The retina is a network of nerves that flow into the optic nerve. The retina may be found against the inside back of the eye. If the retina has come off it will likely be attached to the eye at a single spot (the blind spot).
   - The back of the eye may appear black or blue. In sheep, there is also a shiny or iridescent layer that helps the sheep to see in low-light conditions.
   - Humans do not have this layer, and the layer under the retina in our eyes is black, to absorb stray light.
10. Place all of the eye parts in a plastic disposal bag. Clean up all equipment and work areas with a 10 percent bleach solution. Remove and dispose of your gloves as your teacher instructs.
11. Wash your hands thoroughly with warm soapy water.

Analyze

1. List four differences between the anatomy of a sheep eye and a human eye.
2. Is the image that is cast on the retina at the back of the eye upright or inverted? Draw a ray diagram to explain your observations.
3. Describe the appearance, colour, shape, and feel of the lens from the sheep eye.

Conclude and Apply

1. Make a labelled diagram of a cross section of the sheep eye that includes all of the structures you studied.
2. You may have observed that the retina seemed to be continuous with the optic nerve. Do you think the retina is part of the brain? Explain.

Wild, Weird, Wonderful

WWW Science

Can You See What I Hear?

Bats, dolphins, and whales all use natural sonar systems to perceive the world around them. Do you? You may be surprised. If you have normal hearing, then you might want to try this experiment. Have 10 people stand in a line. Face away from them and then have one person make a sound. You are likely to be able to turn and face the exact person who made the sound.

There are some interesting reasons for this. The sound reaches each ear at different times, and your brain can detect the difference in the arrival times of the sound signals. Another reason is that you have an awareness of the space around you, and when you hear your friend make the sound, you locate him or her in this space. You can even keep track of this as you turn around to face your friend. In other words, you can "see" what you just heard.

Echolocation involves producing sounds and then interpreting the environment based on the echo. Bats emit high-pitched chirps. They can use the echoes of the chirps to avoid wires and find insects to eat. Some people who are blind make their own clicking sounds when walking. Then they interpret the echoes to find out about objects close by.

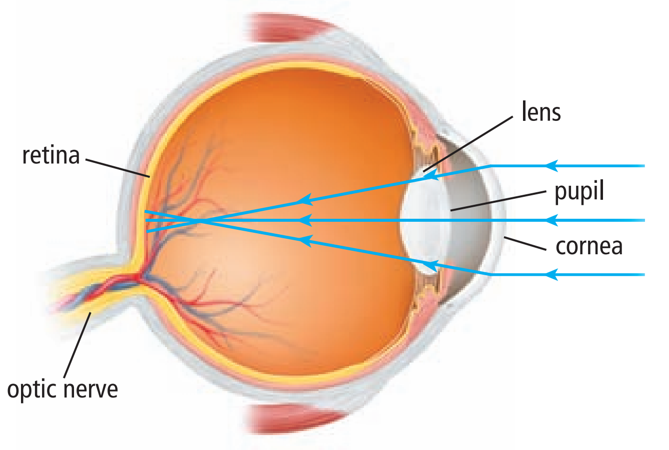
This ability has inspired a number of researchers to construct devices that produce sounds that people who are blind can use to find out about the location, size, shape, and even texture of objects around them. For example, a loud, clear echo might represent a close, hard object. We all have an inborn ability to interpret sounds in a visual way, and those who practise it get much better at it .

The woman above is wearing a video camera. The camera is mounted in her sunglasses, as is the digital equipment that creates an audio signal of every object she faces. The woman listens to the sounds and converts the "sound scape" into a mental image of her environment.

The use of these devices is very experimental. With the current technology, bright objects are made to produce a loud sound. Black objects are silent. As objects get closer to you they look bigger. This translates as a higher pitch. A car driving away from you sounds like a falling tone. Although we are still a long way from getting to "I can see what you see," we may be only a big step away from "I can hear what you see."

Checking Concepts

1. Make a table that lists the parts of the eye in one column and the function of each part in the other.
2. (a) Which parts of your eye are involved in focussing an image?
   (b) What is the role of each part?
3. (a) Describe the vision problem shown by the illustration below.
   (b) What could be done to correct this problem?



4. Why can the human eye see colours better in bright light than in dim light?
5. Write a definition of blindness in your own words.

Understanding Key Ideas

6. What would happen to a person's vision if the eye's lens was unable to change shape?
7. Why is it necessary to have three kinds of cone cells operating in order to have full colour vision?
8. Describe how the eye adapts to the following changes in conditions:
   (a) sudden increase in brightness
   (b) gradual dimming of light until it is almost dark
   (c) looking at a kite, then down at your hand to let out string
9. Most mammals, including dogs and cats, cannot see colours. Infer how the retina of a cat's eye might be different from the retina of a human eye.

Pause and Reflect

After years of work in the field of vision and community service, you have been selected to become the high commissioner for the Elimination of Preventable Vision Disabilities. You have a budget of $1 billion. Your commission is responsible for defining four goals that will improve vision in the developing world. Reflect on this problem and then list your four goals along with the portion of the budget that each should receive. Briefly explain your choices.

6.3 Extending Human Vision

Microscopes and refracting telescopes use lenses to capture and focus light. Reflecting telescopes use both mirrors and lenses to gather light. The Hubble Space Telescope can obtain clearer images than ground-based telescopes because there is no atmosphere to interfere with images from the Hubble Space Telescope. Camera design and human vision have a number of similarities and differences.

Key Terms

aperture
charge-coupled device (CCD)
diaphragm
refracting telescope
reflecting telescope

Human knowledge about our planet and the universe was very limited until we developed tools to extend our vision. We now have the ability to peer into the tiny world of micro-organisms and out into the vast reaches of outer space. The tools we use for these inquiries may seem quite different from each other, but they are based on the same understanding of light, mirrors, and lenses.

Ray diagrams demonstrate how light behaves when it strikes a mirror or passes through a lens. Microscopes, telescopes, and other optical instruments use multiple lenses and/or mirrors to magnify images. You could use ray diagrams to determine the images these instruments produce, but the diagrams would be rather complicated. Scientists often use simplified diagrams to help explain how optical instruments work.

6-3A Experimenting with a Simple Lens — Find Out ACTIVITY

In this activity, you will observe some properties of a test tube lens.

Materials

- glass test tube with stopper
- water
- paper or note card

What to Do

1. Fill a glass test tube with water and seal it with the stopper.
2. Print the name of your favourite scientist in capital letters on a piece of paper or a note card.
3. Lay the test tube flat on the note card, running left to right over the words you have written.
4. Observe whether the letters are magnified, whether the letters are in focus, and whether the image is upright or inverted. Record your observations.
5. Hold the tube about 1 cm above the card and observe the letters. Record your observations.
6. Repeat, holding the tube at several other heights above the words.

What Did You Find Out?

1. Describe what happens to the images of the letters as the lens is gradually moved away from the note card.
2. Draw and label a ray diagram showing the situation when the image appeared to be inverted and magnified.

How to Bring an Image into Focus

In order for the light rays passing through a lens to form a clear image, the screen that is receiving the image must be the correct distance from the lens. The screen must be at the place where all the light rays from a given point on the object converge. If the screen is placed too close to the lens, then the light rays do not fully converge by the time they strike the screen. There will be an image formed, but it will appear blurred. On the other hand, if the screen is too far away, then the light rays converge and then begin to diverge before they strike the screen, resulting in a blurred image. Adjusting the distance between the screen and the lens to make a clear image is called focussing. Focussing is an important step in using optical devices such as microscopes, telescopes, binoculars, and cameras.

Microscopes

A compound light microscope uses two convex lenses with relatively short focal lengths to magnify small, close objects. To *magnify* means to cause to look larger than the real size.

Figure 6.26 shows a microscope. The object to be viewed is placed on a transparent slide and illuminated from below. The light passes by or through the object on the slide and then travels through the objective lens.

The objective lens is a convex lens. Recall that if the distance from an object to a convex lens is between one and two focal lengths, it forms an enlarged image of the object. The eyepiece lens, which is another convex lens, then magnifies the image again. This final image can be hundreds of times larger than the actual object, depending on the focal lengths of the two lenses.

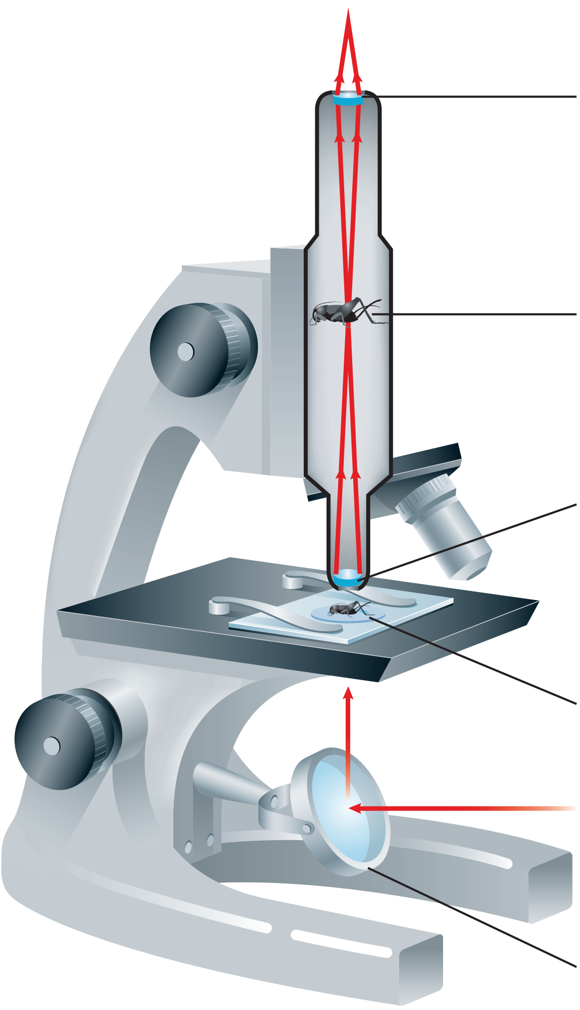


Figure 6.26 This microscope uses two convex lenses to magnify small objects. To focus the image, you have to move the object you are studying closer to or farther from the objective lens.

6-3B Microscopes on the Job

Think About It

In previous studies, you may have seen how biologists use microscopes. However, biologists are not the only people who need microscopes in their daily work. In this activity, you will find out how microscopes are used in other occupations. You will share your information in a brief presentation.

What to Do

1. Work in groups of two or three. In your group, select an occupation in which a microscope is used, for example:
   - medical laboratory technician
   - mineralogist (someone who studies minerals)
   - forensic laboratory technician (someone who studies evidence related to crimes)
   - gemologist (someone who studies precious stones)
   - metallurgist (someone who studies the properties of metals)
   - petrologist (a geologist who studies the origin and composition of rocks)
2. Research the type of work done by a person in the occupation you have selected. You can find information in the library or on the Internet, or by interviewing people in the occupation. Start your search at www.discoveringscience8.ca. Find answers to the following questions.
   (a) For what purpose does the person use the microscope?
   (b) What type of microscope does the person use?

A forensic scientist uses a microscope to examine a beetle found on a corpse.

   (c) What can be seen through the microscope? (In your presentation, include a typical view. Show this in a circle to represent the field of view of the microscope. Include the magnification, if possible.)
   (d) What does the person do with the information obtained by using the microscope?
   (e) How does using a microscope assist the person at work?
3. Create a presentation based on the occupation you have selected. Make sure you include information on all the questions that you researched. Use appropriate support materials, for example, a pamphlet, poster, overhead transparencies, video, computer, or web site. If possible, produce a multimedia presentation.

What Did You Find Out?

Based on the information in the presentations:

1. List those occupations that make similar uses of the microscope.
2. Identify which occupation uses the microscope in the greatest number of different ways.
3. (a) Which of these occupations is the most interesting to you?
   (b) What do you find interesting about the occupation?
4. Describe how your group's presentation could be improved.

An electron microscope image displayed on a computer screen

Telescopes

You know from experience that it is difficult to see faraway objects clearly. When you look at an object, only some of the light reflected from its surface enters your eye. As the object moves farther away, the amount of light entering your eye decreases, and so the object appears to be dimmer. Scientists have been designing and constructing telescopes for more than 400 years to gather and focus light from faraway stars (Figure 6.27).

A telescope uses a lens or a concave mirror that is much larger than your eye to gather more of the light from distant objects. The largest telescopes can gather over a million times more light than the human eye. As a result, objects such as distant galaxies appear much brighter. Because the image formed by a telescope is so much brighter, the image can be magnified to a greater extent to reveal more detail.

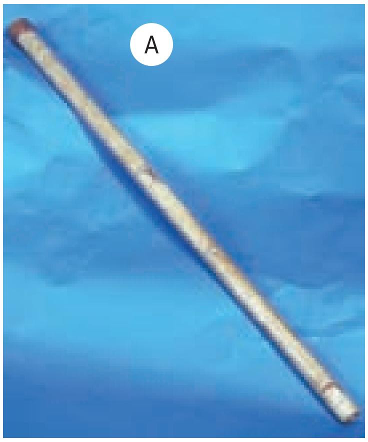


Figure 6.27 (A) Galileo used lenses to build simple telescopes that he used to make discoveries about the Universe. (B) Isaac Newton improved on Galileo's design by using a mirror to collect and begin to focus the light from the stars. This is now known as a reflecting telescope.

Refracting telescopes have similarities to microscopes

A telescope, like a microscope, has an objective lens and an eyepiece lens. However, the objective lens in a telescope has a longer focal length than in a microscope because the objects viewed are far from the lens. The simplest microscopes and telescopes use only two lenses. The lenses bend the light to focus it, which is why a telescope with this design is called a **refracting telescope** (see Figure 6.28).

In both the microscope and the refracting telescope, an objective lens collects light and focusses it into an image (see Figure 6.29). This image is formed inside the microscope or telescope and is never seen directly. Instead, the image is magnified by the eyepiece lens, and directed into the eye of the operator or into a camera.

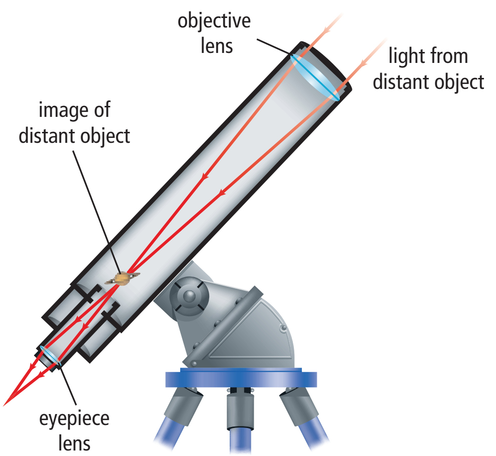


Figure 6.28 Light from a distant object passes though an objective lens and an eyepiece in a refracting telescope. The two lenses produce a large image.

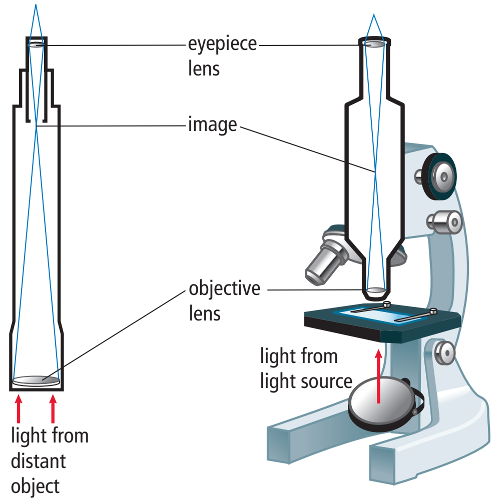


Figure 6.29 In order to focus with a microscope, the object being viewed is moved. In order to focus with a telescope, its eyepiece and the observer are moved.

Figure 6.30 The 102 cm refracting telescope at the Yerkes Observatory in Wisconsin is the largest refracting telescope ever used.

Problems with refracting telescopes

In order to form a detailed image of distant objects, such as planets or galaxies, the objective lens must be as large as possible (Figure 6.30). A large lens is heavy and can be supported in the telescope tube only around its edge. The lens can sag or flex due to its own weight, distorting the image it forms. Also, heavy glass lenses are costly and difficult to make, and even when the highest quality of glass is used, the lens absorbs some of the light.

Reflecting telescopes

Due to the problems with making large lenses, most large telescopes today are **reflecting telescopes**. A reflecting telescope uses a concave mirror, a plane mirror, and a convex lens to collect and focus light from distant objects. Figure 6.31 shows a reflecting telescope. Light from a distant object enters one end of the telescope and strikes a concave mirror at the opposite end. The light reflects off this mirror and converges. Before it converges at a focal point, the light strikes a plane mirror that is placed at an angle within the telescope tube. The light is reflected from the plane mirror toward the telescope's eyepiece. The light rays converge, creating an image of the distant object. Just as in a refracting telescope, a convex lens in the eyepiece then magnifies this image.

Some telescopes used to study distant galaxies collect the light rays from several mirrors and then combine the rays into a single image. One such telescope is the Keck telescope located in Hawaii (see Figure 6.32).

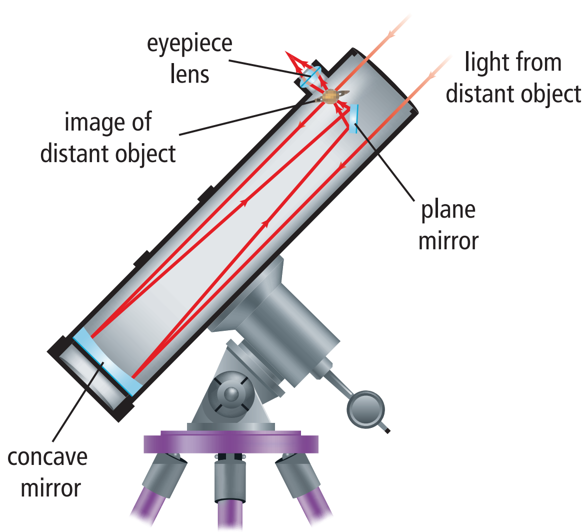


Figure 6.31 Reflecting telescopes use two mirrors to create an image, which is then magnified by a convex lens. In order to focus an image on a reflecting telescope, the eyepiece (convex lens) is moved.

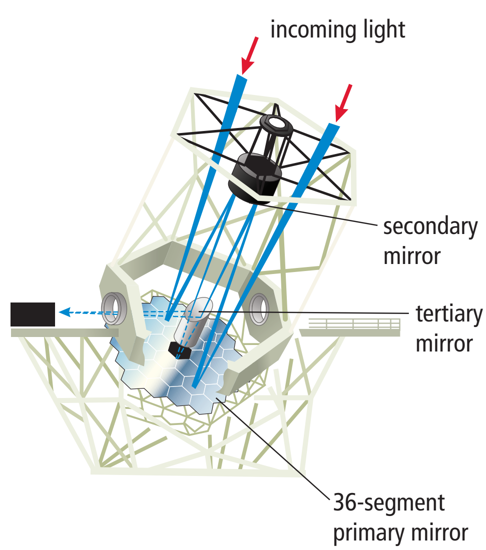


Figure 6.32 The Keck telescope combines light from two mirror systems like the one in the diagram to make a single image that is many times clearer than an image produced by one mirror.

The Hubble Space Telescope

Imagine being at the bottom of a swimming pool and trying to read a sign by the pool's edge. The water in the pool would distort your view of any object beyond the water's surface. In a similar way, Earth's atmosphere blurs the view of objects in space. To overcome the blurriness of our view into space, the Hubble Space Telescope was launched in 1990. The Hubble Space Telescope is a type of reflecting telescope that uses two mirrors to collect and focus light to form an image. The primary mirror in the telescope is 2.4 m across and can collect visible light—as well as other types of electromagnetic radiation—from planets, stars, and distant galaxies. Freed from the distortion caused by Earth's atmosphere, the Hubble Space Telescope has produced images much sharper and more detailed than the largest ground-based telescopes (see Figure 6.33).

internet connect

Find out more about the Hubble Space Telescope, the images it has produced, and Canada's role in servicing the telescope. Start your search at **www.discoveringscience8.ca.**

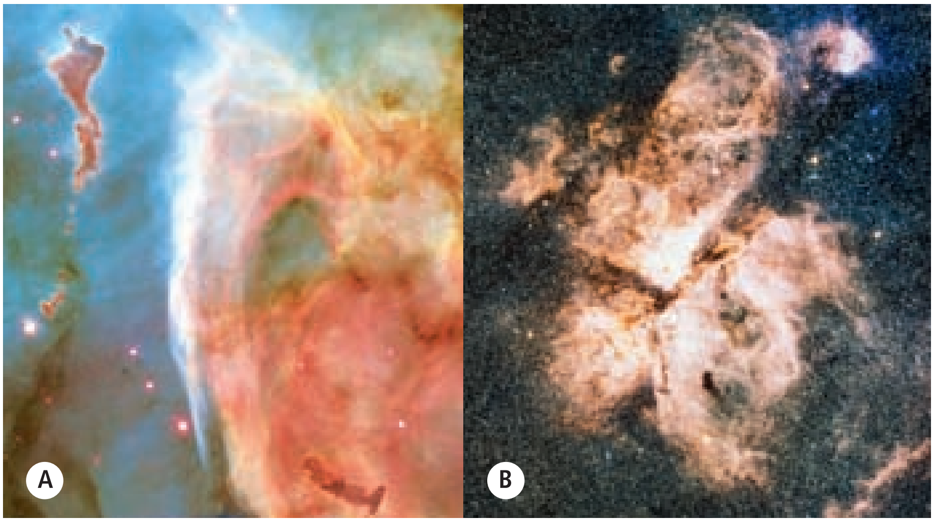


Figure 6.33 The image from the Hubble Space Telescope is clear (A), not blurred by Earth's atmosphere (B).

Binoculars

Binoculars are actually two refracting telescopes mounted side by side. You can imagine how difficult it would be to hold up two long telescopes. The telescopes in binoculars are shortened by placing prisms inside that serve as plane mirrors. Rather than travelling down the long tube of a telescope, the prisms reflect the light in binoculars back and forth inside a shorter tube (see Figure 6.34).

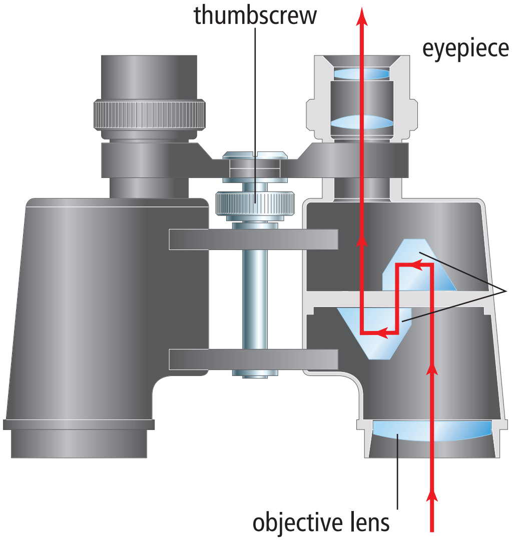


Figure 6.34 The thumbscrew on binoculars is used to change the focal length in order to focus on the objects being viewed.

Cameras

A digital camera works by gathering and bending light with a convex lens. The lens then projects an image onto a light detector to record a digital image of a scene. When you take a photograph, a shutter opens to allow light to enter the camera for a specific length of time. The light reflected off your subject enters the camera through an opening called the **aperture**. The light then passes through the lens, which focusses the image on the light detector. Because a convex lens is used, the image is inverted and smaller than the actual object.

Wide-angle lenses

Suppose you and a friend use two different cameras to photograph the same object at the same distance. If the cameras have different lenses, your pictures might look different. For example, some lenses have short focal lengths that produce a relatively small image of the object but have a wide field of view (see Figure 6.35). These lenses are called wide-angle lenses. Wide-angle lenses must be placed close to the light detector to form a sharp image.

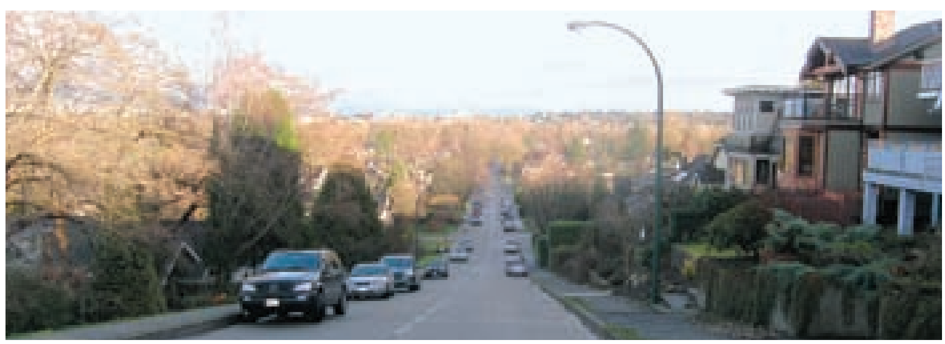


Figure 6.35 A photograph taken with a wide-angle lens

Telephoto lenses

Telephoto lenses have longer focal lengths. The image through a telephoto lens seems enlarged and closer than it actually is (see Figure 6.36). Telephoto lenses are easy to recognize because they usually protrude from the camera to increase the distance between the lens and the light detector (see Figure 6.37).

Figure 6.36 A photograph of the same scene as Figure 6.35 taken with a telephoto lens

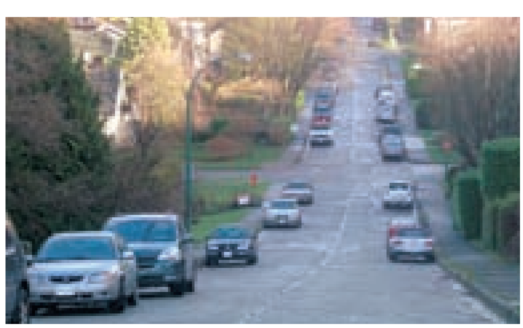


Figure 6.37 A telephoto lens

Cameras Have Similarities to Human Eyes

There are many structural similarities between a camera and the human eye (see Figure 6.38). For example, compare the lens cap for a camera to the human eyelid. Both reduce the chance of accidental damage. An iris limits the amount of light entering the eye. In cameras, this function is accomplished using a device called a **diaphragm**. The diaphragm is made of a number of opaque circles that are arranged in a circle. The circles can be moved to make the central hole larger or smaller. Light passes through the lens and forms an inverted image in both the camera and the eye.

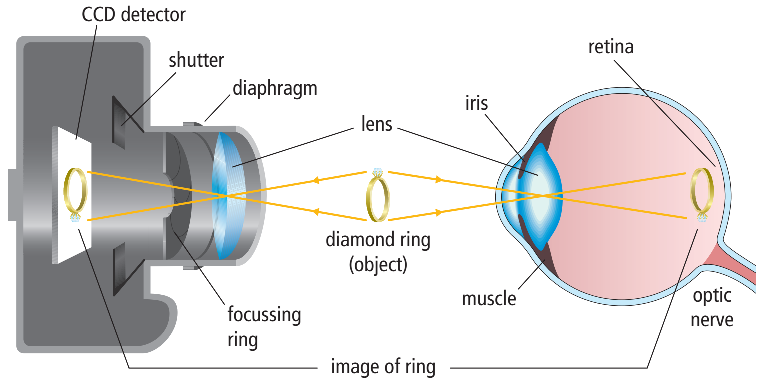


Figure 6.38 A comparison of the camera and the human eye

Not all structures in a camera work the same way as in the human eye. For example, changing the distance between the lens and the detector does the focussing in a camera. Recall that in humans, the lens changes shape, rather than moving closer to the retina.

At the back of the camera is a detector called a **charge-coupled device (CCD)**, which absorbs light and provides the electrical signals needed to produce a digital image. The CCD has many tiny regions, called pixels, each of which is capable of recording a tiny part of the whole image. The pixels correspond to the rods and cones that detect light in our eyes. Research is currently being done to try to connect the electrical signals from a digital camera directly to human optic nerves. This may one day provide a working vision system that will allow people who are blind to see.

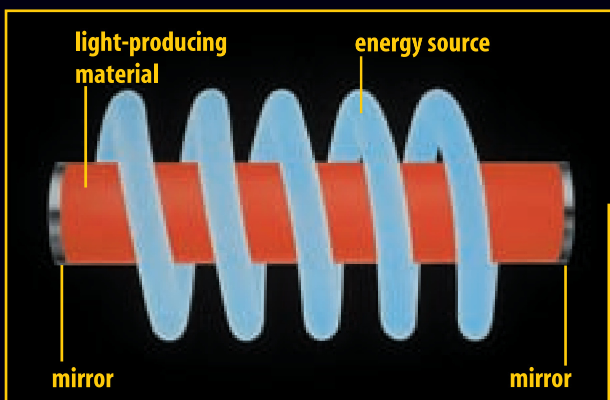
Reading Check

1. How does a microscope magnify an image?
2. How is a reflecting telescope similar to a microscope?
3. How is a reflecting telescope different from a refracting telescope?
4. Why is the Hubble Space Telescope able to produce clearer images than telescopes on Earth?
5. What is the function of prisms in binoculars?
6. How does the focal length of a telephoto lens compare to the focal length of a wide-angle lens?
7. What are two ways in which a camera is similar to a human eye?
8. What are two ways in which a camera is different from a human eye?

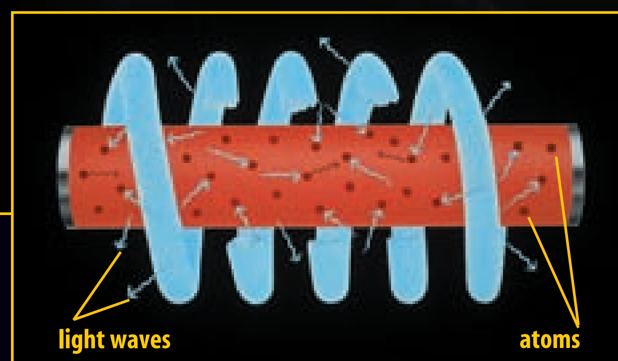
NATIONAL GEOGRAPHIC

VISUALIZING LASERS

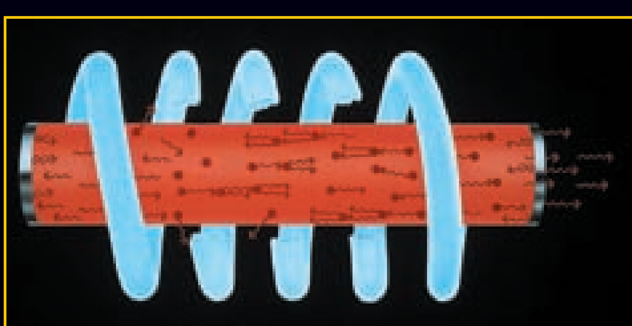
Lasers produce light waves that have the same wavelength. Almost all of these waves travel in the same direction. As a result, beams of laser light can be made more intense than ordinary light. In modern eye surgery, shown at the right, lasers are often used instead of a traditional scalpel.



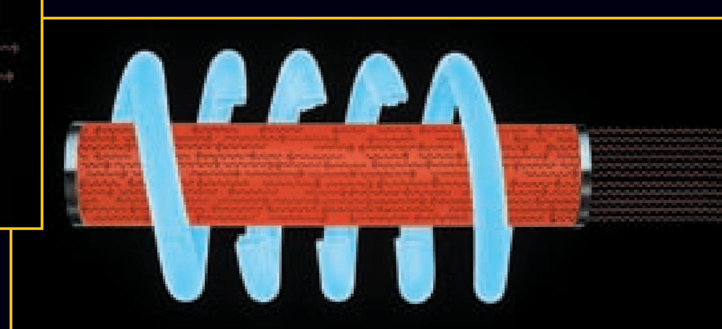
A The key parts of a laser include a material that can be stimulated to produce light, such as a ruby rod, and an energy source. In this example, the energy source is a light bulb that spirals around the ruby rod and emits an intense light.



B When the light bulb is turned on, energy is absorbed by the particles in the rod. These particles then re-emit that energy as light waves that all have the same wavelength. As well, all of the crests and troughs of the waves are aligned.



C Most of these waves are reflected between the mirrors located at each end of the laser. One of the mirrors, however, is only partially reflective, allowing one percent of the light waves to pass through it and form a beam.



D As the waves travel back and forth between the mirrors, they stimulate other particles in the ruby rod to emit light waves. In a fraction of a second, billions of identical waves are bouncing between the mirrors. The waves are emitted from the partially reflective mirror in a stream of laser light.

Will & Deni McIntyre/Photo Researchers

Check Your Understanding

Checking Concepts

1. Make a table that lists the parts of a camera in one column and the function of each part in the other.
2. (a) Make a labelled diagram to show the arrangement of lenses in a refracting telescope.
   (b) Show how light rays pass from a distant object to the eye of a person looking through the eyepiece.
3. (a) Which lens in a microscope is responsible for producing a magnified image on the inside of the microscope that is not seen directly by the person using the microscope?
   (b) Why is this image produced?
4. Explain the difference(s) between a reflecting telescope and a refracting telescope.
5. Compare the focal length, image size, and field of view for wide-angle lenses and telephoto lenses.

Understanding Key Ideas

6. (a) Explain why telescopes used to study distant galaxies need to have such large mirrors.
   (b) Give two reasons why a large lens is inferior to a large mirror in a telescope.
7. Is the image produced by a microscope real or virtual? Draw a ray diagram to support your answer.
8. Why do you think that modern research telescopes are so large?
9. Centuries ago, Galileo and Isaac Newton worked independently to construct refracting and reflecting telescopes. Why do you think it is necessary for large groups of scientists and engineers to work together to design and build modern telescopes, such as the Hubble Space Telescope?

Pause and Reflect

Below are two photographs, one taken through a telescope and the other through a microscope. One is of Earth, taken from above the Moon. The other is of common bacteria called *E. coli*, which are found in the mouth of every healthy person on Earth. These two viewpoints were unknown to humans only three generations ago. Reflect on each, select one, and explain why being able to see this scene might be important to how humans see the world.

Prepare Your Own Summary

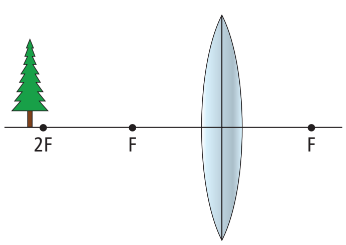
In this chapter, you investigated how lenses work, how we see, and how human vision can be extended using optical systems. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. Use the following headings to organize your notes:

1. Ray Diagrams for Convex and Concave Lenses
2. How We See
3. Correcting Focus Problems
4. Using Optical Systems to Magnify Close Objects
5. Using Optical Systems to See Distant Objects

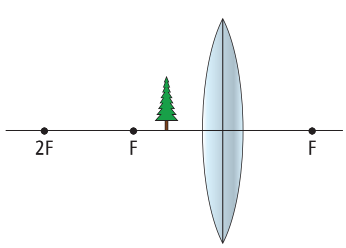
Checking Concepts

1. What type of lens can make parallel rays converge, or come together?
2. What type of lens always makes parallel rays diverge, or spread out?
3. Copy the following diagrams of convex lenses in your notebook. For each, complete a ray diagram using three rays. Describe the characteristics of the image.

(a)



(b)



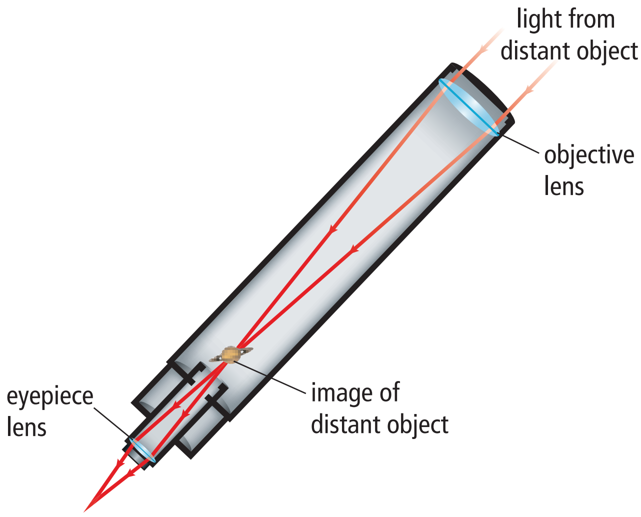
4. (a) Which type of lens, convex or concave, should a person who is near-sighted use? Explain.
   (b) Which type of lens, convex or concave, should a person who is far-sighted use? Explain.
5. What is astigmatism?
6. Draw a diagram showing the mirror and lens arrangement in a reflecting telescope.
7. (a) Explain how focussing occurs in a microscope.
   (b) Explain why this type of focussing would not work for a telescope.
8. Binoculars are similar to two telescopes mounted in parallel, except that they are not very long. How is this shortening accomplished?

Understanding Key Ideas

9. Many people over 50 years old wear reading glasses. Why do you think this is the case?
10. Explain why it takes a few minutes to be able to see when you walk from full daylight into a darkened room. List the adaptations that happen in the eye to adjust to low-light vision.
11. Explain why mirrors have one focal point but lenses have two focal points. Describe the relationship between the two focal points of a lens.
12. When a nearsighted person looks at an object without wearing glasses or contact lenses, the image is blurry. Explain the cause of this blurriness.

13. One type of lens can produce an image that is inverted, real, larger than the object, and farther from the lens than the object. Is this lens convex or concave? Where is the object relative to the focal point? Sketch a ray diagram that verifies your answer.

14. State the function in a telescope of:
   (a) objective lens or mirror
   (b) eyepiece lens



15. Why is the image that you observe in a refracting telescope inverted?

16. Suppose your camera is focussed on a person who is 2 m away. You now want to focus on a tree that is farther away. Should you move the lens closer to the CCD or farther away? Explain your answer.

17. When you use the highest magnification on a microscope, the image is much darker than it is at lower magnifications.
   (a) What are some possible reasons for the darker image?
   (b) What could you do to obtain a brighter image?

Pause and Reflect

Eyeglasses were first developed in Italy in the 13th century and were used mainly by nobles and the clergy. Then, in 1456, Johannes Gutenberg invented the printing press. What effect do you think the availability of eyeglasses had on the number of books printed? What effect do you think the number of books printed had on the production of eyeglasses? If eyeglasses were not available, would books have become an important source of information? Explain your ideas.

UNIT 2

Unit Summary

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

- Humans built telescopes and microscopes before they understood the nature of light. (4.1)
- Waves are disturbances that transmit energy from one place to another. (4.2)
- Waves have amplitude, wavelength, and frequency. (4.2)
- As wavelength decreases, frequency increases. (4.2)
- Different colours of light have different wavelengths. (4.3)
- White light is a mixture of many wavelengths of light. (4.3)
- A prism can separate and recombine different colours of light (4.3)
- The electromagnetic spectrum is made up of waves that are similar to light waves that have much longer or shorter wavelengths. (4.4)
- Radio waves, microwaves, and infrared waves have longer wavelengths than visible light. (4.4)
- Ultraviolet waves, X rays, and gamma rays have shorter wavelengths than visible light. (4.4)

5 The law of reflection allows mirrors to form images.

- The angle of reflection is equal to the angle of incidence. (5.1)
- Reflection can be either specular or diffuse, depending on the reflecting surface. (5.1)
- An image in a plane mirror is virtual and is the same size, orientation, and distance from the mirror as the object. (5.2)
- A concave mirror curves in at the centre and a convex mirror curves out. (5.3)
- Images in concave mirrors can be real or virtual, upright or inverted, larger or smaller than the object, depending on the distance between the object and the mirror. (5.3)
- Images in a convex mirror are virtual, upright, and smaller than the object. (5.3)
- Ray diagrams allow you to predict the characteristics of images in mirrors. (5.3)

6 Lenses refract light to form images.

- The characteristics of images produced by convex lenses depend on the distance of the object from the lens. (6.1)
- Images produced by concave lenses are always upright, virtual, closer to the lens, and smaller than the object. (6.1)
- Light is detected by the eye using the cornea-lens-retina system. (6.2)
- Rod cells detect dim light but are not sensitive to colour. (6.2)
- Cone cells dominate in bright light and distinguish between colours. (6.2)
- Vision deficiencies include near-sightedness, far-sightedness, astigmatism, and deficiencies in distinguishing between different colours. (6.2)
- Eyes, cameras, microscopes, and telescopes have some similarities in the way they operate. (6.3)
- Microscopes and refracting telescopes use only lenses to magnify objects, while reflecting telescopes use both mirrors and lenses. (6.3)

Key Terms

- amplitude
- compression wave
- crest
- electromagnetic radiation
- energy
- force
- frequency
- gamma rays
- hertz
- infrared waves
- medium
- microscope
- microwaves
- Pythagoras
- radiant energy
- radio waves
- reflection
- refraction
- spectrum
- telescope
- transverse wave
- trough
- ultraviolet waves
- visible light
- wave
- wave model of light
- wavelength
- X rays

Key Terms

- angle of incidence
- angle of reflection
- angle of refraction
- concave mirror
- convex mirror
- diffuse reflection
- extended rays
- focal point
- image
- image distance
- incident ray
- inverted
- law of reflection
- normal
- object distance
- opaque
- particle model of light
- plane mirror
- principal axis
- ray diagram
- ray model of light
- real image
- rectilinear propagation
- reflected ray
- refracted ray
- specular reflection
- translucent
- transparent
- upright
- vertex
- virtual image

Key Terms

- aperture
- astigmatism
- blind spot
- blindness
- charge-coupled device (CCD)
- colour blindness
- concave lens
- cone cells
- convex lens
- cornea
- diaphragm
- far-sighted
- focal length
- iris
- lens
- near-sighted
- night blindness
- optical centre
- optic nerve
- pupil
- reflecting telescope
- refracting telescope
- retina
- rod cells
- sclera
- snow blindness

Building an Optical Device

Modern optical technologies make use of combinations of lenses, mirrors, prisms, and other optical elements. In this project, you will design, build, and test a device that uses both mirrors and lenses.

Problem

Design an optical device that uses at least three stages. You must use at least one mirror and at least one lens. You can use more if you choose. You will use the device to see behind you or around corners and to see distant objects clearly.

Safety

- use care when handling sharp glass objects and scissors.

Materials

- variety of lenses (convex and concave)
- plane mirrors (one or more)
- cardboard
- tape
- scissors
- glue
- ruler
- pencil

Criteria

- In a small group, design and build an optical device.
- The device must use both mirrors and lenses.
- The device must allow you to magnify tiny or distant objects, or to see behind you, over a barrier, or around a corner.
- The image must be clear.

Procedure

1. With your group, brainstorm ideas about what you will build. The toy periscope shown here might give you some ideas.
2. Make a sketch of the device with specifications including dimensions. List the materials that you will need.
3. Collect the materials that you will need.
4. Show your plans to your teacher and get approval before you begin to build your device.
5. Assemble and test your device. If it does not work the way you intended for it to work, discuss what modifications you could make.
6. If necessary, make modifications until your device functions properly.

Report Out

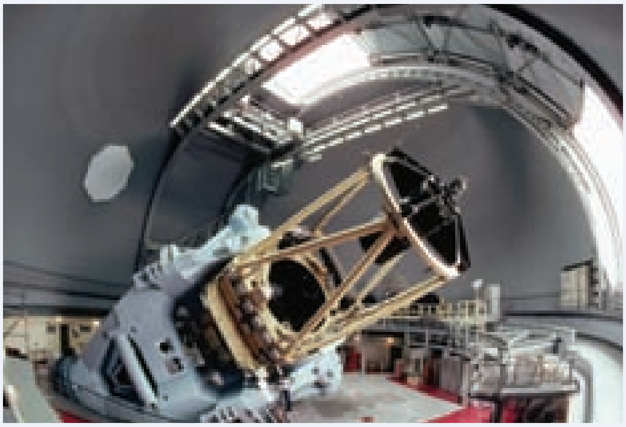
1. In your small group, plan a presentation that you can report to your class.
   - Include the materials that you used.
   - Explain and demonstrate how your device works.
   - Discuss the problems that you encountered and how you solved them.
2. Evaluate your device. Discuss how well it met your original expectations.

Mirrors for Reflecting Telescopes

You have learned a lot about mirrors and lenses and how they are used. In this investigation, you will do research to learn more about one specific application of mirrors for astronomical telescopes.

Background

Galileo designed and built refracting telescopes. Isaac Newton designed and built the first reflecting telescope in 1668. These early telescopes were used to make important discoveries, such as the moons of Jupiter. Astronomers today, however, are building "bigger and better" telescopes. Most large astronomical telescopes are reflecting telescopes. Some, like the one shown here, do not even look like telescopes.



All modern reflecting telescopes have very large mirrors. Some are as large as 10 m in diameter. Other telescopes have several different mirrors that work together. Some institutions are developing liquid mirrors like the one in the photograph on the right for use in telescopes.

Find Out More

Use print resources and the Internet, starting at **www.discoveringscience8.ca**, to learn more about mirrors for large astronomical telescopes. The following questions provide a starting point.

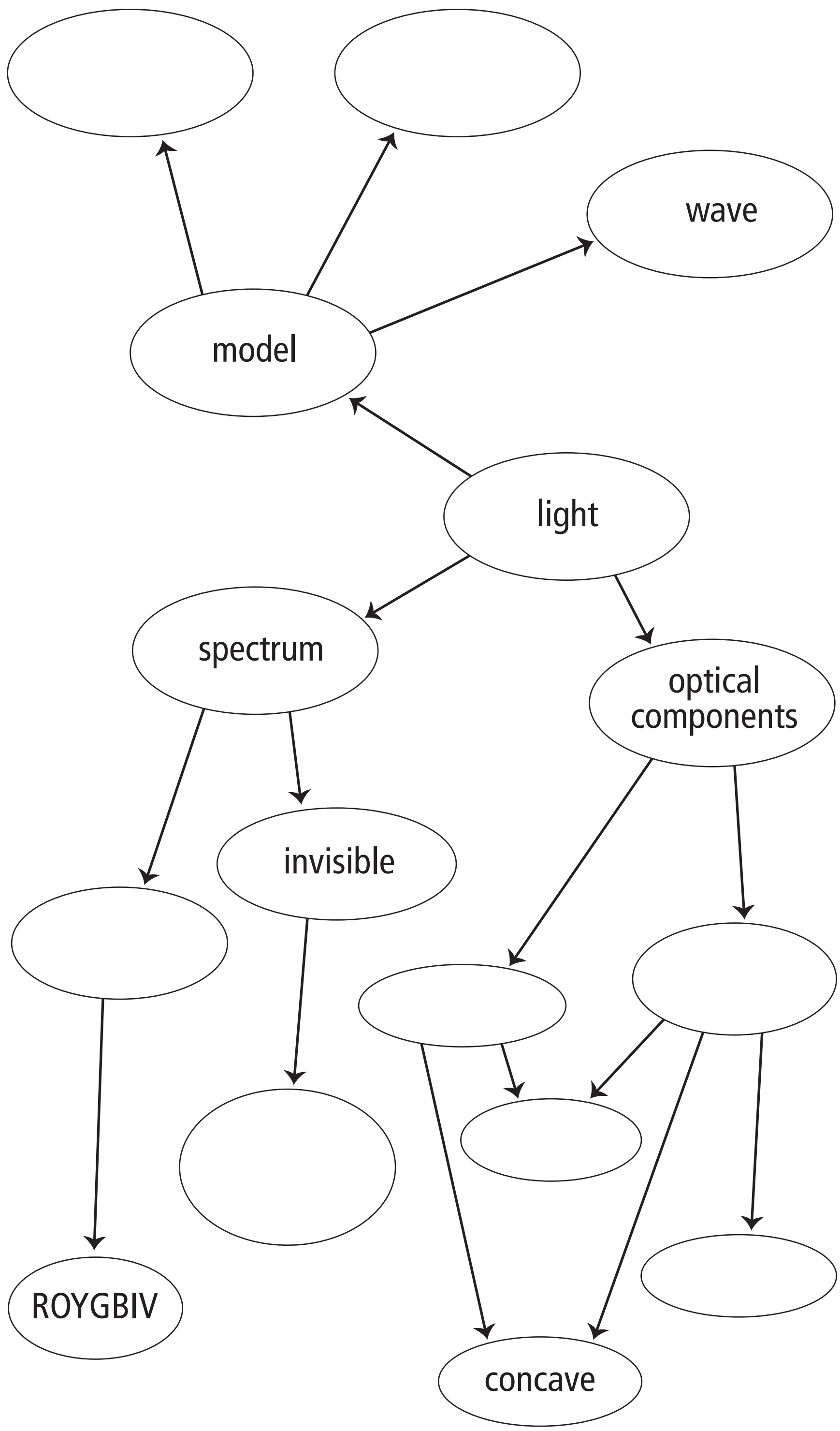
- Why are telescope mirrors so large? What can astronomers learn by using these extremely large mirrors that they cannot learn with smaller telescopes?
- What is a liquid mirror? How can a liquid have a curved surface necessary for collecting and focussing light?
- How big is the largest mirror for a telescope?
- How heavy are the large mirrors?

Report Out

Prepare a poster, brochure, or electronic presentation that you could use to provide information to your classmates. Include photographs, a discussion, and a summary or the things that you learned through your research. If possible, give an oral presentation to your class.

Visualizing Key Ideas

1. Copy the concept map about light into your notebook. Complete the concept map to help review Unit 2.



Using Key Terms

2. Indicate whether the following statements are true or false. If a statement is false, rewrite it to make it true.
   (a) The amplitude of a wave is the distance from a crest to a tough.
   (b) Infrared waves transfer heat.
   (c) Translucent materials prevent light from penetrating the object.
   (d) Refraction is the bending of the direction of a wave when it passes from one medium to another.
   (e) Specular reflection scatters light, preventing the formation of an image.
   (f) The angle of reflection is the angle between a reflected wave and the reflecting surface.
   (g) A real image can be seen if you place a screen where the image is focussed.
   (h) When parallel rays are reflected from a convex mirror, they travel toward each other and pass through the focal point.
   (i) Concave mirrors always spread light out, and therefore cannot form images.
   (j) When a ray passes from a less dense medium to a more dense medium, the ray bends away from the normal.
   (k) Far-sighted vision results when light rays produce an image before they reach the retina.
   (l) Convex lenses always form virtual images.
   (m) Microscopes have objective lenses but telescopes do not.
   (n) A refracting telescope is made of a combination of lenses and mirrors.

Checking Concepts

4

3. Describe one situation in which early technologies involving light made new scientific discoveries possible.
4. Draw a light wave. Label amplitude, wavelength, trough, and crest.
5. Explain how a prism affects white light that passes through it.
6. How do transparent and translucent materials differ when light strikes them?
7. Explain why light, but not sound, can travel through a vacuum.
8. Describe one application of microwaves and one application of X rays.

5

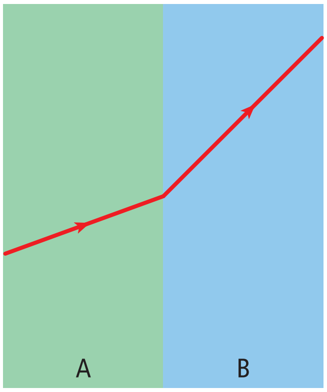
9. State the law of reflection.
10. How can light rays that are involved in both specular and diffuse reflection all follow the law of reflection?
11. Explain how a change in the speed of a wave can cause a change in the direction of a wave.
12. Describe the characteristics of images formed by plane mirrors.
13. When drawing a ray diagram for a concave mirror, one of the rays that you draw goes from the top of the object through the focal point to the mirror. How will you draw the reflected ray?
14. What will be the characteristics of the image of an object that is between the focal point and twice the distance to the focal point from a concave mirror? If you need to, draw a ray diagram to analyze the image.
15. Make a sketch to show how you would find the focal point for a convex mirror.
16. Explain the difference between real and virtual images.

6

17. When you are drawing a ray diagram for convex lenses, one of the rays you draw goes from the top of the object, parallel to the principle axis, to the lens. How do you draw the refracted ray?
18. Where must the object be located in order for a convex lens to produce an image that is real, inverted, smaller than the object, and closer to the lens than the object? If you need to, sketch a ray diagram to find an answer.
19. How does the distance of the object from a concave lens affect the image? For example, as the object moves farther from the lens, what happens to the characteristics of the image?
20. Describe how the shape of the lens in your eye changes when you look at a nearby object, and then at a distant object.
21. What type of lens can correct nearsightedness? Use a diagram to demonstrate why your answer is correct.
22. List and describe four common defects in human vision.
23. Draw a labelled diagram showing how binoculars work.
24. Compare and contrast a refracting telescope and a microscope.

Understanding Key Ideas

25. Summarize two uses of the invisible spectrum in producing medical images of the human body.
26. Describe two properties of light and one other type of electromagnetic wave that support the idea that they are two different types of the same general kind of wave.
27. Explain the properties of light and reflection that make it possible to read black print on a white piece of paper.
28. Explain why you can see your image in a mirror but when you look at a piece of very smooth white paper, you do not see an image even though the paper reflects the light according to the law of reflection.
29. Defend the statement: A concave mirror could be used to form an image on a screen, but a convex mirror could not.
30. Compare how colour vision works with how black-and-white vision works.
31. Explain the functions of the objective and eyepiece lenses in a microscope.
32. Examine the ray diagram below in which the green and the blue regions represent different media. Which medium is more dense? Explain.



33. Explain how you would determine the focal length of a convex lens.
34. Why do mirrors have only one focal point but lenses have two?

Thinking Critically

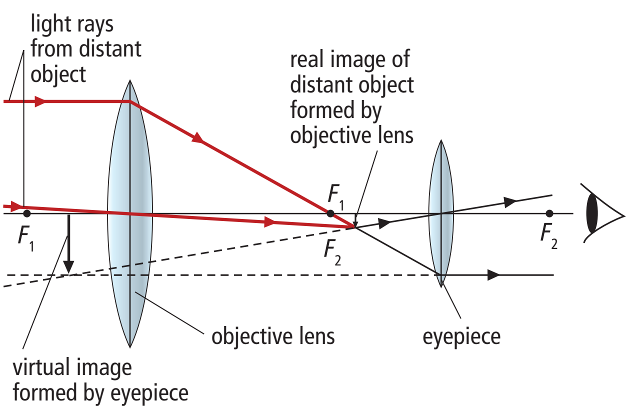
35. A lens made of plastic is placed in a liquid. Light rays travelling in the liquid are not refracted when they pass through the lens. Compare the speed of light in the plastic and in the liquid.

36. A person takes a photograph of an image in a plane mirror. If the camera is 2 m in front of the mirror, at what distance should the camera lens be focussed?

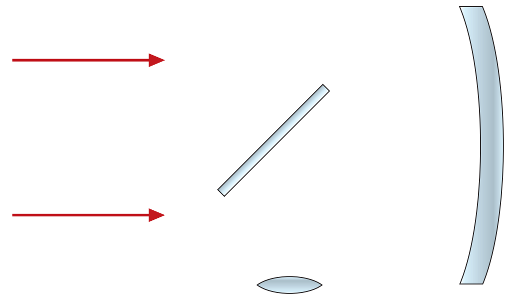
37. What would happen to an image made by projecting light through a lens onto a screen if you cover the left half of the lens with your hand?

Developing Skills

38. The diagram below is a ray diagram for a refracting telescope. Follow each ray. Explain why each ray was drawn as it was according to the rules for drawing ray diagrams.



39. The diagram below shows the elements in a reflecting telescope. There is a concave mirror, a flat mirror, and a convex lens. The arrows represent light rays coming from a distant star. Copy the diagram and show where the rays go and how they reach the observers eye.



Pause and Reflect

As people age, the lenses of the eyes stiffen and the muscles cannot make the lenses change shape. This makes it difficult to focus on nearby objects. Some people wear reading glasses to correct for this problem. Others need bifocal glasses, which have a small section in the lower part of the lens that corrects for reading. Do you think bifocals would be worn by near-sighted or far-sighted individuals?