Chapter - 9
Light

We see different colourful objects throughout the day but in a dark room or in night our vision and capacity to distinguish colours diminisihes. When we use a bulb then in the light of the bulb we can see even in dark room or in night. Sun is our source of light on earth. When light falls on an object then the object absorbs a few of the colours of light and reflects the rest of the colours. When this reflected light from object reaches our eyes then an image is formed on retina and we can see the object and its colour. An object appears red when it reflects red colour from the light falling on it. If an object transmits all colours through it then we see it as transparent and when object absorbs all colours falling on it then the object appears black. Similarly when an object reflects all colours falling on it then it will appear white to us.

We observe light travelling in straight lines in day to day life but it does not travel in straight line always. When light rays falls on very small obstacles (of the order of the wave length of the light) then light bends around the edges of the object. Wave nature of light is used to understand interference and diffraction phenomena. Interpretation of interaction of light with matter and photo electric effect could not be done with wave nature of light and particle nature of light was used in such explanations. Scientist de Broglie proposed dual nature of light and said that light behaves both as wave and as particle. This dual nature is represented as wavepacket in quantum mechanics. According to this concept the light photons behave some times as wave and some times as particles.

We also observe that when light falls on an opaque object then an image is formed. Image formation is because of linear propagation of light. Light travel in all directions from a light source but in laboratory experiments we restrict light in special direction for the ease of conducting experiments. In figures we usually represent light rays as straight lines but practically isolating a single light ray is almost impossible. In this chapter we shall study phenomena of reflection and refraction using linear propagation of light.

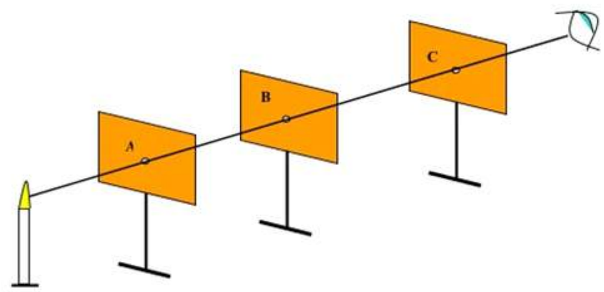


Fig. 9.1 (a) Linear propagation of light

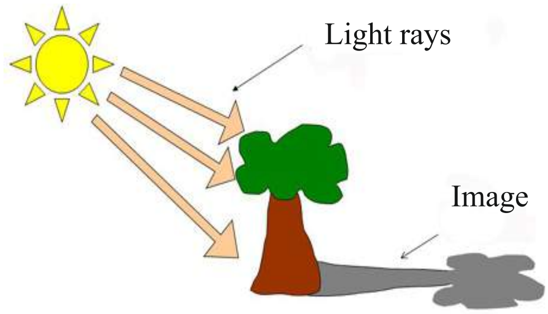


Fig. 9.1 (b) Image of an object

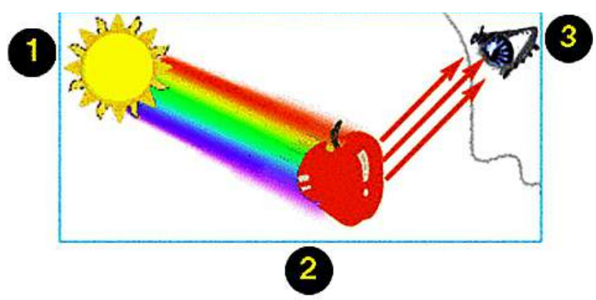


Fig. 9.1 (c) Red colour of an apple

9.1 Reflection of light

Reflection is the change in direction of a wave front at an interface between two different media so that the wavefront returns into the medium from it originated. We encounter two types of reflections in routine : - regular reflection and diffused reflection.

Regular reflection

When light is incident on any smooth plane surface (like mirror) then on looking from a specific direction that plane surface looks shinning while from other direction the surface does not shine. If we change the plane of the mirror then the mirror shines from some other direction. Similarly if the direction of incidence of light is changed then morror gives shining from some other direction decided by the laws of reflection. This deflection of incident light beam by smooth plane surface in the specific direction in the same medium is known as regular reflection.

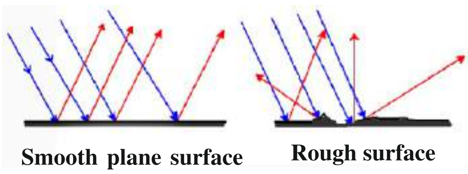


Fig. 9.2 (a) Regular reflection Fig. 9.2 (b) diffused reflection

Diffused Reflection

You might have observed that when light falls on any part of wall from any opening or window then that part of the wall looks bright from every where in the room. This happens because light reflect in all directions after striking the wall. We see almost all objects because of this reason. Rough surfaces, dust particles and microscopic smoke particles diffuse the light in different directions. When sun-light enters the atmosphere then the air molecules scatter blue light more than they scatter red light and thus day time sky is blue. During sunset or sunrise we see red and orange colour because the blue light has been scattered out and away from the line of sight. If we look the outer space from outside our atmosphere then we shall see it black.

Scattering of light in all directions in the same medium by rough surface is known as diffused reflection. Generally, reflecting surface is applied (like silver or aluminum layer) on the back or front of glass or transparent material and then it is used as mirror or reflecting plane.

9.2 Laws of reflection

When light rays propagating through medium-strike at the surface of medium and return back in a particular direction in the medium, then this phenomena is known as reflection of light.

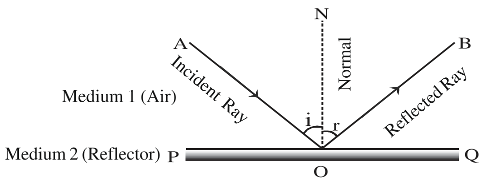


Fig. 9.3 Reflection

Mirrors are often used as reflectors and are made by silvering a surface of a glass. In fig 9.3 PQ is a plane mirror. Light ray AO is incident on the mirror at point O. This ray is reflecting in the direction OB. ON is perpendicular on mirror. Angle AON is known as incident angele 'i' (or angle of incidence) and angle BON is known as angle of reflection 'r'.

By performing a simple activity we can find relation between angle of incidence and angle of reflection.

On a cardboard sheet draw a line PQ and a perpendicular ON from a point O. At any angle 'i' draw a line AB and push two all pins on it. Place a plane mirror upright on line PQ with reflecting surface facing towards line AB and perpendicular ON. View the image of these two all-pins in the mirror and push two more all pins C and D on the card board in such a way that images of A, B and allpins C and D look in straight line. Draw a straight line CD and extend it till mirror. You will see that line CD will meet the line PQ at point O.

You can see that angle AON and DON are

equal. AB is called incident ray and CD is its reflected ray.

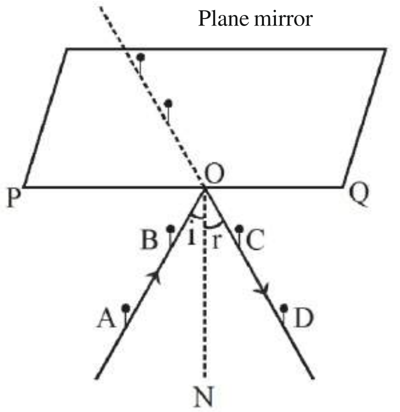


Fig. 9.4 Reflection from plane mirror

Following are rules of reflection

(i) Incident ray, reflected ray and perpendicular on point of incidence are in same plane.

(ii) The angle extended by incident ray with the perpendicular is same as the angle extended by reflected ray with the perpendicular

Angle of incidence i = angle of reflection r

or $\angle i = \angle r$

Image formation in plane mirror

The image formed in a plane mirror is virtual. The image is at the same distance from mirror as the distance of object from mirror though both are in opposite directions. Size of the image is same as that of object. When we look at our image in a mirror then we observe that our left part is right in the image and vice-versa. Similarly if we write letter 'p' on a paper and turn it towards a mirror then we see 'q' in the mirror. This change is known as lateral inversion.

Have you ever pondered why mirror does not invert our image from upside down? If we look carefully and observe then we shall notice that mirror does nothing on its own. To see our image we have to turn towards mirror (left to right) If we place our face and mirror in the same direction then our back will be towards the mirror and we shall not see our image.

Similarly, if we place a mirror in such a way that when we see towards it our face is towards north. In this case when we extend our right hand to point towards east we shall see that our image is also pointing towards east. Now we extednd our hand towards north direction (towards mirror) then our image in mirror will point towards south (towards us). If we cut a cardboard in p shape (or take some toy shaped p) and keep it in our hand while standing in front of mirror then we shall observe that we are holding a p shape in our hand while our left part will be seen right in the mirror . If your analyse these events you shall observe that when you turn the paper (on which p is written) towards the mirror then you are showing q to the mirror as you have rotated the paper by 180^0. In case of a p shaped cardboard you see it as p in image but you may obseve that if one side of this cardboard is red and other is blue then if you are having red facing side of p towards you then the image will be having blue colour.

Example 1 : Prove that image in the mirror is at the same distance from mirror as that of the distance of object from the mirror.

Solution : MM' is a reflecting surface in fig 9.5. P is an object from which rays PO and PO' are incident on MM'. Rays OQ and O'Q' are reflected rays of PO and PO' respectively.

Extending these reflected rays construct a virtual image P' of the object P. ON and O'N' are perpendiculars on mirror.

In triangle POO' and P'OO', line OO' is common therefore from the laws of reflection

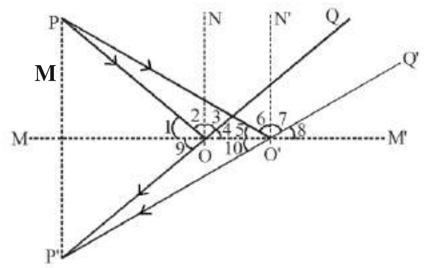


Fig. 9.5 Object- image geometry

$$\angle 2 = \angle 3$$

$$\therefore \quad \angle 1 = \angle 4 = \angle 9$$

or $180° - \angle 1 = 180° - \angle 9$

or $\angle POO' = \angle P'OO'$

similarly $\angle PO'O = \angle P'O'O$

Thus $\Delta POO'$ and $\Delta P'OO'$ are similar triangles

$\therefore$ PO=P'O

& PO'=P'O'

Similarly in triangles PO'M & P'O'M

$\angle$ PO'M=$\angle$ P'OM

& PO' = P'O'

Arm MO' is commom

Therefore $\Delta PO'M$ & $\Delta P'O'M$ are congruent

hence PM=P'M

Thus we see that the distance of object P from the mirror (PM) is same as the distance of image P[1] from the mirror (P[1]M) in the opposite direction. From the geometry we see that line PP[1] is perpendicular on the plane of the mirror

9.3 Spherical mirror

There are a few mirrors whose surfaces are curved. Images from such surfaces are different in shapes. Shape and size of the image depends upon the nature of curved surface. Mirrors having spherical reflecting surfaces are called spherical mirrors. Their surfaces are just like a part of hollow spheres. There are two types of spherical mirrors. Spherical mirrors whose curved reflecting surface is curved from inside are known as concave mirrors. For safety purpose the outer surface of (convex back part) of these mirrors are coloured after depositing a layer of aluminum or silver on them. These are back coated mirrors.

Scientific equipments generally have mirrors having front side coated with reflecting layer so that accurate measurements may be made. Such mirrors are known as front coated mirrors. Such spherical surfaces whose outer part is used as mirror surface are known as convex mirrors. To obtain convex mirror the inner side of the spherical surface is coated with reflecting surface and then protective colour is applied on it. These are also back coated convex mirrors. In a front coated convex mirror the reflecting surface is applied directly on convex surface.

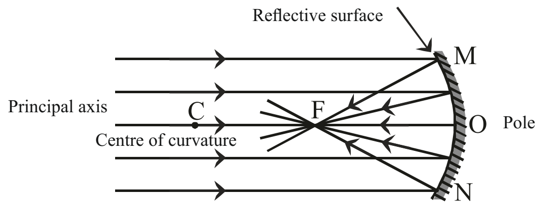


Fig. 9.6 (a) Concave mirror

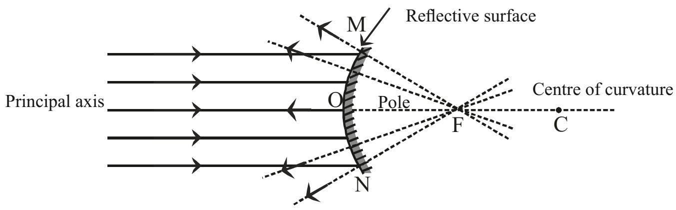


Fig. 9.6 (b) Convex mirror

When paralled ray beam gets reflected from a concave mirror then the reflected rays converge at a point in front of mirror. This point is called focus of a concave mirror. When parallel rays reflect from a convex mirror then they diverge in such a way that when extended backwards these rays meet at a point behind the mirror (fig. 9.6 (b)). It seems that the reflected rays are originating from this point. This point is called the focus (F) of a convex mirror. Centre point (O) of the curved surface of mirror is called pole. Sphereical mirror may be considered as part of a hollow sphere and the centre (C) of that sphere is known as centre of curvature. Distance from pole to centre of curvature (OC)is called radius of curvature and the distance (OF) from pole to focus is known as focal length and is represented as f. In large spherical mirrors the direction of reflected rays changes with distance of point of reflection from pole and thus they do not converge at focus and reflected beam loses the intensity. In this chapter we shall discuss those mirrors only whose aperture (length) is much much smaller than their radius of curvature. In diagram these mirrors are not to the scale and are looking bigger for the sake of understanding. Radius of curvature of these spherical mirrors is double the focal length.

In real life situations light beams are reflected and converged by a parabolic mirror like in a telescope. In the headlight of an automobile the light is fixed at the focus of a parabolic mirror so that we get parallel light beam when light get reflected from parabolic reflectors. In figure 9.6 we observe that the focus of a concave mirror is towards its reflecting face while for a convex mirror it is at the other side of the reflecting face. Therefore if we consider focal length of one type of mirror as positive then the focal length of other type of mirror will have to be taken as negative. We follow Cartesian sign convention for reflection from spherical mirrors.

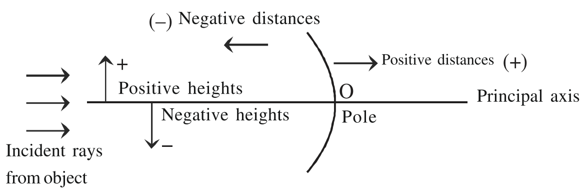


Fig. 9.7 Cartesian sign convention

In Cartesian sign convention all signs are taken from pole of the mirror, also called as origin point and principal axis is considered as x-axis. Rules are as follows.

(i) All distances parallel to principal axis are measured from pole or origin point.

(ii) Object is placed left to the mirror and thus the incidint rays from object are always from the left.

(iii) All distances parallel to principal axis and towards left side of origin point (along-x axis) are taken as negative. For example the distance of object in a convex as well as concave mirror is always negative. Similarly all distances towards right side of the origin point (along + x axis) are taken as positive.

(iv) Heights measured above the principal axis are taken as positive (along + y axis) while heights measured below the principal axis (along - y axis) are taken as negative.

According to Cartesian sign convention the object distance, focal length and radius of curvature are always negative in concave mirror. When image is formed towards left of the origin in a concave mirror then its distance will be taken as negative while the distance will be positive for images formed towards right side of a concave mirror. When image is upright then its height will be taken as positive and when image is below the principal axis and downwards then its height is taken as negative.

For a convex mirror the object distance will be negative as per the sign convention. In convex mirror the focal length and radius of curvature are always towards the right side of the origin point and hence focal length and radius of curvature are always taken positive in a convex mirror. In convex mirror the image is always towards right side of the pole and hence image distance is always positive. Similarly the image is always upright and thus height of image is always positive in this case.

Example 2 : Prove that radius of curvature is double of the focal length for a small aperture concave mirror.

Solution : Reflection from a concave mirror is shown in the figure 9.8. Rules of reflection of plane mirror also applies to spherical mirror.

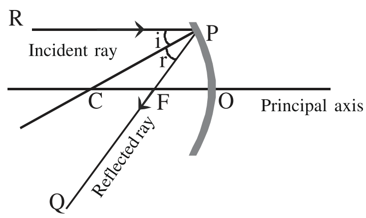


Fig 9.8 Reflection from concave mirror

In the figure RP is incident ray that is parallel to principal axis and after reflecting from concave mirror goes in PQ direction. It passes through point F on the principal axis. Line CP is perpendicular to mirror at point P and hence CP is the radius of curvature of this concave mirror.

From the laws of reflection

Angle of incidence i = angle of reflection r

$$\angle RPC = \angle QPC$$

As incident ray is parallel to principal axis

$$\angle RPC = \angle PCF \quad \text{(Alternate angels)}$$

$$\angle PCF = \angle QPC = \angle FPC$$

Therefore in triangle PCF

$$PF = FC$$

When aperture is small then point P will be near to the pole

$\therefore \quad PF \simeq OF$

or $\quad FC \sim OF$

or $\quad OF = \frac{1}{2} OC$

$OC = 2.OF$

Thus when aperture is small then radius of curvature OC = R is double the focal length OF = f and focus point F is the middle point of OC.

$\therefore \quad R = 2f$

9.4 Image formation in spherical mirror

When focal length and radius of curvature of a convex or concave mirror is known then position of image of any object can be ascertained. At least two reflected rays should intersect to get the image. Generally we use specific incident rays to get the position of image in both the concave and convex mirrors.

(i) Incident rays parallel to principal axis

Ray AL parallel to principal axis of a concave mirror gets reflected from point L of mirror and passes through focus in the A' direction (fig 9.9 (a). In a convex mirror the ray AL diverges after reflection and when extended backwards the reflected ray AL' meets at focus. It seems as if the ray is diverging from focus. (fig 9.9(b)).

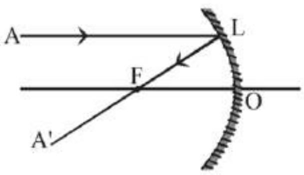


Fig 9.9 (a)

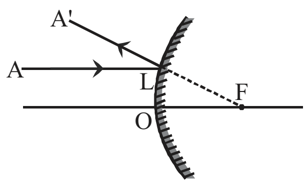


Fig. 9.9 (b)

(ii) Incident rays towards focus

A ray BM passing through focus of a concave mirror (fig 9.10 (a)) gets reflected from the mirror and becomes parallel to principal axis in MB' direction. Similarly in a convex mirror a ray towards focus strike the mirror at M and gets reflected in MB' direction paralled to principal axis (fig 9.10(b)).

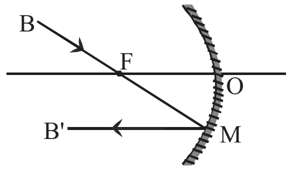


Fig. 9.10 (a)

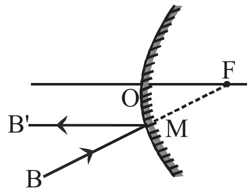


Fig. 9.10 (b)

(iii) Incident ray perpendicular to mirror

Ray that passes through radius of curvature in concave mirror and ray that approaches towards centre of curvature in convex mirror get reflected in the same direction from which they are arrived. (fig 9.11(a) & (b)). The reason is that any line joining any point of mirror to the centre of curvature is a perpendicular on that point and hence angle of incidence and angle of reflection in such case is zero.

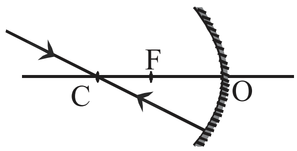


Fig. 9.11 (a)

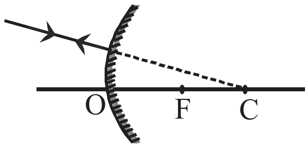


Fig. 9.11 (b)

(iv) Oblique rays

All rays that are obliquely incident on convave or a convex mirror will reflect in another oblique direction as per the rules of reflection. It is to be noted that the point, where oblique ray is incident on morror , is joined with centre of curvature and then the angle

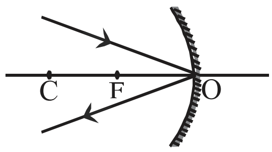


Fig. 9.12 (a)

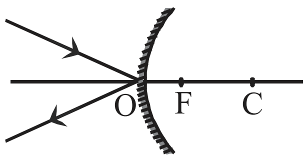


Fig. 9.12 (b)

subtended by incident ray with that radius of curvature (at the point where ray is incident) is the angle of incidence. Now as per rules of reflection, the reflected ray may be drawn. In fig. 9.12 (a) and (b) the point of incidence is O i.e. pole of the mirror.

By keeping in mind the above points we can understand the position and nature of image in concave and convex mirrors. When the reflected rays actually meet at certain point then the image is real. If the reflected rays meet when they are extended backwards (i.e they seems to meet at certain point) then image is virtual. Generally real image is inverted while imaginary image is upright.

Image formation in concave mirror

Ray diagrams of image formation for different position of object for a concave mirror are shown in figure 9.13

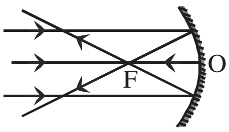


Fig 9.13 (a)
Parallel rays

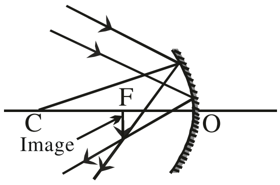


Fig 9.13 (b)
Object at infinity

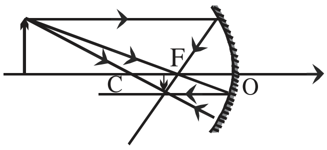


Fig 9.13 (c) Object far from centre of curvature

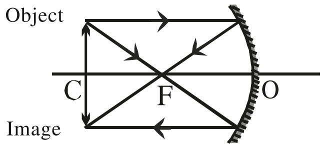


Fig 9.13 (d) Object at cnetre of curvature

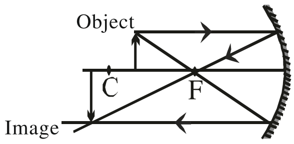


Fig 9.13(e) Object anywhere between centre of curvature & focus

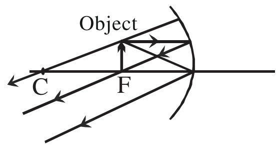


Fig 9.13 (f) Object at focus

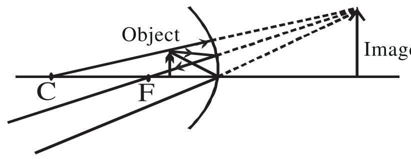


Fig 9.13(g) Object any where between focus and pole

Table 9.1 Nature of image for different positions of object in concave mirror

Sr. No.	Position of object	Position of Image	Image type	Image size
1	At infinity	At focus F	Real and inverted	Very small
2	between centre of curvature and infinity	Between focus F and centre of curvature C	Real and inverted	Small
3	At centre of curvature C	At centre of Curvature C	Real and inverted	Same size
4	Between centre of curvature C and focus F	Away from centre of curvature C	Real and inverted	Magnified
5	At focus F	At infinity	Real and inverted	Very large
6	Between focus F & pole	Behind the mirror	Virtual and upright	Image is large

The table 9.1 represents details of images formed for different object positions. Students can perform simple experiments by taking a wax candle and experimentally observe the image for different positions of candle on a concave mirror.

In routine life you see satellite dish antenna that collect the signals received from satellite through a receiver placed at the focus of concave shaped dish. Similarly, reflecting telescopes also use concave mirror and image of sun, moon or distant object is formed at focus as these rays are parallel. Remember not to look at the image of sun directly otherwise it may damage your eyes. To observe sun, the image is projected on a screen or wall and we observe that projection or special optical filters are used to observe the sun.

Besides the concave mirror is routinely used as shaving mirror (to observe larger image of face). In case of motorcycles etc these mirrors reflect light from powerful bulbs placed at the focus of reflector mirror. The reflected light is in the form of parallel beam. Dentist use concave mirror and light combination to see those parts that are not easily visible because of poor light. In addition it gives larger image of the teeth to a dentist.

Image formation in convex mirror

Light rays diverge after reflection from a convex mirror and we feel as if the light is coming from behind. As focus and centre of curvature of a convex mirror are behind the mirror therefore we can draw image using geometry for object position from infinity to pole. Figure 9.14 shows ray diagrams of images for a few positions of object.

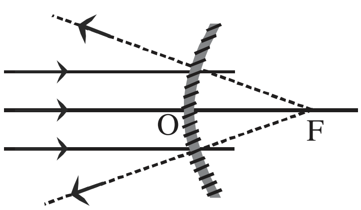


Fig 9.14 (a) Parallel rays

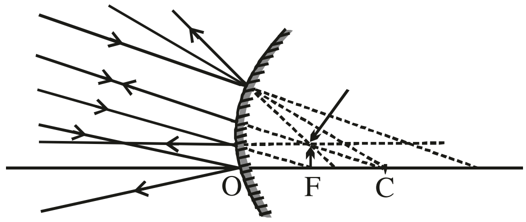


Fig 9.14 (b) object at infinity

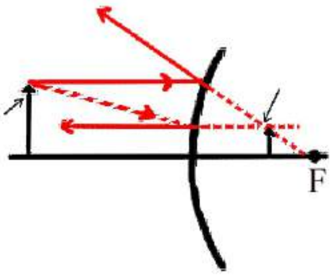


Fig 9.14 (c) object at certain distance

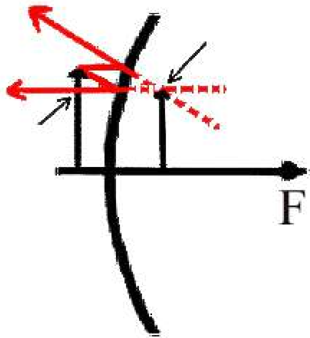


Fig 9.14 (d) object just near the pole

Fig 9.14 Image formation in convex mirror

We observe that the image in a convex mirror is always virtual and upright. As object is brought near the mirror the image increases in size but it is always smaller than the object. Table 9.2 shows details of image for various positions of object.

Convex mirrors make virtual upright image of an object and shows a wide viewing area and thus these are used as rear view mirror and side mirrors in motor vehicles. Drivers thus make an informed guess about the position of vehicles and the scene behind the drivers. Now -a-days convex mirrors are also used in ATM machines for security reasons so that the person using the ATM can observe the activity behind him.

Table 9.2 Details of image for different positions of object in a convex mirror

Sr. no.	Position of object	Position of image	Image type	Image size
1	At infinity	At focus behind the mirror	Virtual & upright	Point like small
2	Any distance between infinity and pole	Behind the mirror between pole and focus	Virtual & upright	Smaller than object

9.5 Mirror formula

In a spherical mirror

(i) Distance of object from pole is u

(ii) Distance of image from pole is v

(iii) Distance of focus from pole is f

All three are related by an equation known as mirror formula

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

This formula is valid for all spherical mirrors. While solving numerical problems when we put values of u, v, f and R (radius of curvature) then we use proper sign of u, v, f and R as per the Cartesian sign convention. Let us derive it for a concave mirror.

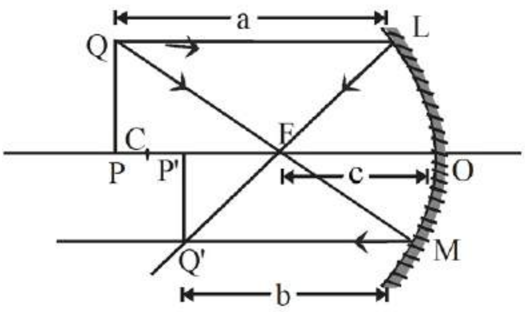


Fig 9.15 Image in a concave mirror

We see that triangle PQF and triangle MOF are similar (here we assume that O and M are so close to each other that distance OM is taken as straight line).

$$\therefore \quad \frac{OM}{PQ}=\frac{OF}{PF}=\frac{c}{a-c}$$

$$\because \quad P'Q' \simeq OM$$

so $$\frac{P'Q'}{PQ}=\frac{c}{a-c} \quad .....(1)$$

Similarly in similar triangles OLF and P'Q'F

$$\frac{OL}{P'Q'}=\frac{OF}{P'F}=\frac{c}{b-c}$$

$$\because \quad OL = PQ$$

so $$\frac{PQ}{P'Q'}\simeq\frac{c}{b-c} \quad .....(2)$$

From (1) & (2) $$\frac{c}{a-c}=\frac{b-c}{c}$$

or $$ab - ac - bc + c^2 = c^2$$

or $$bc + ac = ab$$

Dividing both sides by abc

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{c}$$

Acording to Cartesian sign convention a, b & c are all negative here so

Distance of object from pole u = - a

Distance of image from pole v = - b

Distance of focus from pole f = - c

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

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

This is mirror formula and it is applicable for convex mirror as well.

9.6 Magnification

Ratio of image height to object height is known as magnification It is represented as m. It shows us that how much magnified is the image with respect to the object. The power of a mirror to magnify the object is known as magnifying power.

If object height is h and image height is h' then magnification m from spherical mirror is given as

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

From the geometry of fig. 9.16 the magnification can be related with image distance v and object distance u for a concave mirror. Triangles PQO and ABO similar so

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

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

As object is above the principal axis while image is below it so as per Cartesian sign convention

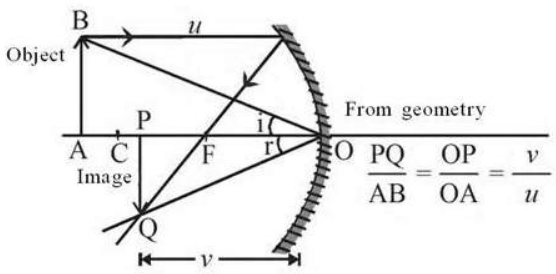


Fig. 9.16 Magnification

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

Generally object is placed upright on principal axis so its height is taken as positive. If image is upright, as is in virtual image, then image height is also taken as positive,. If image is real and inverted then image height is taken as negative if

(i) m is negative and v>u then image is real, inverted and magnified.

(ii) m is negative and v=u then image is real, inverted and equal to the object.

(iii) m is negative and v<u then image is real, inverted and smaller than object

(iv) m is positive then image is virtual and upright.

The image will be magnified $(\because\ v > u)$

Magnification formula is same for a convex mirror as well. In a convex mirror m will always be positive for all reals objects as v is positive while u is negative. Also the value of h' and v will always be less than h and u respectively therefore in a convex mirror the image is always virtual, upright and smaller than the object.

Example 3 : A shaving mirror is at 20 cm from the face of a person. If the focal length of a shaving mirror is 80cm then find the distance of image from the mirror and magnification of mirror.

Solution :

focal length f = - 80 cm (concave mirror)

object distance u = - 20 cm

image distance v = ?

magnification m = ?

From mirror formula $$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

or $$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{(-80)} - \frac{1}{(-20)}$$

$$= -\frac{1}{80} + \frac{1}{20} = \frac{-1+4}{80} = \frac{3}{80}$$

$$v = \frac{80}{3} \simeq +26.67\,cm$$

Image will be formed at 26.67 cm behind the mirror

Magnification m

$$m = \frac{h'}{h} = -\frac{v}{u} = -\frac{26.67}{(-20)}$$

$$= +\ 1.33$$

Thus image will be virtual, upright and magnified (1.33 times the object)

Example 4: Focal length of a convex mirror is 30cm. If the virtual image of an object is at 20cm distance then find the distance of object from mirror.

Solution : focal length $f = +\ 30$ cm

Image distance $v = +\ 20$ cm

Object distance $u = ?$

From mirror formula $\frac{1}{v} + \frac{1}{u} \quad \frac{1}{f}$

Or $\frac{1}{u} = \frac{1}{f} - \frac{1}{v} = \frac{1}{30} - \frac{1}{20}$

$= \frac{2-3}{60} = -\frac{1}{60}$

Or $u = -\ 60$ cm

So the object is 60cm towards left of mirror.

Example 5 : From the side mirror of a motor cycle a car is at 4m distance. If the focal length of side mirror is 1m then find the details of the image in the mirror

Solution : Rear and side mirrors are convex mirrors thus

Focal length of mirror f = + 1m

Distance of object from mirror u = - 4m

Distance of image from mirror v = ?

Magnification m = ?

From mirror formula $\frac{1}{\text{v}} + \frac{1}{\text{u}} = \frac{1}{\text{f}}$

Or $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{1} - \frac{1}{(-4)} = \frac{1}{1} + \frac{1}{4}$

$= \frac{4+1}{4} = \frac{5}{4}$

$v = \frac{4}{5} = 0.8\,m$

and magnification $m = -\frac{v}{u} = -\frac{4/5}{(-4)} = +\frac{1}{5}$

therefore image will be at 0.8m from mirror and the image will be virtual, upright and one fifth (0.2times) the object.

9.7 Refraction

You might have observed many times that a scale partly submerged in water is observed as bent inside the water. Similarly a coin or other object inside the watertank is seen at higher level and near our eyes than its actual depth. You might also have observed that when a glass paperweight is palced over a written sheet then the words below the paper weight looks higher in level in comparison to the rest of the words of the sheet when viewed from upside.

When a pen, pencil or rod is obliquely submerged partly in a water container then, just after the interface of air-water medium, that object seems to bend. If you look from the side then you will see that the submerged part is a bit bigger. If the same experiment is performed with a transparent plastic contain or with some other liquid then you may observe that this effect of bending is different for different mediums.

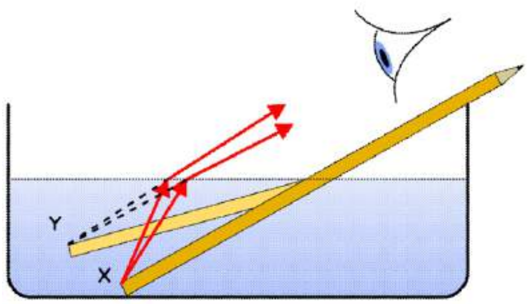


Fig 9.17 (a) Pencil partly submerged in water

The reason for seeing the partly submerged object as bent is that the direction of light rays from the object out of water and from the object submerged in water is different and because of this the submerged part looks a bit higher in level.

Fig 9.17 (b) Straw in a glass

By performing a simple expereiment you can observe the change of direction of light rays. In a beaker or a small container put a coin. Now adjust that container with respect to your eyes such that the coin just becomes invisible to your eyes. Now pour water or ask your friend to pour water into it . You will see that as soon as water is filled in the container the coin will reappear and will be visible to your eyes.

When light travels from one medium to another medium then at the plane of separation of both mediums the direction of light rays changes. This effect is known as refraction.

The incident light should not be perpendicular to the surface of interface of both the mediums otherwise the direction of incident light will not change during refraction though the speed of the refracted light will be different but we shall not be able to view it easily.

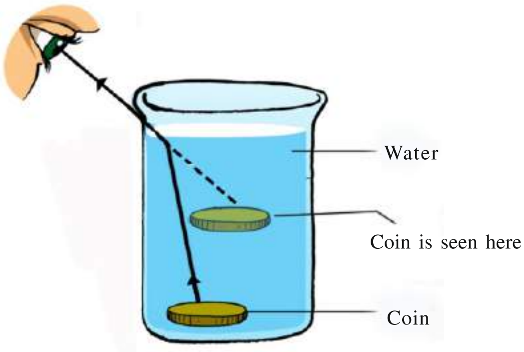


Fig. 9.18 Visibility of coin by Refraction

Velocity of light in vacuum is 3×10^{8} m/s. When light refracts from one medium to another medium then its velocity changes. Glycerin, water, glass etc are denser with respect to air. If the second medium is denser releative to the first medium then the velocity of light will be relatively less in denser medium while the frequency does not change. Because of this while going from rarer to denser medium the light rays bend towards the perpendicular. On the contrary when light travels from denser to rarer medium its velocity increases and light rays bend away from the perpendicular. Here density in strict sense is optical density.

With the help of a glass slab the phenomenon of refraction can be understood with a simple experiment. Put a rectangular glass slab on a paper and draw its edges with the pencil. On this rectangular slab ABCD draw a perpendicular ON on face AB at point O. At some angle of incidence 'i' draw a line PQ as incident ray. Place two all-pins on PQ. Now place two more all-pins R & S towards the face CD of the slab in such a way that all the four all-pins look in straight line. Now draw another perpendicular EF (normal) on face AB at some other point F and place all pins on it. Again look from the side CD and put two all-pins G&H corresponding to these two pins. Now remove the slab. This has be shown in fig. 9.19

Now we join the RS line and extend the ray backwards so that it meets the CD face at point O' and then join OO' by a straight line. Similarly join F&G point and draw the line GH. Draw perpendicular on O' as MM' and extend the perpendicular ON to NN'. Now extend the ray PQ straight (dashed line in figure). From the figure it is clear that ray PQ bend towards perpendicular at interface AB and goes towards OO' and again bends away from perpendicular at CD interface and goes towards RS. We also observe that PQ and RS are parallel. This shows that the bending of rays at interface AB and CD are equal and opposite. You will also obseve that EF ray, that is incident perpendicularly on face AB goes undeviated.

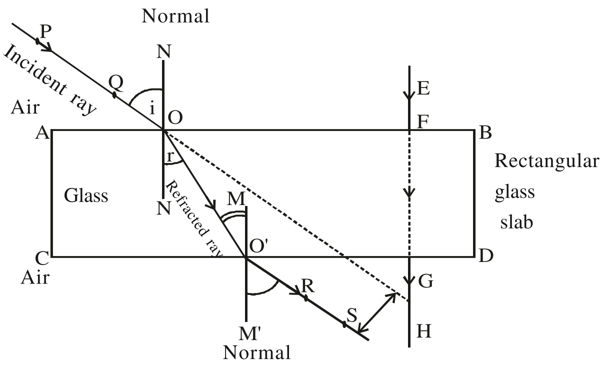


Fig. 9.19 Refraction from glass slab

The refraction is also governed by certain rules. From fig 9.19 we see that incident ray, refracted ray and normal are in the same plane. This is the first to law of refraction.

In refraction the ratio of sine of angle of incidence i and sine of angle of refraction r remains constant

$$\frac{\sin i}{\sin r} = \text{constat}$$

This is second law of refraction that is also known as snell's law. It is also known as refractive index of medium 2 with respect to medium 1 μ_{21} :

$$\mu_{21} = \frac{\sin i}{\sin r}$$

When light travels from vacuum to a medium then refractive index of that medium with respect to vacuum is known as absolute refractive index . Similarly refractive index of a medium with respect to air (or another medium) known as relative refractive index is given as ratio of speed of light in air' to the speed of light in the medium

$$\mu_{21} = \frac{speed\ of\ light\ in\,medium\ 1(air)}{speed\ of\ light\ in\ medium\ 2} = \frac{v_1}{v_2}$$

$$\mu_{wa} = \frac{speed\ of\ light\ in\ air}{speed\ of\ light\ in\ water} = \frac{v_a}{v_w}$$

Refractive index depends upon nature, density of medium and colour (or wavelength) of light. Refractive index is highest for violet colour and lowest for red colour light. A list of refractive indices of a few material are given in table-3.

Table3 : Refractive indices of various materials

Material	Refractive index	Material	Refractive index
Vacuum	1	Glycerive	1.47
Air	1.0003	Turpentine oil	1.47
Water	1.33	Carbon disulphide	1.64
Kerosence	1.44	Diamond	2.42
Glass	1.50		

Examples of Refraction

1.Visibility of the Sun before sunrise and after sunset

We can see the Sun even when it is geometrically just below the horizon during sunrise and sunset. The reason is the refraction of sun-light from different layers of atmosphere. We know that as we go up the atmosphere the air density reduces. Thus rays from sun encounter progressively increasing air density while it enters earth's atmosphere and travels towards earth's surface. This produces deviation of light towards the normal at the interface of different medium of constantly incresing density. Becuase of this reason when the Sun is actually below the horizon Becuase of this reason when sun is actually below the horizon we are able to see the image of sun (fig 9.20) just before the sunrise. This is also the reason that we see the image of sun just after sunset.

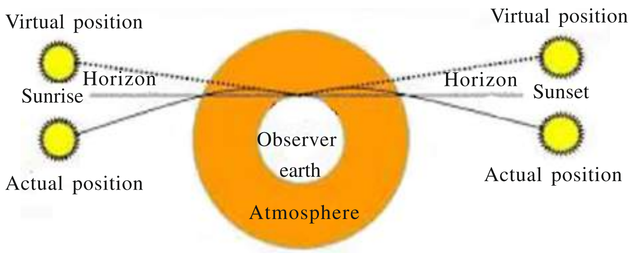


Fig. 9.20 Effect of atmospheric refraction on sunrise and sunset

2. Total internal reflection

When light rays travel through denser medium to rarer medium then they deviate away from the normal at the interface (r>i). If we keep on increasing the angle of incidence then at specific value of angle of incidence the refracted ray goes in the direction of interface of both the medium and angle of refraction r becomes 90^o. This angle of incidence is known as critical angle.

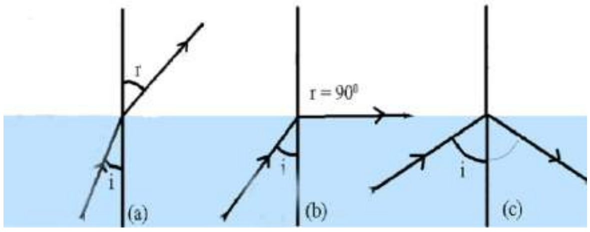


Fig. 9.21 Total internal reflection

If we keep on increasing the angle of incidence beyond critical angle then the light rays reflect back in the denser medium instead of rafracting in the rarer medium. This phenomenon is called total internal reflection. In communication technology the fiber optic cable uses this phenomenon for faster and efficient data transfer.

3. Dispersion of light by prism

When sun light passes through glass prism then the light disperse in seven different colours that can be observed on a screen. In laboratory white light bulb can be used to get chromatic dispersion. We must not see towards the sun or refrated sunlight as it may impair our vision or may cause blindness.

The refracted image at the screen is called spectrum. Newton was the first who proved that white light contains all colours of spectrum. The reason to get this seven colour image is that different colours (having different wavelenghts) travel with different velocities in any medium. In every medium, except vacuum, the speed of red colour is highest and speed of violet colour is minimum. Therefore, after refraction the violet colour bend highest towards the normal. The order of this dispersion is known as VIBGYOR. Yellow is generally considered mean colour of the spectrum.

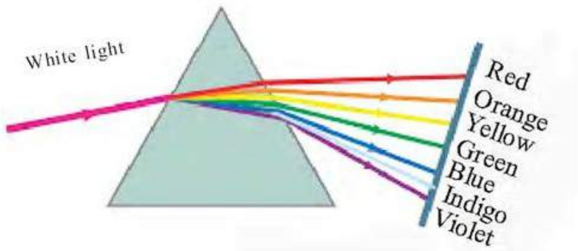


Fig. 9.22 Dispersion of white light

Example 6 : Refractive index of water and glass are 1.33 and 1.5, respectively. Find the refractive index of glass with respect to water.

Solution : μ_w (water) = 1.33

μ_g (glass) = 1.50

Refractive index of glass with respect to water

$$\mu_{gw} = \frac{\textit{velocity of light in water}}{\textit{velocity of light in glass}} = \frac{v_w}{v_g}$$

if velocity of light is c then

$$\mu_w = \frac{\textit{velocity of light in vacuum}}{\textit{velocity of light in water}} = \frac{c}{v_w}$$

Thus $$v_w = \frac{c}{\mu_w}$$

and similarly, velocity of light in glass $v_g = \dfrac{c}{\mu_g}$

therefore $$\mu_{gw} = \frac{v_w}{v_g} = \frac{c/\mu_w}{c/\mu_g}$$

$$= \frac{\mu_g}{\mu_w} = \frac{1.5}{1.33}$$

$= 1.12$

(Note : Refractive index of water is 1.33 that means the velocity of light in water is 1.33 times slower than its velocity in vacuum i.e. its velocity will be c/1.33).

9.8 Refraction through spherical lens

Generally we use such transparent material for focusing light that has cuved surfaces either on one

9.6 Magnification

Ratio of image height to object height is known as magnification It is represented as m. It shows us that how much magnified is the image with respect to the object. The power of a mirror to magnify the object is known as magnifying power.

If object height is h and image height is h' then magnification m from spherical mirror is given as

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

From the geometry of fig. 9.16 the magnification can be related with image distance v and object distance u for a concave mirror. Triangles PQO and ABO similar so

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

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

As object is above the principal axis while image is below it so as per Cartesian sign convention

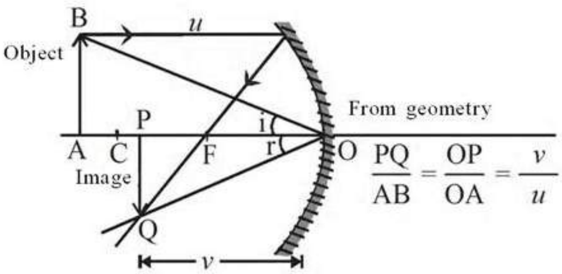


Fig. 9.16 Magnification

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

Generally object is placed upright on principal axis so its height is taken as positive. If image is upright, as is in virtual image, then image height is also taken as positive,. If image is real and inverted then image height is taken as negative if

(i) m is negative and v>u then image is real, inverted and magnified.

(ii) m is negative and v=u then image is real, inverted and equal to the object.

(iii) m is negative and v<u then image is real, inverted and smaller than object

(iv) m is positive then image is virtual and upright. The image will be magnified $(\because\ v > u)$

Magnification formula is same for a convex mirror as well. In a convex mirror m will always be positive for all reals objects as v is positive while u is negative. Also the value of h' and v will always be less than h and u respectively therefore in a convex mirror the image is always virtual, upright and smaller than the object.

Example 3 : A shaving mirror is at 20 cm from the face of a person. If the focal length of a shaving mirror is 80cm then find the distance of image from the mirror and magnification of mirror.

Solution :

focal length f = - 80 cm (concave mirror)

object distance u = - 20 cm

image distance v = ?

magnification m = ?

From mirror formula $$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

or $$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{(-80)} - \frac{1}{(-20)}$$

$$= -\frac{1}{80} + \frac{1}{20} = \frac{-1+4}{80} = \frac{3}{80}$$

$$v = \frac{80}{3} \simeq +26.67\,cm$$

Image will be formed at 26.67 cm behind the mirror

Magnification m

$$m = \frac{h'}{h} = -\frac{v}{u} = -\frac{26.67}{(-20)}$$

$$= +\ 1.33$$

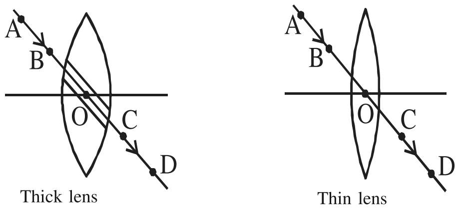


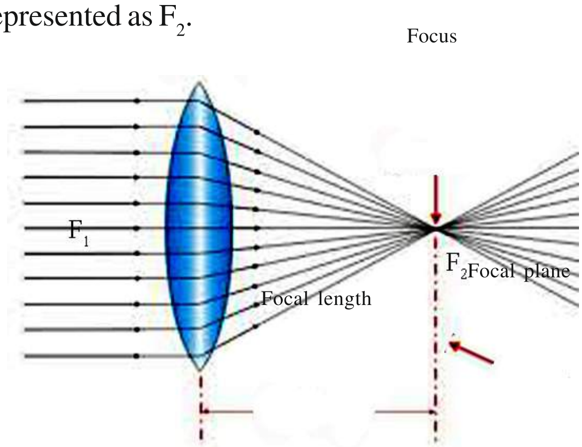
Fig 9.26 Propagation of light through optical centre

Any ray passing trough the optical centre will emerge as parallel to the incoming ray as it will be refracted twice by two surfaces of lens having opposite curvatures. When the lens is not thick (ratio of its thickness with radius of curvature r_1 & r_2 is very small) then the incident and emerging light will be in a straight line.

Optical centre is used in determining position of image by geometrical method. Distance of object and image for a lens system are taken from optical centre. For thin lenses this distance may be measured from their corresponding curved surfaces for ease of experiments.

(v) Principal focus

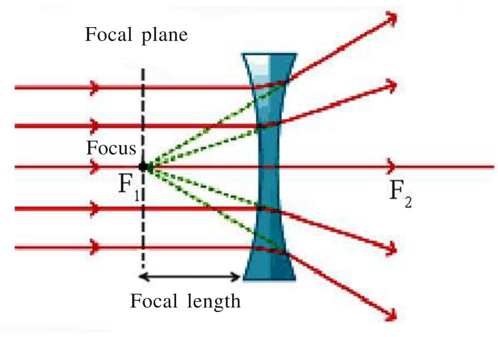
Incident rays parallel to principal axis refract from the lens and converge at a point (or seems to meet at a point) known as focus. There are two foci for lens one on each side. According to conventions the incident light comes from left side and thus left side focus represented is as F_1 and right focus is represented as F_2.



(a) Convex Lens

(vi) Focal Length

Distance between the optical centre and principal focus of a lens is known as focal length



(b) Concave lens

Fig 9.27 Principal focus, focal length & focal plane

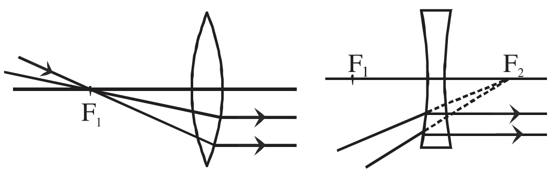
(vii) Focal Plane

A plane passing through focus and perpendicular to the principal axis is known as focal plane.

Laws of refraction from a spherical lens

(a) Incident rays parallel to principal axis of a convex lens converge at focus after refraction (fig 9.27(a)). When such parallel rays are incident on a concave lens then they diverge and when extended backwards they meet at focus (fig 9.27(b)) or we may say that they seem to emerge from the focal point.

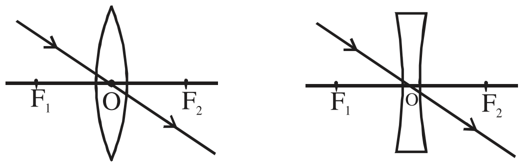
(b) When light rays pass through focus before their incidence on curved surface of a convex lens then such rays become parallel to principal axis after refraction. When light rays are incident on a concave lens in such direction that they seem like they are going towards focus then after refraction such rays become parallel to principal axis (fig 9.28(a) and (b).



Convex Lens　　Concave Lens

Fig. 9.28 Refraction of rays passing through focus

(c) When light rays pass through optical centre of a lens then the rays remain undeviated after refraction (fig 9.29(a) &(b)).



(a) Convex Lens **(b) Concave Lens**

Fig. 9.29 Path of ray passinng through optical centre

9.9 Formation of image by lens

Object kept at different distances from lens form images at different distances. We select at least two such refracted rays that intersect to find the position and shape of image geometrically. In case of virtual image we extend the rays backward to find point of intersection.

Image formation by convex lens

(i) When object is at infinity - Rays from infinity are parallel and thus they converge at focus and image is formed. When rays from infinity are parallel but slanted with respect to principal axis then they form image at a point on focal plane. (Fig. 9.30)

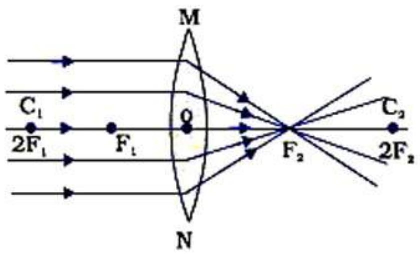


Fig 9.30 Rays parallel to principal axis

(ii) When object is at finite distance - fig 9.31 shows positions of image for different positions of object.

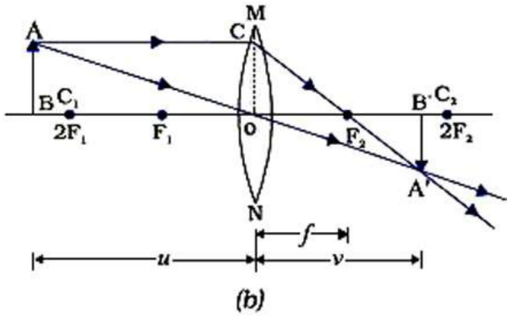


Fig 9.31 (a) Object between infinity and $2F_1$

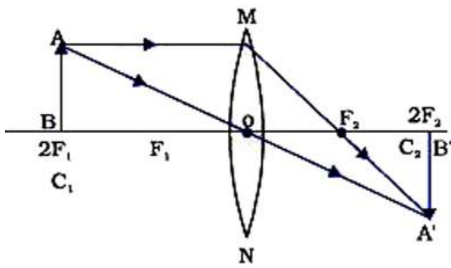


Fig 9.31 (b) Object at $2F_1$

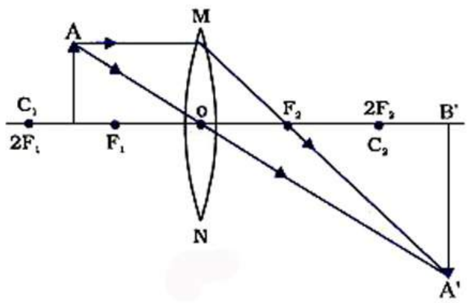


Fig 9.31 (c) Object between $2F_1$ & F_1

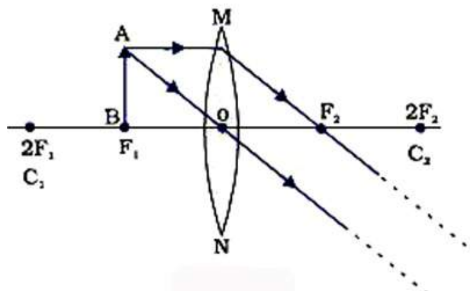


Fig 9.31 (d) Object at F_1

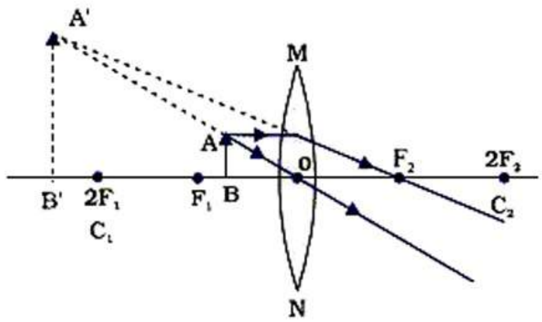


Fig 9.31 (e) Object between F_1 & optical centre

Fig. 9.31 Image formation for different positions of object by convex lens

You may observe that nature of image depends upon the position of object. Starting form infinity as object comes nearer to focus the image size incrases and image remains real and inverted. When object is between focus and optical centre then image is virtual and bigger then object and upright. If object is placed adjacent to lens such that u=0 then the image will be virtual, upright and of same size as object. Image will be formed at optical centre. Table 9.4 shows nature of image for different object positions.

Table 9.4 Nature of image for different object positions for a convex lens

Sr. no.	Position of object	Position of image	Nature of image	Size of image
1.	At infinity	At focus F_2	Real and inverted	point like
2.	Between infinity and $2F_1$	Between F_2 and $2F_2$	Real and inverted	Small
3.	At $2F_1$	At $2F_2$	Real and inverted	same size
4.	Between $2F_1$ and F_1	Between $2F_2$ and infinity	Real and inverted	enlarged
5.	At F_1	At infinity	Real and inverted	very large
6.	Between F_1 & Optical centre	At the same side of the lens and behind the object	Virtual & upright	enlarged

Image formation by concave lens

(i) Object is at infinity

Parallel rays from infinity and parallel to principal axis diverge after refraction from a concave lens and when we extend these diverging rays backwards then a virtual image is formed at focus. This image is very small and upright. If the parallel rays are incident on a concave lens obliquely then the image is formed at focal plane. (Fig. 9.32)

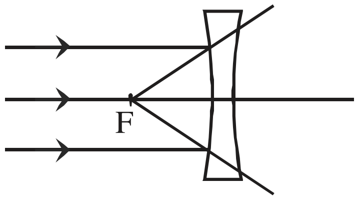


Fig. 9.32 (a) Object at infinity

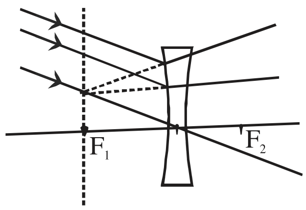


Fig 9.32 (b) Object at infinity

(ii) Object is at finite distance

When object is at a finite distance from a concave lens (anywhere between infinity and optical centre) then a virtual, upright image is formed that is smaller than the object. As object is brought near to the lens, the size of image increases but it always remains smaller then the object. (Fig. 9.33)

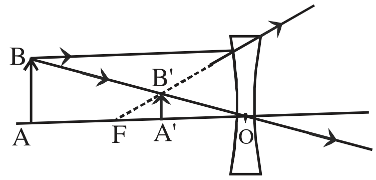


Fig. 9.33 Object at finite distance

Table 9.5 Nature of image for different object positions for a concave lens

Sr. no.	Position of object	Position of image	Nature of image	Size of image
1	At infinity	At focus F_1	Virtual and upright	very small
2	Between infinity and optical axis	Between focus and optical centre	virtual and upright	smaller than object

Lens formula

Just like spherical mirror, in a lens system we have relation between object distance u, image distance v and focal length f and is given as

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

u, v and f are measured from optical centre of lens.

Cartesian sign convention is used similar to spherical mirrors. Accordingly the focal length of a convex lens is taken as positive and focal length of a concave lens is taken as negative. Object is always placed towards the left of the lens and thus incident rays are always from the left. Therefore object distance is taken as negative. While solving numerical problems appropriate sign is chosen for u,v and f while substituting them in the lens formula.

Magnification

Magnification is defined as increase in the size of image with respect to object and is represented as a ratio of image height h' to object height h. Capacity of lens to magnify an image is known as magnifying power.

Generally, object height is taken as positive as it is placed upright at principal axis. When image is inverted then image height is taken as negative.

Magnification can also be represented as ratio of image distance v and object distance u.

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

Magnification for a real and inverted image will be negative while for virtual and upright image it will be positive.

Example 7. A 3.0 cm long object is placed upright on principal axis of a convex lens of focal length 20cm. If real image is at 60cm from lens then find the distance of object from lens and magnification.

Solution : height of object h = +3.0cm

image distance v = +60cm

focal length f = +20cm

object distance u = ?

magnification m = ?

from lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

or $$\frac{1}{u} = \frac{1}{v} - \frac{1}{f} = \frac{1}{60} - \frac{1}{20} = \frac{1-3}{60}$$

$$= -\frac{2}{60} = -\frac{1}{30}$$

or u = – 30 cm

So the object is at 30cm towards left of lens

magnification $m = \frac{h'}{h} = \frac{v}{u} = \frac{+60}{-30} = -2$

or $$h' = \frac{v}{u} \cdot h = \frac{60}{(-30)} \times (3) = -6\,cm$$

Thus the image is real and inverted and the size of image is double the size of object.

Example 8 : Focal length of a concave lens is 30cm. If object is placed at 15cm from lens then find the image position and magnification by lens.

Solution : object distance u = -15cm

focal length f = -30cm

image distance v = ?

magnification m = ?

from lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

or $\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{(-30)} + \frac{1}{(-15)} = -\frac{1}{30} - \frac{1}{15}$

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

or v = –10 cm

The image is at 10cm distance and is towards left of lens.

magnification $m = \frac{v}{u} = \frac{-10}{-15} = \frac{2}{3} = 0.66$

Image is 0.66 or two third of the object and the positive sign of m shows that image is virtual and upright.

Example 9 : Focal length of a convex lens is 50cm. If object is placed at 30cm then find nature and size of image

Solution : focal length f = 50cm

object distance u = -30 cm

image distance v = ?

from lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

or $\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{50} + \frac{1}{(-30)} = \frac{1}{50} - \frac{1}{30}$

$= \frac{3-5}{150} = -\frac{2}{150}$

or v = – 75 cm

Image will be formed at 75cm towards left of the lens.

Now $m = \frac{v}{u} = \frac{-75}{-30} = \frac{5}{2} = 2.5$

Thus image will be 2.5 times the object. Image will be virtual and upright.

9.10 Power of lens

Power fo a lens is defined as its capacity to diverge or converge light rays. A low focal length convex lens will converge the rays nearer to it and thus rays will bend more. On the contrary for a convex lens of larger focal length the rays will bend less and will converge at larger distance. When light rays are incident on a concave lens then depending upon its focal length they will diverge to different degree. A concave lens of low focal length will diverge the rays more and rays will bend more.

We see that the capacity of diverging or converging is inverse to the focal length of lens

Hence power of a lens is defined as $P = \frac{1}{f}$

If f is in meter then P is in dioptre. Power of a convex lens is positive and power of a concave lens is negative. We generally, call this the number of eye lenses. If focal length of a lens is 2m then its power will be p=0.5 dioptre.

If we combine two or more lenses then the resultant power of that combination of lenses is given as

$$P = P_1 + P_2 + P_3 + ...$$

Where P_1, P_2, P_3 etc are power of individual lenses.

Example 10 : An eye -lens projects the light from infinity on a wall at 25 cm. Find the power of lens.

Solution : focal length of lens f = +25cm = 0.25m

Power $P = \frac{1}{f} = \frac{1}{0.25} = +4$ dioptre

Hence the lens is convex lens.

9.11 Defects in eye vision and their corrections

Eyes are one of the most important organ of our body. We experience many things around the world by seeing through our eyes. When we are not able to see clearly then we consult an ophthalmologist (or an eye-specialist) to rectify the defect in our eyes. Let us first try to understand the structure of eye before studying the types of defects and their remedies in eyes.

Structure of eyes

Working of a human eye resembles to an autofocus camera. It is an organ around 2.5 cm and is almost round. Its components are shown in figure 9.34 The eye is made up of three layers, out of which the outer most part is cornea and sclera, the middle layer consist of choroid, ciliary body and iris and the inner most layer is retina

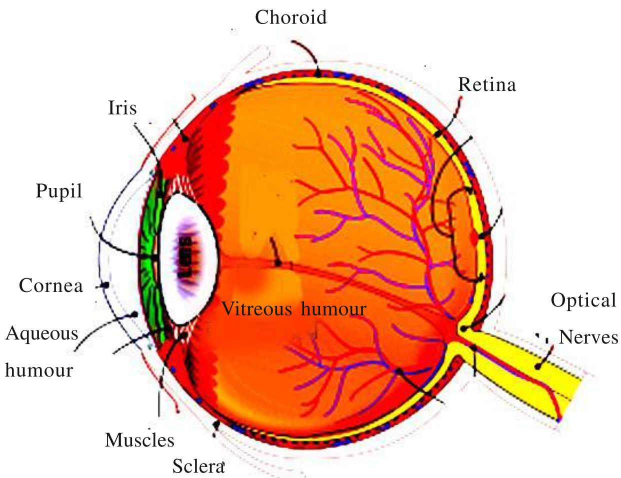


Fig. 9.34 Structure of an eye

1. **Sclera -** It is also known as the white of the eye. It is an opaque, fibrous protective outer layer of the eye. It contains collagen and elastic fiber.

2. **Cornea -** It is the front part of the eye and it covers iris, pupil and interior chamber of eye. It is transparent and refracts the light entering to eye It accounts for around two third of our eye's total optical power. Its focus is fixed.

3. **Iris-** It is fibrous structure behind the cornea having a hole in the middle. Generally it is dark in colour having brown or blue area. Iris can contract or expand.

4. **Pupil -** The hole at the centre of the iris is called pupil. Its size changes depending upon the available light. Fibrous muscles of iris expand or contract to allow different amount of light through pupil. In intense light pupil size reduces while in low light condition the size of pupil increases. Because of this reason we do not see properly when we suddenly move from an intense light region to low light region. After some time the pupil dilates and again we get the ability to see properly.

During total solar eclipse the pupil dilates and then when suddenly the sun light reappearss our eyes may get damaged becuase pupil wouldn't adjust to this sudden change of light. Therefore, it is advised not to see solar eclipse through naked eyes.

5. **Eye lens –** Lens is a flexible transparent structure behind iris and is suspended in place by a ring of suspensory fibrous tissue around the lens. The pressure from these muscles change the shape of the lens and thereby change the focal length of lens or eye. To focus refracted light from cornea the radius of curvature of eye lens is adjusted or accomodated by appropriate pressure on it by fibrous tissue surrounding it. In that way we focus object at various distances. The image formed by lens is real, inverted and small.

6. **Aqueous humour –**In between eye lens and cornea a transparent water fluid is filled. It contains low protein concentrations. It maintains the intraocular pressure and helps in keeping the eye ball in a roughly spherical shape. It also provides nutrition to cornea, lens and other surrounding parts.

7. **Choroid–** It is a vascular layer of eye that has connective tissues. The choroid provides oxygen and nourishment to the outer layer of retina. It is between sclera and retina. It also absorbs the light entering the eye and thereby stops uncontrolled reflections of light from inner layers of eye.

8. **Retina-** Retina is a light sensitive layer of tissue and is below the choroid. Light coming from the object

refracts through cornea and eye lens and gets focussed at retina. Light sensitive tissues of retina get activated on receiving the light. In a complex process they produce electrical signals. Optic nerve send this electrical signal of image to the visual centres of brain. This image received by brain is inverted and the brain now performs a set of processes to give us the final upright image.

9. Vitreous humour – The space between eye lens and retina is filled with a transparent gel like matter known as vitreous humour.

Under normal conditions the image of an object kept at infinity from our eyes is clearly formed at retina. When object is near, the tissues of eye lens produce appropriate pressure so that eye lens becomes thick from middle. This process reduces the focal length of the lens and the imge of a nearby object is formed at retina. Capacity of eye lens to change the focal length is known as accomodation power of eyes.

When we try to see an object from very near to our eyes then we find it difficult to get a clear image and the reason is that the eye lens has limit to accomodate the focal length. The least distance from which an object is clearly seen is known as near point of the eye. For a normal eye this distance is 25cm. Similarly, the farthest point from which on object is clearly visible is known as far point of the eye. For normal eyes this is infinity. Distance between near point to the far point is known as range of the vision.

Defects of vision and their corrections

With age the eye loses its power of accomodation. Sometimes because of stress, injury or other reasons the eye can not accomodate for near object or far object or both. Sometimes the eye lens loses its transparency. Because of such varied reasons the eye is not fully able to see objects and we call it defect in vision. A few of the major vision defects and their probable corrections are as follows.

Myopia or short sightedness

Myopia is also known as short sightedness or near sightedness. A person suffering from myopia can see the nearby objects clearly but distant objects are not very clear or distinct. One of the main reason for this defect is the increase in the curvature of eye lens. Therefore, the image of a far obejct is formed infront of the retina while the image of nearby objects is formed at retina. We can say that far point of such persons is not infinity but nearer.

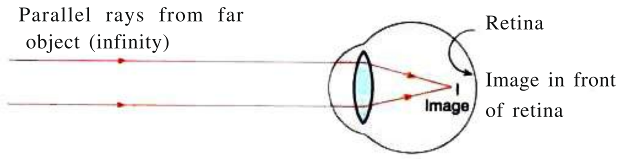


Fig 9.35(a) Short sightedness

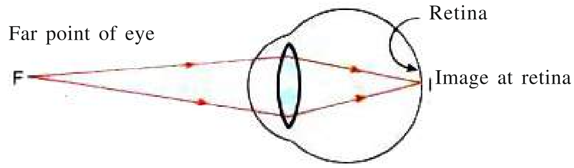


Fig 9.35(b) Far point of a myopic eye

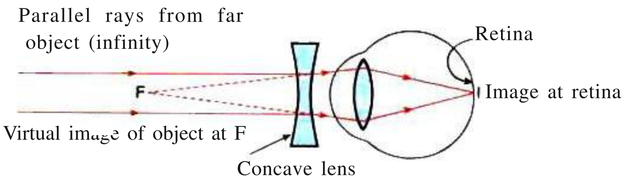


Fig 9.35(c) Correction of myopic eye

To correct the defects of short sightedness a concave lens of apporpriate power is placed before the eye. The concave lens diverge parallel rays from infinity and when extended backwards they seem to originate from the focus of concave lens. When this focal length is equal to the far point of a person suffering from myopia then the person will see clearly. Nowadays laser technique is used to correct short-sightedness.

Hypermetropia or long sightedness

Hypermetropia is also known as long sightedness or far sightedness. A person suffering from hypermetropia is able to see distant objects clearly. Such persons connot see the nearby objects clearly. So an object placed at near point (25cm) is not clearly visible but as we move it away from eyes the obejct gradually becomes clearer. So we can say that the near point of a person with hypermetropia is not at 25cm but at some longer distance.

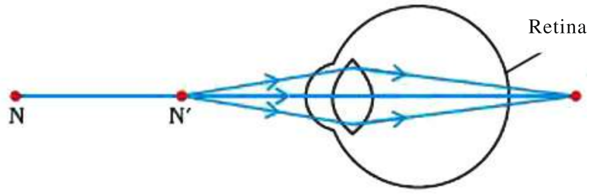


Fig.9.36 (a) Long sightedness

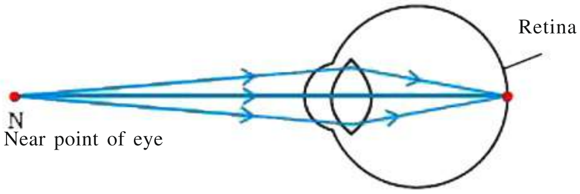


Fig 9.36 (b) Near point of an eye with hypermetropia

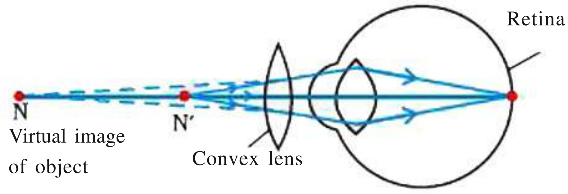


Fig. 9.36 (c) Correction for hypermetropic eye

To correct the defect of long sigthedness a convex lens of appropriate power is placed before the eye. The convex lens makes virtual image of a nearby obejct at such long distance, that is the near point of hypermetropic eye. The eye will then see that nearby object at a distance, away from eye and at the near point of that eye with defect. In that way the eye will see the object clearly

Presbyopia

The flexibility of eye lens and its surrounding fibrous structure decreases with age and thereby the accomdation power of eye reduces. This makes it difficult for people to clearly see the nearby objects. Sometimes with age people can not clearly see the distant objects either. The problem of eye in which person cannot see nearby as well as distant object clearly is known as presbyopia and it generally occur with age. To correct this defect a bifocal lens is used. The upper portion of these lenses is concave and lower portion is convex.

Astigmatism

Astigmatism is beacuse of irregular curvature of the cornea and people of all ages can be affected by this problem. A person with astigmatism cannot clearly see horizontal and vertical lines at the same distance simultaneouly. Cylindrical lenses are used to correct this defect of eye.

Cataract

With aging the transperancy and flexibility of eye lens reduces. The eye starts reflecting light because of this reduction in transperancy and the object is not clearly visible to such an eye. This defect is known as cataract (fig 9.37). The eyelens is removed to improve vision. Earlier a person had to use a very high powered and dark colured lens and still the vision recovery was not proper. Now -a-days becuase of advancement of technology the eye lens is replaced with an artificial lens to correct the vision. These lenses are known as interaocular lenses. It is also possible to use lens such that either long sigthness or short sighedness of the vision is corrected in that lens.

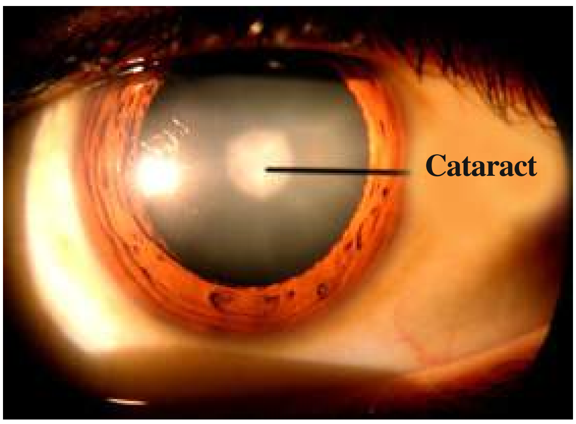


Fig 9.37 Cataract

Important Points

1. When light is incident on an obejct then the object reflects a few colours of light and absorbs others. We see the object and its colour because of this reflected light.
2. Rules of reflection of light :

   (i) incident light, reflected light and perpendicular on the plane of reflection are in the same plane.

   (ii) Angle of incidence 'i' is equal to the angle of reflection 'r'
3. Image in a plane mirror is virtual and is at the same distance behind the mirror as that of the distance of object in front of mirror.
4. Cartesian sign conventions are used for spherical mirror and lens. According to this convention the object is always towards left. Distances of the left of the mirror or lens are taken as negative and distances towards the right are taken as positive. Focal length and radius of curvature of a concave mirror are always negative while they are always positive for convex mirror. Similarly, the focal length of a concave lens is always taken as negative and focal length of convex lens is taken as positive.
5. In convex mirror, the image is always virtual, upright and simaller than the object. For a concave mirror the nature of image depends upon distance of object from the mirror.
6. If object distance for a mirror is u, image distance is v and focal length is f then the morror formula is given as

   $$\frac{1}{v} \quad \frac{1}{u} + \frac{1}{f}$$
7. Radius of curvature of a spherical mirror is double of the focal length of the mirror.
8. Ratio of height of image to the height of an object is called magnification.
9. Rules of refraction

   (i) Incident ray, refracted ray and the perpendicular on the plane of refraction are in the same plane.

   (ii) For a refracting medium the ratio of sine of angle of incidence 'i' and sine of angle of refraction 'r' is constant.
10. When light rays travel through rarer medium to denser medium then at the plane of separation of both the mediums the rays bend towards the perpendicular after refraction. On the contrary when rays go from denser to rarer medium then after refraction the rays bend away from the perpendicular
11. Ratio of speed of light in vacuum to the speed of light in a transparent medium is called refractive index of the transparent material.
12. A refracting medium of two curved surfaces or one curved surface and one plane surface is called a lens. Lens are of two types.

   (i) Convex lens or converging lens

   (ii) Concave lens or diverging lens
13. Image from a concave lens is always virtual, upright and smaller than the object. Image in a convex lens depends upon the distance of object from the lens.
14. If an object is at a distance u from a lens, image is at distance v and focal length of lens is f then lens formula is given as

   $$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$
15. Reciprocal of the focal length of a lens is known as the power of the lens. Its unit is diopter.
16. Eye forms an image of an object at the retina. For a normal eye the near point is 25cm and far point is at infinity
17. Following defects are commonly observed in eyes

   (i) Myopia

   (ii) Hypermetropia

   (iii) Presbyopia

   (iv) Astigmatism

   (v) Cataraet

Practice questions

Objective type questions

1. Which mirror will show a wide area view
   (a) plane mirror (b) convex mirror
   (c) concave mirror (d) parabolic mirror
2. Speed of light will be maximum in
   (a) water (b) glass (c) vacuum (d) glycerin
3. A coin at the bottom of a water tank appears to be raised because of the phenomenon of
   (a) refraction
   (b) reflection
   (c) total internal reflection
   (d) None of these
4. If focal length of a mirror is + 60cm then the mirror is a
   (a) concave mirror (b) parabolic mirror
   (c) plane mirror (d) convex mirror
5. Focal length of a plane mirror is
   (a) 0 (b) 1 (c) Infinity (d) None of these
6. Image in a convex mirror will always be
   (a) real and upright
   (b) real and inverted
   (c) virtual and inverted
   (d) virtual and upright
7. The power of a lens is +2 diopter. What will be its focal length?
   (a) 2m (b) 1m (c) 0.5m (d) 0.2m
8. In hypermetropia a person
   (a) can see nearby objects
   (b) can see far objects clearly
   (c) Neither nearby obejcts nor far objects are clearly visible
   (d) None of these
9. To get a real image of the same size of object, where shall the object be placed before a convex lens of focal length 15cm?
   (a) 30cm (b) 15cm
   (c) 60cm (d) None of these
10. An object is placed at infinity with respect to a concave lens of focal length 20cm. Distance of virtual image from lens will be
    (a) 10cm (b) 15cm
    (c) 20 cm (d) at infinity

Very short type questions

1. When an object absorbs all colours of light then which colour of the object will be seen by us ?
2. To see our full image in a plane mirror what should be the lowest height of the mirror?
3. A light ray is incident on a plane mirror at an angle of 30^0. What will be the angle between the reflected and incident ray?
4. Write two uses of a convex mirror.
5. Write two uses of a concave mirror.
6. Write mirror formula.
7. Write the relation between radius of curvature and focal length of a spherical mirror.
8. Give the magnification formula.
9. Give snell's law.
10. Write lens formula
11. Parallel rays from an object are incident on a convex lens. Where will the image be formed?
12. What is the unit of power of lens?
13. In which conditions a person with myopia cannot dearly see the object?
14. Which defect of eye can be rectified with the help of a convex lens of appropriate power.
15. What is cataract?
16. What will be the nature of our image in a shaving mirror?

Short type questions

1. What do you mean by regular reflection and diffused reflection?
2. Explain lateral inversion.
3. An object is placed between radius of curvature and focus of a concave lens. Show

the image formation by ray diagram.

4. Explain Cartesian sign convention for spherical mirrors.

5. Discuss refraction of light and write the laws of refraction .

6. What are the different types of convex lenses & concave lenses?

7. Define principal focus and optical centre of a spherical lens.

8. What do you mean by radius of curvature and centre of curvature of a spherical lens?

9. Write the laws of refraction for spherical lens.

10. Explain the image formation by a concave lens with ray diagram.

11. What do you mean by power of a lens?

12. What do you mean by myopia? How it is corrected?

13. What is hypermetropia? How this defect is corrected?

14. What do you mean by presbyopia and astigmatism?

15. What is the power of accomodation of an eye and what is the range of the vision?

16. An object is placed on principal axis between infinity and $2F_1$ of a convex lens. Show the image formation with ray diagram.

Essay type questions

1. With the help of ray diagram explain the position and nature of image for following positions of object for a concave mirror.

(i) When object is between infinity and centre of curvature

(ii) When object is at the centre of curvature

(iii) When object is between centre of curvature and focus

(iv) When object is at focus

(v) When object is between focus and pole

2. What do you mean by refraction? write laws of refraction and explain the refraction of light rays with the help of a glass slab.

3. With the help of ray diagram explain the nature and position of image for following positions of object for convex mirror

(i) When object is at infinity

(ii) When object is at certain distance

4. Explain the nature and position of image with the help of ray diagram for a concave lens when object is placed

(i) at focus point of lens

(ii) between focus F_1 and $2F_1$

(iii) Between $2F_1$ and infinity

5. For a convex lens explain the formation of image and nature of image with ray diagram when object is placed.

(i) between focus and optical centre

(ii) at focus F_1

(iii) between focus F_1 and $2F_1$

(iv) at $2F_1$

6. Discuss in detail different types of defects in vision and methods to correct the defects of vision.

Numerical questions

1. Focal length of a concave mirror is 30cm. If an object is placed at 40cm then find the position of image and also get the magnification (-120cm, 3 times & real)

2. An image of an object is seen at 8cm from the convex mirror . If focal length of convex mirror is 16cm then find the position of the object (-16cm)

3. An object is placed at a distance of 60cm from the convex lens of focal length 30cm. If object height is 3cm then find the position and nature of the image (60cm, 3cm real and inverted)

4. An object is placed at 10cm from a convex lens. If focal length of convex lens is 40cm then find the position and nature of the image (-13.33cm, 1.33 times, virtual & upright)

5. Focal length of a concave mirror is 30cm. If an object is placed at 20cm from the mirror then find the image position and its nature (+60cm, 3times & virtual)

6. Image of an object placed in front of a concave lens is at 10cm. If focal length of concave lens is 15cm then find the distance of object from the lens. (-30cm)

7. Find the magnification of a convex lens of focal length 10cm when the upright image of the lens is formed at distance of near point of eye. (3.5)

Answer keys

1. (b)	2. (c)	3. (a)	4. (d)	5. (c)
6. (d)	7. (c)	8. (b)	9. (a)	10. (c)