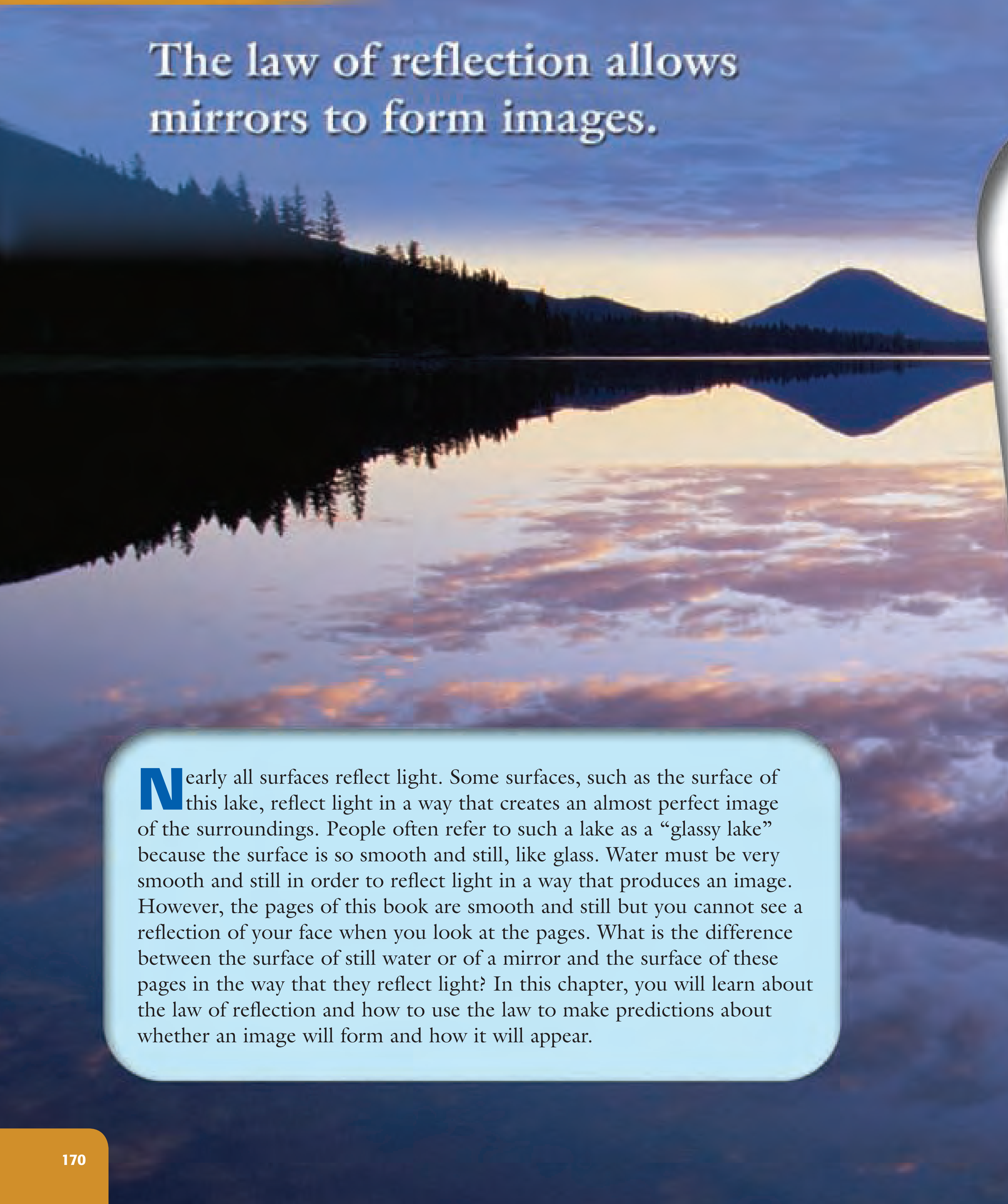
Chapter 5

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.

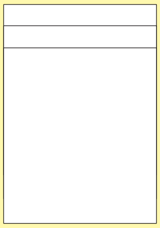
Skills You Will Use

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

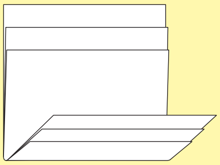
FOLDABLES™ Reading & Study Skills

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

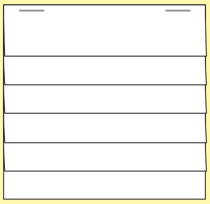
STEP 1 **Collect** 3 sheets of letter-sized paper and layer them about 2.5 cm apart vertically. (Hint: from the tip of your index finger to your first knuckle is about 2.5 cm.) Keep the edges level.



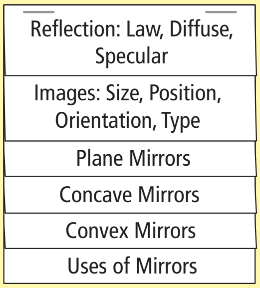
STEP 2 **Fold** up the bottom edges of the paper to form 6 tabs.



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).

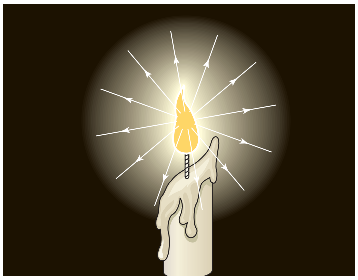


Figure 5.2 A ray is an imaginary line showing the direction in which light is travelling.

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.

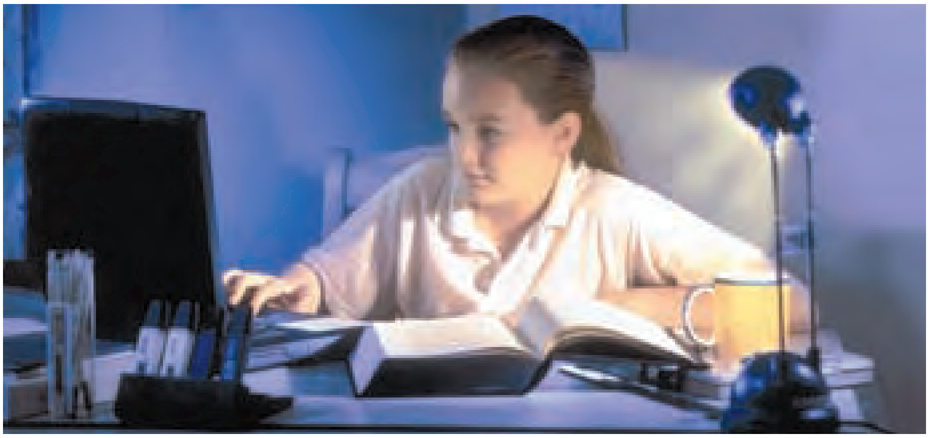
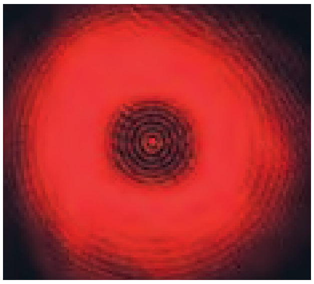


Figure 5.3 In order for you to see an object, it must reflect some light back to your eyes.

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.

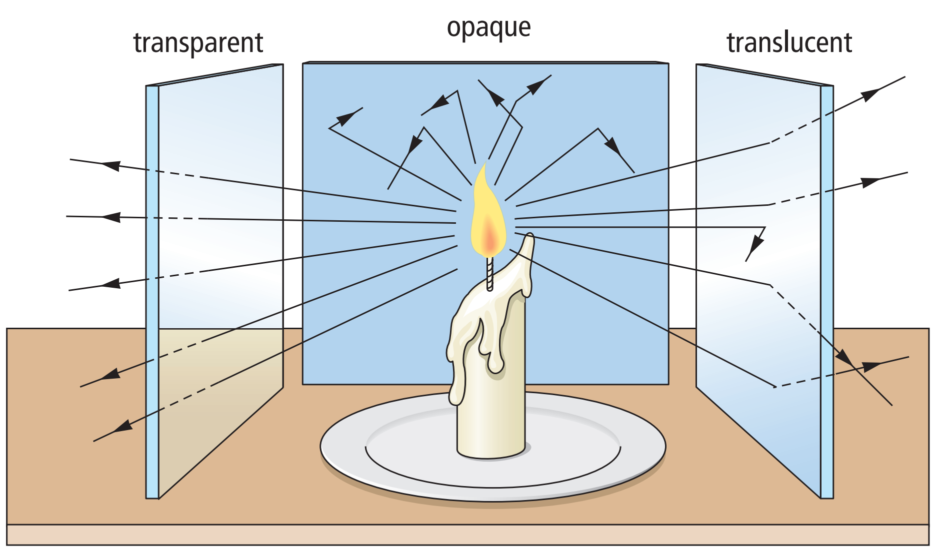


Figure 5.5 Light travels in straight lines until it strikes something.

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.**

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.

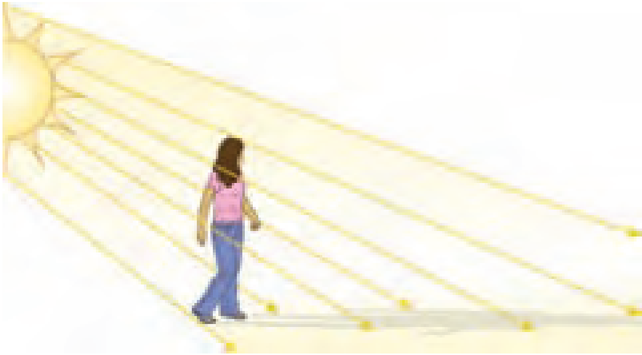


Figure 5.6 Ray diagrams can show how shadows are cast.

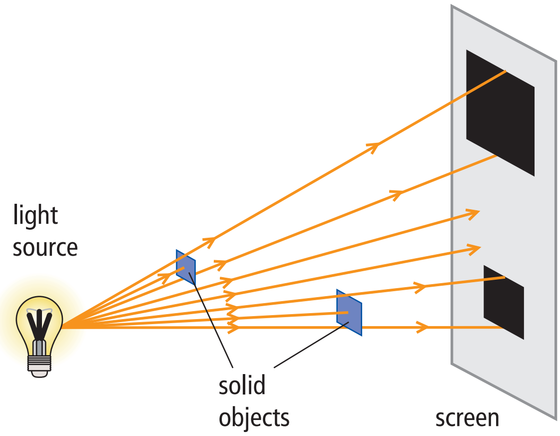


Figure 5.7A A ray diagram shows how the distance from the light source affects the size of the shadow that an object makes. The smaller object casts the larger shadow because it is closer to the light source.

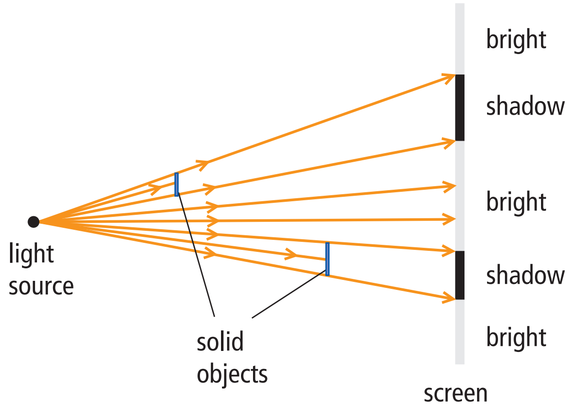


Figure 5.7B To make ray diagrams easier to draw and to visualize, you usually draw them as though you were looking at the objects from the side. You can represent the light source with a dot.

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?

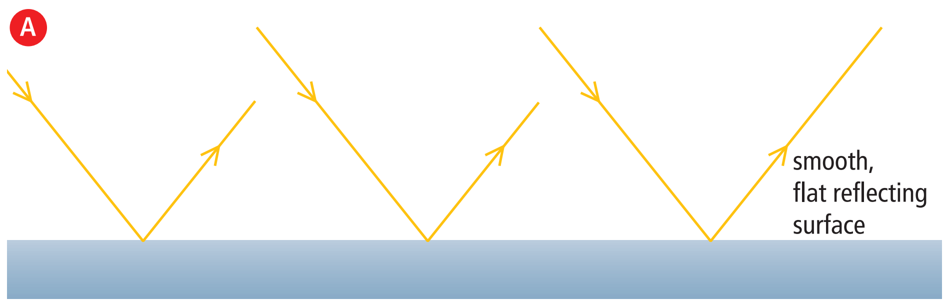
Light Can Be Reflected

Suggested Activity

Find Out Activity 5-1C on page 183

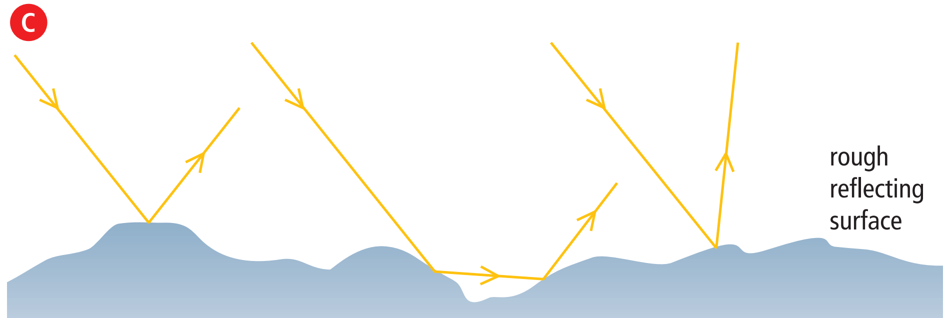
This book uses black letters printed on white paper. The black ink is opaque because all the light falling on the ink is absorbed. But the white paper reflects all of the light that falls on it. Does that mean the white paper is a mirror? If so, why can you not see your reflection in the white parts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

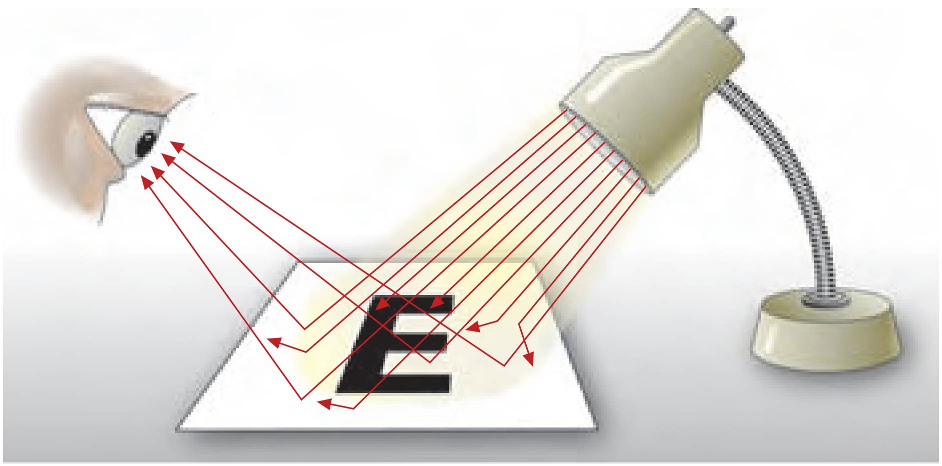


Figure 5.9 The black print ink on the page absorbs all of the light that hits it. No light from the black areas reaches your eyes. Diffuse reflection from all of the rest of the page reaches your eyes, allowing you to see the uneven surface of the paper.

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°.

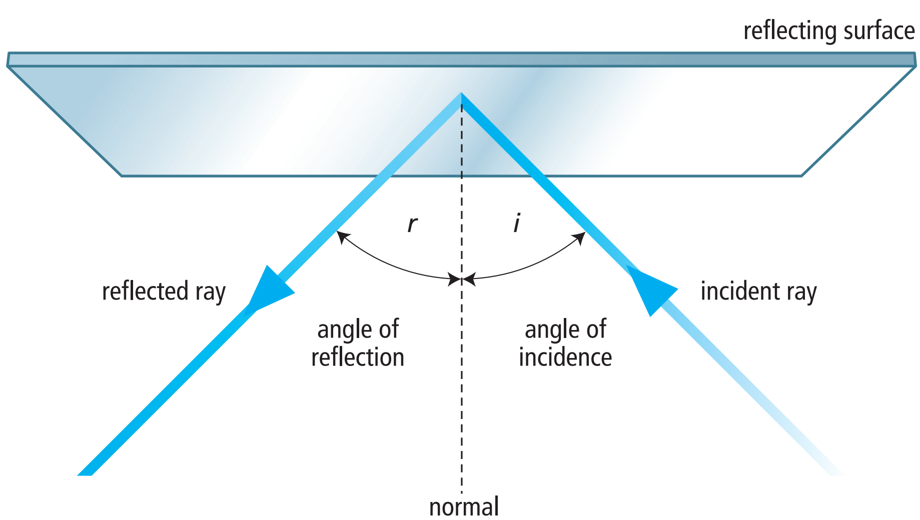


Figure 5.10 Light reflected from any surface follows the law of reflection.

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.

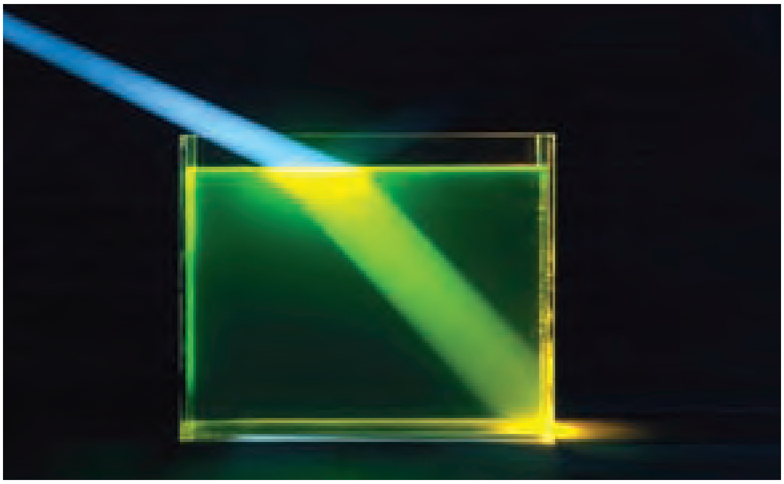


Figure 5.11 You can see the beam of light in air because there are dust particles in the air that scatter the light. You can see the beam of light in the water because there is a substance in the water that fluoresces. (To fluoresce means to give off more visible light than is absorbed.) These "tricks"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

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.

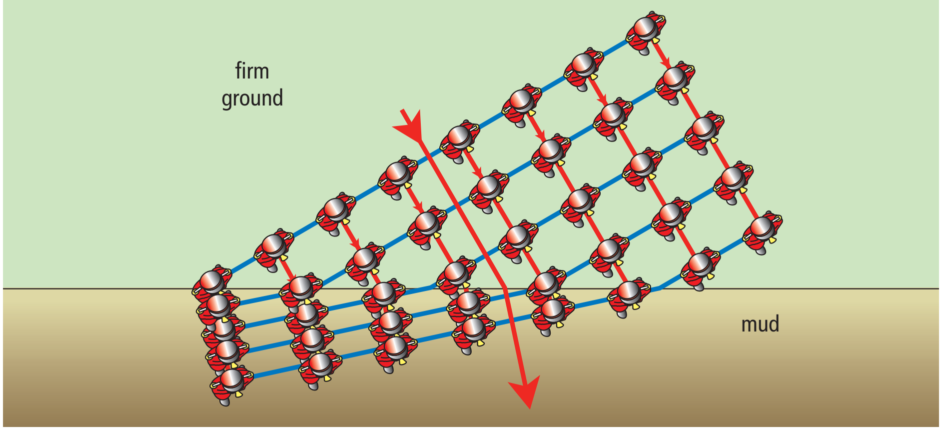


Figure 5.12 Each row of students represents the crest of a wave. When one end of the wave front slows down, the direction of the wave changes.

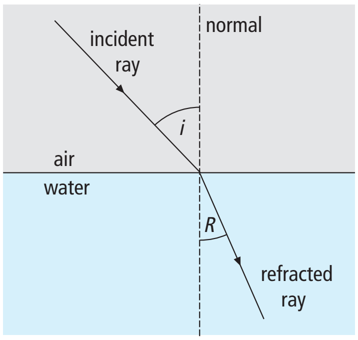


Figure 5.13 The terms, incident ray, normal, and angle of incidence all have the same meaning in refraction that they had in reflection. The new terms are "refracted ray" and "angle of refraction."

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.

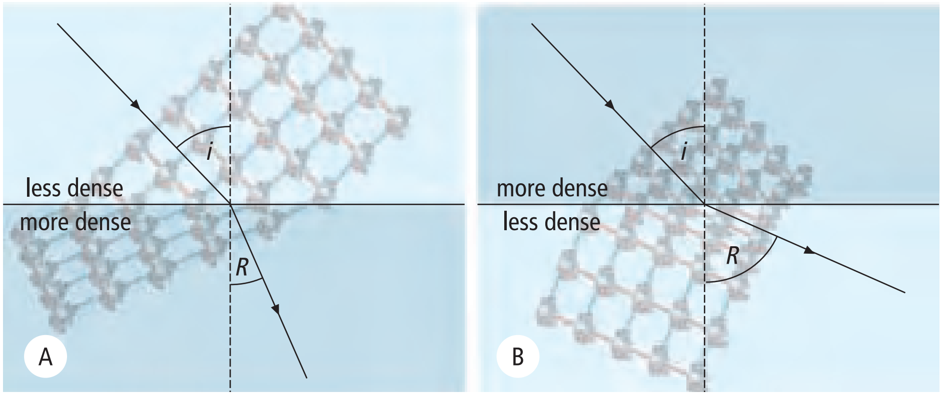


Figure 5.14 The direction in which a refracted ray travels depends on whether the second medium is more dense or less dense than the first medium. In A, the light is slowing down as it enters the denser medium, just as the marching band is slowing down as they march into the mud. In B, the light is speeding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

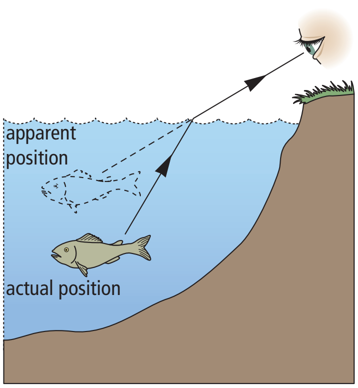


Figure 5.16 Objects under water are never where they appear to be. Water never looks as deep as it really is.

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.

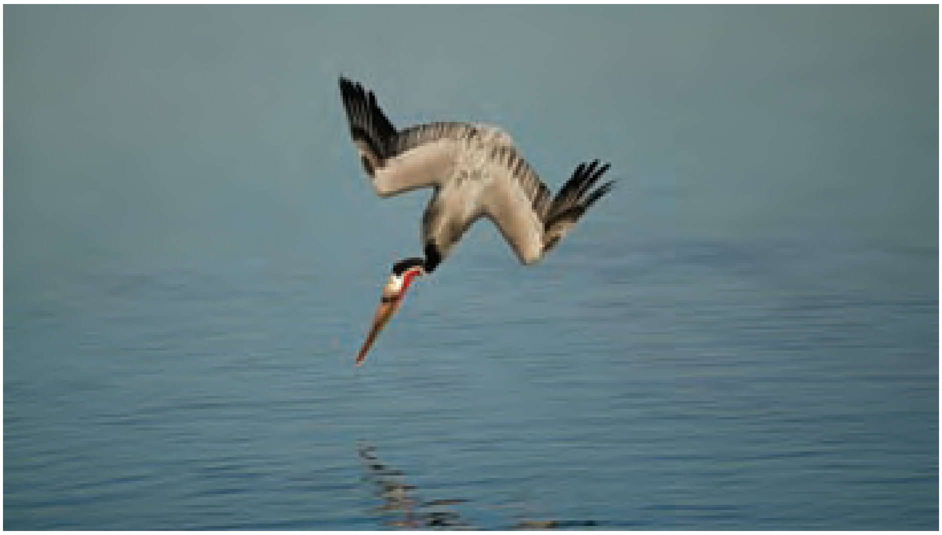


Figure 5.17 Fishing birds dive under water to catch their meal.

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

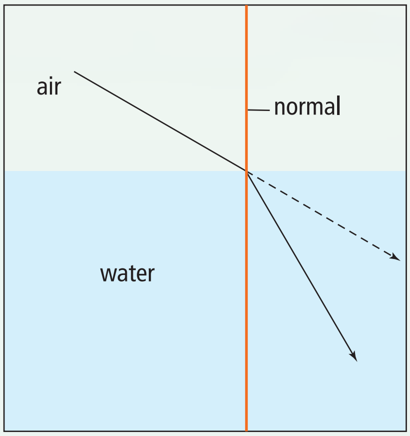
Materials
- ray box
- sheet of white paper
- transparent plastic, watertight tray (box top from greeting cards, candles, etc.)
- ruler
- protractor
- water
- vegetable oil
- rubbing alcohol

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.

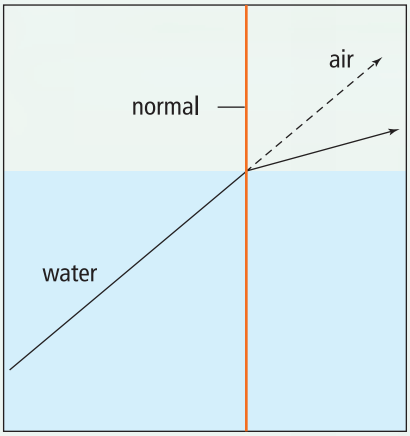
Question
Is there a pattern that describes the path of light during refraction?

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.

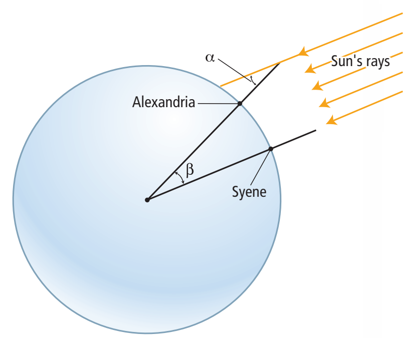
Eratosthenes was a Greek mathematician, born in North Africa in 276 B.C.E.

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

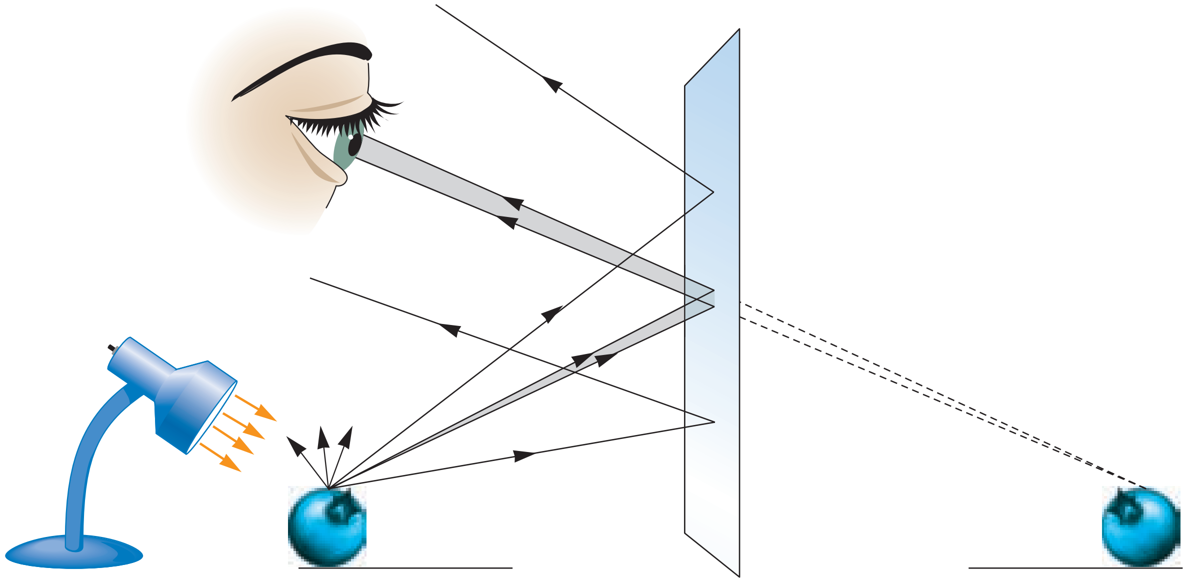


Figure 5.18 Only a small fraction of the light reflecting from an object enters the eye of the observer.

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).

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.

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.

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.

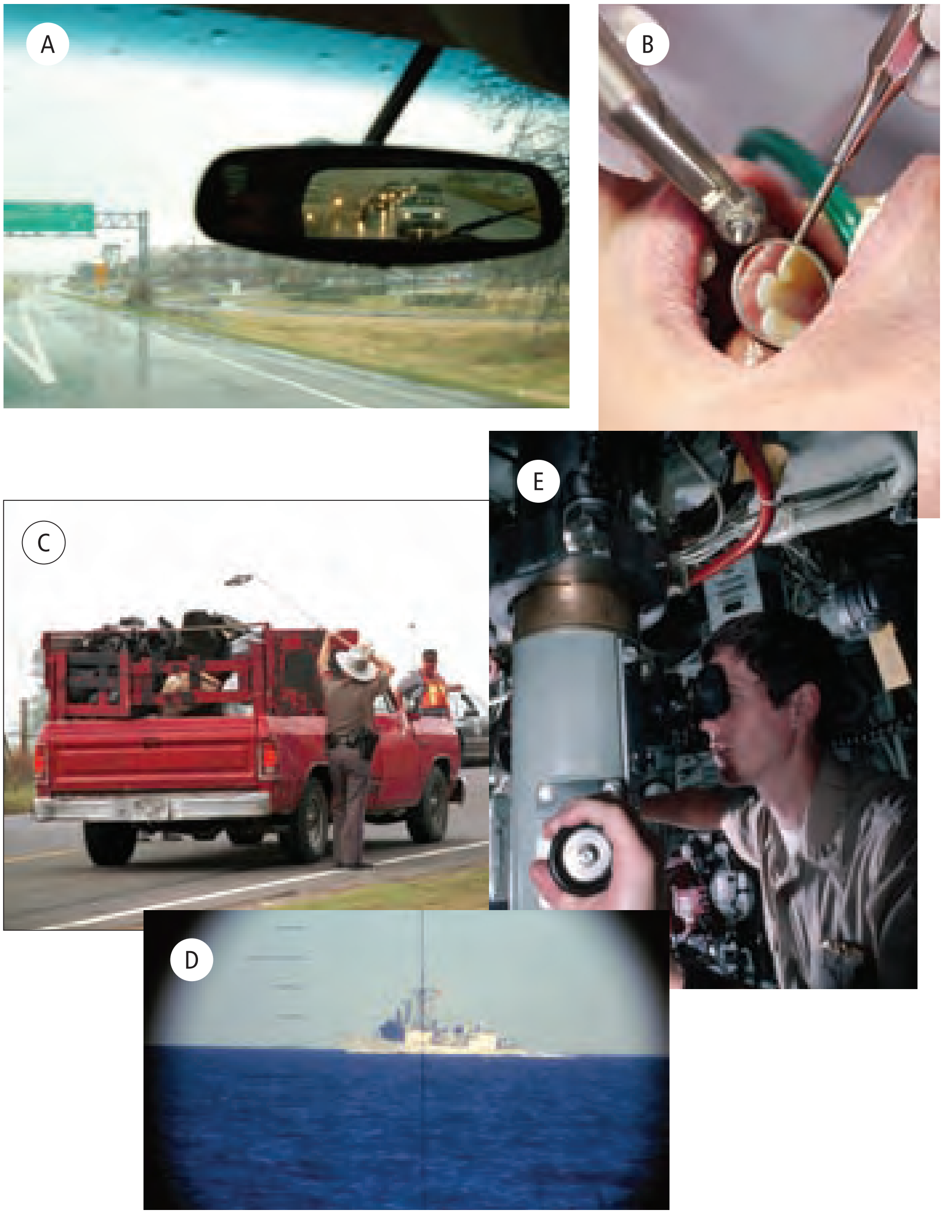


Figure 5.20 Some mirrors are just for convenience. However, many mirrors have a very important function. (A) A driver needs a rear view mirror to see what is behind the car without turning all the way around. (B) The dentist needs a dental mirror to see the inside of your teeth in order to find cavities 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."

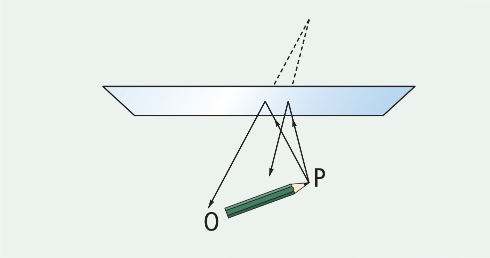
2. Lay the small object on the paper. Place it about 5–10 cm in front of the line representing the plane mirror. Trace the shape of the object. Label the pointed end "P" and the blunt end "O."
3. Remove the object. Draw two different straight lines from point P to the line labelled "plane mirror." On 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.

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

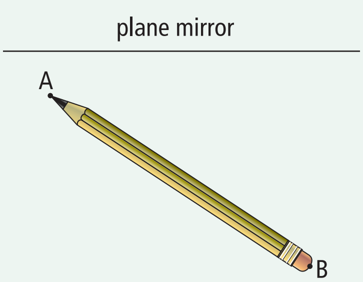
- Predicting
- Observing
- Analyzing
- Communicating

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?

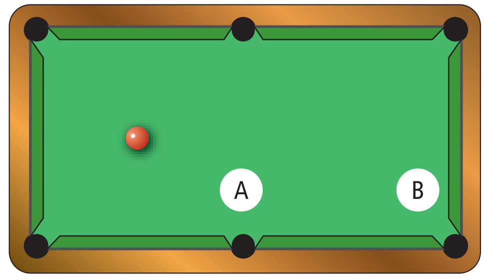
Check Your Understanding

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.

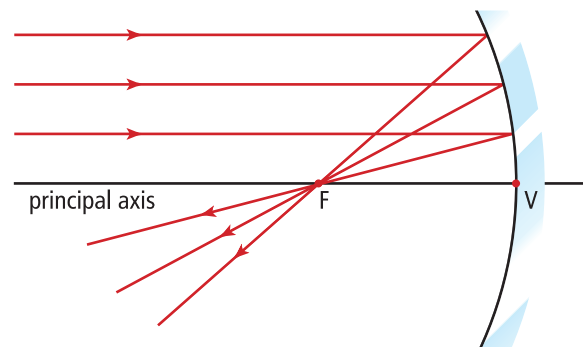


Figure 5.23 The principal axis is normal to the centre of the concave mirror. Rays that are parallel to this axis will all reflect through the focal point.

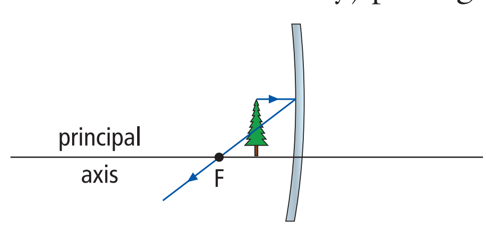
Ray Diagrams for Concave Mirrors

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.

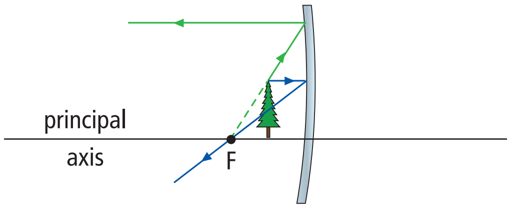
Finding the position of the bottom of the image is easy if you place the object on the principal axis, which is normal to the mirror. A light ray travelling from the bottom of the object to the mirror will reflect directly backward, so the bottom of the image will also sit on the principal axis.

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

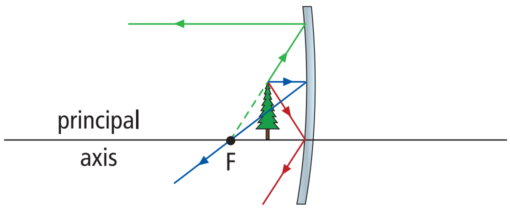
1. Draw a ray parallel to the principal axis, with the reflected ray (or an extension of the reflected ray) passing through the focal point.



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.)

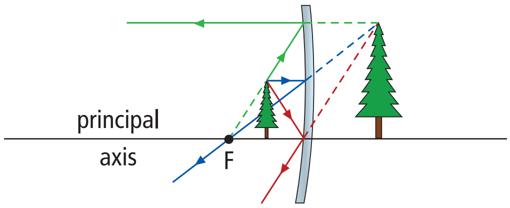


3. Draw a ray travelling to the vertex and reflecting at the same angle.



(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.

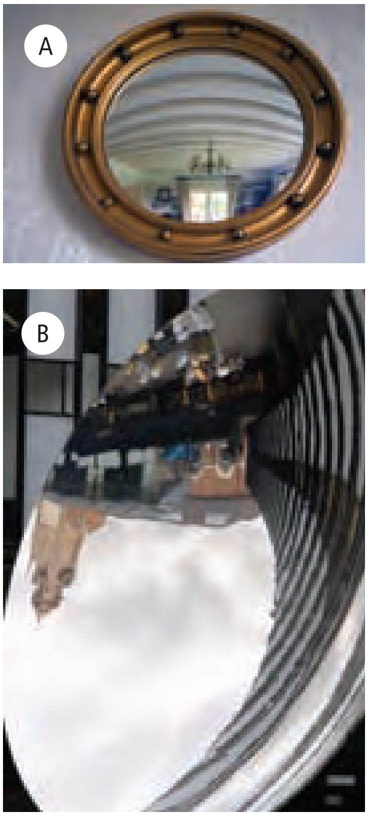


Figure 5.24 Both of these mirrors are concave mirrors. Why is one image upside down and the other right side up?

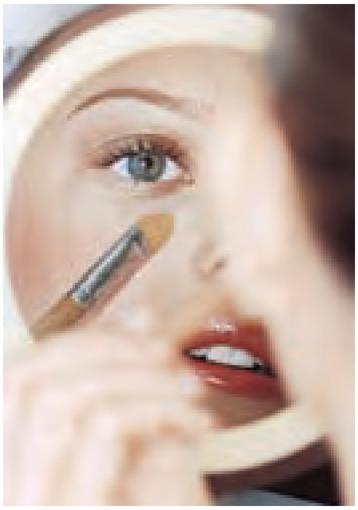


Figure 5.25 When the object is located between the focal point and the concave mirror, the image is larger than the object. Therefore, concave mirrors are often used as magnifying makeup mirrors.

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.

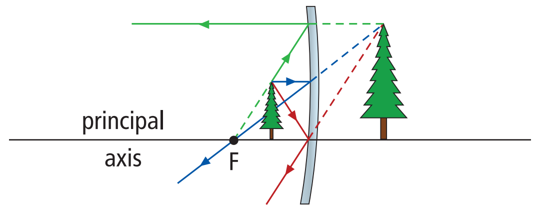


Figure 5.26 Ray diagram for an object between F and V

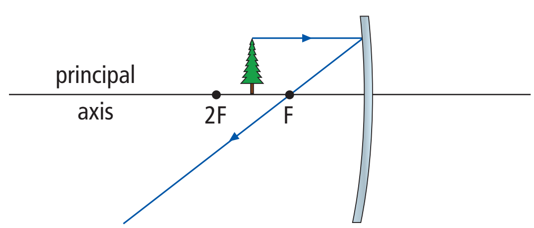
For a concave mirror, when an object is between the focal point and the mirror, the image has the following characteristics:

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

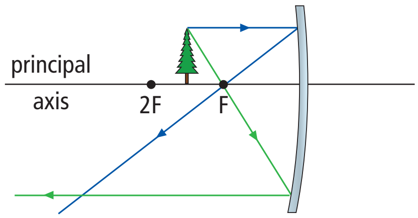
Object Between the Focal Point and Two Times the Focal Point

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.

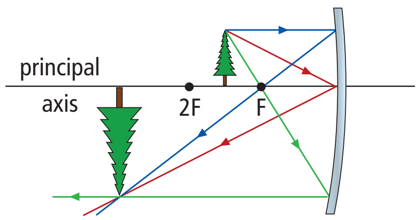


Figure 5.27 Ray diagram for an object between F and 2F

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.

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.

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.

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.

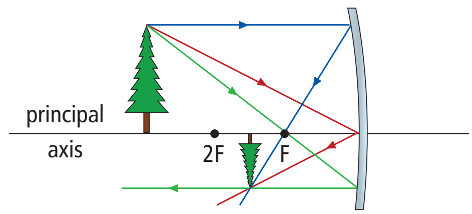


Figure 5.28 Ray diagram for an object beyond 2F

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.

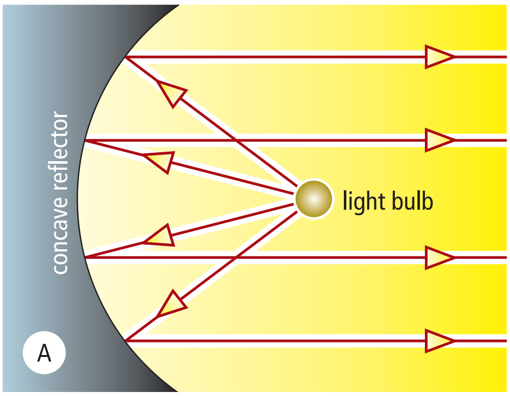
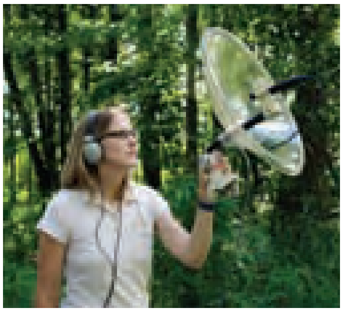


Figure 5.29 (A) A concave reflector collects the light coming from the bulb and directs it forward as parallel rays or headlight. This provides a bright beam of light directed in front. (B) a flashlight.

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.

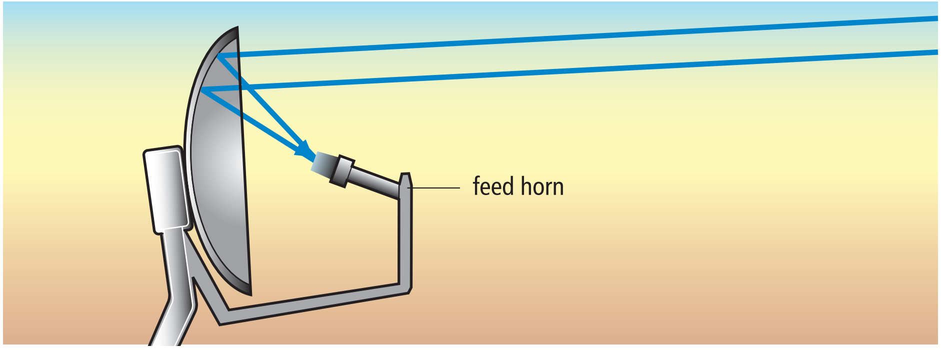


Figure 5.30 Microwave signals from a satellite orbiting Earth arrive at a satellite dish as parallel rays. The dish is curved to reflect all of the signals to the microwave detector that is located at the focal point of the curved dish.

Convex Mirrors

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

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.

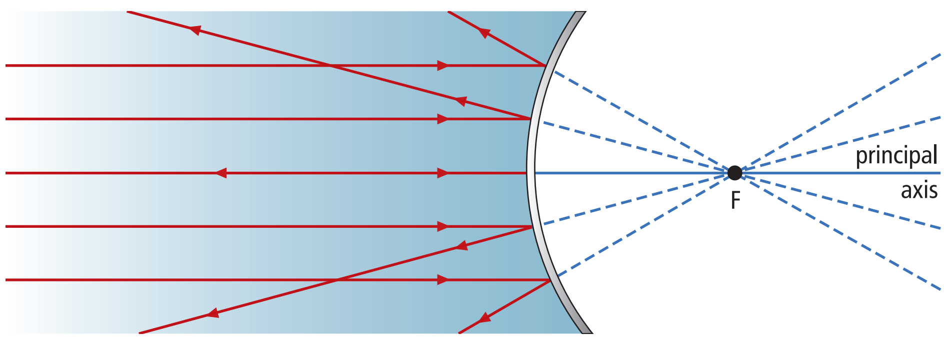
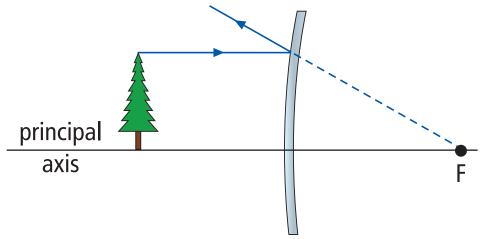


Figure 5.32 The focal point for a convex mirror is always behind the mirror. Nevertheless, you can use it to draw ray diagrams.

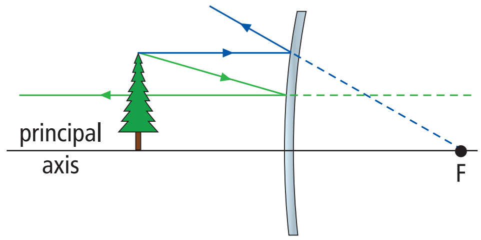
Ray Diagrams for Convex Mirrors

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.

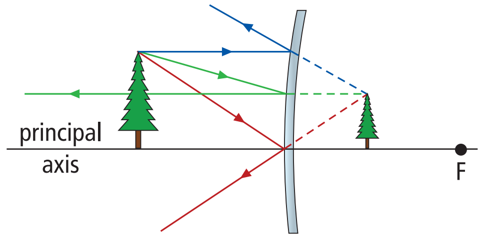


Figure 5.33 Ray diagram for an object in a convex mirror

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

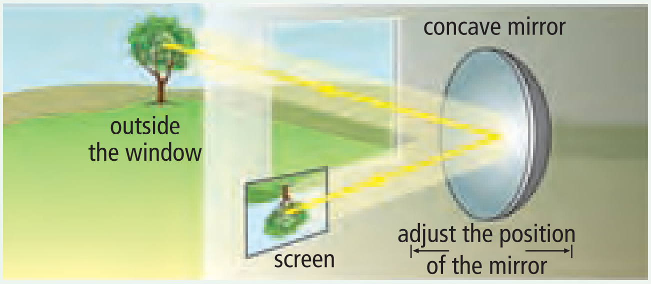
Safety
- The edges of the mirror might be sharp. Be careful not to cut yourself.
- Be careful not to drop any mirrors.

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.

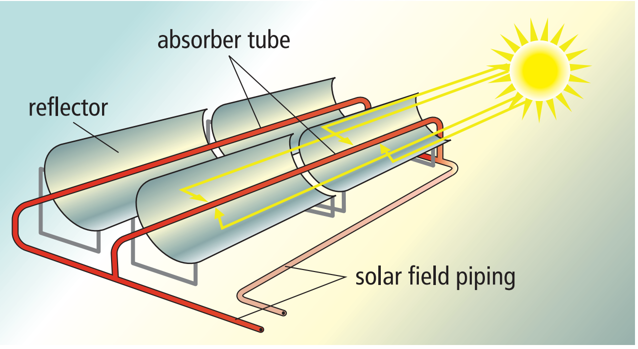
Science Watch

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

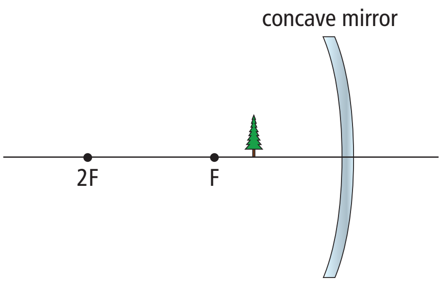
1. Explain why curved reflective surfaces are better than flat surfaces for collecting radiant solar energy.
2. Why do you think that shiny metal surfaces are used for the curved troughs instead of glass mirrors?

Check Your Understanding

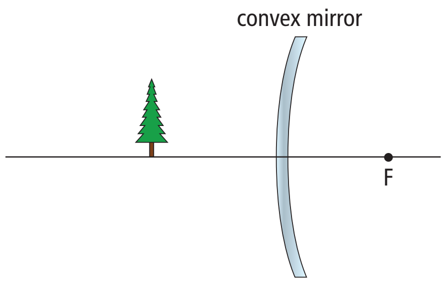
Checking Concepts

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?

Chapter Review

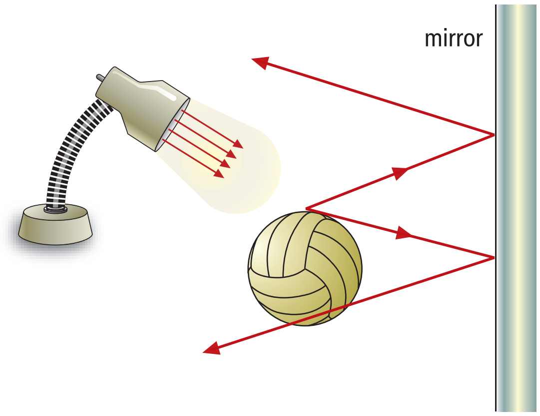
Prepare Your Own Summary

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.

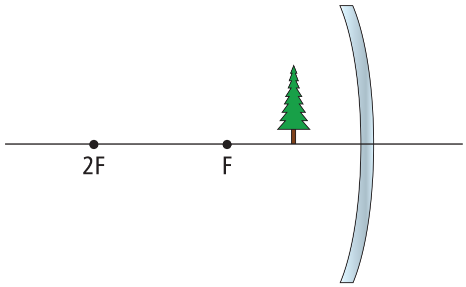
1. Law of Reflection
2. Specular and Diffuse Reflection
3. Refraction of Light
4. Plane, Concave, and Convex Mirrors
5. Ray Diagrams
6. Uses of Mirrors

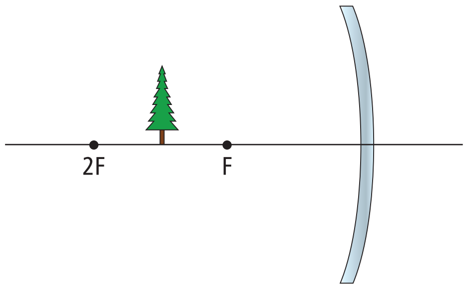
Checking Concepts

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.

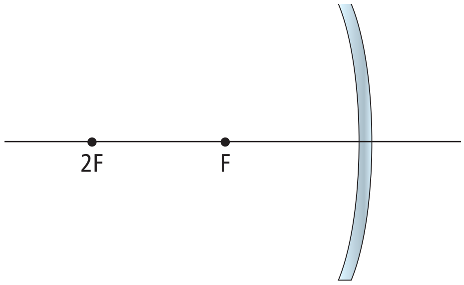


5. Examine the sketch you made for question 4. Is the image real or virtual? Explain.
6. Copy the following drawings in your notebook.
   (a) Complete ray diagrams for both drawings.
   (b) Use your ray diagrams to show and explain how a concave mirror can form upright images and inverted images.
  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