

Mirrors

Mirrors may be the most ancient optical device, dating to the time of the Egyptians. We take mirrors for granted and why not, they're everywhere. Even things not designed as mirrors can become one in certain situations, e.g., look at a window when it is dark outside and see yourself. We look at a mirror and see a reflection but do we understand why we see what we do? The reflection we see depends on the relative positions of ourselves, the mirror and the object sending its light rays toward the mirror.

Types of Mirrors Mirrors are of two basic designs, flat (plane) and curved (convex or concave). In both types, the incident and reflected light rays obey the law of reflection, i.e., a ray's angle of incidence equals its angle of reflection.

Types of Images Look in the bathroom mirror and you see "you", unless you come from Transylvania. Now, turn and look at the wall opposite the mirror and what do you see? Does the plane mirror project an image there? Why not? Reflected light streams from the mirror's surface toward the wall. You certainly see yourself if you stand back there. Now, move closer to the mirror and hold a piece of clean white paper beside your face. Both your eyes and the paper receive the same type of light. In fact, even more reflected light from the mirror falls onto the paper than enters your eyes but you still see nothing of your reflection on the paper. What is happening to the reflected light?

Now, try this: get a concave mirror, e.g., a magnifying mirror or make-up mirror, and take it into a dark room with just one bright lamp on. Position yourself so there is a smooth behind wall behind the lamp. Stay in front of the lamp but aim the magnifying side of the mirror so its reflection hits the wall. Start close to the lamp and move slowly backwards – keep looking at the reflection on the wall. At some point, you see a recognizable image – a small, inverted, lamp. Try this during the day by standing close to a bright window in a dark room. Aim the magnifying side of the mirror at the wall beside the window. Again, move back slowly until you see an image. What do you see? An inverted window. See if you can create sharp images of objects out beyond the window itself.

Because our eyes seem to work automatically, we may overlook how they interpret some aspects of reflection and images. Actually, there are two types of images – virtual and real. The plane mirror in your bathroom and the convenience store convex mirrors produce virtual images which are upright but can not be captured on a piece of paper held in front of the mirror. We say the virtual image is "behind" the mirror. Again, look at your reflection in the bathroom mirror – it is as far in back as you are out in front.

Your investigation of the magnifying mirror showed it creates a real image which is inverted and can be seen on a piece of paper held at the proper distance out in front of the mirror. (In one situation, a concave mirror will also create a virtual image.)

But, who goes around holding a piece of paper out in front of mirrors trying to capture reflections? Perhaps not paper but astronomers place photographic film at the correct spot in front of large concave mirrors in telescopes to capture light energy that has been travelling toward Earth for millions of years. Why? To see what (or who) is out there and catch a glimpse of the Universe as it appeared millions of years ago. After all, look up and you are literally looking at history. If the sun just disappeared suddenly, we wouldn't know for 8 minutes!

Spherical Aberration A careful look at the optical geometry of spherical concave mirrors reveals that incoming parallel rays, i.e., rays from distant objects like stars, do not congregate at the focal point as we might expect. Rays striking the periphery of the mirror reflect to a point closer to the mirror than do rays reflected from other places on the mirror's surface. This behavior is called spherical aberration and it means star images on a piece of film placed at the reflection point in front of the mirror may be fuzzy because not all the reflected rays come to the same point. Since the image of a star will of course be small, even a tiny bit of blurring can be disastrous. To avoid the fuzzy images from spherical aberration, a parabolic shaped mirror may be used in more expensive telescopes because all its incoming parallel rays of

starlight will reflect to the focal point.

Think of a reverse situation – car headlights. The lamp is at the mirror’s focal point and its light reflects outward! But, we want headlights to send out their reflected light in a bright, tight, sharply defined pattern, not as a wide, weak, blurry wash. To achieve this, headlight manufacturers use parabolic mirrors and place the head lamps at their focal points.

Mirror Cases When an object is moved closer to or farther from a mirror, the image is formed in different but predictable spots. Because of the reflection law, reflections can be classified into situations or cases. Plane and convex mirrors each show one case of reflection while concave mirrors show six cases! Think of the concave mirror as part of a large circle. The circle’s center, the center of curvature or the C point, is at a set distance from the mirror, i.e., the radius of the circle. Demonstrations reveal the presence of another key spot out in front of the mirror – the focal point or f point. It also is at a set distance which is half that of the C point. Note: the degree of mirror curvature, i.e., the mirror shape itself, determines how far out in front of the mirror the C and f points are located. The C and f points are far out in front of a nearly flat mirror; the C and f points are closer to a more curved mirror. (flat = far, curved = close)

The paragraphs below contain descriptions of the six concave mirror cases. To create your own understanding of the mirror cases, make your own versions in your notebook. Work with your diagrams until, for each mirror and case, you can confidently:

- a) state the mirror's shape and behavior name,
- b) describe the object and image location with respect to the mirror,
- c) describe the object and image location with respect to each other,
- d) state if the image is real or virtual.
- e) state the relative sizes of the object and image.

Case 1 telescope looking at edge of universe

object at ∞
life size (of course)
upright (of course)

image at the f point
just an inverted dot
 $M \doteq 0$

Case 2 telescope looking at Solar System

object closer than ∞
life size (of course)
upright (of course)

image between f and C
a tiny, inverted image
 M a bit >0

Case 3 artists projecting a traceable portrait image

object at C point
life size (of course)
upright (of course)

image at the C point
life size
 $M = 1$

Case 4 projecting an image in a theater, artists projecting a traceable landscape

object between C and f points
life size (of course)
upright (of course)

image out beyond C
a large inverted image
 $M \gg 1$

Case 5 application unknown

object at f point
life size (of course)
upright (of course)

image out at ∞
image huge beyond
understanding
 $M = \infty$

Physics texts usually indicate no image is formed in case 5 but, at infinity, there could be an infinitely large one. Infinity is a neat but baffling concept. Any value you can image can be topped by just imagining a larger one. And a larger one. And. . . Where does this stop? There is no “largest” value, a concept we find difficult to grasp, especially the more we contemplate it.

Case 6 shaving or applying make up.

object closer than f point
life size (of course)
upright (of course)

image behind mirror
an upright image
 $M > 1$

Some Case Questions

Q. Compared to the mirror, which way does the object move? the image?

What happens to the size of the object? of the image?

What is the orientation of the object? of the image?

Which case gives a life-size image? the largest possible image? the smallest image?

Which cases are the opposite of each other?

Mirror Equation The positions of the object, image and mirror are easily related by:

$\frac{1}{f} = \frac{1}{s_i} + \frac{1}{s_o}$ where f = mirror focal length, s_i = distance of image to mirror surface, and s_o = distance from object to mirror surface. The difficulty in using this equation is the use of negative terms. When a value that should be negative is inputted, place the negative sign with it; when a value that should be negative is the answer, the negative sign should show up in the answer. The following chart may help may help you remember in which cases the f and/or s_i terms should be negative. See that the s_o is always +.

Mirror shape	sign			image type
	f	s_i	s_o	
concave	+	+ (c. 6, -)	+	real (c. 6, virtual)
convex	-	-	+	virtual

Q. What type of image is associated with a - s_i ? with a - f ?