LESSON 19

Modeling Reflection and Refraction

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What does the law of reflection have to do with this game?

INTRODUCTION

In Lesson 7, you modeled light as particles and as waves. Can you remember what represented the particles and waves in these models? In this lesson, you use these models again. This time you are going to see whether they can be used to model how light is reflected and refracted. You first will design experiments that use your models to model the reflection of light from plane, convex, and concave mirrors. Next you will investigate whether the same models can be used to model refraction. You then will compare your observations of the models with the observations you made of light being reflected and refracted. You will use these comparisons to reevaluate the models.

OBJECTIVES FOR THIS LESSON

Design ball bearing (particle) and water wave models of reflection of light from plane and curved mirrors.

Observe ball bearing (particle) and water wave models of refraction.

Compare and evaluate the ball bearing (particle) and water wave models with the behavior of light.

Getting Started

1. With your group, use your notes from Lesson 7 and the following questions to help you review the models that you used to model light as waves and particles:

What did you use to represent light waves or particles?

What aspects of light's behavior did you model?

How did you compare the two models?

2. Participate in a class review of these models.

MATERIALS FOR LESSON 19

For you

- 1 copy of Student Sheet 19.1: Can Particles Model Reflection From a Plane Mirror?
- 1 copy of Student Sheet 19.2: Using Particles To Model Reflection From Curved Mirrors
- 1 copy of Student Sheet 19.3: Using Waves To Model Reflection
- 1 copy of Student Sheet 19.4: Modeling Refraction
- 1 copy of Student Sheet 19.5: Assessment Review: Part 2
- 1 copy of Student Sheet 19.6: Sample Assessment Questions for Part 2

For your group

- 15 ball bearings (in a resealable plastic bag)
- 1 transparent tray
- 1 metric ruler, 30 cm (12″)
- 1 straight metal barrier
- 1 curved plastic barrier
- 1 cardboard tube
- 1 piece of modeling clay
- 1 piece of card
- 1 copy of Inquiry Master 19.1: Protractor Paper for Lesson 19
- 2 wooden blocks
- 1 wooden dowel
- 1 folding lamp
- 4 AA batteries
- 1 transparent cup
- 1 sheet of white paper

Inquiry 19.1
Can Particles Model Reflection From a Plane Mirror?

PROCEDURE

1. One member of your group should collect the plastic box of materials.

2. Working as a group, set the transparent tray on the table. Place the metal barrier in the tray as shown in Figure 19.1.

3. Tilt the cardboard tube to an angle of about 30°. Roll one ball bearing down the tube so that it strikes the barrier (see Figure 19.1).

4. Discuss with your group how the simple activity you have just done *could be adapted* to investigate whether the ball bearing you used follows the law of reflection.

5. Using the materials provided, devise a procedure to model the reflection of light from a plane mirror.

6. Discuss the type and quantity of data you need to collect. Devise a table for your data.

7. Outline your procedure on Student Sheet 19.1: Can Particles Model Reflection From a Plane Mirror?

8. Use your procedure to collect data. Record your data and observations.

9. Discuss your results with your group. Record any conclusions/comments you may have about the model. Be prepared to share your procedures, observations, and data with the class.

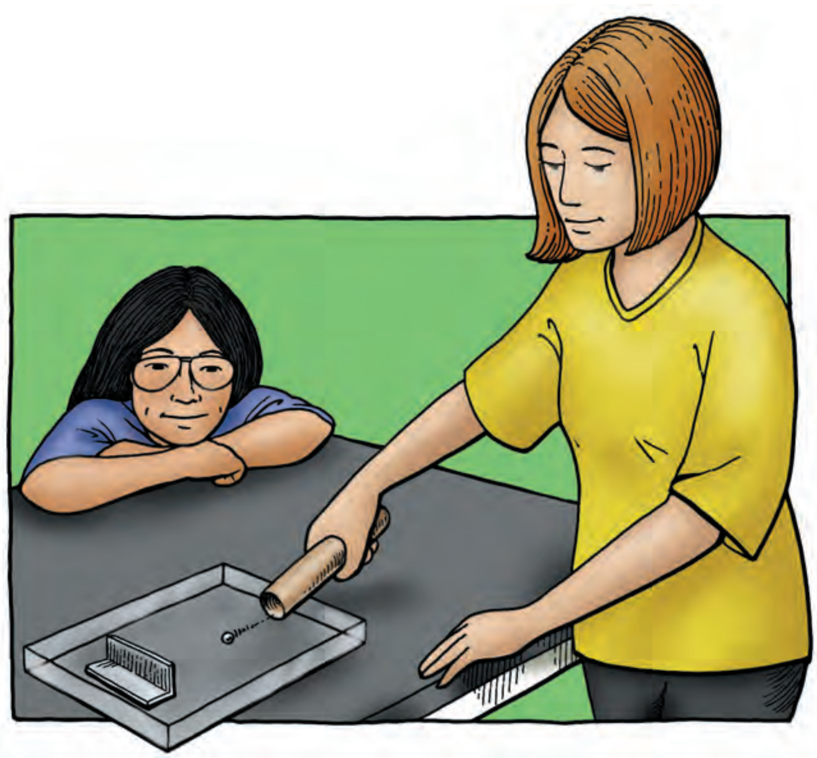


Figure 19.1 *Roll the ball bearing down the cardboard tube while holding the tube at a 30° angle.*

Inquiry 19.2
Using Particles To Model Reflection From Curved Mirrors

PROCEDURE

1. Use the materials provided to devise and conduct an inquiry with your group to model the reflection of light from curved mirrors.

2. Record your procedure, data, and observations on Student Sheet 19.2: Using Particles To Model Reflection From Curved Mirrors.

3. Discuss your results with your group. Record any conclusions/comments you have about the model on the student sheet. Be prepared to share your procedures, observations, and data with the class.

4. Return the ball bearings to the plastic bag and seal the bag.

Inquiry 19.3
Using Waves To Model Reflection

PROCEDURE

1. While your teacher reviews how to use the ripple tank apparatus, think about how you can use this apparatus to model the reflection of light.

2. Working with your group, use the ripple tank to model the reflection of light off plane, convex, and concave mirrors.

3. Record your procedure, data, observations, conclusions, and comments about the model on Student Sheet 19.3: Using Waves To Model Reflection.

4. Discuss with your group how the behavior of the model compares with the behavior of light rays striking these types of mirrors. Be prepared to share your ideas with the class.

SAFETY TIP

Make sure the battery box of the lamp is outside of the tray and does not touch the water.

Inquiry 19.4
Modeling Refraction

PROCEDURE

1. Spend a few minutes reviewing the inquiries you have conducted on refraction.

2. Discuss the following questions with your group:

   Why is light refracted when it passes from one transparent material to another?

   What determines the direction—toward or away from the normal—in which light is refracted?

3. Set up the apparatus as shown in Figure 19.2.

4. Roll one ball bearing down the ramp. Make observations. Repeat this procedure as many times as you consider necessary to obtain a valid result. Record your responses for this inquiry on Student Sheet 19.4: Modeling Refraction.

   A. What happens to the speed of the ball bearing as it rolls over the folded card?

   B. The denser a transparent material, the higher its refractive index and the slower the speed of light as it passes through it. For example, light travels faster in less dense air than it does in denser transparent plastic. Which part(s) of this model represents a less dense material (like air), and which part(s) represents a more dense material (like transparent plastic)?

   C. Record what happens to the direction of the ball bearings as they are rolled along the normal line.

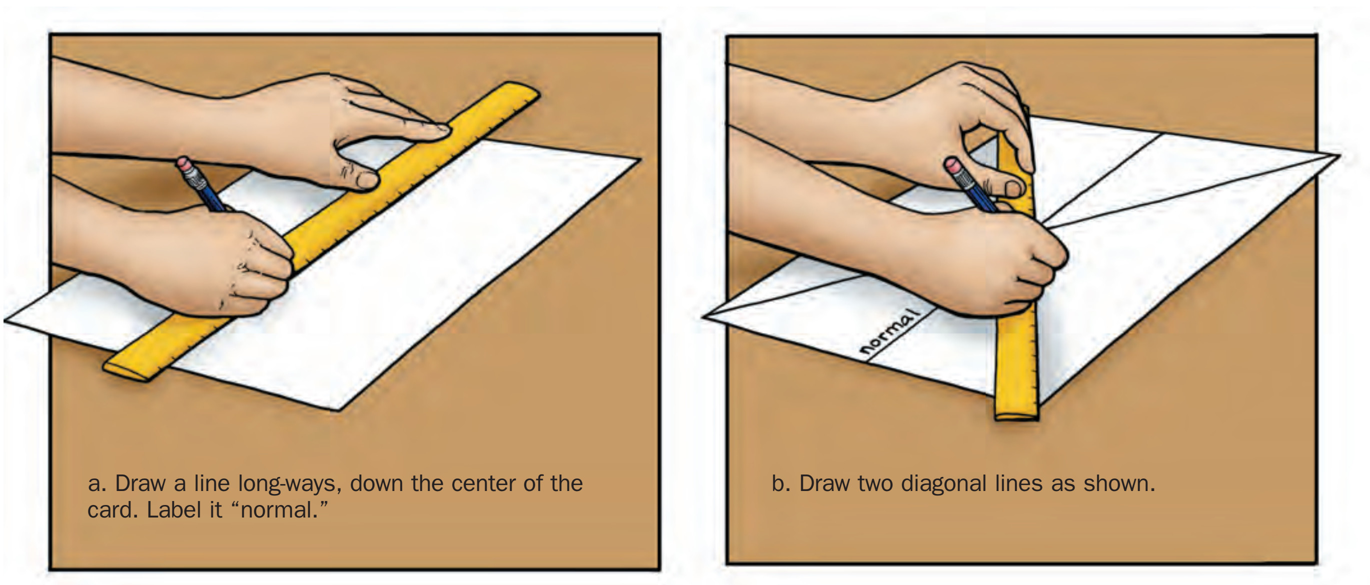


Figure 19.2 *Set up the apparatus as shown using the diagrams labeled a–d as a guide.*

5. Realign the v-ramp so that it lies along one of the diagonal lines you have drawn. Repeat Step 4.

D. Record what happens to the direction of the ball bearings as they are rolled along the diagonals.

6. Use the following question to help you comment on your observations:

E. How does the behavior of the ball bearing model compare with the behavior of light?

7. Watch carefully as your teacher demonstrates water waves passing over a transparent block.

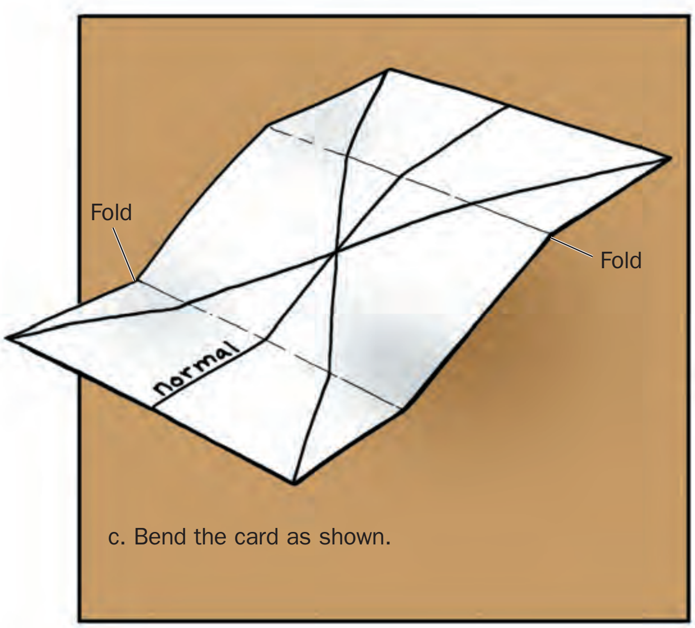
F. Draw on the diagrams on Student Sheet 19.4 what you observe occurring in the ripple tank as waves travel over the transparent block.

8. Discuss with your group and then answer these questions (be prepared to share your answers with the class):

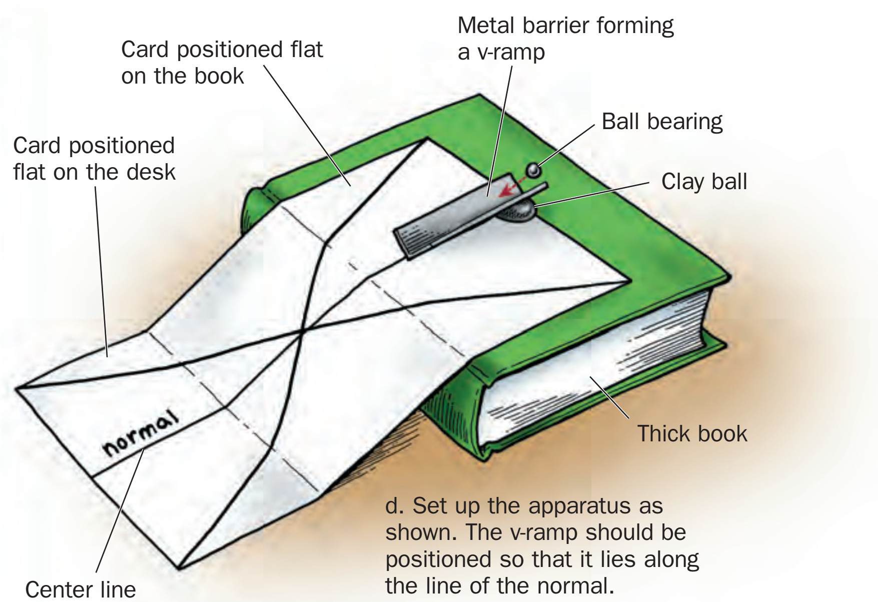
G. What evidence (if any) is there that the waves are being refracted?

H. Can you explain your observations and compare them with the behavior of light?

9. Dismantle your ripple tank. Pour the water out of the tray. Dry the tray with a paper towel. Return all the materials to the plastic box.



c. Bend the card as shown.



d. Set up the apparatus as shown. The v-ramp should be positioned so that it lies along the line of the normal.

REFLECTING ON WHAT YOU'VE DONE

1. Discuss with your group your observations and conclusions from Inquiries 19.1–19.4.

A. Summarize your observations in Table 1 on Student Sheet 19.4.

2. Review your completed Table 1 and the Table 1 you completed on Student Sheet 7.2 in Lesson 7. Discuss these questions with your group (be prepared to contribute your ideas to a class discussion):

Which of these models best models light?

Do you think both models could be useful in helping to explain how light behaves?

3. Based on your experiences in Lesson 7 and this lesson and using what you have read, write a paragraph that answers this question:

B. Do you that think light behaves like waves, like particles, or like both waves and particles?

4. Read "The Greatest Scientific Argument of the Millennium?"

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

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The Greatest Scientific Argument of the Millennium?

Why do transparent soap bubbles display these colors? Thomas Young explained this phenomenon in terms of light waves interfering with each other.

Scientists often debate ideas or theories for long periods of time. Sometimes more than one theory fits the facts. This is the case with the nature of light. The result has been a reasoned argument and debate that has lasted over 200 years.

Particles or Waves?

Until the 1670s, people were very confused about what light was. At about that time, two scientists came up with different models to describe and explain light. You have already heard of one of these scientists—Isaac Newton (1642–1727). Newton suggested that light consisted of streams of particles moving at very high speeds. He called these particles "corpuscles" and used this model to explain the fact that light travels in straight lines. Newton's model could explain how light formed shadows, bounced off mirrors, and shined through the vacuum of space. He suggested that the different colors that make up white light were different particles.

For Newton to be able to explain refraction in terms of particles, light would have to travel faster in water or glass than it does in air. (We now know that light passing from air to water or glass slows down.) However, as you have read, at that time nobody could accurately determine the speed of light in air or in any other transparent material. So nobody could tell if Newton's theory best explained refraction.

At about the same time, another scientist, Christian Huygens (1629–1695), had a different explanation. Huygens suggested that light moved like waves traveling across the surface of a pond. He explained color by suggesting that each color was a different wavelength. According to Huygens, refraction occurred because light traveled slower in transparent materials such as water or glass than it did in air.

Huygens's theory of the nature of light was quite different from Newton's explanation. Both theories, however, could explain all the experimental data on refraction that was then available. As new discoveries were made and new data became available, whose theory would ultimately be correct?

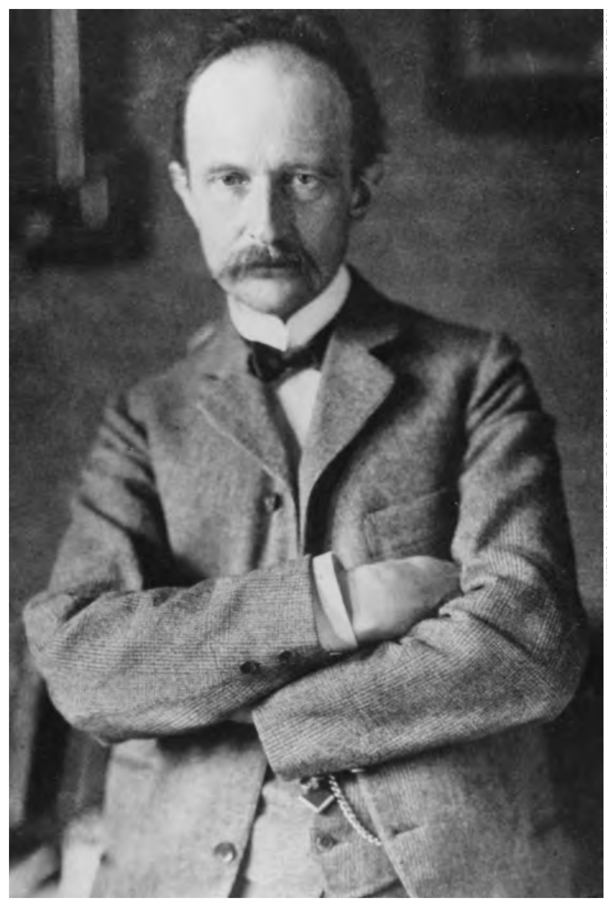
Most scientists preferred Newton's idea. Some were betting on his reputation as the greatest scientist of all time. Others couldn't see how Huygens's light waves could travel through a vacuum. After all, how could you have waves in nothing? For more than a century, Newton's corpuscles were in and Huygens's waves were out.

Then along came Thomas Young with a new type of experiment. In 1801, Young discovered that it was possible for two beams of light to interfere with each other and result in different colors or even darkness. He used this idea to explain why transparent materials such as oil films and soap bubbles often look multicolored.

Young called this process "interference" and explained it in terms of "out-of-step" waves interacting with each other. That is, light waves (or other waves) traveling in the same or different directions in the same space disturbed each other. (Try this tonight in the bathtub.) For example, the crest of one wave would cancel or partly cancel the trough of another wave. Young theorized that this activity apparently resulted in some colors being enhanced and others being cancelled out altogether.

Other new discoveries were beginning to make waves look like a better model for light. Many invisible forms of light were being found, all of which could be explained as different wavelengths in the continuous electromagnetic spectrum.

Eventually, waves became the number-one theory. Had Newton at last been proven wrong? Was the debate over? That would be too simple! At the turn of the 20th century, German scientist Max Planck (1858–1947) was studying how hot objects gave off electromagnetic radiation. He discovered that these hot objects did



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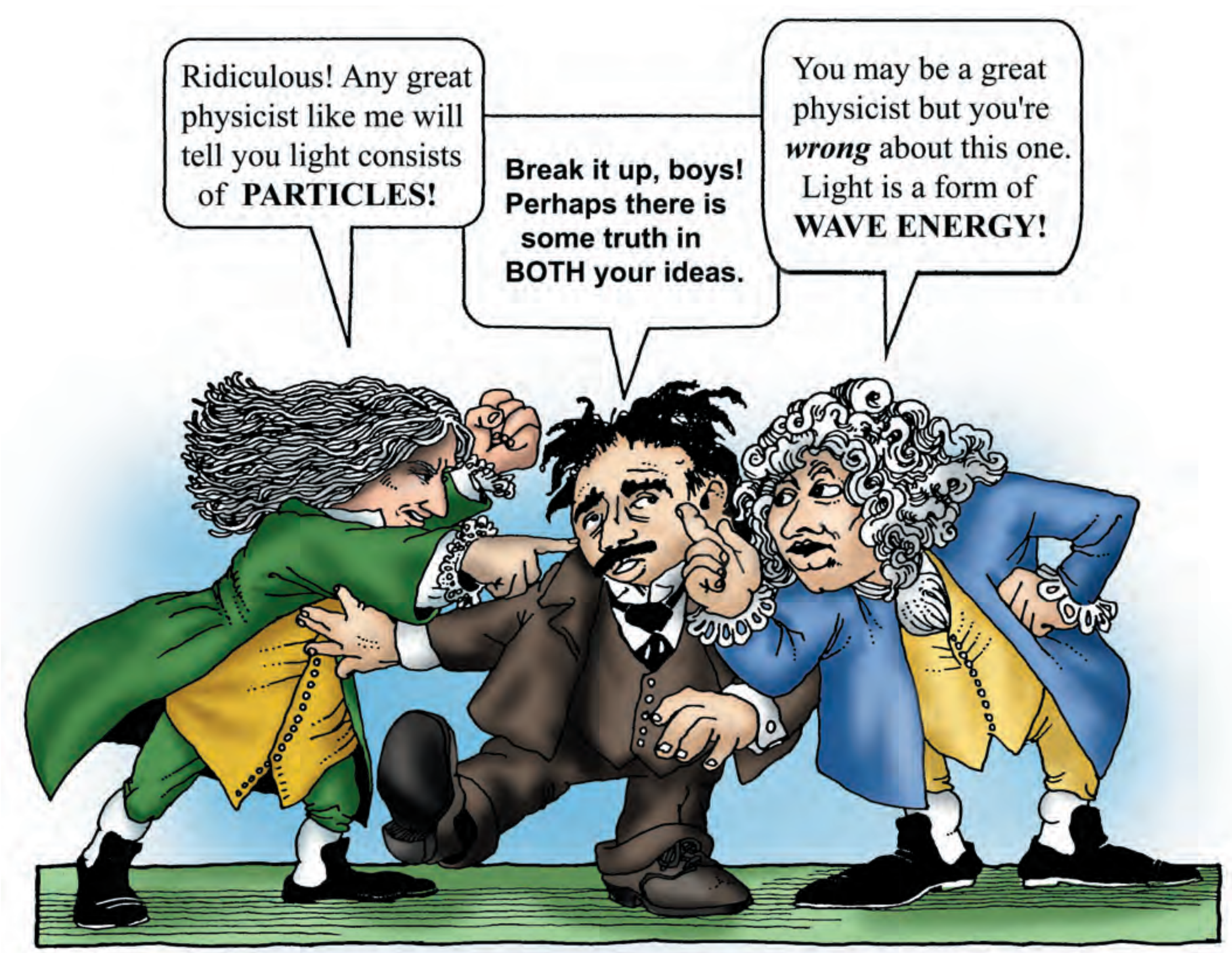
Max Planck suggested that, although light had many of the characteristics of waves, it also behaved like packets of energy. Were these packets of energy the same as Isaac Newton's corpuscles?

not give off light energy continuously, but rather as packets of specific amounts of light energy (rather like the difference between integer and real numbers). He called these packets of energy "quanta."

This new evidence stirred up the debate even more, and attracted some of the world's greatest scientific minds. One of these scientists was Albert Einstein (1879–1955). Einstein used the idea of light as packets of energy to explain how light can knock electrons off the surface of some metals to produce an electric current. He called these packets of light energy "photons." Were these the same as Newton's corpuscles? Not exactly.

The Dual Nature of Light Revealed

Einstein was not reviving Newton's 200-year-old idea. Instead, he was suggesting that light behaved like both particles and waves. He described light as being waves that come in discrete packages, each containing a fixed amount of energy. This theory explained the existing data better because it clarified why light sometimes behaved like waves and sometimes like particles. Light had dual characteristics—some particle-like and some wave-like. The riddle of the nature of light had taken a new turn, and neither Newton nor Huygens had won or lost the debate. □



Newton (left) suggested that light consisted of streams of moving particles. Huygens (right) took the view that light moved like waves. More recently, scientists like Einstein (center) have suggested that light has the characteristics of both.