LESSON **17**

Introducing Refraction

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We look through transparent materials—solids, liquids, or gases—all the time. Do transparent materials affect the appearance or position of what we observe?

INTRODUCTION

Have you looked through a window today? For that matter, did you observe your hands while washing them this morning, or look at juice through the side of a glass during breakfast? If you did, you observed light passing from one transparent material to another. What happens when light strikes a transparent object or material like a window or the surface of water? You may already have some ideas.

Here are a few questions to ask yourself. Does all the light striking a transparent object enter it? Does the light entering a transparent object leave it? Does the light entering a transparent object travel in a straight line through it? Does the composition or shape of a transparent object affect the behavior of light? Get ready to share your ideas before you launch into three inquiries that will help test your ideas—and raise other questions—about how light interacts with transparent objects.

OBJECTIVES FOR THIS LESSON

Discuss how light interacts with transparent objects.

Make observations through a transparent block.

Observe and make measurements of a light ray as it interacts with a transparent block.

Use standardized terms to describe the behavior of a light ray as it interacts with a transparent block.

Getting Started

1. Use the questions in the Introduction to help you with your thinking in Steps 2 and 3.

2. Discuss with your group where, in previous lessons, you have observed light interacting with transparent objects. Discuss what you observed in each case.

3. Brainstorm with the class examples of these and other observations you have made of light interacting with transparent objects and materials.

MATERIALS FOR LESSON 17

For you

- 1 copy of Student Sheet 17.2: Shining Light Into a Transparent Block
- 1 copy of Student Sheet 17.3: Measuring Refraction in a Transparent Block

For you and your lab partner

- 1 transparent block
- 1 white screen
- 1 copy of Inquiry Master 17.1: Protractor Paper for Inquiries 17.2 and 17.3
- 1 protractor
- 1 metric ruler, 30 cm (12″)
- 1 box of colored pencils
- 1 pair of scissors

For your group

- 1 ray box
- 1 ray box lid
- 1 60-W clear halogen lightbulb
- 1 extension cord
- 1 bulb holder
- 2 narrow-slit ray box masks
- 2 no-slit ray box masks

Inquiry 17.1
Looking Through a Transparent Block

PROCEDURE

1. One member of your group should collect the plastic box of materials. Divide the materials between the pairs in your group. (Your group will share a ray box in Inquiries 17.2 and 17.3.) There is no student sheet for this inquiry. Record your responses in your science notebook.

2. Examine the transparent block. Look through the block from different angles. Discuss what you observe with your partner. Make a list of all your observations in your notebook.

3. Rest the block on top of the page of this book. Record what you observe.

4. Look sideways through the block. Hold your finger up behind the block. Look at your finger through the block and slowly rotate the block from side to side (see Figure 17.1). What do you observe when you rotate the block? Record your observations and share them with your partner.

5. What do you think is happening? Be prepared to share your observations and ideas with the class.

Figure 17.1 *Look at your finger through the block. What do you observe when you rotate the block?*

Inquiry 17.2
Shining Light Into a Transparent Block

PROCEDURE

1. Set up the ray box and white screen so that the side of the ray box at which your pair is working will produce a single ray of light.

2. Use the scissors to cut along the cutout lines on the protractor paper.

3. Place the protractor paper on top of the white screen. The curved side of the protractor diagram should face the mask (see Figure 17.2). It should be no more than 3 centimeters from the ray box.

4. Place the transparent block on the paper so that it is parallel to the ray box with its top edge along the baseline of the protractor paper (see Figure 17.2).

5. Plug in the ray box. Make sure the ray passes through your block.

6. Shine the ray along the 0° line (the normal) of the protractor paper. Observe what happens when the light ray strikes the transparent block.

SAFETY TIP

Do not touch the lightbulb. It gets hot and may burn your fingers.

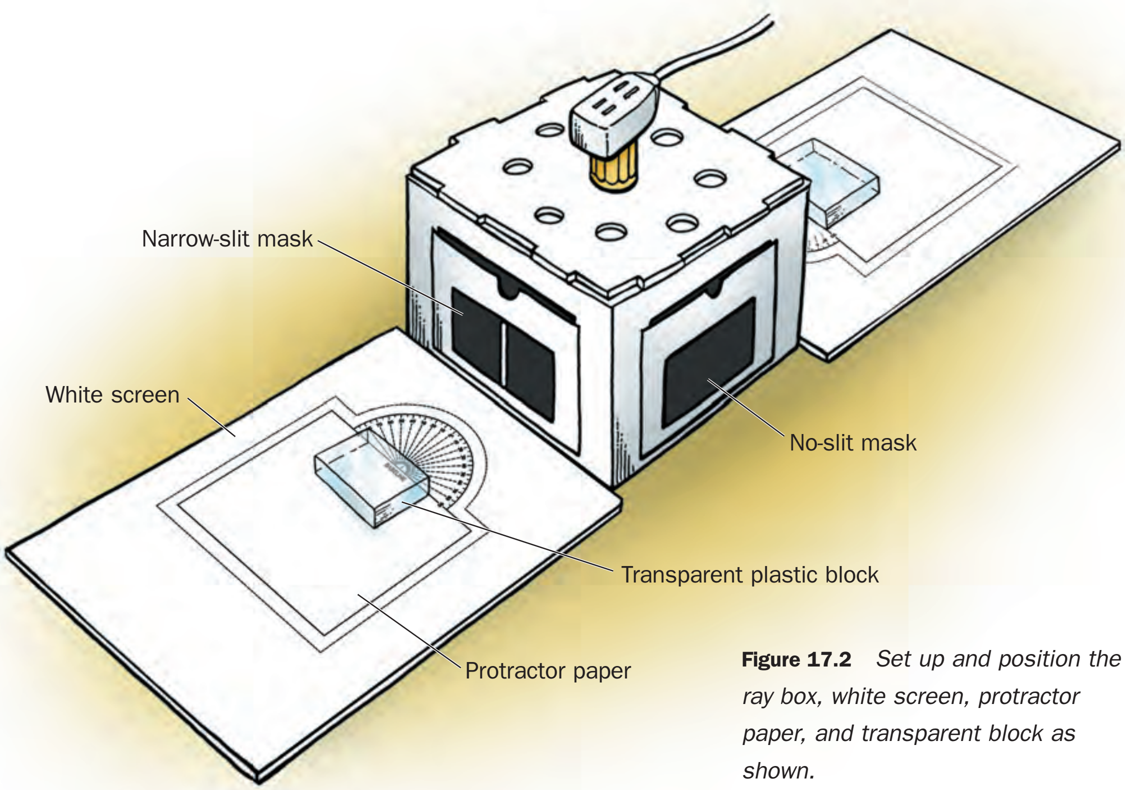


Figure 17.2 *Set up and position the ray box, white screen, protractor paper, and transparent block as shown.*

A. On Student Sheet 17.2: Shining Light Into a Transparent Block, complete the diagram by recording what you observe. Draw all the rays you observe. Do not forget to draw arrows to show the direction you think the light is traveling.

B. Describe what happens to the ray of light as it strikes the block.

7. *Very slowly* turn the block clockwise on the protractor paper (as shown in Figure 17.3). Carefully observe the behavior of the light as it strikes the rotating block.

C. As you rotate the block, stop about every 15–20° and use a diagram and words to record what you observe.

D. What do you notice about the angle of the reflected ray as you rotate the block?

E. How do your observations fit in with what you know about reflection?

F. Can you observe the ray inside the block?

G. What do you observe about the position and direction of the ray as it leaves the block?

H. What do you think happens to the direction of the light ray as it enters and leaves the block?

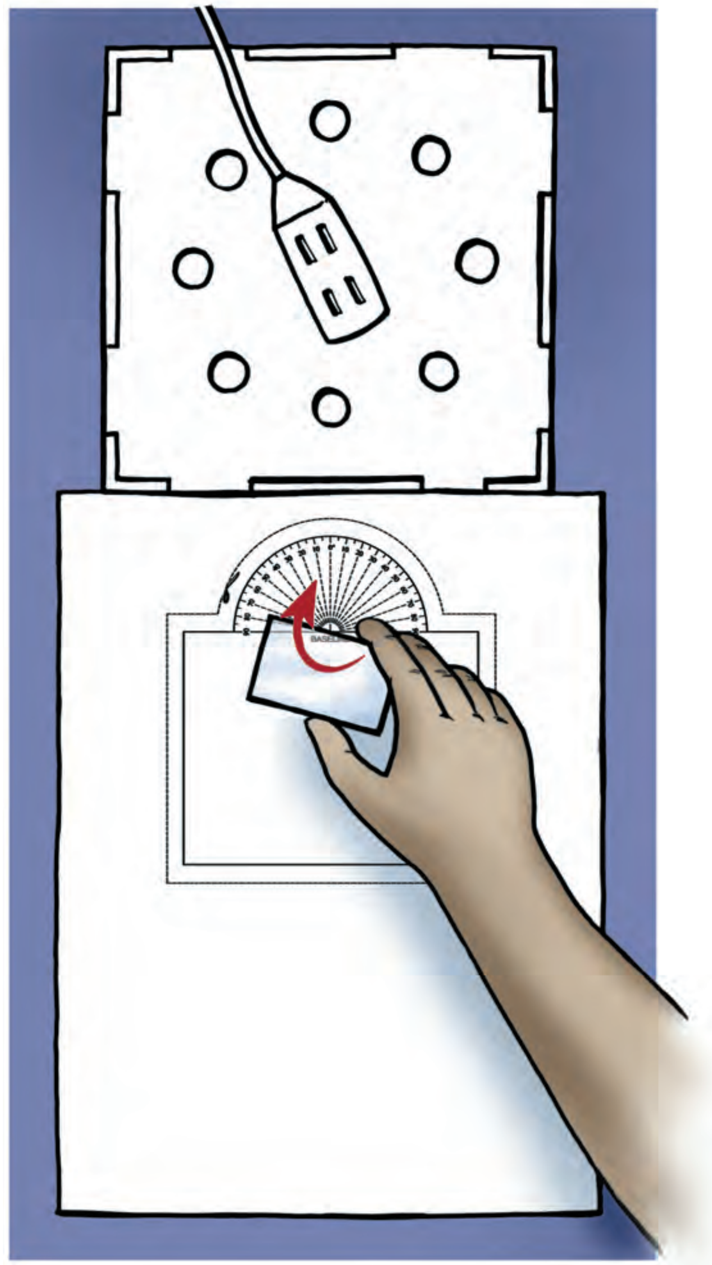


Figure 17.3 *Very slowly rotate the block clockwise.*

8. Read "Reflection and Refraction."

REFLECTION AND REFRACTION

Light changes direction when it reflects off a surface. We call this change in direction reflection. Light also may change direction when it travels from one transparent material into another. (What were the two transparent materials involved in your investigation?) This change in the direction of light is called refraction. Once light has been refracted, it continues in a straight line within that material until it strikes another surface.

I. Where did refraction of the ray take place in this inquiry?

Inquiry 17.3
Measuring Refraction in a Transparent Block

PROCEDURE

1. Reposition the block and protractor paper so that the light ray strikes the block along the 0° line on the protractor paper.

2. *On the protractor paper,* use a colored pencil to draw around the block (see Figure 17.4). Draw lines showing where light enters and leaves the block.

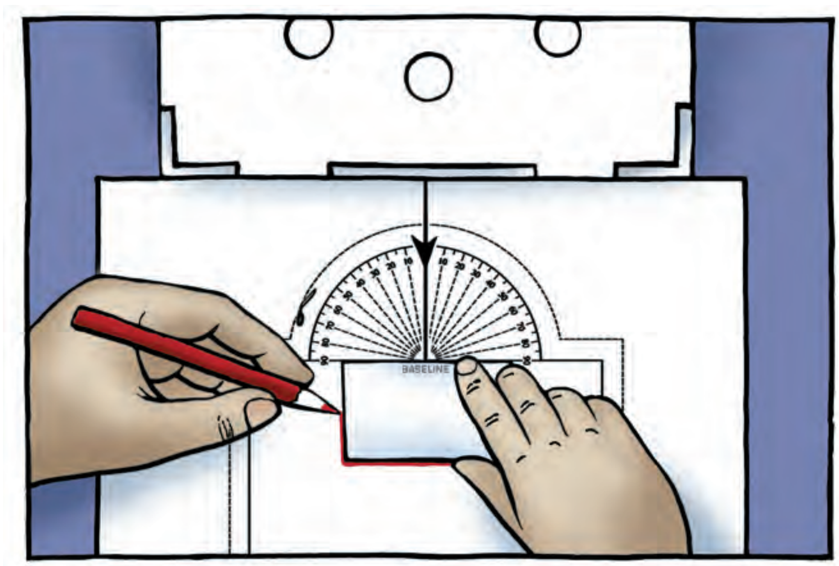


Figure 17.4 *Draw around the block. Draw lines showing where light enters and leaves the block.*

3. Turn *both* the transparent block and protractor paper 20° clockwise (see Figure 17.5). (The front face of the block should still lie along the baseline of the protractor paper.) The light ray now has an angle of incidence of 20°.

4. Use a different colored pencil to draw the rays entering and leaving the block as before.

5. Rotate the block and protractor paper 20° more. Use a third colored pencil to draw the rays.

6. Remove the block from the paper. For each different angle of the incident ray, use the ruler and appropriate colored pencil to draw in the path of the light rays *as they pass through* the block.

A. Transfer what you have recorded onto the three diagrams of blocks on Student Sheet 17.3: Measuring Refraction in a Transparent Block. (You may find it useful to rotate the protractor paper so that the angle of the block's outline matches the angle shown in the diagram.)

7. Compare how light behaved when the block was in the three different positions.

B. Did the light ray entering the block always behave in the same way?

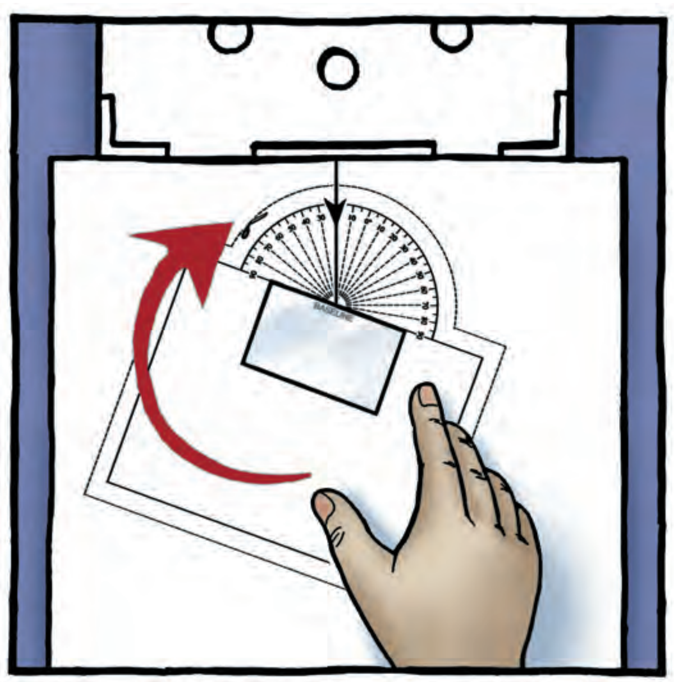


Figure 17.5 *Rotate the transparent block and the protractor paper 20° clockwise. Use a different colored pencil to draw rays entering and leaving the block.*

8. Look at the diagrams you have completed for the blocks with angles of incidence of 20° and 40°.

C. Describe exactly what happens to the light ray as it passes from air into the transparent block at each angle.

D. Describe exactly what happens to the light ray as it passes from the transparent block into the air.

E. How does changing the angle at which the light ray strikes the block affect the position of the ray as it leaves the block?

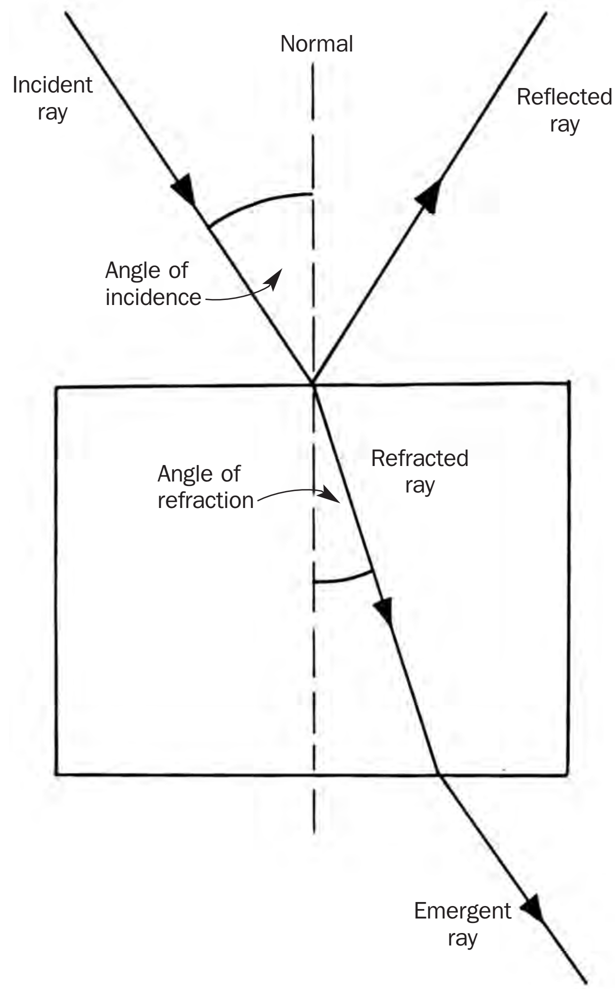
F. Is there any relationship between the direction of the ray striking the block and the direction of the ray leaving the block?

9. Read "Introducing Refraction."

INTRODUCING REFRACTION

When a ray of light (the incident ray) strikes the transparent block, some light is reflected (the reflected ray) and some light enters and passes through the block. If the ray enters at right angles (along the normal) to the block's surface, the light passes through the block in a straight line. If the ray has a different angle of incidence, the ray bends at the boundary—it is refracted—between the air and the transparent block. The light ray inside the block is called the refracted ray. The angle between the normal and the refracted ray is called the angle of refraction.

The refracted ray travels in a straight line and emerges from the block. At this point, the ray emerges from the block and changes direction again because it has been refracted by passing through the second surface of the block to re-enter the air. This refracted ray is called the emergent ray. Look at the diagram—it shows some of the rays you may have seen entering and leaving the transparent block.



10. On one of the diagrams you completed under A on your student sheet, identify the incident, reflected, refracted, and emergent rays. Label them on your diagram.

G. When light passes into, through, and out of the transparent block, where does refraction occur?

H. When light passes from air into transparent plastic, does it behave in the same way as it does when it passes from transparent plastic into the air? Describe any differences or similarities that occur.

11. Write in values for the angles of incidence on each diagram.

12. Use a protractor to measure the angles (on the protractor paper) of refraction you obtained. Write these in on each diagram.

I. Describe the effect that changing the angle of the incident ray has on the angle of refraction.

SAFETY TIP

Turn off the ray box immediately after you finish using it. Allow the ray box to cool.

REFLECTING ON WHAT YOU'VE DONE

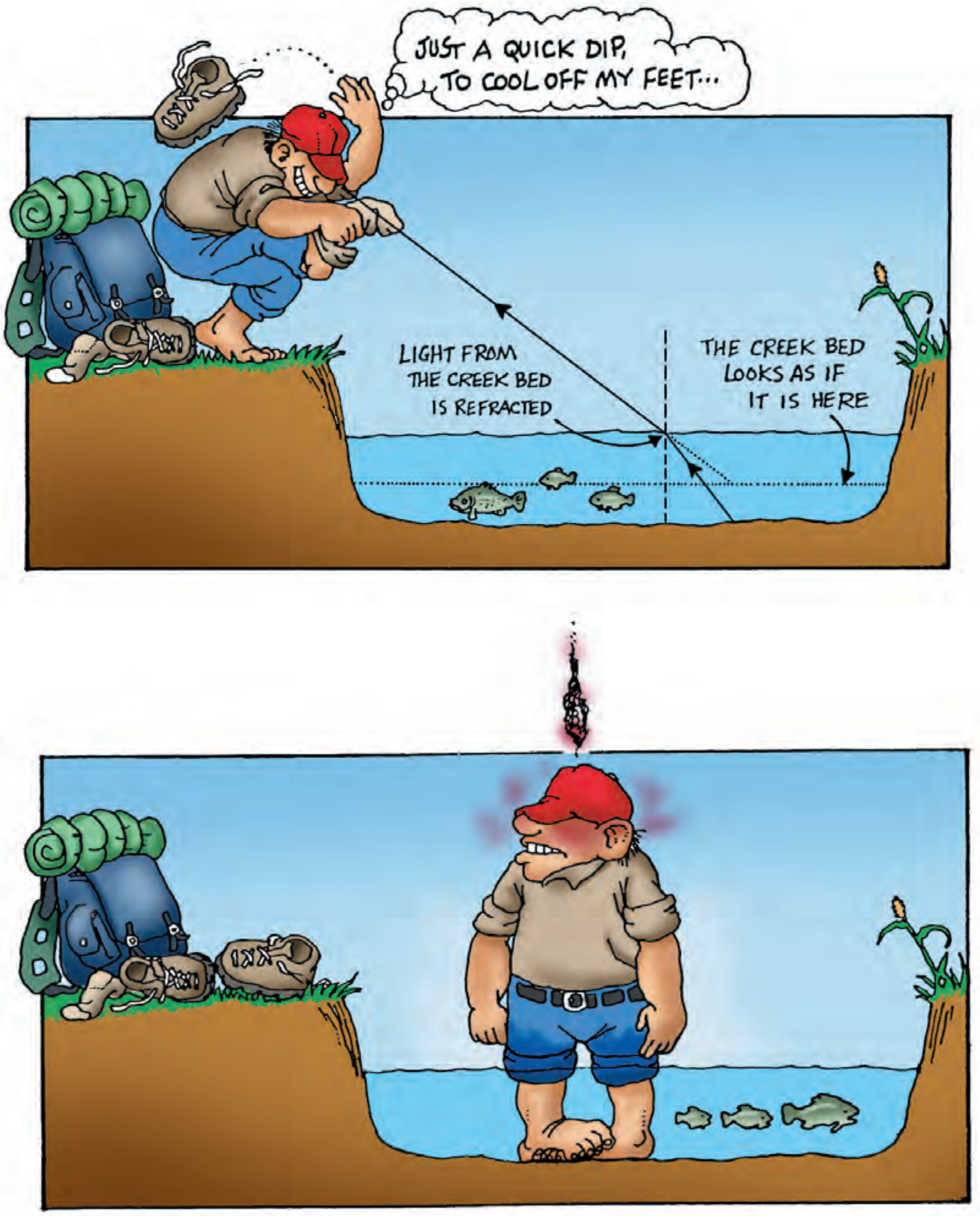
1. Record your responses to the following on Student Sheet 17.3. Be prepared to share your responses with the class.

A. What is the difference between reflection and refraction?

B. Write a paragraph summarizing what you have learned about the behavior of light after it strikes and passes through a transparent block. When writing your description, try to use the correct names for the rays and the angles they have to the normal.

2. Review the question bank cards generated in Lesson 1. Can you answer any more of them now? Identify those that you feel comfortable answering.

Refractive Index and Wet Pants



The water is deeper than it looks. Knowledge of how light is refracted when it passes from water into the air might have saved this hiker the embarrassment of wet pants.

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Refraction between the air and this jar of water makes this student look distorted. What causes refraction?

Phew! It's a scorching day, and that creek looks very inviting to a hot, tired hiker. His feet are aching, and he's dying to slip off his stiff hiking boots and thick socks and wade in that nice cool water. In he goes, and . . . Splash! Instead of being up to his ankles, the water is up to his knees. Why was the water much deeper than it appeared—and how will the hiker dry his pants? If only he had paid attention in science class! Why? Because he would have known that the apparent depth of the water was an illusion. Look at the picture of the hiker. Can you see how the hiker's brain was tricked by refraction?

What Causes Refraction?

Light is refracted when it changes speed. Light changes speed when it passes from one transparent material into another. For example, light travels slower in water than in air—about three-quarters as fast. Light therefore bends when it passes from air into water. (Do you remember the nail in water in Lesson 1? Did it appear bent?) The difference between the speed of light in two transparent materials determines how much the light bends as it passes between them. The bigger the difference in the speed of light in the two materials, the more bending, or refraction, takes place when the light passes from one material into another.

Refractive Index

Scientists find it useful to compare the light bending abilities of different transparent materials. They make this comparison using something called the refractive index. The refractive index of a transparent material is defined as the speed of light in a vacuum divided by the speed of light in the transparent material. Each transparent material has a different refractive index.

The slower the speed of light in a material, the higher its refractive index. In a vacuum—where there is no matter to slow down the light—light travels at its fastest speed. The refractive index of a vacuum is 1. This is the lowest refractive index. In glass, light travels much slower, about two-thirds the speed of light in a vacuum. The refractive index for glass is about 1 divided by two-thirds—a refractive index of about 1.5. Table 1 shows refractive indices of a vacuum and of different transparent materials.

In which of these transparent materials does light travel the slowest?

Bird Brains and Fishy Physics

If you know the refractive index of two materials, you can predict which way light will bend when it passes from one to another. Light passing from a material with a lower refractive index to one with a higher refractive index bends toward the normal (just as you observed when light passed from the air into the transparent plastic block).

What happens when light travels in the opposite direction? When light passes from a material with a higher refractive index into one with a lower refractive index (for example, from the transparent plastic block into the air), it is refracted in the opposite direction. The light ray bends away from the normal.

If the hiker had known this, could he have avoided getting his pants wet? Look back at the picture of the soggy hiker. Light reflected from the creek bed travels from water into the air. Air has a lower refractive index than water. As light passed from the water into the air it was

Table 1 Refractive Indices of Some Transparent Materials

Transparent Materials	**Refractive Index**
Vacuum (A vacuum contains no matter.)	1.00
Air	Slightly higher than 1.00 (1.000293)
Glass	1.53
Diamond	2.42
Transparent plastic	1.50
Water	1.33

refracted away from the normal. This made the water look shallow. The hiker was tricked by refraction!

Some birds that are expert fishers, such as the great blue heron, don't make the mistake the hiker made. They take refraction into account when they lunge underwater for their prey. They must lunge at a position deeper and at an angle different than where the fish appears to be. Did you know that birdbrains were so good at physics?

Now imagine you're a fish looking up from the water into the air. You would have the reverse problem of the hiker or the heron. Light traveling from the air into the water is refracted in the opposite direction, toward the normal. From underwater, objects look farther away than they actually are.

Can you use refractive indices to predict how light will behave when it passes from water to glass? Will a ray of light be refracted toward or away from the normal? ☐

The archerfish squirts water at insects to knock them off overhanging waterside plants. Archerfish have evolved a shooting technique to deal with the refraction that takes place between water and air. Each time the fish shoots a stream of water it takes into account that the insects are nearer, and at a different angle, than they appear.