Topic 4.5

What is refraction and how can it be used?

Key Concepts

- Refraction is the bending of light when it crosses a boundary between two substances.
- Refraction is used in communications and other technologies.

Key Skills

Inquiry
Literacy

Key Terms

medium
refraction
refracted ray
angle of refraction
total internal reflection

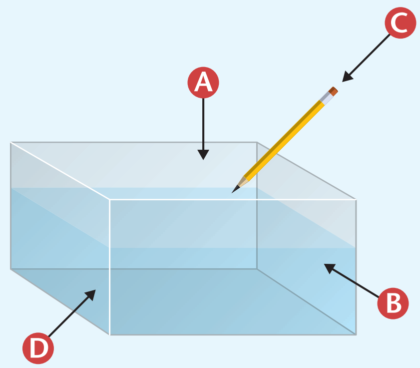
Each of the objects or situations in the photos on these two pages involves a specific property of light. When light enters some transparent materials from an angle, it reflects many times from the carefully shaped surfaces *inside* the materials before it leaves them along a different angle. In some cases, such as a fibre optic lamp or a cut diamond, the aim is simply for beauty. In other cases, such as a bicycle reflector, the aim is for safety. Still other examples of this property of light help us see objects at a distance, communicate along specially designed telephone cables, and perform delicate surgery with the tiniest of incisions.

Starting Point Activity

In this activity, you will observe a pencil moving in and out of water from different places around a transparent tank. Some of the effects you observe are related to how light works in the photos on these two pages.

What To Do

1. Fill a transparent tank about two- thirds full of water as shown in the diagram.

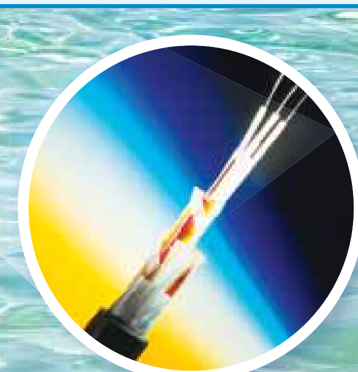


The transparent tank could be an aquarium or a plastic storage box. You could use a large beaker if a tank is not available.

2. Hold a pencil as shown in the diagram. You will move it straight into and out of the water while observing it from different places, marked A, B, C, and D.
   a) For A, look straight down to the surface of the water as you move the pencil in and out of the water.
   b) For B, your eyes should be level with the surface of the water.
   c) For C, look straight down the pencil from behind.
   d) For D, look up from near the bottom of the water. You will be looking at the pencil from below the surface of the water.

What Did You Find Out?

1. What was similar in all of the observations?
2. What was the most striking difference in the appearance of the pencil when looking at it from different directions?
3. What does the water's surface look like when observing it from below?
4. Propose an explanation for your observations.



Refraction is the bending of light when it crosses a boundary between two substances.

medium: the substance or material that light is travelling through (the plural of medium is *media*)

refraction: the change in the direction of light when it crosses a boundary between two media

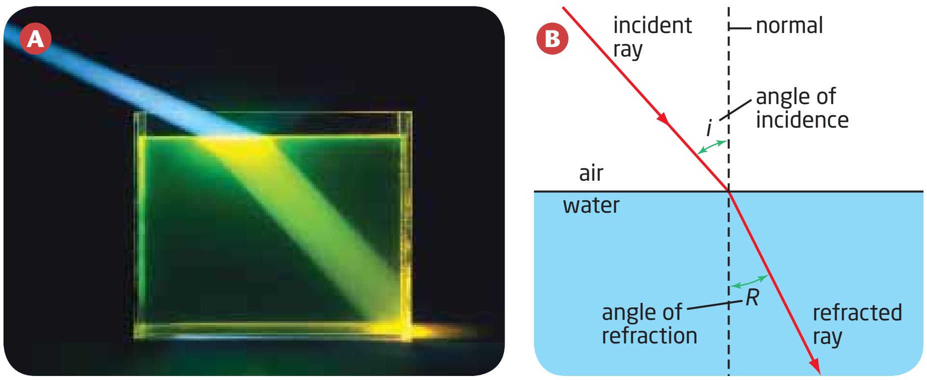
refracted ray: the ray after crossing a boundary between two media

angle of refraction: the angle between the refracted ray and the normal

The effect in **Figure 4.34** occurs because a ray of light can bend when it travels from one substance across the boundary to another substance. Any substance light rays travel through is called a **medium**. The plural of medium is media. In the spoon photo, the two media are air and water. The bending effect of light when it crosses a boundary between two different media is called **refraction**.

You can see light refracted as it goes from air to water in **Figure 4.35A**. This photo is translated into a ray diagram in **Figure 4.35B**. You know all the terms in the diagram except for two new ones. The **refracted ray** is the ray that travels through the second medium. The **angle of refraction** is the angle between the normal and the refracted ray.

▶ **Figure 4.34** This bending effect is the result of a property of light called refraction.

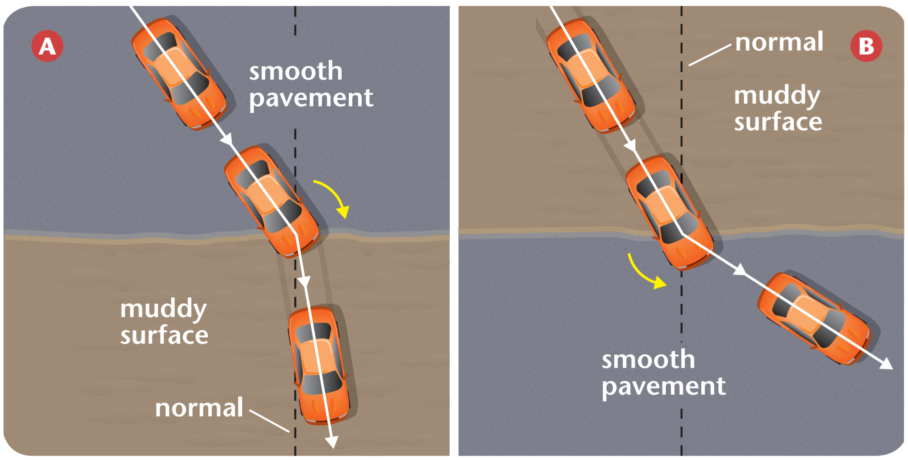


▲ **Figure 4.35** In (A), you can see the path of light bend as it meets the boundary between one medium (air) and another medium (water). Use the ray diagram in (B) to help you understand the terms that are used to discuss refraction of light.

What Causes Refraction

Light refracts because light travels at different speeds in different media. Figure 4.36 is a model to help you understand why.

In Figure 4.36A, you see a car travelling along smooth pavement and entering an area of muddy surface. When the tires enter the mud, they move more slowly than they did on the pavement. As a result, the path of the travelling car bends toward the dashed line in the diagram. In Figure 4.36B, the situation is reversed. The car is travelling along a muddy surface and entering an area of smooth pavement. When the tires enter the smooth pavement, they move more quickly than they did on the mud. As a result, the path of the travelling car bends away from the dashed line in the diagram.



◄ **Figure 4.36** Using a model of a car on pavement and mud to describe refraction

Literacy Focus

Activity 4.15

INTERPRET A MODEL TO DESCRIBE REFRACTION

The car in Figure 4.36 represents a light ray. Other parts of the diagrams represent two different media and the normal. Assume the media being represented are air and water.

1. Make a new sketch of Figure 4.36 to translate each of the two diagrams into a ray diagram. Use labels to identify the ray, the media, the normal, the angle of incidence, and the angle of refraction in each diagram.
2. Write a caption for each diagram that explains how the light ray refracts. Start the first caption like this: "When the speed of a light ray slows down". Start the second caption like this: "When the speed of a light ray increases."

LEARNING CHECK

1. Explain how refraction is different from reflection.
2. Use a graphic organizer such as a Venn diagram to compare the similarities and differences between a ray diagram for reflection and a ray diagram for refraction.

ACTIVITY LINK

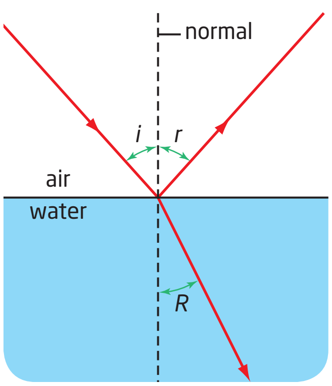
Activity 4.17, on page 340
Activity 4.18, on page 341

Refraction is used in communications and other technologies.

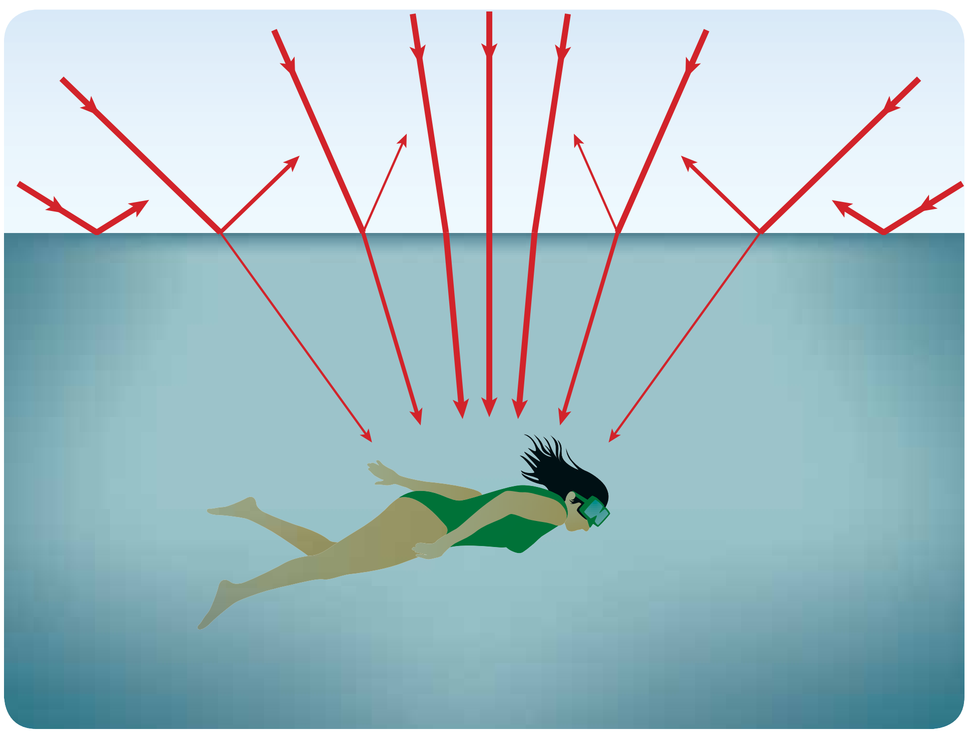
▲ **Figure 4.37** Sunlight reflecting off water can be so bright it is almost blinding.

Seeing sunlight reflecting from the surface of water, as in **Figure 4.37**, is a common sight. But at the start of this topic, you learned that when light hits the surface of water, it travels into the water and refracts. So which is it: does light reflect from water or refract in water? The answer is: both! As you can see in **Figure 4.38**, light reflects and refracts when it reaches water.

When the angle of incidence of the light entering water from the air is very small, nearly all of the light penetrates the water and refracts. As the angle of incidence gets larger, more and more of the light reflects and less refracts into the water. At very large angles of incidence, most of the light reflects off the surface. As well, light moving toward a diver at a large angle of incidence will refract away from the diver. This explains why people swimming under water see only a small area where light is penetrating the surface and reaching their eyes. As shown in **Figure 4.39**, most of the light reflects off the water and never reaches the diver.



▲ **Figure 4.38** When light travels from air to water, some light reflects from the surface and some light travels into the water and refracts.



▲ **Figure 4.39** Most of the light coming from directly above the scuba diver penetrates the water and the diver sees it. Most of the light coming at larger angles is reflected. The bottom of the surface of the water that is not directly above the diver looks nearly black to the diver because very little light penetrates there.

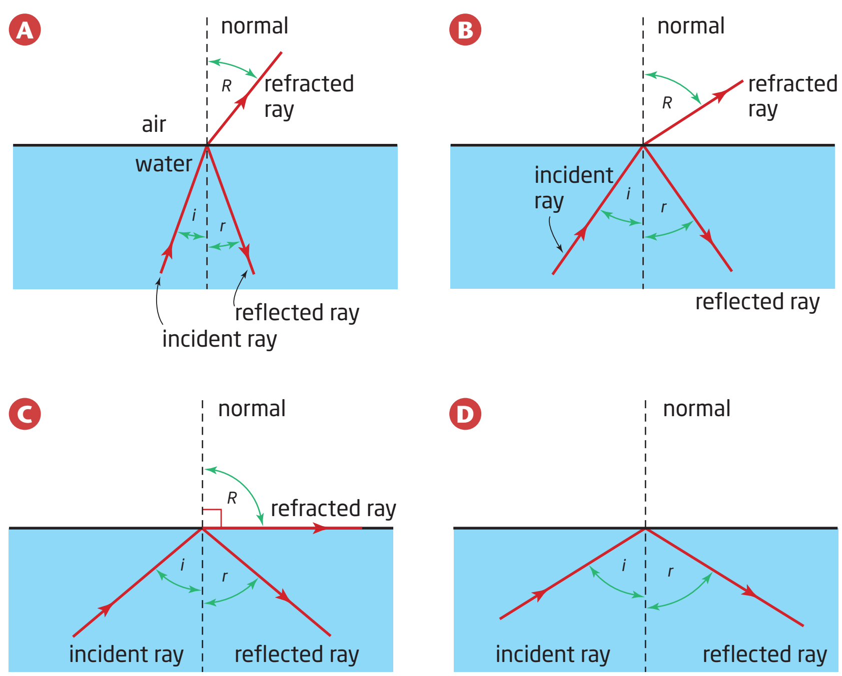
Total Internal Reflection

The technology that makes highspeed Internet and other communications technologies possible is linked to what happens when light travels from a medium in which its speed is lower to a medium in which its speed is higher. Examine **Figure 4.40** which shows what happens as the angle of incidence increases.

In **Figure 4.40A**, a ray of light is travelling upward from the water to the air at a small angle of incidence. And you can see that the angle of refraction is larger than the angle of incidence. In **B**, the angle of incidence is slightly larger, and the angle of refraction is much larger. Eventually, as shown in **C**, the angle of incidence gets so large that the angle of refraction is 90°. So in **C**, the refracted ray skims the surface of the water. The angle of incidence, when this occurs, is called the *critical angle*, because the angle of refraction cannot get any larger.

At any angle of incidence larger than the critical angle, all light is reflected back into the water. This condition, shown in diagram **D**, is called **total internal reflection**. All the technologies at the start of the topic are based on total internal reflection.

total internal reflection: The condition in which no light can escape the medium because the angle of incidence is larger than the critical angle



◄ **Figure 4.40** In diagrams A and B, the angle of refraction is increasing more rapidly than the angle of incidence. In diagram C, the angle of refraction has reached 90° making the angle of incidence the critical angle. At all angles beyond the critical angle, as in diagram D, all light is internally reflected.

LEARNING CHECK

1. In a case where light is entering water from air, describe what happens to the light a) when the angle of incidence is very small and b) when the angle of incidence is very large.
2. Describe how total internal reflection is related to refraction, even though the word "refraction" doesn't appear in its name.

ACTIVITY LINK
Activity 4.19 on page 342

continued on the next page…

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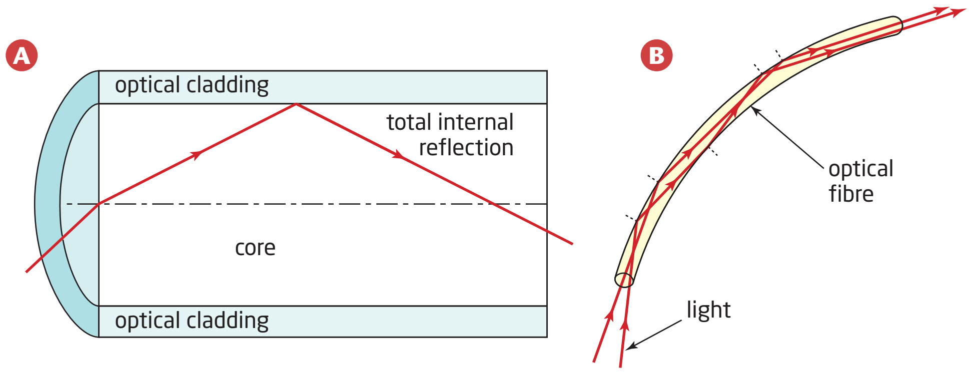
Fibre Optics

An optical fibre, as shown in **Figure 4.41A**, is made of a tiny glass fibre called the core that is about the size of a human hair. A cladding (protective coating) made of a different type of glass covers the core. The speed of light in the cladding is higher than it is in the core. Thus, light that enters the core and reaches the boundary between the core and the cladding at an angle greater than the critical angle will be totally internally reflected. Light will travel down the core as shown in **Figure 4.41B**.

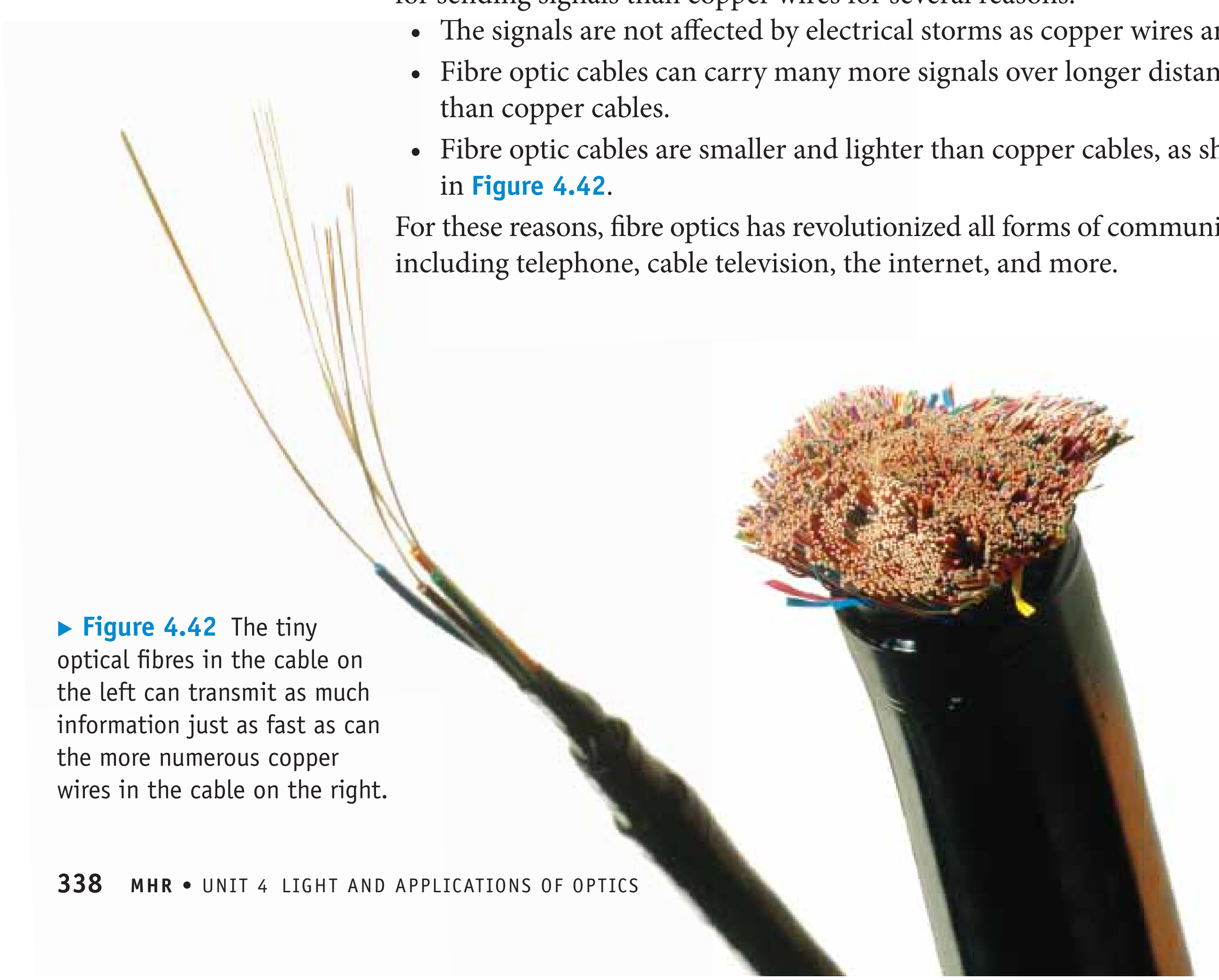


▶ **Figure 4.41** Light is sent into the ends of a fibre in a way that ensures that the angle of incidence will be larger than the critical angle. Even when the fibres are bent, total internal reflection still occurs.

The core and cladding are protected by more coatings of plastic. Many individual fibres are combined into a cable with is encased is a larger coat of plastic. By sending light in pulses, optical fibres can carry information long distances at nearly the speed of light. Optical fibres are more practical for sending signals than copper wires for several reasons.

- The signals are not affected by electrical storms as copper wires are.
- Fibre optic cables can carry many more signals over longer distances than copper cables.
- Fibre optic cables are smaller and lighter than copper cables, as shown in **Figure 4.42**.

For these reasons, fibre optics has revolutionized all forms of communication including telephone, cable television, the internet, and more.



▶ **Figure 4.42** The tiny optical fibres in the cable on the left can transmit as much information just as fast as can the more numerous copper wires in the cable on the right.

Inquiry Focus

Activity 4.16

MODELLING AN OPTICAL FIBRE

In this activity, you will observe a demonstration of total internal reflection in a stream of water. The effect you see is a model of how light travels inside an optical fibre.

What You Need

- clear plastic bottle
- duct tape (about 5 cm)
- thumbtack
- masking tape (about 3 cm)
- water
- bucket (or sink)
- flashlight

What To Do

1. Your teacher has set up the materials and equipment as shown in the picture. To make the bottle, your teacher has put a short piece of duct tape about 6 to 8 cm from the bottom of the clear plastic bottle. A small hole has been made in the centre of the duct tape with a thumbtack. The hole has been covered with a small piece of masking tape. And the bottle has been filled with water.
2. Your teacher will ask a volunteer to shine a beam of light from a flashlight through the bottle from the side that is opposite the hole.
3. Another volunteer will remove the masking tape so a stream of water can flow out of the bottle.
4. Observe the water as it leaves the hole. Also keep an eye on the level of the water in the bottle as it lowers closer to the hole.
5. Be on the lookout for the moment when total internal reflection suddenly occurs. You'll know, because the beam of light from the flashlight moves with stream of the water.

What Did You Find Out?

1. In what ways did this activity model the way that light travels in an optical fibre? (Refer to the text and diagrams on page 338 to help you answer this question.)

LEARNING CHECK

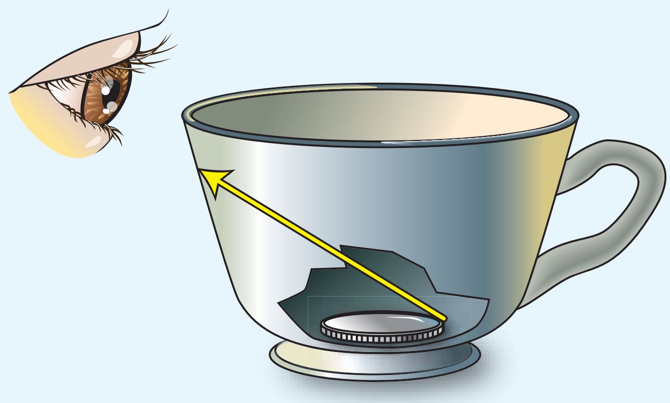
1. Give an example that demonstrates that reflection and refraction happen at the same time.
2. What conditions must be met in order for total internal reflection to occur?
3. When you are looking down into a pond and see a fish, it isn't where it appears to be. Suggest a possible reason why this happens.
4. List two reasons why optical fibres are preferred over copper wires for many types of communication.

Inquiry Focus

Activity 4.17

THE REAPPEARING COIN

How can you see an object that is not in your "line of sight?" You will find out in this activity.



What You Need

- cup or another container with opaque sides
- coin
- water

What To Do

1. Work with a partner. Place the coin at the bottom of the empty cup. Cover one eye with your hand and look down at the coin. Lower your head until the edge of the cup just blocks your view of the coin. Keep your head in this position.
2. Your partner will slowly pour water into the cup. If the coin starts to move, your partner should hold it in place with the end of a pencil. Your partner will continue to pour water into the cup until you can see the coin again.
3. Empty the water into a sink.
4. Change places so that your partner can watch the coin while you pour water into the cup.

What Did You Find Out?

1. Copy the diagram above. Note that the ray in the diagram shows that light from the coin cannot reach your eye when the cup is empty.
2. Sketch a ray diagram to show what must happen to light that travels from the coin to your eye when water is in the cup. (Note: A light ray must travel in a straight line in air and it must travel in a straight line while in the water.)

Inquiry Focus

Activity 4.18

REFRACTION OF LIGHT

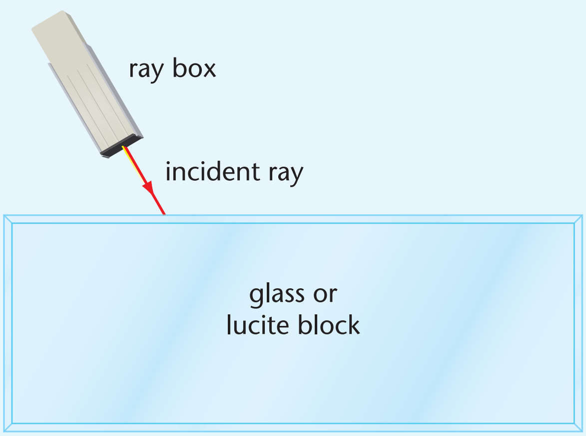
In this activity, you will investigate the refraction of light as it enters and as it leaves a block of transparent, solid material.

What You Need

- blank sheet of paper
- ray box with a single slit
- rectangular block of plastic or glass
- pencil and ruler

What To Do

1. Place the rectangular block on the sheet of paper. Trace around the edge of the block.
2. Shine an incident light ray into the block near the left edge of the block, as shown in the figure.



3. You should see at least two light rays outside of the block. Place dots along their paths.
4. Remove the ray box and the block. Join the dots to show the paths of the light outside of the block. Include arrowheads to show the direction in which each ray was going.
5. Draw a line from the point where the incident light ray *entered* the block to the point where it *left* the block. This will indicate the path of the light *inside* the block. Draw an arrowhead on this ray to show the direction in which it was going.
6. Compare the direction of the ray that emerged from the block to the direction of the incident ray.
7. See if you can find any evidence of reflection at the second surface.

What Did You Find Out?

1. What happened to the incident light ray as it struck the surface of the block?
2. From your observations, did the path of the light ray bend at the surface of the block or during its travel through the block?
3. How did the direction of the light ray that emerged from the block compare to the direction of the incident ray?
4. Did light reflect at any of these surfaces? If so, where did this reflection occur?

Inquiry Focus

Activity 4.19

REFLECTION AND REFRACTION OF LIGHT (GLASS TO AIR)

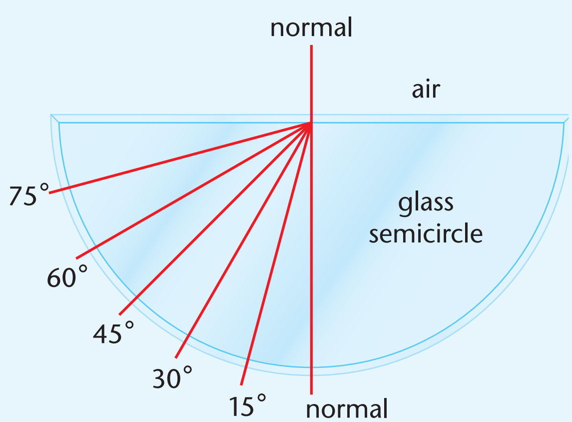
In this activity, you will investigate the refraction of light as it goes from a medium in which the speed of light is slower to a medium in which the speed of light is faster.

What You Need

- blank piece of paper
- ray box with a single slit
- pencil and ruler
- protractor
- glass semicircle

What To Do

1. Read the procedure and make a table to record your data.
2. Place the glass semicircle on the paper and trace its outline.
3. Remove the semicircle and locate the centre of the flat face on the outline. Draw the normal at that point.
4. Draw angles of 15°, 30°, 45°, 60° and 75° to the normal as shown in the diagram.



5. Replace the glass semicircle. Position the ray box on the rounded side at the 15° mark. Shine an incident ray in along the 15° line toward the flat face of the glass semicircle.
6. Measure the angle of refraction where the light leaves the glass semicircle. Compare the sizes of the angles of incidence and refraction.
7. Do you see any reflection occurring? If so, how does the size of the angle of reflection compare to the size of the angle of incidence?
8. Repeat steps 4 through 6 for the rest of the angles of incidence.
9. Observe and record how the brightness of the refracted and reflected rays changes as the angle of incidence increases.

What Did You Find Out?

1. How does the angle of refraction compare to the angle of incidence when light passes from glass into air?
2. How does the angle of reflection (if any) compare to the angle of incidence?
3. Estimate the critical angle of glass. Explain how you made your estimate.
4. If the angle of incidence is greater than the critical angle, how much refraction occurs?
5. What happens to the brightness of the refracted and reflected rays as the angle of incidence increases?

Inquire Further

6. Design a procedure to investigate the reflection and refraction of light from air to glass. (Hint: Use your experiences in this activity.) Show your procedure to your teacher. With your teacher's approval, test your procedure.

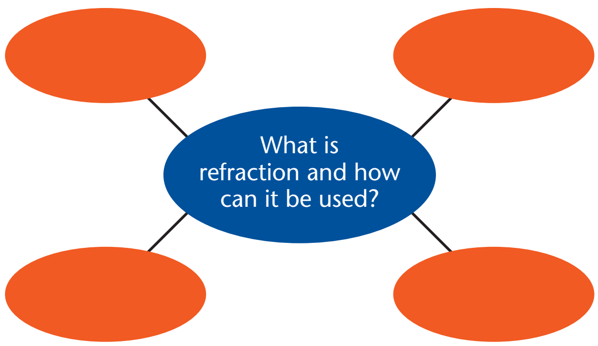
Topic 4.5 Review

Key Concept Summary

- Refraction is the bending of light when it crosses a boundary between two substances.
- Refraction is used in communications and other technologies.

Review the Key Concepts

1. K/U Answer the question that is the title of this topic. Copy and complete the graphic organizer below in your notebook. Fill in four examples from the topic using key terms as well as your own words.

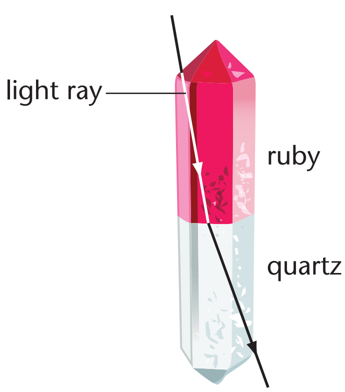


2. K/U Does light refract toward the normal or away from the normal when going from:

a) a medium in which the speed of light is lower to a medium in which it is higher?

b) air into plastic?

3. T/I The diagram below shows a light ray travelling from a ruby crystal to a quartz crystal. In which substance is the speed of light greater?



4. K/U Explain the concept of total internal reflection.

5. T/I You are given two blocks of glass that look just alike. A classmate tells you that they are really two different types of glass. Describe an experiment that you could carry out that would determine whether the blocks of glass were identical or different types of glass.

6. C Draw a sketch to show how an optical fibre could guide a light beam around a 90° corner.

7. T/I The diagram below shows a beaker of cooking oil and water. A light ray is about to enter the cooking oil. The speed of light for the three media—air, oil, and water—are recorded beside the beaker.

a) Predict the path the light ray will take as it passes from the air, through the oil, and through the water.

b) Copy the diagram into your notebook. Complete it by drawing the path of the light ray from your prediction in part a).