Light-Reflection and Refraction

Refraction of Light

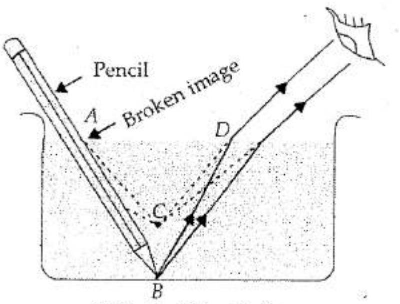
The bending of light rays when they pass obliquely from one medium to another medium is called refraction of light.

In other words when light rays traveling in one medium are incident on a transparent surface (medium), they are bent as they enter in second transparent medium. This phenomenon of bending of ray of light in second medium is called refraction of light.

This phenomenon of light can be easily demonstrated by the following activity.

ACTIVITY CORNER

A pencil appears bent and short, when immersed obliquely (at an angle) in water. Take a pencil and dip it obliquely in a beaker, half filled with water. The pencil appears to be bent or displaced at the surface of separation between the two media (water - air interface). This apparent bending or displacement of pencil is due to the refraction of light. The ray coming from the portion of the pencil is due to the refraction of light. The ray coming from the portion of the pencil above and below the water reaches our eyes from different directions and the pencil appears to be bent or broken



The pencil inside the water appears to be broken

Explanation: Consider a ray of light starting from the end point P or the pencil passing from water to air at point D and reaching the eye. It appears to be coming from a different point C. The point C is therefore the virtual image of the end point B of the pencil and lies exactly above point B. In the same way each point on the portion AB (dipped in water) of the pencil has a corresponding virtual image above the point. Thus the virtual image of the portion AB of the pencil appears at AC due to refraction of light.

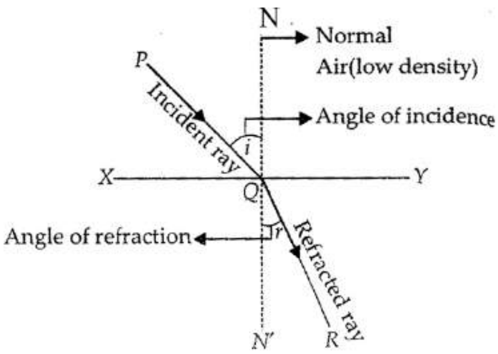
Cause of Refraction

Light rays get deviated from their original path, while entering from one transparent medium to another medium of different density. This deviation (change in direction) in the path of light is due to the change in velocity of light in the different medium. The velocity of light depends on the nature of the medium in which it travels. Velocity of light in a rarer medium (low optical density) is more than in a denser medium (high optical density).

Refraction of light from a plane transparent surface

In diagram, XY is section of a plane transparent surface of a denser medium.

A ray of light PQ strikes the surface at Q and goes along QR in denser medium. It is bent towards normal. This bending of ray of light when it travels in different medium, is called refraction. The surface is said to have refracted the light.



(i) Transparent surface: The plane surface which refracts light/ is called transparent surface.

In diagram, XY is the section of a plane transparent surface.

(ii) Point of incidence: The point Q on the boundary of two media where the incident ray strikes is called the point of incidence.

(iii) Normal: A perpendicular drawn at the point of incidence is called normal. In diagram, NQN' is the normal on surface XY.

(iv) Incident ray: The ray of light which strikes the transparent surface at the point of incidence is called incident ray. Here the ray PQ is the incident ray.

(v) Refracted ray: The ray of light on entering the second medium is called refracted ray. In diagram, QR is the refracted ray.

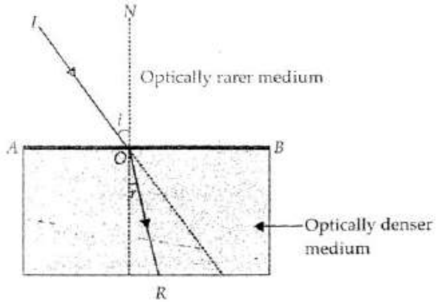
(vi) Angle of incidence: The angle between the incident ray and the normal is called angle of incidence $(\angle i)$

(vii) Angle of refraction: The angle between the refracted ray and the normal is called angle of refraction $(\angle r)$

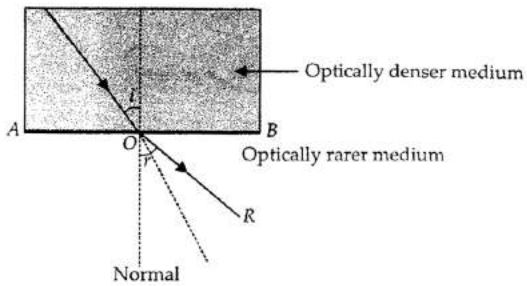
(viii) Plane of incidence: The plane containing the normal and the incident ray is called plane of incidence. For the diagram, plane of paper is the plane of incidence.
(ix) Plane of refraction: The plane containing the normal and the refracted ray is called plane of refraction. For the diagram/ plane of paper is the plane of refraction.

Characteristics of Refraction of Light

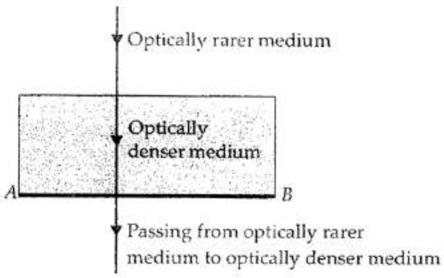
The bending of light follows the following rules:
(i) In going from a rarer to a denser medium: A ray of light passing obliquely from an optically rarer medium to an optically denser medium, bends towards the normal. In this case the angle of refraction is always less than the angle of incidence.

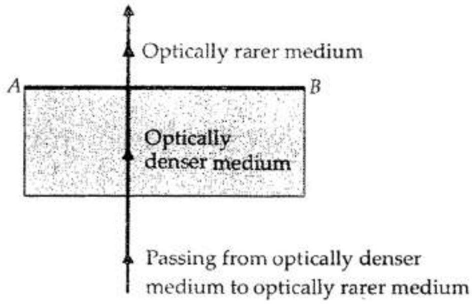


(ii) In going from a denser to a rarer medium: A ray of light passing obliquely from an optically denser medium to an optically rarer medium bends away from the normal. In this case the angle of refraction is always greater than the angle of incidence.



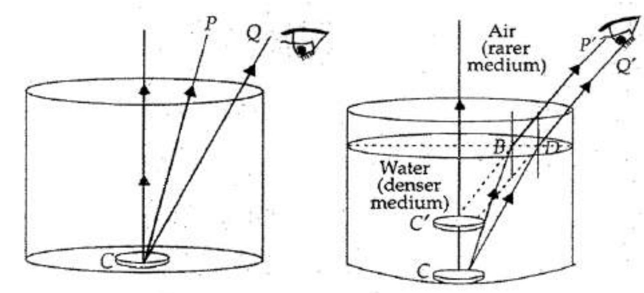
(iii) When light is incident normally on a optically denser medium: A ray of light passing normally, i.e./ at right angles from one optical medium to another optical medium, does not bend or deviate from its path. In this case, angle of incidence and angle of refraction both are equal to zero.





ACTIVITY CORNER

Place a coin C at the bottom of an empty metallic vessel as shown in figure (a). Now slowly move away from the vessel until you reach a place where the coin just disappears. Now ask somebody to slowly fill the vessel with water without disturbing the position of the coin. Maintain a steady gaze at the coin. The coin gradually begins to appear and can be seen completely from the same position of the eye after the level of water reaches a certain height.



(a) Coin not visible in an empty metallic vessel

(b) Coin now visible and also appears to be raised inwater

As shown in figure (b), rays like CP and CQ cannot reach the eye, so the coin was not visible. A ray of light, CB coming from the lower end C of the coin passes from water in to air at a point B arid gets refracted away from the normal in the direction BP'. Another ray of light, CD gets refracted in the direction DQ'. There refracted rays BP' and DQ' reach the eye of the observer, who sees the coin raised to C. Thus the coin, which was not visible earlier, come's in to view. C is the apparent position of the coin C, which appears to be raised up due to refraction of light.

Laws of Refraction of Light

Refraction of light follows the following two laws:

- **First Law:** The incident ray, the normal to the transparent surface at the point of incidence and the refracted ray, all lie in one and the same plane.

- Second Law: The ratio of sine of the incidence angle ($\angle i$) to the sine of the refracted angle ($\angle r$) is constant and is called refractive index of the second medium with respect to the first medium. It is denoted by n.

  i.e., . $\frac{\sin i}{\sin r} = n$ ...(i)

  Refractive index of second medium with respect to the first medium is denoted by $_2n_1$

  Thus, eqn. (i) can be written as $_2n_1 = \frac{\sin i}{\sin r}$

  This law is called Snells' law as it was stated by Prof. Willenbrord Snell (Dutch mathematician and astronomer).

Refractive index

Light travels the fastest in vacuum with the highest speed of 3×10^8 m s^{-1}. In air, the speed of light is only marginally less, compared to that in vacuum. But for all practical purposes, we consider the speed of light in air equal to the speed of light in vacuum. However speed of light decreases in denser media like water, glass etc. It means when light goes from air to some other medium like water and glass, its speed decreases. The amount of change in the speed of light in a medium depends upon the property of the medium. This property is known as refractive index of the medium. Refractive index is a measure of how much the speed of light changes when it enters a medium from air.

Absolute Refractive index

Absolute refractive index of a medium is defined as the ratio of the speed of light in vacuum or air to the speed of light in the medium. It is denoted by n.

Then, $n = \frac{\text{speed of light in air}}{\text{speed of light in water}} = \frac{c}{v}$

It has no unit.

ILLUSTRATION

1. The speed of light in air is 3×10^8 m s^{-1} and the speed of light in water is 2.26×10^8 m s^{-1}. Find the refractive index of water.

Sol: Given, $c = 3\times10^8$ m s^{-1}, $v = 2.26\times10^8$ m s^{-1}

Using, $n = \frac{c}{v}$ we have

$$n = \frac{3\times10^8 ms^{-1}}{2.26\times10^8 ms^{-1}} = 1.33$$

Thus, refractive index of water = 1.33

Relative Refractive index

When light passes from medium 1 to another medium 2, the refractive index of medium 2 with respect to medium 1 is written as $_2n_1$,and is called relative refractive index.

$$\frac{\text{speed of light in medium 1}}{\text{speed of light in medium 2}} = \frac{v_1}{v_2}$$

Multiply and divide R.H.S. of eq. (i) by c (speed of light in air), we get

$$_2n_1 = \frac{cv_1}{cv_2} = \left(\frac{c}{v_2}\right)\times\left(\frac{v_1}{c}\right) = \left(\frac{c/v_2}{c/v_1}\right)$$

But $\frac{c}{v_1} = n_1$ (absolute refractive index of medium. 1)

and $\frac{c}{v_2} = n_2$ (absolute refractive index of medium 2)

Hence, eqn. (ii) can be written as $_2n_1 = \frac{n_2}{n_1}$

Thus, relative refractive index of medium 2 with respect to medium 1 is defined as the ratio of absolute refractive index of medium 2 to the absolute refractive index of medium 1.

Also $_2n_1 = \frac{\sin i}{\sin r}$

Comparing eqns. (iii) and (iv), we get $\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$ or

$n_1 \sin i = n_2 \sin r$

We know, refractive index of medium 2 with respect to medium 1 is given by, $_2n_1 = \frac{v_1}{v_2}$

Similarly, refractive index of medium 1 with respect to 2 is given by, $_1n_2 = \frac{v_2}{v_1}$

Multiplying eqn. (vi) and (vii), we get,

$_2n_1 \times {}_1n_2 = \frac{v_1}{v_2}\times\frac{v_2}{v_1} = 1$ or $_2n_1 = \frac{1}{_1n_2}$

i.e., refractive index of medium 2 with respect to medium 1 is the reciprocal of refractive index of medium 1 with respect to medium 2.

For example, refractive index of water with respect to air,

For water, $_{\omega}n_a = \frac{4}{3}$ or 1.33 for glass $_gn_a = \frac{3}{2} = 15$

When light goes from water to glass,

Refractive index of glass with respect to water,

$$_gn_{\omega} = \frac{3/2}{4/3} = \frac{9}{8} = 1.125$$

Values of Refractive Indices of Some Transparent media

Names of Substance	Refractive Index	Names of Substance	Refractive Index
Air	1.0003	Glycerine	**1.47**
Hydrogen	1.00013	Benzene	**1.501**
Carbon dioxide	1.00045	Crown glass	**1.52**
Ice	1.31	Rock salt	**1.54**
Water	1.333	Carbon disulphide	**1.63**
Alcohol	1.36	Flint glass	**1.66**
Kerosene	1.44	Ruby	**1.71**
Carbon tetrachloride	1.46	Diamond	**2.42**
Turpentine oil	1.47		

Do You Know

Refractometer is a device used to measure the refractive index of a substance.

ILLUSTRATION

2. Light travels from a rarer medium 1 to a denser medium 2. The angle of incidence and refraction are respectively 45°and 30°.
Calculate the refractive index of second medium with respect to the first medium.

Sol: Given, angle of incidence, i = 45°angle of refraction, r = 30°

From relation, $n = \frac{\sin i}{\sin r}$

Putting values, we get $_2n_1$

$$_2n_1 = \frac{\sin i}{\sin r} = \frac{\sin 45°}{\sin 30°} = \frac{1\sqrt{2}}{\frac{1}{2}} = \sqrt{2} = 1.414$$

3. In above problem, calculate the refractive index of first medium with respect to second medium.

Sol: From relation $_1n_2 = \frac{1}{_2n_1}$

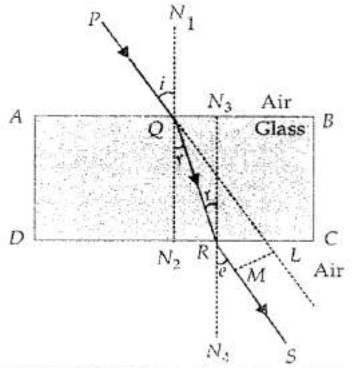
Putting values, we get $_1n_2 = \frac{1}{_2n_1} = \frac{1}{\sqrt{2}}$

Multiplying and dividing eqn.(i) by $\sqrt{2}$

$$_1n_2 = \frac{1}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}} = \frac{\sqrt{2}}{2} = \frac{1.414}{2} = 0.707$$

Refraction Through a Rectangular Glass Slab

Consider a rectangular glass slab ABCD. Ray PQ is incident on it on face AB at point Q, making angle PQN_1= i, called angle of incidence. It refracts in glass slab and goes along QR as refracted ray and becomes incident on face DC at point R from inside the slab.
Angle RQN_2 = angle QRN_3 = r and is called angle of refraction.



Refraction of light through a rectangular glass slab

The ray emerges (comes out) from the slab along RS making $\angle SRN_4$= e, called angle of emergence. For refraction at Q (from air to glass),

According to Snell's law, $n = \frac{\sin i}{\sin r}$ ... (i)

For refraction at R (from glass to air), $\frac{1}{n} = \frac{\sin r}{\sin e}$ or

$n = \frac{\sin e}{\sin r}$ ... (ii)

From eqns. (i) and (ii), $\sin i = \sin e$

i.e., $i = e$ angle of incidence = angle of emergence

It means that in refraction through a rectangular glass slab the incident ray and emergent ray of light are parallel to each other.

Lateral Displacement

The perpendicular distance between the original path of incident ray and the emergent ray coming out of a glass slab is called lateral displacement of the emergent ray of light.
In above diagram, LM represents lateral displacement for a glass slab.

Factors on which lateral displacement depends

(a) Lateral displacement is directly proportional to the thickness of glass slab.
(b) Lateral displacement is directly proportional to the incident angle.
(c) Lateral displacement is directly proportional to the refractive index of glass slab.
(d) Lateral displacement is inversely proportional to the wavelength of incident light.

ACTIVITY CORNER

To verify the laws of refraction and determine the refractive index of the glass

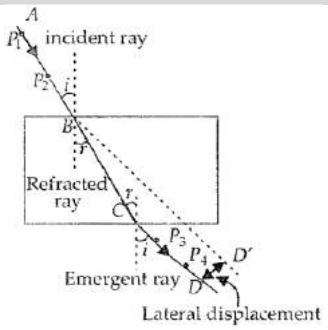
Materials required: Rectangular glass slab. White sheet of drawing paper. Drawing board. Drawing pins and all-purpose pins.

Procedure: Fix a plain sheet of paper on a drawing board with the help of drawing pins. Place a rectangular glass slab in the middle of the paper and draw its boundary with a sharp pencil.

Fix two pins (P_1 and P_2) vertically along a straight line AB. Now look through the glass slab from the other side and fix two pins (P_3 and P_4) so that those pins and the images of the pins P_1 and P_2 are in a straight line (when seen through the glass slab). Remove the glass and all the pins. Mark the positions of the pins.

Join the points P_1 and P_2 and extend the line to meet one face of the slab (Pointer B). Similarly, extend the line obtained by joining the points P_3 and P_4 to meet the other face of the slab (point C). Also the points B and C. Draw perpendiculars to the two faces of the slab at point B and point C. Measure and record the angle of incidence (i) and the angle of refraction (r).

Repeat the experiment for different angles of incidence and determine the corresponding angles of refraction.

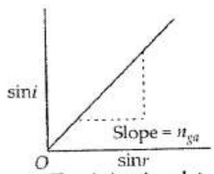


Refraction of light through a glass slab

Calculations: (i) Calculate the ratio $\sin i / \sin r$ for all the observations.

Calculate the average of all these values.

(ii) Plot a graph of $\sin i$ vs $\sin r$. Determine the slop of the plot.



The $\sin i$ vs $\sin r$ plot

Results: From the calculations, following results are obtained

(i) The ratio $\sin i / \sin r$ for all observations is constant.

(ii) The plot of $\sin i$ vs $\sin r$ is a straight line passing through the origin.

The slope of $\sin i$ vs $\sin r$ plot is equal to the ratio $\sin r$.

Conclusions: (i) The constant value of the ratio $\sin i / \sin r$ and the straight line plot between sin *i* and $\sin r$ verify the first law of refraction or Snell's law.

(ii) The incident ray, refracted ray and the normal, all lie in the same plane, i.e., plane of the paper.

This verifies the second law of refraction.

(iii) The average value of the $\sin i / \sin r$ ratio is equal to the refractive index of the glass of the slab.

(iv) The slop of $\sin i$ vs $\sin r$ plot is equal to the refractive index of the glass of the slab.

Spherical Lenses

A piece of transparent medium bounded by at least one spherical surface is called a spherical lens.

Lenses are of two types:

(i) Convex or converging lenses.

(ii) Concave or diverging lenses

- **Convex Lens**
  A lens having both spherical surfaces or one spherical surface and other plane surface such that it is thick in the middle and thin at the edges is known as convex lens.

(a) double convex (b) plano-convex (c) concavo- convex

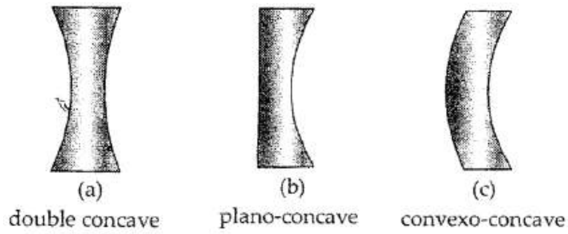
There are three types of convex lenses:

(i) Bi-convex or double convex lens: It has both the surfaces convex as shown in figure (a).

(ii) Plano-convex lens: It has one surface plane and the other surface convex as shown in figure (b).

(iii) Concavo-convex lens: It has one surface concave and the other surface convex as shown in figure (c).

- **Concave Lens**
  A lens which is thicker at the edges and thin at the centre i.e., curved inwards is known as concave lens. Concave lens are of three types:
  (i) Double concave lens: It has both the surfaces concave as shown in figure (a).



(ii) Plano-concave lens: It has one surface plane and the other surface concave as shown in figure (b).

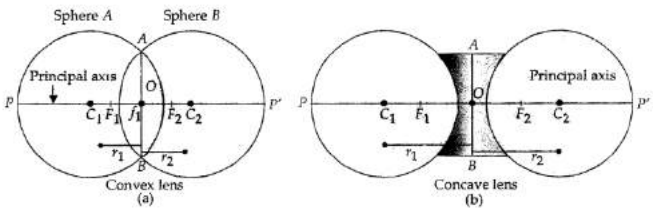
(iii) Convexo-concave lens: It has one surface convex and the other surface concave as shown in figure (c).

- **Terms Associated with Spherical Lenses**

(i) Aperture: The diameter of the circular edge of the lens, is called the aperture of the lens. In diagram, AB is the aperture of the lens.

(ii) Centre of curvature: The centre of curvature of a lens is defined as the centre of the spherical surface from which the lens has been cut. Thus, each surface of the lens is a part of a sphere. There will be two centres of curvature. In figures (a) and (b), C_1 and C_2 are the centres of curvature of the two lens surfaces.

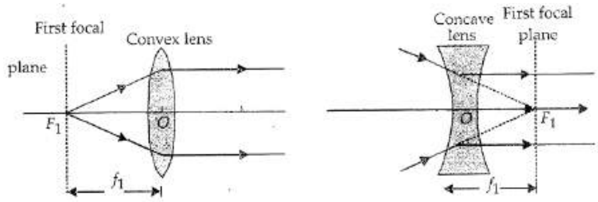
(iii) Principal axis: An imaginary straight line passing through the two centers of curvature of two spherical surfaces of the lens (or through one centre of curvature of one spherical surface and normal to the other plane surface), is called the principal axis of the lens. For a plane concave or plane convex lens, the principal axis is a line, which is normal to the plane surface and passing through the centre of curvature of the curved surface.



(iv) Optical centre: It is a point on the principal axis of the lens, such that a ray of light passing through it goes undeviated. In diagram '0' is optical centre of the lens.

(v) First principal focus (F_1): The position of a point on the principal axis of a lens so that the rays of light starting from this point after passing through the lens travel parallel or appear to travel parallel to the principal axis is called first principal focus (F_1)

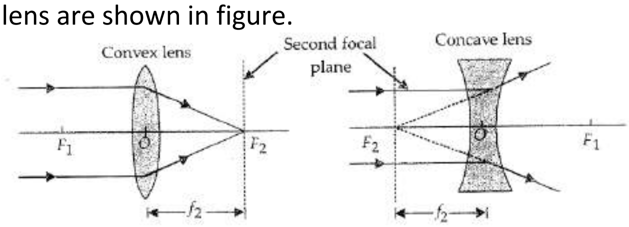
First principal focus (F_1) of a convex lens and a concave lens are shown in figure.



1(a)

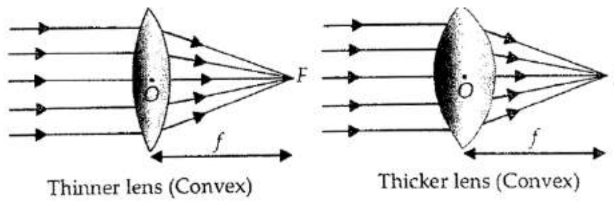
(vi) Second Principal focus (F_2): The position of a point on the principal axis of a lens where a beam of light parallel to the principal axis meets or appears to meet after passing through the lens is called second principal focus (F_2).

Second principal focus (F_2) of a convex and a concave lens are shown in figure.



1(b)

(vii) Focal length: The distance between the optical centre of the lens and the principal focus (first or second) of the lens, is called focal length of the lens. It is represented by the symbol f. In diagram, OF = f.



(viii) Focal plane: A vertical plane perpendicular to the principal axis, passing through the principal focus of the lens is called a focal plane. As shown in figure 1 (a) and 1(b), the plane passing through the first principal focus is called first focal plane and that passing through the second principal focus is called second focal plane.

Do You Know

For concavo-convex and convexo-concave lens, optical
centre may be outside the lens.

Activity Corner

Activity to determine the principal focus and rough focal length of a convex lens.

Fix a convex lens in a holder. Allow sunlight to fall on the convex lens. Now take a sheet of paper and adjust

its position on the other side of the lens till a small but bright spot of light is formed on the paper as shown in figure. This spot of light is the principal focus of the given convex lens. Measure the distance of the paper from the lens.
This distance is equal to the rough focal length of the lens.

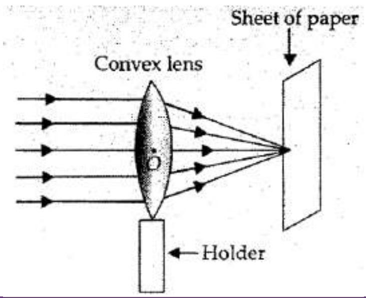
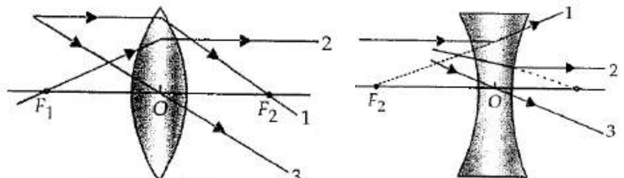


Image Formation in Lenses Using Ray Diagrams

For geometrical construction of an image formed by a lens, any of three of following rays of light are used:



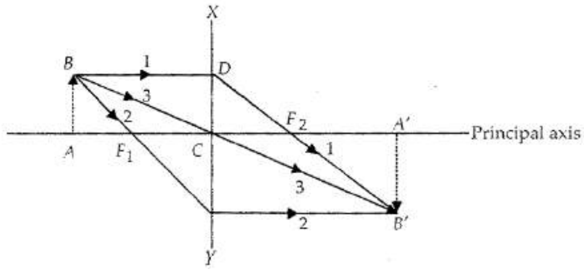
Convex lens
(a)

Concave lens
(b)

- **Incident on the lens parallel to principal axis:** After refraction from the lens, it actually passes through second principal focus F_2 (in case of a convex lens) or appears to come from the second principal focus F_2, (in case of a concave lens).
  [Object at infinity, image at focus F_2]
- **Incident on the lens through first principal focus F_1 (in case of a convex lens) or in direction of first principal focus F_1 (in case of a concave lens):** After refraction from the lens, it goes parallel to the principal axis.
  [Object at focus F_1, image at infinity]
- **Incident on the lens in direction of optical centre:** It passes undeviated through the lens.
- These special rays are very useful in drawing ray diagram in different cases.

Image Formation of Big Objects

The object is divided into many points. Point to point images are obtain. By combining the point images, the image of the whole object is obtained. Real point images give real image and virtual point images give virtual image of the complete object.
Note: Since lenses used are supposed to have a small aperture, their surfaces can be taken as plane and their principal sections can be represented by a straight line.
Example: In figure, XY represent principal section of a convex lens. It is taken plane due to its small aperture.



AB is a real object having bottom A on the principal axis and top B upwards. Three special rays are shown coming from top B, incident on the lens and refracted as shown. They actually meet at a point B', which becomes real image of B.A' lies perpendicularly below B', on the principal axis.
A' must represent image of bottom A of the object. A'B' represents real image of complete object AB. For small distances and sizes involved, the ray diagram can be drawn on same scale. For bigger distances and sizes, the diagram has to be drawn on a chosen scale.

Sign Convention

Description: It is a convention which fixes the signs of different distances measured. The sign convention to be formed is the new cartesian sign convention. It gives the following rules.

- The principal axis of the lens is taken along the X-axis of the rectangular coordinate system, and optical centre of the lens is taken as the origin.
- All distances are measured from the optical centre of the lens.
- The distances measured in the same direction as the direction of incident light, are taken as positive.
- The distances measured in the direction opposite to the direction of incident light, are taken as negative.
- Distances measured upward and perpendicular to the principal axis, are taken as positive.
- Distances measured downward and perpendicular to the principal axis, are taken as negative.
- In short:
  Right $\rightarrow$ positive   Left $\rightarrow$ negative
  Upward $\rightarrow$ positive   Downward $\rightarrow$ negative.

Lens Formula

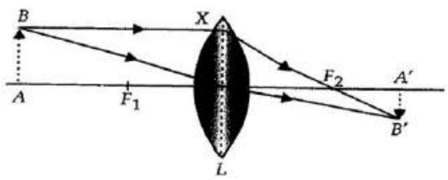
The equation relating the object distance, the image distance and the focal length, is called the lens formula.

Assumptions made

- The lens is thin.
- The lens has a small aperture.
- The object lies close to principal axis.
- The incident rays make small angles with the lens surface or the principal axis.

Lens Formula for Convex Lens

The diagram shows the principal section of a convex lens L, forming a real and inverted image A'B' of a real and erect object AB. The object is beyond distance 2f, while the image is between distance f and 2f.



Ray diagram for a convex lens forming a real image

Object distance (measured from C to A), $CA = -u$ (object on the left of the lens)

Image distance (measured from C to A'), $CA' = +v$ (image on right of the lens)

Focal length (measured from C toF_2), $CF_2 = +f$ (focus on right of the lens)

In similar triangles A'B'F, and CFX_2,

$$\frac{A'B'}{CX} = \frac{F_2A'}{CF_2} = \frac{CA' - CF_2}{CF_2} = \frac{v-f}{f}$$

In similar triangles A'B'Cand ABC,

$$\frac{A'B}{AB} = \frac{CA'}{CA} = \frac{v}{-u}$$

But since CX = AB

$$\frac{A'B'}{CX} = \frac{A'B'}{AB} = \frac{v}{-u}$$

Hence/ from eqns. (i) and (ii),

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

$$-uv + uf = vf$$

$$uf - vf = uv$$

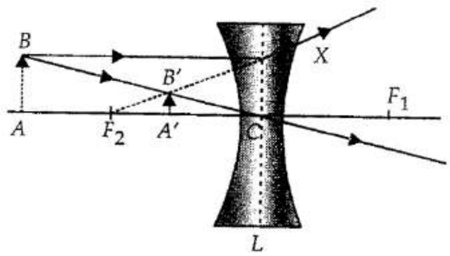
Dividing by uvf, we get,

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

This is the required lens formula.

Lens Formula For Concave Lens

The diagram shows the principal section of a concave lens L forming a virtual and erect image A 'B' of a real and erect object AB. The object is beyond distance If, while the image is in between focus and optical centre on same side as the object.



Ray diagram for a concave lens forming a image which is always virtual

Here,

Object distance (measured from C to A), $CA = -u$ (object on the left of the lens)

Image distance (measured from C to A'), $CA' = -v$ (image on left of the lens)

Focal length (measured from C to F_2) $CF_2 = -f$ (focus on left of the lens)

In similar triangles and CXF_2

$$\frac{A'B'}{CX} = \frac{F_2A'}{CF_2} = \frac{F_2C - A'C}{CF_2} = \frac{-f-(-v)}{-f} = \frac{f-v}{f}$$

In similar triangles A'B' C and ABC

$$\frac{A'B'}{AB} = \frac{CA}{CA} = \frac{-v}{-u} = \frac{v}{u}$$

But since CX=AB

Hence/ from eqns. (i) and (ii),

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

$$uf - uv = vf$$

$$uf - vf = uv$$

Dividing by uvf, we get,

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

This is the required lens formula.

Linear Magnification

The ratio of the size of the image as formed by refraction from the lens to the size of the object, called linear magnification produced by the lens. It is represented by the symbol m.

If I be the size of the image and 0 be the size of the object/ then $m = \frac{I}{O}$

If we represent size of the object by h_1 and size of image by h_2, Then, $I = h_2$ and $O = h_1$

Hence, $m = \frac{h_2}{h_1}$

Expression:

(i) For convex lens forming real image in figure (1).

$I = A'B' = -h_2$ (inverted image)

$O = AB = +h_1$ (erect object)

Then, $m = \frac{-h_2}{h_1} = \frac{-A'B'}{AB}$

In similar triangles A'B'C and ABC, $\frac{A'B'}{AB} = \frac{CA'}{CA}$

Then, $m = -\frac{CA'}{CA} = \frac{-v}{-u}$ i.e., $m = \frac{v}{u}$

(ii) For concave lens forming virtual image,

$I = A'B' = -h_2$ (erect image)

$O = AB = +h_1$ (erect object)

Then $m = \frac{-h_2}{h_1} = \frac{A'B'}{AB}$

In similar triangles A'B'C and ABC, $\frac{A'B'}{AB} = \frac{CA'}{CA}$

Then, $m = -\frac{CA'}{CA} = -\frac{v}{-u}$ i.e., $m = \frac{v}{u}$

Hence we concluded that the linear magnification produced by a lens is equal to the ratio of the image distance to the object distance with a plus sign.

Note: For mirror, $m = -\frac{v}{u}$. It is so because for an inverted image v is negative in case of mirrors while it is positive in case of lenses.

ILLUSTRATION

4. A 4.0 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 20 cm. If the distance of the bisect is 30cmfrom the lens, find the position, nature and size of the image. Also find its magnification,

Sol.: Here, $h_1 = ? v = ?, m = ?$

Step 1. Determination of v

Using lens formula $-\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ we have

$-\frac{1}{(30)} + \frac{1}{v} = \frac{1}{20}$ or $\frac{1}{v} = \frac{1}{20} - \frac{1}{30}$

Or $\frac{1}{v} = \frac{1}{60}$ or $v = +60$ cm

Thus, the image is formed at 60 cm on other side (i.e., right side) of the lens.

Step 2. Determination of h_2

Using $\frac{h_2}{h_1} = \frac{v}{u}$ we have

$h_2 = \frac{v}{u} h_1 = \frac{60}{-30} \times 4 = -8.0$ cm

Thus, size of the image is 8.0 cm. Negative sign shows that the image is inverted.

So, a real and inverted image of large size is formed.

Step 3. Determination of magnification

Using $m = \frac{h_2}{h_1}$ we get

$m = \frac{-8.0\,cm}{4.0\,cm} = -2$

Image Formation By a Convex Lens

From lens formula, we find that for a lens of a fixed focal length *f*, as object distance u changes, image distance v also changes. Moreover, as u decreases, v increase. This change the position, the nature and the size of the image.

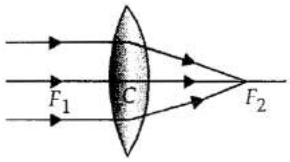
Different cases, are as given below with their ray diagram

- **Object at infinity:**

A point object lying on the principal axis:

Rays come parallel to the principal axis and after refraction from the lens, actually meet at the second principal focus F_2

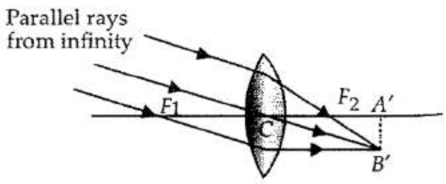
The image is formed at focus F_2. It is real and point sized.



Convex lens; Point object at infinity, image at focus

- **A big size object with its foot on the principal axis**

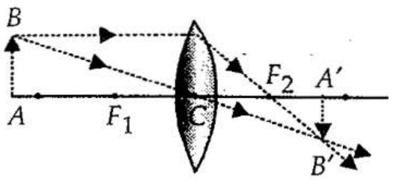
Parallel rays come inclined to the principal axis. Image is formed at the second principal focus F_2.It is real, inverted and diminished (smaller in size than the object)



Convex lens; Big object at infinity, image at focus

- **Object at distance more than twice the focal length**

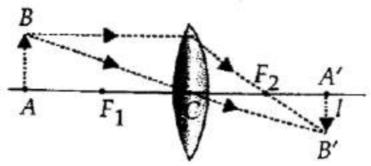
Real object AB has its image A'B' formed between distance f and 2f.
The image is real, inverted and diminished (smaller in size than the object).



Convex lens; object beyond 2f, image between f and 2f

- **Object at distance twice the focal length**

Real object AB has its image A'B' formed at distance If.
The image is real, inverted and has same size as the object.

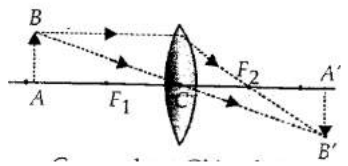


Convex lens; object beyond 2f, image between f and 2f

- **Object at distance more than focal length and less than twice the focal length**

  Real object AB has its image A'B' formed beyond distance If.

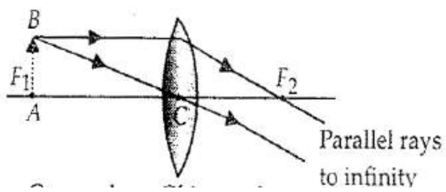
  The image is real, inverted and enlarged (bigger in size than the object)



Convex lens; object between f and 2f image beyond 2f

- **Object at focus**

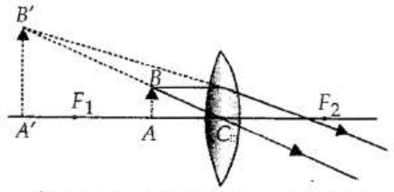
Real object AB has its image formed at infinity.
The image is real and, inverted (refracted rays go downward) and must have very large size.



Convex lens; object at focus, mage at infinity

- **Object between focus and optical centre**

Real object AB has its image A'B' formed in front of the lens.
The image is virtual erect and enlarged.



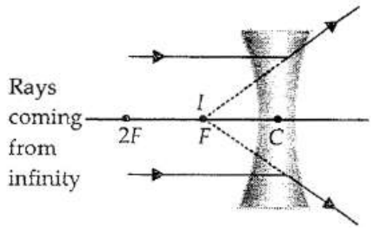
Convex lens; Object between focus and optical centre, image in front of the lens

Image Formation by a Concave Lens

Different cases, are as given below with their ray diagrams.

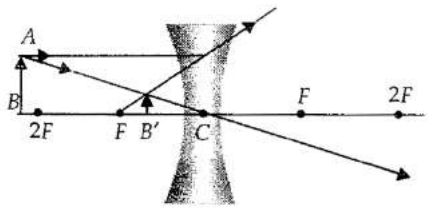
- **When the object is at infinity.**

Appears to be formed at the focus (F), virtual, erect arid very small on the same side as the object.



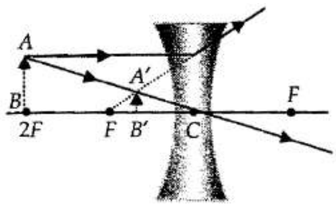
- **When the object is beyond 2F.**

Appears to be formed between F and C, virtual, erect and smaller than the object on the same side as the object.



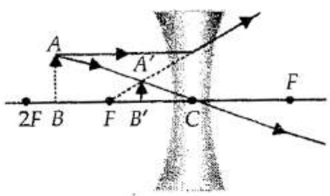
- **When the object is at 2F.**

Virtual, erect, diminished and on the same side as the object,



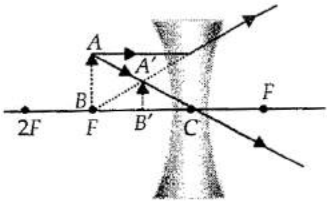
- **When the object is between F and 2F.**

Virtual, Erect, Diminished and on the same side of the lens.



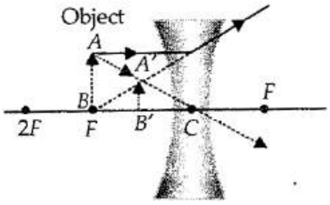
- **When the object is at F.**

Virtual, erect, diminished and on the same side of the object.



- **When the object is anywhere near the lens, i.e., between F and C.**

Virtual, erect, diminished and on the same side of lens.



ILLUSTRATION

5. A concave lens of focal length 20 cm form an image at a distance of 10 cm from the lens. What is the distance of the object from the lens? Also draw ray diagram.

Sol:

Here, $f = -20\,\text{cm}$(Sign convention)

$u = -10$ ($\because$ Image formed by concave lens is virtual)

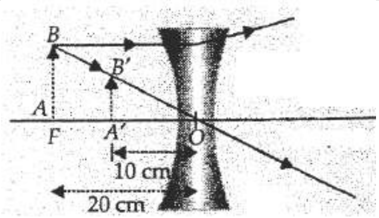
Step 1. Using, $-\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ we have

$-\frac{1}{u}-\frac{1}{10}=-\frac{1}{20}$ or $-\frac{1}{20}+\frac{1}{10}=\frac{1}{20}$

or $u = -20\,\text{cm}$

Thus, the object is placed at 20 cm from the concave lens.

Step 2.



- **Distinction Between a Plane Glass Sheet, a Convex and a Concave Lens (without touching Surface)**

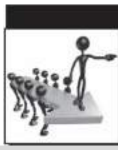
  The glass sheet is placed over a printed page and the virtual image of the print is seen. The magnification of the image is observed. Then make an idea of the magnification.

  If magnification is one, glass sheet is plane. If magnification is more than one, it's a convex lens.

  If magnification is less than one, it's a concave lens.

Power of a Lens

A convex lens converges (brings closer) and a concave lens diverges (spreads) the light rays incident on it. More is the convergence or divergence produced by a lens, more powerful the lens is said to be. It is the capacity or the ability of a lens to deviate (converge or diverge) the path of rays passing through it. A lens producing more convergence or more divergence, is said to have more power. It is represented by the symbol P.



DO YOU KNOW

(i) Power of convex lens is positive because its focal length is positive.

(ii) Power of concave lens is negative because its focal length is negative.

- **Relation of Power with Focal Length**

A lens of less focal length focuses a parallel beam of light at near point. It produces more convergence or more divergence. It is said to have more power.

Hence, Power $\propto \frac{1}{\text{focal length}}$ i.e., $P \propto \frac{1}{f}$

We have, $P = \frac{1}{f}$

- Units of power is dioptre (D). One dioptre is the power of a lens or focal length 1 m.

  In general, P (dioptre) $= \frac{1}{f\,(metre)} = \frac{100}{f\,(cm)}$

ILLUSTRATION

6. What will be the focal length of a lens whose power is given as +2.0 D?

Sol: Here, P = 2 D

Using $P = \frac{1}{f\,(in\,m)}$ we get

$f = \frac{1}{P} = \frac{1}{2} = 0.5m = 50cm$

7. What is the power of a convex lens o local length 40 cm

Sol. Here, $f = 40$ cm

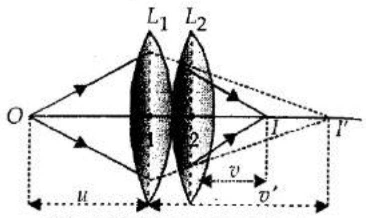
Using, $P = \frac{100}{f\,(in\,cm)}$

We have $P = \frac{100}{40} = +2.5\,$D

Number of a Lens

(i) A convex lens of focal length +50 cm (+0.5 m), has power +2 dioptre. Its number is +2.
(ii) A concave lens of focal length – 20 cm (-0.2 m), has power -5 dioptre. Its number is – 5.

- **Focal Length and Power of a Lens Combination**
  The power of the combination of a number of thin lenses placed in contact is equal to the algebraic a sum of the powers of the individual lenses.
- **For a Two Lens Combination**
  Let lenses L_1 and L_2 'have focal lengths $f_1$and f_2 and powersP_1 and P_2 respectively. They are very thin so that their optical centers C_1 and C_2 lie very close.
  Let for the combination/ focal length = F, Power = P
  Lens L_1, forms real image of point object 0 at point I'. acts as virtual object for lens L_2 which makes final real image at I.



Two thin lenses in contact

For lens $L_1, C_1O = -u, C_1I' = +v'$

For lens $L_2, C_2I' = C_1I' = v', C_2I = +v$

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

For lens $L_1, \frac{1}{v'} - \frac{1}{u} = \frac{1}{f_1}$

For lens $L_2, \frac{1}{v} - \frac{1}{v'} = \frac{1}{f_2}$

Adding equations (i) and (ii) $\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2}$

For the combination, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Hence, from equation (iii) and (iv), $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$ or

$P = P_1 + P_2$

Note:

- For a number of thin lenses having very close optical centers $P = P_1 + P_2 .... + P_n$ or
  $P = \sum P_n (n = 1 \ to \ n)$
- P is positive for convex lens and negative for concave lens.
  Then P = algebraic sum of power.

ILLUSTRATION

8. Two lenses one of focal length 20 cm (convex lens) and another of focal length -15 cm (concave lens) are placed in contact. What is the focal length and power of the combination?

Sol: Here, f_1=+20cm=+0.2m

$f_2 = -15cm = -0.15m$

F =?

P =?

From relation, $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

Putting values, we get

$\frac{1}{F} = \frac{1}{0.2} + \frac{1}{-0.15} = \frac{3-4}{0.6} = -\frac{1}{0.6}$

Or F = - 0.6 m

From relation, $P = \frac{1}{F} = -\frac{1}{0.6} = -1.67$

i.e., $p = -1.67$ D

ESSENTIAL POINTS For COMPETITIVE EXAMS

- Refraction of light: The bending of light when it passes obliquely from one transparent medium to another is called refraction of light.
- Medium: A transparent substance in which light travels is known as a medium. A medium in which the speed of light is more is known as an optically rarer medium. A medium in which the speed of light is less is known as an optically denser medium.
- Laws of refraction: (i) The incident ray, the refracted ray and the normal to the surface separating two medium all lie in the same plane.
  (ii) The ratio of the sine of the incident angle ($\angle$i) to the sine of the refracted angle ($\angle$r) is
  i.e., $n = \frac{\sin i}{\sin r} =$ constant.
  This constant is known as the refractive index of second medium with respect to the first medium.
- Lateral shift (displacement): The perpendicular distance between the original path of the incident ray and the emergent ray coming out of a glass slab is called lateral shift.
- Lens: It is a transparent medium bounded by two spherical refracting surfaces or by one spherical and other plane refracting surfaces.
- Power of a lens: It is defined as the reciprocal of the focal length of a lens.

- Dioptre: It is the S.I. unit of power. One dioptre is the power of a lens where focal length is one metre.
- Lens formula: $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$
- Magnification: $m=\frac{h'}{h}=\frac{v}{u}$
- Power of lens: $P=\frac{1}{\text{focal length (in meters)}}$
- Power of a convex lens is positive.

Power of a concave lens is negative.

CONCEPT MAP

Refraction : It is the Phenomenon of change in path of light as it goes from one medium to another.

Spherical lenses : A lens is piece of transparent medium bounded by two spherical refracting surfaces or by one spherical and other plane refracting surface.

Two laws of refraction :
- The incident ray, refracted ray and the normal all lie in the same plane.
- Snell's Law : $\frac{\sin i}{\sin r}=\text{constant}$

Convex : It is thick at the centre and thin at the edges.

Concave : It is thick at the edges and thin at the centre.

Lens formula :
$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$
where
v = image distance
u = object distance
f = focal length

u	v
(i) Between C and infinity	(i) Between C and f
(ii) At infinity	(ii) At f

Refractive index (n) : It is the ratio of speed of light in vacuum(c) to the speed of light in the medium (v)

i.e., $n=\frac{c}{v}$

Thin lenses have the following main features :
- Optical centre
- Principal axis
- Focal point (principal focus)
- Focal length f
- Focal plane

Power of lens :
It is the reciprocal of focal length
$$P=\frac{1}{f}$$
Units : diopter

Linear magnification :
$$=\frac{\text{Size of image}}{\text{Size of object}}$$

u	v
(i) Between f and optic centre	(i) On the same side of the lens
(ii) At f	(ii) At infinity
(iii) Between f and $2f$	(iii) Beyond $2f$
(iv) At $2f$	(iv) At $2f$
(v) Beyond $2f$	(v) Between f and $2f$
(vi) At infinity	(vi) At f

The power of the combination of lenses in contact is equal to the algebraic sum of the powers of individual lenses.
$P=P_1+P_2$