TOPIC 3.4

# How does light behave when it is reflected?

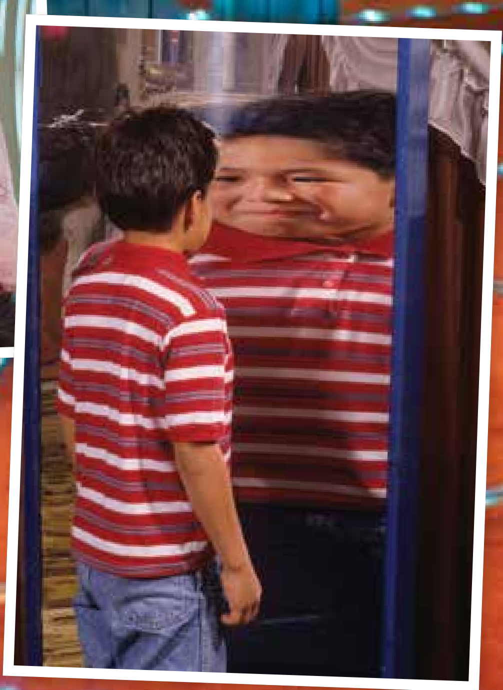
## Key Concepts

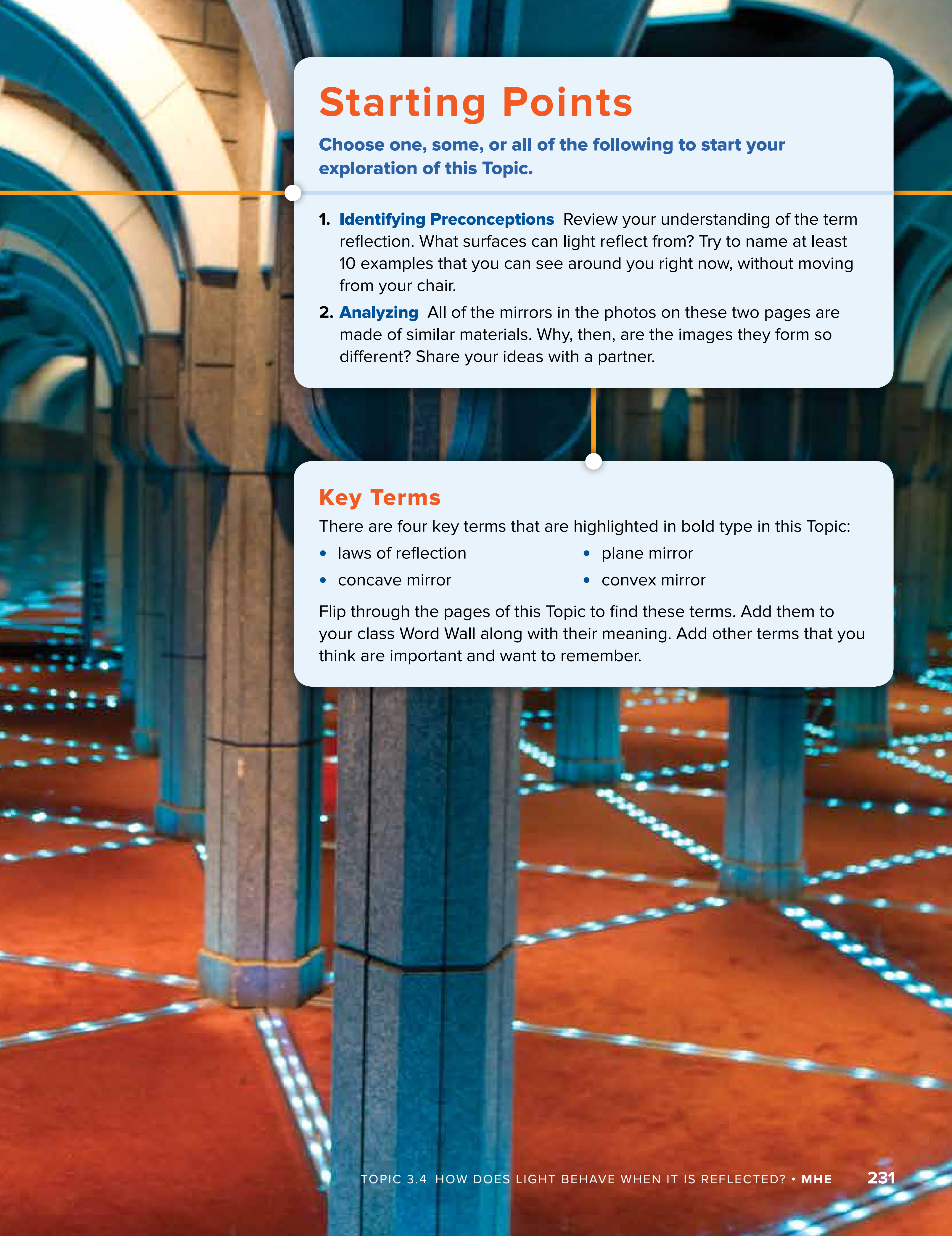
- Light is reflected in predictable patterns.
- Light reflected by a plane mirror produces an image that is nearly identical to the object.
- Light reflected by curved mirrors behaves in unique ways.
- Many technologies take advantage of light's behaviour when it strikes a reflective surface.

## Curricular Competencies

- Seek patterns and connections in data
- Use scientific understandings to identify relationships and draw conclusions
- Construct and use a range of methods to represent patterns or relationships in data
- Measure and control variables through fair tests

Funhouse mirrors are designed to amuse and confuse. Some, like the ones in the maze shown here, form clear images that are almost identical to the objects they reflect. When they are cleverly placed in the maze, you may find yourself walking into one that forms an image of an empty hallway. Other funhouse mirrors form misshapen images like the ones in the insets.





# Starting Points

**Choose one, some, or all of the following to start your exploration of this Topic.**

1. **Identifying Preconceptions** Review your understanding of the term reflection. What surfaces can light reflect from? Try to name at least 10 examples that you can see around you right now, without moving from your chair.
2. **Analyzing** All of the mirrors in the photos on these two pages are made of similar materials. Why, then, are the images they form so different? Share your ideas with a partner.

## Key Terms

There are four key terms that are highlighted in bold type in this Topic:

- laws of reflection
- concave mirror
- plane mirror
- convex mirror

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meaning. Add other terms that you think are important and want to remember.

CONCEPT 1

# Light is reflected in predictable patterns.

Light rays always follow a predictable path, no matter what surface they reflect from. Three key ideas determine this path. These ideas are called the **laws of reflection**. Use **Figure 3.24** to help you understand them.

**laws of reflection** three laws that describe the predictable path light follows when it strikes a reflective surface

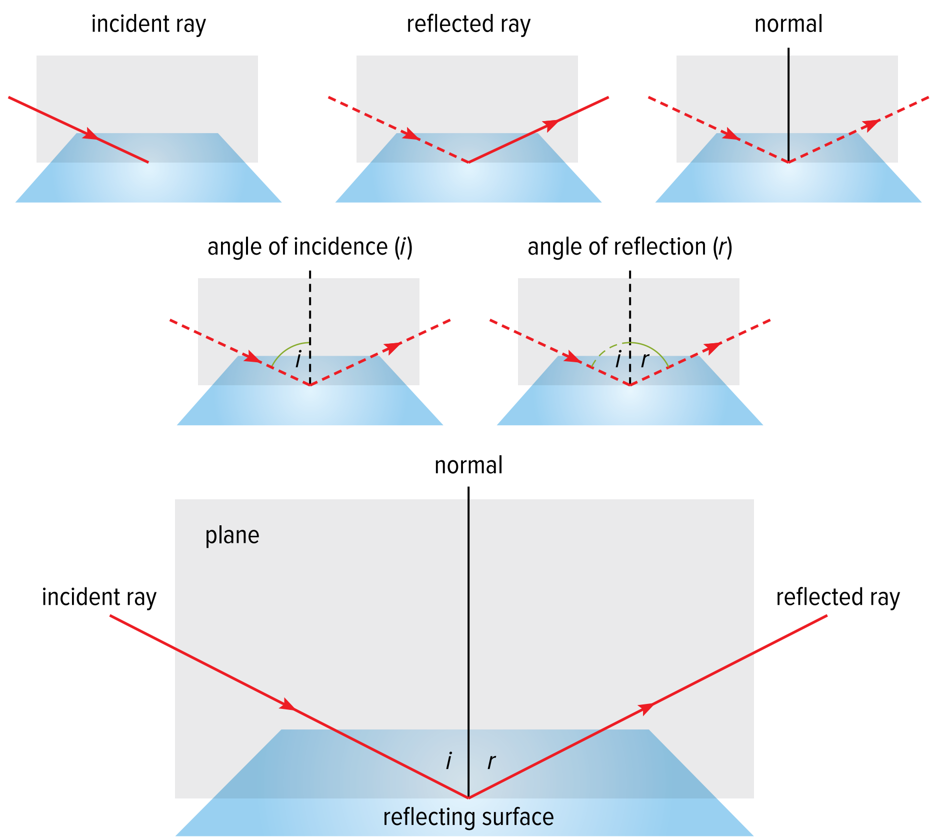



**Figure 3.24** All light rays obey the laws of reflection, as shown here. The word *plane* refers to any flat surface.

**incident ray**: the light ray travelling toward the reflecting surface

**reflected ray**: the light ray that has bounced off a reflecting surface

**normal**: a line perpendicular to a surface such as a mirror

**angle of incidence (*i*)**: the angle between the incident ray and the normal

**angle of reflection (*r*)**: the angle between the reflected ray and the normal

## Laws of Reflection

- The angle of reflection ($r$) is equal to the angle of incidence ($i$).
- The reflected ray and the incident ray are on opposite sides of the normal.
- The incident ray, the normal, and the reflected ray lie on the same plane (flat surface).

## Visualizing the Laws of Reflection

You can use a game of pool to help you visualize the laws of reflection. If the player shoots a ball into a bumper head-on (perpendicular to it), the ball will bounce straight back in the opposite direction (**Figure 3.25A**). If the player shoots the ball so it strikes the bumper at an angle, the ball will also bounce off at this angle, but in the opposite direction (**Figure 3.25B**).

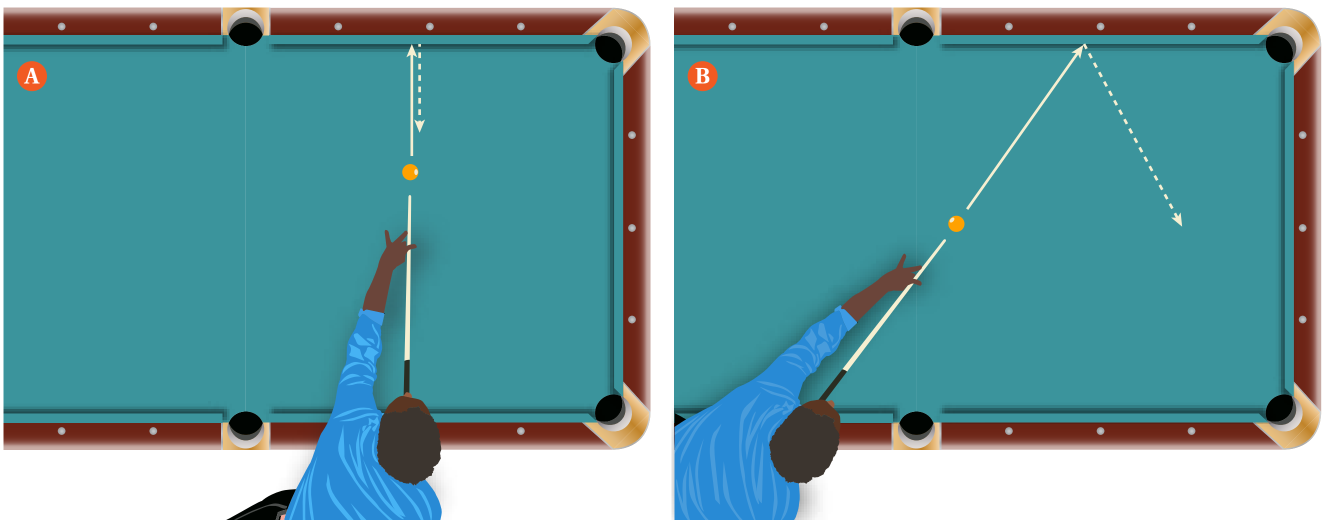



**Figure 3.25** Pool shots made head-on A and at an angle B can help you visualize the laws of reflection.

### Activity

#### Game On!

Sometimes the best way to remember something is to make a game of it.

Design a game to help you and your classmates remember the terms introduced in this Concept, as well as the laws of reflection. The form your game takes is up to you. Have others play your game to see how effective it is, and use their feedback to make improvements.

### Before you leave this page . . .

1. What do the angle of reflection and the angle of incidence have in common? Consider how they are measured and how they compare to one another.
2. Why does an expert billiards (pool) player need to understand the laws of reflection to make an accurate shot?

CONCEPT 2

# Light reflected by a plane mirror produces an image that is nearly identical to the object.

## Activity

### Reflection Obstacle Course

Safety: Do not shine a light directly in someone's eyes.

1. Reflect light from a flashlight off two flat mirrors to hit a target.
2. Reflect light from an infrared remote control off two mirrors to turn on a remote-controlled device.
3. Explain how this activity demonstrates the laws of reflection.

An extremely smooth, flat reflective surface like the one in Figure 3.26 is called a **plane mirror**. Figure 3.27 shows how an image forms in a plane mirror.

**plane mirror** an extremely smooth, flat reflective surface

- When light shines on an object, such as the tomato, it reflects off all points of the object in all directions.
- When some of these reflected rays reach the plane mirror, they follow the laws of reflection and reflect backwards.
- Some rays reach your eyes if you are looking at the mirror. They carry the same pattern of light to the eye that was reflected off the tomato. The brain assumes light travels in a straight line and thinks the image is behind the mirror.

**Figure 3.26** Reflection in a plane mirror.

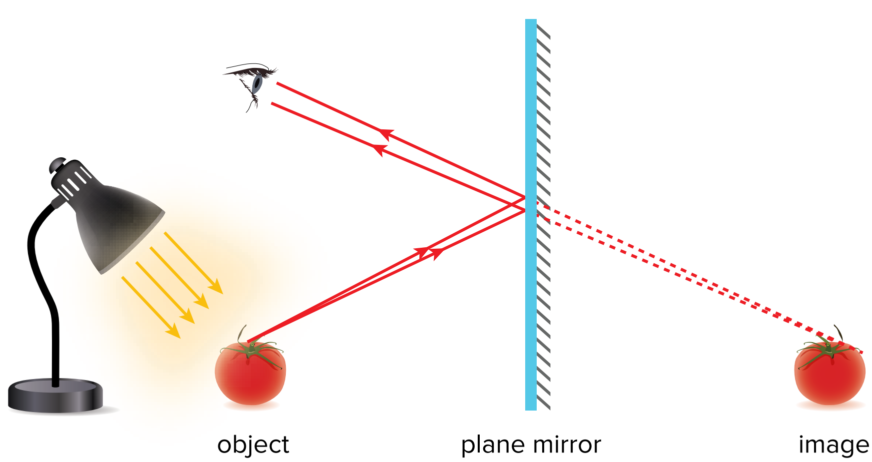



**Figure 3.27** Light rays follow the laws of reflection when they reflect from a plane mirror. To find out where the image appears to be, you can extend the reflected rays backwards until they meet. This is shown by the dotted line.

## Characteristics of Images

Now that you know how an image forms in a plane mirror, what characteristics does it have? To answer this question, it helps to know the different characteristics an image can have. These apply to any images, not just images in plane mirrors.

**Four Characteristics of Images**

**Location:** An image may be closer to or farther from the mirror than the object. The object may also be the same distance from the mirror as the object.

**Orientation:** An image may be upright or inverted (upside-down).

**Size:** An image may be the same size as, larger than, or smaller than the object.

**Type:** An image may be real or virtual.

A *virtual image* is not a real image. In Figure 3.27 no light rays are going to or coming from the image behind the mirror. Light rays only appear to be coming from the image. The reflected rays do not actually meet. Only the extended rays do. Your brain imagines that an image forms behind the mirror. There is no way that light could get there.

A *real image* is formed when reflected rays (not extended rays) meet. While virtual images form behind the mirror, real images are located in front of the mirror. If you place a screen at the position of a real image, the rays will meet at the screen and form an image. An image on a movie screen is a real image.

## Images in Plane Mirrors

Look at Figure 3.26 and 3.27 again. Notice that an image in a plane mirror

- is the same size as the object
- is the same distance from the mirror as the object
- is upright
- is a virtual image.

A plane mirror produces an image that is nearly identical to the object. But Figure 3.28 shows a difference. The image is reversed compared to the object. The direction of the reversal depends on the position of the object and the mirror. For example, when you see the image of mountains in a lake, the reversal is in the vertical direction. While the orientation of the mountains remains upright, reversals can make you think it does not. If the angle of the mirror is changed, the image looks upright again.


**Figure 3.28** This image in a plane mirror appears reversed. **Can you write your name on paper while looking only in a plane mirror? What do you observe about the writing on the paper?**

### Before you leave this page . . .

1. What is meant when the image is said to be behind the mirror? What do you call this type of image?

CONCEPT 3

# Light reflected by curved mirrors behaves in unique ways.

## Activity

### Exploring Curved Mirrors

1. Hold a plane mirror about 25 cm from your face and observe the image. Move the mirror toward your face, as well as away. Observe any changes.
2. Hold a concave mirror or the inside of a spoon about 25 cm from your face. Observe the image. Move the mirror or spoon toward your face until you no longer see an image. Then move it as far away as possible. Observe any changes in your image.
3. Look at your reflection in a convex mirror or on the back of the spoon. Hold the mirror or spoon close to your face and slowly move it away. Notice how your image changes.
4. Discuss your observations as a class.

The sculpture in **Figure 3.29** is called Sky Mirror. The mirror's reflective surface is made from polished stainless steel.

**Figure 3.29** Sky Mirror is a curved mirror created by artist Anish Kapoor. **What properties of the image in Sky Mirror are different from those seen in plane mirrors?**

Compare what you see in Sky Mirror's reflective surface to what you see in the reflective surface in Figure 3.30. This sculpture is called Cloud Gate. Its reflective surface is made of the same material as Sky Mirror. The images reflected in these two sculptures are very different, but there are also similarities. Sky Mirror and Cloud Gate are both *curved mirrors*. You just learned that a plane mirror produces an image that is nearly identical to the object. With curved mirrors, this is not the case.

**Connect** to Investigation 3-H on page 244

**Figure 3.30** Cloud Gate is another curved mirror created by Anish Kapoor. **How is the image in Cloud Gate similar to the one in Sky Mirror? How is it different?**

## Concave and Convex: Two Types of Curved Mirrors

The portion of Sky Mirror shown in Figure 3.29 is a **concave mirror**. A concave mirror is curved inward like the inner bowl of a spoon. You can remember a concave mirror as a mirror that "caves in" at the centre. The portion of Cloud Gate shown in Figure 3.30 is a convex mirror. A **convex mirror** is curved outward like the back of a spoon.

**concave mirror** a mirror with a reflecting surface that curves inward

**convex mirror** a mirror with a reflecting surface that curves outward

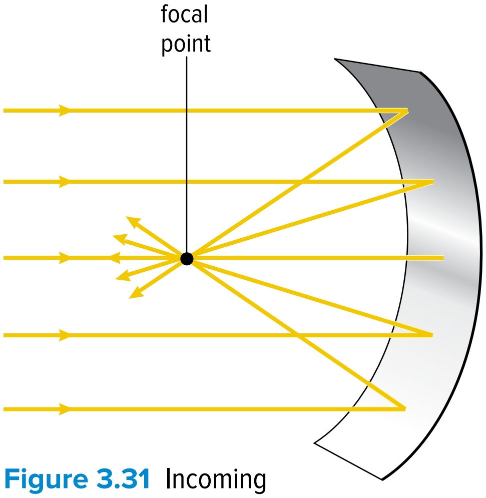



**Figure 3.31** Incoming parallel light rays converge when they reflect off a concave mirror.

## Images in Curved Mirrors

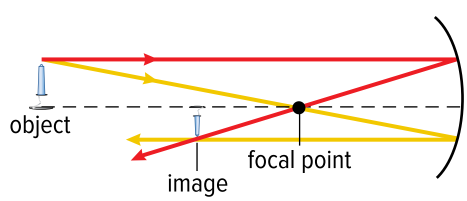
Light rays behave in unique ways when they are reflected off a curved mirror. As you saw in Sky Mirror and Cloud Gate, images in curved mirrors are never identical to the objects they are reflecting.

### Images in Concave Mirrors

As shown in **Figure 3.31**, when incoming parallel light rays reflect off a concave mirror, they come together at a single point. This point is called a *focal point*. When the light rays meet at the focal point, they are said to converge. Converge means "to bring together."

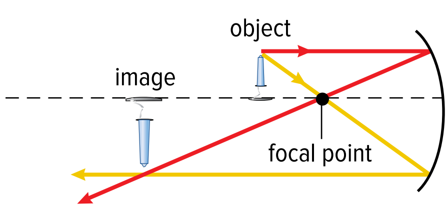
The characteristics of the image formed by a concave mirror depend on where it is located compared to the surface of the mirror and the focal point. This idea is explained in more detail in **Figure 3.32**. Images in a concave mirror, such as the buildings and trees in Sky Mirror, are misshapen, especially toward the edges of the mirror.

A



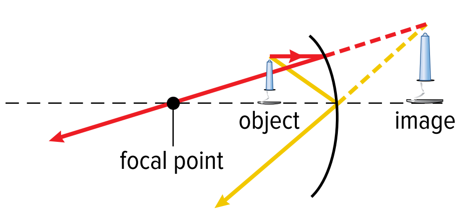

A distant object is located far from the focal point. It is reflected to produce a smaller, inverted (upside-down) image. The rays meet, so the image is real. The image is closer to the mirror than the object.the mirror than the object.

B




The object moves closer to the focal point, but not between the focal point and the concave mirror. It is reflected to produce a larger, inverted image. The rays meet, so the image is real. The image is farther from the mirror than the object.

C




The object moves between the focal point and the concave mirror. The image becomes even larger and is now upright. The reflected rays do not meet, so you have to extend them in the opposite direction. Therefore, the image is virtual. The image is farther from the mirror than the object.

**Figure 3.32** Images in a concave mirror.

## Images in Convex Mirrors

When parallel light rays are reflected off the surface of a convex mirror, they spread apart after they bounce off the mirror's reflective surface. They are said to *diverge*. Diverge means "to spread out in different directions." If the diverging rays are extended back behind the mirror, it looks like they arise from a focal point behind the mirror. **Figure 3.33** shows how only the extended rays meet at a focal point. The actual rays do not meet. This means that an image produced by a convex mirror is always a virtual image, just like an image in a plane mirror.

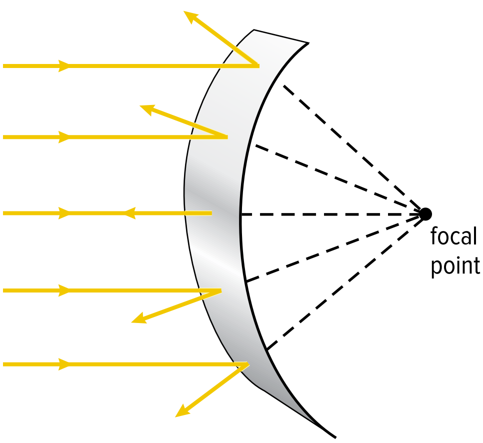



**Figure 3.33** Incoming parallel light rays diverge when they reflect off a convex mirror.

The characteristics of an image formed by a convex mirror do not depend on where the object is located. All reflections in convex mirrors have the same characteristics:

1. The image is smaller than the object.
2. The image is closer to the mirror than the object.
3. The image is a virtual image.
4. The image is upright.

More objects can be seen in a convex mirror than in a plane mirror of the same size. This is because convex mirrors reflect light from a large incoming area. Images in convex mirrors are also distorted, especially at the edges. Only the image in the small centre region is not misshapen.

### Before you leave this page . . .

1. Use a T-chart to compare a convex mirror with a concave mirror.
2. Convex mirrors are often used as security mirrors in convenience stores. Explain why.

CONCEPT 4

# Many technologies take advantage of light's behaviour when it strikes a reflective surface.

## Activity

### Up, Periscope!

What is a periscope and how is it used? What do you need to build your own working model of a periscope? With a partner, decide on a plan for building a periscope using easily available materials. If possible, build and test it, and reflect on how you could improve its design.

Mirrors and other reflective surfaces have a lot of uses. Some are used to reflect images, but often their ability to reflect visible light and other types of electromagnetic radiation is where they really shine!

## Curved Reflective Surfaces

Concave mirrors are often used to concentrate light. When a light source is located exactly at the focal point, the rays that strike the mirror are reflected parallel to each other. This produces a very intense beam of light that is used in car headlights and flashlights.

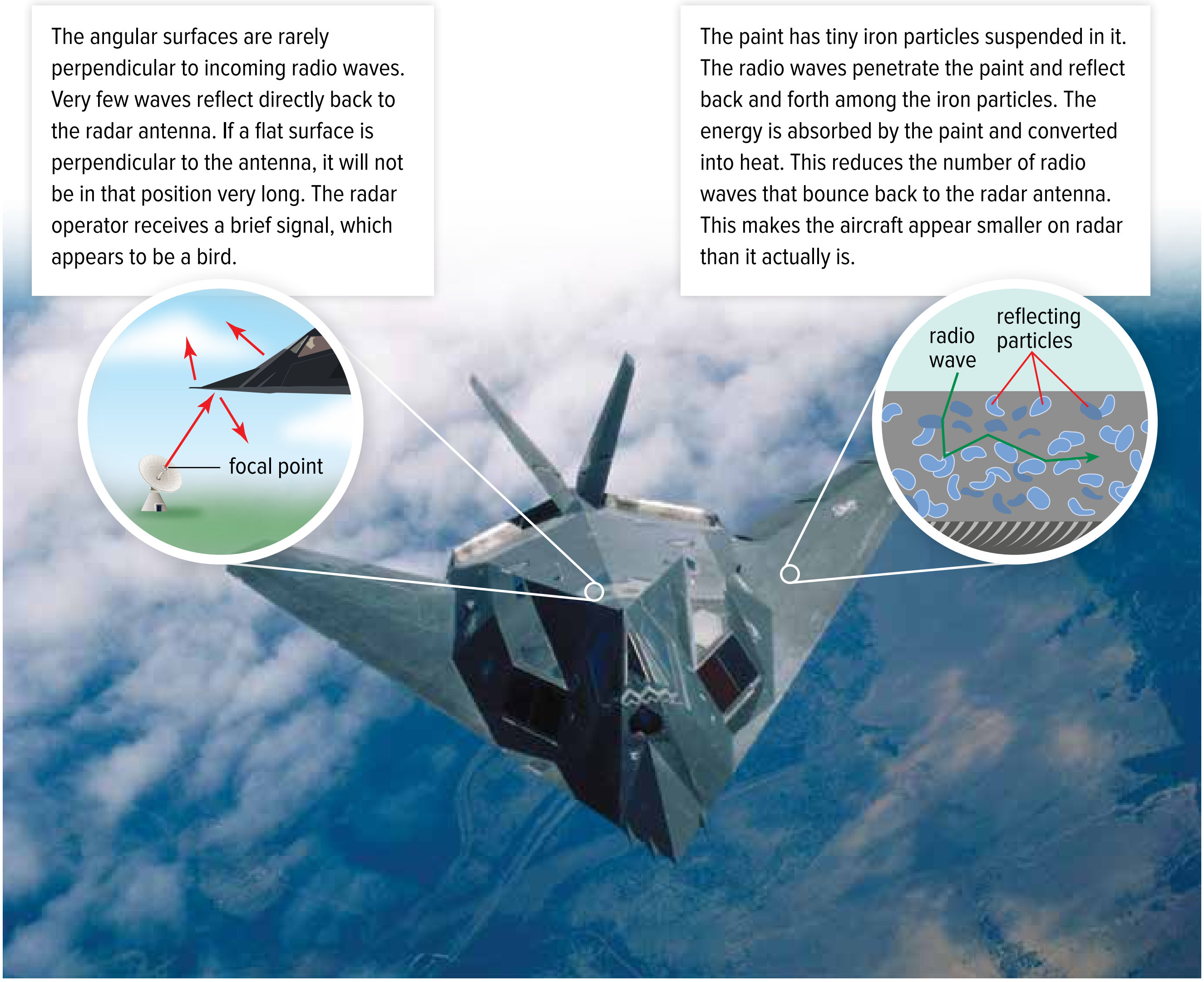
Curved reflective surfaces also play an important role in radar technology. *Radar* stands for **ra**dio **d**etection **a**nd **r**anging. One of its main uses is to detect aircraft. The radar antenna in **Figure 3.34** uses a concave reflective surface to do this. A radio wave generator and detector are located at the focal point of the antenna. First, a pulse of radio waves is generated and sent out toward the sky. The rounded surfaces on a typical airplane are convex reflective surfaces. At least some part of the surface is perpendicular to incoming radar waves and will reflect the waves directly back to the antenna. The antenna's concave surface directs the reflected rays to the detector at the focal point to locate the airplane.


**Figure 3.34** Concave and convex reflective surfaces both play a role in aircraft detection by radar.

## Plane Reflecting Surfaces

Military aircraft such as the stealth fighter need to avoid radar detection. Two features make the aircraft almost invisible to radar. These are explained in **Figure 3.35**.

**Figure 3.35** Plane reflecting surfaces help this Lockheed F-117 Nighthawk avoid radar detection.




### Before you leave this page . . .

1. Explain how car headlights create an intense beam of light.
2. Radio telescopes can detect radio waves from outer space. What shape would a radio telescope most likely be and why?

AT ISSUE

# How Can Mirror Technology Help Us See in New Ways?

## What's the Issue?

Mirrors can help us see beyond the vision of the unaided eye. Omnidirectional cameras use curved mirrors to record images and video in all directions at once. The doughnut-shaped image at the bottom of this page was captured using an omnidirectional camera on a ship in Alaskan waters. A spherical panorama of the image is also shown.

One high-profile use for omnidirectional cameras is on the Mars Exploration Rovers. These robotic geologists on wheels were launched in 2004 as part of NASA's mission to find clues of past water activity in the rocks and soil on Mars. Only one rover is still operational. Its omnidirectional camera allows its controllers back on Earth to see in all directions as they drive the rover remotely. It also gives scientists a great deal of information about the surface of Mars.

### Dig Deeper

Collaborate with your classmates to explore one or more of these questions—or generate your own questions to explore.

1. Find out more about another technology that uses reflection. Choose one of the following technologies, or find another that interests you.
   - holograms
   - glitter cloud telescope
   - rear view motorcycle helmet
   - reflecting telescope

   Research the technology to understand how it works and how it is used. Use this information to create an advertisement for the technology. Your advertisement should explain how the technology uses reflection. The format is up to you.

2. Omnidirectional cameras aren't just useful on Mars. Suggest one way an omnidirectional camera could be used on Earth. Why would an omnidirectional camera be beneficial for this application?

# Check Your Understanding of Topic 3.4

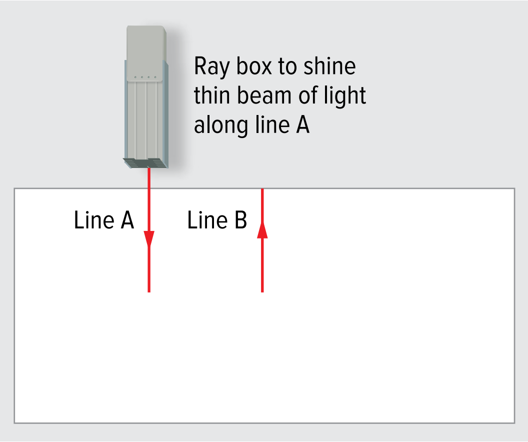
QP Questioning and Predicting   PC Planning and Conducting   PA Processing and Analyzing   E Evaluating
AI Applying and Innovating   C Communicating

## Understanding Key Ideas

1. Make a simple, accurate drawing in which you show and label the following: PA C
   - an incident ray
   - a reflected ray
   - the normal
   - the angle of incidence
   - the angle of reflection

2. Makeup mirrors usually have two sides. On one side, the mirror is flat, and on the other side the mirror is slightly curved inward. PA AI
   a) What are the correct terms to describe the two types of mirrors?
   b) How do the images that you see in the two mirrors differ from each other?
   c) Explain why the curved mirror is helpful for applying makeup.

3. Examine the diagram below, which shows a sheet of white paper with straight lines drawn on different parts of it. QP PC PA AI




Predict how you could use mirrors to make a light ray that travels along Line A reflect back along Line B. How can you test your prediction?

4. You are looking in an amusement park mirror. Your image appears smaller than you and closer to the mirror than you are. Your image is upright and looks like it is behind the mirror. PA
   a) What type of mirror are you looking at?
   b) Explain how you decided on your answer.

5. Describe all the ways that an image in a mirror can differ from the original object. PA C

## Connecting Ideas

6. In large warehouses where forklifts are used to transport large crates, you often see convex mirrors like the one below hanging from the ceiling. E AI

   a) What do you think is the purpose of these mirrors?
   b) Why are convex mirrors used instead of plane mirrors?

## Making New Connections

7. Design an efficient "hotdog oven" that uses energy from the Sun and a mirror made with aluminum foil on a sturdy cardboard backing to cook the hotdog. Make a sketch of your hotdog oven with dimensions included. Write a paragraph to describe how it works. Hint: Think focal line instead of focal point. QP PC AI C

INVESTIGATION
# 3-H

STRUCTURED INQUIRY AND GUIDED INQUIRY

**Skills and Strategies**

- Questioning and Predicting
- Processing and Analyzing
- Evaluating
- Communicating
- Applying and Innovating

**Safety**

- The edges of the mirrors may be sharp. Be careful not to cut yourself.
- Be careful not to drop the mirrors.

**What You Need**

- blank sheet of paper (letter size)
- pencil
- ruler
- small, standing object (such as an action figure)
- hinged plane mirror
- protractor
- a variety of mirrors and materials for Part B

## Exploring Mirror Images

### Question

How can you create cool effects and investigate characteristics of images using mirrors?

### Procedure: Part A—Structured

1. Stand a hinged mirror upright so that both mirrors face you at an angle. Place a small, object between the mirrors.

2. Make the angle between the mirrors smaller and larger. Record any changes you observe in the images that form.
3. Copy the table below.

| Angle Measurement | Number of Images |
|---|---|
| 180° | |
| 120° | |
| 90° | |
| 72° | |
| 60° | |
| 45° | |
| 30° | |

4. On a piece of paper, use a ruler and protractor to draw the first angle on the table. Place the hinged mirror on the paper. Adjust the sides so that they sit on the angle. Record the number of images you see.

5. Repeat step 4 for every angle in the table.
6. Graph the data in your table. Give your graph a title, and label the $x$-axis and the $y$-axis appropriately.

## Procedure: Part B—Guided Inquiry

7. Choose one (or more) of the questions below to investigate, or come up with a question of your own.
   a) How can you use two mirrors to create an infinite (endless) number of images?
   b) How can you use one mirror, a pencil, and paper to form an image of a word that is not reversed left to right?
   c) How can you use a mirror and a projector to project a word on a screen, if the projector and the screen are both facing away from you?
   d) How can you use a mirror and a light source to create an intense beam of light?
   e) How can you use three mirrors to make a kaleidoscope?
   f) How can you use a mirror to make it look (to a viewer) like both your feet are off the ground?
8. With a partner or group, plan how you could answer the question you chose in step 7.
9. Carry out your plan. Assess how well your plan is working as you carry it out. Adjust your plan if necessary.

## Process and Analyze

1. Use your graph from Part A to answer the questions that follow.
   a) Write a statement that describes how the number of images changes as the angle between the mirrors changes.
   b) Predict the angle between the mirrors if six images were visible. Explain how you made your prediction.
   c) Predict the number of images you would see if the angle between the mirrors was 20°. Explain how you made your prediction.
2. For Part A, why do you think the number of images changes as the angle between the mirrors changes?

## Evaluate

3. For Part B, how well did your plan help you answer the question you chose to investigate?
4. For Part B, did adjusting your plan help you answer the question? If so, explain how.

## Apply, Innovate, and Communicate

5. Magic shows have been described as being “all smoke and mirrors.” Do research to find out how mirrors are used in magic shows. Choose one mirror trick and share it with your class, either by describing the trick or performing it for your classmates.