Topic 4.4

What is the law of reflection and how do mirrors form images?

Key Concepts

- The angle of reflection is equal to the angle of incidence.
- Plane mirrors form images that are nearly identical to the object.
- Concave mirrors can form images that are larger than the object.
- Concave mirrors can form images that are smaller than the object.
- Convex mirrors always form images that are smaller than the object.

Key Skills

Inquiry

Key Terms

incident ray
reflected ray
normal
angle of incidence
angle of reflection
object
image
plane mirror
concave mirror
principal axis
focal point
centre of curvature
convex mirror

Fall in Ontario is a feast of colour. The sky is a vivid blue, and the trees are ablaze in reds and yellows. The northern lakes reflect the scenery, adding to the beauty. The reflection in the still water is just like reflection in a mirror. But if you toss a pebble in the water, the waves destroy the image. Why does still water reflect a perfect image but wavy water doesn't?

You know that white paper is reflecting all of the light that hits it, but all you see is white. How does reflection with a white piece of paper differ from reflection with a mirror or in still water? This topic explores answers to these questions.

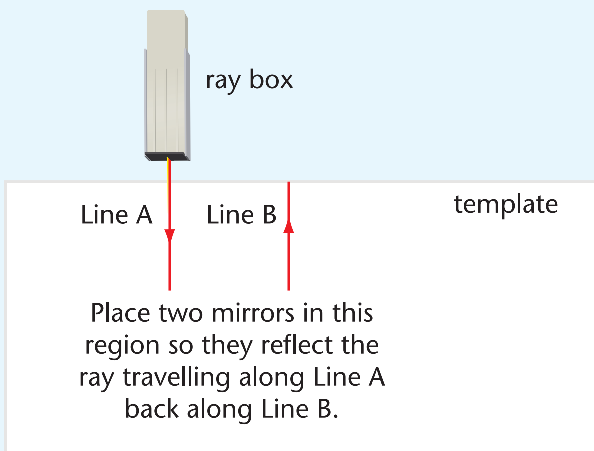
Starting Point Activity

What You Need

Reflection Obstacle Course Templates

ray box with slit

2 mirrors with stands (or modelling clay to support the mirrors in an upright position)



What To Do

1. Your teacher will give you a Reflection Obstacle Course Template—a sheet of white paper with straight lines drawn on different parts of it. You will also need two mirrors with stands and a ray box with one slit.
2. Place the ray box so the slit lines up with Line A on the sheet of paper.
3. Your challenge is to use the mirrors to make the light ray travel along Line A and then back along Line B. When you have successfully completed the challenge, make a sketch to show where you placed the mirrors.
4. Get another Reflection Obstacle Course Template for a new challenge. Better yet, design your own to try out with your classmates. See who can design the "Ultimate Obstacle Course Challenge."

The angle of reflection is equal to the angle of incidence.

Key terms that apply to light rays and reflection are shown in Figure 4.18. Each small diagram adds a new feature. The label is the key term that describes that feature. The large diagram brings them all together. Make sure you understand these terms. Then study the law of reflection in the box below.

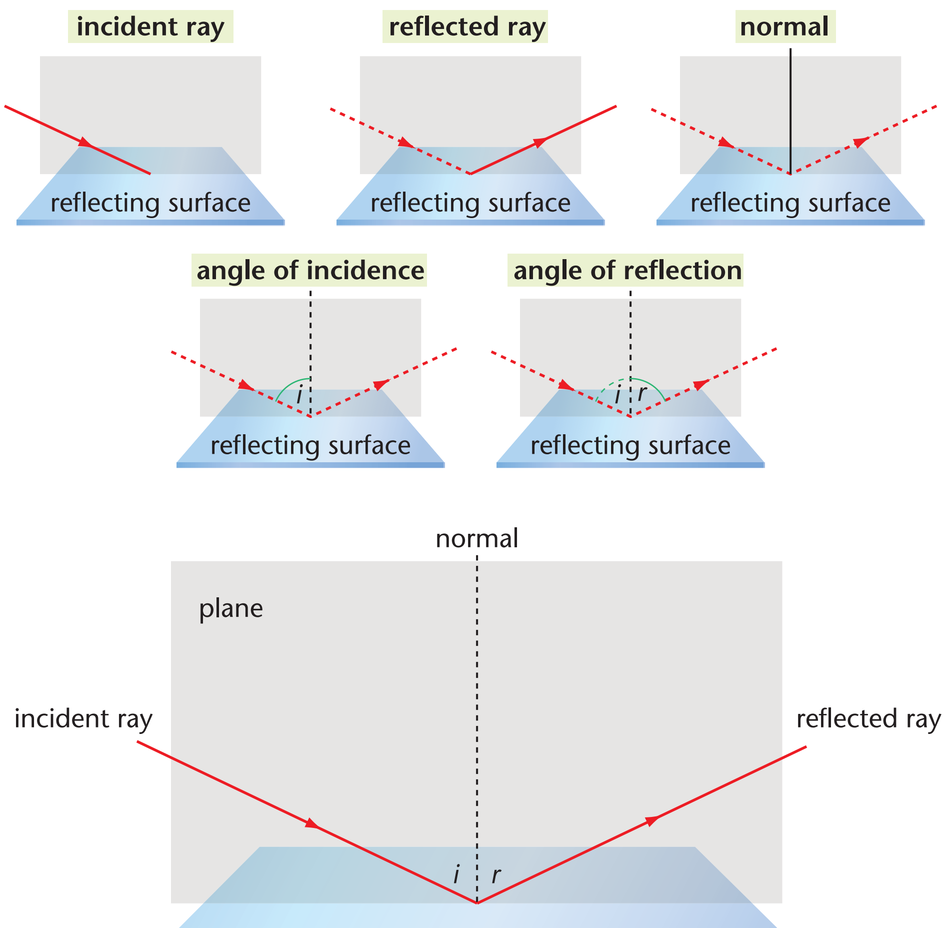
incident ray: the light ray travelling toward the mirror or other surface

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

normal: 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



▶ Figure 4.18 All light rays obey the law of reflection as shown here. The word "plane" refers to any flat surface.

Law 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).

INVESTIGATION LINK

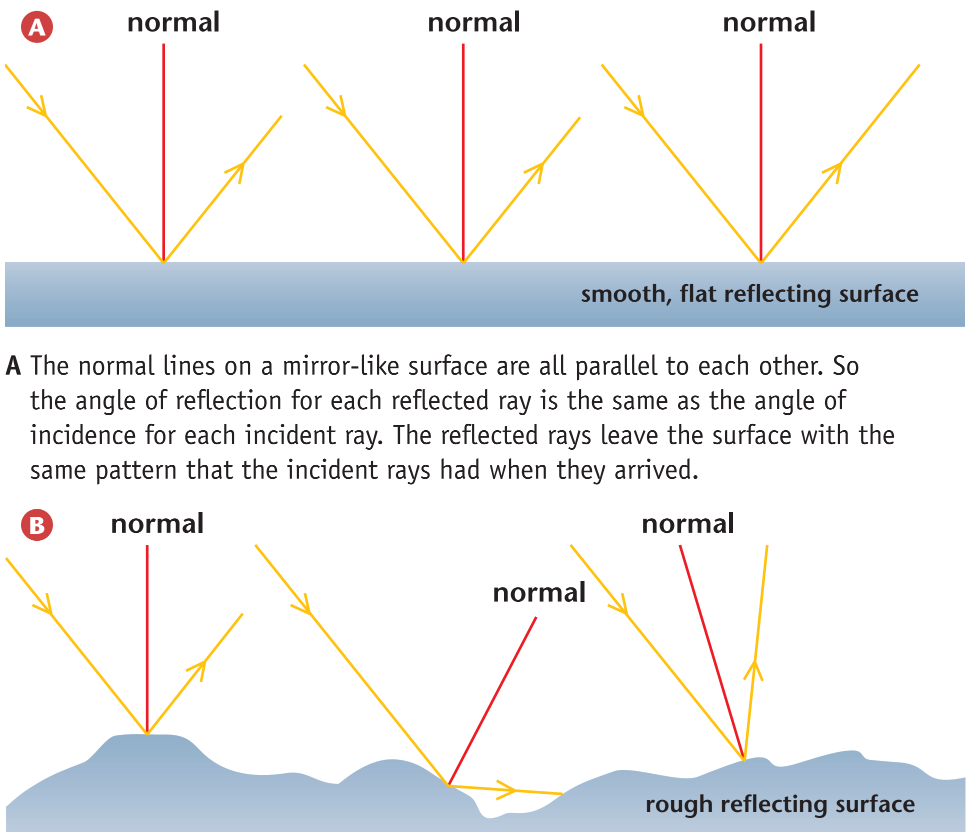
Activity 4.11, on page 322

How Smooth Reflecting Surfaces Differ from Rough Reflecting Surfaces

The law of reflection applies to every reflecting surface. So why can you see yourself in a mirror but not in a sheet of white paper? The answer lies in the smoothness of the surface. Paper might look smooth to the naked eye, but **Figure 4.19** shows that paper is quite rough when you observe it under a microscope. **Figure 4.20** shows how the law of reflection applies to a rough surface and a smooth surface.

▲ **Figure 4.19** When you look at paper under a microscope, you see that the surface is actually very rough.

▼ **Figure 4.20** Comparing how parallel light rays reflect from a smooth flat surface and from a rough surface



A The normal lines on a mirror-like surface are all parallel to each other. So the angle of reflection for each reflected ray is the same as the angle of incidence for each incident ray. The reflected rays leave the surface with the same pattern that the incident rays had when they arrived.

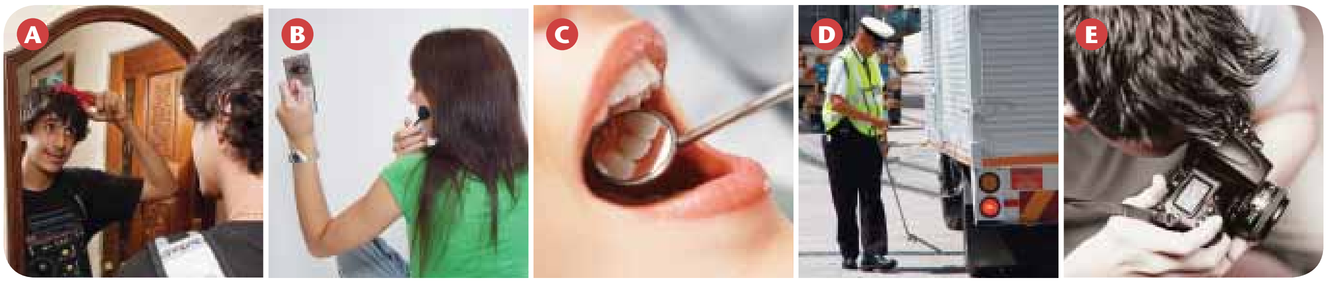
B The normal lines on a rough surface point in different directions. Although the incident rays are parallel to each other, the angles of incidence are all different. Therefore, the angles of reflection are different from each other. As a result, the reflected rays leave the surface with a totally different pattern than the incident rays had.

LEARNING CHECK

1. The angle of reflection is the angle between what two lines?
2. Explain the meaning of each of the three parts of the law of reflection.

Plane mirrors form images that are nearly identical to the object.

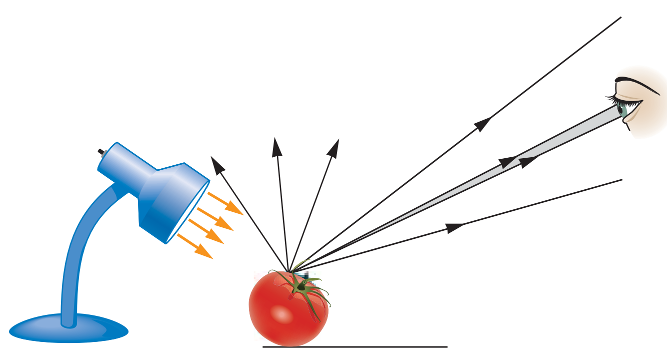
Any smooth, flat reflecting surface, such as a mirror, is called a *plane mirror*. (The word *plane* means "flat surface.") **Figure 4.21** shows some examples of plane mirrors and their uses.



▲ **Figure 4.21** Mirrors such as those in (A) and (B) are mostly for personal grooming. Dentists use flat mirrors like the one in (C). A mirror like the one in (D) is just a large-scale version of a dentist's mirror. The viewfinder in an SLR (single lens reflex) camera (E) includes a flat mirror system.

Seeing Objects

To understand how you "see" a reflection in a mirror, you need to first know how you see the object directly. **Figure 4.22** shows a lamp shining on a tomato. The surface of a tomato is not mirror-smooth so light rays reflect in all directions from any small spot. If you are looking at the tomato, a few of those light rays reach your eye. The lens of your eye focuses the rays and your eyes send messages to your brain about the tomato. The figure shows only the rays hitting one small spot on the tomato, but the same thing is happening all over the tomato. So your eyes see the whole tomato, because reflected light from every part of the tomato is reaching your eyes.



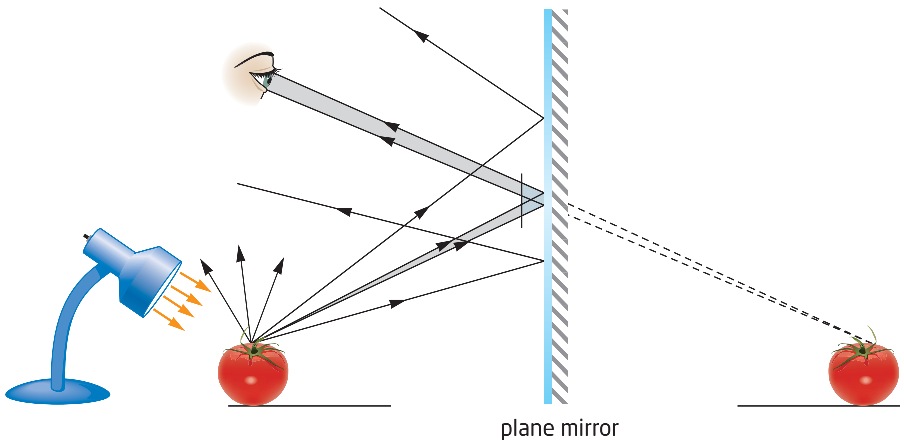
▲ **Figure 4.22** Every part of the tomato is reflecting light in all directions. Here you see some reflections from one spot. Only a small part of the light reflecting off the tomato reaches your eyes. But that is plenty of light for you to see it.

Images in Plane Mirrors

Figure 4.23 shows what happens to the light rays when you put a mirror in front of the tomato from Figure 4.22. All the rays from the tomato that strike the mirror reflect from it according to the law of reflection. The rays that reach your eye appear as if they are coming from a point behind the mirror. Your brain "knows" that light travels in straight lines. So your brain interprets the pattern of light that reaches your eye as an image of the tomato behind the mirror.

ACTIVITY LINK

Activity 4.12, on page 323

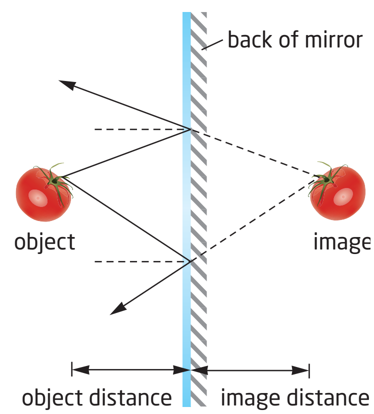


◄ Figure 4.23 When light rays reflect from a mirror, they follow the law of reflection. To find out where the reflection appears to be, extend the reflected rays backwards until they meet.

Ray Diagrams for Plane Mirrors

You need just two rays reflecting from a mirror to find the point where the reflection of an object is located. The point where the two reflected rays meet is the location of the image—the reflection of the object. You need to know the terms **object**, **image**, and the three other terms below to draw ray diagrams for plane mirrors. Refer also to Figure 4.24.

- Object: the item in front of the mirror
- Image: the reflection of the object in the mirror
- Object distance: the distance from the mirror to the object
- Image distance: the distance from the mirror to the image
- Virtual image: an image that is located where no light rays ever meet (This occurs when reflected rays are separating and must be extended backwards to find out where they meet.)



▲ Figure 4.24 You will be using the terms shown here to draw ray diagrams. Diagonal lines, called hatch marks, indicate the back of the mirror.

LEARNING CHECK

1. When drawing light rays, how do you determine where the image is located?
2. In Figure 4.24, which tomato is the object and which is the image? What parts of the diagram help you know?

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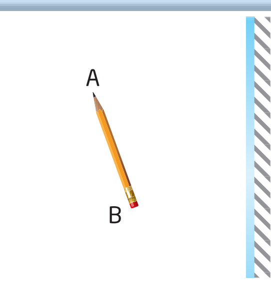
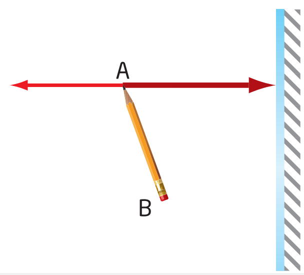
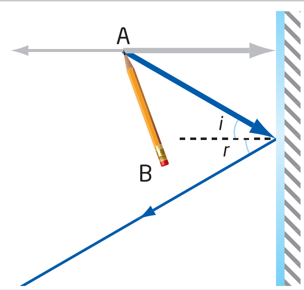
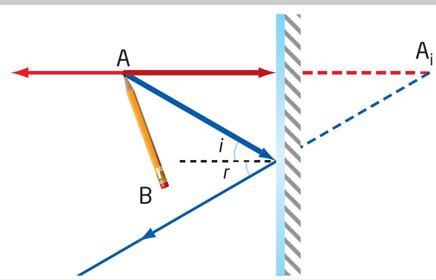
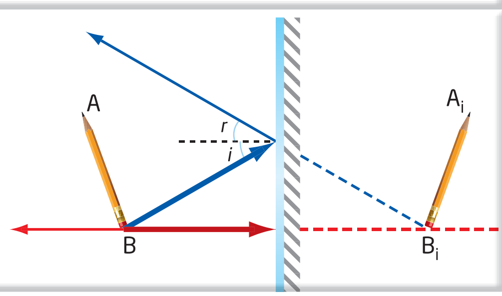
Drawing Ray Diagrams for Plane Mirrors

To find the image of an object in a plane mirror, you need to find the image location of at least two points on the object. **Table 4.2** gives directions and an example for drawing these diagrams. Study the steps in the table and then practice drawing your own diagrams in Activity 4.10.

Table 4.2 Locating an Image in a Plane Mirror Using a Ray Diagram

Directions	Example
Step 1 • Draw a line to represent a plane mirror. • Draw a simple object. • Label a point at one end of the object "A", and label a point at the other end "B."	
Step 2 • Draw an incident ray from point A directly to the mirror at a 90° angle. • Draw the reflected ray backward along the same line as the incident ray.	
Step 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. (That's the dashed line shown here.) • Measure the angle of incidence with a protractor. • Using the law of reflection (angle of incidence = law of reflection), draw the reflected ray.	
Step 4 • Using dashed lines, extend both reflected rays behind the mirror until they meet. • Label the point where they meet "A_i" to indicate that it is the image of point A.	
Step 5 • Repeat steps 2 to 4 for point B. • Draw the image between points A_i and B_i.	

Inquiry Focus

Activity 4.8

DRAWING RAY DIAGRAMS FOR PLANE MIRRORS

In this activity, you will be making your own ray diagram. Measure the angles accurately so you can compare sizes of the object and image and their distances from the mirror.

What You Need

- paper
- pencil
- ruler
- protractor

What To Do

1. Copy the following diagram on a piece of paper. Put the mirror in the centre of the paper and leave plenty of space for drawing rays.

2. Follow each step in Table 4.2 to complete a ray diagram of the tree.
3. In your final diagram, measure and record the height of the tree and the height of the image of the tree.
4. Pick one point on the object. Measure and record the object distance and the image distance for that point.

What Did You Find Out?

1. How did the sizes of the tree and its image compare?
2. How did the image and object distances compare?
3. What would you predict about all images in plane mirrors relative to the objects?

All images in plane mirrors have many of the same characteristics. A few are listed below.

- The size of the image is the same as the size of the object.
- The image distance is equal to the object distance.
- The image is always oriented in the same direction as the object is.
- Images in plane mirrors are always virtual images, located behind the mirror.

LEARNING CHECK

1. When you draw an incident ray directly toward a mirror, why is it easy to draw the reflected ray?
2. Why must you find images of two points on an object in order to locate an image in a plane mirror?

Concave mirrors can form real, inverted images.

concave mirror: a mirror whose reflective surface is on the "caved-in" part of it

principal axis: a straight line that passes through the centre of curvature, *C*.

vertex: The point where the principal axis meets the mirror.

focal point: the point where reflected rays meet when incident rays are parallel to and near to the principal axis

centre of curvature: the centre of the sphere that the mirror fits on

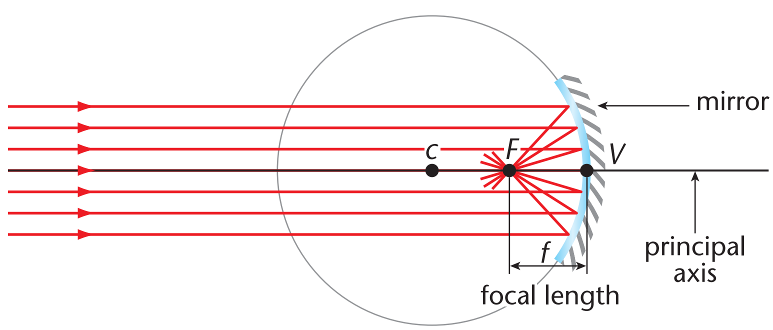
radius of curvature: the distance between *C* and *V*, or the radius of the sphere that the mirror fits on

focal length: the distance from the mirror to the focal point

A **concave mirror** is a mirror that "caves in" at its centre. If you cut a small section out of a ball, as in Figure 4.25, and if you coat the inside with a reflecting surface, you have a concave mirror. Use Figure 4.26 and the points below to learn about concave mirrors.

- A line drawn from the centre of the circle through the centre of the mirror is called the **principal axis**.
- The point where the principal axis meets the mirror is the **vertex** (*V*).
- All light rays (red arrows) that are parallel and close to the principal axis reflect from the mirror and meet at the **focal point**, labelled *F*.
- The centre of the sphere that the mirror fits on is the **centre of curvature** (*C*). The focal point is exactly halfway between the centre of curvature (*C*) and the mirror.
- The distance from *C* to the mirror is called the **radius of curvature**.
- The distance from *F* to the mirror is the **focal length**, labelled *f*.

▲ **Figure 4.25** If you coat the inside of a section cut out of a ball with a reflective surface, you will have a spherical, concave mirror.



▲ **Figure 4.26** The red arrows represent light rays travelling parallel to the principal axis. If they are all close to the principal axis, the reflected rays will meet at the focal point. The focal point is half as far from the mirror as *C*.

ACTIVITY LINK

Activity 4.13, on page 324

Characteristics of Images in Curved Mirrors

Images in curved mirrors have four key characteristics. These characteristics are location, orientation, size, and type. They are described below.

Location: You describe the location of the image by stating whether the image distance is shorter or longer than the object distance. You must also report whether the image is behind the mirror or in front of the mirror.

Orientation: If the image is oriented in the same direction as the object, or right side up, you would say that it is *upright*. In the image is oriented opposite to the object, or upside down, you would say that it is *inverted*.

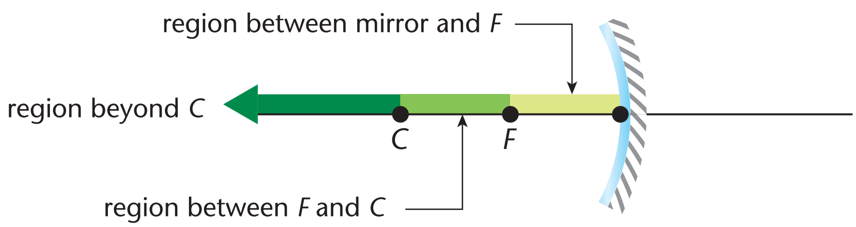
Size: You describe the size of the image by stating whether it is larger or smaller than the object. Scientists sometimes call this the *magnification* of the image.

Type: The "type" of an image refers to whether the image is real or virtual. You learned, with plane mirrors, that when the reflected rays do not meet and you have to extend them backwards, the image is virtual. Thus, if reflected rays do meet, the image is *real*. Another way to determine whether the image is real or virtual is to place a screen (such as a piece of white paper) at the location of the image. If you see an image on the screen, it is a real image.

Ray Diagrams for Concave Mirrors

The characteristics of concave mirrors make it easy to draw two rays from any point on an object. The first ray is drawn parallel to the principal axis. It will reflect back through the focal point. The second ray is drawn from a point on the object through the focal point toward the mirror. It will reflect back parallel to the principal axis.

Figure 4.27 shows three regions where an object can be located.Images of objects in different regions are quite different. When you turn the page, you will find directions for drawing a ray diagram for an object between *F* and *C*.



◀ **Figure 4.27** Three regions where an object can be located in relation to a concave mirror.

LEARNING CHECK

1. How would you draw a principal axis for a concave mirror?
2. Where is the focal point located relative to the centre of curvature of the mirror?
3. Make a sketch of a stick-figure person to show the difference between an image that is upright and an image that is inverted.

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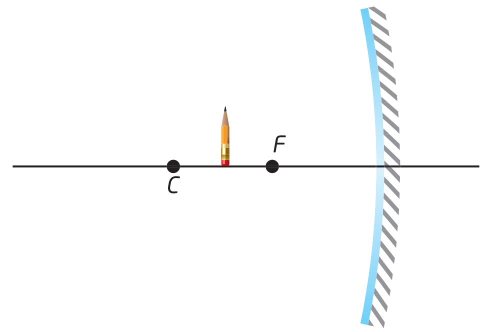
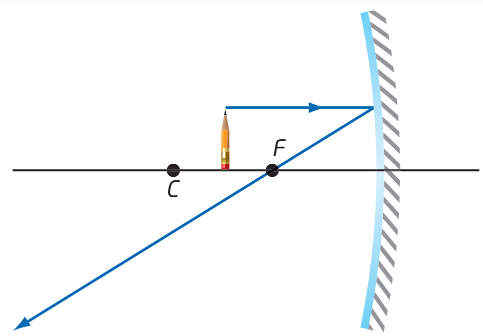
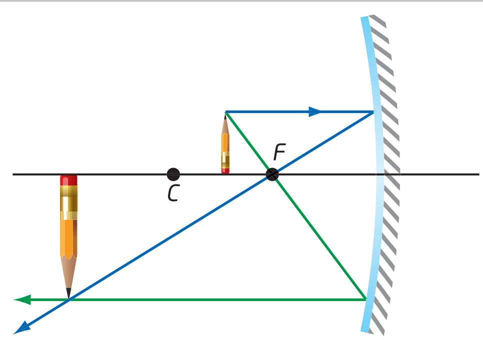
Ray Diagrams for Objects beyond *F* for Concave Mirrors

Figure 4.27 on page 313 showed two regions that are farther from a concave mirror than the focal point. **Table 4.3** below shows how to draw ray diagrams for an object in the region between F and C. Then you will draw your own ray diagram for an object in the region beyond C.

Table 4.3 Ray Diagram for an Object between F and C of a Concave Mirror

Directions	Example
Step 1 • Draw the principal axis and a very slight curve to represent the concave mirror. • Mark *F* and *C* so that *C* is twice as far from the mirror as *F*. • Draw the object between *F* and *C* with the bottom on the principal axis.	
Step 2 • Draw a ray (shown in blue) from the top of the object toward the mirror and parallel to the principal axis. • Draw the reflected ray back through *F*.	
Step 3 • Draw a ray (shown in green) from the top of the object through *F* and continuing to the mirror. • The reflected ray will travel backward, parallel to the principal axis. • Draw the image so the top is at the point where the rays meet and the bottom is on the principal axis. (Since the reflected rays meet, you don't have to extend them backwards. So the image is real.)	

ACTIVITY LINK

Activity 4.14, on page 325

The characteristics of the image of an object placed between *F* and *C* of a concave mirror are as follows.

- The image is farther from the mirror than the object is.
- The image is inverted.
- The image is larger than the object.
- The image is real.

Inquiry Focus

Activity 4.9

DRAWING RAY DIAGRAMS FOR THE REGION BEYOND C

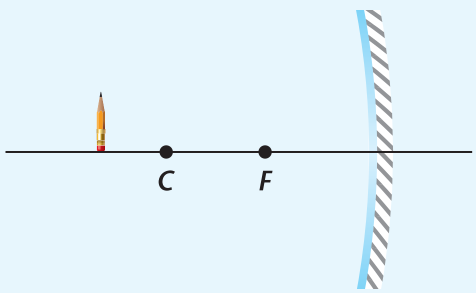
In this activity, you will be drawing a ray diagram for an object in the region beyond *C* of a concave mirror. You will analyze the image and compare it to the image of an object between *F* and *C*.

What You Need

- paper
- pencil
- ruler

What To Do

1. Copy the following diagram on a piece of paper. Put the mirror on the right hand side of the paper and leave plenty of space for drawing rays.



2. Draw the rays according to the directions in **Table 4.3**. The rays will be similar but not identical to those in the table. Draw carefully so you will be able to accurately analyze your image.
3. When you have completed drawing your diagram, make the following measurements.
   a) the image height
   b) the object height
   c) the image distance
   d) the object distance
4. Was the image in front of the mirror or behind the mirror?
5. Was the image real or virtual. Explain how you know what type it is.
6. Summarize your results by stating the following characteristics of the image relative to the object.
   a) location
   b) orientation
   c) size
   d) type

What Did You Find Out?

1. How does the image of an object beyond *C* compare to the image of an object between *F* and *C*? Compare each of the characteristics listed in question 6.

LEARNING CHECK

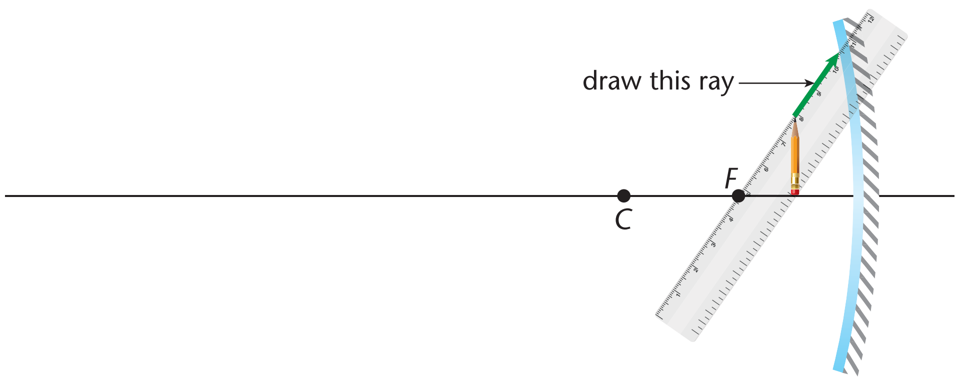
1. Make a Venn diagram to compare the images of objects between *F* and *C* of a concave mirror with the images of objects beyond *C*.
2. Where would you place an object in front of a concave mirror if you wanted an image that is real and larger than the object?
3. How do you draw the reflected ray of an incident ray that is going toward the mirror parallel to the principal axis?
4. Based on your comparisons of images formed from objects in the regions that you have explored, what do you think would be the characteristics of an object that is placed directly at *C*?

Concave mirrors can form upright, virtual images.

▲ **Figure 4.28** Concave mirrors can form inverted images as well as upright images.

Both of the photos in **Figure 4.28** show images in concave mirrors. You have drawn ray diagrams for concave mirrors which have generated inverted images. However, most makeup mirrors and shaving mirrors are concave. They produce upright, magnified images.

Table 4.4 shows how a concave mirror can form a magnified, upright image. Notice that the object is in the region between the mirror and *F*. The first ray is drawn in the same way that you drew it for objects beyond *F*. However, the second ray must be drawn in a slightly different way. When the object is closer to the mirror than *F*, the ray cannot go through *F*. As shown in **Figure 4.29**, place your ruler on the paper so it touches *F* and the top of the object. Then draw the ray from the top of the object to the mirror. The reflected ray will go back parallel to the principal axis.

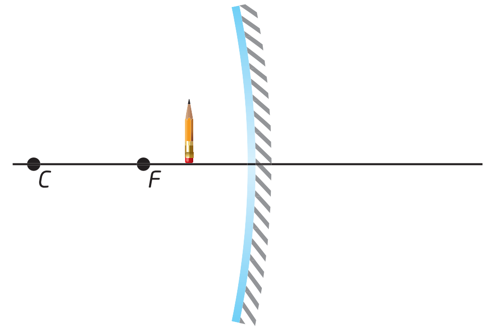
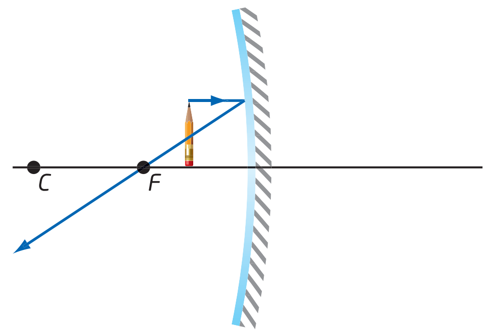
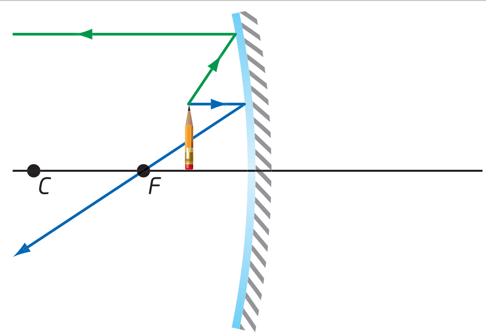
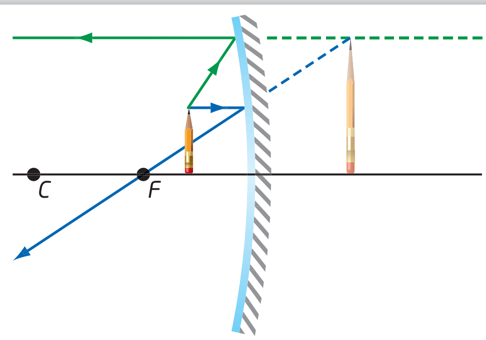


▲ **Figure 4.29** The green ray usually passes from the object, through *F*, and to the mirror. However, when the object is closer to the mirror than *F*, draw the ray *as though it was coming from F* then going from the object to the mirror.

LEARNING CHECK

1. How can the same mirror produce images that are upright in some cases and inverted in others?
2. Explain how you use *F* to draw a ray when there is no ray that really goes through *F*.
3. What would you predict about the characteristics of the image if you placed an object directly on *F* of a concave mirror?

Table 4.4 Ray Diagram for an Object between a Concave Mirror and the Focal Point (*F*)

Directions	Example
Step 1 • Draw the principal axis and a line with a very slight curve to represent the concave mirror. • Mark *F*. • Draw an object between the *F* and the mirror.	
Step 2 • Draw a ray (shown in blue) from the top of the object toward the mirror and parallel to the principal axis. • Draw the reflected ray back through the focal point.	
Step 3 • Position your ruler as shown in **Figure 4.29** and draw the ray (shown in green) from the top of the object to the mirror. • Draw the reflected ray backward and parallel to the principal axis.	
Step 4 • Extend the reflected rays behind the mirror with dashed lines. • Draw the image between the point where the dashed lines meet and the principal axis.	

The characteristics of images for objects in the region between *F* and a concave mirror are as follows.

- The image distance is greater than the object distance.
- The image is upright.
- The image is larger than the object.
- The image is virtual.

Convex mirrors always form images that are smaller than the object.

convex mirror: a mirror that bulges out in the centre

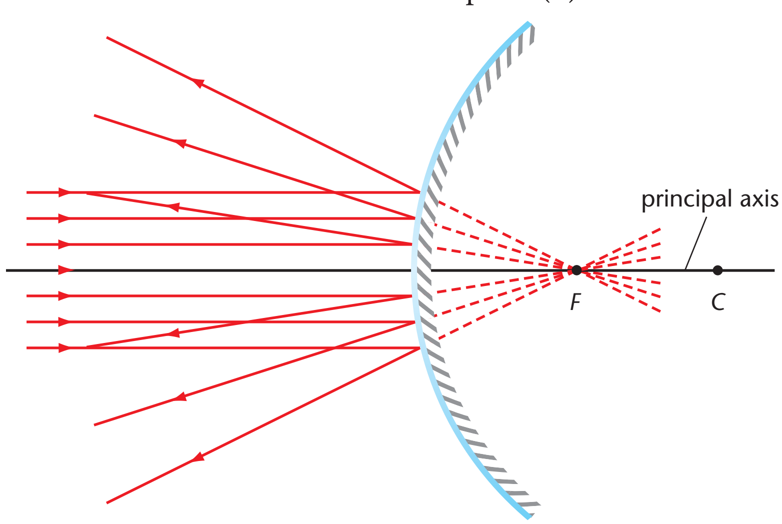
You have probably seen safety mirrors like the one in **Figure 4.30**. In a warehouse or underground parking area with a mirror like this, a driver would be able to see if anyone is in the next aisle and avoid an accident. In a convenience store, a mirror like this would let the person behind the counter see down each aisle and see everyone in the store.

A mirror that bulges out in the centre is called a **convex mirror**. You can picture a convex mirror as a section taken from a basketball as shown in **Figure 4.31**. To make a convex mirror, though, you would put the reflective surface on the outside of the ball.

▲ **Figure 4.30** If you were pushing a gurney down the hall in a hospital, a mirror like this one would prevent anyone in another hallway from running into the gurney.

▲ **Figure 4.31** If you cut a section from a basketball and cover the outside surface with a reflective material, you would have a convex mirror.

A convex mirror has a focal point and a centre of curvature just as a concave mirror does. However, you find them in a different way. **Figure 4.32** shows how to find the focal point of a convex mirror. As you can see, when rays travel toward a convex mirror parallel to the principal axis, the reflected rays spread out. You must extend them backwards, behind the mirror, to find the focal point. The centre of curvature of the mirror (C) is then twice the distance from the mirror as the focal point (F) is.



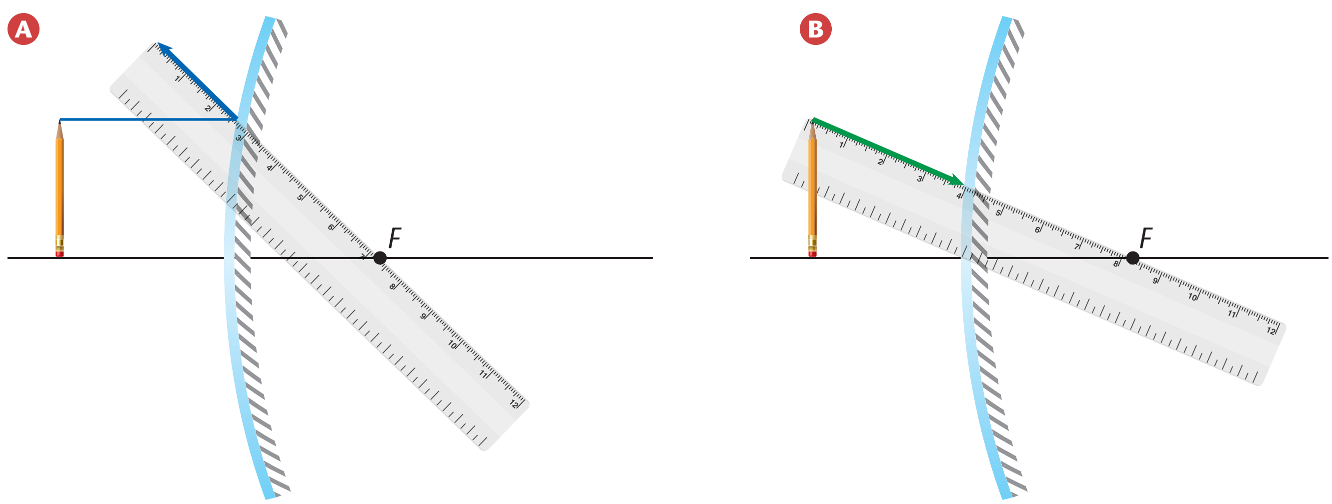
▶ **Figure 4.32** The focal point of a convex mirror is behind the mirror.

Ray Diagrams for Convex Mirrors

The rays that you use to draw a ray diagram for a convex mirror are similar to those for a concave mirror. However, because the focal point is behind the mirror, rays never go through it. You can describe the two rays as follows.

- A ray that is travelling parallel to the principal axis will reflect as though it was coming from the focal point.
- A ray that is travelling as though it is going toward the focal point will reflect back parallel to the principal axis.

Examine **Figure 4.33** to see how to draw those rays. To draw the first ray, use your ruler to draw a ray from the top of the object to the mirror going parallel to the principal axis. Then, as shown in **A** of the figure, position your ruler on the point where the ray hits the mirror and on *F*. Draw the reflected ray away from the mirror. To draw the second ray, position your ruler on the tip of the object and on *F*. As shown in **B** of the figure, draw the ray from the object to the mirror. Next, you will use your ruler to draw the reflected ray back away from the mirror and parallel to the principal axis. **Table 4.5**, on the following page, shows you all of the steps for drawing a ray diagram for convex mirrors.



▲ **Figure 4.33** Use the focal point, *F*, to align your ruler.

LEARNING CHECK

1. How can a spoon be used both as a concave mirror and as a convex mirror?
2. How does the focal point of a convex mirror differ from the focal point of a concave mirror?
3. Could you put an object between *F* and *C* of a convex mirror and get an image? Explain.

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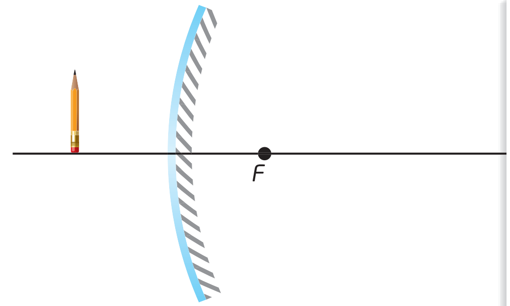
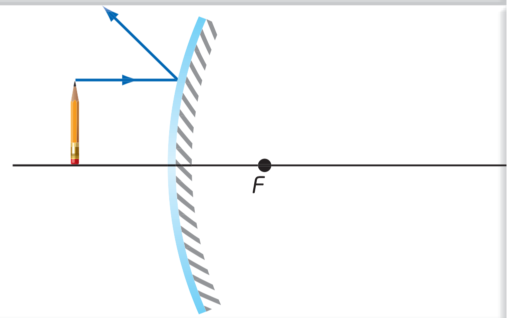
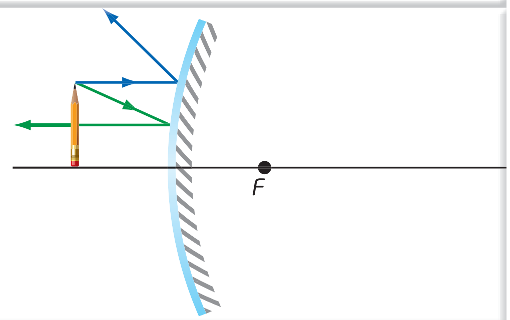
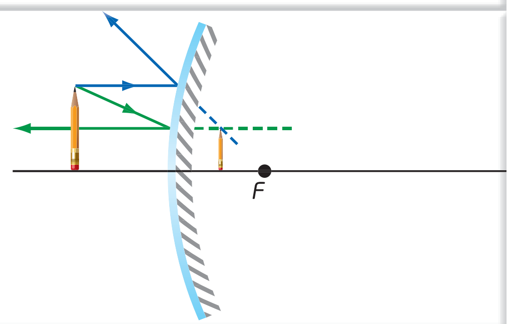
Table 4.5 Ray Diagram for Convex Mirrors

Directions	Example
Step 1 • Draw the principal axis and a slightly curved line to represent the convex mirror. • Mark *F*. • Draw the object so that the bottom is on the principal axis.	
Step 2 • Draw a ray (shown in blue) from the top of the object toward the mirror and parallel to the principal axis. • Position your ruler as shown in **Figure 4.33A** and draw the reflected ray as though it was coming from *F*.	
Step 3 • Position your ruler as shown in **Figure 4.33B** and draw the incident ray (shown in green) as though it was going to *F*. Stop when the ray hits the mirror. • Draw the reflected ray backward, parallel to the principal axis.	
Step 4 • Draw dashed lines to extend the rays backward, behind the mirror, until they meet. This is the top of the image. • Draw the image, with the bottom of the image on the principal axis.	

The image of an object in a convex mirror will have the following characteristics.

- The image is closer to the mirror than the object is.
- The image is upright.
- The size of the image is smaller than the size of the object.
- The image is virtual.

The images in convex mirrors are much more similar to each other than those in concave mirrors. There are no separate regions for the object that cause the images to change significantly. However, there is a relationship between the size and location of the image and the location of the object. You can discover this relationship by drawing ray diagrams for objects at different distances from the mirror and comparing the images.

Inquiry Focus

Activity 4.10

TRENDS IN IMAGES IN CONVEX MIRRORS

You will draw ray diagrams for objects at different distances from a convex mirror and compare the images. What do you think will happen to the size of the image as the object moves farther from the mirror?

What You Need

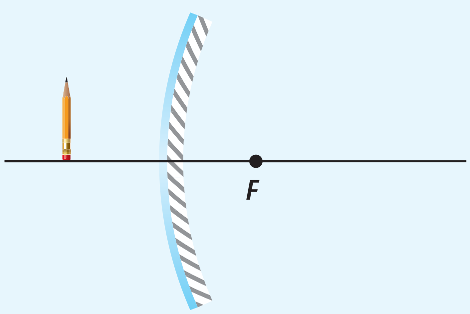
- pencil
- paper
- ruler

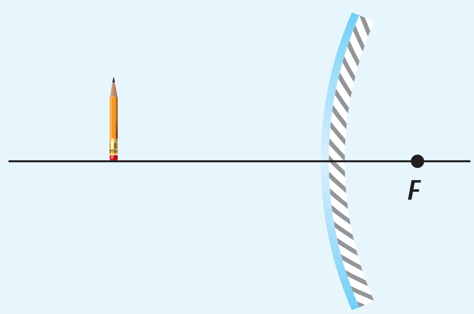
What To Do

1. Draw two diagrams like the two shown here. Be sure that the objects are exactly the same size and the focal points are the same distance from the mirrors. The object in the second diagram should be about twice as far from the mirror as the object in the first diagram.
2. For each diagram, follow the steps in **Table 4.5** to complete ray diagrams.
3. For both images, measure and record the height of the images and the image distances.

What Did You Find Out?

1. Which image was larger?
2. Which image was closer to the mirror?
3. Write a statement that describes the trends in size and location for an image in a convex mirror as the object moves away from the mirror.





LEARNING CHECK

1. Which side of a spoon acts as a convex mirror?
2. Explain how to find the focal point for a convex mirror.
3. Do you think that an image would ever be located farther from a convex mirror than the focal point? Explain why or why not.

Inquiry Focus

Activity 4.11

HOW LIGHT REFLECTS

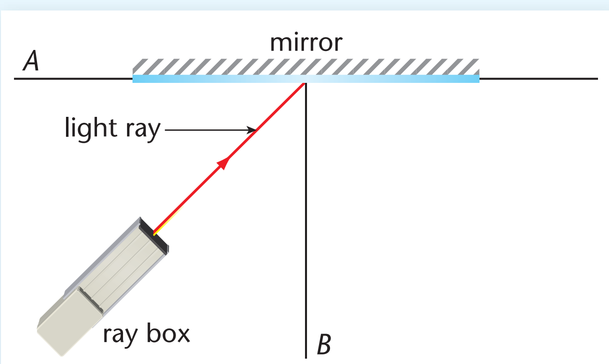
In this activity, you will make observations and measurements that will allow you to then predict the direction in which a mirror will reflect light.

What You Need

- plane (flat) mirror
- ray box with single slit
- ruler and protractor
- white paper

What To Do

1. Using a ruler, draw a straight line (A) about 5 cm from the long side and parallel to the long side of a piece of paper, as shown in the diagram.
2. Near the centre of line A, draw another straight line (B) that is perpendicular (90°) to the first line.
3. Place a mirror along line A so the reflecting surface (usually the silvered back surface) lies on the line.
4. With the ray box, shine a light ray so that it hits the mirror exactly where lines A and B meet.



5. Make several dots on the paper along the light rays leading toward and away from the mirror.
6. Turn off the ray box and remove the box and the mirror.
7. Draw straight lines along the dots to represent the light rays.
8. Measure the angles between a) the ray going toward the mirror and line B and b) the ray leaving the mirror and line B.
9. Place the ray box in a slightly different place and repeat steps 4 through 8.

What Did You Find Out?

1. How did the two angles that you measured for the first placement of the ray box compare to each other?
2. How did the angles that you measured for the second placement of the ray box compare to each other?
3. What conclusion would you draw about rays going toward a mirror and the rays reflected from a mirror?
4. Where would you place the ray box if you wanted the reflected ray to go straight back along the ray going from the ray box toward the mirror?

Inquiry Focus

Activity 4.12

LIKE, WHERE'S THE LIKENESS?

When you see a likeness in a mirror, where does it appear to be? You will make observations to see if you can answer that question. Work in pairs for this activity.

What You Need

- 2 candles in holders (the candles must be identical)
- plane mirror with stand
- sheet of paper
- ruler

What To Do

1. Fold the paper in half and draw a line along the fold.
2. Place the mirror on the line.
3. Place one candle about 10 cm in front of the mirror. Trace the bottom of the candle.
4. Stand or sit so that you are at eye level with the mirror. Place the second candle behind the mirror so that it is exactly where the reflection of the candle in the mirror appears to be.
5. While looking in the mirror from behind the first candle, move up just slightly so you can see the candle behind the mirror. Adjust the candle so it appears to be a perfect extension of the reflection of the candle in the mirror. View the candle and reflection from several directions to be sure that the second candle is lined up exactly with the reflection of the candle in the mirror.
6. Trace the bottom of the second candle.
7. Remove the candles and mirror. Measure the distance from the centre line where the mirror was sitting to each of the candle positions.

What Did You Find Out?

1. How are the distances from the line to the two candles related?
2. How were the orientations (right side up or upside down) of the two candles related?
3. How do the apparent sizes of the candle and its reflection compare?

Inquiry Focus

Activity 4.13

SEE YOURSELF IN A SPOON

You will observe your image in a curved mirror and compare it with your image in a plane mirror.

What You Need

- plane (flat) mirror
- large kitchen spoon with very shiny, reflective surfaces

What To Do

1. Hold the plane mirror about 25 cm from your face. Try to estimate the size of the image and its distance from the mirror relative to your face.
2. Hold the spoon the same distance from your face, looking at the inside or "caved-in" side of the spoon. Once again, with the spoon about 25 cm from your face, try to estimate the size of the image and its distance from the mirror relative to your face.
3. Still looking at the "caved-in" side of the spoon, move the spoon as close to your face as you can and still see an image. Then move it as far away as possible and observe any changes in your image.
4. Turn the spoon over and look at your reflection on the back of the spoon. Once again, hold the spoon fairly close to your face and slowly move it away. Notice how your image changes.

What Did You Find Out?

1. In which "mirror" was your image larger?
2. In which "mirror" did the image appear to be farther behind the mirror?
3. Describe any observations about your image in the curved "mirror" that were quite different than your image in the flat mirror.
4. What was the biggest difference that you noticed between your image on the inside and on the back of the spoon?

Inquiry Focus

Activity 4.14

REFLECTING AN IMAGE

In this activity, you will work in pairs. Together, you will attempt to direct an image onto a screen.

What You Need

- concave mirror
- sheet of white paper for a screen

What To Do

1. Turn off the lights in the classroom. Stand as far from a window (or bright light source) as you can.
2. One partner will hold the mirror so it is nearly facing the window (or light source).
3. The other partner will hold the screen (paper) while facing the partner with the mirror.
4. Adjust the positions of the mirror and screen until the light from the window is reflected onto the screen.
5. Move the screen back and forth until the shape of the window is as sharp as possible.
6. Note the size and shape of the reflection of the window on the screen.

What Did You Find Out?

1. How did the size of the image on the screen compare with the object (the window or bright light source)?
2. Was the image right side up or upside down?

Investigation 4A

Skill Check

initiating and planning
✓ performing and recording
✓ analyzing and interpreting
✓ communicating

What You Need

- concave mirror
- lighted object such as a candle
- metre stick
- white piece of cardboard to act as a screen
- two small pieces of masking tape

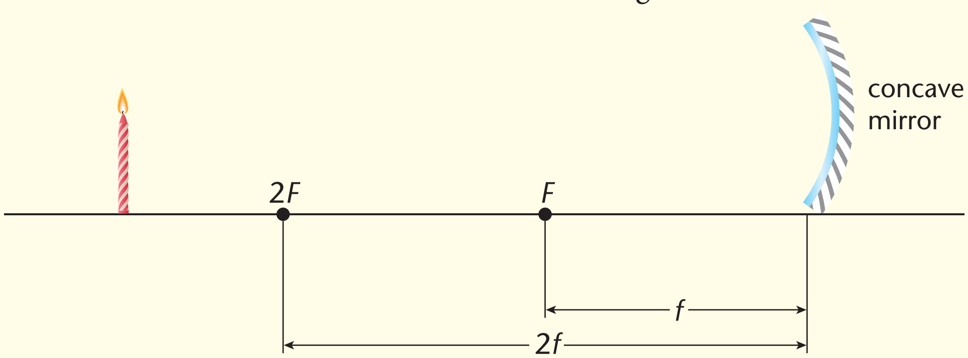
Exploring Images with a Concave Mirror

What To Do

1. Copy the following observation table into your notes.

Object Distance	Image Distance	Size of Image	Orientation of Image	Type of Image
greater than 2*f*				
equal to 2*f*				
between 2*f* and *f*				
less than *f*				

2. Measure the focal length of the mirror by focusing on a distant object and measuring the distance between the image and the concave mirror. (**Hint**: Review Activity 4.14.)
3. Place the mirror upright on the desk. Do not move the mirror during this part of the investigation.
4. Measure out distances of one focal length (*f*) and two focal lengths (2*f*) from the mirror and mark each location on the desk with masking tape.
5. Place the candle more than two focal lengths away from the mirror. Move the screen back and forth until you find a sharp image of the flame. It is best to have the candle a bit off to one side so that the screen can be moved back and forth without touching the flame.



6. Record the distance between the image and the mirror in terms of focal lengths. For example, you might describe the image distance as greater than $2f$, equal to $2f$, between $2f$ and f, equal to f, less than f, and so on.
7. Record the size of the image relative to the size of the object. That is, is the image larger, the same size, or smaller than the object?
8. Record the orientation of the image. That is, is the image upright (right side up) or inverted (upside down)?
9. Record the type of image. If you can find the image on the screen, then it is a real image because light actually comes from it. If you must look into the mirror to see the image, then it is a virtual image. The light only seems to come from it, just as in a plane mirror.
10. Repeat steps 4 to 9 for the other object distances in the table.

What Did You Find Out?

1. What was the focal length of the mirror?
2. As the object moves towards the mirror, what happens to the location of the image?
3. At what distance from the mirror were the object and image the same distance from the mirror (side by side)?
4. As the object moves toward the mirror, what happens to the size of the image?
5. For what range of object distances do you find a) a real image? b) a virtual image?
6. Describe the image formed when the object is less than one focal length away from the concave mirror.

Case Study Investigation: How Can Mirrors Help Keep You Safe?

What's the Issue?

Thousands of Canadians are injured in automobile-related accidents every year. Even if you don't drive, road safety is an issue that affects you, as a passenger, cyclist, skateboarder, or simply as a pedestrian. So how do we make roads safer for us all? One surprising answer may lie in a familiar optical technology—mirrors.

The Science behind the Issue

How do mirrors help improve road safety? Designers and engineers are coming up with innovative ways to incorporate mirrors into technology designed to keep our highways, streets, and intersections safe.

A Helmet with a Rear View

Restricted vision is a factor in many motor vehicle accidents. Often, drivers claim they simply didn't see a car, bike, or pedestrian. While rearview mirrors help automobile drivers see what is behind them, things are more difficult when driving a motorcycle. Motorcycles do not have rearview mirrors. Instead, drivers must rely on their side mirrors to see what is going on behind them. But the Reevu™ motorcycle helmet has changed all that. This ingenious helmet incorporates mirrors directly into its design, giving its wearer a clear view of the road behind. The mirror fits directly beneath the visor and is fully adjustable. It allows drivers to see what lies behind them (not just their forehead) by way of angled mirrors that reflect light over the head.

The helmet this rider is wearing provides a view of what's behind the rider that is similar to the view a car driver gets from a rearview mirror and two sideview mirrors.

“Look behind You” Lenses

For skateboarders, cyclists, and rollerbladers, designers in the United Kingdom have discovered that clever placement of reflective coating in the corners of sunglasses enable wearers to see what is going on behind them. It’s as simple as looking out of the corner of your eye. If wearers look straight ahead, their vision isn’t distorted at all. Originally conceived as a novelty gadget, rearview glasses may also have a lot of applications when it comes to road safety.

Panoramic Vision

While rearview mirrors give drivers the ability to see behind them, convex mirrors allow people to see what is going on all around them. Convex mirrors are being placed in intersections where incoming streets are hidden by vegetation or buildings. Because intersections are the most common locations for accidents, placing mirrors here plays an important safety function. A solar powered light may be used to alert drivers to the mirror’s presence. Light from different angles strikes the mirror’s surface and reflects back to drivers, allowing them to see driveways and roads that were originally hidden from view. These mirrors are also used in underground parking lots and other places where visibility is limited.

Convex traffic mirrors provide drivers with a view of hidden streets and driveways.

Over To You

1. Rearview mirror helmets and glasses could have other applications in society. Describe another way these technologies might be used.
2. Do research to find one other way that mirrors are used to solve problems in society. Write up your research in a short paragraph. Hint: Mirrors are often used to make very small or very distant objects appear larger.
3. Create an action plan that explains how road safety could be improved in your area. Suggest the use of at least one of the mirror-based technologies covered in this feature. Share your ideas as a class and write a joint plan to email to your municipal council.

Strange Tales of Science

Not Seeing is Believing

Move over Invisible Woman and Harry Potter. Science will soon be bringing you something you probably never thought you'd see (or not see!)—a way to turn invisible, for real! Brought to you by metamaterials, the invisibility cloak of the future might be just around the corner.

Human-made materials called metamaterials are designed to cause light to bend (refract) in ways that it normally wouldn't, including backwards and around objects.

Metamaterials can render an object invisible by bending light waves around it so they reconnect behind the object. Think of water flowing around a tree stump and you get the idea.

One day, perhaps soon, metamaterial fabrics will be made into clothing such as this prototype jacket. While wearing the jacket, light will bend around you so the space behind you is visible, but you are not!

So... What do you think?

1. What are some beneficial uses for this technology? What are some negative uses? Do the positives outweigh the negatives? Explain your opinions.
2. Imagine you are wearing an invisibility cloak. Create a graphic novel or script that tells the tale of a day in your life.
3. Do you think you would cast a shadow while wearing the cloak? Why or why not?

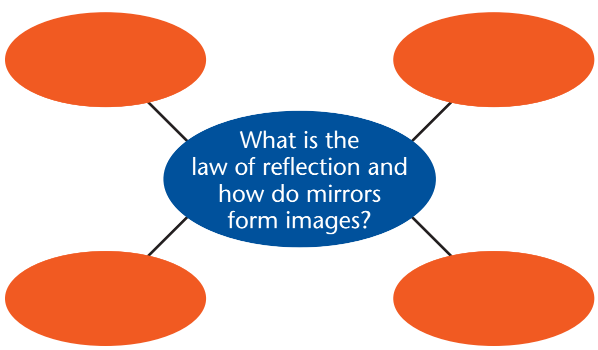
Topic 4.4 Review

Key Concept Summary

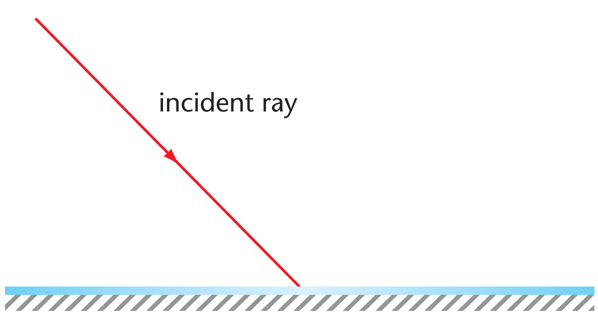
- The angle of reflection is equal to the angle of incidence.
- Plane mirrors form images that are nearly identical to the object.
- Concave mirrors can form real, inverted images.
- Concave mirrors can form upright, virtual images.
- Convex mirrors always form images that are smaller than the object.

Review the Key Concepts

1. K/U Answer the question that is the title of this topic. Copy and complete the graphic organizer below in your notebook. Fill in four examples from the topic using key terms as well as your own words.



2. K/U Copy the diagram below into your notebook. Using the law of reflection, draw the reflected ray. Explain how your drawing meets the requirements of each of the three parts of the law of reflection.



3. K/U Explain how you would use a ball to make a convex mirror and a concave mirror.

4. T/I What type of mirror would you use and where would you place it in relation to an object in order to produce:

a) a real image that is larger than the object?

b) a virtual image which is smaller than the object?

c) a virtual image which is the same size as the object?

5. K/U Describe how you would draw the two rays that would allow you to locate the image in a concave mirror.

6. A Makeup mirrors and shaving mirrors form upright images that are larger than the object. You would say that the mirror magnifies the person's face. Assume that the person's face is about 25 cm from the mirror. What type of mirror would have to be used? What would be the smallest focal length that could be used?

7. T/I A concave mirror has a focal length of 8.0 cm. An object, 2.5 cm tall, stands on the principal axis at a distance of 20.0 cm from the vertex. Use ray tracing to determine the characteristics of the image.

8. C Explain, with the aid of a diagram, why the image in a convex mirror is smaller than the object.