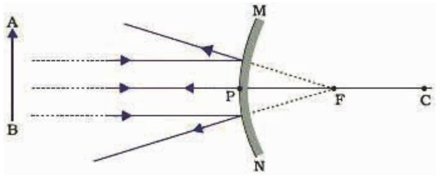
CHAPTER 13

LIGHT: REFLECTION & REFRACTION AT SPHERICAL SURFACES



In the previous chapter, we have learnt about the laws of reflection & refraction at plane surfaces. We also did some activities to observe the phenomena of refraction. Can the same laws be applied to understand reflection & refraction from spherical surfaces?

We will try to discover the answer to the above question in this chapter. We shall also perform experiments involving spherical mirrors and lenses.

13.1 Reflection from spherical Mirrors

Recall, that in class 7th, you had learnt how polishing the inside or outside of a hollow sphere turns it into a mirror. The inner surface of a hollow sphere is called its concave side and the outer surface is called its convex side. If the inner side is polished with silver, then we get a Convex mirror. Alternatively, if the outer side of sphere is polished then we get a Concave Mirror.

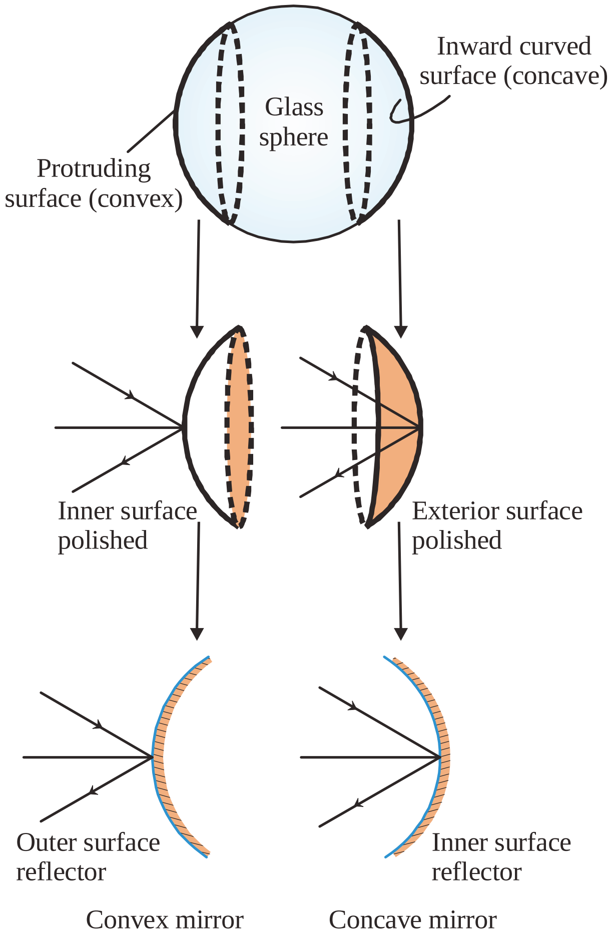


Figure-1: Spherical mirror

Activity-1

Take a serving spoon made of stainless steel. Bring the outer surface of spoon closer to your face and observe. Can you see the image of your face in the spoon? Is the image same as the one you see in a plane mirror, or is it different? Is the image inverted? Is the image bigger, smaller or of the same size as the object (your face)?

Now observe the same characteristics of the image from the inner side of the spoon. You might observe that the image is bigger and erect (not- inverted). Now slowly increase the distance of spoon from your face. May be you will now observe the that the image is inverted. You can repeat the experiment and try to observe the image formation of a Pen or pencil from the two sides of the spoon.

13.1.1 Some important definitions related to spherical Mirrors

The centre of the reflective surface of a spherical mirror is called its POLE and this point is denoted by the letter P in diagrams. Pole is situated on the surface of the hollow sphere from which the mirror has been made. As you know, a spherical mirror is a polished part of a hollow sphere, therefore the Centre of the hollow sphere is called the centre of curvature of the Mirror, and is denoted by C in diagrams. "C" is not a part of the surface of sphere, it lies outside the surface. The distance between C & P, which is also the radius of the hollow sphere is called the Radius of curvature of the spherical mirror. It is denoted by "R" in diagrams.

The line passing through the Centre of Curvature "C" and pole "P" is called the principal axis. It is perpendicular to the Pole because any line through centre of a circle is perpendicular to the circumference. The diagram represents the cross section of a spherical lens which is a circle.

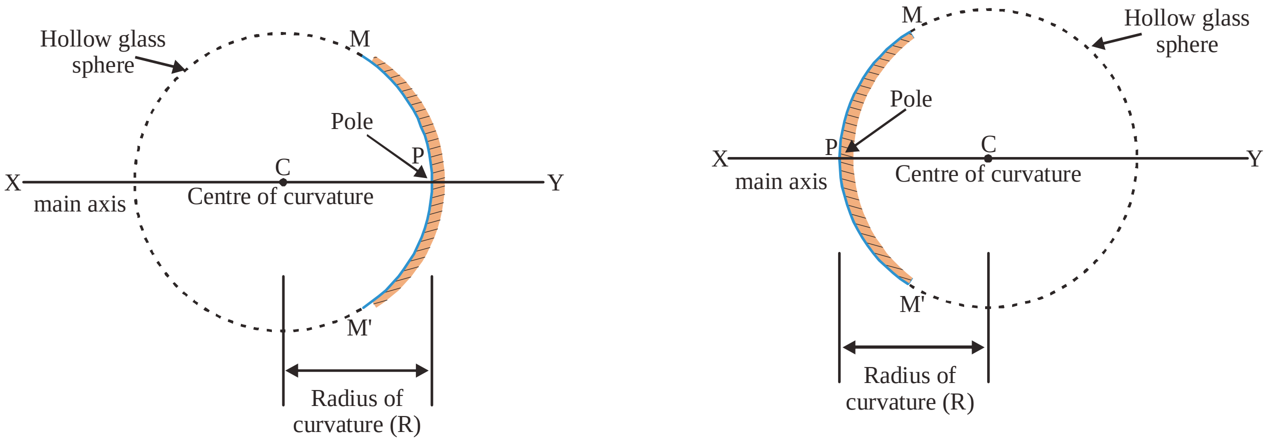


Figure-2

Another important location in the discussion of spherical mirrors is the FOCUS. To understand the concept of focus, let's perform an activity.

Activity-2

Take a concave mirror and place its so that the reflecting surface is facing towards the sun. The light coming from sun gets reflected from the mirror. We will try to obtain the reflected light on a piece of paper. Place a paper in front of mirror and adjust its position till a very sharp bright point is seen. This is the image of sun, formed from the mirror and obtained on the paper (which acts as a screen to obtain image). What will happen if this arrangement of paper and mirror is maintained for some time?

The image of the sun formed has been obtained on a screen outside mirror, so it is a Real image.

The point at which the image is obtained is called the focal point of the mirror. As you can see, the focal point lies outside the mirror. The focal point is indicated in diagrams by the letter "F".

In the case of concave mirror, light rays coming parallel to principal axis converge after reflection at the focal point F. In the case of convex mirror, Rays coming parallel to principal axis, appear to be coming from the focal point. The image formed in case of a convex mirror cannot be obtained on screen and is called a Virtual Image.

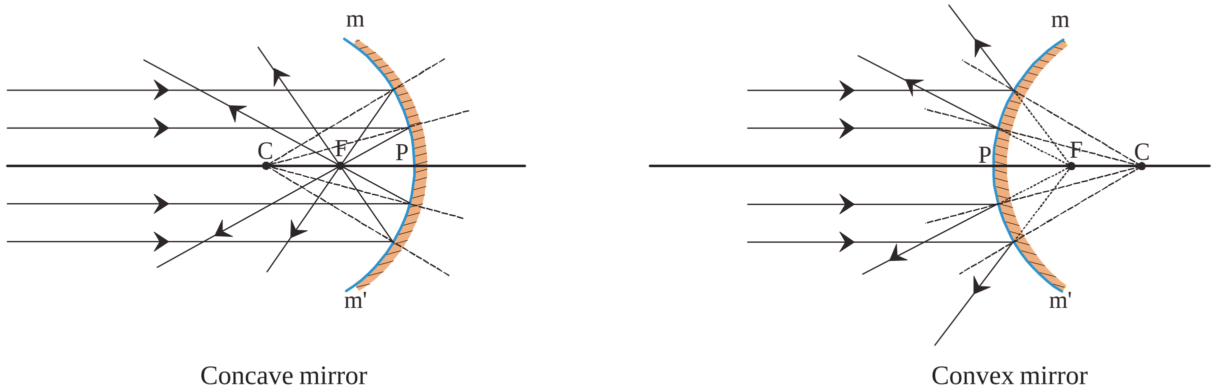


Figure-3

The distance between Pole P and focal Point (or Focus) F of a spherical mirror is called the focal length of the mirror and is denoted by "f".

The boundary of the curved surface of a spherical mirror is called its aperture. In figure-2, mm' represents the aperture of the mirror.

For mirrors with small aperture, the focal length "f" is half of the radius of curvature "R". Mathematically, $R = 2f$. In other words, (for small aperture mirrors) the focal point is the mid-point of the line joining the centre of curvature C and Pole P.

13.1.2 Laws of Reflection at Spherical Surfaces

In the previous chapter, we had learnt the laws of reflections. These laws apply uniformly to all surfaces - plane & curved. If we know the angle of incidence of a ray of light on a curved surface, then we can get information about the angle of reflection as well. The angle of incidence is the angle between the incident ray of light and the normal to the surface. To understand the concept of normal on a curved surface, Let us perform an activity.

Activity-3

Take a hollow rubber ball and cut it into two halves. As shown in the figure, put some pins on the inner and outer surfaces of the ball. All these pins are perpendicular (or Normal) to the surface of the ball on the point where they have been inserted. In the case when pins are put on the outer surface of the ball, they appear to diverge from each other, while, the pins inserted on the inner face appear to converge in the same direction.

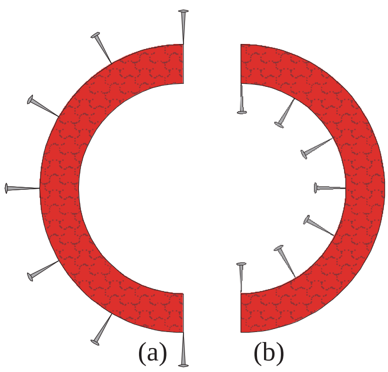


Figure-4

From this, we can get an idea of what happens to the normal on the surface of a spherical surface.

A convex mirror is like the outer surface (Figure- 4a) of the ball and a concave mirror is like the inner surface of the ball (Figure- 4b).

The point where pins appear to meet is called the Centre of curvature of concave mirror. According to geometry, any line passing through the centre of a sphere to its surface its Normal to that point on surface.

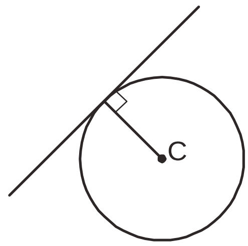


Figure-5

Discuss

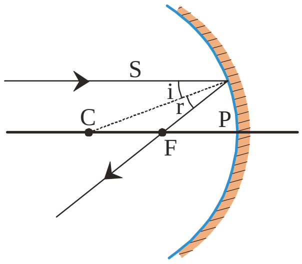


Figure-6

Why do the light rays falling on a convex mirror appear to be coming from a point while those falling on a concave mirror meet at a point.

For the light ray S, the angle of incidence is equal to the angle of reflection. $\angle i = \angle r$.

13.1.3 Sign convention for Reflection at spherical surfaces

For the study of reflection at spherical surfaces, we will follow a fixed sign convention system called the Cartesian coordinate sign convention. In this convention, we take the pole P to be the origin and the principal axis (XX') as the X axis. The following features of this convention must be kept in mind:

(i) The object is always placed towards left hand side of the mirror. This means that light from the object travels towards right and gets reflected and then travels towards left side direction again.

(ii) All measurements taken in X-direction are measured through the pole and parallel to Principal axis.

(iii) Distances measured towards right side of the pole (along +X axis) are taken to be positive and those measured towards left (along +X axis, or against the direction of travel of incident light) are taken to be negative.

(iv) The distances measured perpendicular to X-axis, in upwards direction (+Y-axis) are taken to be positive.

(v) The distances measured perpendicular to X-axis, in downwards direction (–Y-axis) are taken to be negative.

The above sign convention is represented pictorially below. This sign convention will be used in deriving the mirror formulae and in solving problems.

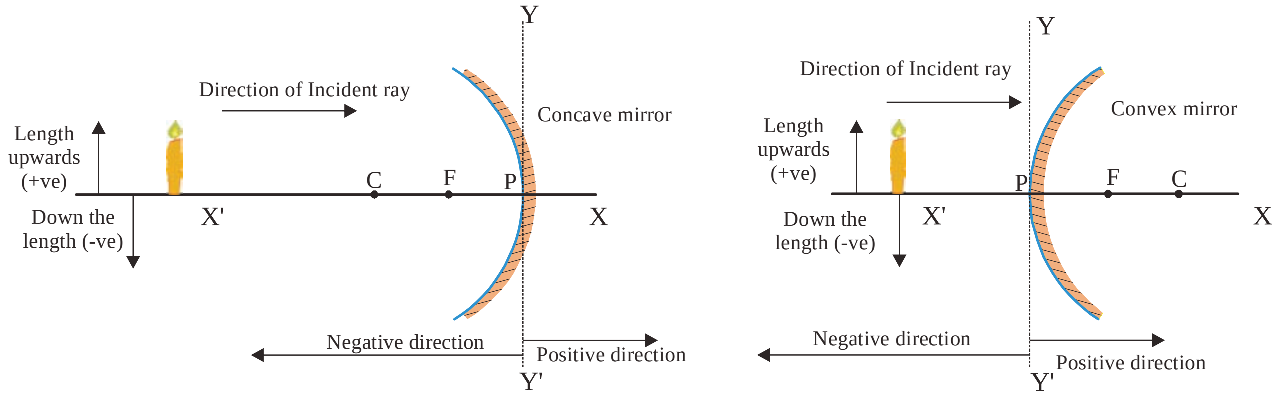


Figure-7

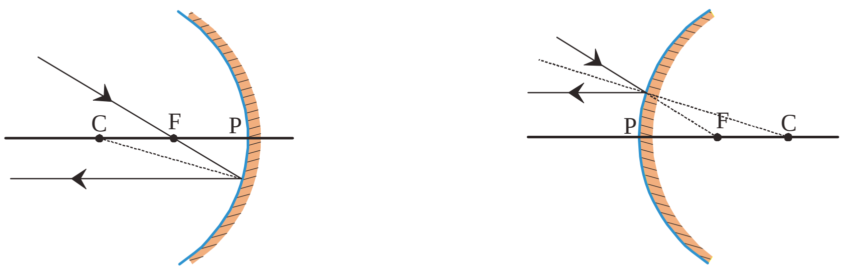
13.2 Laws of Image formation from spherical mirror

1. The light rays incident on the mirror parallel to the principal axis:
   - (a) Converge at the focal point (before travelling away from there), in the case of concave mirror.
   - (b) Appear to be coming from the focal point, in the case of convex mirror.

(a) Concave mirror (b) Convex mirror

Figure-8 (a)

2. The light rays, which:
   - (a) Pass through the focus of concave mirror, travel parallel to principal axis after reflection.
   - (b) Appear to travel towards the focus of a convex mirror, travel parallel to principal axis after reflection.



(a) Concave mirror (b) Convex mirror

Figure-8 (b)

3. We know that light rays incident normally on a mirror retrace their path after reflection. Therefore:

(a) Light rays travelling through the centre of curvature "C" retrace their path after reflection, in the case of concave mirrors.

(b) Light rays that appear to be directed towards the centre of curvature "C", for a convex mirror, retrace their path.

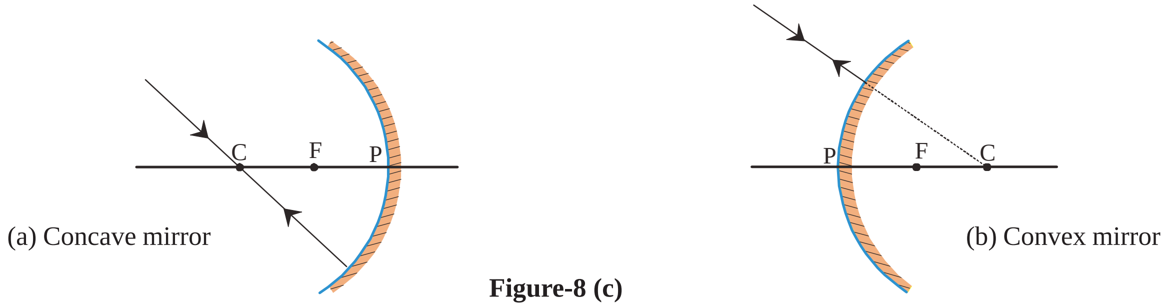


Figure-8 (c)

4. When a ray of light is incident on the pole, making some angle with the principal axis, then after reflection, it makes the same angle with principal axis in the opposite Y-axis side. This is because the Principal axis is Normal to the mirror at the pole P.

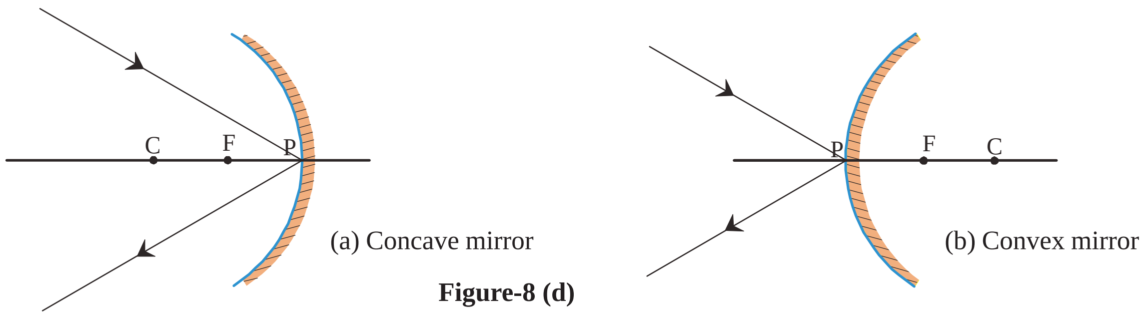


Figure-8 (d)

13.2.1 Image formation by Spherical Mirrors

Now, we will perform an activity to understand the Size, Position and orientation of image of an object formed by spherical mirrors.

Activity-4

White paper, V-Stand, Meter scale, Concave Mirror with known focal length, candle.

Procedure: Place the concave mirror on the V-stand and arrange the mirror, Candle, meter-scale and paper as shown in the diagram below. If V-sand is not available, then place some pins on a piece of thermocol to firmly hold the mirror.

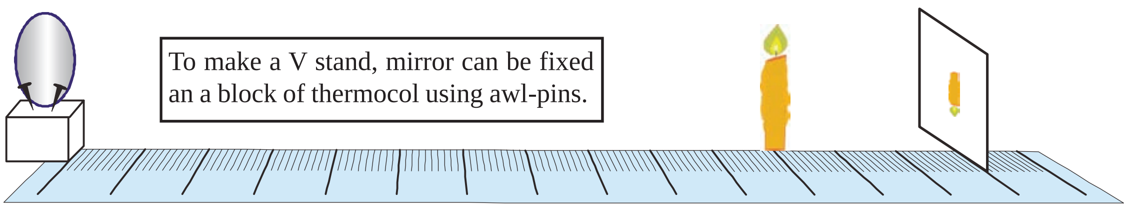


Figure-9

Vary the location of the candle and the paper to obtain a sharp image of the candle on the paper. When a sharp image is obtained, take down the readings and fill the table given below.

Table-1

S. No	Candle-Mirror Distance (u)	Paper-Mirror Distance (v)	Size of Image in comparison to object (Larger, Smaller, Same)	Image orientation (Erect/ Inverted)	Nature of Image (Real/ Virtual)
1	At infinity				
2	Beyond C				
3	At C				
4	Between C & F				
5	At F				
6	Between F & mirror				

In this activity, the Candle was an object, and the paper acted as a screen on which we tried to obtain image of the object. From the above activity, we can say that the Size, Position, Nature, & orientation of the Image depends on the position of the Object with respect to the mirror. For some cases, the Image is virtual and cannot be obtained on the paper, while for others the image is Real. Depending on the position of the object, the image can be larger/smaller/of same size as that of the object. To further understand the concept of image formation, let us try to make ray-diagrams for different positions of the object with respect to the mirror.

To see the real image, you have to place your eyes in a location from where your eyes can receive the light coming from the image. It is impossible to see the image from the backside because no light from the image is travelling in that direction. If you place a screen at the exact position of the image, then the screen will display the image and now it is possible to look at the screen from backside because screen is reflecting the light of the image in that direction.

However, If the image is virtual image, then you have to look into the mirror as it cannot be obtained on the screen.

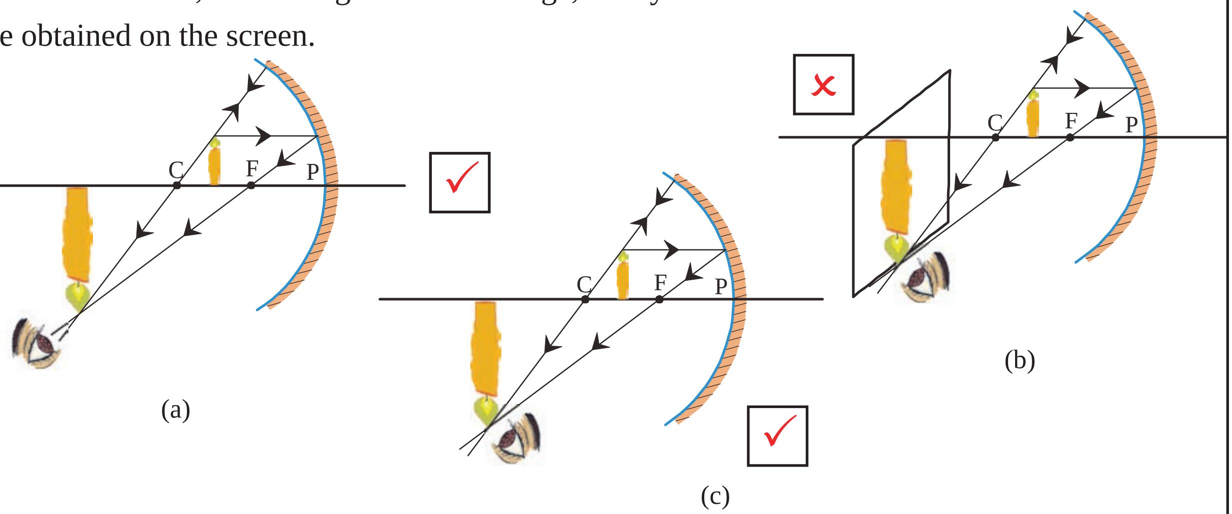
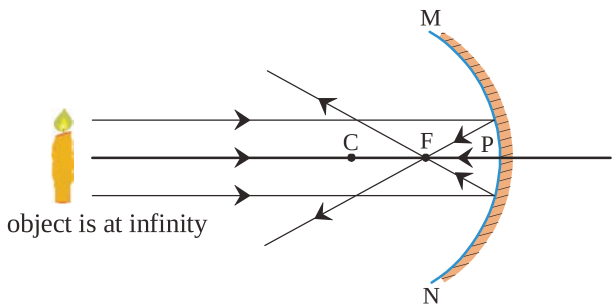


Figure-10

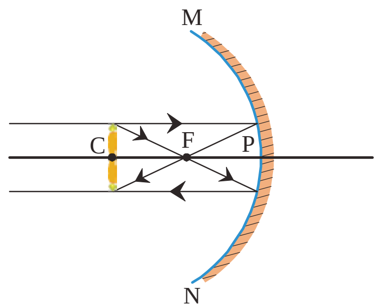
13.2.2 Ray Diagrams for different positions of the object

Based on the experience from Activity-4 and the knowledge of laws of reflection for spherical surfaces, try to draw ray diagrams for the image of the candle by assuming the candle in different positions.

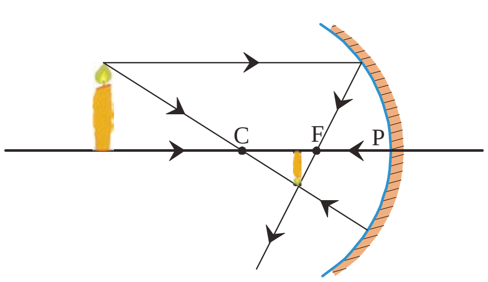
(a) Ray Diagram for Concave Mirrors



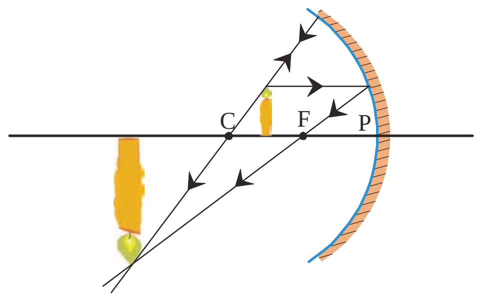
(i) When the object is at infinity



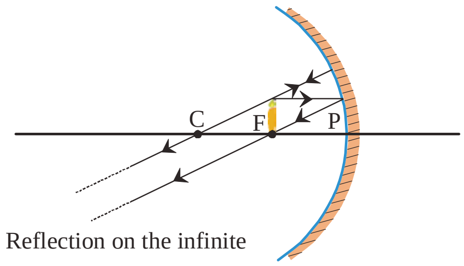
(ii) When the object is at C



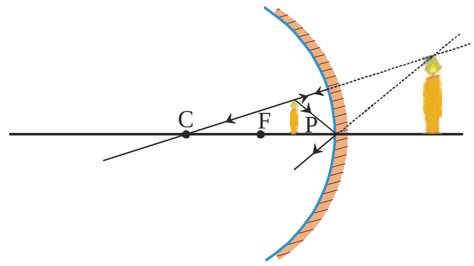
(ii) Behind the object C



(iv) When the object is between F and C



(v) On the object F



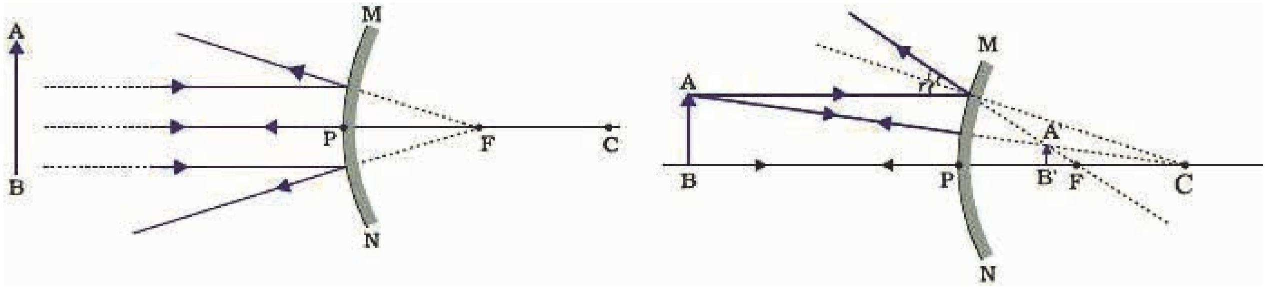
(vi) When the object is between F and the mirror

Figure-11

(b) Ray diagrams for convex mirrors

For the study of image formation by convex mirrors, we will allow two types of position for the object. Firstly, the object can be placed at infinity and second, at a finite distance from the mirror.

Fill table-2 for the size, position, orientation of image formed by a convex mirror. You can take the help of figure-12 for this.



(a) When the object is at infinity (b) when at a finite distance from the mirror.

Figure-12

Table-2

S.No.	Mirror-candle Distance (u)	Image-Mirror distance (v)	Size of Image in comparison	Image orientation (Erect/ Inverted) to object (Larger, Smaller, Same)	Nature of Image (Real /Virtual)
1	At infinity				
2	Between infinity & P				

In concave mirror, the reflected light rays actually meet at a point, while in plane mirror and convex mirrors, they only appear to be coming from a common point. The position, Size, etc. of a Virtual image is found by extending the light rays in the ray-diagram backwards. This artificial extension is shown by dotted lines.

Did you note that Real image is always inverted and virtual image is always erect?

Question

- How can you differentiate between a plane, convex & concave mirror by either touching the mirror or observing image formations?

13.2.3 Relation between Parameters for spherical mirrors

For different positions of the object placed in front of a spherical mirror, the position of the image and size of the image also varies. Can we find a relation between the various parameters involved in image formation, so that we can calculate the image properties? First of all, let's classify the various parameters into - variables & Constants of the mirror.

1. Variable: These are those quantities which can change in value for each instance of image formation.
2. Fixed: These are those quantities that hold the same value once the mirror & object have been chosen. They can only be changed if the mirror is changed.

We begin by tabulating these properties.

Variables	**Fixed**
Focal length of mirror (f)	Object-mirror distance (u)
Radius of curvature (R)	Image-Mirror distance (v)
Object height (h)	Height of Image (I or h')
Magnification (m)	

Now, let's try to understand the relation between them.

13.2.4 Relation between focal length (f) and radius of curvature (R)

We shall try to arrive at a relation between f & R, using previously learnt Mathematical knowledge and by drawing ray diagrams for a concave mirror.

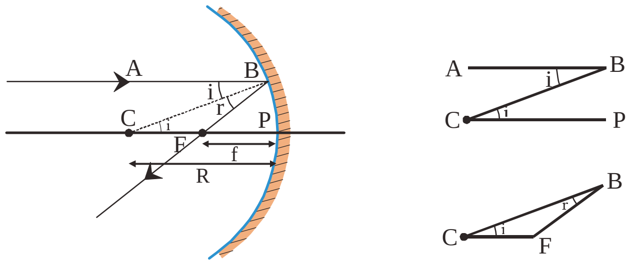


Figure-13

Take a concave mirror with centre of curvature C, pole P, focus F and axis CP. From the diagram, we can see that ray AB parallel to axis CP gets reflected along BF direction. We know that the line CB will be normal at B.

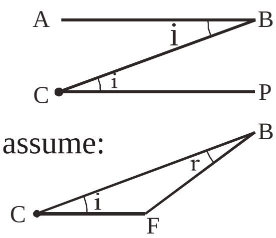
Therefore:

∠ABC = ∠CBF (from law of reflection) (Eq. 1)

∠ABC = ∠BCF (Because AB || CP, and CB is transversal. Alternate interior angles)(Eq. 2)

So, in ∠CBF, from (Eq. 1 & Eq. 2), ∠BCF = ∠CBF

Hence, CF = BF (Because ∠CBF is isosceles triangle) (Eq. 3)



If the mirror is small and point P is very close to point B, then we can assume:

BF = PF (Eq. 4)

From (Eq. 3 & Eq. 4): CF = PF.

Also, CP = CF + FP = PF + FP

(from Eq. 5) = 2 PF

So, PF = $\frac{PC}{2}$. In other words, focal length = (½) Radius of curvature

$$f = \frac{R}{2}$$

This relation is valid for all spherical mirrors, convex & concave. The only condition is that the Radius of curvature should be very large so that the points B & pole P can be assumed to be close enough.

13.2.5 Relation between object distance (u), image distance (v) and focal length (f): Mirror Formula

The distance of object from pole P is called the object distance (u), distance of image from the pole is called image distance (v), and distance between the focal point F & pole P is called the focal length of the mirror.

These three quantities are related by the mirror formula, given below.

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

This relation holds true for all spherical mirrors. While solving Questions, take care to insert u, v, & f in the mirror formula with proper signs (+ or -) using the Cartesian sign convention system.

For concave mirror, u & f are always negative. For real image formation to take place, v will be negative. If v is positive, then it means that the Image is virtual.

13.2.6 Magnification (m)

Magnification produced by a spherical mirror is the proportional change in the size of the image as compared to that of the object. It is expressed as the ratio of the height of the image to the height of the object.

If height of the object is (h) and that of the image is (I), then magnification is given by:

$$m=\frac{I}{h}$$

It can also be expressed in terms of the object distance (u) & image distance (v).

$$m=\frac{(I)}{(h)}=-\frac{\mathrm{v}}{\mathrm{u}}$$

It is obvious that this is a measure of the proportional change in size. We know that for a given mirror and object, the object height (h) is fixed, but with change in the position of the object, the image height (I) can change.

If I = h, then, m = $\frac{I}{h}=1$

If I > h, then, m = $\frac{I}{h}>1$

If I < h, then, m = $\frac{I}{h}<1$

Please note that h is taken as positive because usually, the object is place on the principal axis and standing upwards. For virtual image, the image height should be taken as positive and for real images as negative. This means that magnification will be positive for virtual images and negative for real images.

13.2.7 Uses of spherical mirrors

(a) Uses of concave mirror

Usually, concave mirrors are used in Torch, Searchlights and headlights of vehicles to obtain a parallel beam of light. They are also employed as shaving mirrors to obtain a large image of face. Dentists use this type of mirror to obtain magnified image of tooth. Large sized concave mirrors are used to focus sunlight in solar power plants.

(b) Uses of convex mirror

The mirror that you see on the side of a car, which the driver uses to see the image of vehicles behind him are convex mirrors. They are used as rear view mirror because they always form erect image, not inverted. But the disadvantage is that the image is smaller than the object. Since they are curved in a manner bulging outwards, they have a larger field of view than the concave type. Some super markets have now installed large concave mirrors at the turning so that two customers don't collide.

Example-1: An object is placed at a distance of 10 cm from a convex mirror with focal length 15 cm. Find the position, size and orientation of the image.

Solution: Focal length of convex mirror (f) = 15 cm

Object distance (u) = –10 cm

(Here the negative sign has been taken as per convention)

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

Putting values of u and f with proper signs, we get:

$$\frac{1}{15} = \frac{1}{-10} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{15} + \frac{1}{10}$$

$$\frac{1}{v} = \frac{2+3}{30}$$

$$\frac{1}{v} = \frac{5}{30}$$

$$\frac{1}{v} = \frac{1}{6}$$

V = 6 cm

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

$$= m = \frac{-6}{-10}$$

m = 0.6

So we conclude by saying that a mirror of focal length 15cm, forms the image of an object placed 10 cm away from it, at a distance of +6 cm from the mirror. The size of the image is 0.6 times the size of the object. Also, since the magnification produced is positive, we can say that the image will be virtual and erect.

13.3 Refraction at spherical surfaces

You would have seen many people wearing spectacles for correcting their vision. Have you ever touched the surface of the glass used? Is it thicker on the sides or thicker in the middle?

In the previous chapter, we had learnt about refraction at plane surfaces. In this chapter we extend our understanding of refraction phenomena to curved surfaces.

13.3.1 refraction by lenses

Lens is a transparent medium covered by two sides. At least one of the sides is curved. Such type of lenses either converge a parallel beam of light to a point of diverge the light away.

If a lens has both sides concave, then it is called a bi-concave (or concave) lens. If a lens has both sides convex, then it is called a bi-convex (or convex) lens. Bi-concave lenses are thinner in the centre and thicker on the sides. Bi-convex lenses are thicker in the centre and thinner on the sides.

In all our discussions, we will discuss only those lenses which are called thin lenses - it means they can be either concave or convex, but the thickness of the lens is negligible. So, the thickness of lens will not be a part of our calculations.

13.3.2 Some definitions related to spherical lenses

Each of the two surfaces of a spherical lens is part of a sphere. Since, lenses have two surfaces, there are two centres of curvature for a lens. These are called C_1 & C_2. The distances of the centre of lens (equivalent of pole of mirrors) to the centres of curvature are called the radii of curvature R_1 & R_2. The line joining C_1 & C_2 is called the principal axis and centre of lens (o) is called the Optical centre of lens.

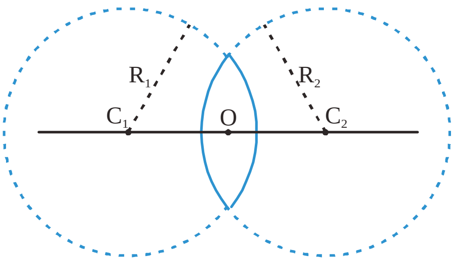


Figure-14

The effective diameter of the curved surface of a lens is called its aperture.

- Can you find the focus of a lens? Try repeating Activity-2 with lenses.

Think: what happens when a parallel beam of light is passed through a lens.

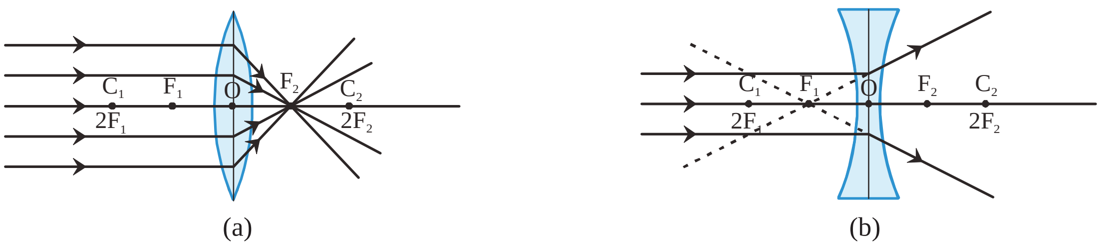


Figure-15

Observe figure 15 (a) carefully.

A beam of light parallel to principal axis converges at a point after refraction through the lens. The point of convergence on the principal axis is called Focus (F_1) of the lens. The distance between optical centre O and focus F, is called the focal length f of the lens.

A bi-concave lens is made up of two spheres bent towards inside. It is thin in the centre and thick at the sides. When a beam parallel to the principal axis of such a concave lens gets refracted due to the lens, then the rays diverge. The refracted rays appear to be coming from a point on principal axis, called the focus point (F_1) of the concave lens. Both, Convex and concave lens have two foci, which are at equal distances from optical centre O and on the opposite side. The foci are situated mid-way between the optical centre and the centres of curvature. This means, R = 2 f, Radius of curvature is double the focal length of the lens. The focal plane is the plane which is perpendicular to the principal axis and passes through the focus point.

13.3.3 Sign convention for spherical lenses

For lenses, we will use a sign convention similar to that used for spherical mirrors. We will use the same rules. The measurements in case of mirror was taken from the pole of mirror. Similarly, in the case of lenses, all measurements will be made from the optical centre of the lens. According to this convention, the focal length of convex lens will be taken to be positive and that of concave lens will be taken as negative. All measurements above principal axis will be positive while those below will be negative. We will always draw diagram so that light travels left to right. Measurements taken towards right will be positive and that towards left will be taken as negative. For all calculations, the quantities must be used with their proper signs, positive or negative.

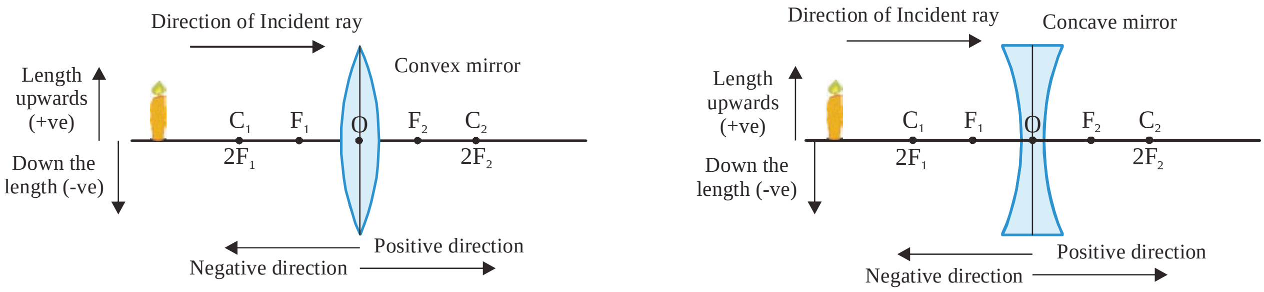


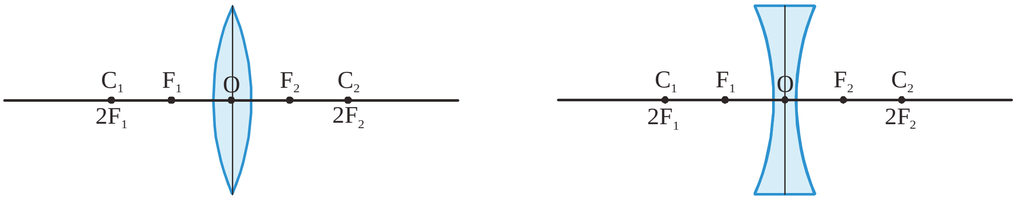
Figure-16

13.3.4 Rules for image formation by lenses

Because we are considering lenses with negligible thickness, so we can treat two surfaces of the lens as one.

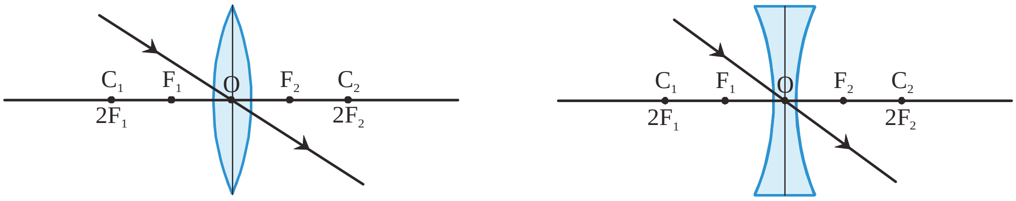
As per the rules of refraction, analyse the ray diagrams given below. Discuss amongst your-selves-

- What will happen to a ray of light travelling along the principal axis as it gets refracted by the lens?



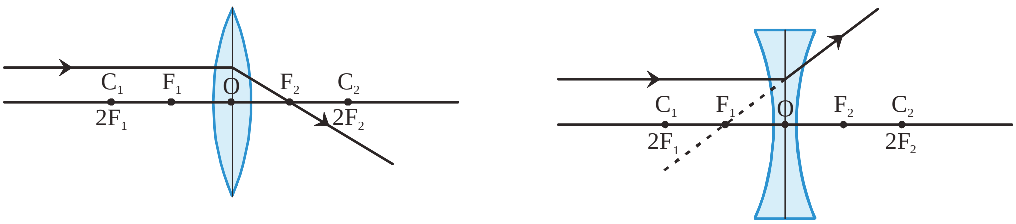
(a) Convex mirror (b) Concave mirror

- What will happen to a ray of light passing through the optical centre?



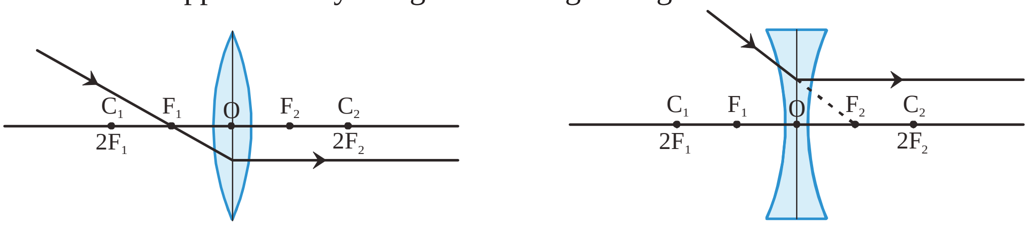
(a) Convex mirror (b) Concave mirror

- What will happen to a ray of light travelling parallel to principal axis?



(a) Convex mirror (b) Concave mirror

- What will happen to a ray of light travelling through the focus?



(a) Convex mirror (b) Concave mirror

Figure-17

Think about another situation. What will happen to a parallel beam of light passing through the lens, if it is inclined at some angle to the principal axis?

In this case, the light rays will appear to diverge from a point on the focal plane for concave lens. The light rays will converge at a point on the focal plane for convex lens.

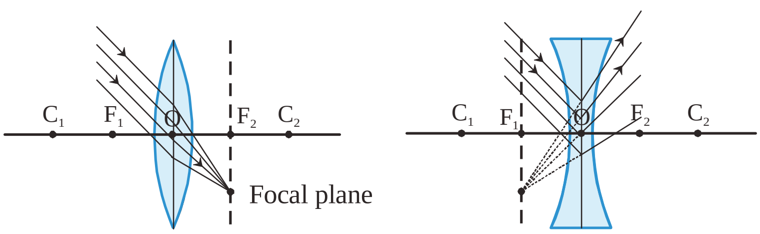


Figure-18

13.3.5 Image formation by lenses

Activity-5

Take a convex lens and find out its focal length or take a convex lens with known focal length.

Now set the lens near a scale on a V-stand, like we did in Activity-4 for mirror.

Mark both foci of the lens as F_1 & F_2 on the scale, using a chalk. Similarly mark distances $2F_1$ & $2F_2$.

Put a burning candle much behind $2F_1$. Obtain an image of the candle on a screen kept on the opposite side of the lens. Note down the size, position and orientation of the image.

Put candle in various locations, as mentioned in the table below, observe the image and fill the table.

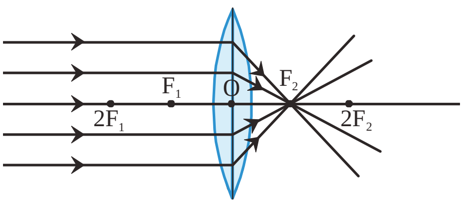
Table-3

S. No.	Candle-Mirror Distance (u)	Paper-Mirror Distance (v)	Size of Image in comparison to object (Larger, Smaller, Same)	Image orientation (Erect/ Inverted)	Nature of image (Real/Virtual)
1	At infinity				
2	Beyond $2F_1$				
3	At 2F1				
4	Between $2F_1$ & F_1				
5	At F_1				
6	Between F_1 &optical centre				

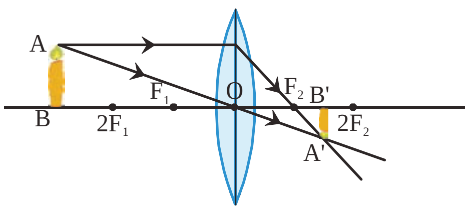
13.3.6 Ray diagrams for images formed by lenses for various object positions

(A) Ray diagrams for convex lens

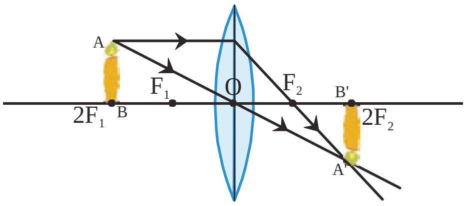
The ray diagrams for image formed by varying object position for a convex lens, as per the table-3, are given below: (Insert figure 19 here)



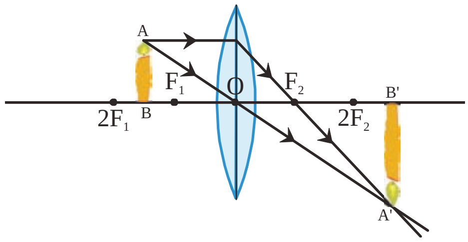
(i) When the object is at infinity



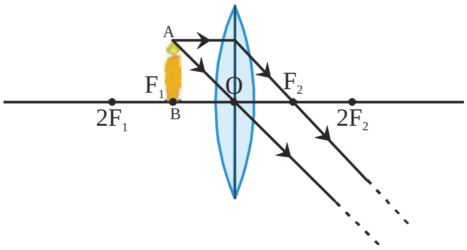
(ii) Behind the object $2F_1$



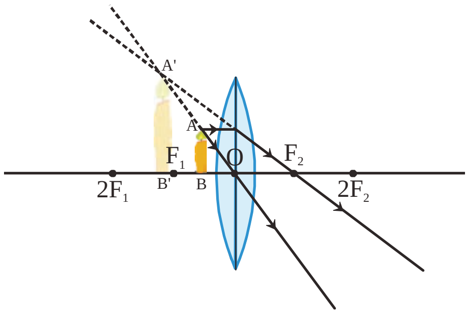
(iii) On the object $2F_1$



(iv) When the object is between $2F_1$ and F_1



(v) On the object F_1



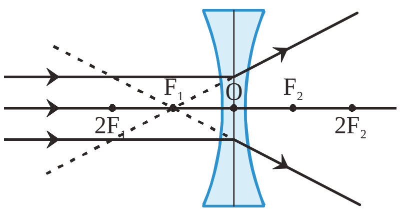
(vi) When the object is between F_1 and optical center

Figure-19

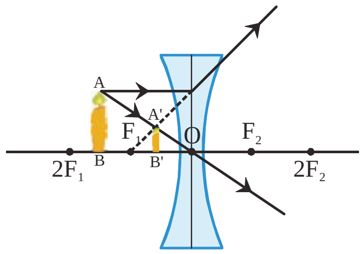
When the object is placed between Focus and optical centre, then we get a Virtual, erect, magnified image on the same side of the lens where object is placed. This characteristic of the convex lens is exploited in making simple microscopes or magnifying glasses. When the object is placed at a distance less than focal length, then the image appears magnified.

(B) Ray Diagrams for concave lens

As done above, make ray diagrams for various positions of object on the principal axis of a concave lens. You will find that for all positions, the image is virtual, erect, smaller than the object and the image is located between the focus & optical centre of concave lens.



(i) When the object is at infinity



(ii) When object is between infinity and optical center O

Figure-20

According to ray diagrams, fill table-4 given below with the position, size, orientation and nature of image.

Table-4

S. No.	Mirror-candle Distance (u)	Image-Mirror distance (v)	Size of Image in comparison to object (Larger, Smaller, Same)	Image orientation (Erect/ Inverted)	Nature of Image (Real/ Virtual)
1.	At infinity				
2.	Between infinity& optical centre				

13.3.7 Relation between parameters for lenses

Like we did for mirrors, we will first tabulate the parameters and study them.

S.No.	Fixed	Variables
1.	Focal length of Lens (f)	Object-mirror distance (u)
2.	Radius of curvature of Lens (R)	Image-Mirror distance (v)
3.	Object height (h)	Height of Image (I or h')
4.	Power of lens (P)	

13.3.8 Relation between object distance (u), Image distance (v) and focal length of Lens (f): Lens Formula

Just like we saw a formula relating u, v & f for mirrors, there is a relation between these 3 quantities for lenses as well. It is called Lens formula and is expressed as:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

The above relation holds true for all spherical lenses and in all cases of image formation. While solving the questions, take care about the proper signs of u, v & f.

13.3.9 Magnification (m) produced by a lens

Like a mirror, the magnification produced by a lens is the ratio of height of the image to the height of the object and is denoted by the letter 'm'. If the height of the object is h, and height of image is h', then:

$$m = \frac{height\ of\ image}{height\ of\ object} = \frac{h'}{h}$$

Magnification can also be expressed in terms of the object distance and image distance as:

$$(m) = \frac{h'}{h} = \frac{v}{u}$$

13.3.10 Power of lens

By now, you know that the function of a lens is to refract (bend) the light rays passing through it. A convex (converging) lens bends the rays towards the principal axis while a concave (diverging) lens bends them away from the principal axis. The power of a lens to converge or diverge light rays, depends on its focal length. Lenses with less focal length bends light more than lenses with more focal length. Therefore, less focal length means more power and Vice-versa.

On the basis of above discussion, we can say that Power of a lens is inversely proportional to its focal length (f - measured in Meters). Power of a lens is denoted by the letter "P". The power of a lens whose focal length is f-meters is given by:

$$Power\ of\ lens\ (P) = \frac{1}{focal\ length\ (f)}$$

The SI unit of Power is called Diopter (D). 1 Diopter = 1/(1 m) . or,

1 D = 1 m-1

So, the power of a lens whose focal length is 1 m, will be 1 Diopter (D).

Because focal length of a convex lens is taken to be positive, its power will be positive. Similarly, because focal length of a concave lens is taken to be negative, its power will be negative.

Practically, when ophthalmologists make corrective-eye glasses, they express lens characteristics in terms of Power of lens and not the focal length. If the power of a lens is given to be +4.0 D, then the positive power suggests that the lens is a convex lens and its focal length can be calculated as under:

$$Power\ of\ lens\ (P) = \frac{1}{focal\ length\ (f)}$$

So, focal length (f) = $\frac{1}{P} = \frac{1}{4.0}$

= 0.25/D = 0.25 m = 25 cm.

So, the focal length of a lens with power 4.0 D will be 25 cm and the positive power means that the lens is a convex lens.

13.3.11 Uses of lenses

We use lenses in many forms in our daily lives. The spectacle use concave, convex, or mixed type of lenses. Even water drops function like a convex lens. Similarly, water or other transparent liquid kept in transparent containers act like lenses. The transparent gems (like Diamond etc.) used in ornaments also act like lenses.

The use of concave or convex lenses is seen in many optical instruments like camera, projector microscope, telescope, etc. The eyes of humans and animals too use a lens to form image of the outside world.

Example-2: A convex lens has focal length 10 cm. An object, 2 cm long, is kept at a distance of 15 cm from the lens. Find the position, size, orientation of the image and the magnification produced by the lens.

Solution: Given: focal length = +10 cm (since lens is convex),

h= 2 cm,

u = –15 cm (using proper sign convention).

We know the lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

On putting values of f and u, we get:

$$\frac{1}{10} = \frac{1}{v} - \frac{1}{-15} \qquad = \frac{1}{v} + \frac{1}{15}$$

$$\frac{1}{v} = \frac{1}{10} - \frac{1}{15} \qquad = \frac{3-2}{30} \qquad = \frac{1}{30}$$

The positive sign of v indicates that the image is Real and inverted. Also,

$$m = \frac{h'}{h} = \frac{v}{u}$$

$$\frac{h'}{2} = \frac{30}{-15}$$

$$h' = \frac{-30 \times 2}{15} = -4 \text{ cm}$$

We know that magnification is given by:

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

$$m = \frac{30}{-15}$$

m = –2

This means that the image will be two times bigger than the object. Since h = 2 cm, h' = 4 cm.

The negative sign of magnification again confirms that the image is real and inverted.

13.4 Some optical instruments made using Lenses

1. **Photographic Camera:** A camera not only produces the image of objects but also captures it for later use.

A camera is made of plastic or metal with the internal body kept completely Black. Towards the front end of camera, is a converging lens whose focus can be adjusted. This lens has less focus and is called the objective. This lens forms a perfect image of the objects facing it. Behind this lens is a screen with a tiny hole in it. This controls the amount of light entering the camera and forms the image on a photographic film. The shutter controls the time duration for which the film is exposed to the incoming light. The object, whose image is desired, is kept at a distance more than twice the focal length of the objective lens. This results in a small, real, inverted image being formed on the photographic film.

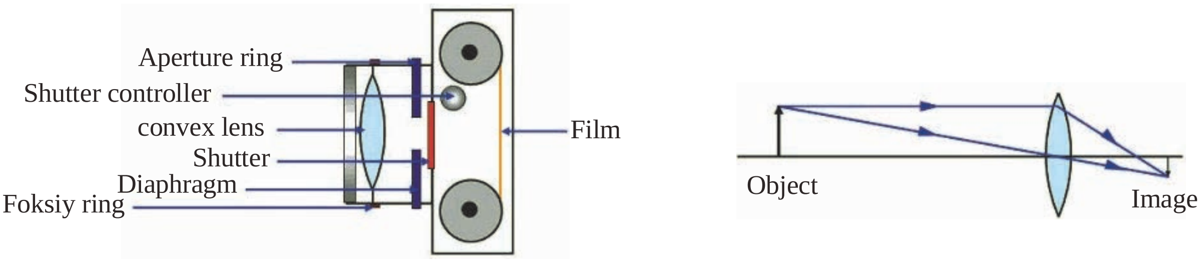


Figure-21 (a)

2. **Microscope:** A convex lens is called a microscope and is used as a "Reading lens" or "magnifying lens". A convex lens with very small focal length is called a simple microscope. If a combination of lenses is used, then the assembly is called a compound microscope.

Simple Microscope: When the object is placed between the optical centre and focus of lens, then the image is magnified, virtual and erect.

Compound Microscope: It is built by inserting a Lens L1in a hollow pipe. This lens is kept towards the object. This is called the objective lens. Another hollow pipe is mounted on this hollow pipe and the position of both pipes can be adjusted by sliding mechanism. This new hollow pipe has a lens L2 Mounted on it. The lens L2 is called the eye piece and is used by the observer to see. The objective lens has smaller aperture and focal length than that of the eye-piece lens. In this assembly, the objective forms a magnified image A'B' of the object AB. The image A'B' works like an object for the eyepiece which forms another magnified image A"B". This is the final image that observer sees.

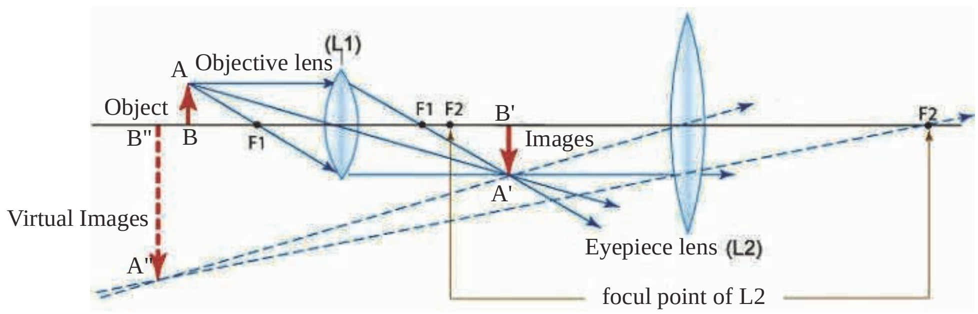


Figure-21 (b)

3. **Telescope:** It is a device used to view far away objects. It can be used to view far away objects on earth or even celestial objects like sun, moon etc.

Astronomical Telescope: There are two convex lenses L_o - the objective and L_e - the eye piece. The effective focal length of telescope is equal to $F_o + F_e$, whereFo is the focal length of the objective and F_e is the focal length of the eye piece.

When the object PQ is far away, the objective forms an image P'Q' at its focus. This image serves as the object for the eye piece. The eye piece forms the image P"Q" of the object which is real, inverted and magnified.

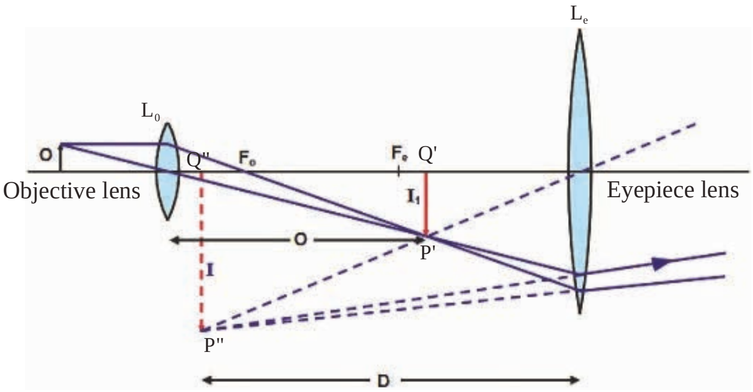


Figure-21 (c)

Keywords

Concave mirror, convex mirror, Pole, focus, focal length, centre of curvature, radius of curvature, principal axis, Lens, convex lens, concave lens, aperture, Eye piece, objective lens

What we have learnt

- Spherical mirrors and lenses form image of objects placed before them. Depending upon the position of object, the image can be real or virtual.
- All reflective surfaces obey the laws of reflection. All refractive surfaces obey the laws of refraction.
- Cartesian sign convention is used for spherical mirrors and lenses.
- Mirror formula relates object distance (u), image distance (v) and focal length of the mirror (f) as: $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

- The focal length of a spherical mirror is half its radius of curvature. $f = \frac{R}{2}$
- Magnification produced is defined as the ration of height of image to the height of object. $m = \frac{h'}{h}$
- The speed of light is different in different media. In vacuum, speed of light: c = 3 × 10^8 m/s.
- Lens formula relates object distance (u), image distance (v) and focal length of the lens (f) as: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$
- The power of a lens is defined as the inverse of its focal length (taken in meters). The SI unit of power is Diopter D. $Power\ of\ lens\ (P) = \frac{1}{focal\ length\ (f)}$

Exercise:

1. Choose the correct option-

(i) Concave lens is -

(a) Only diverging (b) only converging

(c) Neither converging nor diverging (d) Both converging & diverging

(ii) If a mirror forms erect image for objects placed between pole and focus, and it forms Real-Inverted image for object placed anywhere between focus and infinity, then the mirror is-

(a) Concave (b) convex

(c) Plane (d) Convex or Plane

(iii) The image formed by convex mirror is always-

(a) Smaller than object (b) Larger than object

(c) same sized as object (d) Real

(iv) The image formed by a convex lens is always-

(a) smaller and virtual (b) larger and erect

(c) smaller and inverted (d) smaller and real

(v) The focal length of a concave lens is 40 cm. For an object placed 40 cm away from the lens, the image will be formed at-

(a) Infinity (b) 40 cm from lens on the opposite side

(c) Behind the object (d) Between object and lens

(vi) A lens is kept on the book and then raised by 3 cm. The text now appears erect and larger. The focal length of lens is-

(a) 3 cm (b) Less than 3 cm

(c) more than 3 cm (d) 1/3 cm

2. Fill in the blanks:

(i) The image formed by convex mirror is always .... and ...., in all cases.

(ii) To obtain a real image of same size as object, from a convex lens, the object must be placed at ....

(iii) The power of a lens is +5.0 D. The focal length of the lens will be .... cm.

(iv) The focal length of a convex lens is 25 cm. The power of this lens will be .... D.

3. Write down the relation between radius of curvature and focal length of a spherical mirror.

4. In what type(s) of mirrors is the linear magnification less than 1, equal to 1 or greater than 1.

5. The rear-view mirrors used in vehicles are convex mirrors. Why?

6. If image is to be obtained on a screen, what type of mirror should be used?

7. By drawing the ray diagrams for parallel incident beam of light, express what type of mirrors are converging & what type are diverging.

8. Define the following for spherical mirrors:

(i) Centre of curvature (ii) Radius of curvature (iii) Pole (iv) Aperture

9. Write a note on the converging and diverging nature of lenses.

10. What is power of a lens. Write its unit.

11. Write down the sign convention used for lenses.

12. What will be the power of a convex lens of focal length 50 cm? What if the lens is concave?

13. An object is placed at 15 cm from the pole of a concave mirror of focal length 10 cm. What is the size, position, nature and magnification of the image? **(Ans: v = -30, m= -2)**

14. The radius of curvature of a convex mirror is 30 cm. An object of height 5 cm is kept at a distance of 10 cm from the pole. Find the nature, size and magnification of image.

(Ans: v = 6 cm, I = 3cm).

15. The focal length of a concave mirror is 10 cm. To obtain an image 5 times bigger than the object, where should the object be placed so that the image is (i) Real (ii) Virtual.

(Ans: (i) u = –12 cm, (ii) u = –8 cm)

16. The radius of curvature of a convex mirror is 30 cm. What will be the size, position and nature of the image if the object is placed at 12 cm from the pole. Do the same calculation for a concave mirror? (Ans: (convex) v = 6.66 cm, (concave) v = 60 cm).
17. The image of an object kept at 30 cm from the pole of a convex mirror forms at 10 cm. What is the focal length of the mirror?
18. The focal length of a concave mirror is 12 cm. If the object is placed at focus, where will the image be formed?
19. The focal length of a convex lens is 15 cm. Where should be the object placed to obtain a Real image 3 times magnified. **(–20 cm))**
20. The focal length of a concave lens is 30 cm. What will be the position and size of the image if a 30 cm long object is placed at the focus. **(V=15,h'=15cm)**
21. For an object kept at 30 cm from a concave lens, the magnification achieved in 2/3. What is the focal length of lens? **(–60 cm)**
22. For a convex lens of focal length 50 cm, what is the position of image if the object is placed at a distance of: (i) 25 cm, (ii) 75 cm , from the optical centre. **(–50 cm, 150 cm)**
23. What is the focal length of a lens whose power is +1.5 D? **(50 cm)**
24. What is the power of a concave lens of focal length 20 cm? **(–5D)**