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Changing your Tomorrow

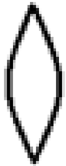
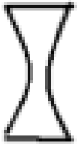
Lenses , Thin Lens Formula , Lens maker’s formula

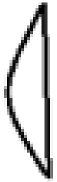
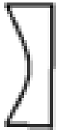
XII- SCIENCE

SUBJECT : PHYSICS
CHAPTER NUMBER: 9
CHAPTER NAME : RAY OPTICS

LENS

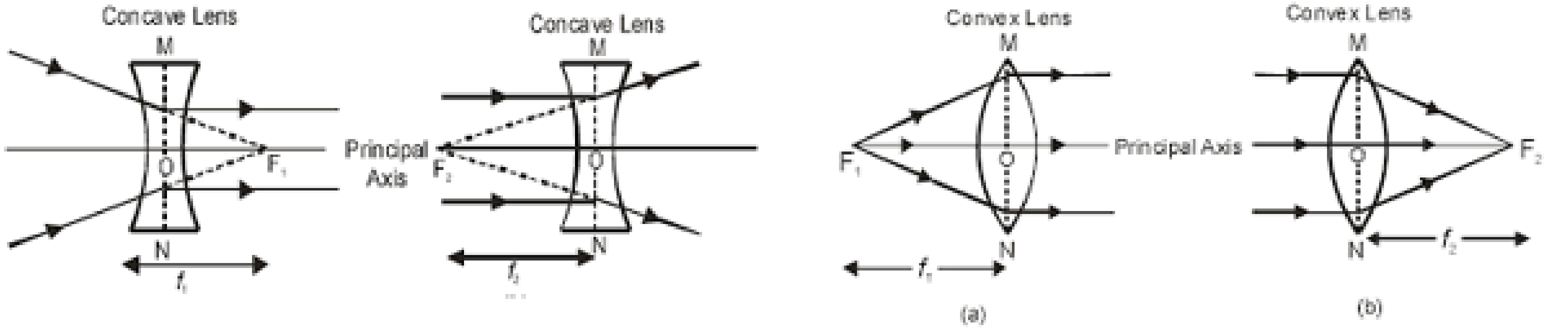
Lens is a refracting medium bounded by two spherical surfaces. As per the shapes of the two boundary surfaces the lens is named.

e.g.: (i) double convex  (ii) double concave 

(iii) plano convex  (iv) plano concave etc. 

Some important terms related to lenses:

(i) **Principal Focus and focal lengths:** Lenses have two principal foci at two sides of lens i.e. 1st focus (F_1) and 2nd Focus (F_2). For convergent lens , if $u = - f_1$, then $v = \infty$ and for divergent lenses, if $u = f_1$, then $v = \infty$. Similarly. For convergent lens , if $u = -\infty$, then $v = f_2$ and for divergent lenses, if $u = -\infty$, then $v = - f_2$.

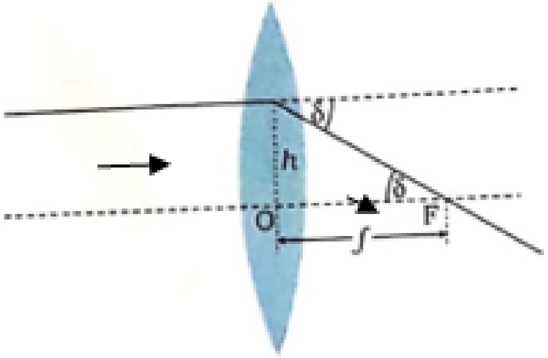


(ii) If both sides of lens have same medium then magnitude of both focal lengths are same and taken as f.

Some important terms related to lenses:

(iii) **Power of lens:** Power of a lens is a measure of the convergence or divergence , which a lens introduces to the light falling on it.

Power of a lens is numerically equal to the tangent of the angle by which it converges or diverges a beam of light falling at unit distance from optical centre.



In the figure a beam parallel to principal axis strikes the lens at a height h.

From figure , δ = deviation angle

As $\tan \delta = h/f$. If h = unity , then $\tan \delta = 1/f$

So power of lens is ; $\mathbf{P = 1/f}$

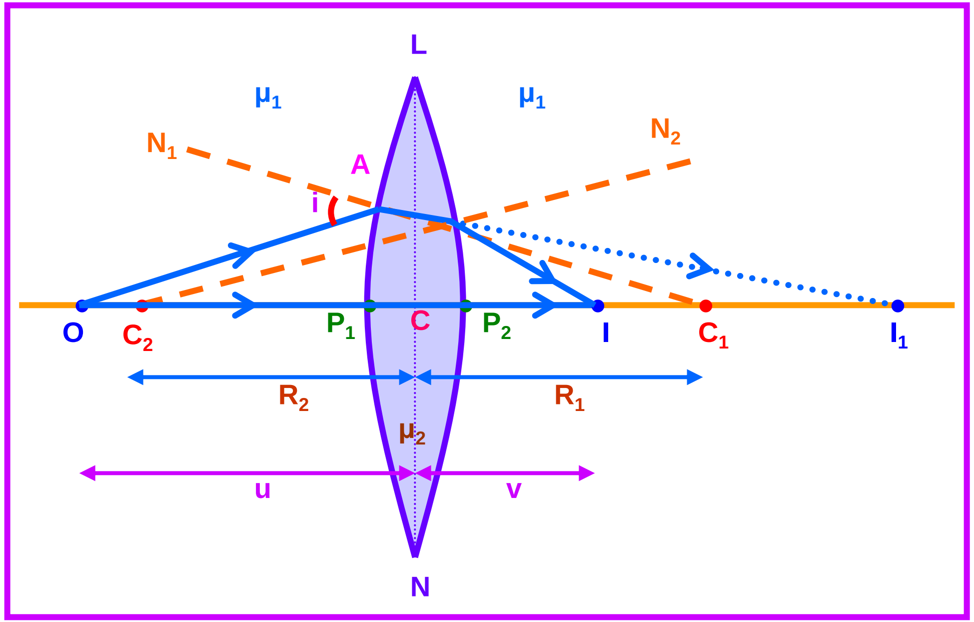
S.I. unit of power is dioptre (D) and $\mathbf{1\ D = 1 m^{-1}}$.

Lens Maker's Formula:

For refraction at LP_1N,

$$\frac{\mu_1}{CO} + \frac{\mu_2}{CI_1} = \frac{\mu_2 - \mu_1}{CC_1}$$

(as if the image is formed in the denser medium)



For refraction at LP_2N,

$$\frac{\mu_2}{-CI_1} + \frac{\mu_1}{CI} = \frac{-(\mu_1 - \mu_2)}{CC_2}$$

(as if the object is in the denser medium and the image is formed in the rarer medium)

Combining the refractions at both the surfaces,

$$\frac{\mu_1}{CO} + \frac{\mu_1}{CI} = (\mu_2 - \mu_1)\left(\frac{1}{CC_1} + \frac{1}{CC_2}\right)$$

Substituting the values with sign conventions,

$$\frac{1}{-u} + \frac{1}{v} = \frac{(\mu_2 - \mu_1)}{\mu_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Lens Maker's Formula:

Since $\mu_2 / \mu_1 = \mu$

$$\frac{1}{-u} + \frac{1}{v} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

or

$$\frac{1}{-u} + \frac{1}{v} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

When the object is kept at infinity, the image is formed at the principal focus.

i.e. $u = -\infty$, $v = +f$.

So,

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

This equation is called 'Lens Maker's Formula'.

Also, from the above equations we get,

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

Change of focal length and power of a lens by changing the surrounding medium:

If surrounding medium changes then n1 changes.

From lens maker's formula we have $\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ...(i)

If n_1 increases then

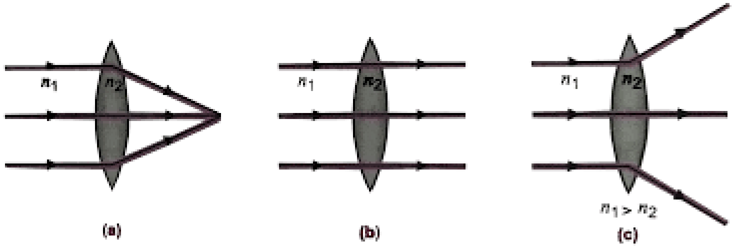
(i) till $n_1 < n_2$; sign of R.H.S. does n't change, so sign of f does n't change. but f increses. Hence lens behaves as of its nature with greater focal length and less power.

(ii) When $n_1 = n_2$; then R.H.S. of equation = 0. So 1/f = 0 i.e. P = 0 and f = ∞. Hence the lens behaves as a plane glass slab and dissapears in the medium.

(iii) When $n_1 < n_2$; then $\left(\frac{n_2}{n_1} - 1\right) < 0$. Hence sign of R.H.S.of equation (i) changes and hence sign of f changes. Hence lens behaves opposite to its nature i.e. convex lens behavees as divergent lens and concave lens as convergent lens.

NUMERICAL

- **Question: Draw the ray diagrm showing the refraction of parallel beams through a convex lens of refractive index n_2 kept in the surrounding of refractive index n_1 for**
  (a) $n_1 < n_2$ (b) $n_1 = n_2$ (c) $n_1 > n_2$.
- **Answer:** (a) Lens is convergent
- (b) Lens is as a plane sheet
- (c) Lens is divergent.



NUMERICAL

- Numerical: (a)If f = 0.5 m for a glass lens , what is the power of the lens ?
- (b) The radii of curvature of a double convex lens are 10 cm and 15 cm. Its focal length is 12 cm. What is the refractive index of the lens ?
- (c) A convex lens has focal length 20 cm in air ? What is its focal length in water ? (Refractive index of glass is 1.5 and of water is 1.33.)

NUMERICAL

Answer: (a) P = 1/f = 1/0.5m= 2 D

(b) For conve lens ; R_1 = + 10 cm nd R_2 = -15 cm

As from lens maker's formula we have $\frac{1}{f}=(n_{21}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=\left(\frac{n_2}{n_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$$\Rightarrow \frac{1}{12}==\left(\frac{n}{1}-1\right)\left(\frac{1}{10}+\frac{1}{15}\right)\Rightarrow \frac{1}{12}=(n-1)\left(\frac{3+2}{30}\right)=(n-1)\left(\frac{1}{6}\right)$$

$$\Rightarrow n-1=\frac{6}{12}=0.5\Rightarrow n=1.5$$

(c) In air , $\frac{1}{f_{air}}=\left(\frac{n_{glass}}{1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$ ....(i)

In water ; $\frac{1}{f_{water}}=\left(\frac{n_{glass}}{n_{water}}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$ ....(ii)

Now eqn. (i) divided by eqn. (ii) ; $\frac{f_{water}}{f_{air}}=\frac{(n_{glass}-1)}{(n_{glass}/n_{water}-1)}$

$$\Rightarrow \frac{f_{water}}{f_{air}}=\frac{(1.5-1)}{(1.5/1.33-1)}=4\Rightarrow f_{water}=4f_{air}=4\times 20cm=80cm$$

NUMERICAL

- **Numerical: A bi- convex lens of radius of curvature R and refractive index n_1 is kept in such a region that medium left to it is air and medium right to it has refractive index of n_2. Find is focal length. Obtain the condition when it behaves as divergent lens.**

NUMERICAL

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Answer: For refraction at first face , $\frac{n_1}{v_1} - \frac{1}{u} = \frac{n_1 - 1}{R}$ ....(i)

For second face R2 = -R , So $\frac{n_2}{v} - \frac{n_1}{v_1} = \frac{n_2 - n_1}{-R} = \frac{n_1 - n_2}{R}$ ....(ii)

Adding equations (i) and (ii) we have ; $\frac{n_2}{v} - \frac{1}{u} = \frac{n_1 - n_2}{R} + \frac{n_1 - 1}{R} = \frac{2n_1 - n_2 - 1}{R}$ ......(iii)

Generally focal length means 2nd focal length. i.e. when u = - ∞ , v = f

Hence equation (iii) becomes ; $\frac{n_2}{f} - \frac{1}{\infty} = \frac{2n_1 - n_2 - 1}{R} \Rightarrow \frac{n_2}{f} = \frac{2n_1 - n_2 - 1}{R}$

$\Rightarrow f = \frac{n_2 R}{2n_1 - n_2 - 1}$. This is the expression for focal length.

Lens behaves as divergent lens if , f = -ve

This is possible if , $2n_1 < n_2 + 1$

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