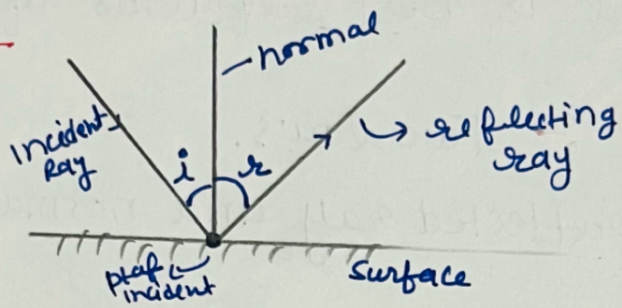
# OPTICS

* Speed of light in vaccum or air is $3 \times 10^8$ m/sec.

**Reflection of light :-** The bouncing back of light in same medium on striking a surface is known as Reflection of light.

**Some imp points :-**




(I) The object having polished (or shining surface) reflect more light than the object having unpolished (dull surface).

(II) **Incident Ray :-** The ray of light which falls on the mirror surface is called incident ray.

(III) **Reflected Ray :-** The ray of light which is sent back by the mirror is called reflected ray.

(IV) **Point of incident :-** The point at which the incident ray falls on the mirror is called point of incident.

(V) **Normal :-** The 'normal' is a line which is perpendicular to the surface of mirror at the point of incident.

(VI) **Angle of Incident :-** The angle b/w incident ray and normal is known as angle of incident. ($\angle i$)

(VII) **Angle of Reflection :-** The angle b/w normal and Reflected Ray is called angle of Reflection.

(VIII) **Beam of light :-** A bundle of light rays is called Beam of light.

(IX) **Regular Reflection :-** A parallel beam of incident light is reflected in only one direction are called regular reflection.

eg :- Plane mirror show Regular reflection

(ii) Diffuse reflection :- A parallel beam of incident light is reflected in different direction are called diffuse reflection.

eg → sheet of paper, chalk piece, table, card board, unpolished metallic

* Silver metal is best reflactor of light.

Laws of Reflection :- Two laws. 2020

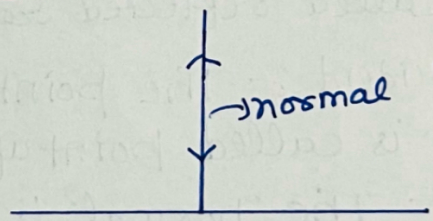
(i) Incident ray, reflected ray and normal all line in same plane.

(ii) Angle of incident is equal to the angle of Reflection.

$\angle i = \angle r$

Note :- Angle of Incident & angle of Reflection always measure from normal not from the surface.

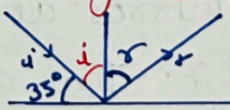
(ii) Agr surface के साथ angle dia हो तो angle of incident निकालने के लिए 90 में से घटाएंगे ।।




$\angle i = \angle r = 0°$

Que 2020 - Find angle $\angle i$ & $\angle r$.

Que-2 2019 An incident ray maken an angle 55° with the surface of a plane mirror. Find angle of Reflection.




$35° + i = 90°$, $i = 55°$

$\angle i = \angle r = 55°$

Image :- The ray coming from an object is meet or appear to meat at a point after reflection or refraction is known as image

Types of Image :- Two types.

| Real Image | Virtual Image |
|---|---|
| (I) The image which can obtain on screen is called Real image. | (I) The image which can not be obtain on screen is called virtual image. |
| (II) The image formed on cinema screen. | (II) The image of our face in plane mirror. |
| (III) Ray actually meet | (III) Ray appear to meet. |
| (IV) Inverted | (IV) Erect. |

# Mirror

* Reflection of light takes place through mirror.

**Types of mirror :-** Two types.

(I) Plane mirror
(II) Spherical mirror

**Plane mirror :-**

(i) Image formed by plane mirror is equal size and same distance.

2019
(II) Image formed by plane mirror is always virtual and ~~r~~rect.

(iii) Focal length of plane mirror is infinity.

2014,15,16 17,18,19
(IV) If two ~~object~~ plane mirror are inclined at angle $\theta$ then the no of image of an object placed b/w them is

$$N = \frac{360}{\theta} - 1$$

N = No of image
$\theta$ = angle b/w two plane

(V) The image formed by plane mirror is laterally inverted (or sideways reversed).

**Use of plane mirror :-**

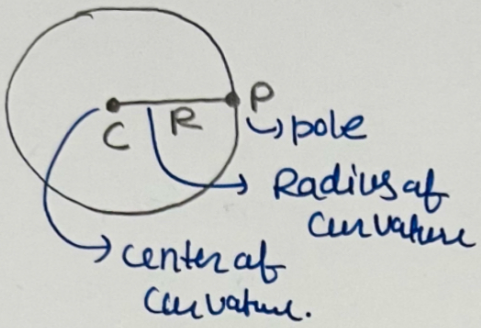
(I) plane mirror are used to see ourselves.
(II) In our dressing table & bathroom.
(III) In certain shop (like jewellary shops) to make them look bigger.
(IV) Plane mirror are fitted in blind turns of sum busy road.
(V) Plane mirror are used in making periscope.

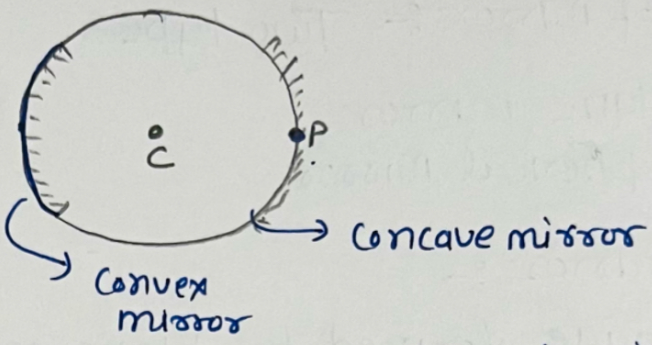
Que. Find the no of images if two plane mirror are inclined at angle $\theta = 60°$ (II) $\theta = 50°$

(I) $N = \frac{360}{60} - 1 = 6 - 1 = 5$ images

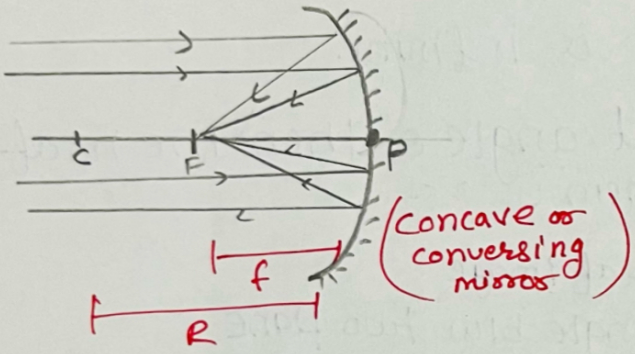
(II) $N = \frac{360}{50} - 1 = 7.2 - 1 = 6.2$ means (7 images)

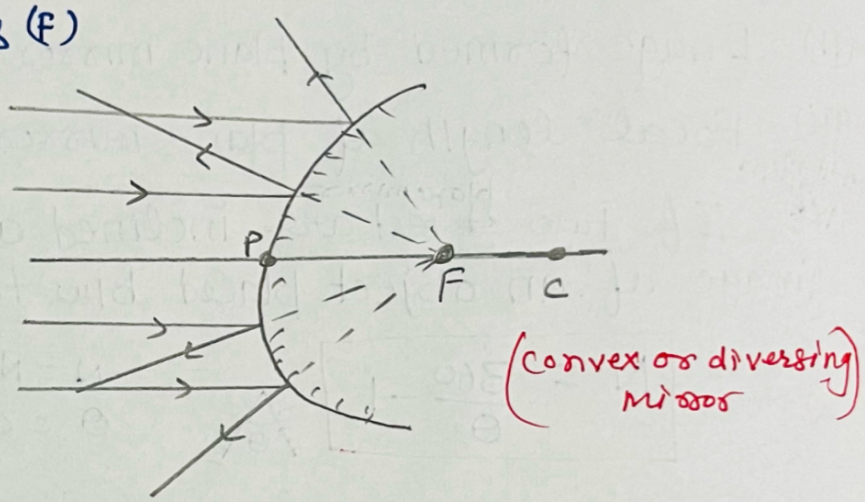
## Spherical mirror :-




**Focus :-** The parrallel rays after reflection through mirror meet at a point is known as Focus (F)




* Focal length = $\frac{\text{Radius of curvature}}{2}$

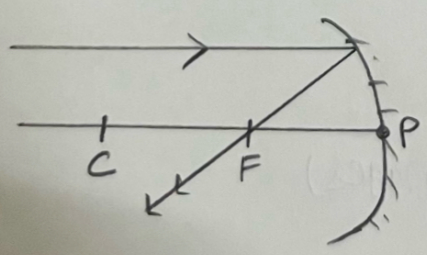
$$F = \frac{R}{2}$$

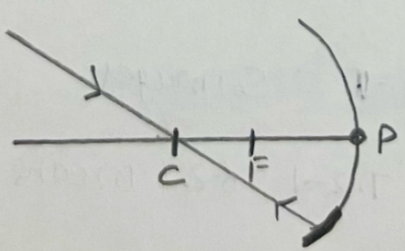
**Rule for image formation :-**

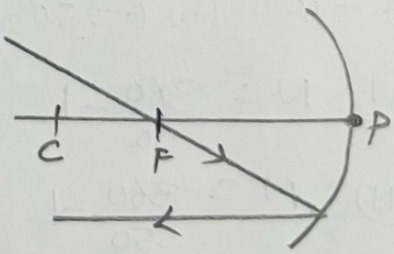
(i) If any ray of light which is ||el to the principle axis of a concave mirror passes through its focus after reflection.

(ii) If a ray of light passing through the center of curvature of a concave mirror is reflected back along the same path.

(iii) If a ray light passing through the focus of a concave mirror become parallel to the principle axis after reflection.

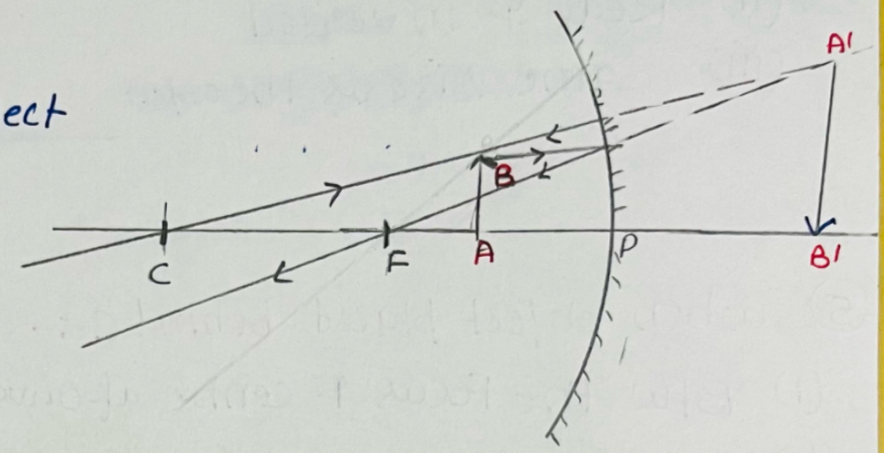


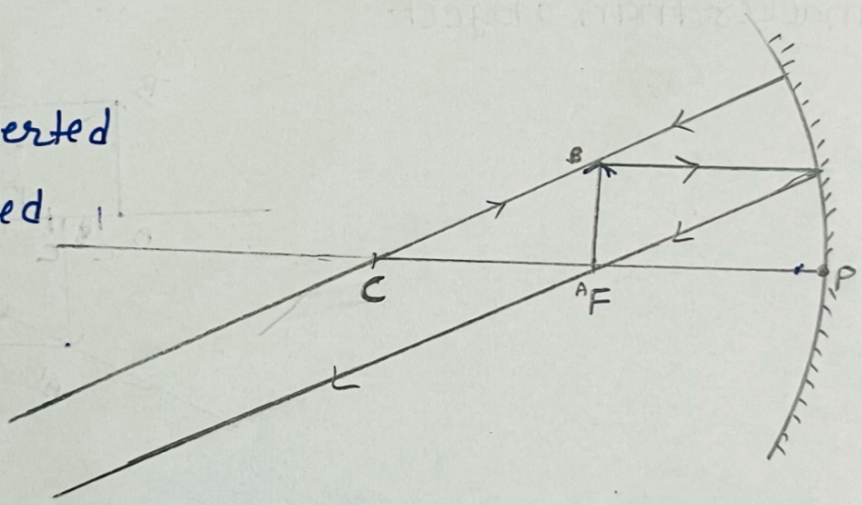
① When object is placed b/w pole & focus :-

(i) behind the mirror
(ii) Virtual & erect
(iii) larger than the object



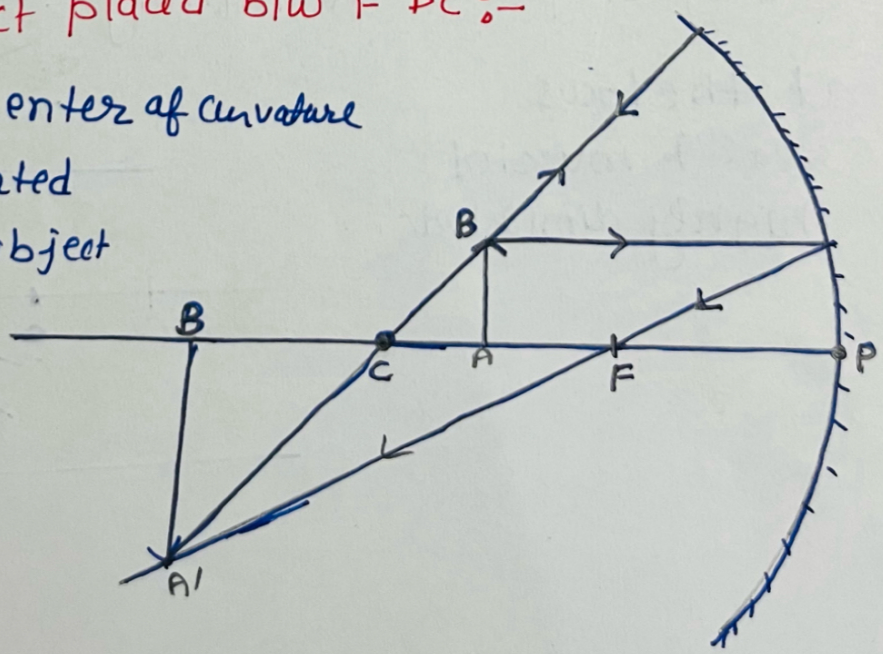

② When object placed at f :-

(i) at infinity
(ii) Real & Inverted
(iii) Highly enlarged



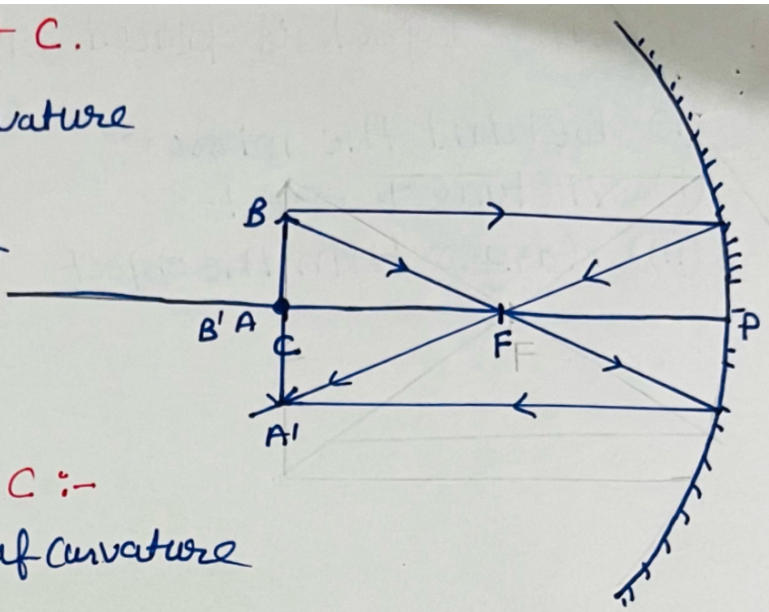

③ When object placed b/w F & C :-

(i) Beyond the center of curvature
(ii) Real & Inverted
(iii) larger than object



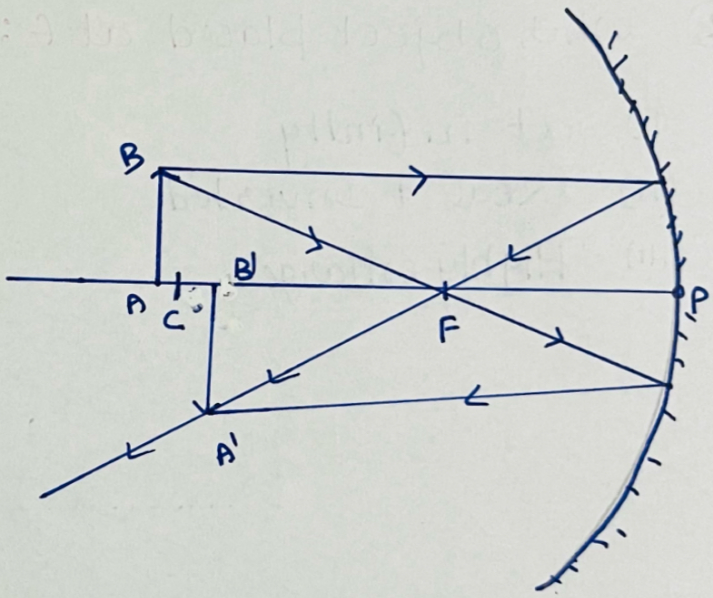
④ when object placed at C.

(i) at the centre of curvature
(ii) Real & inverted
(iii) Same size as the object



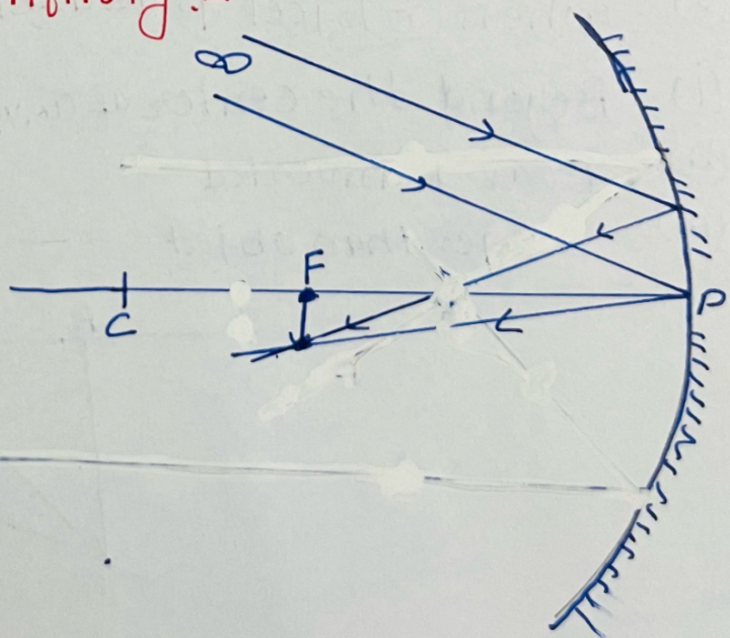

⑤ when object placed behind C :-

(I) B/w the Focus & centre of curvature
(II) real & inverted
(III) Smaller than object




⑥ when object placed at infinity :-

① at the focus
(II) real & inverted
(III) highly diminished.



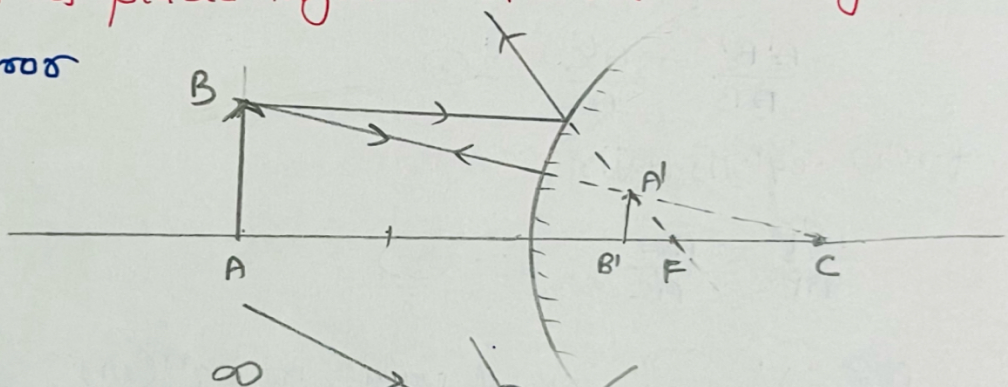
## Summary of Imaged formed by concave mirror

| Posn of object | Posn of Image | Size of image | Nature of Image. |
|---|---|---|---|
| ① B/w P & F | Behind the mirror | Enlarged | Virtual and erect |
| ② At F | At ∞ | Highly enlarged | Real & inverted |
| ③ B/w F & C | Beyond C | enlarged | " |
| ④ at C | At C | equal to object | " |
| ⑤ Beyond C | B/w F & C | Diminished | " |
| ⑥ At ∞ | At F | highly diminished | " |

For convex Mirror :- only two case.

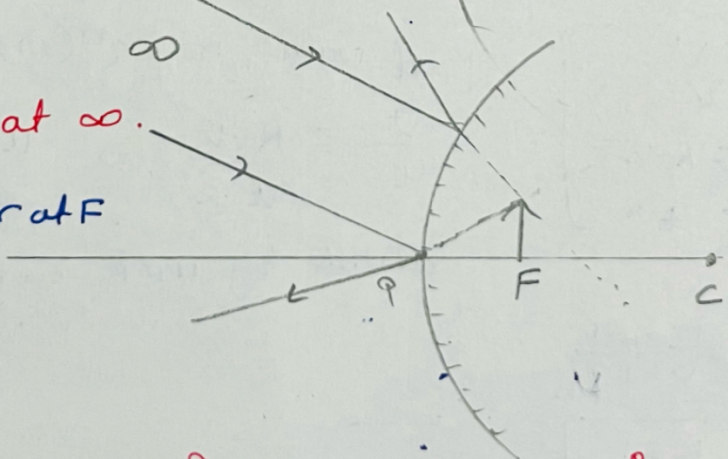
(I) when object is placed anywhere b/w Pole & infinity :-

(i) Behind the mirror b/w P & F
(ii) Virtual & erect
(iii) diminished.




(II) when object is at ∞.

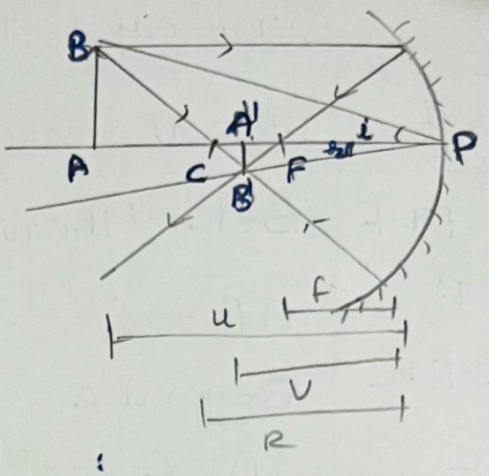
(i) Behind the mirror at F
(ii) Virtual & erect
(iii) highly diminished.




Note :- (1) Convex mirror हमेशा virtual & erect image बनाएगा चाहे object कहीं भी रखा हो।

(11) Concave mirror में सिर्फ एक case में virtual & erect image बनेगी जब object P & F के बीच रखा हो।

## Mirror Formula :-




Consider a concave mirror of focal length 'f' An object AB is placed beyond C, an image is A'B' is formed In b/w C & F

In $\Delta ABP \sim A'B'P$

because $\angle i = \angle r$ ⇒

$\angle BAP = \angle B'A'P = 90°$

$$\frac{A'B'}{AB} = \frac{A'P}{AP} \quad -①$$

$\Delta ABC \sim \Delta A'B'C$

because $\angle A'CB' = \angle ACB$ (VOA)

$\angle CA'B = \angle CAB = 90°$

$$\therefore \quad \frac{A'B'}{AB} = \frac{A'C}{AC} \quad -②$$

from eqn (i) & (ii)

$$\frac{A'P}{AP} = \frac{A'C}{AC} \quad -③$$

$A'P = v$
$AP = u$
$A'C = R - v$
$AC = u - R$

put value in eqn (iii)

$$\frac{v}{u} = \frac{R-v}{u-R} \Rightarrow uv - vR = uR - uv$$

$$2uv = uR + vR$$

divide by uvR both side

$$\frac{2}{R} = \frac{1}{v} + \frac{1}{u}$$

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

**Defination :-** A formula which give the relationship b/w image distance (v), object distance (u) & focal length (f) of a spherical mirror is known as the mirror formula.

**magnification :-** The ratio of the height of image to the height of object is known as magnification.

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

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

$$\frac{h_2}{h_1} = \frac{+v}{u}$$

If m is -ve than → Real & inverted image

If m is +ve than → virtual & erect image

**Use of concave & convex mirror :-**

**Concave mirror :-**

(I) use in torches, search light & vehicle head light to get powerful parallel beam of light.

(II) This mirror is used by dentist.

(III) use as shaving mirror

(IV) used in solar furnace.

**Convex mirror :-**

① used in rear view mirror in vehicles.

② used in shop at security mirror.

| Concave mirror | Convex mirror. |
|---|---|
| ① Reflecting surface is curved inward. | ① Reflecting surface is curved outword. |
| ② Form both enlarged and smaller image. | ② Always form a smaller image |
| ③ Converging mirror | ③ Diversing mirror. |
| ④ magnification $<7=1$ | ④ magnification $<1$ |
| ⑤ Form both Real & virtual image | ⑤ Form only virtual image. |

Some Imp points:-

(I) If an image is formed behind the mirror than v is positive. +

(II) If an image is formed in front of the mirror than v is negative. -

(I) $m = \frac{h_o}{h_i}$ ($h_o$ is always +ve) & $h_i$ is +ve for virtual image & -ve for real image.

(I) magnification of plane mirror is +1.
↳ means the image formed by plane mirror is virtual & erect & same size of object.

(II) m is less than 1 for convex mirror. (real mirror.)

Concave mirror:-

(III) m is less than 1, equal to 1 & greater than 1 for concave mirror

case:- (I) m = +ve means object placed b/w (P & F).

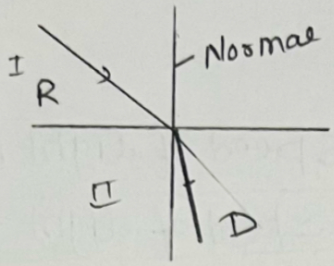
(II) m = -1 means object placed at C

(III) m का value - sign के साथ एक से बड़ी आए तो object focus & center के बीच होगा (eg -> -2)

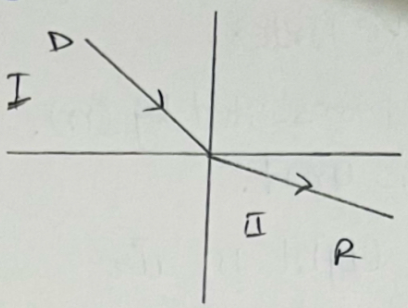
(IV) अगर m का value - sign के साथ एक से छोटी आए तो object beyond C पर होगा || (eg - 0.6)

Note:- Concave mirror को Dentist mirror भी बोलते है।

**Refraction of Light:-** when a light passes from one medium to other than it bend something this is known as refraction of light.




Rare to Dense




Dense to Rare.

* जिस medium मे speed of light ज्यादा होती है वो Rare होता है और जिसमे speed of light कम होती है वो dense होता है। $[V_{Rare} > V_{Dense}]$

Air always rare होता है।
↳ because इसकी speed of light max होती है।

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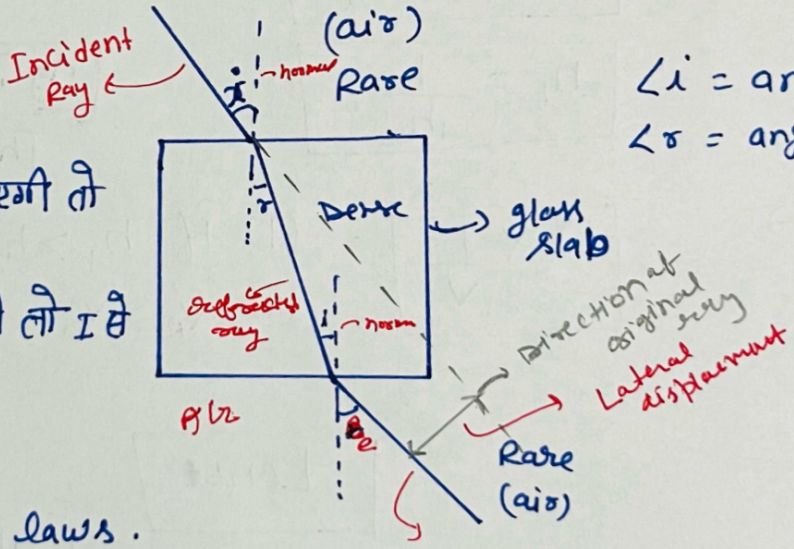
**Imp points:-**

(i) जब Rare से dense मे जाएगी तो I के तरफ झुकेगी ॥

(ii) जब Dense से Rare जाएगी तो I से दूर जाएगी ॥




$\angle i$ = angle of incident
$\angle r$ = angle of refraction

**Laws of Refraction :-** Two laws.

(1) Incident ray, Refracted ray and normal all lie in same plane.

**Second law :-** The ratio of sine of angle of incident to the sine of angle of refraction is always constant. This law is always known as Snell's law.

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

This constant is also known as refractive index of the medium

Refractive Index :- The ratio of speed of light in air or vaccum to the speed of light in any medium is also known as Refrective index.

(I) It is represented by (n).
(II) It has no unit.
(III) Speed of light in air
$c = 3 \times 10^8$ m/sec

$$n_x = \frac{\text{Speed of light in air (or vaccum)}}{\text{Speed of light in any medium}}$$

so $$n = \frac{c}{v}$$

c = speed of light in air
v = speed of light in any medium

Relative refractive Index :- Refractive Index of second medium with respect to 1st medium.

$$^1n_2 = \frac{n_2}{n_1}$$

e.g. - $$^gn_w = \frac{\text{Refractive index of water}}{\text{Refractive index of glass}}$$

Note :-

$$_2n_1 = \frac{1}{_1n_2}$$

$n_g > n_w$ ***
$n_w = 1.33$ ***

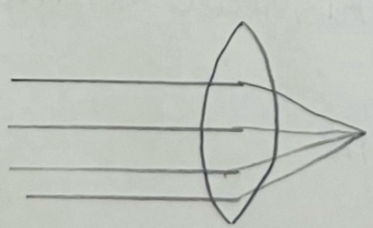
$$n \propto \frac{1}{v}$$

(I) If $n_1 > n_2$ then $v_1 < v_2$
(II) $v_R > v_D$ than $n_R < n_D$

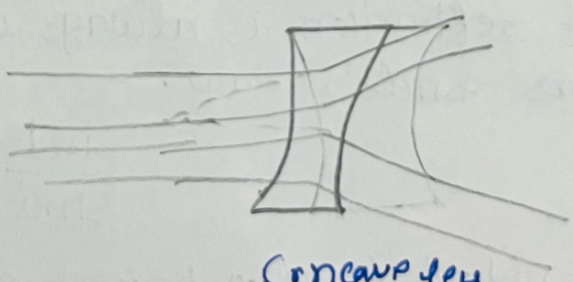
## Lens

Lens :- Lens is a piece of transparent glass bound by two spherical surfaces

Type of Lense :- (I) Concave Lens
(II) Convex Lens



Convex lens.



Concave lens

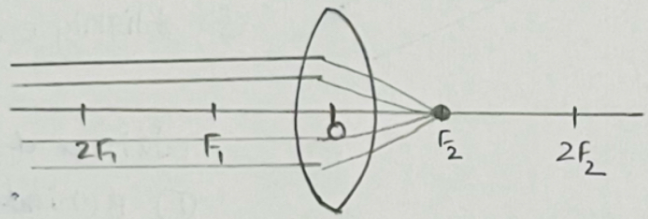
Convex Lens :-

Rule 1 :- जो Ray principal axis के ||el आएगी वो मुड़ने के बाद focus से जाएगी ||

Rule 2 :- जो Ray center से आएगी वो सीधी जाएगी ||

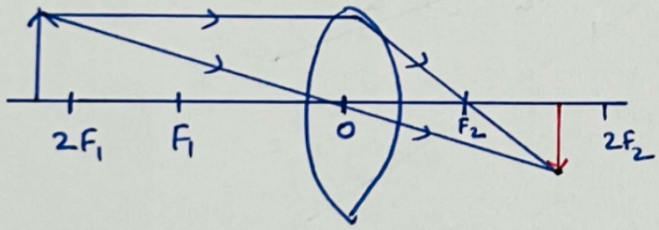
**Image Formation of convex Lens**

Case 1 :- Object at infinity :-



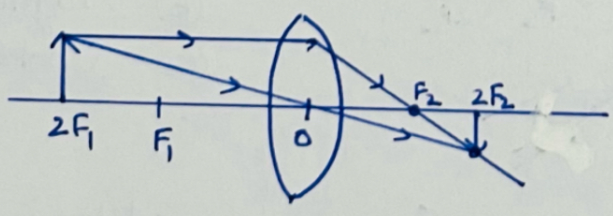

(a) At $F_2$
(b) Highly diminished
(c) Real & Inverted

Case 2 :- object beyond $2F_1$ :-



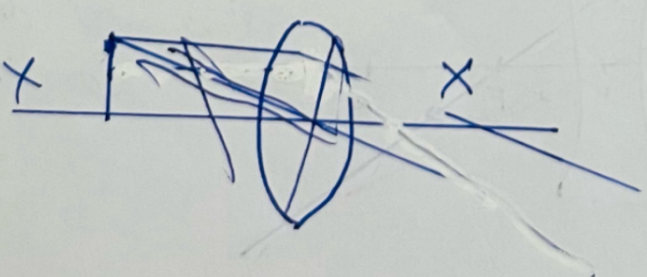

Nature of Image :-
(1) b/w $F_2$ & $2F_2$
(2) Real & Inverted
(3) Diminished

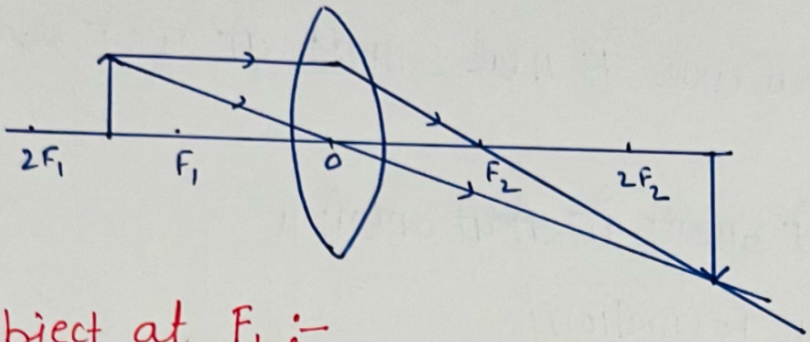
Case 3 :- Obect at $2F_1$




Nature of Image :-
(a) at $2F_2$
(b) Real & Inverted
(c) Same size

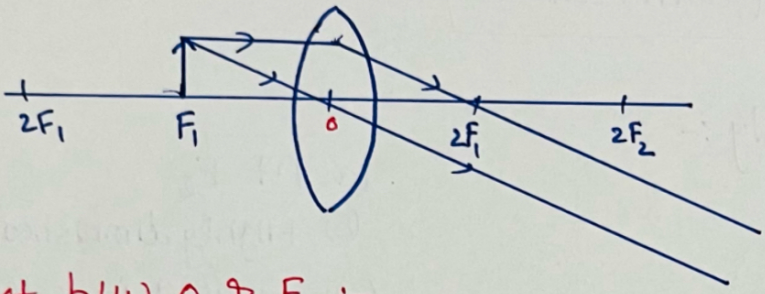
Case 4 :- object at b/w $2F_1$ & $F_1$





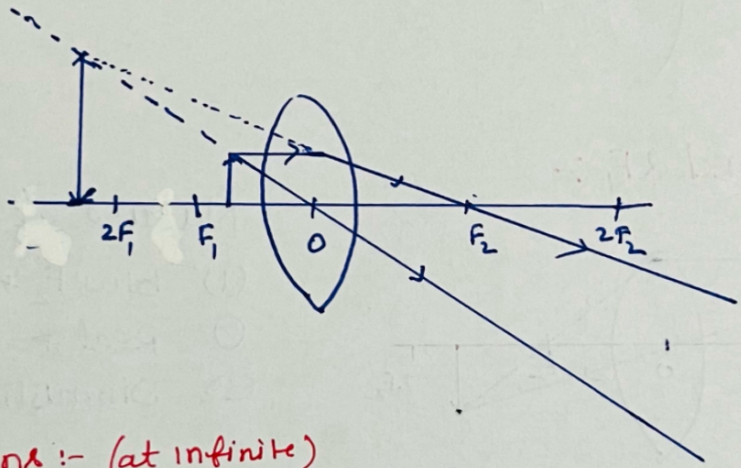

Nature of Image :-
① Beyon 2F2
② Real & Inverted
③ enlarged

(V) object at $F_1$ :-



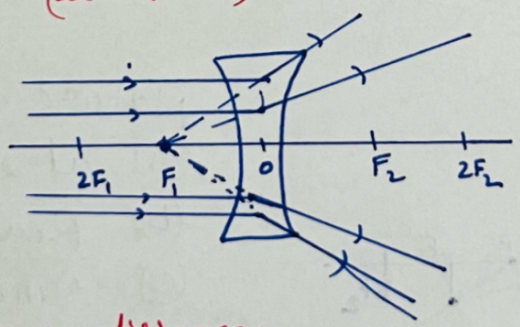

Nature of Image :-
① at ∞
② Real & Inverted
③ Highly enlarged

(VI) object b/w O & $F_1$ :-



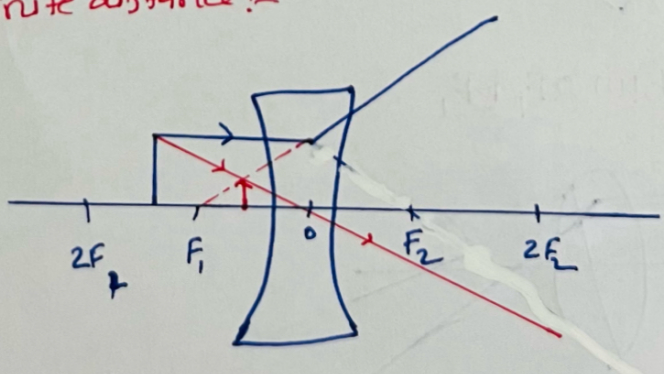

Nature of Image :-
① Behind the lens
② virtual & Erect
③ enlarged.

(I) concave lens :- (at infinite)




Nature of Image :-
(a) at $F_1$
(b) highly diminished
(c) virtual & erect

(II) object at finite distance :-




Nature of Image :-
ⓐ Beyond $F_1$ & O
ⓑ diminished
ⓒ Virtual & erect.

**Power of lens :-** It is reciprocal to the focal length of a lens. It is represented by P. SI unit of Power Diopter (D).

$$P = \frac{1}{f}$$

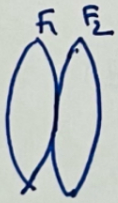
* F always in mtr में लेते हैं।
* if P = +ve than (convex lens)
* If P = -ve than (concave lens)

**Que-** If the focal length of a lens is 20cm find its power & find which lens.

$F = 20cm = \frac{1}{5}$ mtr $\qquad P = \frac{1}{F} = \frac{1}{1/5} = 5D$

+ve sign means (convex lens होता)

**Combination of lens :-** If two lenses are placed in contact at this combination of lens is replaced by a single lens which give same image as this combination so it is known as equivalent lens and its Focal length is known as equivalent focal lenth.




Combined Focal length, $\boxed{\frac{1}{F} = \frac{1}{F_1} + \frac{1}{F_2}}$

Combined Power of lens, $\boxed{P = P_1 + P_2}$

**Que-** If the power of two lenses are 6D & -4D. Find the power & Focal length of combination.

$P_1 = 6D$
$P_2 = -4D$

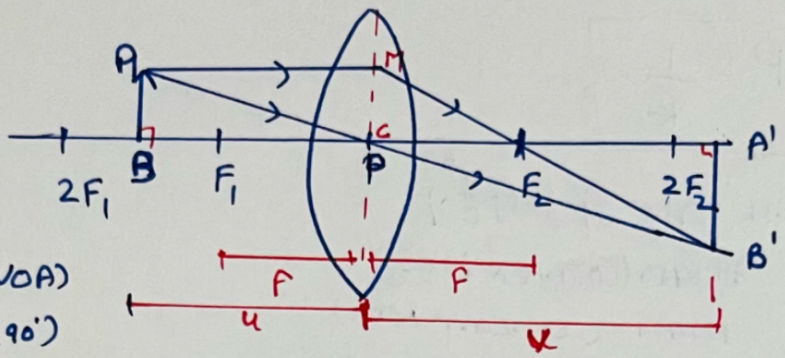
$P = P_1 + P_2$
$P = 6 - 4$
$\boxed{P = 2D}$

$P = \frac{1}{F}$

$F = \frac{1}{P} = \frac{1}{2} \times 100 = 50cm$

$\boxed{F = 50cm}$

Derive Lens Formula:-




In $\Delta ABP$ & $\Delta B'A_1P$

$\angle APB = \angle A'PB'$ (VOA)

$\angle ABP = \angle B'A'P$ (90°)

By AA rule $\Delta ABP \sim B_1A_1P$

$$\frac{AB}{A'B'} = \frac{BP}{A'P} \quad \text{——(i)}$$

In $\Delta MPF_2$ & $\Delta A'B'F_2$

$\angle MCF_2 = \angle B'A'F_2$ (90°)

$\angle MF_2C = \angle B'F_2A'$ (VOA)

$\therefore \Delta MPF_2 \sim \Delta A'B'F_2$ (By AA rule)

$$\frac{MP}{A'B'} = \frac{PF_2}{A_1F_2}$$

$$\frac{AB}{A'B'} = \frac{PF_2}{A_1F_2} \quad \text{——(ii)} \quad (MP = AB)$$

from (i) & (ii)

$$\frac{BP}{A'P} = \frac{PF_2}{A_1F_2} \Rightarrow \frac{-u}{v} = \frac{f}{v-f}$$

$$-uv + uf = vf$$

divide both side $uvf$

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

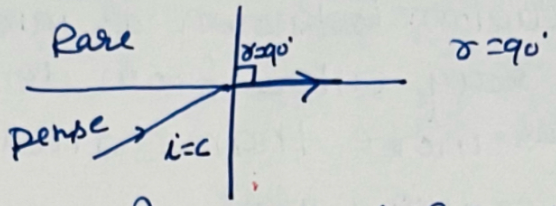
$$\boxed{\frac{1}{f} = \frac{1}{v} - \frac{1}{u}}$$

$$\boxed{m = \frac{h_2}{h_1} = \frac{v}{u}}$$

$f$ = focal length
$v$ = distance of image
$u$ = distance of object
$h_1$ = height of image
$h_2$ = heigh of object
$m$ = magnification

m ~~A~~ value -ve → Real
or +ve means → virtual

Critical angle :- when the light rays goes from dense to rare medium than the angle of incident at which refracted angle become 90° is known as critical angle.




* is condition में light हमेशा dense to Rare जायेगी.

Relation b/w critical angle & refrective index (n) :-

$$n = \frac{1}{\sin c}$$

2018-20

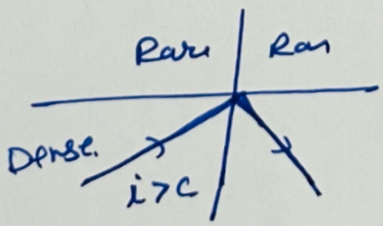
Que- If the critical angle of a medium is 45° then find the refractive index of the medium.

$$n = \frac{1}{\sin 45^\circ} = \frac{1}{\frac{1}{\sqrt{2}}} = \sqrt{2}$$

$$n = \sqrt{2}$$

2018

Total Internal Refraction :- when the light ray goes from dense to rare medium and the angle of incident is slightly more than the critical angle then ray back to the same medium this phenomen is known as TIR.




Condition for TIR :-

(i) Ray should go from Dense to Rare medium.

(ii) Angle of incident should slightly more than the critical angle. ($i > c$)

## Phenomena based on TIR :-

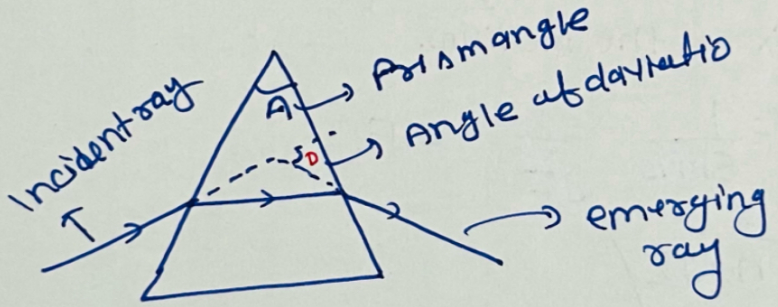
2019
(i) Mirage :- In desert area passenger and animal have optical illusion due to which it feel water instead of sand. This illusion is known as mirage. It is based on TIR in which ray enter from dense to rare medium and angles comes more than critical angle.

(ii) Shining of cracking glass

(iii) Optical fibre

MJune
Refraction through prism :- when the light ray falls on the surface of prism than it become parallel inside the prism and finally come out in the form of emerging ray.

*The angle b/w the incident ray & ~~one~~ finally emerging ray is known as angle of deviation. which is rep by 'D'.




For minimum deviation :-

(a) $\boxed{i = \frac{A+D}{2}}$

(b) $\boxed{r = A/2}$

(c) $\boxed{n = \frac{\sin i}{\sin r}}$

2018
Que- A ray of light falling at an angle of 45° is ~~refracted~~ through prism & so after minimum deviation. The angle of prism is 60° find refractive index for prism.

$i = 45°$ $\quad$ ~~$i = \frac{A+D}{2}$~~

$A = 60°$ $\quad r = \frac{A}{2} = \frac{60}{2} = 30°$

$n = \frac{\sin i}{\sin r} = \frac{\sin 45°}{\sin 30°} = \frac{1/\sqrt{2}}{1/2} = \sqrt{2}$

Refraction through thin prism :- If the prism is thin of prism angle 'A' & minimum deviation through prism is $D_m$ then,

$$D_m = (n-1)A$$

$D_m$ - minimum Deviation
$n$ - Refractive index
$A$ - Angle of prism

Qu- A thin prism of angle 5° give a minimum deviation of 3.2 : what is n of prism?

$A = 5°$
$D_m = 3.2$
$n = ?$

$D_m = (n-1)A$

$3.2 = (n-1) \times 5$

$n = \frac{3.2}{5} + 1 = \frac{8.2}{5} = 1.64$ Ans.

Lens Maker Formula :- Suppose Radius of curvature of two surface for a spherical lens are $R_1, R_2$ & the refractive index of its material is 'n' then its focal length.

$$\frac{1}{F} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Condition :-

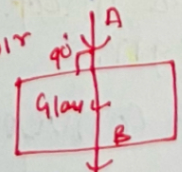
(i) In Biconvex Lens
$R_1 = +ve$
$R_2 = -ve$

(ii) Biconcave lens
$R_1 = -ve$
$R_2 = +ve$

(iii) Plane surface
$R = \infty$

(Like numerical + Book ⁂ N + difference b/w concave lens & convex)

Lateral displacement :- The perpendicular distance b/w the original path of the incident ray & the emergent ray coming out of the glass slab is called lateral displacent of the emergent ray of light.




Note :- If the incident ray falls normally (or perpendicularly) to the surface of a glass slab, then there is no bending of ray of light & goes straight.

## Effects of Refraction of light :-

(i) A stick (or pencil) held obliquely and partly immersed in water appears to be bent at the water surface.

(ii) An object placed under the water appears to be raised.

(iii) A pool water appears to be less deep than it actually is.

(iv) when a thick glass slab is placed over some printed matter than letter appear raised when viewed from top.

(v) A lemon kept in water in a glass tumbler appears to be bigger than its actual size, when viewed from the sides.

(vi) The star appear to twinkle on a clear night.

| Concave lens | Convex Lens |
|---|---|
| ① A concave lense is thinner at the centre than at the edges. | ① A convex lens is thicker at the center than at the edges. |
| ② It is also called diversing lens. | ② It is called as conversing lens. |
| ③ It produce virtual Image | ③ It produce both virtual & real Image. |
| ④ It has -ve focal length. | ④ It has +ve focal length. |
| ⑤ This lens used to myopia. | ⑤ This lens used to correct hypermetro -pia. |
| ⑥ The lens makes object smaller & farther. | ⑥ The lens makes an object appear closer and larger. |
| ⑦ The principal focus is virtual | ⑦ The principal focus is real. |
| ⑧ used in glasses, spy holes in door, | ⑧ eg. used in simple telescope, magnifying glass. |

* Mirror के case में virtual image means positive sign & lens के case में virtual image means -ve sign.

* Mirror के case में Real image means -ve sign or Lens के case में Real image means +ve sign.

Note:- ① Concave lens & Convex Mirror हमेशा virtual image बनाएँगे
↳ (-ve) ↳ (+ve)

② Convex Lens & concave mirror 5 Real & 1 virtual image बनाएँगे।
↳ R → +ve, V → +ve ↳ R → -ve, V → +ve

Que- The radius of curvature of a bi convex lens are 20cm & 30cm It's refractive index is 1.5. Find its focal length.

$R_1 = 20cm$
$R_2 = -30cm$
$n = 1.5$

$\frac{1}{F} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.5-1)\left(\frac{1}{20} + \frac{1}{30}\right)$

$\frac{1}{F} = (0.5)\left(\frac{50}{60}\right) = \frac{5}{2\cancel{0}} \times \frac{\cancel{6}}{\cancel{6}0_{12}} = \frac{1}{24}$ $\boxed{F = 24cm}$

Que-2 The radius of curvature of biconcave lens is 15cm & 60cm and its refractive index is 1.5. Find its focal length.

$R_1 = -15cm$
$R_2 = 60cm$
$n = 1.5$

$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.5-1)\left(-\frac{1}{15} - \frac{1}{60}\right) = \left(\frac{5}{10}\right)\left(\frac{-4-1}{60}\right)$

$\frac{1}{F} = \frac{5 \times -\cancel{5}}{2\cancel{6} \times \cancel{6}0_{12}} = \frac{-1}{24}$ $\boxed{F = -24cm}$

③ Find the focal length of a thin lens for which radius of one surface is 20cm and other surface is plane. (Refractive index of its material is $\frac{3}{2}$).

$R_1 = 20cm$
$R_2 = \infty$
$n = 1.5$

$\frac{1}{F} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.5-1)\left[\frac{1}{20} - \frac{1}{\infty}\right] = \left(\frac{5}{10}\right) \times \left\{\frac{1}{20} - 0\right\}$

$\frac{1}{F} = \frac{5}{2\cancel{0}} \times \frac{1}{20} = \frac{1}{40}$ $\boxed{F = 40cm}$

④ If the focal length of bi-convex lens is 20cm and radius of its spherical surface are same. Find Radius ($n = 1.6$)

$F = 20cm$
$R_1 = R$
$R_2 = -R$
$n = 1.6$

$\frac{1}{F} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \Rightarrow \frac{1}{20} = (1.6-1)\left(\frac{1}{R} + \frac{1}{R}\right)$

$\frac{1}{2\cancel{0}} = \frac{6}{1\cancel{0}} \times \frac{2}{R} \Rightarrow \boxed{R = 24}$

$R_1 = 24cm$
$R_2 = -24cm$

⑤ The focal length of lens (convex) is 30 cm and the radius of curvature of its surface are 15cm, 60cm. Find its refractive index.

$F = 30cm$
$R_1 = 15cm$
$R_2 = -60cm$
$n = ??$

$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \Rightarrow \frac{1}{30} = (n-1)\left(\frac{1}{15} + \frac{1}{60}\right) = (n-1)\left(\frac{4+1}{60}\right)$

$(n-1) = \frac{1}{\cancel{30}} \times \frac{\cancel{60}^2}{5} \Rightarrow n = \frac{2}{5} + 1 = \frac{7}{5}$

$\boxed{n = 1.4}$

⑥ The focal length of a lens is 20cm. If this lens is immersed in water. Find its new focal length. (given $n_g = 3/2$, $n_w = 4/3$)

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

$$\frac{1}{20} = \left(\frac{3}{2}-1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{R_1} - \frac{1}{R_2} = \frac{1}{20} \times 2 = \frac{1}{10} \quad \text{— (1)}$$

Now in water,

$$\frac{1}{F_1} = \left(\frac{\frac{3}{2}}{\frac{4}{3}} - 1\right)\frac{1}{R_1} - \frac{1}{R_2}$$

$$\frac{1}{F_1} = \left(\frac{9}{8} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{F_1} = \frac{1}{8} \times \frac{1}{10} = \frac{1}{80} \quad \text{(from eqn i)}$$

$$\boxed{F_1 = 80\text{cm}}$$