SECTION 6

Reflected Light

Section Overview

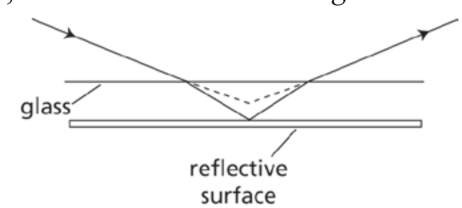
Students begin the study of mirrors by investigating reflections from a plane mirror. To find the direction of a reflected light ray, they measure the angles of incidence and reflection and discover the law of reflection. Then they locate the position of the reflected images formed by plane mirrors and observe how images are reversed in the reflections of letters of the alphabet. Then they locate the reflected image and observe the reversals in reflections of letters of the alphabet. Students also investigate multiple reflections from two mirrors and the resulting symmetrical patterns. They draw ray diagrams at different angles of incidence, observe how the reflection of a hand moves, and locate the image of a glowing bulb and a lamp placed in front of the mirror. Finally, in *Inquiring Further*, students build a kaleidoscope and describe what they see.

Background Information

When light strikes an ordinary object such as a book or a person, the light is reflected in all directions. This reflected light can be represented by light rays that fan out from each point on the object. This is called diffuse reflection. When a light ray strikes a smooth, shiny surface such as the surface of a mirror, the light ray is reflected only in a particular direction.

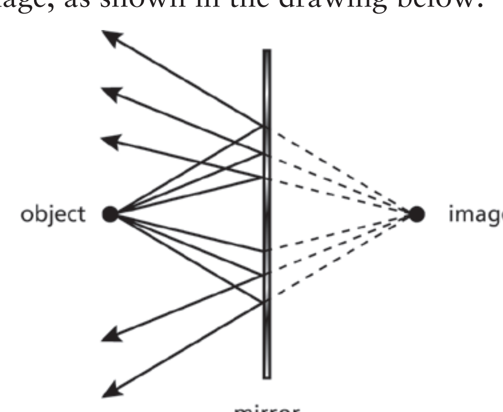
When the object is placed before a mirror, the light rays that fan out from the object can be extended to the mirror. As shown in the drawing following *Step 9* in the *Investigate*, the angles of incidence and reflection at the mirror surface for each of these rays are equal. By the standard convention used in optics, these angles are measured between the incident ray and a line perpendicular to the surface at the point where the incident ray hits the surface. The perpendicular line at the point of contact is called the "normal." The term normal is still in use in science and mathematics and has nothing to do with the everyday sense of normal (as compared to abnormal). You might encourage students to use the phrase "perpendicular line" every time they say "normal."

These angles are straightforward to measure, but there is a minor complication to interpreting the results. Some mirrors are rear-surface mirrors; that is, the reflecting coating is on the rear of the mirror. In these mirrors the light must first pass through glass before being reflected, and then must pass through glass again before again entering the air. The light is refracted (bent) at each air-glass interface, as shown in the drawing below:



The net effect is that the light acts as if it had been reflected from a surface located approximately in the middle of the mirror (where the dotted lines meet in the drawing). Notice that the angle of incidence is still equal to the angle of reflection, by symmetry. However, when the reflected ray is extended behind the mirror to locate the image, the extension will be shifted away from the point where the incident ray hits the mirror. The size of the shift increases with the angle of incidence, and the shift is zero for a light beam coming in along the normal. The result is that the image is slightly blurred.

Extending the paths of the reflected rays back behind the mirror allows you to find the location of the image, as shown in the drawing below:



The image location is where the extended lines cross. Note that the image is as far behind the mirror as the object is in front. Also, the image is located on the line that goes through the object and is perpendicular to the mirror surface. If you walk toward a mirror, your reflection seems to walk toward you. With a flat mirror, the image appears to be behind the mirror because that is where the light rays seem to emerge, which means that they come to your eyes as if they had emerged from the image location. Such an image is a called a virtual image, in contrast to a real image, where the light rays actually converge. Real images are investigated later when students learn about concave mirrors and lenses.

The language used to talk about mirror images often leads to great confusion. A flat mirror is said to reverse the image right and left. If your right hand reaches out to shake hands with your reflection in a flat mirror, a reflected hand reaches toward you… but it is a left hand. Or is it? If you have a ring on a finger on your left hand, which hand in the image has a ring on one of the fingers? Move your hand to the left, and the reflection moves to your left. Move your hand to the right, and the reflection moves to your right. What is inverted in the mirror is not right to left, and not up to down, but rather, toward the mirror and away from the mirror.

Crucial Physics

- A flat mirror reflects light rays with the angle of incidence equal to the angle of reflection. By convention, the angles are measured relative to the normal (perpendicular line) where the light ray hits the mirror surface.
- For a flat mirror, the (virtual) image formed by the mirror is located behind the mirror at a distance equal to the distance which the object is in front of the mirror.
- All objects reflect some of the light incident upon them. For surfaces that are not highly polished, the rays are reflected in all directions.
- Light waves also show diffraction when they pass through very small openings or when they "reflect" from very close-spaced grooves (for example, when reflecting off a CD).
- Light waves carry energy.

Learning Outcomes	Location in the Section	Evidence of Understanding
Observe the reflection of light by a mirror.	***Investigate*** Step 1.a)	Students observe the reflection of their face and the image of a light bulb.
Identify the normal of a plane mirror.	***Investigate*** Step 5	Students draw a perpendicular to the line drawn along the front edge of a mirror.
Measure angles of incidence and reflection for a plane mirror.	***Investigate*** Step 9.a)	Using a protractor, students measure and record the angle of incidence and the angle of reflection.
Collect evidence for the relationship between the angle of incidence and the angle of reflection for a plane mirror.	***Investigate*** Steps 9.b) and 9.c)	Students record the angle of incidence and the angle of reflection for several angles and determine the relationship between the two angles.
Observe changes in the reflections of letters.	***Investigate*** Step 11.b)	Students write their name in block capital letters along the normal and observe the reflection.
Identify patterns in multiple reflections.	***Investigate*** Step 12.b)	Students position two mirrors at right angles and observe the multiple reflections of an object placed in front when the angle between the mirrors changes.

Section 6 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Mirror support	2 per group	
Light bulb socket with switch and 40W bulb	1 per group	
Mirror, plane, 7.5 x 12.5 x 4 mm	2 per group	
Clear glass rod 4”- 8”	1 per group	
Laser pointer - class 2	1 per group	
Plastic rod holder	1 per group	
Protractor	1 per group	
Cardboard, 14” x 14”	2 per group	
Access to a electrical outlet*	1 per group	
Paper*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for students to complete the *Investigate* portion of the section.

Teacher Preparation

- Assemble the necessary equipment. If glass mirrors are used, be sure to tape the edges.
- Darken the room as much as possible so students can see the laser light path easily. Using additional curtains, if available, to darken the room is helpful.
- If no mirror holders are available, attach clothespins at the bottom sides to hold the mirror vertical.
- The glass rods used to spread the laser beam can be made from stirring rods. These should be cut to a length of approximately 3 cm.
- If glass rods to place in the laser beam are already made, discuss their preparation with a chemistry teacher if you have not previously made them.

Safety Requirements

- Students should receive instruction on the safe use of the lasers. Although pen lasers typically are of an intensity that is not dangerous, students should none-the-less take precautions to prevent the laser beams from striking any eyes.
- Caution students not to look directly at reflected laser beams from shiny surfaces such as the mirror, since they have the same effect as the direct beam.
- The glass rod placed in the laser beam spreads out the beam into a “fan” of light rather than a direct beam, reducing the intensity.
- Check the power output of all lasers used to ensure they meet safety requirements for use in schools.
- Plastic mirrors are preferable to glass for safety reasons. If glass mirrors are used, tape the edges to prevent cuts.
- If any glass mirrors or rods should break, immediately remove the pieces, being careful to avoid handling the broken glass.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Mirror support	2 per group	
Light bulb socket with switch and 40W bulb	1 per group	
Mirror, plane, 7.5 x 12.5 x 4 mm	2 per group	
Clear glass rod 4″- 8″	1 per group	
Laser pointer - class 2	1 per group	
Plastic rod holder	1 per group	
Protractor	1 per group	
Cardboard, 14″ x 14″	2 per group	
Access to a electrical outlet*	1 per group	
Paper*	1 per group	

*Additional items needed not supplied

Time Requirement

- Allow one class period or 45 minutes for students to complete the *Investigate* portion of the section.

Teacher Preparation

- Assemble the necessary equipment. If glass mirrors are used, be sure to tape the edges.
- Darken the room as much as possible so students can see the laser light path easily. Using additional curtains, if available, to darken the room is helpful.
- If no mirror holders are available, attach clothespins at the bottom sides to hold the mirror vertical.
- The glass rods used to spread the laser beam can be made from stirring rods. These should be cut to a length of approximately 3 cm.
- If glass rods to place in the laser beam are already made, discuss their preparation with a chemistry teacher if you have not previously made them.

Safety Requirements

- Students should receive instruction on the safe use of the lasers. Although pen lasers typically are of an intensity that is not dangerous, students should none-the-less take precautions to prevent the laser beams from striking any eyes.
- Caution students not to look directly at reflected laser beams from shiny surfaces such as the mirror, since they have the same effect as the direct beam.
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- Check the power output of all lasers used to ensure they meet safety requirements for use in schools.
- Plastic mirrors are preferable to glass for safety reasons. If glass mirrors are used, tape the edges to prevent cuts.
- If any glass mirrors or rods should break, immediately remove the pieces, being careful to avoid handling the broken glass.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Understanding academic vocabulary	***Investigate*** ***Physics to Go*** Question 2	**Augmentation** • Show students a plane mirror. • Ask students if they can explain the meaning of the word "plane," and why the mirror is called a plane mirror. • Explain how a plane mirror is different from other mirrors.
Drawing the "normal"	***Investigate*** Step 5 ***Physics to Go*** Questions 2, 4, 6	**Augmentation** • Students may not have learned the word "normal" before and may have forgotten the meaning of perpendicular. Model the process for drawing a line along the front edge of the mirror and then drawing the normal. **Accommodation** • Provide students with a sheet that has two lines drawn on it. The solid line is the place where the mirror should be lined up, and the dotted line is the normal. Students can then use the laser to add incident rays and reflected rays to the drawing.
Labeling a series of rays	***Investigate*** Steps 7-8	**Augmentation** • Students may struggle to differentiate the pairs of rays when there are several pairs on one drawing. Instruct students to use a different colored pencil to draw each pair of rays. Then students only have to label the incident and reflected rays. The pairs will be differentiated by color.
Measuring angles of incidence and reflection	***Investigate*** Step 9	**Augmentation** • Students may struggle to differentiate the angles of rays when there are several rays on one drawing. Students with focus, vision, or organization issues may need to draw each pair of rays on a separate piece of paper and then measure the angles. • Model how to use a protractor on an overhead projector or draw a large-scale model on the board. • Provide opportunities for practice with angles that have already been measured. When students are proficient at measuring these angles, ask them to measure the angles they have drawn for this *Investigate*. **Accommodation** • Use close proximity or hand-over-hand (physically guided) techniques to assist students in measuring angles with a protractor.
Drawing reflections of letters	***Physics to Go*** Question 6	**Augmentation** • Students with visual spatial or graphomotor issues may struggle to visualize and draw reflected letters. Ask students to write the entire alphabet in capital letters in their logs and use it as a reference to answer this question. • Provide students with small mirrors to test their answers. **Accommodation** • Some students still accidentally reverse letters in their daily writing. These students have more severe visual spatial and graphomotor issues and may not be able to complete this question. • Provide students with a list of letters that look just like their reflections. Students could use this list to answer *Questions 6.b), 6c.)*, and *6.d)*.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Comprehension Using tools and manipulatives	***Investigate*** Step 5	Use two pencils to show the meaning of "perpendicular" and contrast this with the term "parallel."
Vocabulary comprehension Understanding concepts	***Investigate*** Steps 7, 8, 9	To help students understand the meaning of "incident ray" and "angle of incidence," explain that "incidence" is the scientific study of light that means "the arrival of a ray of light at a surface." Be sure students comprehend that the incident ray and the reflected ray are a pair; they go together. You do not have one without the other. The same is true for the angle of incidence and the angle of reflection. You may wish to ask a critical thinking question: "What happens to the angle of reflection when the angle of incidence is increased?" [It increases by the same amount.]
Understanding concepts	***Physics Talk*** Locating an Image in a Plane Mirror	Hold a class discussion on the image of a light source that seems to emerge from (come out from) behind the mirror. Is the image really behind the mirror? [No.] Discuss how to measure the incident ray and the reflected ray to determine mathematically where the image is behind the mirror. [It appears to be exactly as far behind the mirror as the real light source is in front of the mirror.]
Background knowledge	***Physics Talk*** Light Waves	Briefly review properties of waves. Explain that light has some properties of waves, and so it is often studied as a wave. Unlike sound, which is a compressional (or longitudinal) wave, light travels as a transverse wave. Challenge students to remember how a transverse wave travels in relation to the direction of disturbance that causes the wave. [The wave travels perpendicularly to the disturbance.] Mention that light waves carry energy, and bring energy from the Sun to Earth.
Vocabulary comprehension	***Reflecting on the Section and the Challenge*** ***Inquiring Further*** Question 2	Model the correct pronunciation of "kaleidoscope." The word may seem odd (it comes from the Greek *kalos*, meaning "beautiful," and *eidos*, meaning "form"), but students are likely to have some experience with the device itself. Bring one to class, if possible, and let students interact with it before they build their own.

Point out new vocabulary words in context and practice using the words as much as possible throughout the section.

angle of incidence	law of reflection
normal	angle of reflection
reflected ray	incident ray

To give ELL students practice with the vocabulary, have them copy each term into their log and write the definitions in their own words. To check their understanding of the terms and the concepts, have them draw a top view of a plane mirror and a light source in their log. They should add the incident ray (with an arrow to show direction) and the reflected ray (with an arrow to show direction). Then they should draw and label the normal, the angle of incidence, and the angle of reflection. Drawings should also indicate that the angle of incidence equals the angle of reflection (the law of reflection).

SECTION 6

Teaching Suggestions and Sample Answers

What Do You See?

This illustration reflects the theme of the section in many subtle images. Students will most likely comment on the reflection of the moonlit, starry night sky in the mirror. Discuss their observations and engage them with questions that draw a variety of responses. Consider asking students how the title of the section connects with the *What Do You See?* illustration. Remind students that their answers are all valuable because each answer represents how they visualize what they see, and that in turn, prepares them for the concepts they are about to study. Encourage students to return to this illustration again later on to note how their understanding of a topic continues to grow after their initial perceptions.

Chapter 5 Let Us Entertain You

Section 6 Reflected Light

What Do You See?

Learning Outcomes

In this section, you will

- **Observe** the reflection of light by a mirror.
- **Identify** the normal of a plane mirror.
- **Measure** angles of incidence and reflection for a plane mirror.
- **Collect** evidence for the relationship between the angle of incidence and the angle of reflection for a plane mirror.
- **Observe** changes in the reflections of letters.
- **Identify** patterns in multiple reflections.

What Do You Think?

Astronauts placed a mirror on the Moon in 1969 so that a light beam sent from Earth could be reflected back to Earth. By timing the return of the beam, scientists found the distance between Earth and the Moon. They measured this distance to within 30 cm.

- **How are you able to see yourself in a mirror?**
- **If you want to see more of yourself in the mirror, what can you do?**

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and with your class.

Investigate

In this section, you will investigate the reflection of light from a plane mirror. You will also make measurements to find the relationship between the angle of incidence and angle of reflection.

1. Look at your face in a small mirror. Keeping the mirror vertical and close to your face, note how much of your face you can see (for example, from your eyebrows to the top of your lips).

 a) Predict what will happen if you move the mirror further from your face.

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Students' Prior Conceptions

This section gives students the opportunity to ladder their concepts about how light travels; to revisit their predictions about what light rays do; to model what they think is happening with incident and reflected light rays; and then to compare predictions with what they measure and observe. Giving students the same experiences is vital to how they will add *Inputs* and *Process* these data when working in cooperative groups on the *Chapter Challenge*. Modeling what they "see" continues to help students address prior conceptions pertinent to the investigations. You may take the incentives to elaborate and extend concepts gleaned in *Sections 5* and *6* to those encountered in subsequent inquiry.

1. **Students do not believe the idea that light travels from one place to another.** This leads to student difficulties in explaining the reflection of light by objects, since the prior student conception is that light between the source and the effect does not exist as an entity. Revisiting the formation of shadows and extending it to this section is helpful, as well as placing objects in different places along the line of sight from the light source to the screen. Students can see that light is traveling through space, since it creates a shadow of an object all along its path. A laser beam that is dusted with chalk or misted from a humidifier will also show the beam as it travels along a straight line and reflects from a mirror.

2. **Students reject the idea that ordinary objects reflect light and that their eyes receive this light when they look at them.** The perception that the eye sees without anything linking it to the object is a common student prior conception. Listen carefully to student language so that they differentiate between what is happening with the formation of an image with the eye and the formation of an image with a mirror. The image on the retina and the image in the mirror will be explained in *Section 9*. Encourage student language to describe an image formed with a mirror as different from an

What Do You Think?

Encourage students to answer all the questions and accept all answers. Remind them to write their responses in their logs. You may want to elicit a general discussion on what students know about mirrors. This is an opportunity for you to be alert to misconceptions. You can guide them toward specific answers when you have them interested and engaged in a meaningful discussion.

What Do You Think?

A Physicist's Response

You can see yourself in a mirror by observing light reflected from you that the mirror reflects back into your eyes. The mirror creates a virtual image of you the same distance behind the mirror as you are in front. But you can see only that part of your body that faces the mirror, since light from the back of your head moves off in another direction and does not hit the mirror. To see the back of your head requires a second mirror, which is why hair stylists hold up a second mirror to show their clients their new haircut. If you covered the walls of a room with mirrors, you could see many different reflections of the back of your head.

Most people believe that if they move the mirror further away, they can see more of themselves. This is not true. You may want to have students carefully try to hold up a small mirror and note how much of their face they can see (for example, from the eyebrows to the top of the lips). They should then move the mirror at arm's length and repeat the observation. They will only be able to see the same amount of their face. The commonsense view is so strong that some students will insist that they can see "a bit" more because they are unwilling (perhaps unable) to get rid of this misconception.

Investigate

1.a)

This step addresses a common student misconception that they can see more of themselves as they move away from a mirror. Students typically expect to see more as they move away. Students will observe that they see the same amount of themselves when they use a plane mirror.

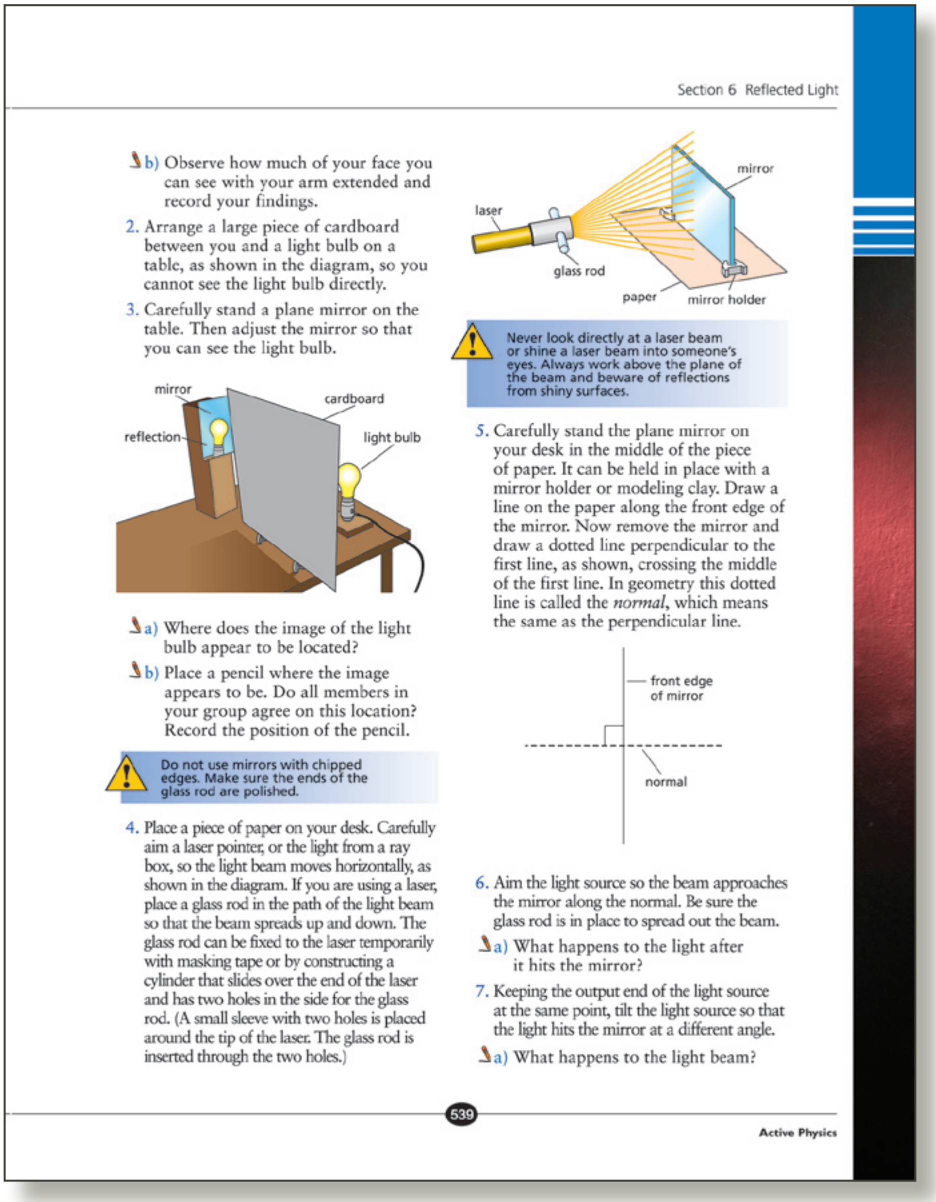
image formed with the eye. These descriptions should involve two different processes at work. As you evaluate student explanations of what they are seeing and why, you may ask if the image of the object could be captured by another tool, if that tool was placed in the exact location of the eye. This prior conception links to the previous one, since many students are not aware that incident and reflected light is necessary for vision as well as for seeing images in mirrors.

3. **Students tend to believe that light reflects more off of a rough surface than a smooth one.** Students may say that a rough surface has more areas for light to hit and to reflect off of than a smooth surface. It is not the amount of light that is reflected off of a rough surface but the increased directions for the reflection of light from a rough surface. Light is scattered more but the amount of incident light hitting a rough surface or a smooth surface is the same as the amount of light reflecting off of the same surfaces.

4. **Students believe that the image is "on" the face of a plane mirror.** This prior conception deals with the location of an image formed with a plane mirror. Student experiences lead them to "see" the image on the mirror; it takes exploration of the geometry of the incident rays and locating the point of their convergence behind the mirror to lead students to understand that the reflected rays appear to originate at this point of convergence.

5. **A mirror needs to be the same height of the student for a "full" view of the student.** Have them look at their image in mirrors of different sizes and see full-sized images in mirrors that are shorter than their actual height. When this is combined with students working through the geometry of incident and reflected rays, it will give clear evidence that mirror height and student height need not be identical for full-height views. Have students observe themselves in a small mirror and have them move toward and away from it.

NOTES



Section 6 Reflected Light

b) Observe how much of your face you can see with your arm extended and record your findings.

2. Arrange a large piece of cardboard between you and a light bulb on a table, as shown in the diagram, so you cannot see the light bulb directly.

3. Carefully stand a plane mirror on the table. Then adjust the mirror so that you can see the light bulb.

mirror
cardboard
reflection
light bulb

a) Where does the image of the light bulb appear to be located?

b) Place a pencil where the image appears to be. Do all members in your group agree on this location? Record the position of the pencil.

Do not use mirrors with chipped edges. Make sure the ends of the glass rod are polished.

4. Place a piece of paper on your desk. Carefully aim a laser pointer, or the light from a ray box, so the light beam moves horizontally, as shown in the diagram. If you are using a laser, place a glass rod in the path of the light beam so that the beam spreads up and down. The glass rod can be fixed to the laser temporarily with masking tape or by constructing a cylinder that slides over the end of the laser and has two holes in the side for the glass rod. (A small sleeve with two holes is placed around the tip of the laser. The glass rod is inserted through the two holes.)

laser
mirror
glass rod
paper
mirror holder

Never look directly at a laser beam or shine a laser beam into someone's eyes. Always work above the plane of the beam and beware of reflections from shiny surfaces.

5. Carefully stand the plane mirror on your desk in the middle of the piece of paper. It can be held in place with a mirror holder or modeling clay. Draw a line on the paper along the front edge of the mirror. Now remove the mirror and draw a dotted line perpendicular to the first line, as shown, crossing the middle of the first line. In geometry this dotted line is called the *normal*, which means the same as the perpendicular line.

front edge of mirror
normal

6. Aim the light source so the beam approaches the mirror along the normal. Be sure the glass rod is in place to spread out the beam.

a) What happens to the light after it hits the mirror?

7. Keeping the output end of the light source at the same point, tilt the light source so that the light hits the mirror at a different angle.

a) What happens to the light beam?

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1.b)

The amount of the student's face that will be seen in a mirror that is held at arms length will depend upon the length of the student's arms, and the size of the mirror. Students should observe that increasing the distance of the mirror from their face will not increase the amount of what they can see. They should be careful to have the mirror at the same angle so they see exactly the same features in the mirror in both cases.

2.

Students set up the equipment. Find some way to support the glass rod, such as with the optional stopper, test-tube holder, and ring stand (or the rod can be taped to a stack of books).

3.a)

The image of the light bulb seems to be behind the mirror. It may take some coaching for students to be able to articulate what they see in terms of image location. Moving the head from side to side while looking at the image may help in identifying the image location. Also, closing one eye and then the other, while looking at the image, may help identify its location by means of parallax.

3.b)

By using parallax, students should see that the image of the light bulb appears to be behind the mirror. You may wish to give students a duplicate light bulb to move around behind the mirror until they see the image and the light bulb line up as the same size and in the same position.

4.

Students set up the equipment.

5.

Support the mirror, using the mirror support in the kit or some clothespins. Students should use a protractor or a drawing triangle to identify the direction perpendicular to the mirror as accurately as possible.

6.a)

It reflects back along the normal.

7.a)

The beam reflects but not along the normal. Explain to students that the normal is also perpendicular to the surface.

7.b)

Encourage students to look straight down to avoid parallax.

8.a)

Students observe that as the incident angle (measured to the normal) increases, the angle of reflection also increases. As students vary the incident angle, the angles should differ by 15˚ or so.

9.a)

The angles should be equal within a few degrees.

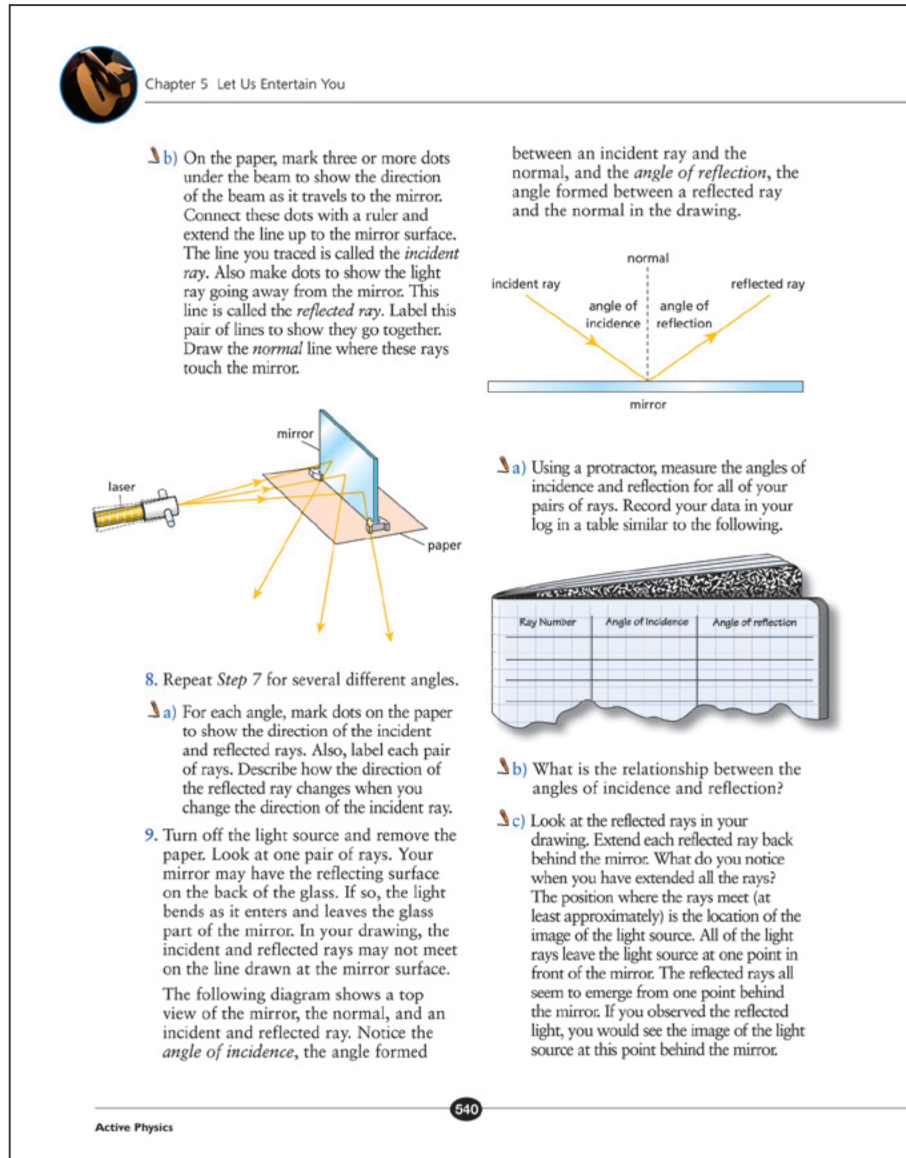
9.b)

The angle of incidence is (approximately) equal to the angle of reflection.

9.c)

The extended rays intersect in the same place (or nearly so). This is the location of the image. Students may note that the distance of the image behind the mirror is equal to the distance of the object in front of the mirror.

5-6a Blackline Master



Chapter 5 Let Us Entertain You

b) On the paper, mark three or more dots under the beam to show the direction of the beam as it travels to the mirror. Connect these dots with a ruler and extend the line up to the mirror surface. The line you traced is called the *incident ray*. Also make dots to show the light ray going away from the mirror. This line is called the *reflected ray*. Label this pair of lines to show they go together. Draw the *normal* line where these rays touch the mirror.

8. Repeat *Step 7* for several different angles.

a) For each angle, mark dots on the paper to show the direction of the incident and reflected rays. Also, label each pair of rays. Describe how the direction of the reflected ray changes when you change the direction of the incident ray.

9. Turn off the light source and remove the paper. Look at one pair of rays. Your mirror may have the reflecting surface on the back of the glass. If so, the light bends as it enters and leaves the glass part of the mirror. In your drawing, the incident and reflected rays may not meet on the line drawn at the mirror surface.

The following diagram shows a top view of the mirror, the normal, and an incident and reflected ray. Notice the *angle of incidence*, the angle formed between an incident ray and the normal, and the *angle of reflection*, the angle formed between a reflected ray and the normal in the drawing.

a) Using a protractor, measure the angles of incidence and reflection for all of your pairs of rays. Record your data in your log in a table similar to the following.

Ray Number	Angle of Incidence	Angle of reflection

b) What is the relationship between the angles of incidence and reflection?

c) Look at the reflected rays in your drawing. Extend each reflected ray back behind the mirror. What do you notice when you have extended all the rays? The position where the rays meet (at least approximately) is the location of the image of the light source. All of the light rays leave the light source at one point in front of the mirror. The reflected rays all seem to emerge from one point behind the mirror. If you observed the reflected light, you would see the image of the light source at this point behind the mirror.

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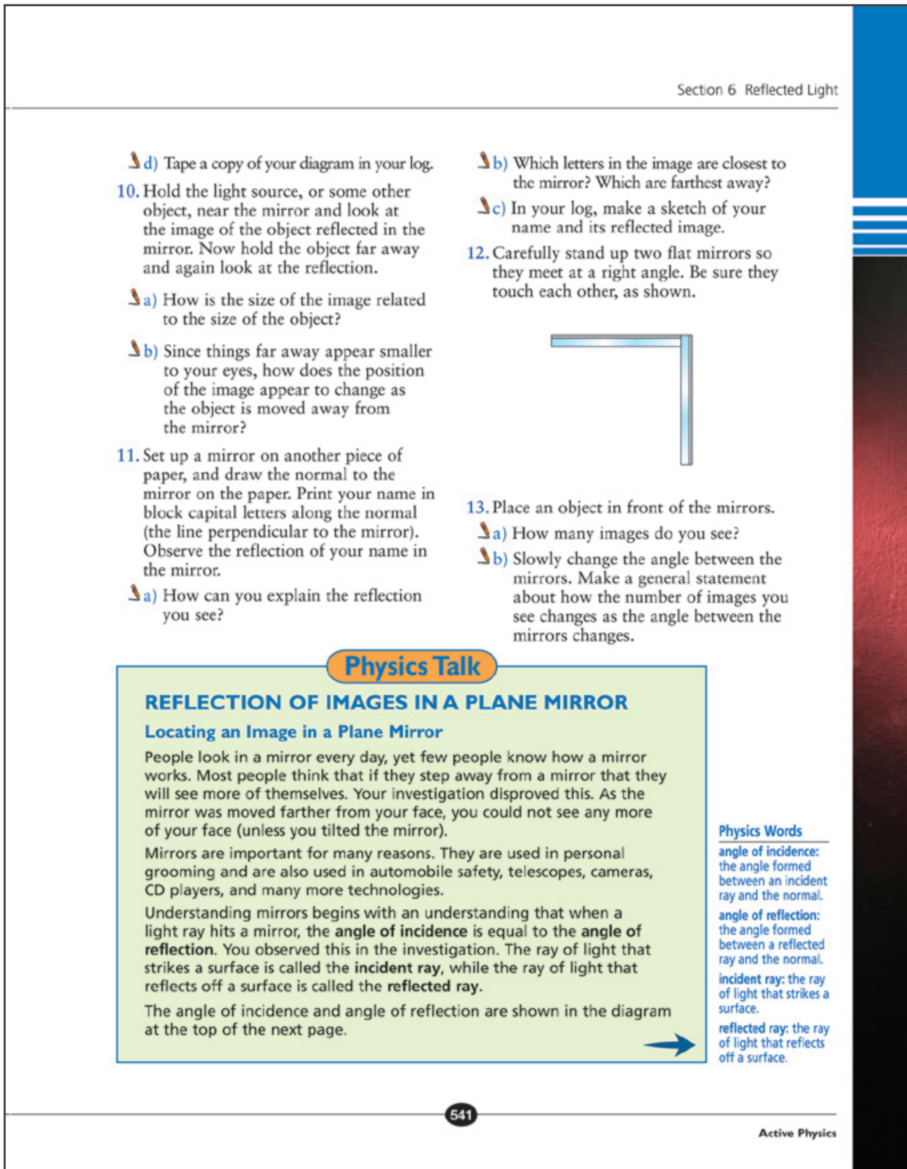


d) Tape a copy of your diagram in your log.

10. Hold the light source, or some other object, near the mirror and look at the image of the object reflected in the mirror. Now hold the object far away and again look at the reflection.

a) How is the size of the image related to the size of the object?

b) Since things far away appear smaller to your eyes, how does the position of the image appear to change as the object is moved away from the mirror?

11. Set up a mirror on another piece of paper, and draw the normal to the mirror on the paper. Print your name in block capital letters along the normal (the line perpendicular to the mirror). Observe the reflection of your name in the mirror.

a) How can you explain the reflection you see?

b) Which letters in the image are closest to the mirror? Which are farthest away?

c) In your log, make a sketch of your name and its reflected image.

12. Carefully stand up two flat mirrors so they meet at a right angle. Be sure they touch each other, as shown.

13. Place an object in front of the mirrors.

a) How many images do you see?

b) Slowly change the angle between the mirrors. Make a general statement about how the number of images you see changes as the angle between the mirrors changes.

Physics Talk

REFLECTION OF IMAGES IN A PLANE MIRROR

Locating an Image in a Plane Mirror

People look in a mirror every day, yet few people know how a mirror works. Most people think that if they step away from a mirror that they will see more of themselves. Your investigation disproved this. As the mirror was moved farther from your face, you could not see any more of your face (unless you tilted the mirror).

Mirrors are important for many reasons. They are used in personal grooming and are also used in automobile safety, telescopes, cameras, CD players, and many more technologies.

Understanding mirrors begins with an understanding that when a light ray hits a mirror, the **angle of incidence** is equal to the **angle of reflection**. You observed this in the investigation. The ray of light that strikes a surface is called the **incident ray**, while the ray of light that reflects off a surface is called the **reflected ray**.

The angle of incidence and angle of reflection are shown in the diagram at the top of the next page.

Physics Words

angle of incidence: the angle formed between an incident ray and the normal.

angle of reflection: the angle formed between a reflected ray and the normal.

incident ray: the ray of light that strikes a surface.

reflected ray: the ray of light that reflects off a surface.

9.d)

Students tape a copy of their drawings into their *Active Physics* logs.

10.a)

Students will notice that as the object moves away from the mirror, the image appears to move away. They may say that it gets smaller, but point out that objects far away always look smaller than those nearby.

10.b)

As the object moves away from a plane mirror, the position of the image also moves away from the back of the mirror. To prove this, you would have to locate the image for several different distances using ray diagrams. It is the effect of the image moving away from the rear of the mirror that makes the image appear smaller. In fact, the image remains the same size as the object, but only appears smaller because it is farther away. When an object is farther away, it extends a smaller angle when it is viewed by your eyes, which is the same effect for when an object stays the same distance away but actually becomes smaller. This is why your eye interprets an object farther away as smaller.

11.a)-b)

The letters that are closest to the mirror make images appear closest to the mirror. The letters that are farthest from the mirror make images appear farthest from the mirror. Moreover, within a letter, the part of the letter closer to the mirror makes an image appear closer to the mirror than the rest of the letter.

11.c)

Students' diagrams will differ.

12.

Students hold two flat mirrors at right angles to each other.

13.a)

Three (one is behind each mirror, as before; the third image is behind the corner where the mirrors meet).

13.b)

As the angle between the mirrors reduces, the number of reflections increases.

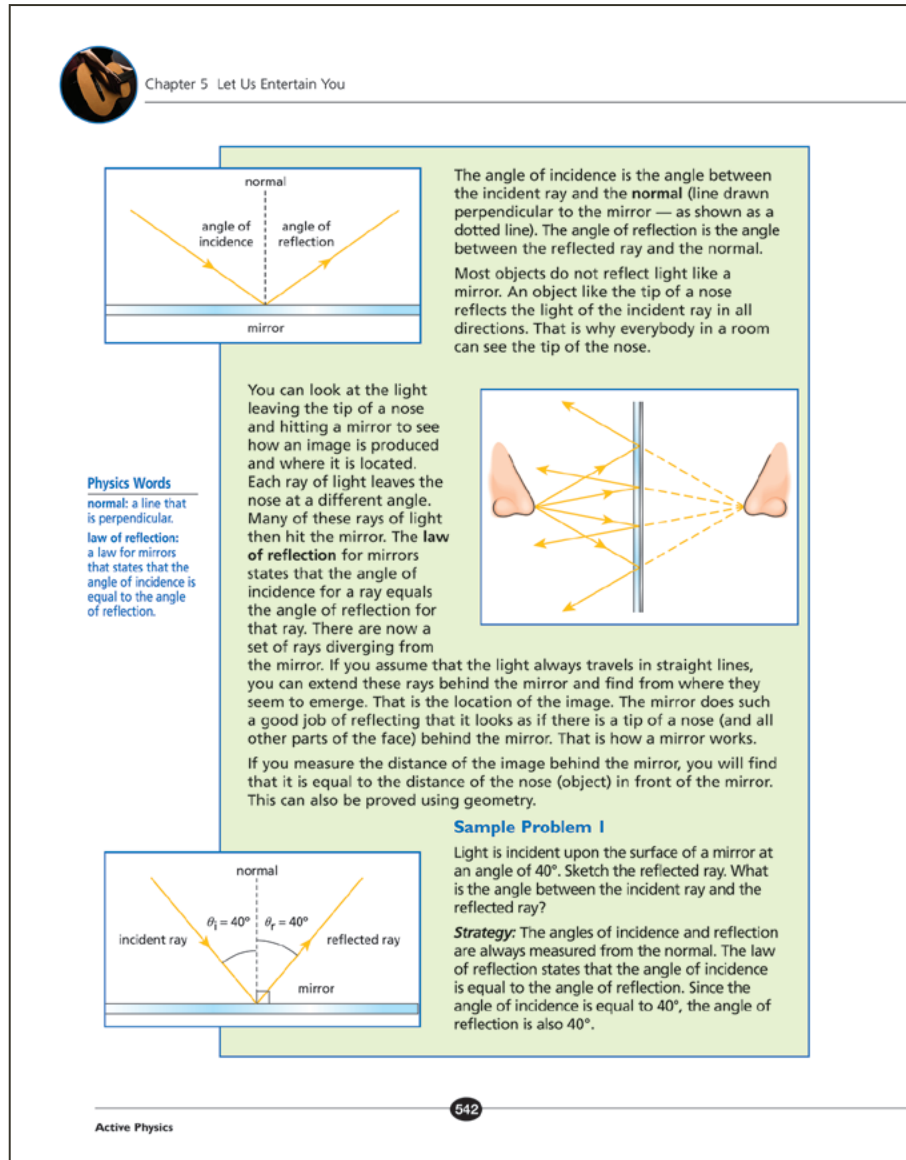
Physics Talk

Students read how mirrors form images. Experiments carried out in the *Investigate* are analyzed so that students can understand image position and size.

Incident rays and the reflected rays are drawn and measured in terms of the normal. The *Physics Talk* then states the law of reflection to explain how the image of an object is located.

An important distinction that should be made is that different objects reflect light in different ways. While the law of reflection holds true for all objects, due to the regular reflection of light rays, a mirror has a surface in which images can be seen. Point out that images that are formed are not located on the surface. Only by extending the reflected rays behind the mirror, the position of an image in a plane mirror can be located. Draw students' attention to how the distance of an image in a plane mirror is determined, and have them note that the distance of the image behind the mirror is equal to the distance of the object in front. Emphasize that the angle of incidence and angle of reflection are always equal and measured to the normal. Ask students questions regarding the two sample problems.

Initiate a discussion on the nature of light. Point out that light waves are transverse waves that carry energy that do not need a medium to travel in, and can pass through a vacuum. Consider asking students to draw a diagram that shows how light waves travel from the Sun to Earth and transfer energy.


Chapter 5 Let Us Entertain You

The angle of incidence is the angle between the incident ray and the **normal** (line drawn perpendicular to the mirror — as shown as a dotted line). The angle of reflection is the angle between the reflected ray and the normal.

Most objects do not reflect light like a mirror. An object like the tip of a nose reflects the light of the incident ray in all directions. That is why everybody in a room can see the tip of the nose.

Physics Words

normal: a line that is perpendicular.

law of reflection: a law for mirrors that states that the angle of incidence is equal to the angle of reflection.

You can look at the light leaving the tip of a nose and hitting a mirror to see how an image is produced and where it is located. Each ray of light leaves the nose at a different angle. Many of these rays of light then hit the mirror. The **law of reflection** for mirrors states that the angle of incidence for a ray equals the angle of reflection for that ray. There are now a set of rays diverging from the mirror. If you assume that the light always travels in straight lines, you can extend these rays behind the mirror and find from where they seem to emerge. That is the location of the image. The mirror does such a good job of reflecting that it looks as if there is a tip of a nose (and all other parts of the face) behind the mirror. That is how a mirror works.

If you measure the distance of the image behind the mirror, you will find that it is equal to the distance of the nose (object) in front of the mirror. This can also be proved using geometry.

Sample Problem I

Light is incident upon the surface of a mirror at an angle of 40°. Sketch the reflected ray. What is the angle between the incident ray and the reflected ray?

Strategy: The angles of incidence and reflection are always measured from the normal. The law of reflection states that the angle of incidence is equal to the angle of reflection. Since the angle of incidence is equal to 40°, the angle of reflection is also 40°.

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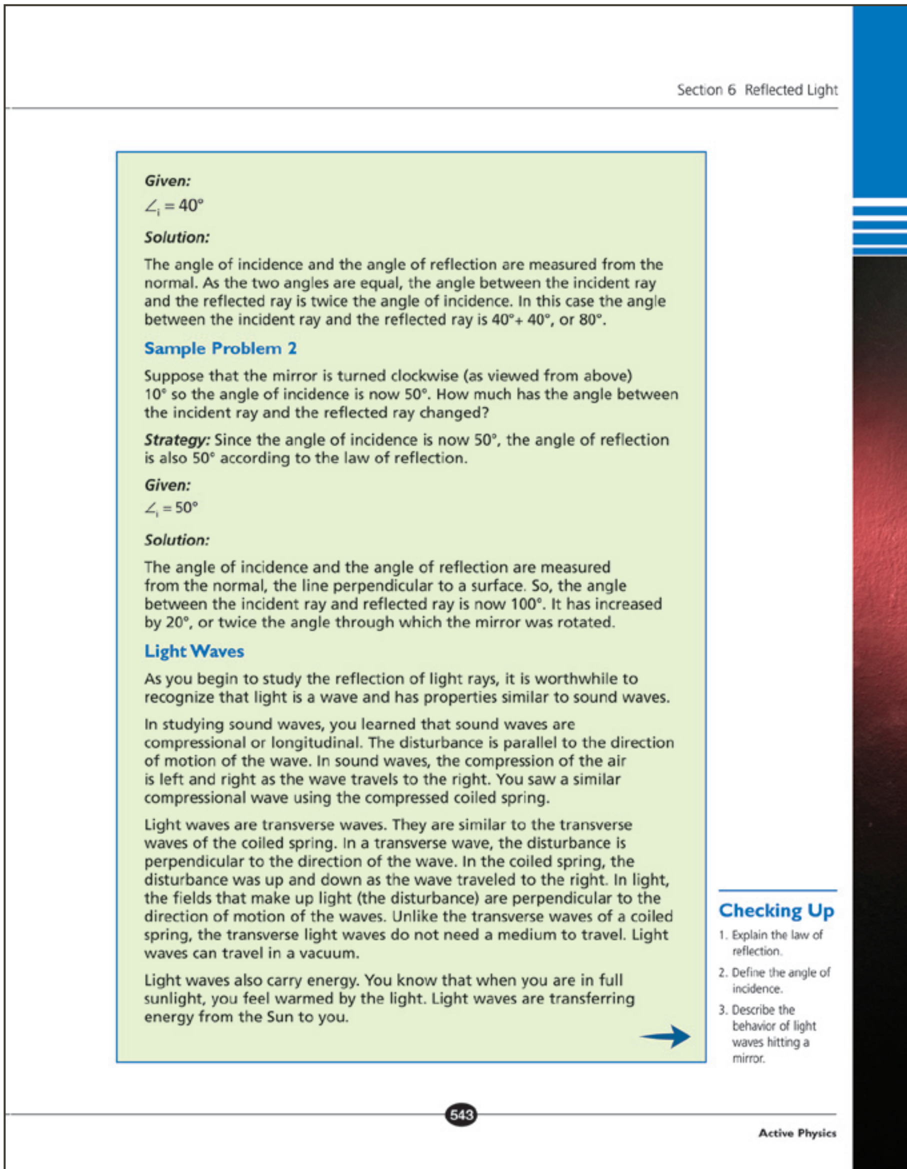
Active Physics



Given:

$\angle_i = 40°$

Solution:

The angle of incidence and the angle of reflection are measured from the normal. As the two angles are equal, the angle between the incident ray and the reflected ray is twice the angle of incidence. In this case the angle between the incident ray and the reflected ray is 40°+ 40°, or 80°.

Sample Problem 2

Suppose that the mirror is turned clockwise (as viewed from above) 10° so the angle of incidence is now 50°. How much has the angle between the incident ray and the reflected ray changed?

Strategy: Since the angle of incidence is now 50°, the angle of reflection is also 50° according to the law of reflection.

Given:

$\angle_i = 50°$

Solution:

The angle of incidence and the angle of reflection are measured from the normal, the line perpendicular to a surface. So, the angle between the incident ray and reflected ray is now 100°. It has increased by 20°, or twice the angle through which the mirror was rotated.

Light Waves

As you begin to study the reflection of light rays, it is worthwhile to recognize that light is a wave and has properties similar to sound waves.

In studying sound waves, you learned that sound waves are compressional or longitudinal. The disturbance is parallel to the direction of motion of the wave. In sound waves, the compression of the air is left and right as the wave travels to the right. You saw a similar compressional wave using the compressed coiled spring.

Light waves are transverse waves. They are similar to the transverse waves of the coiled spring. In a transverse wave, the disturbance is perpendicular to the direction of the wave. In the coiled spring, the disturbance was up and down as the wave traveled to the right. In light, the fields that make up light (the disturbance) are perpendicular to the direction of motion of the waves. Unlike the transverse waves of a coiled spring, the transverse light waves do not need a medium to travel. Light waves can travel in a vacuum.

Light waves also carry energy. You know that when you are in full sunlight, you feel warmed by the light. Light waves are transferring energy from the Sun to you.

Checking Up

1. Explain the law of reflection.
2. Define the angle of incidence.
3. Describe the behavior of light waves hitting a mirror.

Checking Up

1.

The law of reflection states that the angle of incidence is equal to the angle of reflection. Light reflects off a plane mirror in such a way that all the rays emerging from the illuminated object facing a mirror strikes the mirror and reflects back at angles equal to their angles of incidence.

2.

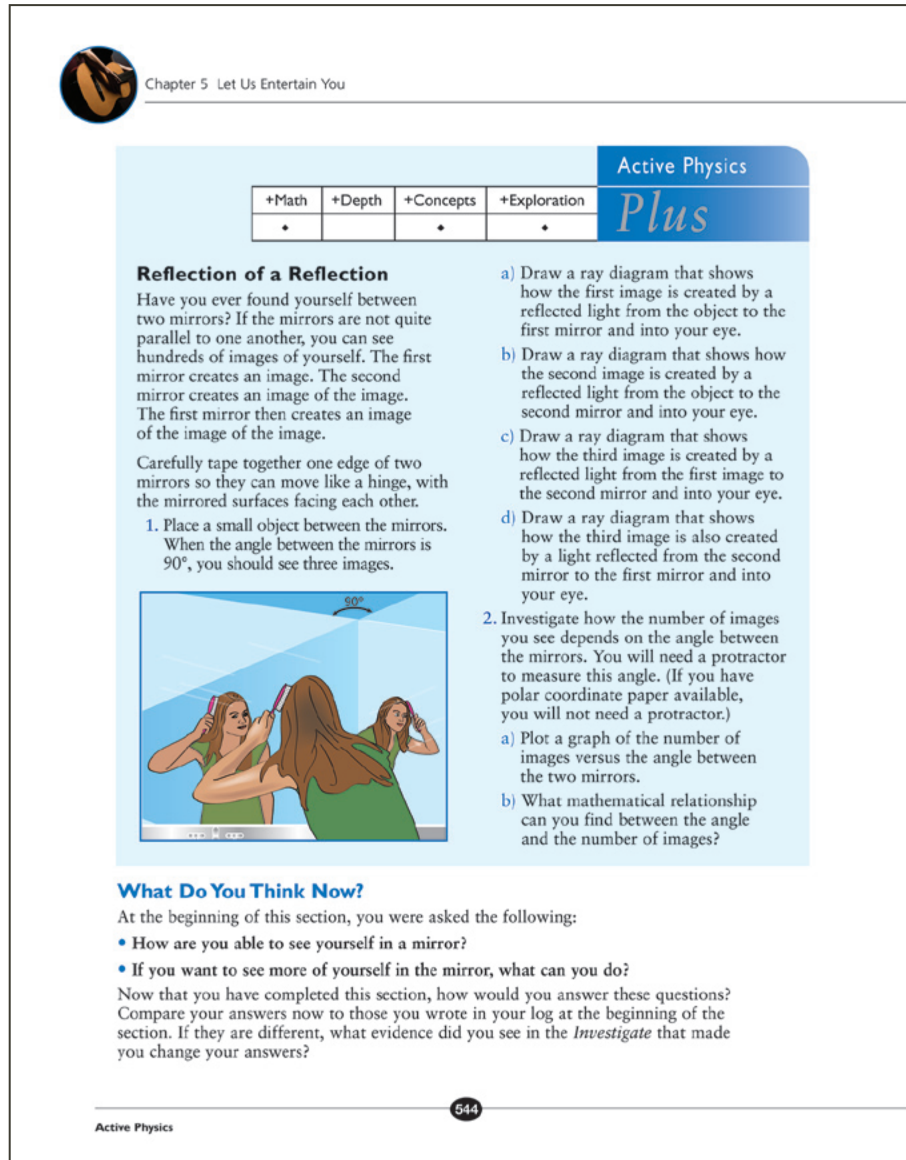
The angle that the incident ray makes with the normal is called the angle of incidence.

3.

Light waves are transverse waves. Their disturbance is perpendicular to the direction of the wave, and they can travel in a vacuum.

Active Physics Plus

The *Active Physics Plus* investigates how images are formed by mirrors placed at right angles to each other. Students draw ray diagrams to show how these images are created. Students also investigate how the number of images that are seen depend on the angle between two mirrors.



Chapter 5 Let Us Entertain You

+Math	+Depth	+Concepts	+Exploration
•		•	•

Active Physics *Plus*

Reflection of a Reflection

Have you ever found yourself between two mirrors? If the mirrors are not quite parallel to one another, you can see hundreds of images of yourself. The first mirror creates an image. The second mirror creates an image of the image. The first mirror then creates an image of the image of the image.

Carefully tape together one edge of two mirrors so they can move like a hinge, with the mirrored surfaces facing each other.

1. Place a small object between the mirrors. When the angle between the mirrors is 90°, you should see three images.
   a) Draw a ray diagram that shows how the first image is created by a reflected light from the object to the first mirror and into your eye.
   b) Draw a ray diagram that shows how the second image is created by a reflected light from the object to the second mirror and into your eye.
   c) Draw a ray diagram that shows how the third image is created by a reflected light from the first image to the second mirror and into your eye.
   d) Draw a ray diagram that shows how the third image is also created by a light reflected from the second mirror to the first mirror and into your eye.
2. Investigate how the number of images you see depends on the angle between the mirrors. You will need a protractor to measure this angle. (If you have polar coordinate paper available, you will not need a protractor.)
   a) Plot a graph of the number of images versus the angle between the two mirrors.
   b) What mathematical relationship can you find between the angle and the number of images?

What Do You Think Now?

At the beginning of this section, you were asked the following:

- **How are you able to see yourself in a mirror?**
- **If you want to see more of yourself in the mirror, what can you do?**

Now that you have completed this section, how would you answer these questions? Compare your answers now to those you wrote in your log at the beginning of the section. If they are different, what evidence did you see in the *Investigate* that made you change your answers?

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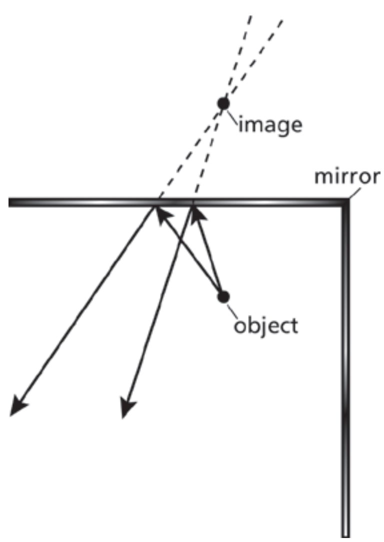
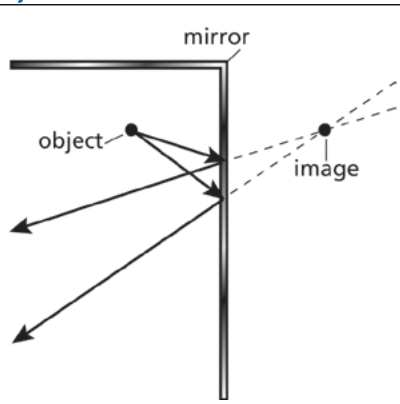
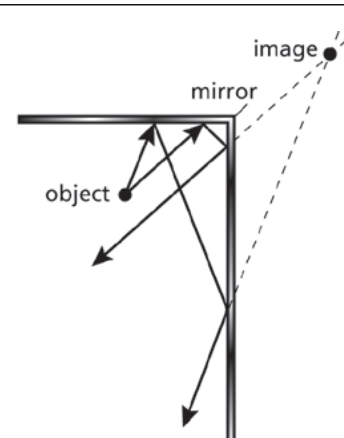
1.a)



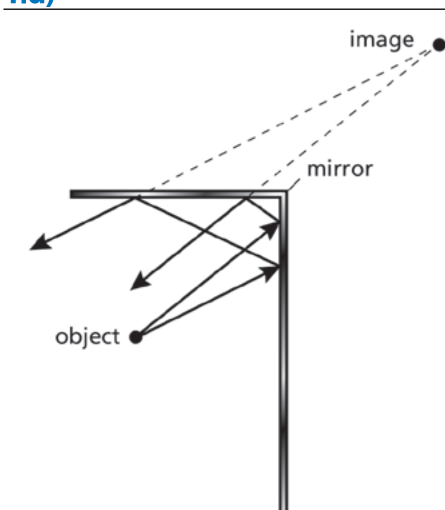
1.b)

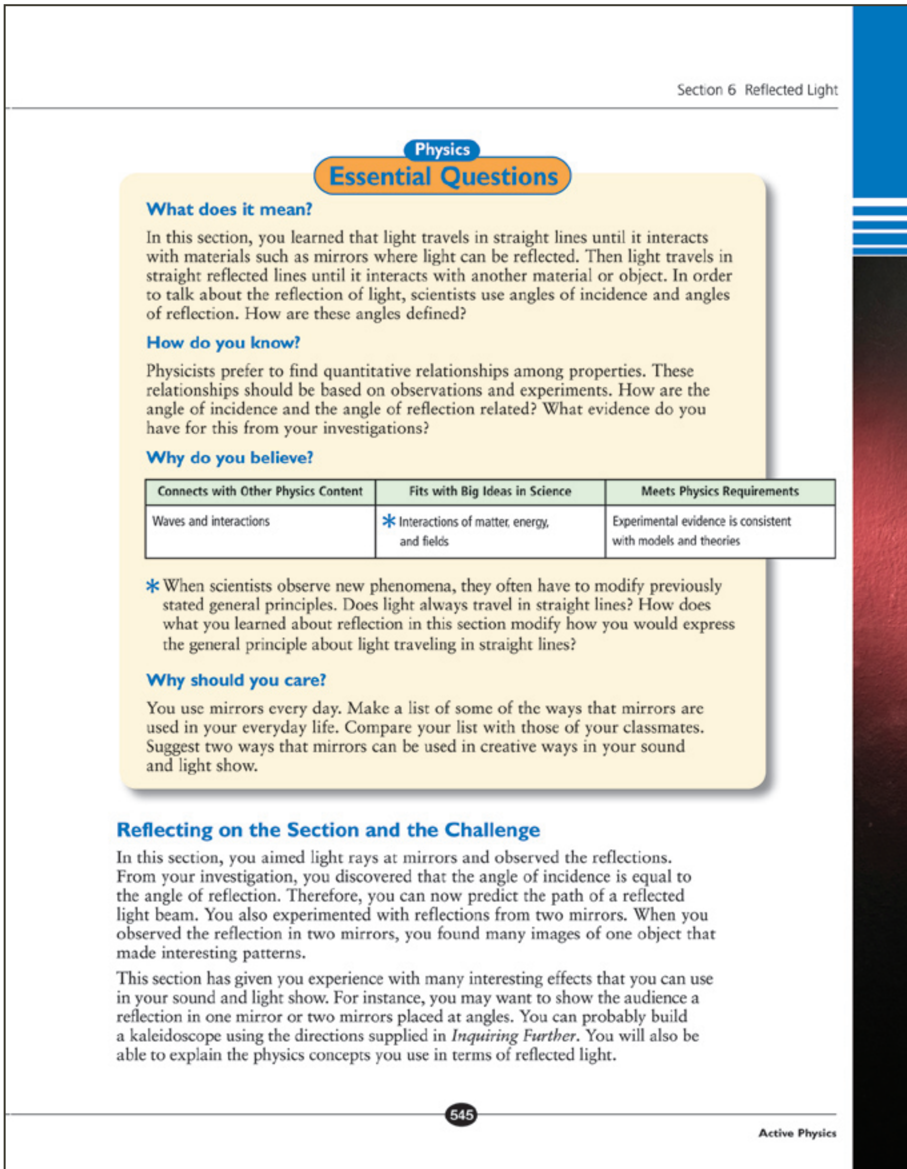


1.c)



1.d)





Section 6 Reflected Light

Physics
Essential Questions

What does it mean?

In this section, you learned that light travels in straight lines until it interacts with materials such as mirrors where light can be reflected. Then light travels in straight reflected lines until it interacts with another material or object. In order to talk about the reflection of light, scientists use angles of incidence and angles of reflection. How are these angles defined?

How do you know?

Physicists prefer to find quantitative relationships among properties. These relationships should be based on observations and experiments. How are the angle of incidence and the angle of reflection related? What evidence do you have for this from your investigations?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Waves and interactions	* Interactions of matter, energy, and fields	Experimental evidence is consistent with models and theories

* When scientists observe new phenomena, they often have to modify previously stated general principles. Does light always travel in straight lines? How does what you learned about reflection in this section modify how you would express the general principle about light traveling in straight lines?

Why should you care?

You use mirrors every day. Make a list of some of the ways that mirrors are used in your everyday life. Compare your list with those of your classmates. Suggest two ways that mirrors can be used in creative ways in your sound and light show.

Reflecting on the Section and the Challenge

In this section, you aimed light rays at mirrors and observed the reflections. From your investigation, you discovered that the angle of incidence is equal to the angle of reflection. Therefore, you can now predict the path of a reflected light beam. You also experimented with reflections from two mirrors. When you observed the reflection in two mirrors, you found many images of one object that made interesting patterns.

This section has given you experience with many interesting effects that you can use in your sound and light show. For instance, you may want to show the audience a reflection in one mirror or two mirrors placed at angles. You can probably build a kaleidoscope using the directions supplied in *Inquiring Further*. You will also be able to explain the physics concepts you use in terms of reflected light.

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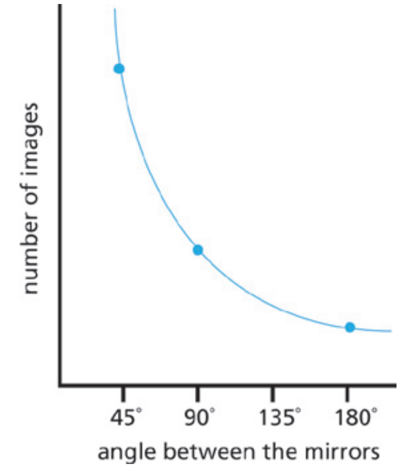
Active Physics

2.a)

Students' graph should look similar to the one below:



2.b)

The equation is the number of images "n" equals 360° divided by the angle between the mirrors (θ) minus one or $n = 360/\theta - 1$. Actually, the image count would be $n = 360/\theta$ but two images overlap at the vertex of the mirrors, reducing the number by 1.

What Do You Think Now?

Students should now be able to explain how they are able to see themselves in a mirror using

CHAPTER 5

Physics Essential Questions

What does it mean?

The angle of incidence is defined as the angle between the ray of light hitting the mirror and the normal line (the line that is perpendicular to the mirror). The angle of reflection is defined as the angle between the ray of light leaving the mirror after reflection and the normal line.

How do you know?

The angle of incidence is equal to the angle of reflection as was observed for multiple angles of incidence in the *Investigate* of this section.

Why do you believe?

Light always travels in straight lines until it hits a mirror and gets reflected. The reflected light changes direction and then continues along other straight lines.

Why should you care?

Mirrors are used to see behind you while driving. They are used for personal grooming. Dentists use mirrors to help see parts of your teeth. Mirrors can be used in your light and sound show to create multiple images of an object. They can also be used to bounce a laser light back and forth.

examples from the *Investigate*. In particular, they should be able to explain why their image appears to be the same distance behind the mirror as it is in front of the mirror. They should know why the size of an image does not increase when an object moves away from the mirror. In a discussion, share *A Physicist's Response* and encourage students to update previous answers they recorded in their *Active Physics* logs.

Reflecting on the Section and the Challenge

Students should be able to summarize their findings in the *Investigate* and reflect on how their knowledge of images in a plane mirror can be used to design the *Chapter Challenge*.

Since they experimented with images of an object made by two reflecting mirrors, have them read aloud the part of this section that suggests how they could build a kaleidoscope by using the directions supplied in the *Physics to Go*. Generate interest in the many possibilities that this section presents in helping students come up with creative ideas to enhance the stage effects of their sound and light show.

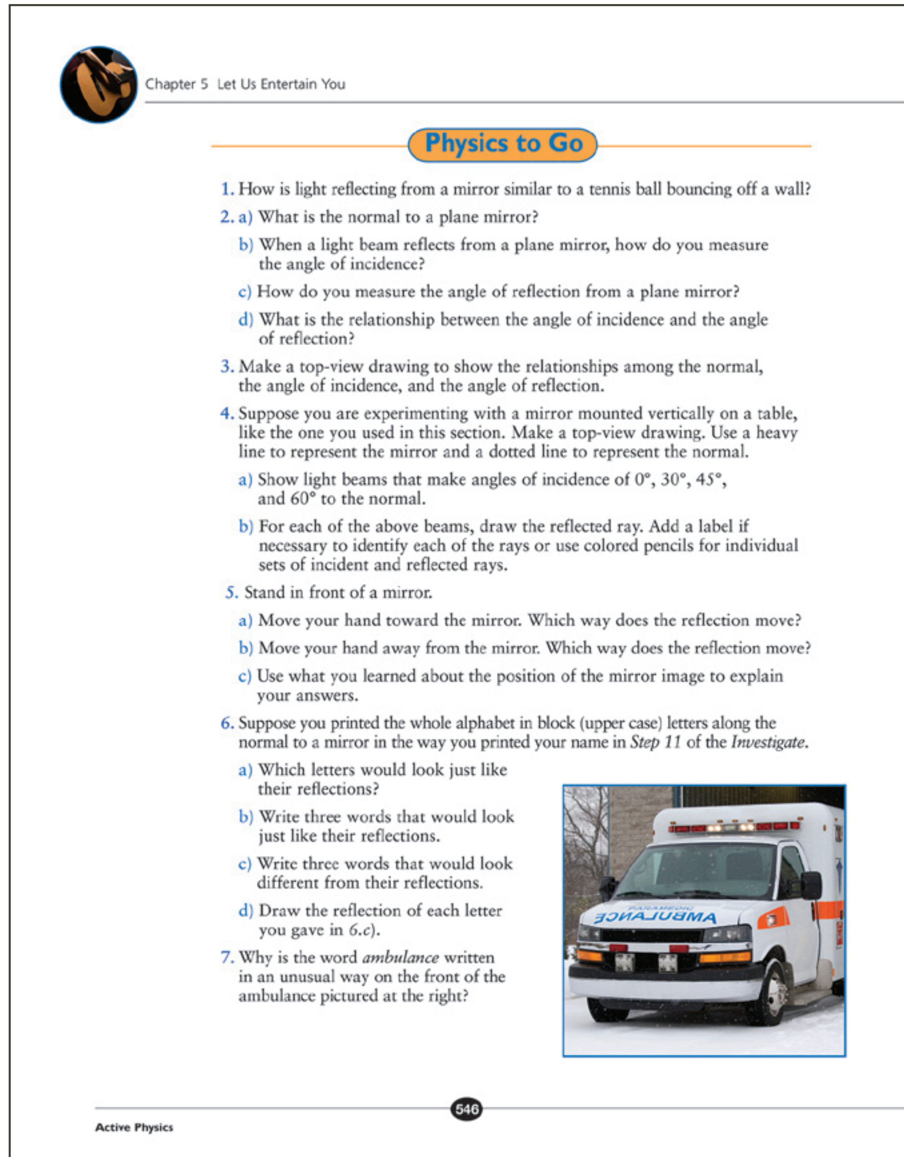
Physics to Go

1.

For the tennis ball and for light, the angle of incidence equals the angle of reflection (except for the effect of the spin on the ball).

2.a)

The normal is a line perpendicular to the mirror surface.



Chapter 5 Let Us Entertain You

Physics to Go

1. How is light reflecting from a mirror similar to a tennis ball bouncing off a wall?
2. a) What is the normal to a plane mirror?
   b) When a light beam reflects from a plane mirror, how do you measure the angle of incidence?
   c) How do you measure the angle of reflection from a plane mirror?
   d) What is the relationship between the angle of incidence and the angle of reflection?
3. Make a top-view drawing to show the relationships among the normal, the angle of incidence, and the angle of reflection.
4. Suppose you are experimenting with a mirror mounted vertically on a table, like the one you used in this section. Make a top-view drawing. Use a heavy line to represent the mirror and a dotted line to represent the normal.
   a) Show light beams that make angles of incidence of 0°, 30°, 45°, and 60° to the normal.
   b) For each of the above beams, draw the reflected ray. Add a label if necessary to identify each of the rays or use colored pencils for individual sets of incident and reflected rays.
5. Stand in front of a mirror.
   a) Move your hand toward the mirror. Which way does the reflection move?
   b) Move your hand away from the mirror. Which way does the reflection move?
   c) Use what you learned about the position of the mirror image to explain your answers.
6. Suppose you printed the whole alphabet in block (upper case) letters along the normal to a mirror in the way you printed your name in *Step 11* of the *Investigate*.
   a) Which letters would look just like their reflections?
   b) Write three words that would look just like their reflections.
   c) Write three words that would look different from their reflections.
   d) Draw the reflection of each letter you gave in 6.c).
7. Why is the word *ambulance* written in an unusual way on the front of the ambulance pictured at the right?

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Active Physics

2.b)

The angle of incidence is the angle between the incident beam and the normal at the point of incidence. This angle is measured by tracing the path of the incident beam and then drawing the normal where the beam hits the mirror. Use a protractor to measure the angle.

2.c)

The angle of reflection is the angle between the reflected beam and the normal. Use a protractor to measure the angle.

2.d)

They are equal.

3.

The drawing should be similar to the first illustration in the *Physics Talk* in the *Student Edition*.

4.a)

Students' drawings should be similar to those shown in the

Physics Talk for this section, showing angles of 0, 30, 45 and 60 degrees.

4.b)

The angles of incidence on the diagrams should be equal to the angle of reflection.

Students should note that at an angle of incidence of 0°, the light ray is striking the mirror perpendicularly, and reflecting back along the normal.

5.a)

The image moves toward the mirror and toward you.

5.b)

The image moves away from the mirror and away from you.

5.c)

The image is the same distance behind the mirror as the object is in front of the mirror. If you move your hand away from the mirror, the distance to the mirror increases, so the image is further from the mirror, too.

6.a)

The letters A, H, I, M, O, T, U, V, W, and X.

6.b)

MOM, TOT, WOW.

6.c)

Any words that have letters that are not symmetric upon reflection would look different from their reflection, such as K, N, and S.

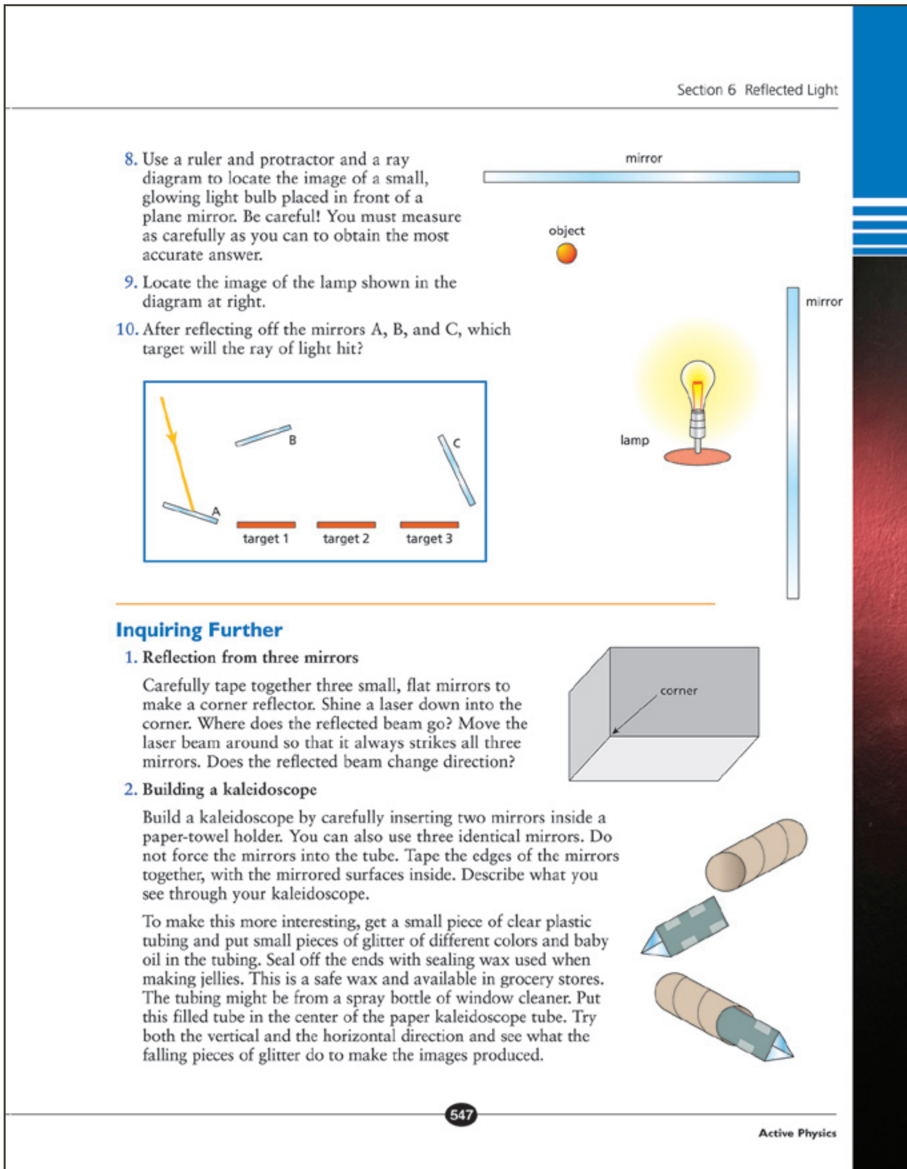
6.d)

7.

The ambulance is seen through a rear-view mirror, otherwise the word reads normally.

NOTES

NOTES



8. Use a ruler and protractor and a ray diagram to locate the image of a small, glowing light bulb placed in front of a plane mirror. Be careful! You must measure as carefully as you can to obtain the most accurate answer.

9. Locate the image of the lamp shown in the diagram at right.

10. After reflecting off the mirrors A, B, and C, which target will the ray of light hit?

Inquiring Further

1. **Reflection from three mirrors**

Carefully tape together three small, flat mirrors to make a corner reflector. Shine a laser down into the corner. Where does the reflected beam go? Move the laser beam around so that it always strikes all three mirrors. Does the reflected beam change direction?

2. **Building a kaleidoscope**

Build a kaleidoscope by carefully inserting two mirrors inside a paper-towel holder. You can also use three identical mirrors. Do not force the mirrors into the tube. Tape the edges of the mirrors together, with the mirrored surfaces inside. Describe what you see through your kaleidoscope.

To make this more interesting, get a small piece of clear plastic tubing and put small pieces of glitter of different colors and baby oil in the tubing. Seal off the ends with sealing wax used when making jellies. This is a safe wax and available in grocery stores. The tubing might be from a spray bottle of window cleaner. Put this filled tube in the center of the paper kaleidoscope tube. Try both the vertical and the horizontal direction and see what the falling pieces of glitter do to make the images produced.

8.

Placement of the original light ray is random. But once the ray has struck the mirror, angles of incidence relative to the normal and angles of reflection relative to the normal must be carefully measured. Students' diagrams should be similar to the *Active Physics Plus 1.a)* or *1.b)* diagrams.

9.

The image of the lamp should be the same distance behind the mirror as the lamp's distance in front of the mirror.

10.

Target 3.

Inquiring Further

1. Reflection from three mirrors

The beam reflects back along the direction it entered the corner mirror, but displaced to the side, depending on where it hits the mirrors. This occurs regardless of the incident angle chosen, as long as it strikes all three mirrors.

2. Building a kaleidoscope

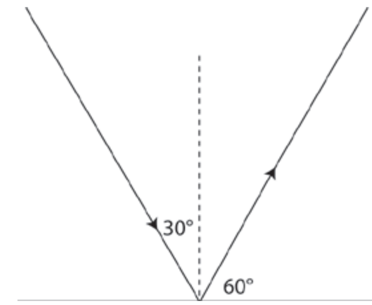
Students build a kaleidoscope.

CHAPTER 5

SECTION 6 QUIZ

5-6b **Blackline Master**

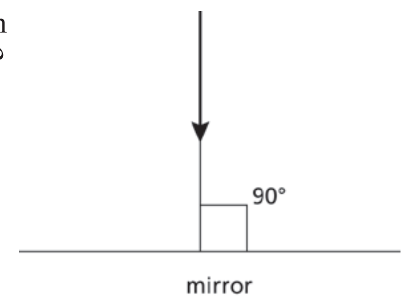
1. The diagram at the right shows a light ray striking a plane mirror. The angle of reflection of the light ray is



a) 30°. b) 45°.

c) 60°. d) 90°.

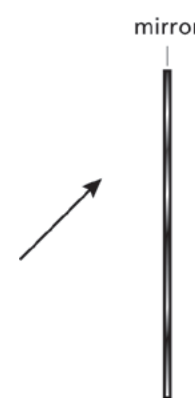
2. When a light ray is incident upon a plane mirror as shown in the diagram to the right, what is the angle of reflection?

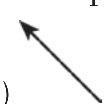


a) 0°. b) 30°.

c) 45°. d) 90°.

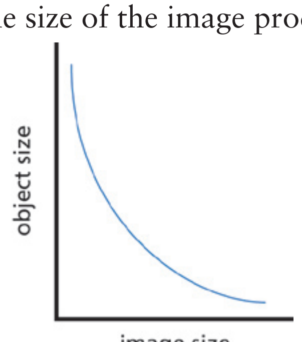
3. An object is placed in front produced by the mirror?

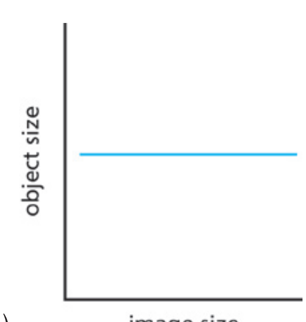


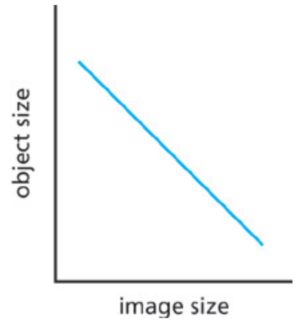
a)  b) 

c)  d) 

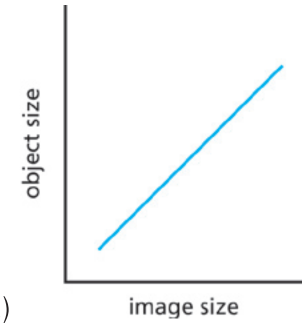
4. Which graph below best represents the size of an object in front of a plane mirror versus the size of the image produced by the mirror?

a) 

b) 



c)



d)

5. A truck has the letters MOMO painted on the front. A student driving a vehicle ahead of the truck sees the letters in the rear-view mirror. How do the letters appear to the student?

a) WOWO.

b) MOMO.

c) OWOW.

d) OMOM.

SECTION 6 QUIZ ANSWERS

1. a) The angle of incidence equals the angle of reflection. The angle of incidence is measured from the perpendicular, not the surface, ruling out choice *c)*.

2. a) The angle of reflection is measured from the perpendicular, so in this case, the angle between the perpendicular and the reflected ray is zero degrees. Many students may choose 90°, choice *d)*, because it is the only angle shown in the diagram. The other answers are simply distracters.

3. b) The part of the object closest to the mirror will be the part of the image closest to the mirror, giving choice *b)*. Choice *a)* is simply the object, and choices *c)* and *d)* are inverted images, which are not produced by a plane mirror.

4. d) As the size of an object increases, and if all other factors remain the same, the size of the image produced by the mirror increases, which is graph *d)*. The other graphs do not show this relationship.

5. d) The letters in a rear-view mirror would appear to be reversed, but not inverted, like choices *a)* and *c)*. Choice *b)* would indicate no change.