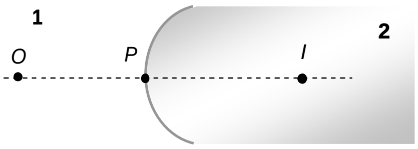
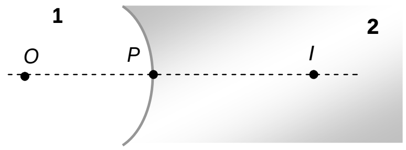
Refraction From Spherical Surface





(1) **Refraction formula :** $\frac{\mu_2 - \mu_1}{R} = \frac{\mu_2}{v} - \frac{\mu_1}{u}$

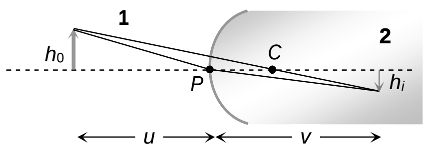
Where μ_1 = Refractive index of the medium from which light rays are coming (from object).

μ_2 = Refractive index of the medium in which light rays are entering.

u = Distance of object, v = Distance of image, R = Radius of curvature

(2) **Lateral magnification :** The lateral magnification m is the ratio of the image height to the object height

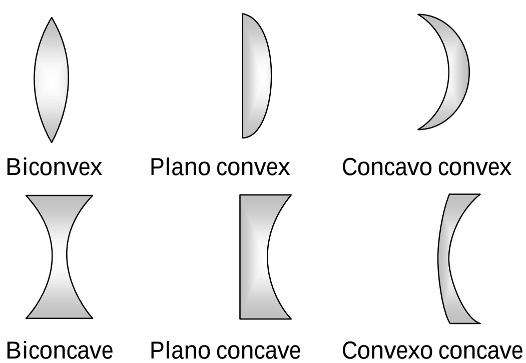
or $m = \left(\frac{h_i}{h_0}\right) = \left(\frac{\mu_1}{\mu_2}\right)\left(\frac{v}{u}\right)$



Lens

(1) Lens is a transparent medium bounded by two refracting surfaces, such that at least one surface is curved. Curved surface can be spherical, cylindrical etc.

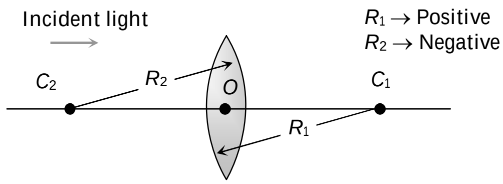
(2) Lenses are of two basic types convex which are thicker in the middle than at the edges and concave for which the reverse holds.



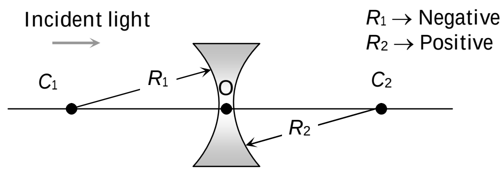
(3) As there are two spherical surfaces, there are two centres of curvature C_1 and C_2 and correspondingly two radii of curvature R_1 and R_2

(4) The line joining C_1 and C_2 is called the principal axis of the lens. The centre of the thin lens which is on the principal axis, is called the optical centre.

(5) A ray passing through optical centre proceeds undeviated through the lens.



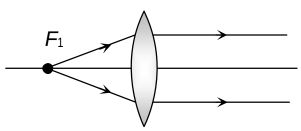
(A)



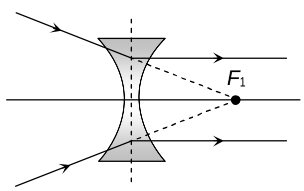
(B)

(6) **Principal focus :** We define two principal focus for the lens. We are mainly concerned with the second principal focus (F). Thus wherever we write the focus, it means the second principal focus.

First principal focus : An object point for which image is formed at infinity.

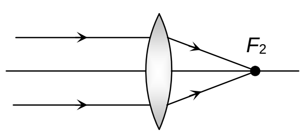


(A)

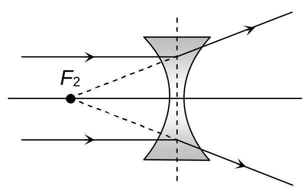


(B)

Second principal focus : An image point for an object at infinity.



(A)



(B)

Focal Length, Power and Aperture of Lens

(1) **Focal length (f) :** Distance of second principle focus from optical centre is called focal length

$f_{\text{convex}} \rightarrow$ positive, $f_{\text{concave}} \rightarrow$ negative, $f_{\text{plane}} \rightarrow \infty$

(2) **Aperture :** Effective diameter of light transmitting area is called aperture. Intensity of image $\propto (\text{Aperture})^2$

(3) **Power of lens (P) :** Means the ability of a lens to deviate the path of the rays passing through it. If the lens converges the rays parallel to the principal axis its power is positive and if it diverges the rays it is negative.

Power of lens $P = \dfrac{1}{f(m)} = \dfrac{100}{f(cm)}$; Unit of power is Diopter (D)

$P_{\text{convex}} \rightarrow$ positive, $P_{\text{concave}} \rightarrow$ negative, $P_{\text{plane}} \rightarrow$ zero .

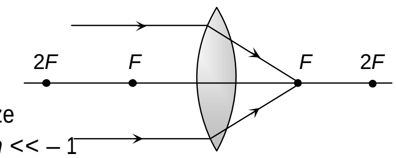
Rules of Image Formation by Lens

Convex lens : The image formed by convex lens depends on the position of object.

(1) When object is placed at infinite (*i.e.* $u = \infty$)

Image

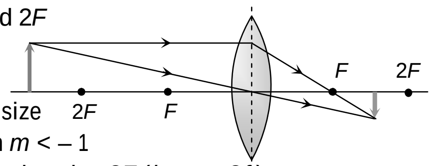
⟶ At F
⟶ Real
⟶ Inverted
⟶ Very small in size
⟶ Magnification $m << -1$



(2) When object is placed between infinite and $2F$ (*i.e.* $u > 2f$)

Image

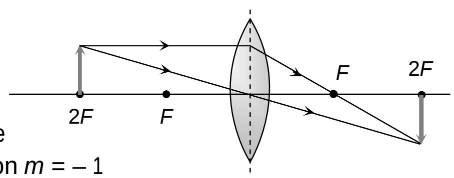
⟶ Between F and $2F$
⟶ Real
⟶ Inverted
⟶ Very small in size
⟶ Magnification $m < -1$



(3) When object is placed at $2F$ (*i.e.* $u = 2f$)

Image

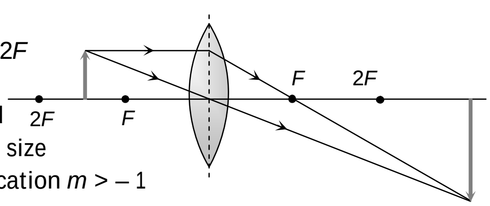
⟶ At $2F$
⟶ Real
⟶ Inverted
⟶ Equal in size
⟶ Magnification $m = -1$



(4) When object is placed between F and $2F$ (*i.e.* $f < u < 2f$)

Image

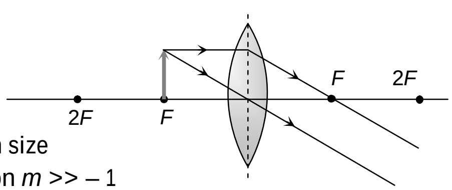
⟶ Beyond $2F$
⟶ Real
⟶ Inverted
⟶ Large in size
⟶ Magnification $m > -1$



(5) When object is placed at F (*i.e.* $u = f$)

Image

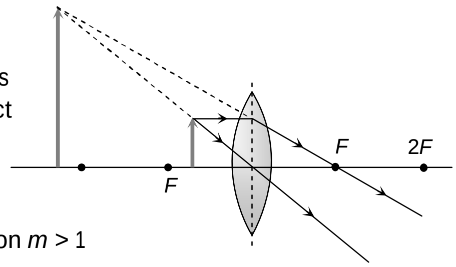
⟶ At ∞
⟶ Real
⟶ Inverted
⟶ Very large in size
⟶ Magnification $m >> -1$



(6) When object is placed between F and optical center ($i.e.$ $u < f$)

Image

- Same side as that of object
- Virtual
- Erect
- large in size
- Magnification $m > 1$

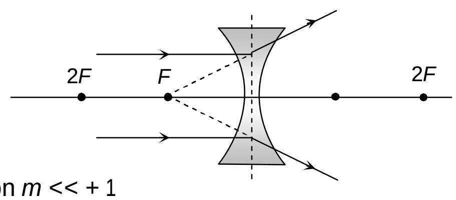


Concave lens : The image formed by a concave lens is always virtual, erect and diminished (like a convex mirror)

(1) When object is placed at ∞

Image

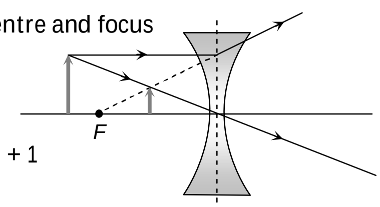
- At F
- Virtual
- Erect
- Point size
- Magnification $m << +1$



(2) When object is placed any where on the principal axis

Image

- Between optical centre and focus
- Virtual
- Erect
- Smaller in size
- Magnification $m < +1$

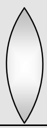
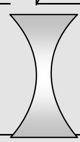


Lens Maker's Formula and Lens Formula

(1) **Lens maker's formula :** If R_1 and R_2 are the radii of curvature of first and second refracting surfaces of a thin lens of focal length f and refractive index μ (*w.r.t.* surrounding medium) then the relation between f, μ, R_1 and R_2 is known as lens maker's formula.

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Table: Focal length of different lenses

Lens	**Focal length**	**For $\mu = 1.5$**
Biconvex lens $R_1 = R$ $R_2 = -R$ 	$f = \frac{R}{2(\mu - 1)}$	$f = R$
Plano-convex lens $R_1 = \infty$ $R_2 = -R$ 	$f = \frac{R}{(\mu - 1)}$	$f = 2R$
Biconcave $R_1 = -R$ $R_2 = +R$ 	$f = -\frac{R}{2(\mu - 1)}$	$f = -R$
Plano-concave $R_1 = \infty$ $R_2 = R$ 	$f = \frac{-R}{(\mu - 1)}$	$f = -2R$

(2) **Lens formula :** The expression which shows the relation between u, v and f is called lens formula.

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

Magnification

The ratio of the size of the image to the size of object is called magnification.

(1) Transverse magnification : $m = \frac{I}{O} = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$ (use sign convention while solving the problem)

(2) Longitudinal magnification : $m = \frac{I}{O} = \frac{v_2 - v_1}{u_2 - u_1}$. For very small object $m = \frac{dv}{du} = \left(\frac{v}{u}\right)^2 = \left(\frac{f}{f+u}\right)^2 = \left(\frac{f-v}{f}\right)^2$

(3) Areal magnification : $m_s = \frac{A_i}{A_o} = m^2 = \left(\frac{f}{f+u}\right)^2$,

(A_i = Area of image, A_o = Area of object)

(4) **Relation between object and image speed :** If an object moves with constant speed (V_o) towards a convex lens from infinity to focus, the image will move slower in the beginning and then faster. Also $V_i = \left(\frac{f}{f+u}\right)^2 . V_o$

Lens Immersed in a Liquid

If a lens (made of glass) of refractive index μ_g is immersed in a liquid of refractive index μ_l, then its focal length in liquid, f_l is given by $\frac{1}{f_l} = ({}_l\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ......(i)

If f_a is the focal length of lens in air, then

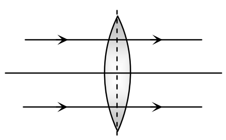
$$\frac{1}{f_a} = ({}_a\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ......(ii)$$

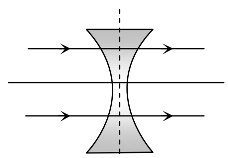
$$\Rightarrow \frac{f_l}{f_a} = \frac{({}_a\mu_g - 1)}{({}_l\mu_g - 1)}$$

(1) If $\mu_g > \mu_l$, then f_l and f_a are of same sign and $f_l > f_a$.

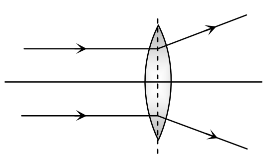
That is the nature of lens remains unchanged, but it's focal length increases and hence power of lens decreases.

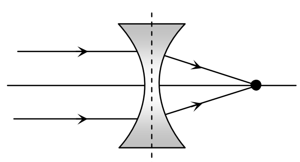
(2) If $\mu_g = \mu_l$, then $f_l = \infty$. It means lens behaves as a plane glass plate and becomes invisible in the medium.





(3) If $\mu_g < \mu_l$, then f_l and f_a have opposite signs and the nature of lens changes *i.e.* a convex lens diverges the light rays and concave lens converges the light rays.



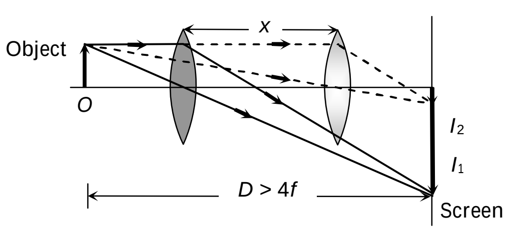


ADDITIONAL TOPICS

Displacement Method

By this method focal length of convex lens is determined.

Consider an object and a screen placed at a distance *D* (> 4*f*) apart. Let a lens of focal length *f* be placed between the object and the screen.



(1) For two different positions of lens two images $(I_1 \text{ and } I_2)$ of an object are formed at the screen.

(2) Focal length of the lens $f = \frac{D^2 - x^2}{4D} = \frac{x}{m_1 - m_2}$

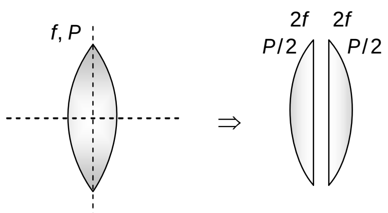
where $m_1 = \frac{I_1}{O}$; $m_2 = \frac{I_2}{O}$ and $m_1 m_2 = 1$.

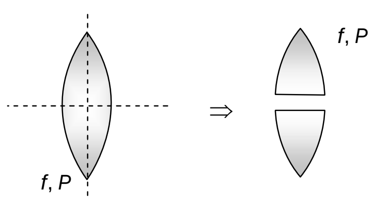
(3) Size of object $O = \sqrt{I_1 . I_2}$

Cutting of Lens

(1) A symmetric lens is cut along optical axis in two equal parts. Intensity of image formed by each part will be same as that of complete lens. Focal length is double the original for each part.

(2) A symmetric lens is cut along principle axis in two equal parts. Intensity of image formed by each part will be less compared as that of complete lens.(aperture of each part is $\frac{1}{\sqrt{2}}$ times that of complete lens). Focal length remains same for each part.





Combination of Lens

(1) For a system of lenses, the net power, net focal length and magnification are given as follows :

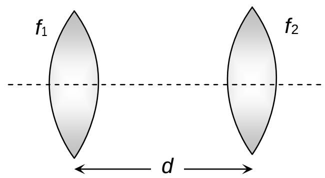
$$P = P_1 + P_2 + P_3 ....\ , \qquad \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + ..., \qquad m = m_1 \times m_2 \times m_3 \times ....\ ..$$

(2) In case when two thin lens are in contact : Combination will behave as a lens, which have more power or lesser focal length.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow F = \frac{f_1 f_2}{f_1 + f_2} \quad \text{and} \quad P = P_1 + P_2$$

(3) If two lens of equal focal length but of opposite nature are in contact then combination will behave as a plane glass plate and $F_{\text{combination}} = \infty$

(4) When two lenses are placed co-axially at a distance *d* from each other then equivalent focal length (*F*).



$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$ and $P = P_1 + P_2 - dP_1P_2$

(5) Combination of parts of a lens :