'Seeing' is one of the most common things we do. When light from an object enters our eyes, we see the object. This light can be that emitted by the object, as in the case of an electric bulb or a red-hot iron nail. It can also be the light bouncing off an object like a book

What is the nature of light Most common phenomena involving light can be understood by thinking of light as a wave, certain phenomena can be explained only if we think of light as being made up of particles. Scientists now understand that light shows the characteristics of both a wave and a particle.

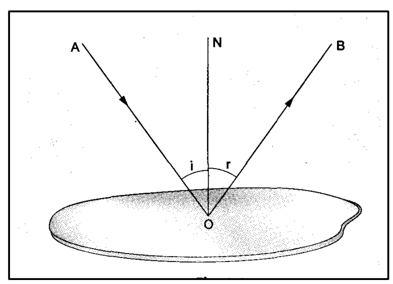
Some Properties of Light

- Light does not need a material medium to travel, i.e., it can travel through a vacuum too. The best example of this is light travelling from the sun to the earth across vast expanses of space that have no material (or matter). Compare this with sound, which is also a wave. Sound needs a material medium to travel.
- Light waves travel at a tremendous speed—whose value scientists have fixed at 299,792,458 rn/s. According to current scientific theories, no material particle can travel at a speed greater than that of light.
- The light that enables us to see has a very small wavelength—less than ten thousandth part of a centimeter. In comparison, the wavelength of audible sound is of the order of a few centimeters to a few meters.

Propagation of Light

Light travels along straight lines in a medium or in vacuum. The path of light changes only when there is an object in its path or where the medium changes. We call this rectilinear (straight-line) propagation of light. Light that starts from a point A and passes through another point B in the same medium actually passes through all the points on the straight-line AB. Such a straight-line path of light is called a ray of light. Light rays start from each point of a source and travel along straight lines till they fall on an object or a surface separating two media (mediums). A bundle of light rays is called a beam of light.

Apart from vacuum and gases, light can travel through some liquids and solids. A medium in which light can travel freely over large distances is called a transparent medium. Water, glycerin, glass and clear plastics are transparent. A medium in which light cannot travel is called opaque. Wood, metals, bricks, etc. are opaque. In materials like oil, light can travel some distance, but its intensity reduces rapidly. Such materials are called translucent.



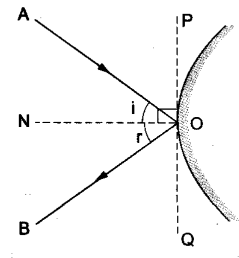
REFLECTION OF LIGHT

When light falls on a smooth surface, a part of it gets reflected as shown in figure. A ray of light being reflected from a flat, smooth surface. The ray AO is incident on the surface at point O and is reflected along OB. The line ON is the normal to the surface at O. This means, ON is perpendicular to the surface. The angle AON that the incident ray makes with the normal is called the angle of incidence, commonly denoted by i. And the angle BON that the reflected ray makes with the normal is called the angle of reflection, commonly denoted by r.

ABHYAS Academy, Behind Pragat Shiv Mandir, Near Govt. College, Nishat Cinema Road, Ambala Cantt.
Ph No. +91-171-2631595, 9416541198, e-Mail: anusethi1968@yahoo.com Website: www. abhyasonline.in

Laws of Reflection:

1. The angle of incidence and the angle of reflection are equal.
2. The incident ray, the reflected ray and the normal to the surface at the point of incidence are in the same plane



In the Figure, angle AON = angle BON, and the three lines AO, OB and ON are in the same plane. The same laws hold for reflection from a curved surface as well. We can determine the path of the reflected ray by drawing the normal to the curved surface at the point of incidence of light. To draw a normal at a point (O) on a curved surface, first draw a tangent (PQ) to the surface at that point. A normal (ON) to this tangent is also normal to the curved surface. For a spherical surface, a radius through a point on the surface is normal to the surface.

Images Formed by Reflection

When light starting from an object is reflected off a smooth surface and reaches our eyes, we see an image of the object. Images are also formed when light reflects off shiny metal surfaces, the calm surface of the water in a pond, etc.

Reflection from plane mirrors

Plane mirrors are commonly used as looking glasses. A plane mirror is made from a glass plate, one surface of the glass is polished to a high degree of smoothness, forming the front surface of the mirror. The back surface is silvered, i.e., coated with a thin layer of silver, aluminium or some other shiny, opaque material. A coat of opaque paint behind this layer protects the silvering. When light from an object falls on the front surface, most of it enters the glass plate and falls on the silvered surface.

(a) (b)

It gets reflected from there and goes out from the front surface. Generally, we neglect the thickness of the glass plate and consider the mirror as a single surface.

Properties of image formed by plane mirrors

- A plane mirror forms a virtual image. Such an image is not formed by the actual intersection of light rays and cannot be formed on a screen.
- The image formed by a plane mirror is erect so, the image of a person formed by a plane mirror has the head at the top and the feet at the bottom.
- The image is formed as far behind the mirror as the object is in front of it.
- The size of the image formed by a plane mirror is equal to that of the object.
- The image is laterally inverted. This means that in the image formed by a plane mirror, the left and right sides are reversed.

Images can be formed by the reflection of light from smooth, curved surfaces like doorknobs, taps, utensils, etc. Hold a large, shiny spoon in front of your face. In spoons, one curved surface is hollow while the other bulges out. Depending on

ABHYAS Academy, Behind Pragat Shiv Mandir, Near Govt. College, Nishat Cinema Road, Ambala Cantt.
Ph No. +91-171-2631595, 9416541198, e-Mail: anusethi1968@yahoo.com Website: www. abhyasonline.in

which surface of the spoon you are looking at, you will see different kinds of images of your face.

The images formed by the two surfaces of the spoon are similar to those formed by curved mirrors.

Spherical Mirrors

Spherical mirrors are special types of curved mirrors in which the surface of the mirror is a part of a sphere. The rear-view mirrors in cars, scooters, etc., are spherical mirrors. They can be thought of as being made from a portion cut off from a hollow glass sphere. Such a portion has two dissimilar surfaces. The hollow surface that is on the same side as the centre of the original sphere is called the concave surface. The other surface which bulges out, is called the convex surface If the concave surface is silvered, we get a convex mirror, and vice versa.

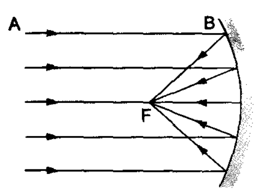
Light falling on the smooth surface of a spherical mirror enters the glass and is reflected at the opaque silvered surface. Again, we neglect the thickness of the glass and represent the spherical mirror by a single curved surface.

Spherical Mirror Terms

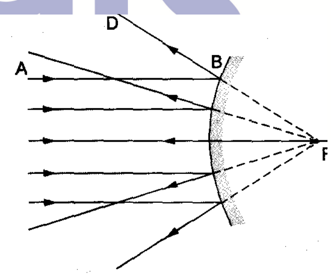
Pole : The central point on the surface of the mirror is called its pole.

Centre of Curvature and Radius of Curvature: The centre of the sphere of which the spherical mirror is a part is called the centre of curvature of the mirror. The radius of this sphere is called the radius of curvature. The centre of curvature lies in front of the mirror in the case of a concave mirror and it lies behind the mirror in the case of a convex mirror. A line joining the centre of curvature with a point on the mirror forms the normal at that point.

Principal Axis: The line joining the pole and the centre of curvature is called the principal axis of the mirror.



(c)



(d)

Aperture The circular area that determines the amount of light falling on a mirror or a lens is its aperture. In case of a spherical mirror, the area of the circle made by its boundary is its aperture.

Converging Mirror: In Figure, a ray AB, parallel to the principal axis, is incident on a concave mirror. After reflection, the ray cuts the principal axis at a point F. In fact, if the aperture of the mirror is small, all rays incident parallel to the principal axis will cut the principal axis at this same point F after reflection. In other words, such incident rays converge to F. A concave mirror is therefore also called a converging mirror.

Diverging Mirror: In Figure two, a ray AB, parallel to the principal axis, is incident on a convex mirror. The ray is reflected along BD. When BD is produced backwards, it intersects the principal axis at F. For a convex mirror of small aperture, all rays incident parallel to the principal axis, when produced backwards after reflection, appear to diverge from this same point F. A convex mirror is therefore also called a diverging mirror.

Focus and Focal Length: The point on the principal axis where rays incident parallel to the principal axis converge to or appear to diverge from after reflection is called the focus of the spherical mirror. The distance of the focus from the pole is called the focal length of the spherical mirror,

An incident ray passing (or appearing to pass) through the focus becomes parallel to the principal axis after reflection. You can see this by reversing the direction of the arrows in Figure 1.7.

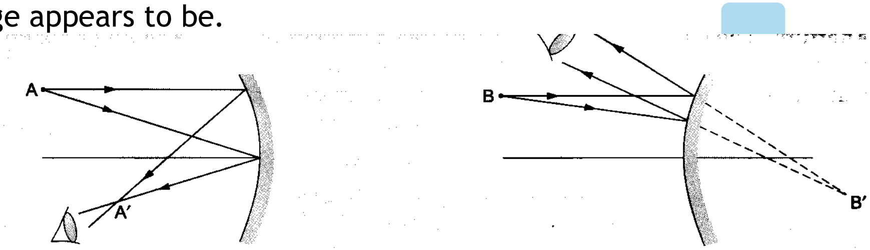
Relation between focal length and radius of curvature: The focal length f and radius of curvature r of a spherical mirror of small aperture are related as

$f=r/2$

The centre of curvature is at a distance of $r = 2f$ from the pole of the mirror.

Question 1: A concave mirror is made by cutting a portion of a hollow glass sphere of radius 24 cm. Find the focal length of the mirror. [12cm]

Real and Virtual Images An image formed by the actual intersection of light rays is called a real image. A real image can be formed on a screen. If the rays of light responsible for an image do not actually intersect, the image is called a virtual image. A virtual image cannot be formed on a screen, as no light reaches where the image appears to be.



(a) Real image (b) Virtual image

Note that in both cases the image is formed at the point of intersection of the lines representing the reflected rays.

Finding the Image by Ray Tracing

Numerous rays of light starting from a point object placed before a spherical mirror fall on the mirror and get reflected. The image of the object is formed at the point of intersection of the reflected rays. Ray tracing means locating the image geometrically. This is done by drawing some of the rays and finding the point of intersection of the reflected rays.

The rays useful for ray tracing

To find the point of intersection of the reflected rays, you need any two rays. We choose two incident rays that get reflected along known paths.

i. The ray that is incident parallel to the principal axis. After reflection, it passes through the focus, which is a known point.
ii. The ray can be the one that is incident perpendicular to the mirror's surface. Since its angle of incidence is zero, the angle of reflection is also zero, i.e., the ray turns right back, or retraces its path. Being perpendicular to the spherical surface, the ray (or its projection backwards) passes through the centre of curvature, another known point.

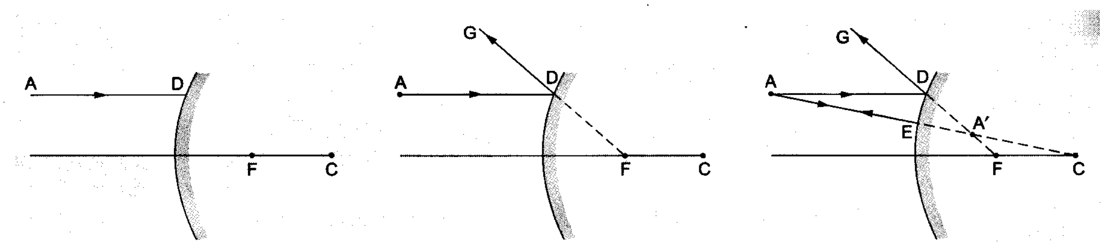
ABHYAS Academy, Behind Pragat Shiv Mandir, Near Govt. College, Nishat Cinema Road, Ambala Cantt.
Ph No. +91-171-2631595, 9416541198, e-Mail: anusethi1968@yahoo.com Website: www. abhyasonline.in

iii. The ray that falls obliquely on the mirror after passing through the focus. After reflection, this ray becomes parallel to the principal axis.

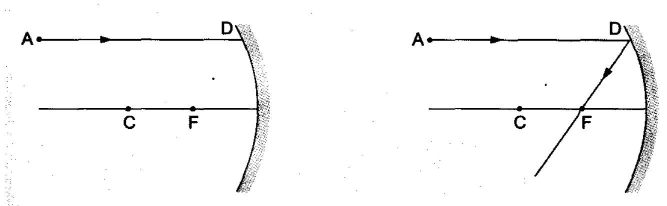
iv. The ray that is incident obliquely on the pole of the mirror. At the pole, the normal to the mirror is its principal axis. So, the principal axis will make equal angles with the incident and reflected rays (law of reflection). Using this, the reflected ray can be drawn.

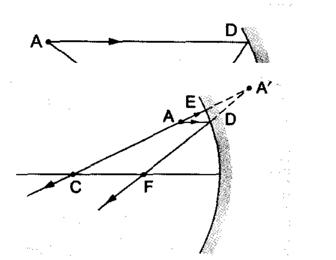
Finding the image of point objects

For a convex mirror figure below illustrates this method for a convex mirror. Starting from the point object A, draw the ray AD, parallel to the principal axis. The reflected ray when produced backwards should pass through the focus, F. So, join FD using dashed lines, and extend it to G to get the reflected ray DG. Now draw a line joining A to the centre of curvature C, as shown. This line is normal to the mirror and cuts it at E. So, the incident ray AE retraces its path along EA. The backward projections of the two reflected rays intersect at A', which is the virtual image of A.



For a concave mirror We shall now locate the image of a point object A placed before a concave mirror as in figure below. First draw a ray AD parallel to the principal axis. After reflection, this ray will pass through the focus, F. Then draw a ray AE through the centre of curvature, C. Since it is incident normal to the mirror at E, it will retrace its path along £C. The reflected rays actually intersect at A', where the real image of A is formed.

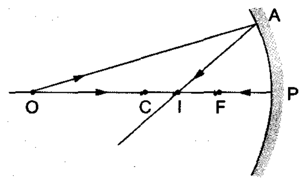




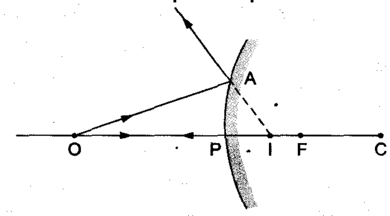
The image formed by a concave mirror is not always real. Figure below shows such a case. As usual, we have chosen two rays—AD, parallel to the principal axis, and AE, passing through the centre of curvature. After reflection, AD passes through F, and AE retraces its path. You will notice that the reflected rays diverge. So they can never actually intersect. However, if they are produced backwards, they meet at A', where the virtual image of A is formed

When the point object is on the principal axis Let us consider a point object 0 placed on the principal axis of a spherical mirror (Figure 1.13 shows this for both types of spherical mirrors). A ray OP along the principal axis falls normally on the mirror and, therefore, retraces its path. Take any other ray OA, incident on the mirror at A. Let the reflected ray (or its projection backwards) cut the principal axis at I. As I is the point of intersection of the reflected rays, it is the image of

0. All reflected rays will pass through (or seem to pass through) it. Thus, the image of a point on the principal axis is formed on the principal axis itself.



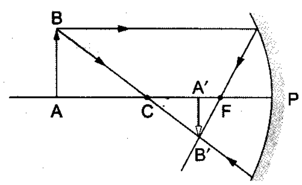
(a)



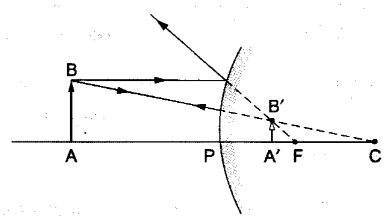
(b)

Finding the image of extended objects

The image of an extended object formed by a spherical mirror can be found by locating the images of the individual points of the object. One case of interest is that of a small, linear object placed on the principal axis, perpendicular to it. We can find the whole image by just locating the images of the points at the top and bottom of the object.



(a)



(b)

• Let AB be an object placed perpendicular to the principal axis, with point A on the principal axis. Locate the image B' of the point B of the object. We know that the image of A will be formed on the principal axis. Drop a perpendicular B'A' from B' to the principal axis. A' is the image of A, and A'B' is the image of AB. The image in relation to the object, is on the opposite side of the principal axis. Such an image is called an inverted image. And an image formed on the same side of the principal axis is called an erect image.

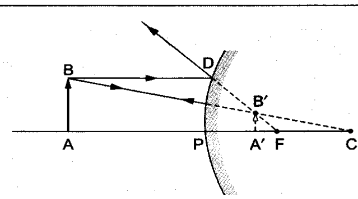
Nature of the Image

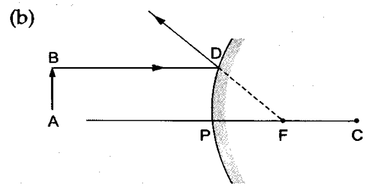
The size, location and nature of the image formed by a spherical mirror depend on the position of the object.

Images formed by a convex mirror

In a convex mirror, the image is always formed behind the mirror, between the pole and the focus. The image is always virtual, erect and smaller than the object. As the object moves away from the mirror, its image moves towards the focus. And when the object is at infinity, the image is formed at the focus. Image formation by a convex mirror is shown above.

Table 1.2 Images formed by convex mirrors

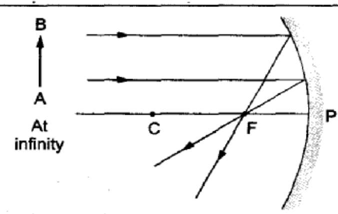
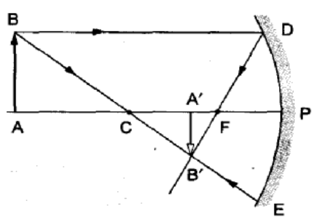
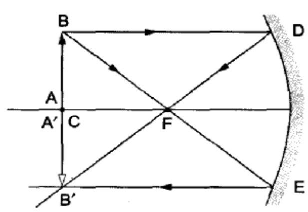
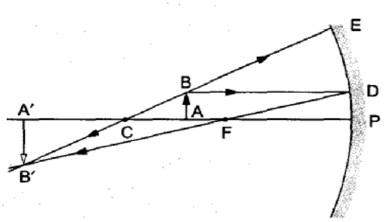
	Object position	Image position	Nature of image
(a) 	between infinity and the pole	between the focus and the pole	virtual, smaller and erect

(b) 	at infinity	at the focus F	virtual, point-sized

In a convex mirror, the image is always formed behind the mirror, between the pole and the focus. The image is always virtual, erect and smaller than the object. As the object moves away from the mirror, its image moves towards the focus. And when the object is at infinity, the image is formed at the focus. Image formation by a convex mirror is shown above.

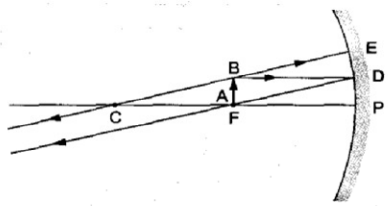
Images formed by a concave mirror

Table 1.1 Images formed by concave mirrors

	Object position	Image position	Nature
(a) 	at infinity	at the focus F	real and point-sized
(b) 	between infinity and the centre of curvature C	between F and C	real, smaller than the object, inverted
(c) 	at C	at C	real, same size, inverted
(d) 	between C and F	between C and infinity	real, enlarged, inverted

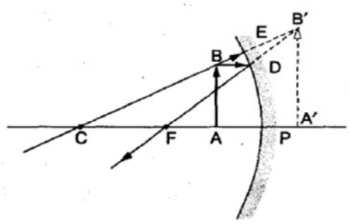
Case (e) needs special attention. The object AB is placed at the focus. The point A is on the focus. The ray BD is parallel to the principal axis. It passes through the point A after reflection. The ray BE passes through C and retraces its path. The reflected rays DA and EB turn out to be parallel. We can say that they intersect at infinity to form a real image of B below the principal axis. In this sense, the image of AB can be considered real and inverted. However, when the reflected rays fall on the eye, they appear to come from a point behind the mirror, above the principal axis. In this sense, the image may be considered virtual and erect.

(e)



(e)	at F *	at infinity	real, infinitely large, inverted
(f)	between the pole P and F	behind the mirror	virtual, enlarged, erect

(f)



In Case (f), rays coming from B diverge after reflection. If the reflected rays are produced backwards, they meet at B'. To the eye, the reflected rays appear to come from B'. Thus B' is the image of B, and A'B' is the image of AB. It is a virtual image because the rays do not actually intersect. The size of the image is larger than that of the object, and the image is erect.

EXAMPLE 1 2 We want a concave mirror to form a virtual image of an object See Table 1 1 and find out where the object should be placed. Is the image erect or inverted? Is the image smaller or larger than the object?

Solution We see from Table 1.1 that a concave mirror forms a virtual image of an object when the object is placed between the pole and the focus. The image is erect and larger than the object.

Sign Convention

With spherical mirrors, we generally come across four distances parallel to and two distances perpendicular to the principal axis. Each of these six distances has a particular mathematical quantity associated with it. These quantities are given in Table 1.3.

Table 1.3

…stanc.	[illegible]	
From the pole to the object	object-distance	u
From the pole to the image	image-distance	v
From the pole to the focus	focal length	f
From the pole to the centre	radius of curvature	r
Height of the object	object-height	h_o
Height of the image	image-height	h_e

The above definitions of u and v are for a point object placed on the principal axis. If an object is placed away from the principal axis, u corresponds to the distance from the pole to the foot of the perpendicular drawn from the object to the principal axis. Similarly, v corresponds to the distance from the pole to the foot of the perpendicular drawn from the image to the principal axis. The quantities h_0 and he are defined for a linear, extended object placed perpendicular to the principal axis.

For finding a particular distance when some others are given, we need to assign these quantities (u, v, f, r, h_0, h_i) positive or negative signs according to a fixed set of rules, or a convention. We follow the Cartesian coordinate's convention. The sign convention for the distances parallel to the principal axis is positive along the positive side of x axis and negative for the negative side of x axis. Height of Image and object is taken as positive along the positive side of y axis and negative along the negative side of y axis.

The Mirror Equation: Relation between u, v, f

For any spherical mirror of small aperture, and for any position of the object, the three quantities

u, v and f satisfy the simple algebraic relation given below.

Mirror Equation $$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

EXAMPLE An object is placed at a distance of 30cm from a concave mirror of focal length 20cm. Where will the image be formed?

Magnification

The size of an image formed by a plane mirror is the same as that of the object. This is not always the case with spherical mirrors. A convex mirror forms an image that js smaller than the object. You might have noticed this in the rear-view mirrors of vehicles. The size of the image formed by a concave mirror can be smaller than, equal to or larger than the size of the object, depending on where the object is placed in front of the mirror. h

Let h_0 and h_i denote the object-height and the image-height respectively. The ratio is called magnification, and it is denoted by m. It turns out that

$$m=\frac{h_e}{h_0}=-\frac{v}{u}.$$

$$m=-\frac{v}{u}$$

Note that m can be either positive or negative, depending on the nature of the image. If m is positive, h0 and he have the same sign. This means that the image is formed on the same side of the principal axis as the object. In other words, the image is erect. If m is negative, the image is inverted.

EXAMPLE A 2.0-cm-high object is placed perpendicular to the principal axis of a concave mirror. The distance of the object from the mirror is 30 cm, and its image is formed 60 cm from the mirror, on the same side of the mirror as the object. Find the height of the image formed.

ABHYAS Academy, Behind Pragat Shiv Mandir, Near Govt. College, Nishat Cinema Road, Ambala Cantt.
Ph No. +91-171-2631595, 9416541198, e-Mail: anusethi1968@yahoo.com Website: www. abhyasonline.in