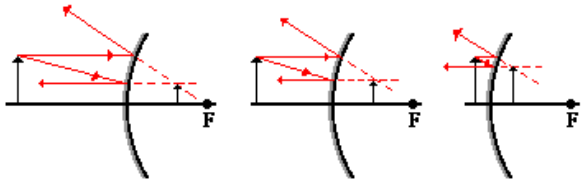
Reflection and Ray Model of Light - Lesson 4

Convex Mirrors

Reflection of Light and Image Formation for Convex Mirrors
Ray Diagrams - Convex Mirrors | Image Characteristics for Convex Mirrors
The Mirror Equation - Convex Mirrors

Image Characteristics for Convex Mirrors

Previously in Lesson 4, ray diagrams were constructed in order to determine the location, size, orientation, and type of image formed by concave mirrors. The ray diagram constructed earlier for a convex mirror revealed that the image of the object was virtual, upright, reduced in size and located behind the mirror. But will these always be the characteristics of an image produced by a convex mirror? Can convex mirrors ever produce real images? Inverted images? Magnified Images? To answer these questions, we will look at three different ray diagrams for objects positioned at different locations along the principal axis. The diagrams are shown below.

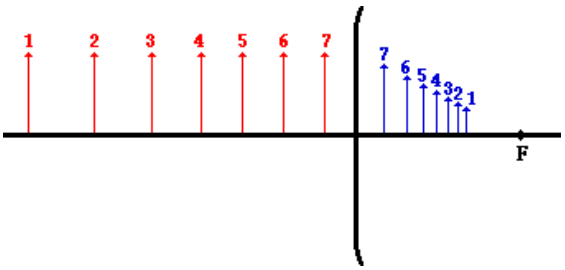


The diagrams above show that in each case, the image is

- located behind the convex mirror
- a virtual image
- an upright image
- reduced in size (i.e., smaller than the object)

Unlike concave mirrors, convex mirrors always produce images that share these characteristics. The location of the object does not affect the characteristics of the image. As such, the characteristics of the images formed by convex mirrors are easily predictable.

Another characteristic of the images of objects formed by convex mirrors pertains to how a variation in object distance affects the image distance and size. The diagram below shows seven different object locations (drawn and labeled in red) and their corresponding image locations (drawn and labeled in blue).

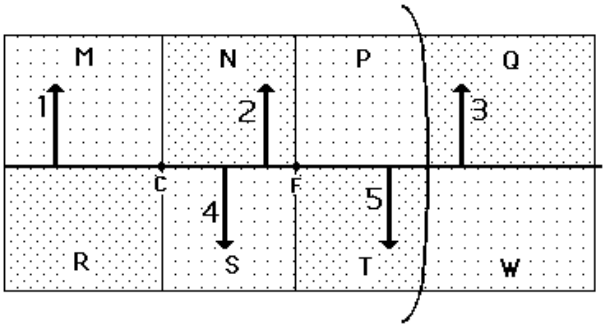


The diagram shows that as the object distance is decreased, the image distance is decreased and the image size is increased. So as an object approaches the mirror, its virtual image on the opposite side of the mirror approaches the mirror as well; and at the same time, the image is becoming larger.

Check Your Understanding

The following questions pertain to the image characteristics of all types of mirrors discussed in this unit - plane mirrors, concave mirrors, and convex mirrors. Use your understanding of the object-image relationships for these three types of mirrors to answer the questions.

The diagram below shows a spherical surface that is silvered on both sides. Thus, the surface serves as double-sided mirror, with one of the sides being the concave and one being the convex side. The principal axis, focal point, and center of curvature are shown. The region on both sides of the mirror is divided into eight sections (labeled M, N, P, Q, R, S, T, and W). Five objects (labeled 1, 2, 3, 4, and 5) are shown at various locations about the double-sided mirror. Use the diagram to answer the questions #1-6.



1. The image of object 1 would be located in section _____.

M N P Q R S T W

See Answer

2. The image of object 2 would be located in section _____.

M N P Q R S T W

See Answer

3. The image of object 3 would be located in section _____.

M N P Q R S T W

See Answer

4. The image of object 4 would be located in section _____.

M N P Q R S T W

See Answer

5. The image of object 5 would be located in section _____.

M N P Q R S T W

See Answer

6. The double-sided mirror would cause virtual image to be formed of objects _____.

a. 1, 2, and 4 b. 1, 2, and 3 c. 3 and 5 d. 4 and 5 e. 3 only

See Answer

7. How can a plane mirror, concave mirror, and/or convex mirror be used to produce an image that has the same size as the object?

See Answer

8. How can a plane mirror, concave mirror, and/or convex mirror be used to produce an upright image?

See Answer

9. How can a plane mirror, concave mirror, and/or convex mirror be used to produce a real image?

See Answer

10. The image of an object is found to be upright and reduced in size. What type of mirror is used to produce such an image?

See Answer

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Ray Diagrams - Convex Mirrors

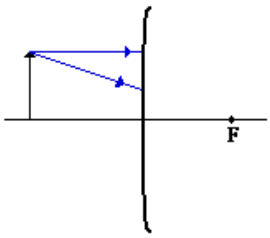
In the first section of Lesson 4, we learned that light is reflected by convex mirrors in a manner that a virtual image is formed. We also learned that there are two simple rules of reflection for convex mirrors. These rules represent slight revisions of the two rules given for concave mirrors. The revised rules can be stated as follows:

- Any incident ray traveling parallel to the principal axis on the way to a convex mirror will reflect in such a manner that its extension will pass through the focal point.
- Any incident ray traveling towards a convex mirror such that its extension passes through the focal point will reflect and travel parallel to the principal axis.

These two rules will be used to construct ray diagrams. A ray diagram is a tool that is used to determine the location, size, orientation, and type of image formed by a mirror. Ray diagrams for concave mirrors were drawn in Lesson 3. In this lesson, we will see a similar method for constructing ray diagrams for convex mirrors.

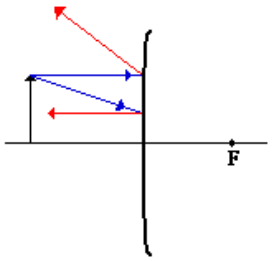
The method of drawing ray diagrams for convex mirrors is described below.

1. Pick a point on the top of the object and draw two incident rays traveling towards the mirror.



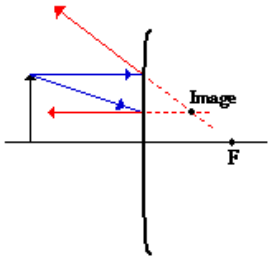
Using a straight edge, accurately draw one ray so that it travels towards the focal point on the opposite side of the mirror; this ray will strike the mirror before reaching the focal point; stop the ray at the point of incidence with the mirror. Draw the second ray such that it travels exactly parallel to the principal axis. Place arrowheads upon the rays to indicate their direction of travel.

2. Once these incident rays strike the mirror, reflect them according to the two rules of reflection for convex mirrors.



The ray that travels towards the focal point will reflect and travel parallel to the principal axis. Use a straight edge to accurately draw its path. The ray that traveled parallel to the principal axis on the way to the mirror will reflect and travel in a direction such that its extension passes through the focal point. Align a straight edge with the point of incidence and the focal point, and draw the second reflected ray. Place arrowheads upon the rays to indicate their direction of travel. The two rays should be diverging upon reflection.

3. Locate and mark the image of the top of the object.



The image point of the top of the object is the point where the two reflected rays intersect. Since the two reflected rays are diverging, they must be extended behind the mirror in order to intersect. Using a straight edge, extend each of the rays using dashed lines. Draw the extensions until they intersect. The point of intersection is the image point of the top of the object. Both reflected rays would appear to diverge from this point. If your were to draw a third pair of incident and reflected rays, then the extensions of the third reflected ray would also pass through this point. This is merely the point where all light from the top of the object would appear to diverge from upon reflecting off the mirror. Of course, the rest of the object has an image as well and it can be found by applying the same three steps for another chosen point. See note below.

4. Repeat the process for the bottom of the object.

The goal of a ray diagram is to determine the location, size, orientation, and type of image that is formed by the convex mirror. Typically, this requires determining where the image of the upper and lower extreme of the object is located and then tracing the entire

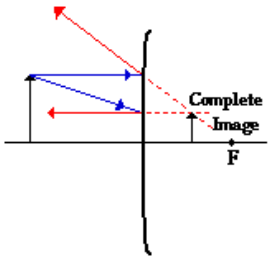
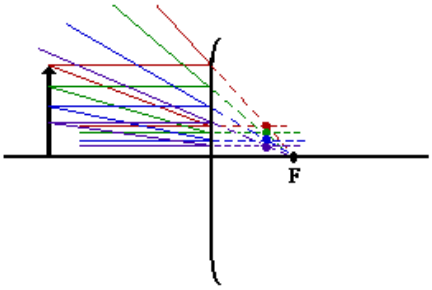


image. After completing the first three steps, only the image location of the top extreme of the object has been found. Thus, the process must be repeated for the point on the bottom of the object. If the bottom of the object lies upon the principal axis (as it does in this example), then the image of this point will also lie upon the principal axis and be the same distance from the mirror as the image of the top of the object. At this point the complete image can be filled in.

a.

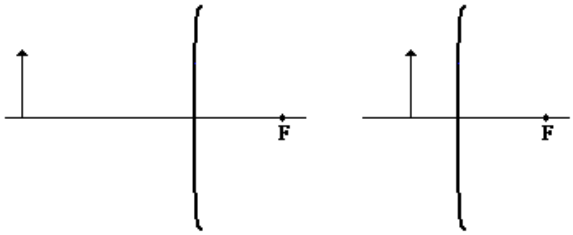
Some students have difficulty understanding how the entire image of an object can be deduced once a single point on the image has been determined. If the object is merely a vertical object (such as the arrow object used in the example below), then the process is easy. The image is merely a vertical line. This is illustrated in the diagram below. In theory, it would be necessary to pick each point on the object and draw a separate ray diagram to determine the location of the image of that point. That would require a lot of ray diagrams as illustrated in the diagram below.



Fortunately, a shortcut exists. If the object is a vertical line, then the image is also a vertical line. For our purposes, we will only deal with the simpler situations in which the object is a vertical line that has its bottom located upon the principal axis. For such simplified situations, the image is a vertical line with the lower extremity located upon the principal axis.

The ray diagram above illustrates that the image of an object in front of a convex mirror will be located at a position behind the convex mirror. Furthermore, the image will be upright, reduced in size (smaller than the object), and virtual. This is the type of information that we wish to obtain from a ray diagram. The characteristics of this image will be discussed in more detail in the next section of Lesson 4.

Once the method of drawing ray diagrams is practiced a couple of times, it becomes as natural as breathing. Each diagram yields specific information about the image. It is suggested that you take a few moments to practice a few ray diagrams on your own and to describe the characteristics of the resulting image. The diagrams below provide the setup; you must merely draw the rays and identify the image. If necessary, refer to the method described above.



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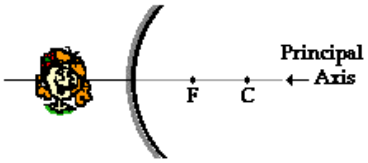
Reflection and Image Formation for Convex Mirrors

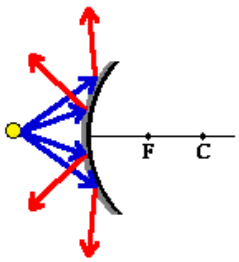
Lesson 3 focused on the reflection of light by concave mirrors and on the formation of images by this reflected light. In that lesson, it was shown that concave mirrors can produce both real and virtual images, depending upon the object location. In Lesson 4, we will follow a similar pattern of inquiry for convex mirrors: investigating how convex mirrors reflect light and produce images. We will also investigate how ray diagrams can be used to estimate image location, size, orientation, and type for objects placed in front of convex mirrors. Finally, we will use the mirror equation to calculate numerical information about image distance and size if given an object distance, object size and focal length.

The diagram at the right depicts a convex mirror. In Lesson 3, a convex mirror was described as a portion of a sphere that had been sliced away. If the outside of the sphere is silvered such that it can reflect light, then the mirror is said to be *convex*. The center of that original sphere is known as the center of curvature (C) and the line that passes from the mirror's surface through the sphere's center is known as the principal axis. The mirror has a focal point (F) that is located along the principal axis, midway between the mirror's surface and the center of curvature. Note that the center of curvature and the focal point are located on the side of the mirror opposite the object - *behind the mirror*. Since the focal point is located behind the convex mirror, such a mirror is said to have a negative focal length value.

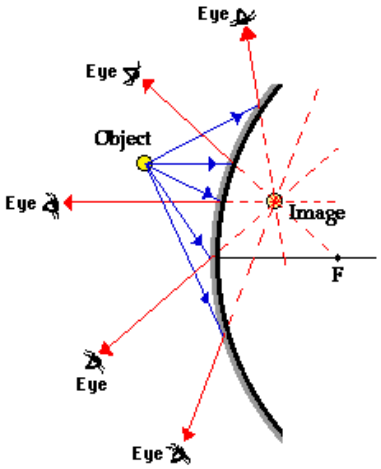


A Convex Mirror with its Negative Focal Length

A convex mirror is sometimes referred to as a diverging mirror due to the fact that incident light originating from the same point and will reflect off the mirror surface and diverge. The diagram at the right shows four incident rays originating from a point and incident towards a convex mirror. These four rays will each reflect according to the law of reflection. After reflection, the light rays diverge; subsequently they will never intersect on the object side of the mirror. For this reason, convex mirrors produce virtual images that are located somewhere behind the mirror.



Throughout this unit on Reflection and the Ray Model of Light, the definition of an image has been given. An image is the location in space where it appears that light diverges from. Any observer from any position who is sighting along a line at the image location will view the object as a result of reflected light. Each observer sees the image in the same location regardless of the observer's location. As the observer sights along a line, a ray of light is reflecting off the mirror to the observer's eye. Thus, the task of determining the image location of an object is to determine the location where reflected light intersects. The diagram below shows an object placed in front of a convex mirror. Light rays originating at the object location are shown approaching and subsequently reflecting from the mirror surface. Each observer must sight along the line of a reflected ray to view the image of the object. Each ray is extended backwards to a point of intersection - this point of intersection of all extended reflected rays is the image location of the object.



The image in the diagram above is a **virtual image**. Light does not actually pass through the image location. It only appears to observers as though all the reflected light from each part of the object is diverging from this virtual image location. The fact that all the reflected light from the object appears to diverge from this location in space means that any observer would view a replica or reproduction when sighting along a line at this location.

Of course to determine the image location, only a pair of incident and reflected rays need to be drawn. It is customary to select a pair of rays that is easy to draw. Of the five pairs of incident and reflected rays in the diagram above, two

correspond to the rays that are customarily drawn. In fact, they may closely resemble the two rays that were used in concave mirror ray diagrams. Recall from Lesson 3 that there were two rules of reflection for concave mirrors. They are:

- Any incident ray traveling parallel to the principal axis on the way to a concave mirror will pass through the focal point upon reflection.
- Any incident ray passing through the focal point on the way to a concave mirror will travel parallel to the principal axis upon reflection.

The revised rules can be stated as follows:

- Any incident ray traveling parallel to the principal axis on the way to a convex mirror will reflect in such a manner that its extension will pass through the focal point.
- Any incident ray traveling towards a convex mirror such that its extension passes through the focal point will reflect and travel parallel to the principal axis.

In the diagram above, the second and third (from the top) blue incident rays exemplify these two rules of reflection for convex mirrors. Using this pair of incident and reflected rays will greatly simplify the task of drawing ray diagrams and determining the location of images. In the next section of this Lesson, such ray diagrams will be shown.

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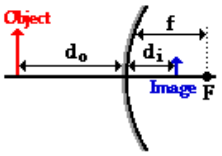

Ray diagrams can be used to determine the image location, size, orientation and type of image formed of objects when placed at a given location in front of a mirror. The use of these diagrams was demonstrated earlier in Lesson 3 and in Lesson 4. Ray diagrams provide useful information about object-image relationships, yet fail to provide the information in a quantitative form. While a ray diagram may help one determine the approximate location and size of the image, it will not provide numerical information about image distance and image size. To obtain this type of numerical information, it is necessary to use the **Mirror Equation** and the **Magnification Equation**. The mirror equation expresses the quantitative relationship between the object distance (d_o), the image distance (d_i), and the focal length (f). The equation is stated as follows:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

The magnification equation relates the ratio of the image distance and object distance to the ratio of the image height (h_i) and object height (h_o). The magnification equation is stated as follows:

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

These two equations can be combined to yield information about the image distance and image height if the object distance, object height, and focal length are known. Their use was demonstrated in Lesson 3 for concave mirrors and will be demonstrated here for convex mirrors. As a demonstration of the effectiveness of the Mirror equation and Magnification equation, consider the following example problem and its solution.

Example Problem #1

A 4.0-cm tall light bulb is placed a distance of 35.5 cm from a convex mirror having a focal length of -12.2 cm. Determine the image distance and the image size.

Like all problems in physics, begin by the identification of the known information.

h_o = 4.0 cm d_o = 35.5 cm f = -12.2 cm

Next identify the unknown quantities that you wish to solve for.

d_i = ??? h_i = ???

To determine the image distance (d_i), the mirror equation will have to be used. The following lines represent the solution to the image distance; substitutions and algebraic steps are shown.

$$1/f = 1/do + 1/d_i$$
$$1/(-12.2\ cm) = 1/(35.5\ cm) + 1/d_i$$

$$-0.0820\ cm^{-1} = 0.0282\ cm^{-1} + 1/d_i$$

$$-0.110\ cm^{-1} = 1/d_i$$

$$\mathbf{d_i = -9.08\ cm}$$

The numerical values in the solution above were rounded when written down, yet unrounded numbers were used in all calculations. The final answer is rounded to the third significant digit.

To determine the image height (h_i), the magnification equation is needed. Since three of the four quantities in the equation (disregarding the M) are known, the fourth quantity can be calculated. The solution is shown below.

$$h_i/h_o = - d_i/d_o$$

h_i /(4.0 cm) = - (-9.08 cm)/(35.5 cm)

h_i = - (4.0 cm) • (-9.08 cm)/(35.5 cm)

h_i = 1.02 cm

The negative values for image distance indicate that the image is located behind the mirror. As is often the case in physics, a negative or positive sign in front of the numerical value for a physical quantity represents information about direction. In the case of the image distance, a negative value always indicates the existence of a virtual image located behind the mirror. In the case of the image height, a positive value indicates an upright image. Further information about the sign conventions for the variables in the Mirror Equation and the Magnification Equation can be found in Lesson 3.

From the calculations in this problem it can be concluded that if a 4.0-cm tall object is placed 35.5 cm from a convex mirror having a focal length of -12.2 cm, then the image will be upright, 1.02-cm tall and located 9.08 cm behind the mirror. The results of this calculation agree with the principles discussed earlier in this lesson. Convex mirrors always produce images that are upright, virtual, reduced in size, and located behind the mirror.

Check Your Understanding

1. A convex mirror has a focal length of -10.8 cm. An object is placed 32.7 cm from the mirror's surface. Determine the image distance.

See Answer

2. Determine the focal length of a convex mirror that produces an image that is 16.0 cm behind the mirror when the object is 28.5 cm from the mirror.

See Answer

3. A 2.80-cm diameter coin is placed a distance of 25.0 cm from a convex mirror that has a focal length of -12.0 cm. Determine the image distance and the diameter of the image.

See Answer

4. A focal point is located 20.0 cm from a convex mirror. An object is placed 12 cm from the mirror. Determine the image distance.

See Answer

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