# 10.2 Properties of Light and Reflection

All light, regardless of its source, behaves the same. What can you learn about the behaviour of light, including reflection, from the photograph in **Figure 10.12**? **Reflection** is the change in direction of a wave when it reaches a surface and bounces off that surface.

All the light that reaches the eyes of an observer standing beside this lake originally came from the Sun. For example, to see the objects in the photograph, the sunlight had to reflect off every object in the scene.

To see the reflection of the sky, hills, and trees in the lake, the light had to reflect from all of these objects toward the water and then reflect from the surface of the water to your eyes. In the photograph, why do you see only the light that is reflected from the surface of the water and nothing in the water? Why is the reflection from the surface of the water such a clear image of the surroundings?

## Rays of Light

Light travels in a straight line as long as it is moving through the same medium. **Medium** is the term for the substance through which light is travelling. This property of light allows you to make predictions about the appearance of objects and, for example, their shadows. You can use a technique called ray tracing to make ray diagrams. A **ray** is a straight line with an arrowhead that shows the direction in which light waves are travelling.

**Key Terms**
- reflection
- medium
- ray
- incident ray
- angle of incidence
- normal
- reflected ray
- angle of reflection
- plane mirror
- virtual image

**reflection** the change in direction of a light ray when it bounces off a surface

**medium** the substance through which light travels

**ray** a straight line with an arrowhead that shows the direction in which light waves are travelling

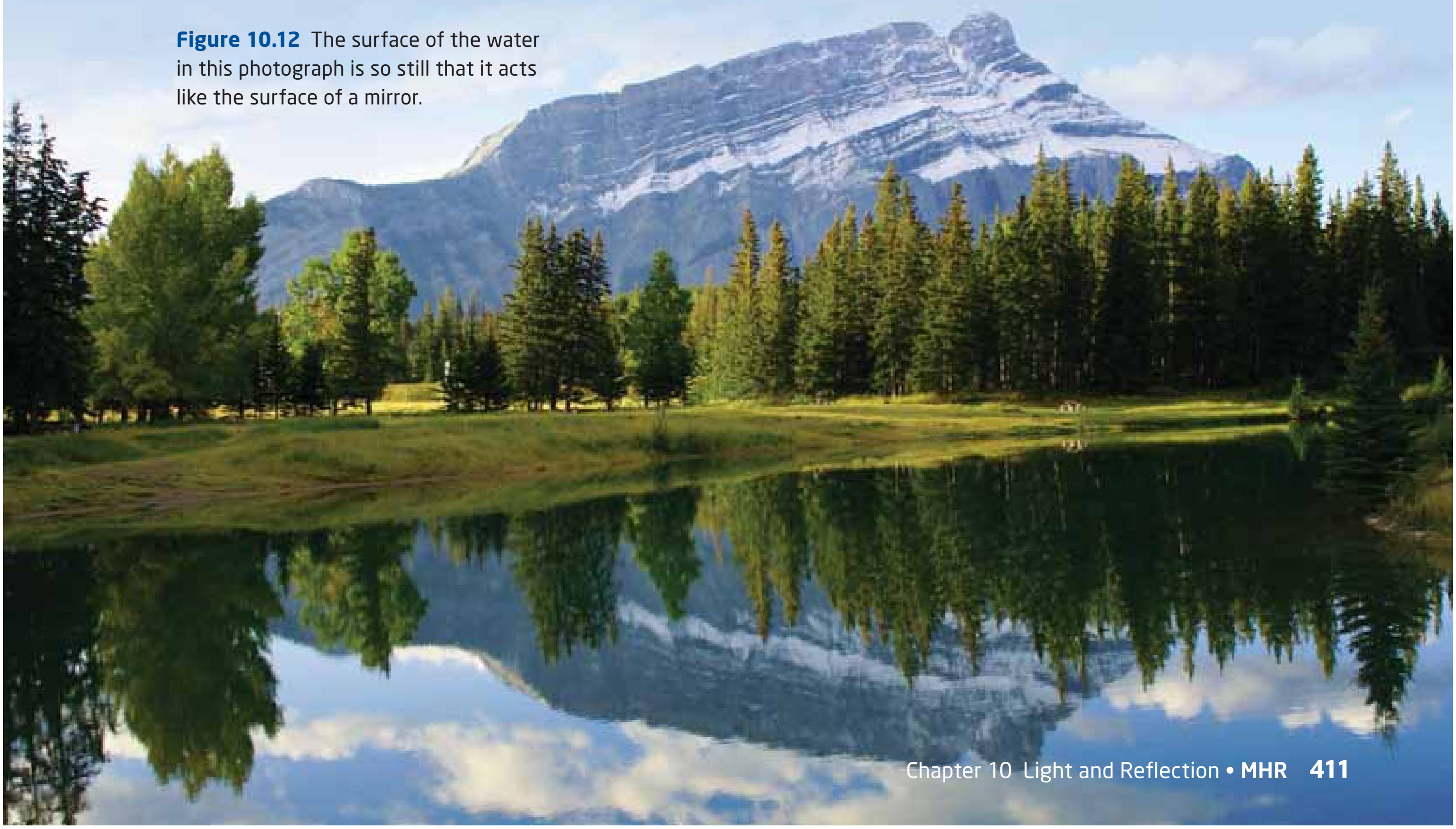


**Figure 10.12** The surface of the water in this photograph is so still that it acts like the surface of a mirror.

## Ray Tracing

**Figure 10.13** shows how to use rays to predict the location, size, and shape of the shadows of two objects. In this diagram, the source of light is a small light bulb. The light bulb sends out light rays in every direction. You can choose any rays that are travelling in the direction of interest. Draw the rays, and then see where they fall. Note that the smaller object casts the larger shadow, due to its location between the source and the screen.

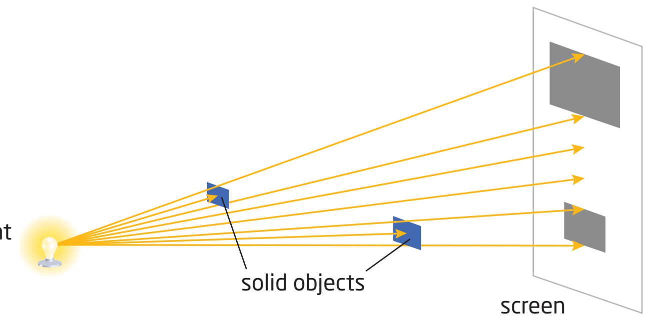



**Figure 10.13** Using the fact that light travels in straight lines, you can predict the size and shape of shadows formed by opaque objects.

## Fermat's Principle

Fermat's principle predicts the path that light will take after reflecting from a surface or passing through more than one medium. According to *Fermat's principle,* light follows the path that will take the least time. When light reflects from a surface and remains in one medium, its speed is constant. Therefore, the path that takes the least time is the shortest path. Fermat's principle leads to the laws of reflection.

**incident ray** a ray of light that travels from a light source toward a surface

**angle of incidence** the angle between the incident ray and the normal in a ray diagram

**normal** a line that is perpendicular to a surface where a ray of light meets the surface

**reflected ray** a ray that begins at the point where the incident ray and the normal meet

**angle of reflection** the angle between the reflected ray and the normal in a ray diagram

## Laws of Reflection

A ray of light coming toward a surface is called an **incident ray**. The **angle of incidence** is measured between the incident ray and a perpendicular line drawn from the point of contact of the incident ray at the surface. This perpendicular line is called the **normal**. The **reflected ray** begins at the point of contact. The **angle of reflection** is measured between the reflected ray and the normal. The incident ray, the normal, and the reflected ray all lie on the same flat surface, or plane.

When you know the angle of incidence, you can predict the angle of reflection because they are the same. The reflected ray always lies on the plane that is defined by the incident ray and the normal. These relationships are called the *laws of reflection*. The laws of reflection apply to light and to all other forms of waves, such as sound waves.

**Suggested Investigation**

Inquiry Investigation 10-B, Studying the Laws of Reflection, on page 440

### Laws of Reflection

1. The incident ray, the reflected ray, and the normal always lie on the same plane.
2. The angle of reflection, $\angle r$, is equal to the angle of incidence, $\angle i$.

$$\angle r = \angle i$$

## Drawing Ray Diagrams

**Figure 10.14** illustrates the steps to draw a ray diagram for an incident ray moving toward a mirror. The steps are numbered, so when you read them, start with step 1.

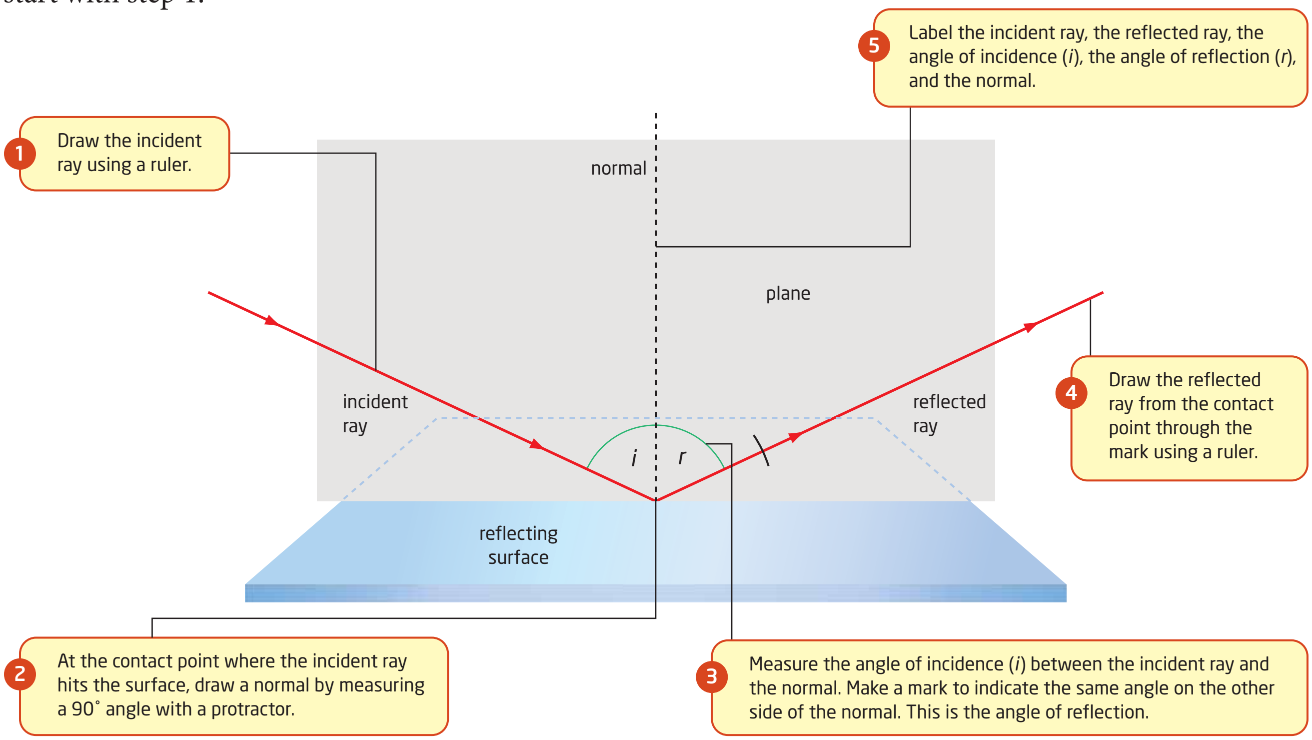



**Figure 10.14** Follow the steps illustrated here to learn how to draw a ray diagram for light reflecting off a smooth surface.

# Activity 10-2

## A Reflection Obstacle Course

Can you use the laws of reflection to hit a target with a light ray? In this activity, you will use two plane (flat) mirrors and a light source to hit the bull's-eye of a target. Then you will use the mirrors and a remote control to turn on a television. Reflection off plane mirrors is discussed on page 414.

### Safety Precaution

- Never direct a light source at someone's eyes.

### Materials

- targets
- 2 plane (flat) mirrors
- 2 mirror stands
- flashlight
- remote control for a television
- television

### Procedure

1. Your teacher will set up different targets at different stations in the classroom, at different heights. One station will have a television and a remote control.
2. Set up two plane mirrors at a target station. Position the mirrors so that you hit the bull's-eye by reflecting the light from the flashlight off the two mirrors.
3. At the station with the television, use the remote control as a source of invisible electromagnetic radiation. Position the mirrors so that you turn on the television by reflecting this invisible source.

### Questions

1. How did you have to position the two mirrors to hit the target?
2. How does this activity provide evidence that invisible sources of light also obey the laws of reflection?

**Learning Check**

1. Why is the fact that light travels in a straight line critical to the technique of ray tracing?
2. Using a diagram, explain the laws of reflection. Include the following labels: normal, angle of incidence, angle of reflection.
3. Using **Figure 10.14** as a guide, draw a ray diagram in which the angle of incidence is 45°.
4. Suppose that you and your classmates are preparing a project to show how the shadow effects from a simple object, such as a cat, can be used to create scary feelings. Develop a procedure that other students in your class could follow to create these feelings with this object. Use **Figure 10.13** as a guide.

## Images in Plane Mirrors

**Suggested Investigation**

Inquiry Investigation 10-A, Applying the Laws of Reflection, on page 439

**plane mirror** a mirror with a flat, reflective surface

Scientists call an object placed in front of a mirror the *object*, and they call the likeness that is seen in the mirror the *image* of the object. If you apply the laws of reflection to rays going from the object, you can predict where the image will be and what the image will look like. In other words, you can predict the *characteristics* of the image. **Figure 10.15** shows an example of tracing rays to find the image of a blueberry in a **plane mirror**. When a light shines on the blueberry, it reflects off all the points on the blueberry, in all directions. Rays reflecting off one point on the blueberry are shown in **Figure 10.15**. These rays reach the plane mirror, follow the laws of reflection, and reflect backward. Some of these rays reach the eyes of a person looking at the mirror.

The brain assumes that a light ray travels in a straight line. Therefore, to find out where the eye "sees" the image, extend the rays that reach the eye backward until they meet at a point behind the mirror. These extended rays are shown by the dashed lines in **Figure 10.15**. The point at which the dashed lines meet is the location of one point on the object. By repeating this process for several points on the blueberry, you can find out exactly where the entire image of the blueberry is located.

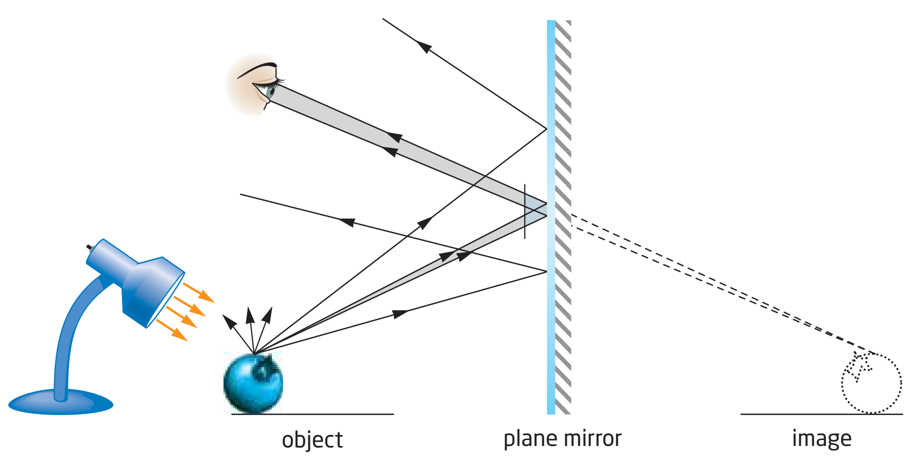



**Figure 10.15** No matter where the observer's eye is located, the image will always be in the same place. All the reflected rays can be extended backward and will reach the same point. The dashed lines represent extended rays.

## Making a Difference

Pénélope Robinson and Maude Briand-Lemay used their knowledge of mirrors and reflection to double energy production from solar panels on residential roofs.

Residential solar panels are usually installed on the south side of a sloped roof because the south side generally receives more sunlight. Pénélope and Maude's system includes a mirror on a pole placed near the north side of a roof. When the Sun's rays hit the mirror, they are reflected toward solar panels on the north side of the roof.

Pénélope and Maude tested their system. Without the mirror, solar panels on the north side did not collect solar energy. With the mirror, the same amount of energy was collected from solar panels on both sides of the roof.

Pénélope and Maude earned an award for their project at the 2007 Canada Wide Science Fair. They have since registered a patent for their design.

**In what other ways could mirrors be used to harness the Sun's energy?**

### Virtual Images

Notice in **Figure 10.15** that there are no light rays actually going to or coming from the image behind the mirror. Light rays only *appear* to be coming from the image. This type of image is called a **virtual image**. One way to decide whether or not an image is virtual is to imagine putting a screen at the location of the image. If light rays hit the screen and form an image, the image is real and not virtual. If no light rays hit the screen, there is no image on the screen and the image is virtual. You could also say that the image is imaginary because you only imagine that an image forms at this location. If an image is behind a mirror, there is no way that light rays could get there. The image must be virtual. When you study curved mirrors in Sections 10.3 and 10.4, you will learn about "real" images.

**virtual image** an image formed by rays that appear to be coming from a certain position, but are not actually coming from this position; image does not form a visible projection on a screen

## Ray Diagrams and Plane Mirrors

In general, an image has four characteristics:

- its location (closer than, farther than, or the same distance as the object to the mirror)
- orientation (upright or inverted)
- size (same size, larger than, or smaller than the object)
- type (real image or virtual image).

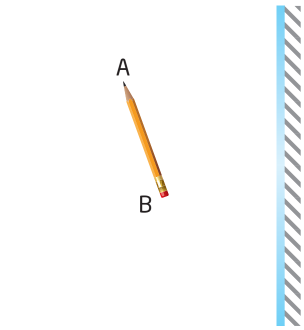
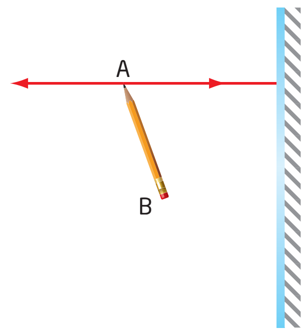
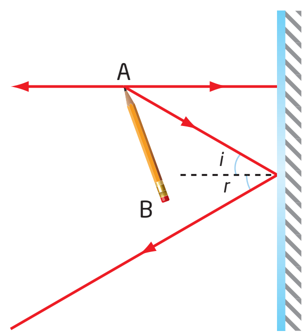
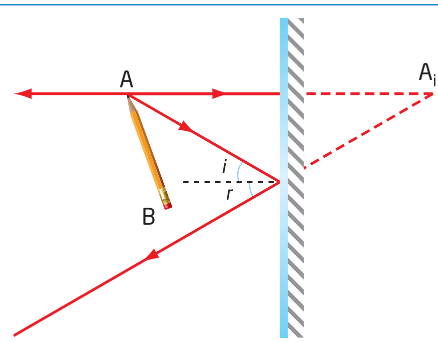
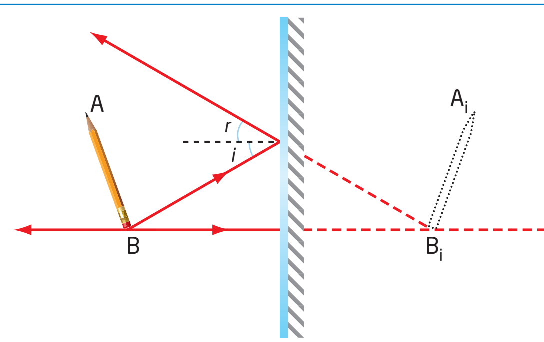
You can predict these characteristics by drawing a ray diagram to locate the image of an object. Follow the steps in **Table 10.1** on the next page to see how to draw a ray diagram for an object placed in front of a plane mirror.

The four characteristics of an image in a plane mirror are the following: An image in a plane mirror is the same size as the object, the same distance from the mirror as the object, and the same orientation as the object. It is also a virtual image.

**Figure 10.16** shows how a non-symmetrical object appears in a plane mirror. When you see writing in a plane mirror, the writing *appears* to be backward in the mirror. This is because you write the word and then turn the paper around to face the mirror. The image in the mirror is not *actually* inverted.


**Figure 10.16** When you look at writing in a mirror, the writing is difficult to read because it looks like it has been written backward. But it is actually difficult to read because the writing has *not* been inverted. If you wrote the word on a transparent surface, like a piece of plastic wrap, your view of the word on the plastic would match the image in the mirror–the letters on the right stay on the right.

**Table 10.1** **Locating an Image in a Plane Mirror Using a Ray Diagram**

| Description | Example |
|---|---|
| **1.** Draw a line to represent a mirror. Add hatch marks to show the non-reflecting surface of the mirror. Draw a simple object. The distance between the mirror and the object is called the *object distance*. Label a point at one end of the object "A," and label a point at the other end "B." |  |
| **2.** Draw an incident ray from point A directly to the mirror at a 90° angle. Because this line is normal to the mirror, the angle of incidence is zero. Therefore, the angle of reflection is also zero. The reflected ray goes directly backward along the same line as the incident ray. |  |
| **3.** Draw another incident ray from point A at an angle to the mirror. At the point where the incident ray hits the mirror, draw a normal. Measure the angle of incidence with a protractor. Using the knowledge that the angle of reflection is equal to the angle of incidence, draw the reflected ray. |  |
| **4.** Using a dashed line, extend both reflected rays behind the mirror until they meet. Label this point "$A_i$" to indicate that it is the image point of the tip of the pencil. |  |
| **5.** Repeat steps 2 to 4 for point B. Join $A_i$ and $B_i$ using a ruler. The distance between the mirror and the image is called the *image distance*. |  |

## Reflection and Stealth Technology

Radar (Radio Detection and Ranging) was invented in 1935 and was used to detect aircraft from the ground during World War II. Military aircraft such as the stealth fighter in **Figure 10.17** need to avoid detection. Two features make the stealth almost invisible to radar. First, the paint used on the aircraft absorbs much of the energy from the radar waves. The base of the paint allows the radar waves to penetrate the surface. Then the radar waves reflect from one particle to the next, losing energy along the way. Although the paint absorbs much of the energy, some radar waves still reflect off the airplane.

The second feature that prevents detection is the shape of the airplane. In **Figure 10.17**, notice that all the surfaces are flat and all the edges are sharp. Most of the incoming radar rays will not hit perpendicular to these surfaces. When the rays reflect from the surfaces of the stealth fighter, most of the reflected rays will not return to the radar antenna. If some of the rays do reflect back to the antenna, it will not be a problem because the signal will be so small that the radar operators will think that the aircraft is a small bird.

Go to **scienceontario** to find out more

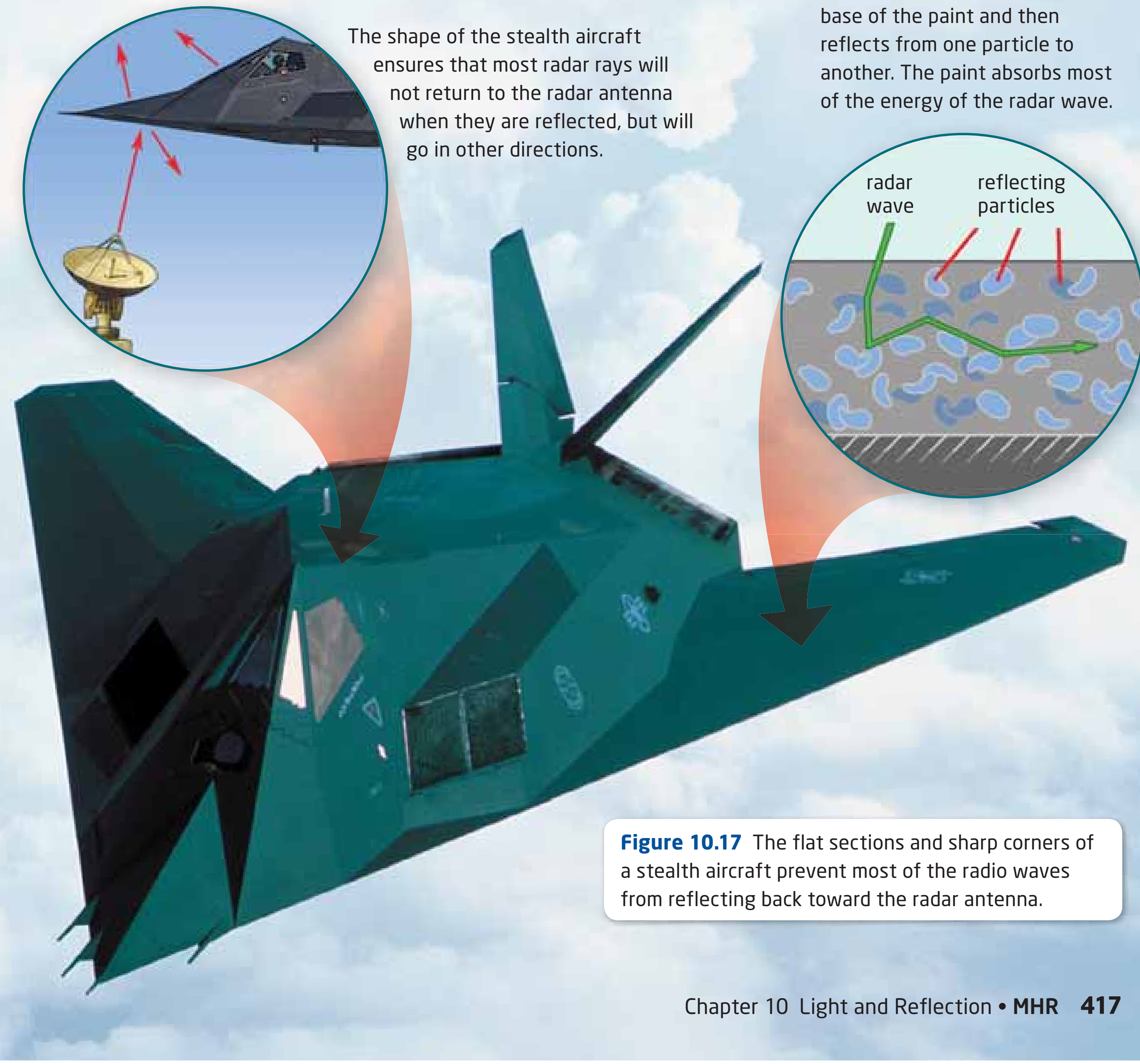



**Figure 10.17** The flat sections and sharp corners of a stealth aircraft prevent most of the radio waves from reflecting back toward the radar antenna.

## Section 10.2 Review

### Section Summary

- A ray is a straight line with an arrowhead that shows the direction in which light is travelling.
- The laws of reflection state that the angle of reflection is equal to the angle of incidence, and that the reflected ray always lies on the plane that is defined by the incident ray and the normal.
- The location of an image in a plane mirror can be found by drawing a ray diagram based on the laws of reflection and tested through inquiry.
- The four characteristics of an image in a plane mirror are the following: the image is the same size as the object, the same distance from the mirror as the object, and the same orientation as the object; the image is a virtual image.

### Review Questions

K/U **1.** There is a special incident ray that reflects right back on itself.

**a.** How would you aim this incident ray to achieve that effect?

**b.** What is the angle of incidence of this incident ray?

K/U **2.** List the four characteristics of an image.

C **3.** Explain to a classmate why you can choose to draw any two rays from a point on an object to determine its image point.

K/U **4.** Define the terms *image distance* and *object distance* as they apply to a reflection in a plane mirror.

A **5.** In what ways is the stealth aircraft evidence for the fact that invisible regions of the electromagnetic spectrum also obey the laws of reflection?

K/U **6.** Follow the steps in **Table 10.1** to locate the image of a small, square object placed in front of a plane mirror. State the four characteristics of the image.

K/U **7.** Draw a ray diagram of an apple in front of a plane mirror. Refer to **Figure 10.15** if necessary. State the four image characteristics.

T/I **8.** The diagram on the right shows four different objects in front of a mirror. For each object, explain how many image points need to be drawn in order to draw an image of the entire object. For each object, how many rays need to be drawn?