2.1 IMAGE FORMATION BY REFLECTION

2.1.1 Image in a Plane Mirror

Consider a **point object** P in front of a plane mirror as in Fig. 2.1. We wish to use the reflected rays to find the location of the image of this point object.

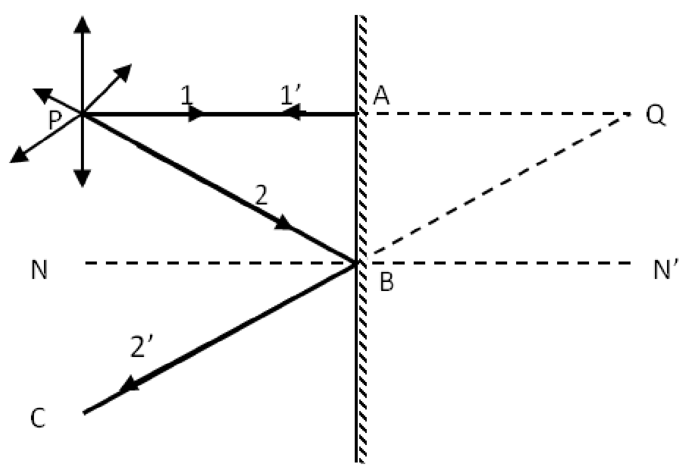


Figure 2.1: Incident rays 1 and 2 from object P are chosen arbitrarily and when they strike the reflecting surface the direction of the reflected rays 1’ and 2’ are obtained using the law of reflection. All reflected rays when extended backwards meet at a single point behind the mirror at the virtual image point Q.

Note that infinitely many rays emanate from a point source. To find the image of point P we follow the paths of two rays shown as P-A-P and P-B-C, which are labelled as 1-1′ and 2-2′. We find that the reflected rays 1′ and 2′ are diverging away from each other. To find the image behind the mirror, we need to extend these rays backwards. Of course there are no real rays behind the mirror; these extensions are called virtual rays. The backward extensions of the real rays meet at point Q. Thus, as far as rays 1′ and 2′ are concerned, they would appear to come from the same point Q behind the plane mirror.

Point Q is the **image** of point P. The image is virtual since only virtual rays meet at the image. We say that plane mirror forms **virtual image**.

Now, if you took any other ray from P and performed the reflection and then backward extension of the reflected ray, you will find

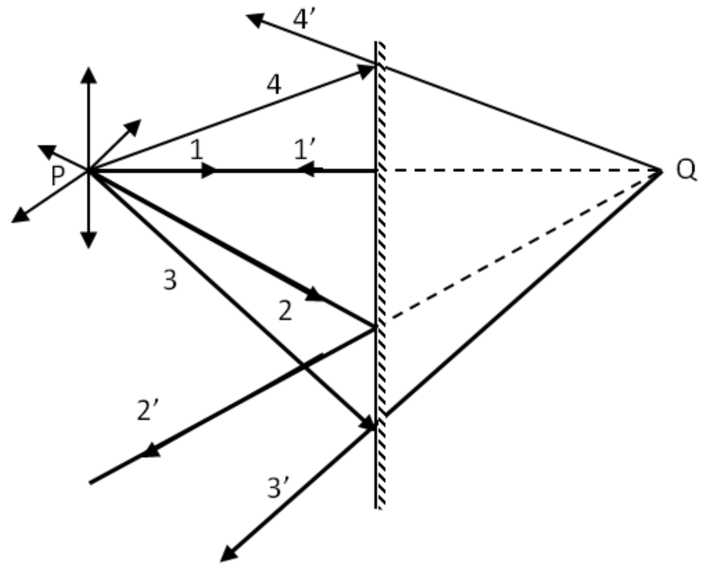


Figure 2.2: All reflected rays from point object P appear to come from the virtual image point Q.

that all the extensions meet at the same point Q as shown in Fig. 2.2.

From the congruent triangles PAB and QAB in Fig. 2.1 we can show that the object distance PA is equal to the image distance QA.

An extended object such as a cup is treated as a collection of points, and its image is found from the image of each of its points. The image of an extended object is then made from the collection of the image points. A simple object OP shown in Fig. 2.3 has two end points. Therefore, you will need to draw four incident rays, two from P and two from O to find the image QI.

Multiple images

If an object is in front of two mirrors, you get images in both mirrors. In addition, the image in one mirror acts as an object for the other mirror and forms an image of the image. If the mirrors are placed parallel to each other and the object is place at a point other than the mid-point between them, then this process of image of an image continues for ever. But, if the mirrors are inclined at an angle, the

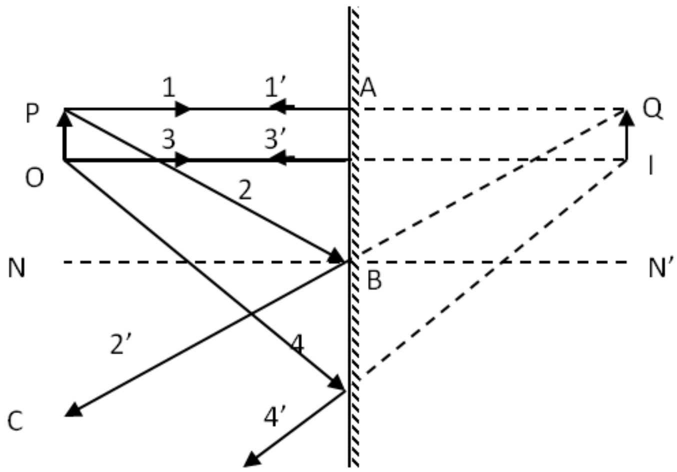


Figure 2.3: Image formation of an extended object.

image-of-image may fall on some other image, and the process may eventually terminate. For instance, two mirrors at right angles form three images as shown in Fig. 2.4. Image Q_1 and Q_2 result from rays that reflect off only one of the mirrors M1 or M2. But Q_{12}, which is the same as the image of Q_1 in M2 or the image of Q_2 in M1, is formed by rays that reflect off both mirrors. To find the image Q_{12} you have to look behind the corner of the two mirrors as shown in Fig. 2.5.

2.1.2 Curved Mirrors

The image in a plane mirror has the same size as the object and forms at the same distance behind the mirror as the object is located in front of the mirror. A **curved mirror**, on the other hand, can form images that may be larger or smaller than the object and may form either in front of the mirror or behind it. Because of the variety of images possible, curved mirrors are exciting optical devices that find many uses. Since it is much easier to manufacture spherical surfaces than other curved surfaces, they are more common. Therefore, here we will study mostly the spherically curved mirrors. If the reflecting surface is the outer side of the spherical surface the mirror is called a **convex mirror**, and when the inside surface is the reflecting surface, it is called the **concave mirror** (Fig. 2.6).

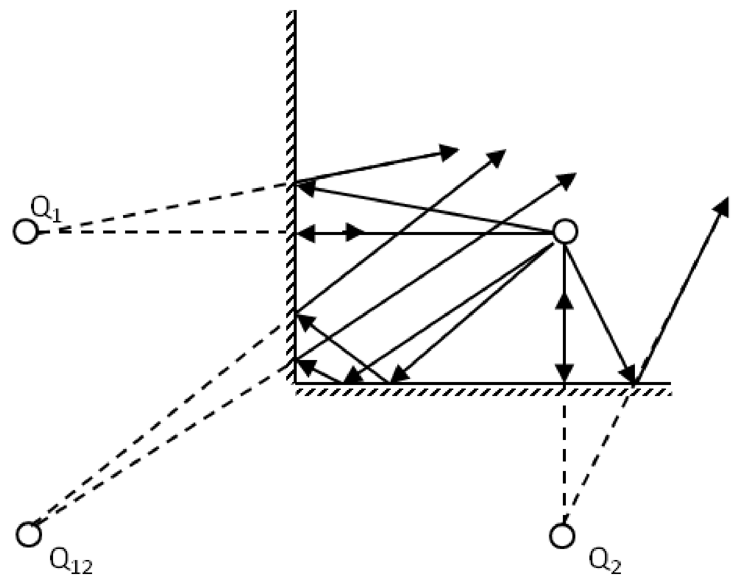


Figure 2.4: Multiple images

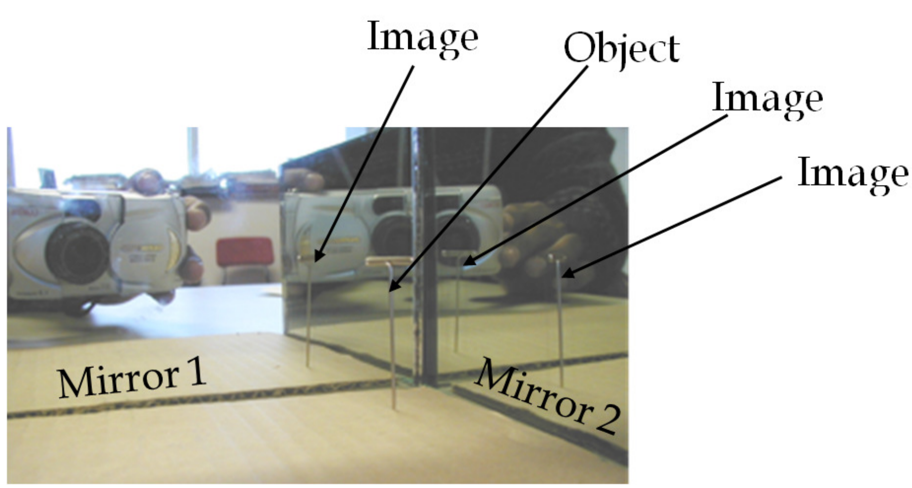


Figure 2.5: Multiple images illustrated. You can clearly see the three images of the pin in the two mirrors approximately at right angle. (Photo by MS)

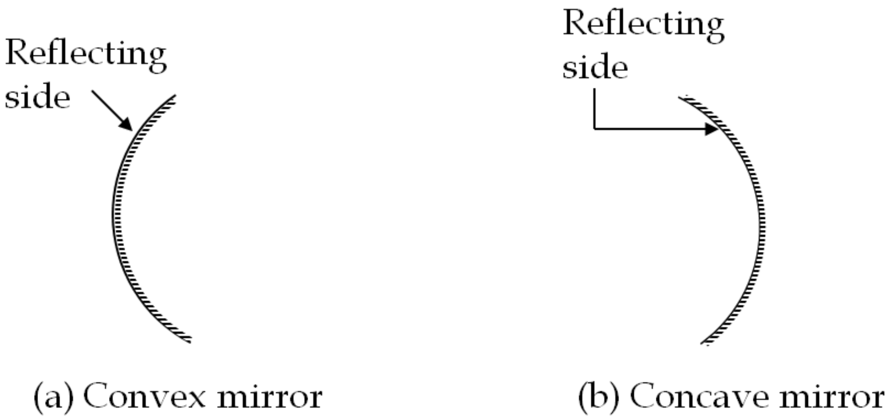


Figure 2.6: Convex mirror and concave mirror

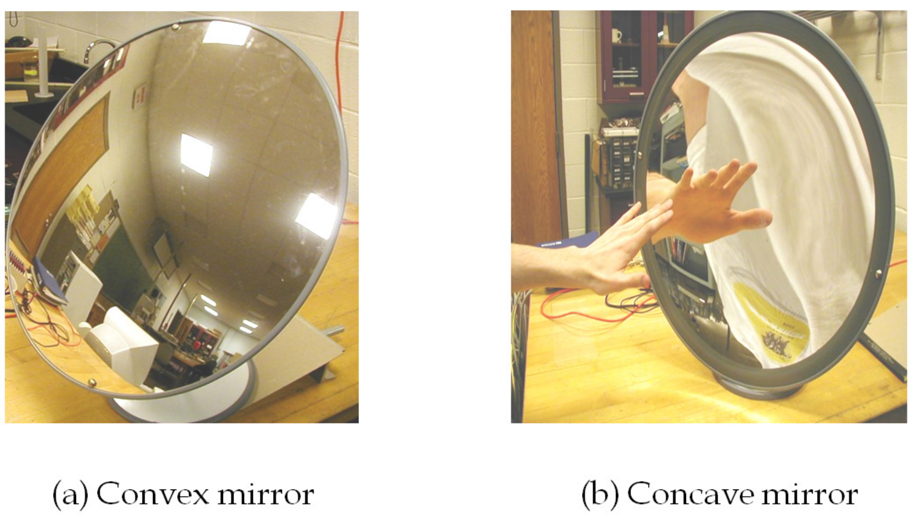


Figure 2.7: (a) Image in a convex mirror appear smaller and closer than the object. (b) Image in concave mirror appear magnified.

Only virtual images form in a convex mirror, while both virtual and real images form in a concave mirror depending upon the distance of the object from the vertex of the mirror and its radius of curvature. In a concave mirror if an object is place within half the radius from the vertex, a virtual image is formed, otherwise a real image is formed. See illustrations in Fig. 2.7 and Fig. 2.8.

Image by a Convex Mirror

Recall from your studies of the plane mirror that, in order to find the image of a point object, we need two rays from the point object that

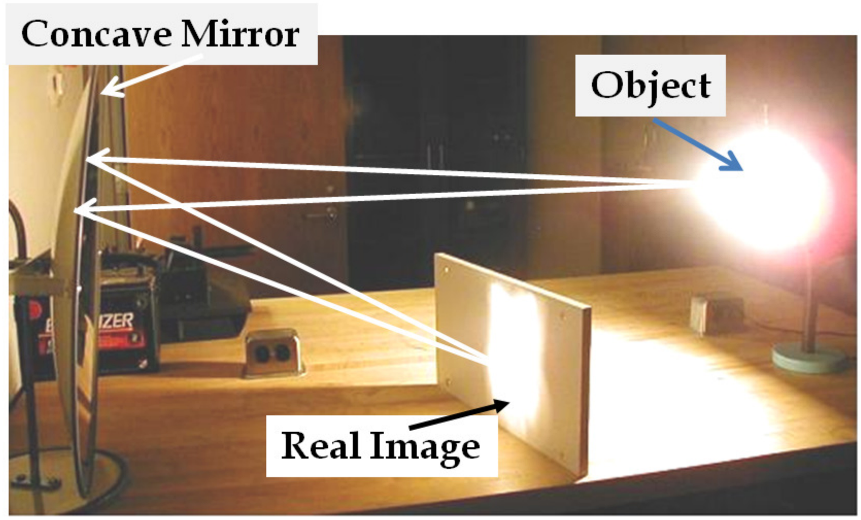
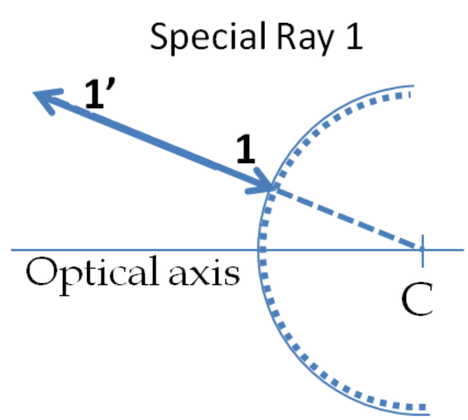


Figure 2.8: Real image indicated by an arrow on a white board formed by a concave mirror.

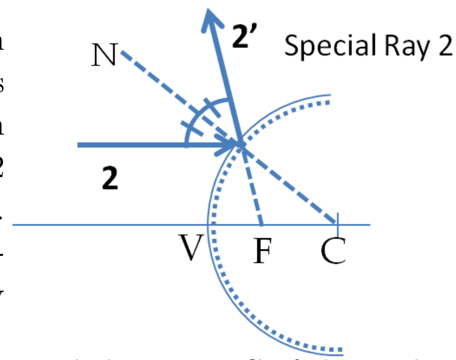
strike the mirror. When you implement the same procedure with a convex mirror, you find that once again the reflected rays diverge away from one another regardless of the location of the object. When the diverging reflected rays are extrapolated backwards they meet at the image point.

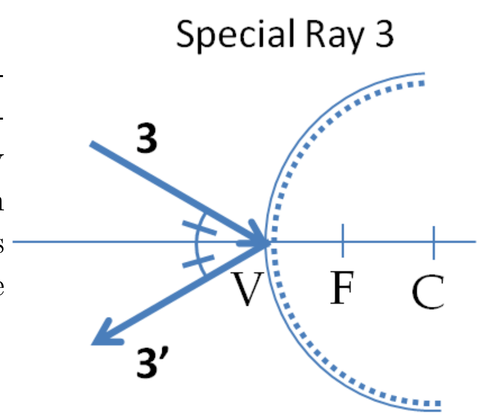
Any two rays from a point object can be used to find the image. However, in practice we use special rays that are simple to work out.

Special Ray # 1:
If you send a ray in the direction of the center of the sphere of the mirror, then it will bounce right back since the angle of incidence for this ray would be zero. This special situation is shown as rays 1 and 1′ in the figure.



Special Ray # 2:
Another special ray comes from examining what happens to rays parallel to the **optical axis** which is the axis of symmetry. Ray 2 in the figure illustrates this case. When the reflected ray 2′ is extended, the extension of the ray crosses the optical axis half-way between the vertex V of the mirror and the center C of the circle of the curvature of the mirror. This special point is called the **focal point** of the mirror and is usually labelled with symbol F.





Special Ray # 3: The third special ray is the ray striking the mirror at the vertex. The reflected ray would come out symmetrically on the other side of the optical axis as shown by ray pair 3 and 3′ in the figure.

Now we use the special rays to locate the image of a point object P in a convex mirror. Fig. 2.9 shows the image formation of a point P by using the special rays 1 and 2. When we extrapolate the reflected rays 1′ and 2′ they meet at the image point Q. The image is a virtual image since only the extrapolated rays and not the real rays meet there.

When you look into this mirror it will appear that a likeness of object P is located at point Q behind the spherical mirror. Unlike the image in the plane mirror, the image behind the convex mirror will appear nearer in the mirror than the actual distance of the object from the mirror. Convex mirror is used in situations where you would want to cover a large area such as in the mirrors of a car and the security systems of stores.

Image by a Concave Mirror

Depending on how far the object is located the image by a concave mirror can form either behind the mirror or in front of the mirror.

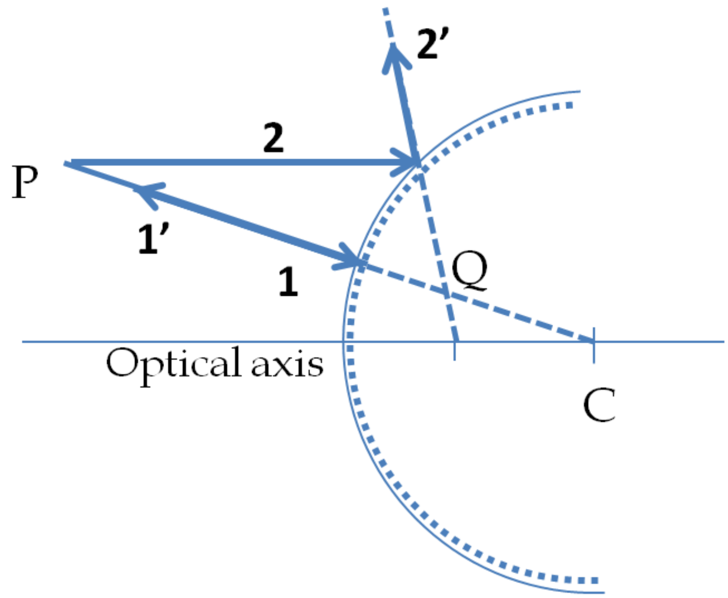


Figure 2.9: Image formation in a convex mirror using special rays.

I leave the exercise for you to show that a virtual image is formed when the object is within a distance of less than half the radius of curvature of the mirror. I will illustrate here the more weird case of image forming in front of the mirror.

Real Image in Front of a Concave Mirror

Fig. 2.10 shows a point object P located more than half the radius of curvature from the vertex. In this case, the ray tracing shows that special rays 1 and 2 upon reflection actually cross at point Q. The reflected rays $1'$ and $2'$ do not need any extension to meet at point Q. As a matter of fact every ray from point P that gets reflected by the concave mirror will pass through point Q. If you place a screen at point Q you will find a likeness of P there. The point Q is called a **real image** of point P.

Virtual Image in Front of a Concave Mirror

The reader is encouraged to work out rays from an object which is located at a distance less than the half the radius of a concave mirror. You will find that the image is formed behind the mirror similar to the case with the plane mirror and convex mirror.

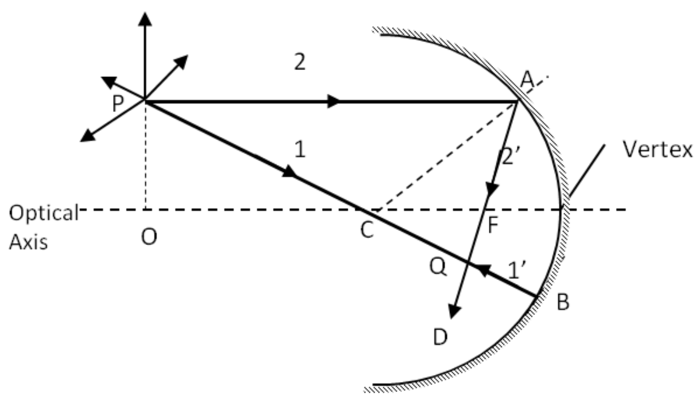


Figure 2.10: Formation of a real image by a concave mirror.