7.2 Reflecting on Reflections

You see some objects because they emit their own light. The Sun, a glowing light bulb, and a burning candle all produce their own light energy. These objects are **luminous.** Most objects, however, do not produce their own light energy — they are **non-luminous.** They can be seen only when light from a luminous source strikes the object and then reflects off the object into your eyes. **Reflection** occurs when light bounces off a surface. When a room is poorly lit, you see less because less light is reflecting off the objects around you. If you shine a flashlight on an object, you can see the object clearly again because you have increased the amount of light reflecting off its surface.

All the light striking an object is not reflected — some light energy is absorbed. Dark surfaces tend to absorb most of the light that strikes them. That is why wearing dark clothes in the summer Sun can make you feel hot. That is also why dark objects are more difficult to see at night. Very little light is reflected from dark surfaces, even in full daylight. On the other hand, light-coloured objects reflect most of the light that strikes them.

STRETCH Your Mind

What you see depends on the images your eyes form using the light reflected off an object, and also on your brain's interpretation of these images. Sometimes the brain misinterprets an image. Optical illusions fool our brains into making false conclusions (see Figures 7.12 and 7.13). Try to create your own optical illusion.

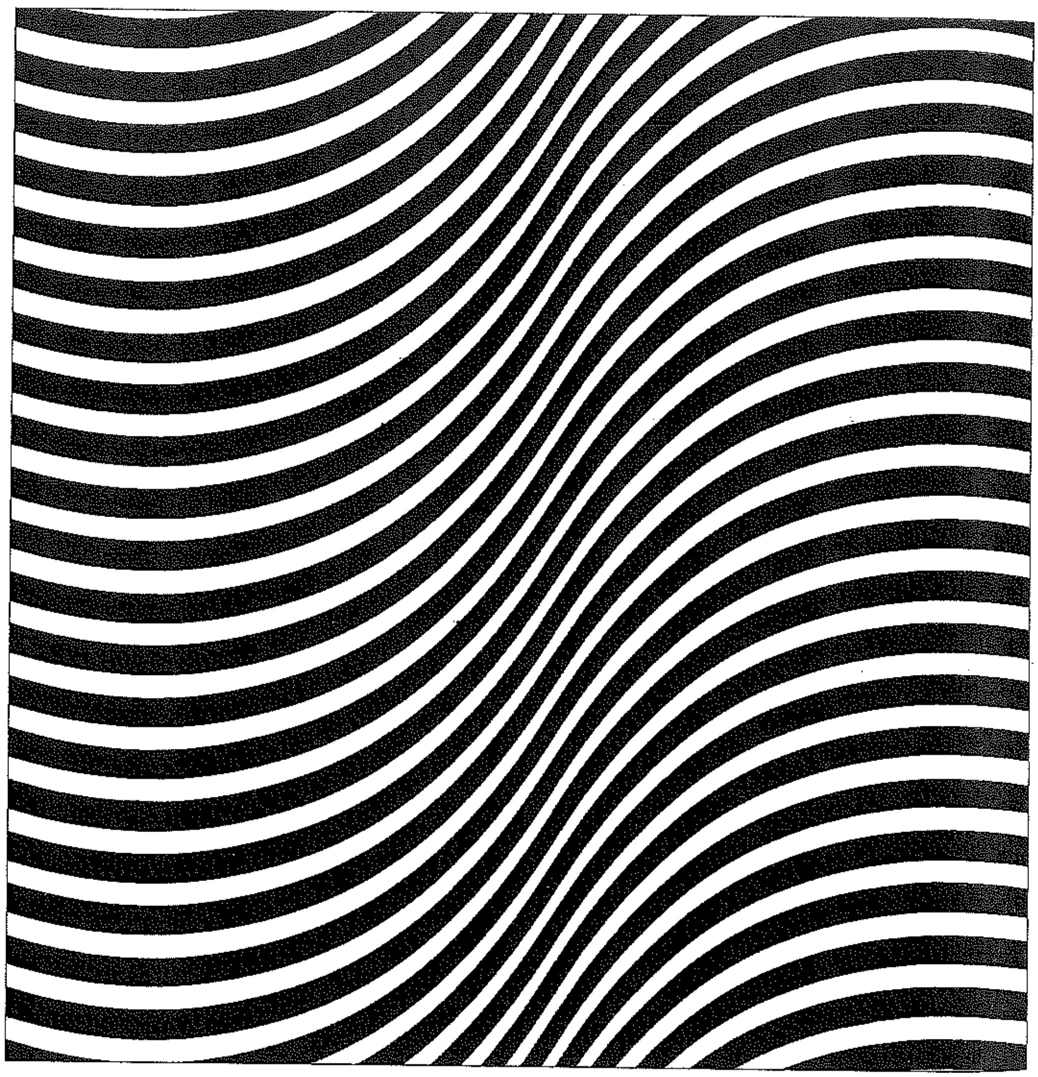
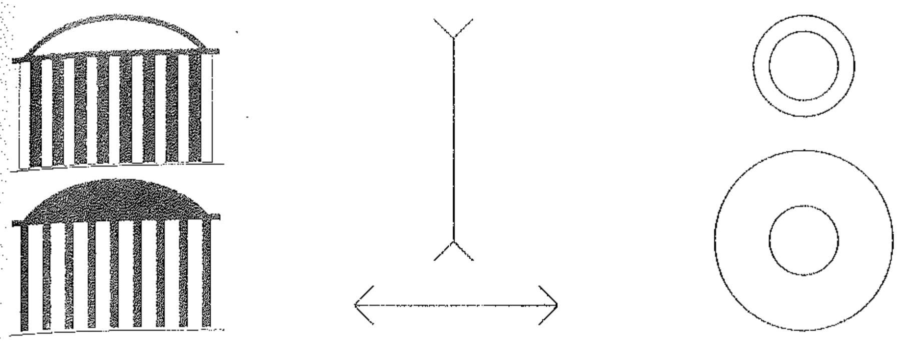


Figure 7.12 Observe this image through one eye while you slowly lift the page up to the level of your chin. Did you see the lines on the flat page appear to rise into a gently sloping hill on the right?



A Which auditorium has the thicker columns?

B Which line is longer?

C Which inner circle is larger?

Figure 7.13 Study these optical illusions and answer the questions.

Stretch Your Mind

Measure and record the dimensions of each diagram on the left to check your answers. Did any of the drawings trick your vision? Why might your brain be fooled by the drawings?

When light strikes a reflecting surface, it bounces off the surface. A light ray that strikes a surface is called an **incident ray**. The light that is reflected from a surface is called a **reflected ray** (see Figure 7.14). To find out in which direction each ray of light is travelling, you can measure an angle. To do this, draw a reference line that is perpendicular (90°) to the reflecting surface at the point where the incident ray strikes the surface. This line is called the **normal**. The angle between the incident ray and the normal is called the **angle of incidence**, *i*. The angle between the normal and the reflected ray is called the **angle of reflection**, *r*. This approach provides a standard way to describe the direction in which light travels during reflection. You will investigate reflection in the next two investigations.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

To see more optical illusions, and to learn about sensory systems and perception, visit the above web site. Go to **Science Resources**. Then go to **SCIENCEPOWER 8** to find out where to go next.

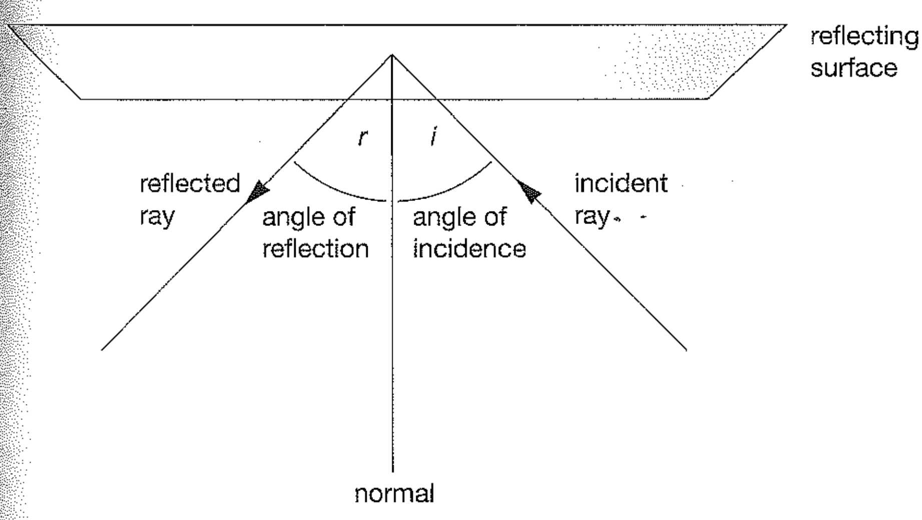


Figure 7.14 The normal is a reference line that is drawn perpendicular to the reflecting surface at the point where an incident ray strikes a reflecting surface. The angle of incidence, *i*, is the angle between the normal and the incident ray. The angle of reflection, *r*, is the angle between the normal and the reflected ray.

CONDUCT AN

INVESTIGATION 7-B

Laws of Reflection

When you look in your bathroom mirror, light from a window or a bulb reflects off your face in all directions. Some of the light from your face reflects off the mirror into your eyes. This reflected light must follow a consistent pattern because you always see the same image of your face when you look in a mirror.

In this investigation, you will demonstrate the two laws that describe the path of light when it bounces off a surface (in this case, a **plane mirror** — one that has a flat surface). In science, a **law** is a statement of a pattern that has been observed again and again, with no exceptions. A law describes an action or condition that has been observed so consistently that scientists are convinced it will always happen.

Problem

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

Safety Precaution

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

Apparatus

ray box

plane mirror (about 5 cm × 15 cm) with support stand

small object such as a short pencil, a common nail (about 5 cm), or a toothpick that is thicker at one end than the other (the object should not be longer than the mirror)

protractor

ruler

pencil (for drawing)

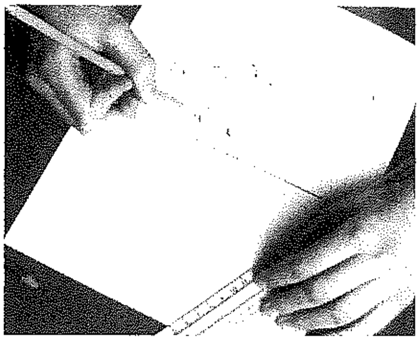
Materials

sheet of blank paper (letter size)

Skill POWER

For tips on making tables, turn to page 546. For tips on measuring angles with a protractor, turn to page 540.

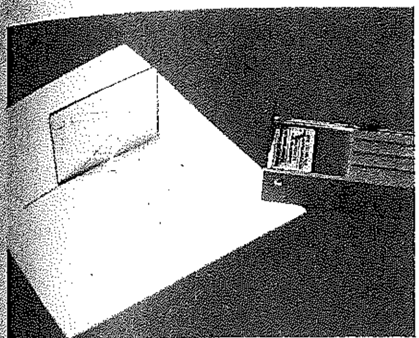
Procedure



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 of the mirror has a protective glass pane.)

2. Lay the small object on its side on the paper about 5–10 cm in front of the line you just drew, and at an angle to the line. Trace the shape of the object. Mark one end of the object **P** and the other end **O**.

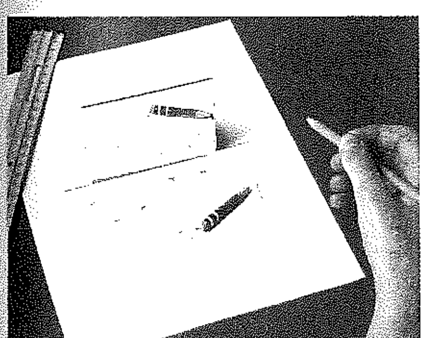
3. Remove the object. Draw two straight lines that start from **P** and that end on the straight line that represents the plane mirror. On each line, neatly draw an arrowhead pointing toward the reflecting surface. These lines represent the paths of two rays of light that come from the object and reflect off the mirror. How many of these incident rays could you draw?



❹ Carefully place the mirror in its stand on the sheet of paper so that the reflecting surface of the mirror is exactly along the line you drew in step 1.

❺ Use the ray box to shine a thin beam of light along each of the incident rays you drew. Where does the reflected light go?

❻ Accurately draw a straight line to show the path of each ray after the light strikes the mirror. On each line, draw an arrowhead pointing away from the mirror. Each line shows a reflected ray.



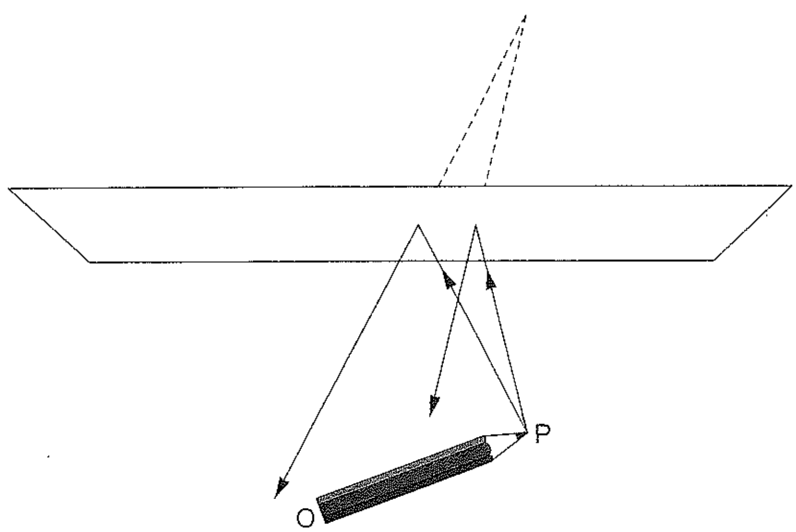
❼ Place the mirror and the object back on the sheet of paper. Observe the reflection of the object and the reflected rays that you drew. What do you notice about the reflected rays? Indicate on your drawing the point from which the two reflected rays seem to come.

Analyze

1. On your sheet of paper, use a protractor to draw the normal at the point where each incident ray strikes the mirror. (You may refer to Figure 7.14 on page 217 as a guide.) Use the normal as a reference line to measure angles.

2. Make a table with three columns that have these headings: "Incident ray," "Angle of incidence," and "Angle of reflection." Give your table a suitable title. Accurately measure the angle of incidence, *i*, and the angle of reflection, *r*, for each of the two light rays. Record the data in your table.

3. Extend each reflected ray behind the mirror, using a dotted line. Measure the perpendicular distance from the mirror to the point where the reflected rays meet (see the diagram below). Compare this distance to where the incident rays started at point **P**.



Conclude and Apply

4. From your data table, describe the pattern relating the angle of incidence and the angle of reflection. This pattern is the first law of reflection. Find two other groups in your class that found a similar pattern. Did any group discover a different pattern?

5. Hold a pencil in front of you. It can be moved in three dimensions — toward or away from you, to your left or right, or up and down. How many dimensions are necessary to contain the incident ray, the normal, and the reflected ray? What is another name for this type of space? (Hint: Think about the name given to the mirror in this investigation.) The second law of reflection describes this arrangement of the three lines — the incident ray, the normal, and the reflected ray. State the second law of reflection.

Predictable Behaviour

Light that is reflected from a surface behaves in two predictable ways. You demonstrated this in Conduct an Investigation 7-B. The two predictable behaviours of light are called the **laws of reflection** (see Figure 7.15). The first law of reflection states that the angle of reflection, *r*, is equal to the angle of incidence, *i*. For example, if the angle of incidence is 30°, then the angle of reflection is also 30°.

The second law of reflection states that the incident ray, the normal, and the reflected ray are all in the same **plane** (an imaginary flat surface). This is why you can draw all three lines on a flat sheet of paper.

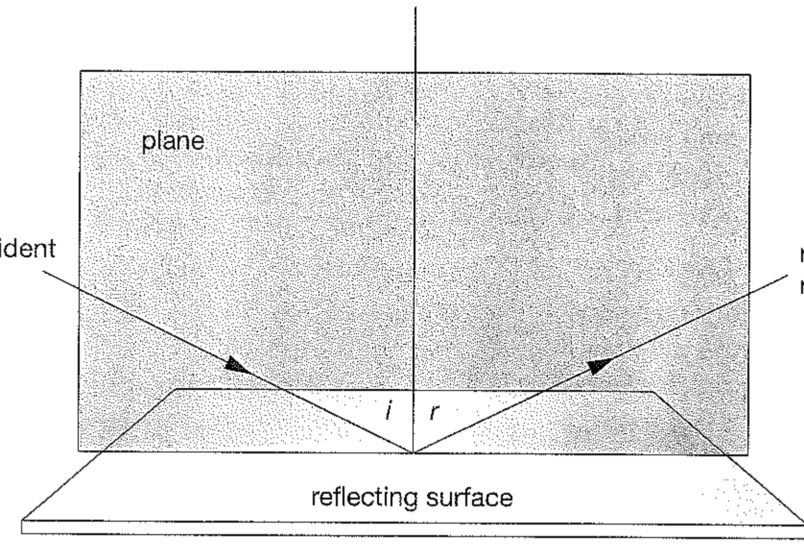


Figure 7.15 The two laws of reflection: 1. The angle of reflection, *r*, is always equal to the angle of incidence, *i*. 2. The incident ray, the normal, and the reflected ray are always in the same plane.

You realize that an object is in front of you only because light is spreading out from that object. As long as your eyes receive light as if it were spreading out from points on an object, you will see that object.

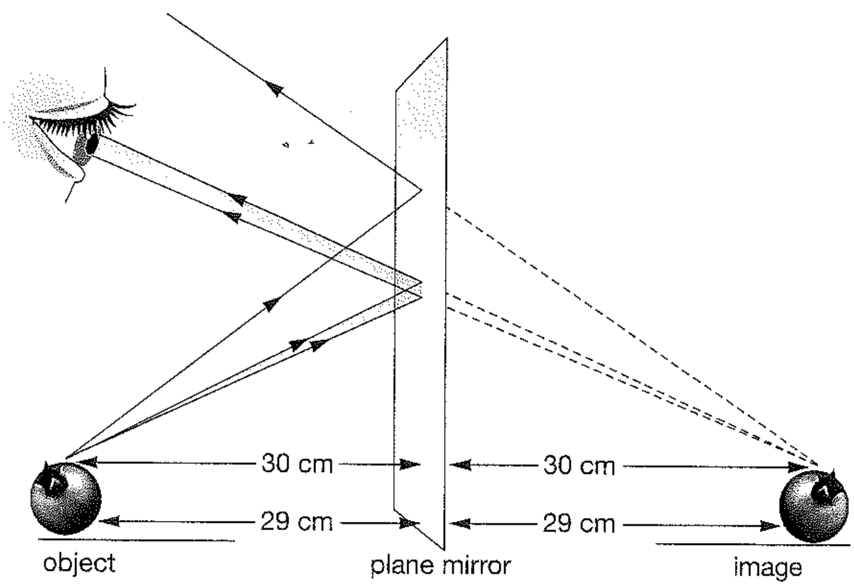


Figure 7.16 Only a small fraction of the light reflecting from an object enters your eyes.

Mirrors can trick your brain. Light is reflected off an object toward the mirror, which reflects the light back to you. The object appears to be located at the point from which the light seems to come — a position behind the mirror's surface. The image appears to be the same size and shape as the real object, and it seems to be the same distance behind the mirror's surface as the real object is in front (see Figures 7.16 and 7.17).

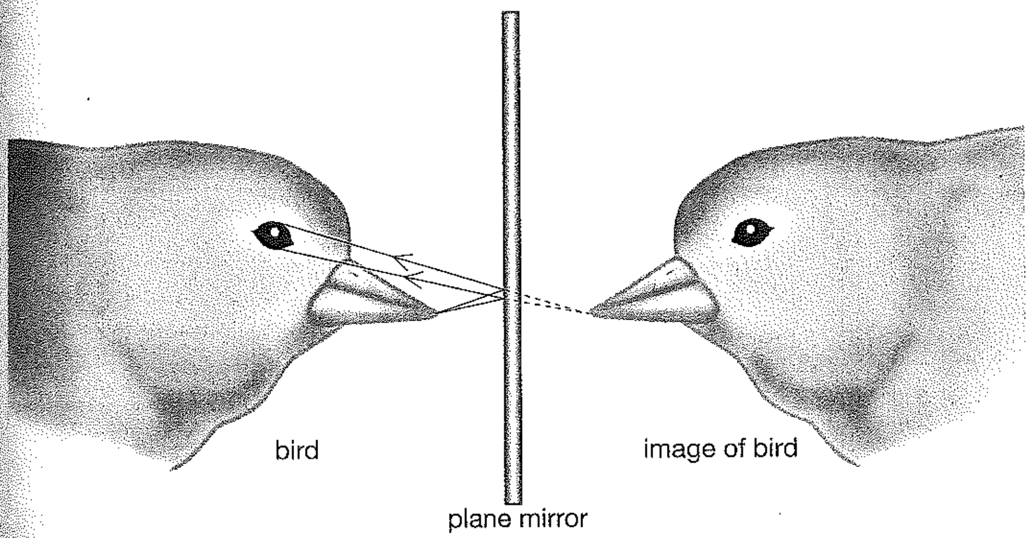


Figure 7.17 We know that what we see in a mirror is just an image. However, a pet bird will chatter for hours to a "friend" in the mirror.

To confirm this, choose a point on a diagram of a reflected object and measure the perpendicular distance between that point and the reflecting surface, as shown in Figure 7.18. Mark a point at the same distance behind the reflecting surface. Do this for several other points on the object until you can see the object's shape and size emerge from the points. If you do this for enough points, you could connect the dots to draw the location and shape of the image formed by the reflection.

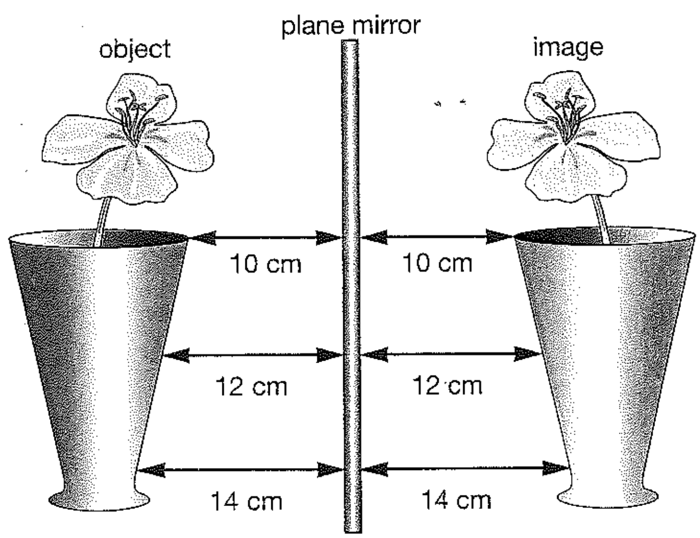


Figure 7.18 The image of an object reflected by a plane mirror appears to be at the same distance behind the mirror's surface as the object itself is in front.

A smooth, flat reflecting surface always produces an image that has the same size and shape as the object. All the normals related to light reflected from a bathroom mirror point in the same direction (see Figure 7.19A). Clear images are created from light reflected by a plane mirror.

Compare the normals related to light reflected from a mirror to the normals related to light reflected from a wall or a piece of paper (see Figure 7.19B). Although the wall and the paper surfaces might appear to be smooth, both are much rougher than the mirror's surface. The normals related to light reflected from rough surfaces will point in random directions, depending on exactly where the incident rays strike the surface. When light reflects off a rough surface, **diffuse reflection** occurs and no image results, as shown in Figure 7.19B.

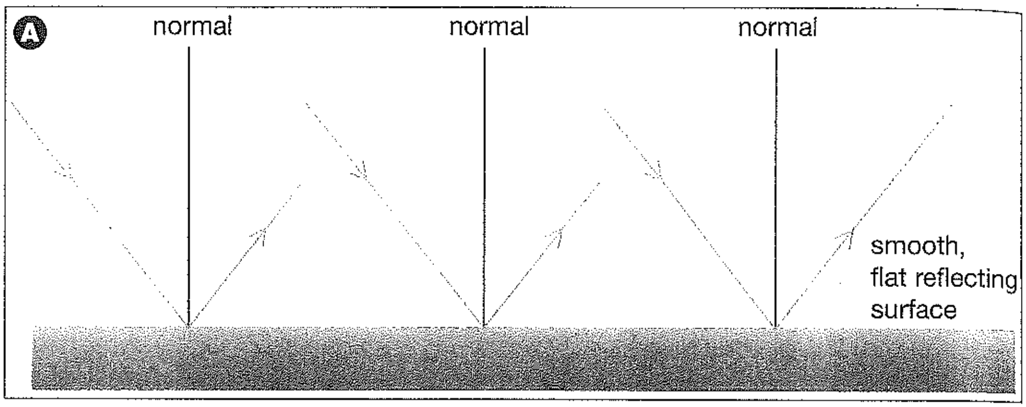


Figure 7.19A Reflected light from a smooth surface

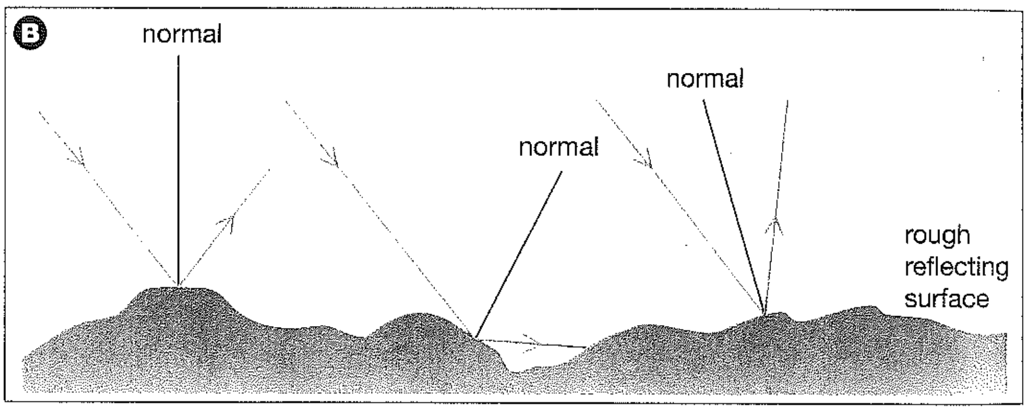


Figure 7.19B Reflected light from a rough surface

Cool Tools

Astronauts have placed corner reflectors on the Moon. Scientists on Earth then aimed pulses of laser light at these reflectors. By measuring the time it took for the light to return to Earth, the scientists determined the distance to the Moon's surface to within a few centimetres!

Using Reflections

Cars and bicycles have reflectors to make these vehicles visible at night. Figure 7.20 shows a reflector in which hundreds of tiny, flat reflecting surfaces are arranged at 90° to one another. These many small surfaces are packed side by side to make the reflector. When light from another vehicle hits the reflector, the light bounces off the many tiny surfaces back toward the source of the light. The driver in the other vehicle sees the reflection and realizes that something is ahead.

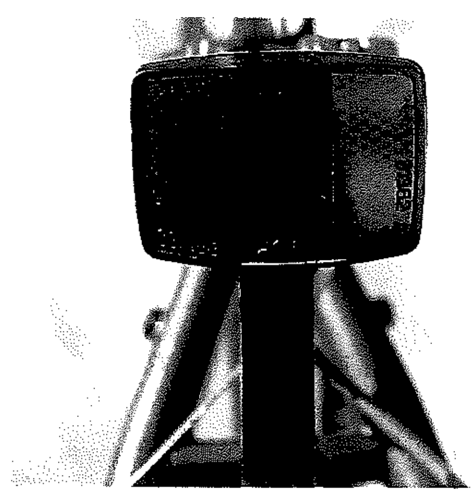


Figure 7.20 A bicycle reflector

Pool players can use the laws of reflection to improve their game. Like a light ray, a pool ball travels in a straight line until it strikes something. In a "bank shot," the white cue ball bounces off a cushion before it strikes the target ball. To decide where to aim the cue ball against the cushion, the player chooses a spot that is the same distance behind the cushion as the target ball is in front (see Figure 7.21). This spot is the "image" of the target ball. The player now shoots the cue ball toward the image. Because the ball bounces off the cushion at the same angle at which it strikes the cushion, the cue ball bounces off the cushion and strikes the target ball.

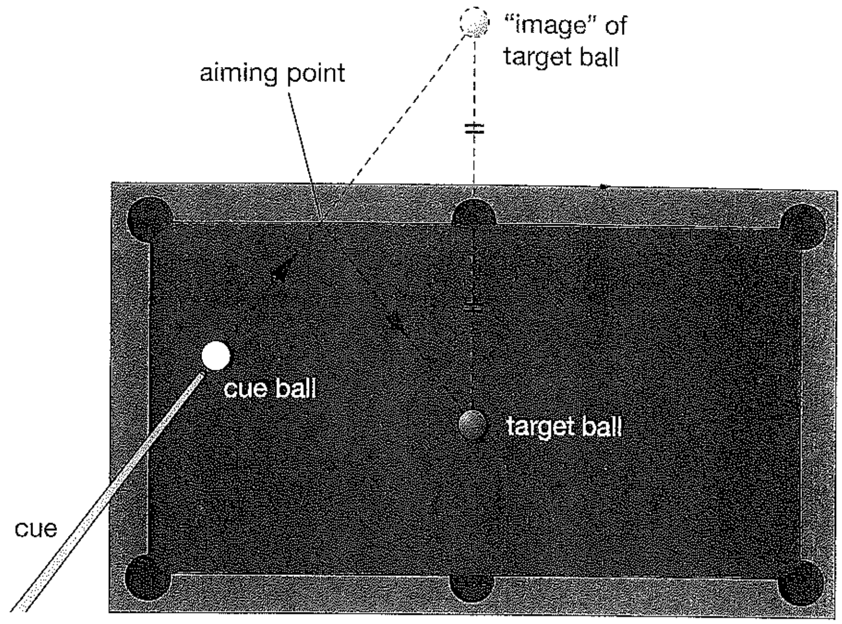


Figure 7.21 You can improve your pool game by applying the laws of reflection.

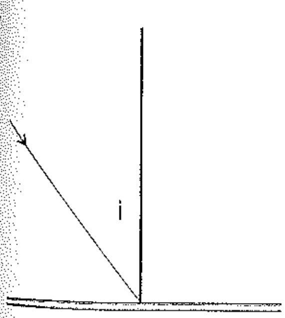
Check Your Understanding

1. Make a simple, accurate drawing in which you show and label: an incident ray, a reflected ray, the normal, the angle of incidence, and the angle of reflection. Write a definition for each term.

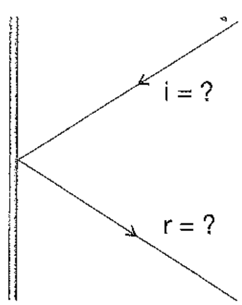
2. State the two laws of reflection.

3. When you see the reflection of the tip of your nose in a plane mirror, from where do the reflected rays of light appear to be coming? If you move twice as far away from the mirror, what happens to the position of the image of your nose?

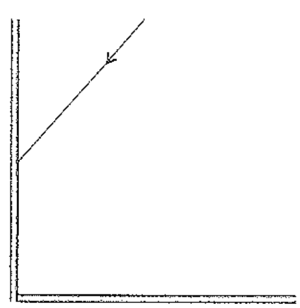
4. In your notebook, trace each diagram below. Make the measurements and draw the missing parts.



r = ?
Draw the reflected ray.



Draw the normal.



Draw the two reflected rays. Compare the directions of the light striking and bouncing off the mirror.

7.3 Refraction

DidYouKnow?

In air, light travels at 300 000 km/s. It slows down to 200 000 km/s in glass and 165 000 km/s in diamond.

You know that reflection occurs when light rays bounce off objects, and you can now accurately predict the direction in which reflected light rays travel by using the laws of reflection. You can also predict where an image will be located in a plane mirror.

What happens when light moves from air into a medium such as water? If you have ever stood on the side of a pool and tried to dive for an object on the bottom, you may have been surprised that the object was not where you expected it to be. **Refraction** is the bending of light when it travels from one medium to another. Light bends because it changes speed when it moves between materials that have different densities. Light usually travels more slowly in comparatively dense material. The bending of light makes the object's image appear to be in a different position from where the object really is (see Figure 7.22). Explore refraction in the next two investigations.

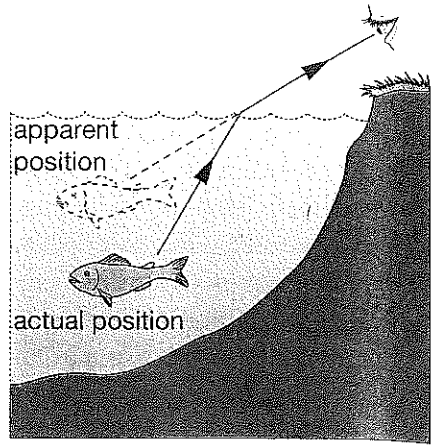


Figure 7.22 The bending of light can make it difficult to see where an object is located in the water.

Find Out **ACTIVITY**

The Re-appearing Coin

You can observe refraction in the following activity.

What You Need

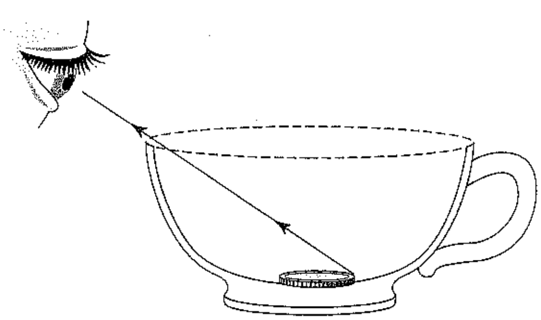
cup or bowl with opaque sides
water
coin

What to Do

1. Work with a partner. Place the coin in the middle of the empty cup or bowl. Look down on the coin with one eye, then lower your head until the edge of the cup blocks your view of the coin. Do not move your head.
2. Your partner now slowly pours water into the cup until you can see the coin again. If the coin moves because of the flow of water, start again. Use a pencil to temporarily hold the coin in place.
3. Wipe up any spills and wash your hands after this activity.

What Did You Find Out?

When water was poured into the cup, you could see the coin, even though the straight-line path of the light was blocked by the cup. Copy the diagram below, indicate the water line, and draw rays to show the light's path. What happened to the rays of light when light passed from air to water?



CONDUCT AN INVESTIGATION 7-C

When Light Refracts

Observe how refraction affects light travelling through different materials.

Problem

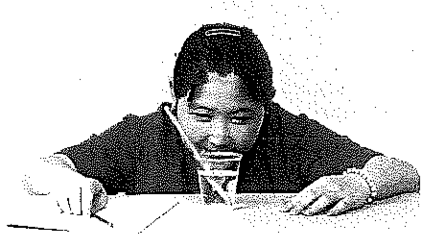
What happens to light when it travels from one medium into another?

Apparatus

clear plastic cup, three quarters full of water
wooden pencil
ruler
pencil (for drawing)

Materials

water
paper



Procedure

1. Lay the pencil on the desk so that the middle of the pencil touches the back edge of the cup. Look at the pencil through the front of the cup. Draw what you see.

2. Lean the pencil, pointed end down, in the cup of water. Lower your eyes so that they are level with the surface of the water. When you look at the pencil from the side, what seems to happen to it at the surface of the water? Draw what you see.

3. Look straight down along the pencil that is standing in the water. What seems to happen to the pencil at the surface between the water and the air? Move your head slightly to the side. Draw the pencil as it appears to you. Wipe up any spills after this investigation.

Analyze

1. In step 1, through what medium did light from the ends of the pencil travel before reaching your eyes? Through what medium did light from the middle of the pencil have to travel? Did this light travel in a straight line all the way? How do you know?

2. In steps 2 and 3, through what medium does the light from the bottom part of the pencil travel before reaching your eyes? Did this light travel in a straight line all the way? What happens to the path of the light when it moves from the water to the air?

Conclude and Apply

3. Through how many different media does light travel during refraction in this activity?

4. What can happen to the path of light during refraction? What can happen to the image you see, compared with the real object?

CONDUCT AN INVESTIGATION 7-D

Follow That Refracted Ray!

Your class will work in groups to design an investigation to study the behaviour of light as it passes through different substances. When you examined the path of light rays that reflected off a plane mirror, you discovered a pattern. The angle of reflection always equals the angle of incidence. Understanding this pattern helps you predict how light reflects off a flat surface. Does refracted light behave according to a consistent pattern as well? Make a hypothesis and then test it.

Problem

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

Apparatus

ray box (placed on the edge of a sheet of white paper)

transparent plastic, watertight tray (box top from greeting cards, candies, etc.)

ruler

protractor

Materials

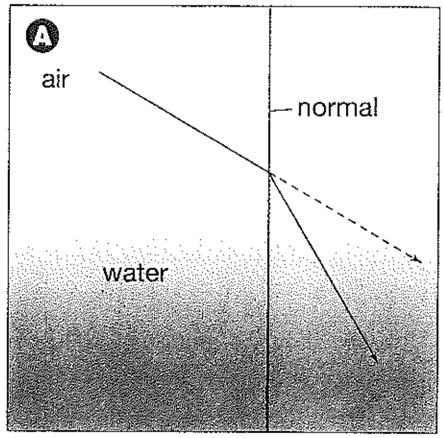
sheet of blank white paper (letter size)

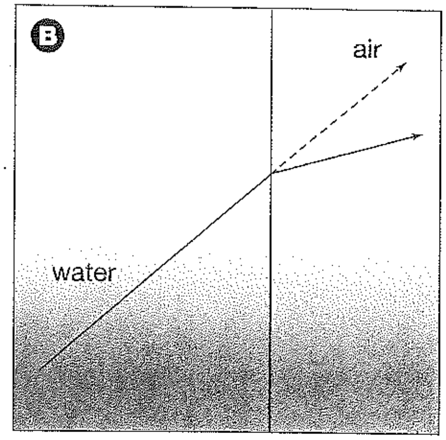
water

liquid other than water (vegetable oil, liquid soap, etc.)

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. After conducting your investigation, 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 two different angles of incidence
   - (b) the path of the same incident rays when there is water in the tray
   - (c) the path of light that travels through one corner of the tray, through the water, and out the adjacent side of the tray back into the air
   - (d) the paths of light travelling through some liquid other than water for the same incident rays you used in (a) and (b)





5 If necessary, you can refer to the diagrams on this page as a guide.

(a) Wipe up any spills as wet floors are slippery.

(b) Wash your hands after this investigation.

Analyze

1. On your diagrams, draw the normal at each point where a light ray travels from one medium into another.

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 at which the light bends when the angle of incidence increases?

5. What happens to the size of the angle at which the light bends when a liquid other than water is used and the angle of incidence is the same?

6. Does light move toward or away from the normal when it travels 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 problem on page 228.

Around a Bend with Light

When light travels from one medium into a denser one — for example, when it moves from air into water — it will bend *toward* the normal. When light exits a denser substance, its direction of travel bends *away from* the normal. How much bending occurs depends on the type of substance through which the light travels. The new direction of the light is called the **angle of refraction,** *R* (see Figure 7.23). When the angle of incidence, *i*, increases, the angle of refraction, *R*, also increases. However, doubling the angle of incidence does not mean that the angle of refraction also doubles.

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. 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. The air close 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 7.24).

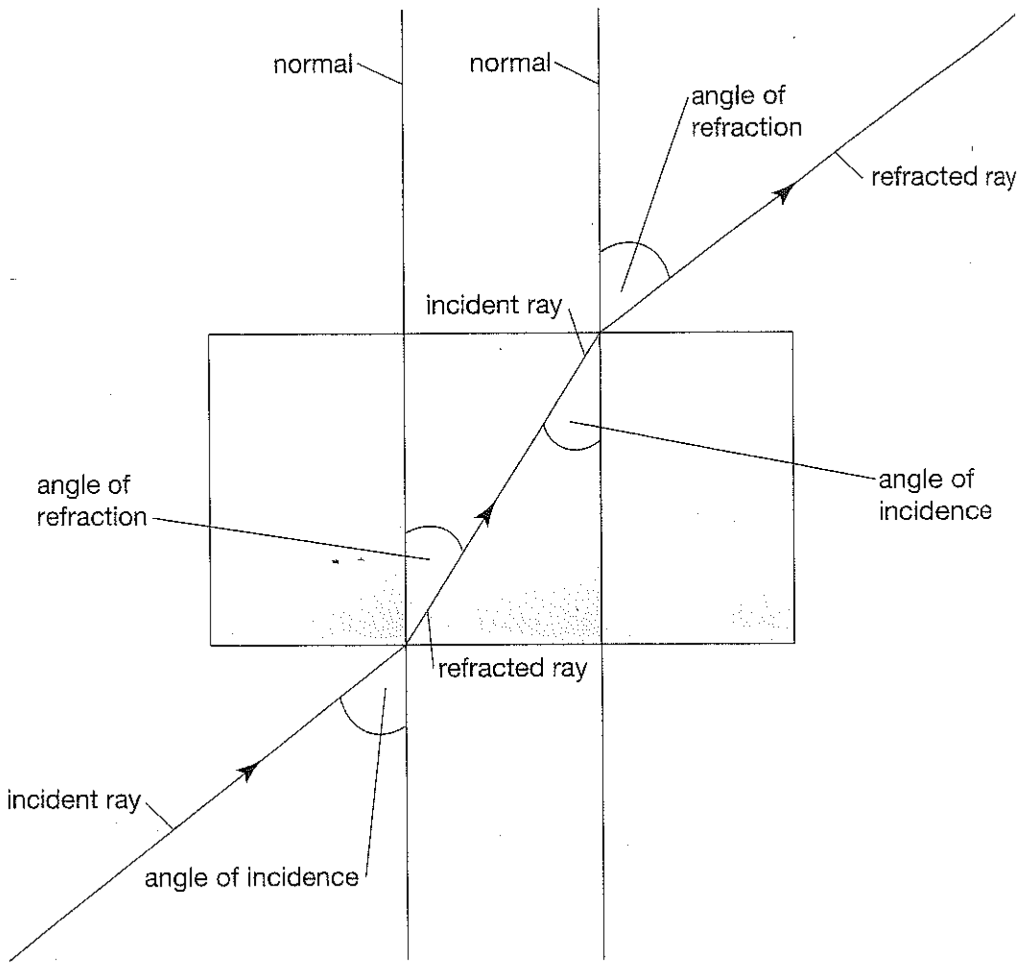


Figure 7.23 Light is refracted as it passes through one medium into a denser medium.

Figure 7.24 Refracted light is responsible for creating mirages. When air near the ground warms up, the light from objects at a distance is refracted into a curved path. This causes the illusion of a water surface, which is really an image of the sky refracted by warm air near the ground.

Is That All There Is to Light?

Table 7.1 summarizes what happens to light when it strikes different surfaces. Sometimes all three light behaviours happen at once. Light from the Sun can reflect off the still surface of a lake to produce a mirrorlike reflection. At the same time, the water can absorb light, transforming the light energy into thermal energy. The water warms during the day and cools off at night. If you are looking down into the water from shore, you might be uncertain about the location of objects on the bottom. This happens because light is refracted as it travels from water into the air.

Table 7.1 What Happens When Light Strikes a Surface?

Type of behaviour	What happens to light striking a surface?	Nature of surface	What else happens?
Absorption	Changes into some other kind of energy.	Occurs mostly on rough, dark, opaque surfaces.	Some light is usually reflected off the surface.
Reflection	Bounces off the surface and travels in a new direction.	Occurs best when light hits a smooth, shiny surface.	Some light is usually absorbed.
Refraction	Travels through the surface, often in a new direction.	Occurs when light strikes a different, transparent medium.	Some light is usually reflected off the surface.