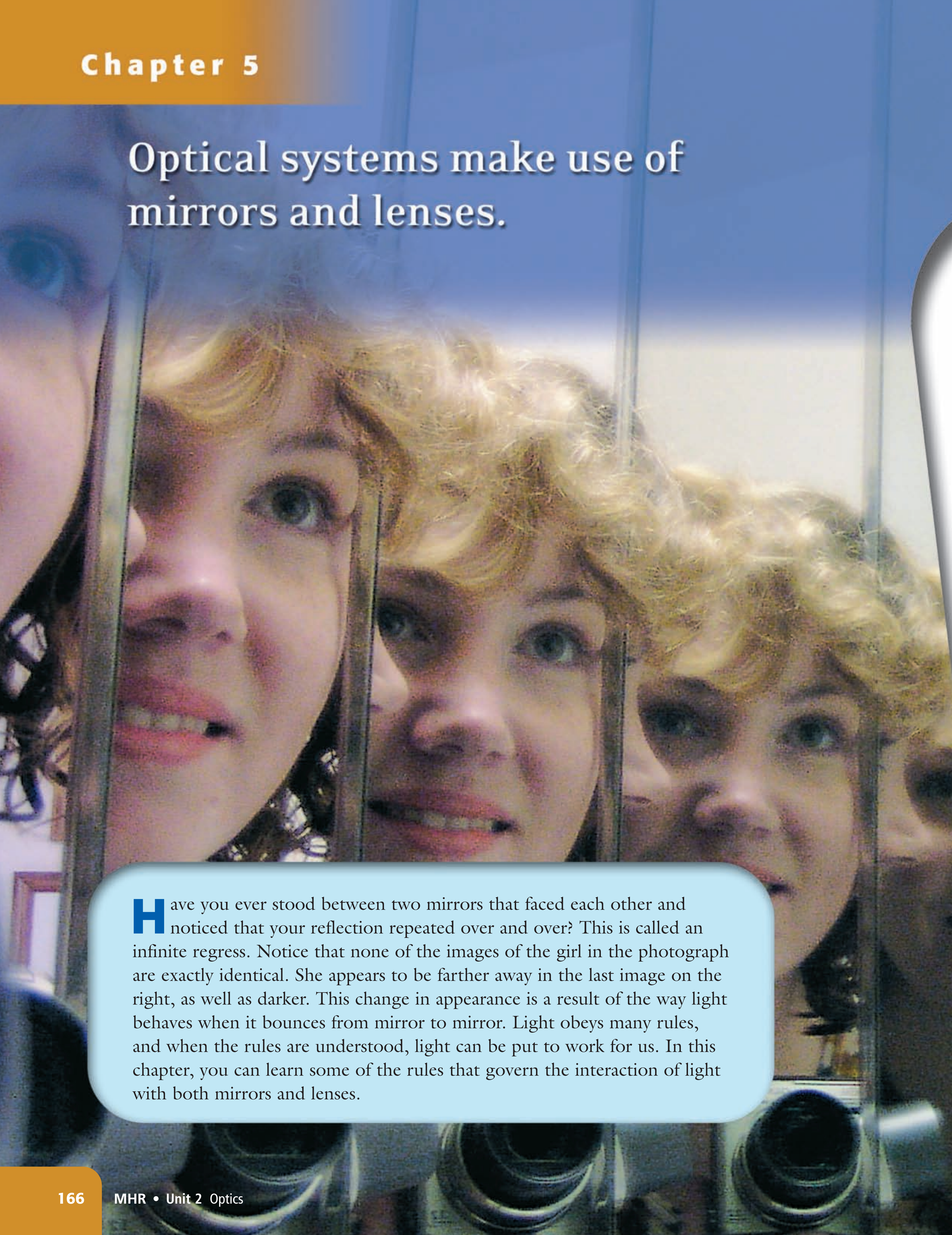
Chapter 5

Optical systems make use of mirrors and lenses.



Have you ever stood between two mirrors that faced each other and noticed that your reflection repeated over and over? This is called an infinite regress. Notice that none of the images of the girl in the photograph are exactly identical. She appears to be farther away in the last image on the right, as well as darker. This change in appearance is a result of the way light behaves when it bounces from mirror to mirror. Light obeys many rules, and when the rules are understood, light can be put to work for us. In this chapter, you can learn some of the rules that govern the interaction of light with both mirrors and lenses.

What You Will Learn

In this chapter, you will
- **describe** the behaviour of light using a ray model
- **observe** how light reflects off different surfaces
- **discover** how to use the law of reflection to describe the behaviour of light
- **investigate** ways in which mirrors and lenses can be used to form images
- **explain** how properties of light rays are used in designing optical instruments

Why It Is Important

How light reflects off a surface into your eyes determines the reflection that you see. Mirrors enable you to see yourself and objects behind you, and to reflect beams of light. Lenses are used to focus light and form images.

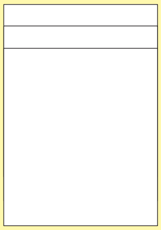
Skills You Will Use

In this chapter, you will
- **observe** images formed by curved mirrors
- **measure** the angles of incident and reflected rays
- **classify** objects on their ability to transmit light
- **model** light using ray diagrams

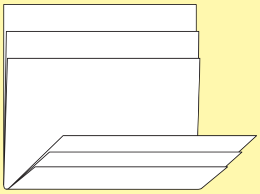
FOLDABLES™
Reading & Study Skills

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

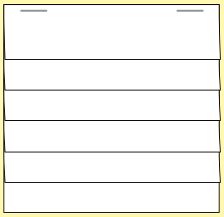
STEP 1 **Collect** 3 sheets of paper and layer them about 2.5 cm apart vertically. (Hint: from the tip of your index finger to your first knuckle is about 2.5 cm.) Keep the edges level.



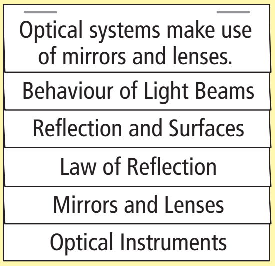
STEP 2 **Fold** up the bottom edges of the paper to form 6 tabs.



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
normal
opaque
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).

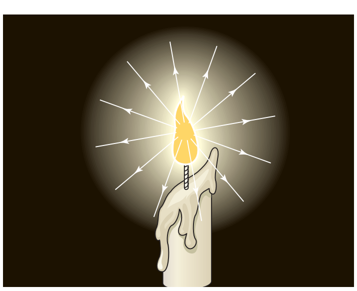


Figure 5.2 A ray is an imaginary line showing the direction in which light is travelling.

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

5-1 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.

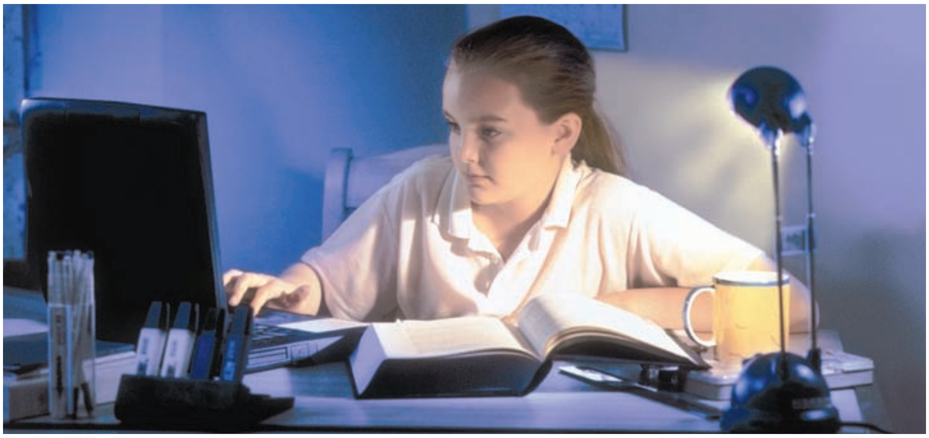
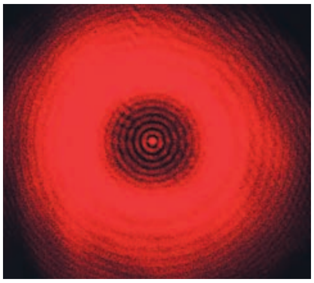


Figure 5.3 In order for you to see an object, it must reflect some light back to your eyes.

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 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.bcscience8.ca.**

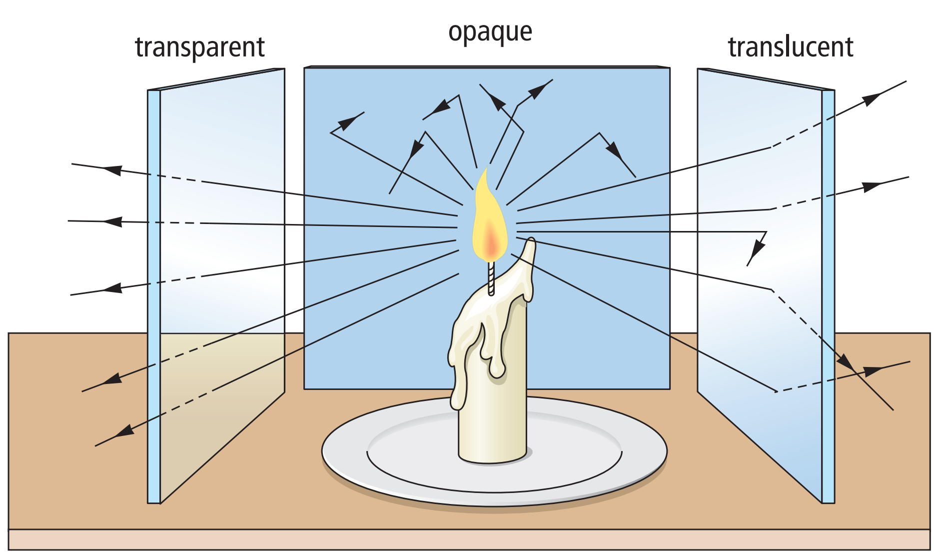


Figure 5.5 Light travels in straight lines until it strikes something.

Shadows

You can also use the ray model to predict where shadows will form and how large they will be. 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.

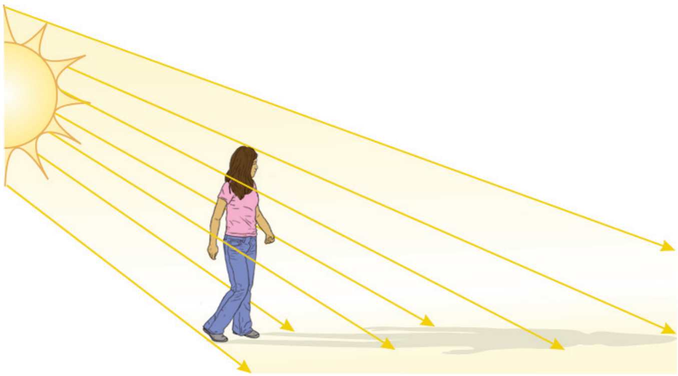


Figure 5.6 Ray diagrams can show how shadows are cast.

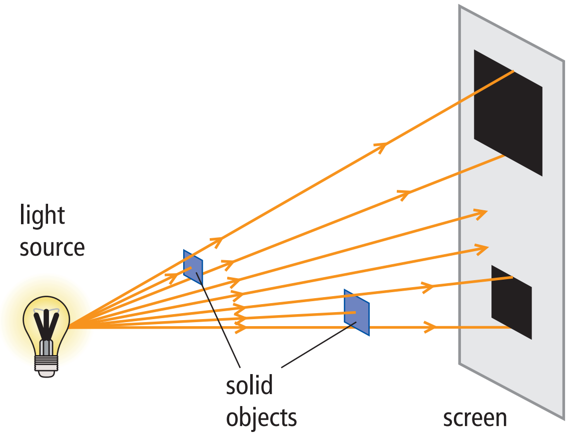


Figure 5.7A A ray diagram shows how the distance from the light source affects the size of the shadow that an object makes. The smaller object casts the larger shadow because it is closer to the light source.

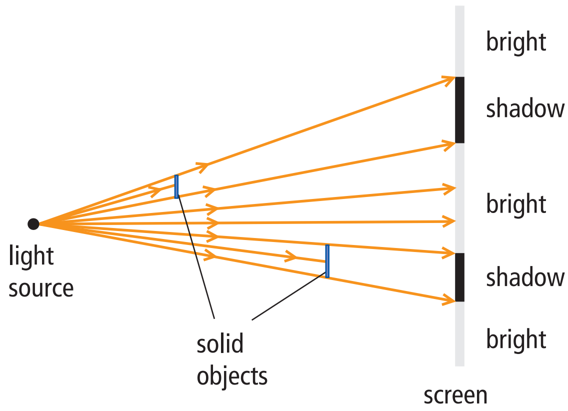


Figure 5.7B To make ray diagrams easier to draw and to visualize, you usually draw them as though you were looking at the objects from the side. You can represent the light source with a dot.

Reading Check

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

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?

To act as a mirror, the surface needs to be smooth compared to the wavelength of the light striking the surface (see Figure 5.8A). Even though the page may feel smooth, a photograph taken through a microscope reveals 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).

Suggested Activities

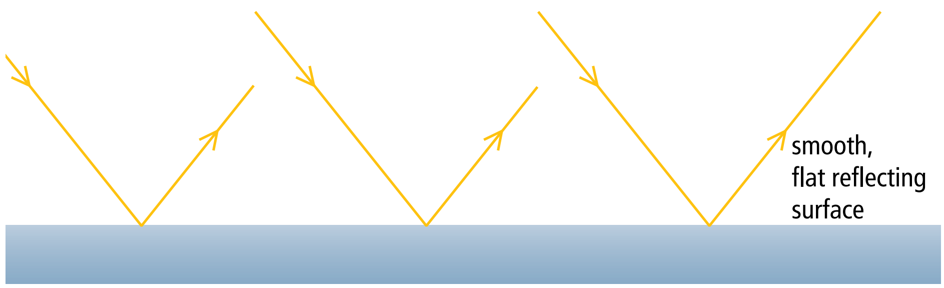
Find Out Activity 5-2 on page 176

Conduct an Investigation 5-5 on page 178

Connection

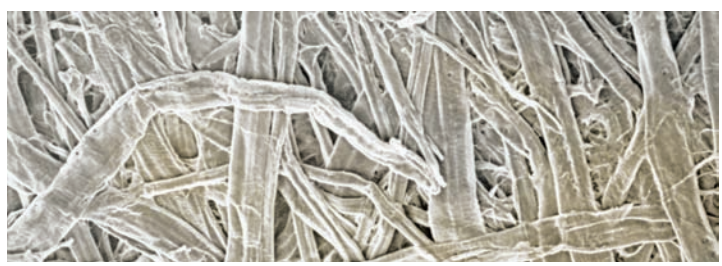
For more examples of electron micrographs, see Section 1.1.

A



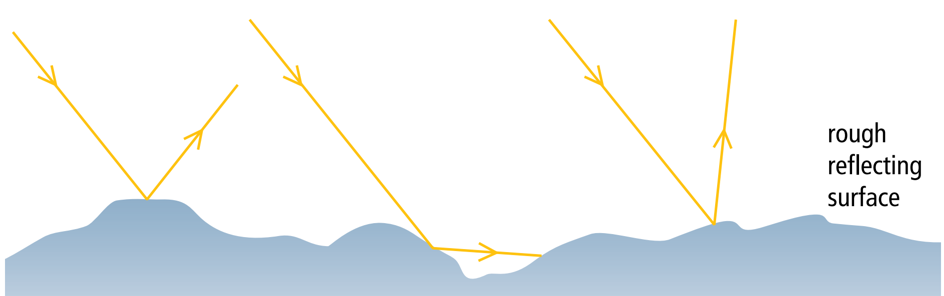
(A) Smooth surfaces reflect all light uniformly.

B



(B) Scanning electron micrograph of the surface of paper

C



(C) Rough surfaces appear to reflect light randomly.

Figure 5.8

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.

The incoming ray is called the **incident ray**. The ray that bounces off the barrier is called the **reflected ray**. Notice in Figure 5.9 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 boundary between two materials (such as air and glass) and intersects the point at which the incident ray reaches the boundary.

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°.

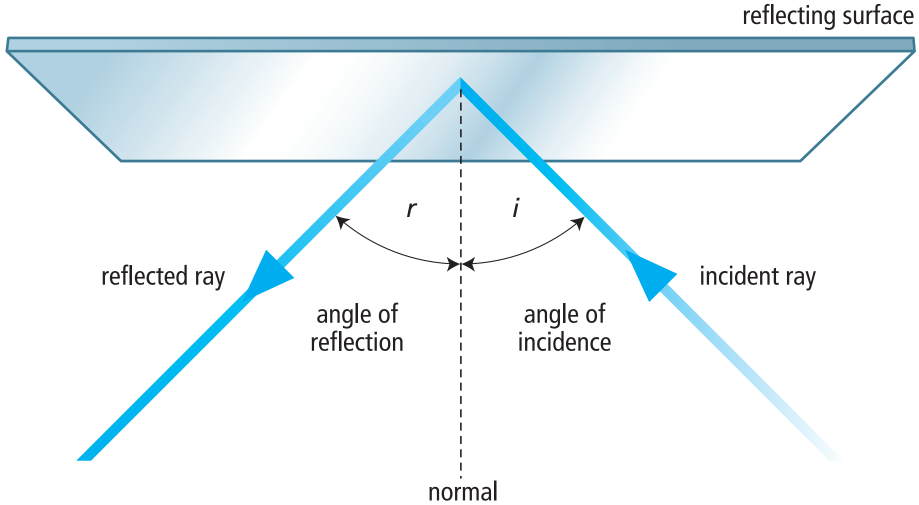


Figure 5.9 Light reflected from any surface follows the law of reflection.

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.

internet connect

Neil Armstrong, the first person to walk on the Moon, placed a special kind of mirror on the Moon's surface. Scientists on Earth regularly shine a laser on this mirror to measure the distance from Earth to the Moon. Find out how this special mirror works. Go to **www.bcscience8.ca.**

Light Can Be Refracted

Recall from Chapter 4 that light can be bent, or refracted, if it changes speed as it travels from one medium into another. You can picture this process by imagining five friends all walking abreast with their elbows locked (see Figure 5.10). If the people on one end of the line slow down, but the people on the other end do not, the line will turn. Then, if they all slow to the same speed, they will continue to move in the new direction.

Figure 5.10 If only one part of a line slows down, the line changes direction.

Word Connect

Density is a measure of how closely the particles in a material are packed together.

Connection

Section 7.2 has more information about density.

When light rays move from air into glass, they slow down and change direction because the glass is *denser* than air. Once inside the glass, the light rays move in a straight line. But if the light rays leave the glass and move back into the air, where they can travel faster, they will change direction again. The **angle of refraction (*R*)** is the angle of a ray of light emerging from the boundary between two materials, such as from air into glass, measured between the refracted ray and the normal.

Figure 5.11A shows what happens when a light ray passes into a medium in which it slows down. The light ray is refracted toward the normal. Figure 5.11B shows what happens when a light ray passes into a medium in which it speeds up. Then the light ray is refracted away from the normal.

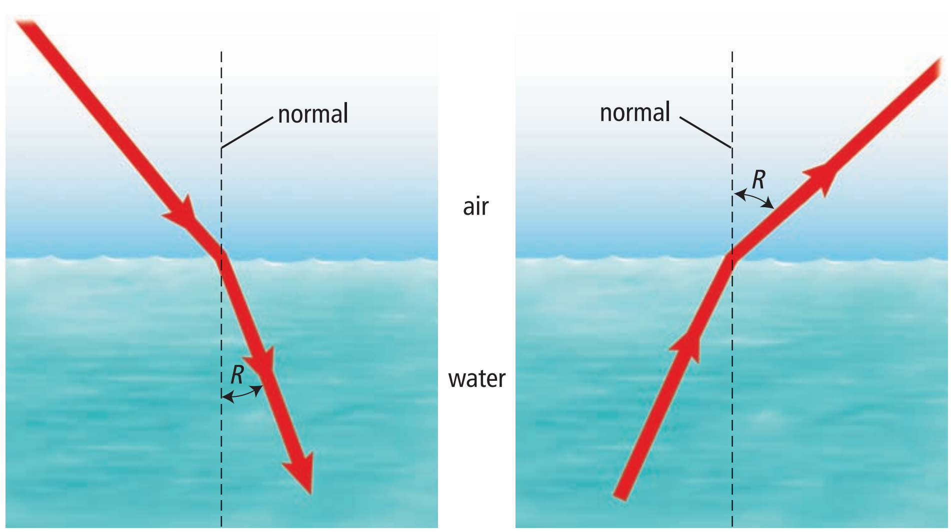


Figure 5.11A When light rays travel from air to water, they slow down and bend toward normal. *R* is the angle of refraction.

Figure 5.11B When light rays travel from water to air, they speed up and bend away from normal.

Refraction of Light in Water

If you have ever stood in a pool or water and tried to reach an object on the bottom, you may have been surprised that the object was not where you expected it to be. Figure 5.12 shows how refraction causes this illusion. The light rays reflected from the fish in Figure 5.12 are refracted away from the normal as they pass from water to air and enter your eyes. However, your brain assumes that all light rays have travelled in a straight line. The light rays that enter your eyes seem to have come from a fish that was higher in the water.

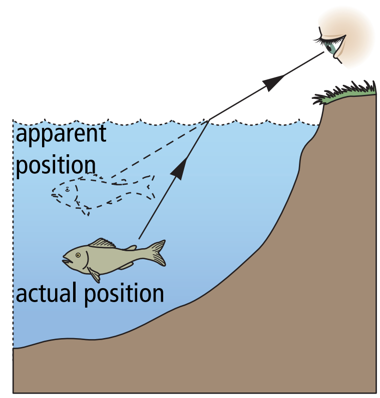


Figure 5.12 Light rays from the fish bend away from the normal as they pass from water to air. This makes the fish seem closer to the surface than it really is.

Refraction of Light in Air

Refraction can also occur when light travels through air at different temperatures. Warm air is less dense than cold air. Light bends as it travels through different densities of air. The refraction of light through air can result in a **mirage**, which is a misleading appearance or illusion.

Have you ever been driving along a highway on a hot summer day and noticed what looked like pools of water lying ahead? However, when you got close to the pools, they mysteriously disappeared. You were seeing a mirage. In this example, the air closer to the ground is hotter and less dense than air higher up. As a result, light from the sky directed at the ground is bent upward as it enters the less dense air. The "pools of water" were actually images of the sky refracted by warm air near the ground (see Figure 5.13).

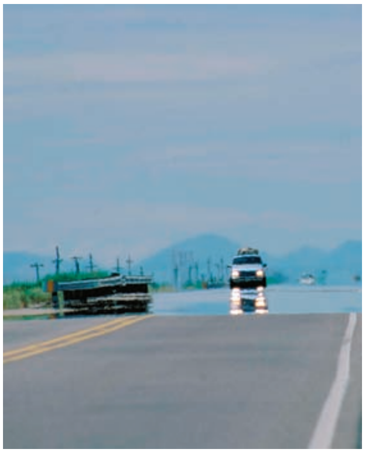


Figure 5.13 Refracted light can create a mirage.

Suggested Activities

Find Out Activity 5-3 on page 177
Find Out Activity 5-4 on page 177

Explore More

A numerical way to measure the ability of a transparent material to refract light is called the index of refraction. Empty space has an index of 1.0, and water has an index of about 1.3. Diamond is extremely refractive and has an index of 2.4. There is a very interesting connection between the speed of light in a material and its refractive index. Find out about this relationship. Go to **www.bcscience8.ca.**

Reading Check

1. Why does a white page not reflect like a mirror?
2. What is the difference between the incident ray and the reflected ray?
3. What point does the normal intersect?
4. What does the angle of incidence always equal?
5. What happens when light rays travel from water into air?
6. Why do objects underwater seem closer to the surface than they are?
7. Why does the highway ahead of you sometimes look wet when it is actually dry?

5-2 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.

5-3 Refraction

Find Out ACTIVITY

In this activity, you will observe what happens when light rays strike a transparent object.

Materials

- ray box
- rectangular block of glass or transparent plastic
- ruler
- protractor

What to Do

1. Lay the block of glass flat on the table. Shine the light from the ray box into the side of the block. Change the angle of the block in relation to the incident beam of light from the ray box. Follow the light ray through the block and then out the far side.
2. Set the glass block in one place. With reference to the point where the light enters the glass block, draw and label the incident ray, the refracted ray, the normal line, the angle of incidence, and the angle of refraction.
3. Continue the diagram showing the light ray as it passes out of the glass block. Draw and label the incident ray, the refracted ray, the normal line, the angle of incidence, and the angle of refraction.

What Did You Find Out?

1. (a) Does the light ray passing through the glass block change direction at the surface of the glass or somewhere in the middle?
   (b) How do you know?
2. (a) Does the light ray entering the glass block bend toward or away from the normal?
   (b) Does the light ray leaving the glass block bend toward or away from the normal?
   (c) What can you infer from your answers to (a) and (b) about the speed of light through glass and through air?

5-4 Observing Refraction in Water

Find Out ACTIVITY

In this activity, you will observe what happens when light rays move from water into air.

Materials

- penny
- short opaque cup or jar lid
- water

What to Do

1. Place a penny at the bottom of a short, opaque cup or jar lid. Set the cup on a table in front of you.
2. Have a partner slowly slide the cup away from you until you cannot see the penny.
3. Without disturbing the penny or the cup and without moving your position, have your partner slowly pour water into the cup until you can see the penny.
4. Reverse roles, and repeat the experiment.
5. Clean up any spills.

What Did You Find Out?

1. What happens to the path of light from the water to the air?
2. Sketch the light path from the penny to your eye
   (a) before the water was added
   (b) after the water was added

5-5 Inferring the Law of Reflection

Skill Check

- 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. From these data, you will be able to infer the law of reflection.

Question

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

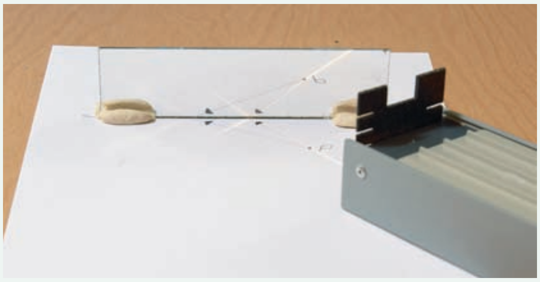
Hypothesis

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

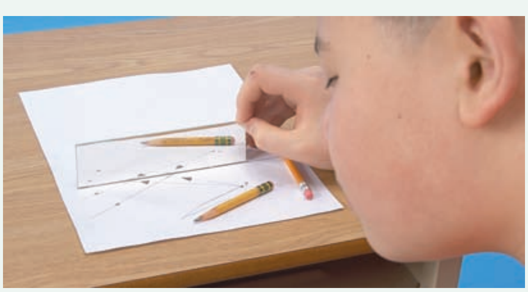
Procedure

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.

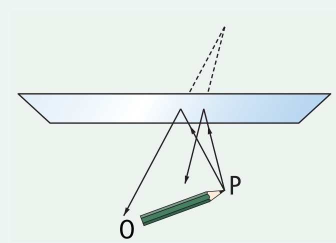


5. Use the ray box to shine a thin beam of light along one of the incident rays that you drew from point P. Mark the reflected ray with a series of dots along the path of the reflected light.
6. Remove the mirror and the ray box. Locate the reflected ray by drawing a line through the dots and ending 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?

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.

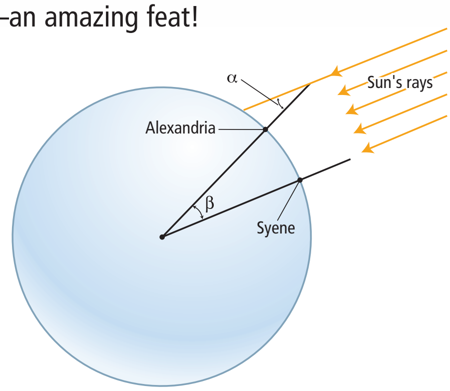
Eratosthenes was a Greek mathematician, born in North Africa in 276 B.C.E.

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?

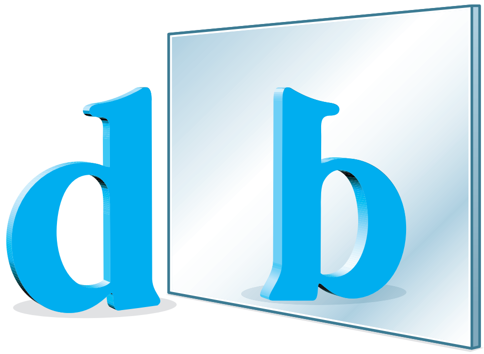
Check Your Understanding

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. A glass window is transparent, but at night you can see your reflection in it. Why?

Understanding Key Ideas

6. Explain why you are more likely to see a mirage on a hot day than on a mild day.
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. Copy the diagram below into your notebook. Explain, using a light ray diagram, why the reflection of the letter *d* looks like the letter *b*.



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.