Mirrors

Unit: Light & Optics

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 13.2.A, 13.2.A.1, 13.2.A.2, 13.2.A.3, 13.2.A.4, 13.2.A.5, 13.2.A.6, 13.2.A.7, 13.2.A.7.i, 13.2.A.7.ii, 13.2.A.8, 13.2.A.9, 13.2.A.9.i, 13.2.A.9.ii

Mastery Objective(s): (Students will be able to…)

- Draw ray tracing diagrams for reflection from flat and curved (spherical) mirrors.
- Numerically calculate the distance from the mirror to its focus and the mirror to the image.

Success Criteria:

- Ray diagrams correctly show location of object, focus and image.
- Calculations are correct with correct algebra.

Language Objectives:

- Explain when and why images are inverted (upside-down) *vs.* upright.

Tier 2 Vocabulary: light, reflection, virtual image, real image, mirror, focus

Labs, Activities & Demonstrations:

- Mirascope
- turn a glove inside-out

Notes:

mirror: a surface that light rays reflect from at the same angle the light rays came from.

convex: an object that curves outward.

concave: an object that curves inward.

flat: an object that is neither convex nor concave.

ray: a beam of light. Rays travel in a straight line unless they are redirected by reflection or refraction.

laser: a beam of coherent light that travels in a straight line without spreading. Laser light is spatially coherent, meaning that it can be focused tightly and does not spread out, and also temporally coherent, meaning that the light is of a very narrow frequency spectrum. (We often describe lasers as emitting light at a single frequency.)

"Laser" is an acronym for "Light Amplification by Stimulated Emission of Radiation". The first laser was built in 1960 by Theodore Maiman.

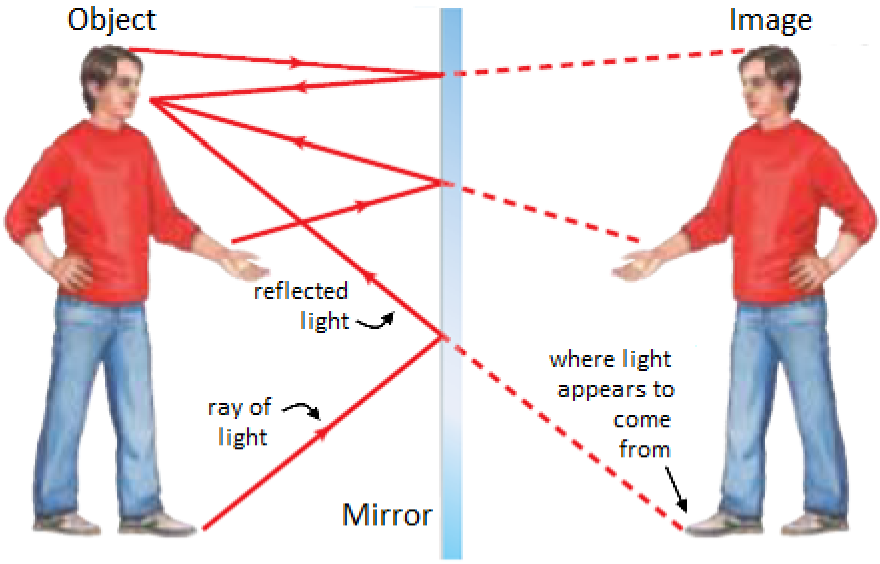
<u>focal point</u>: the point at which parallel rays striking a mirror converge.

<u>principal axis</u>: a line perpendicular to a mirror (*i.e.,* with an angle of incidence of 0°) such that a ray of light is reflected back along its incident (incoming) path.

The principal axis is often shown as a single horizontal line, but every point on a mirror has a principal axis.

Flat Mirrors

With a flat mirror, the light reflected off the object (such as the person in the picture below) bounces off the mirror and is reflected back. Because our eyes and the part of our brains that decode visual images can't tell that the light has been reflected, we "see" the reflection of the object in the mirror.

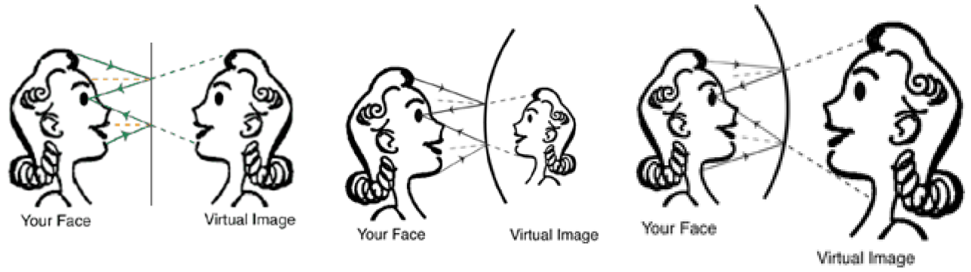


If the mirror is flat, the reflection is the same size and the same distance from the mirror as the actual object. However, the image looks like it is reversed horizontally, but not vertically.

It would seem that the mirror "knows" to reverse the image horizontally but not vertically. (Of course this is not true. If you want the mirror to reverse the image vertically, all you need to do is put the mirror on the floor.) What is actually happening is that light is reflected straight back from the mirror. Anything that is on your right will also be on the right side of the image (from your point of view; if the image were actually a person, this would be the other person's left). Anything that is on top of you will also be on top of the image as you look at it.

What the mirror is doing is the same transformation as flipping a polygon over the *y*-axis. ***The reversal is actually front-to-back*** (where "front" means closer to the mirror and "back" means farther away from it).

Convex and Concave Mirrors



flat mirror	convex mirror	concave mirror
same-size image	smaller image	larger image

With a convex mirror (curved outwards), the reflected rays diverge (get farther apart). When this happens, it makes the reflection appear smaller.

In a concave mirror (curved inwards), the reflected rays converge (get closer together). When this happens, it makes the reflection appear larger.

One place you have probably seen convex mirrors is the passenger-side mirrors in cars. The mirror is slightly convex in order to show a wider field of view. However, this makes the image smaller and appear farther away.

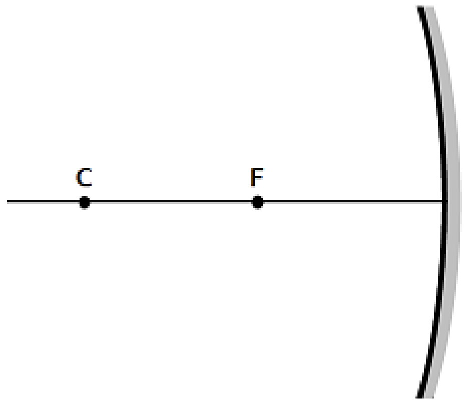
If you wear makeup, you may have used a concave mirror. The larger image makes it easier to see small details. (However, it is important to remember that those details are smaller than they appear!)

Focal Point

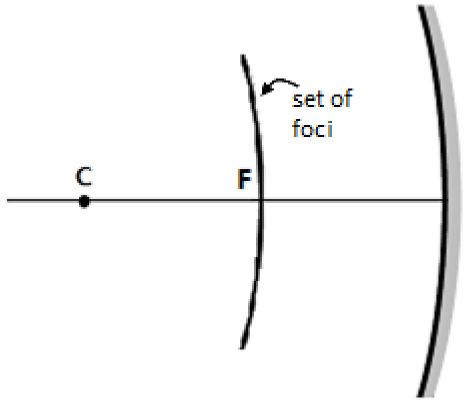
The focal point or focus of a mirror is the point where the rays of reflected light converge. For a spherical mirror (one in which the shape of the mirror is the surface of a sphere), the focus is halfway between the surface of the mirror and the center of the sphere. This means the distance from the mirror to the focus (f)* is half of the radius of curvature (r_c):

$$f = \frac{r_c}{2} \quad \text{or} \quad r_c = 2f$$

In an introductory physics class, the focus of a curved mirror is often described as a single point, as in the following diagram.



However, is important to remember that a principal axis (a line perpendicular to the mirror) can be drawn from any point along the surface of the mirror. This means that the focus is not a single point, but rather the ***set of all points*** that are halfway between the center of the sphere and the surface of the mirror:

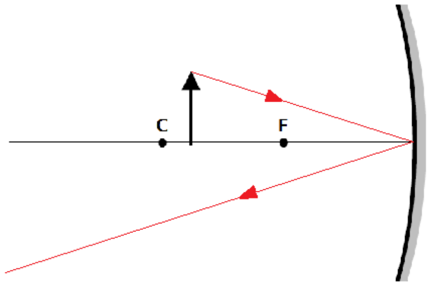


* Some physics textbooks use the variables d_o, d_i, and d_f for distances to the object, image, and focus, respectively. These notes use the variables s_o, s_i, and f in order to be consistent with the equation sheet provided by the College Board for the AP® Physics 2 exam.

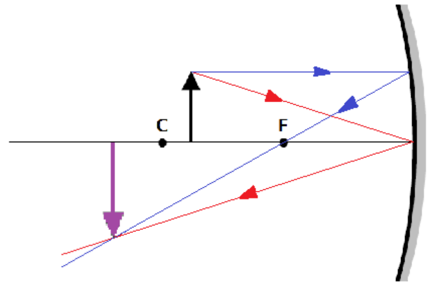
Ray Tracing

An intuitive way of finding the location, size and orientation of an image in a mirror is to draw (trace) the rays of light to see where they converge.

1. A ray of light that hits the mirror on the principal axis is reflected back at the same angle relative to that principal axis. (The angle of incidence relative to the principal axis equals the angle of reflection.)



2. A ray of light that hits the mirror parallel to the principal axis is reflected directly toward or away from the focal point of the mirror (the focus).

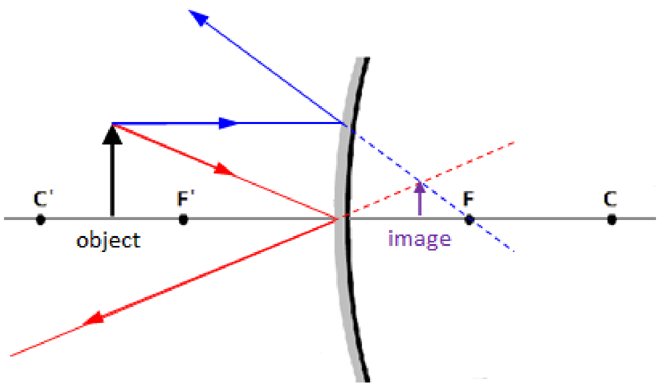


3. If you draw a pair of rays from the top of the object as described by #1 and #2 above, the intersection will be at the top of the image of the object.

These three rays—the ray that strikes the principal axis (step 1 above), the ray that strikes the mirror parallel to the principal axis (from step 2 above) , and that same ray after being reflected through the focus (also from step 2 above)—are called the "three principal rays".

Convex Mirrors

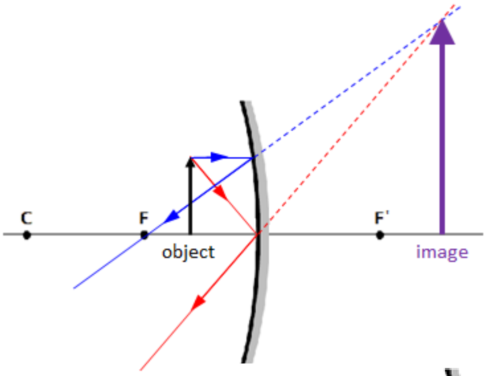
For a convex mirror, the image is always virtual (behind the mirror) and is always smaller than the object:



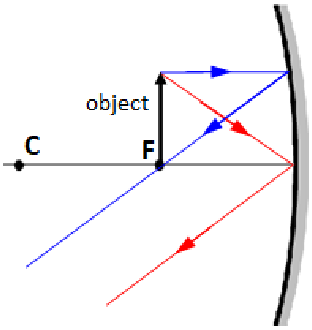
Concave Mirrors

For a concave mirror, what happens with the image changes depending on where the object is relative to the center of curvature and the focus, as shown by ray tracing in each the following cases.

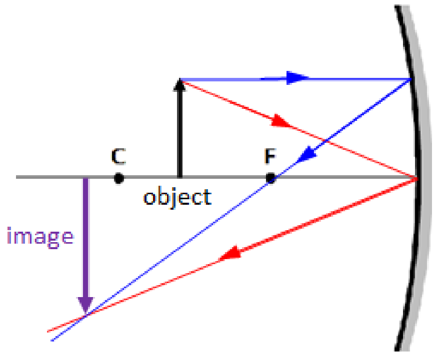
1. If the object is closer to the mirror than the focus, you see a virtual image (behind the mirror) that is upright (right-side-up), and larger than the original.



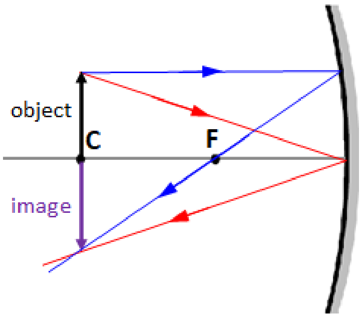
2. If the object is at the focus, there is no image because the rays do not converge.



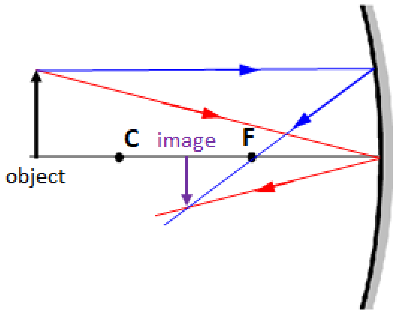
3. If the object is between the focus and the center of curvature, you see a real image (in front of the mirror) that is behind the object, inverted (upside-down), and larger.



4. If the object is at the center of curvature, you see a real, inverted image that is the same size and same distance from the mirror as the object.



5. If the object is farther from the mirror than the center of curvature, you see a real, inverted image that is smaller and closer to the mirror than the object.



Equations

The distance from the mirror to the focus (f) can be calculated from the distance to the object (s_o) and the distance to the image (s_i), using the following equation:

$$\frac{1}{s_o}+\frac{1}{s_i}=\frac{1}{f}$$

Distances for the image (s_i) and focus (f) are positive in front of the mirror (where a real image would be), and negative behind the mirror (where a virtual image would be).

The height of the image (h_i) can be calculated from the height of the object (h_o) and the two distances (s_i and s_o), using the following equation:

$$M=\frac{h_i}{h_o}=-\frac{s_i}{s_o}$$

A positive value for h_i means the image is upright (right-side-up), and a negative value for h_i means the image is inverted (upside-down).

<u>magnification</u>: the ratio of the size of the image to the size of the object.

If $M > 1$, the image is larger than the object. (For example, if $M = 2$, then the image is twice as large as the object.) If $M = 1$, the object and image are the same size. If $M < 1$, the image is smaller. Finally, note that in a mirror, virtual images are always upright, and real images are always inverted.

Sample Problem:

Q: An object that is 5 cm high is placed 9 cm in front of a spherical convex mirror. The radius of curvature of the mirror is 10 cm. Find the height of the image and its distance from the mirror. State whether the image is real or virtual, and upright or inverted.

A: The mirror is convex, which means the focus is behind the mirror. This is the side where a ***virtual*** image would be, so the distance to the focus is therefore negative. The distance to the focus is half the radius of curvature, which means $f = -5$ cm. From this information, we can find the distance from the mirror to the image (s_i):

$$\frac{1}{s_o}+\frac{1}{s_i}=\frac{1}{f}$$

$$\frac{1}{9}+\frac{1}{s_i}=\frac{1}{-5}$$

$$\frac{5}{45}+\frac{1}{s_i}=-\frac{9}{45}$$

$$\frac{1}{s_i}=-\frac{14}{45}$$

$$s_i=-\frac{45}{14}=-3.2\,\text{cm}$$

The value of −3.2 cm means the image is a virtual image located 3.2 cm behind the mirror.

Now that we know the distance from the mirror to the image, we can calculate the height of the image (h_i):

$$\frac{h_i}{h_o}=-\frac{s_i}{s_o}$$

$$\frac{h_i}{5}=-\frac{-3.2}{9}$$

$$(5)(3.2)=9\,h_i$$

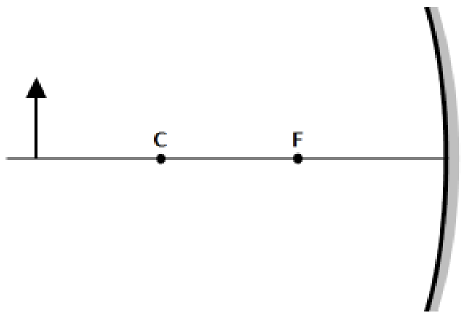
$$h_i=\frac{16}{9}=+1.8\,\text{cm}$$

The image is 1.8 cm high. Because the height is a positive number, this means the image is upright (right-side-up).

Homework Problems

In each of the following problems, an object that is 12 cm tall is placed in front of a curved, spherical mirror with a focal length of 18 cm.

1. **(M)** The mirror is concave and the object is placed 58 cm from the mirror.
   a. Show the location and orientation of the image by accurately drawing a ray diagram on the image below.

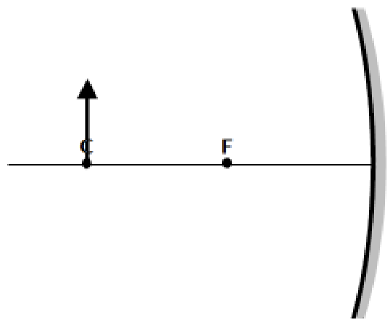


   b. Calculate the height and orientation (upright or inverted) of the image, and its distance from the mirror.

Answers: s_i = 26.1 cm; h_i = −5.4 cm

2. **(S)** The mirror is concave and the object is placed 36 cm from the mirror.

   a. Show the location and orientation of the image by accurately drawing a ray diagram on the image below.

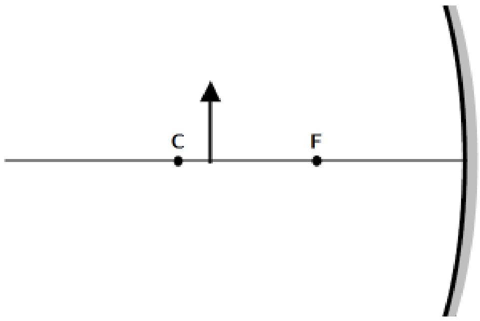


   b. Calculate the height and orientation of the image, and its distance from the mirror.

Answers: s_i = 36 cm; h_i = −12 cm

3. **(S)** The mirror is concave and the object is placed 32 cm from the mirror.

   a. Show the location and orientation of the image by accurately drawing a ray diagram on the image below.

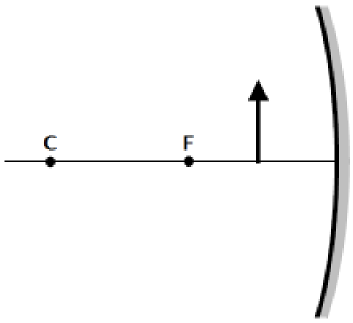


   b. Calculate the height and orientation of the image, and its distance from the mirror.

Answers: s_i = 41.1 cm; h_i = −15.4 cm

4. **(M)** The mirror is concave and the object is placed 6 cm from the mirror.

   a. Show the location and orientation of the image by accurately drawing a ray diagram on the image below.

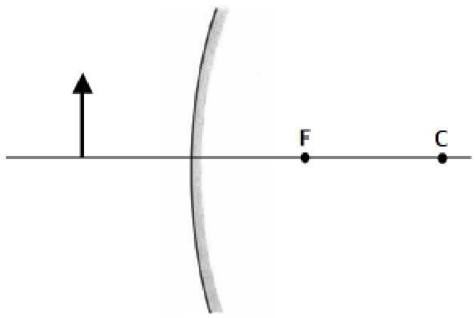


   b. Calculate the height and orientation of the image, and its distance from the mirror.

Answers: $s_i = -9$ cm; $h_i = 18$ cm

5. **(M)** The mirror is convex and the object is placed 15 cm from the mirror.

   a. Show the location and orientation of the image by accurately drawing a ray diagram on the image below.



   b. Calculate the height and orientation of the image, and its distance from the mirror.

Answers: $s_i = -8.2$ cm; $h_i = 6.5$ cm