PHYSICS INDUCTION
An institute of Science & Mathematics

Vinita Chawla
M.Sc. Physics (HRC, Delhi University)
M.Sc. Computer Science, B.Ed.,
CTET, HTET, PSTET, CSB Qualified
Contact: 91-8168258349
physicsinduction@gmail.com

CLASS XII : NOTES : CHAPTER-9: RAY OPTICS & OPTICAL INSTRUMENTS : PHYSICS

OPTICS:- It's the branch of physics that studies the behaviour & props of light, including its interactions with matter & the construction of instruments that use or detect it.
- Geometrical Optics - dim. of objects (Mirrors, lenses, prism) are bigger than λ of light
- Wave Optics - dim. of objects are comparable to λ of light (slit, holes)

LIGHT:- ★ Form of energy. ★ produces the sensation of vision in us.
★ travels in a st. line (Rectilinear propagation of light), ★ EM rad. (doesn't req. mat. md.) ★ $c = 3\times10^8$ m/s (in Vacuum) ★ λ(visible light) = 4000Å – 7000Å (3800Å – 7600Å)

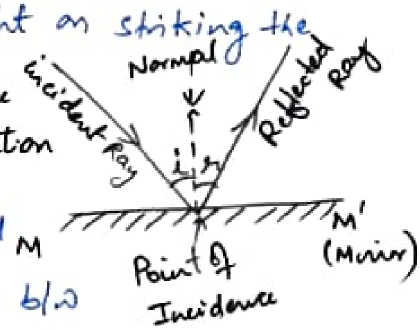
Various Phenomena of Light:- (i) Reflection, (ii) Refraction, (iii) Scattering (iv) Dispersion (v) Interference, (vi) Diffraction (vii) Polarization.

★ $\longrightarrow$ Ray of light $\Longrightarrow$ Beam of light.

REFLECTION OF LIGHT:- Bouncing back of light on striking the surface in the same medium.

Laws of Reflection:-

i : Angle of Incidence
r : Angle of Reflection



(i) The angle of Reflection (i.e., the angle b/w reflected ray & normal) equals the angle of incidence (angle b/w incident ray & normal)

(ii) The incident Ray, reflected ray & the normal to the reflecting surface at the pt. of incidence lie in the same plane.

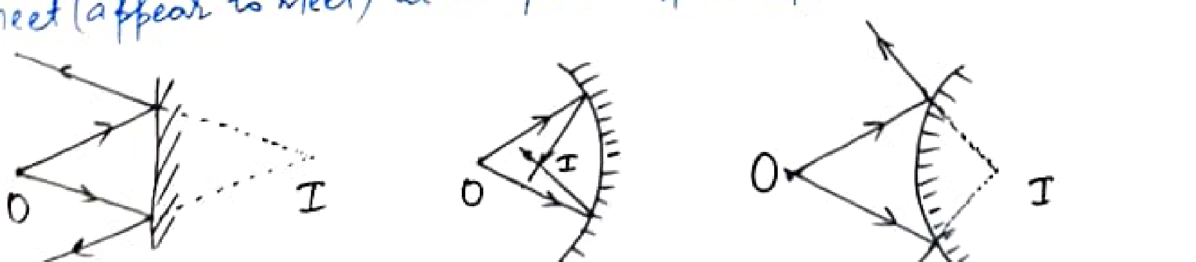
★ If a ray falls normally on the reflecting surface, then it retraces its path after reflection. $\angle i = \angle r = 0^\circ$ (Normal Incidence)

★ The basic laws of Reflection are same for plane & curved surfaces.

IMAGE TRACING:- **Paraxial Rays**:- Rays close to principal Axis.

Object: Anything which gives out light rays.

Image: An image is formed when light rays coming from an object meet (appear to meet) at a point after reflection.



(Virtual Image) (Real Image) (Virtual Image)

Real Image Vs Virtual Image

Real Image

- Real Image is inverted.
- Real Image is formed, when rays actually meet at a point.
- Real Image can be obtained on a screen
- e.g. Image formed on Cinema Hall

Virtual Image

- Virtual Image is erect
- Virtual Image is formed when rays appear to meet at a point.
- Virtual Image can't be obtained on screen
- e.g. Image formed on a plane mirror

Real Object Vs Virtual Object

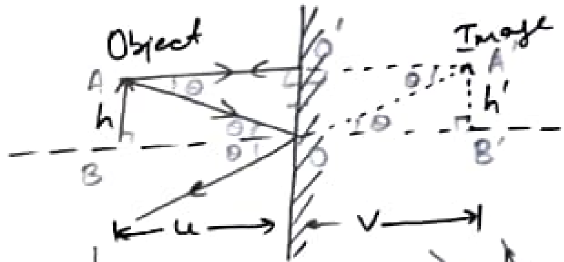
Real Object

- If the incident rays diverge from a pt object, the object is called Real Object.

Virtual Object

- Sometimes, incident rays converge towards the mirror. In this case, the pt., where they would "meet", if there were no mirror, is treated as object.

IMAGE FORMATION BY PLANE MIRROR



AB – object, A'B' – Image

u – object dist   v – Image dist

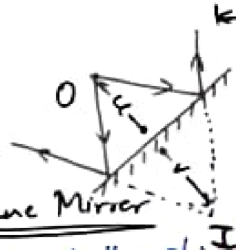
$\Delta AOO' \cong \Delta A'OO'$ (AAS cong. Rule)

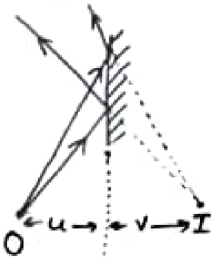
$\therefore O'A = O'A'$ (cpct)

$\Rightarrow OB = OB' \Rightarrow \boxed{u = v}$

$\Delta AOB \cong \Delta A'OB'$ (ASA cong. Rule)

$\Rightarrow AB = A'B' \Rightarrow \boxed{h = h'}$





Characteristics of Image formed by Plane Mirror

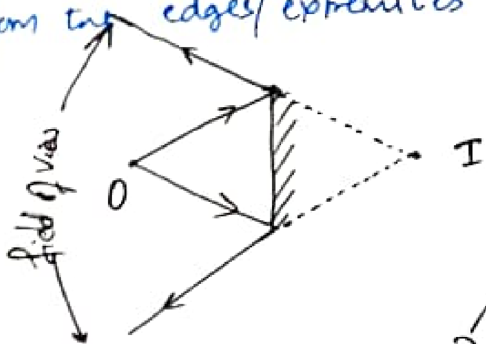
(i) Image is formed as far behind the mirror as the object is in front of it.

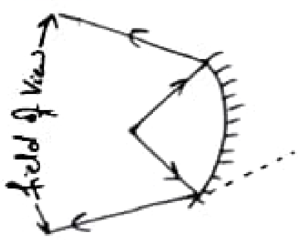
(ii) size of Image = Size of object

(iii) Image formed is Virtual & Erect.

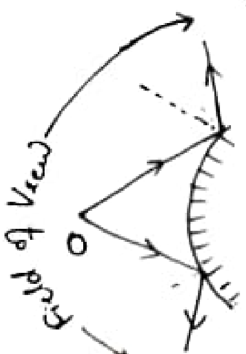
(iv) " " " laterally inverted : Lateral Inversion : sideways reversal of Img.

FIELD OF VIEW:- Field of View is the area bounded by the rays reflected from the edges/extremities of the mirror.





A convex mirror has wider Field of View



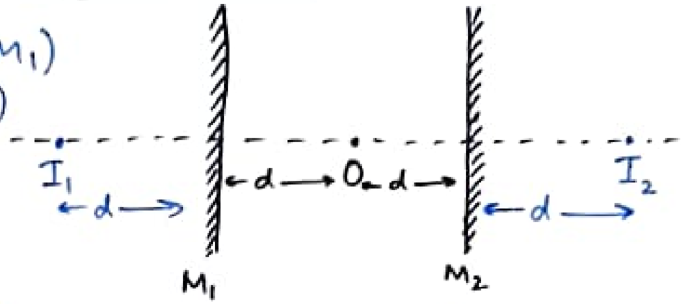
NUMBER OF IMAGES FORMED BY TWO PLANE MIRRORS :-

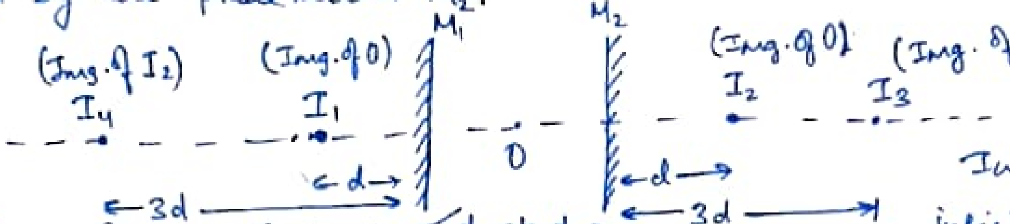
1.) When 2 mirrors are parallel to each other : $\theta = 180^\circ$

I_1 : Image of object, O (by mirror M_1)

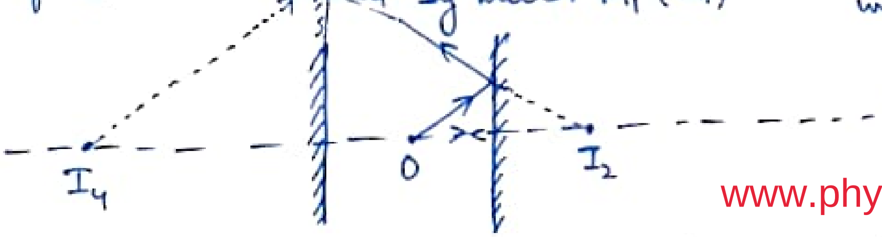
I_2 : " " " " (" " M_2)

I_1 is considered as an object for mirror M_2. ∴ Image of I_1 will be formed by the plane mirror M_2.



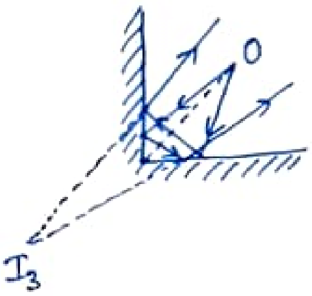


Illy Image of I_2 will be formed by mirror M_1 (I_4)

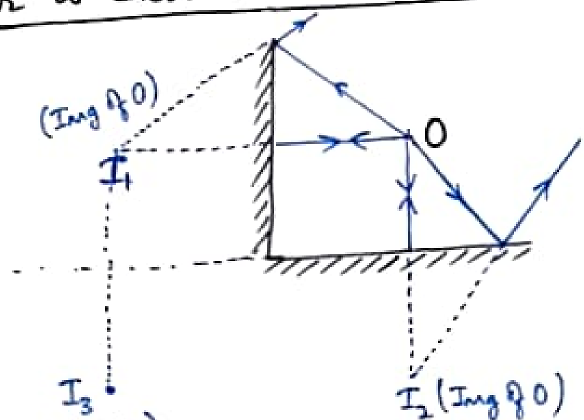


In this way, infinite no. of images will be formed. Intensity of the images will get reduced.

2.) When 2 mirrors are perpendicular to each other : $\theta = 90^\circ$:-



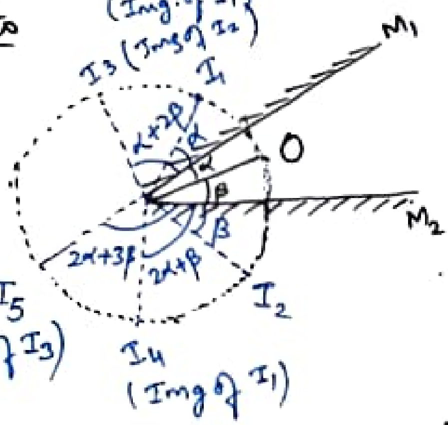
No. of Images formed is <u>three</u>



3.) When 2 mirrors are inclined to each other :

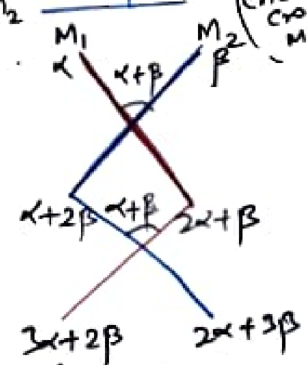
Circular Concept

If angle for any image $\geq 180^\circ$
No further images will be formed.



$\alpha + 2\beta$
$\alpha + \beta$
$2\alpha + 3\beta$

(Criss cross method)



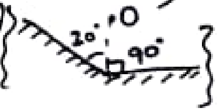
Check if $\angle \geq 180^\circ$: STOP

Formulae :- Let θ be the angle b/w two plane mirrors M_1 & M_2. $m = \frac{360^\circ}{\theta}$

then, total no. of images, n formed is given by :

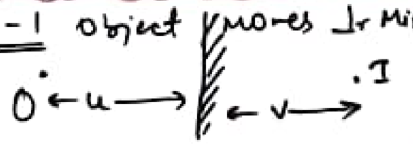
$n = m - 1$ [$m \rightarrow$ even : Object - Symm | Unsymm]

$n = m - 1$ [$m \rightarrow$ odd : object - symmetrical {  }]

$n = m$ [$m \rightarrow$ odd : Object - Unsymmetrical {  }]

VELOCITY IN PLANE MIRROR :-

Case - 1 object moves ⊥r Mirror $u = -v$



differentiating w.r.t t

$\frac{du}{dt} = \frac{-dv}{dt}$ $\Rightarrow \vec{V}_{OM} = -\vec{V}_{IM}$

velocity of object (w.r.t. mirror) ; velocity of Image (w.r.t. mirror)

$\vec{V}_o - \vec{V}_M = -(\vec{V}_I - \vec{V}_M)$

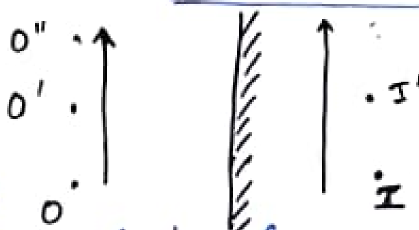
$\Rightarrow (\vec{V}_o + \vec{V}_I) = 2\vec{V}_M$

$\Rightarrow \boxed{\vec{V}_M = \frac{\vec{V}_o + \vec{V}_I}{2}}$

* If Mirror is at rest, $\vec{V}_M = 0 \Rightarrow \vec{V}_o = -\vec{V}_I$

Case-2 : Object moves parallel to mirror :

$\vec{V}_o = \vec{V}_I$

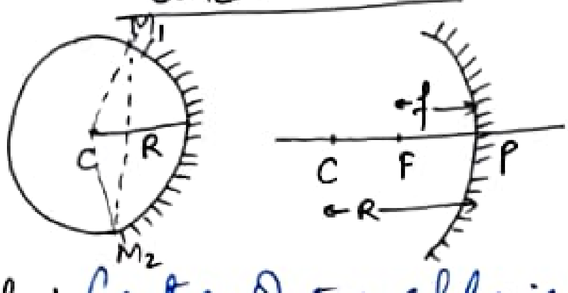


SPHERICAL MIRRORS :-

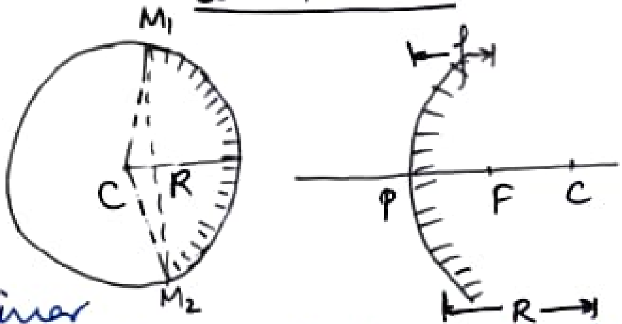
A spherical mirror is a part of a hollow sphere, whose one side is reflecting & other side is opaque.

Two Types of spherical Mirrors :

Concave Mirror



Convex Mirror



Pole : Centre of the spherical Mirror

Principal Axis : The straight line passing thro the centre of curvature & pole.

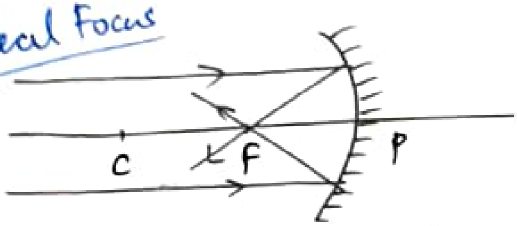
Centre of Curvature (C) : Centre of the hollow sphere of glass of which mirror is a part.

Radius of Curvature (R) : Radius of the hollow sphere of glass of which mirror is a part.

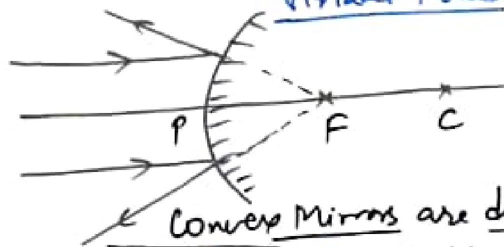
Aperture : That portion of mirror from which the reflection of light actually takes place.

Linear Aperture = The diameter M_1M_2 ; **Angular Aperture** = $\angle M_1CM_2$

Real Focus



Virtual Focus



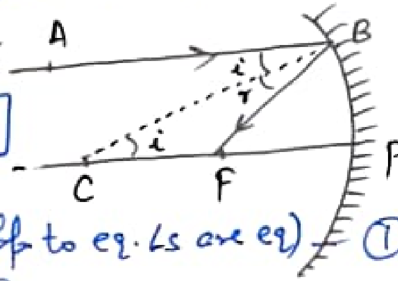
Concave Mirrors are converging mirrors.

Convex Mirrors are diverging Mirrors

Focus / Principal Focus (F): Principal Focus (F) of a spherical mirror is a pt on the principal axis of the mirror at which rays incident on the mirror in a direct^n parallel to the principal axis actually meet (converge) or appears to diverge after reflection from the mirror.

Focal length (f) :- Distance b/w pole & focal pt of the mirror.

RELATION B/W f & R :- (a) Concave Mirror



$\angle ABC (i) = \angle CBF (r)$ [Law of Reflection]

$\angle ABC (i) = \angle BCF$ [alt. int $\angle$s]

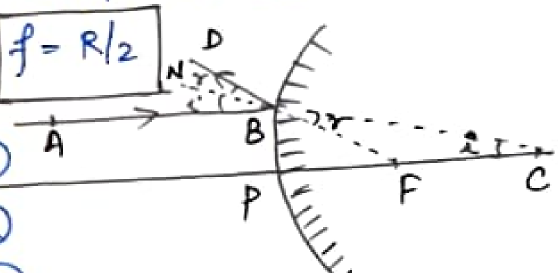
$\therefore$ CF = FB (Isosceles Δ prop - sides opp to eq. $\angle$s are eq) — ①

FB = FP ($\because$ aperture is small) — ②

$\Rightarrow$ CF = FP i.e., F is the centre of PC (from ① & ②)

$\Rightarrow$ $PF = \frac{1}{2} PC \Rightarrow -f = -\frac{R}{2} \Rightarrow \boxed{f = R/2}$

(b) Convex Mirror :-



$\angle ABN (i) = \angle DBN (r)$ [law of Ref] — ①

$\angle DBN (r) = \angle FBC$ (V.O.A) — ②

$\angle ABN (i) = \angle BCF$ (corresp. $\angle$s) — ③

$\Rightarrow \angle FBC (r) = \angle BCF (i)$ [from ①, ② & ③]

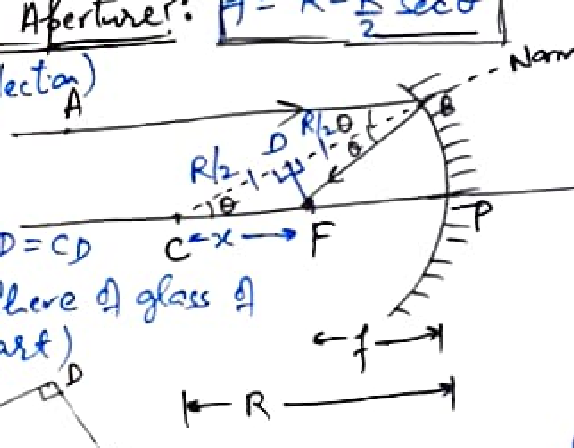
$\Rightarrow$ CF = FB (Isosceles Δ prop) — ④

Also FB = FP (Small Aperture) — ⑤

$\Rightarrow$ CF = PF [from ④ & ⑤]

$\Rightarrow$ $PF = \frac{1}{2} PC \Rightarrow \boxed{f = R/2}$

What if the mirror is not of small Aperture?: $\boxed{f = R - \frac{R}{2} \sec\theta}$



$\angle ABC (i) = \angle CBF (r) = \theta$ (law of Reflection)

$\angle ABC = \angle BCF = \theta$ (alt. int $\angle$s)

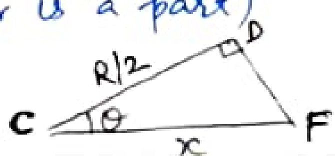
$\Rightarrow$ ΔBCF is an isosceles Δ

Draw FD ⊥ BC → bisects BC at D $\therefore$ BD = CD

BC = R = PC (Radius of the hollow sphere of glass of which mirror is a part)

$\Rightarrow$ $DC = BD = \frac{1}{2} BC = R/2$

Consider ΔCDF :



$$\cos\theta = \frac{R}{2x} \Rightarrow x = \frac{R}{2\cos\theta} = \frac{R}{2}\sec\theta$$

As, $f = R - x = R - \frac{R}{2}\sec\theta \Rightarrow \boxed{f = R - \frac{R}{2}\sec\theta}$

If mirror is of small aperture : Rays → paraxial : θ – very small

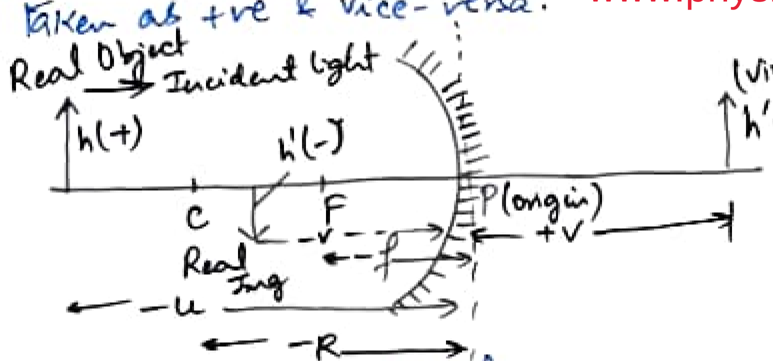
for small θ, $\cos\theta \approx 1 \Rightarrow \sec\theta \approx 1 \Rightarrow \underline{f = R - \frac{R}{2}\times 1} = \underline{\frac{R}{2}}$

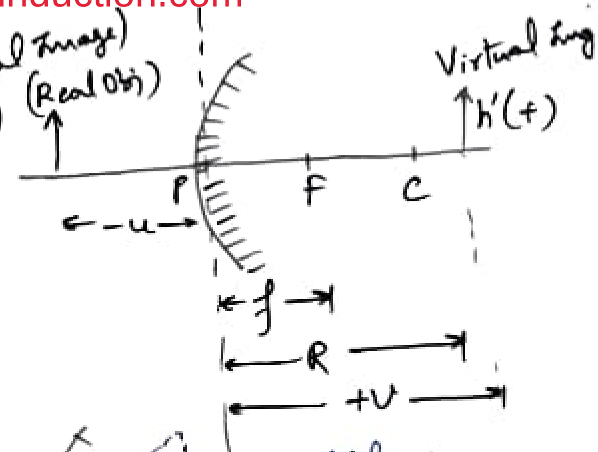
SIGN CONVENTION :-

a) The principal axis of the mirror is taken as X-axis & pole is taken as Origin. All the distances are measured from pole (P) of spherical mirror.

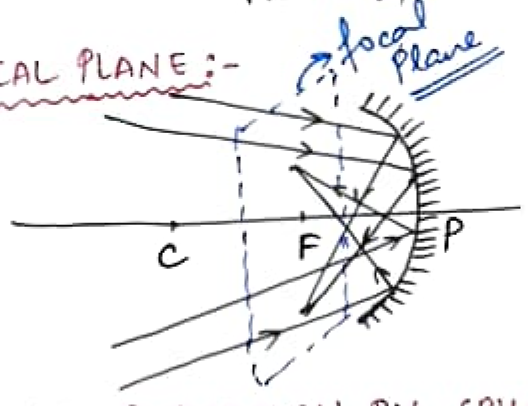
b) The distances measured in the direct^n of incident ray are taken as +ve & the distances measured in a direct^n opp. to the direct^n of incident light are taken as –ve.

c) The heights measured upwards & ⊥r to pri axis of the mirror are taken as +ve & vice-versa.





FOCAL PLANE :-



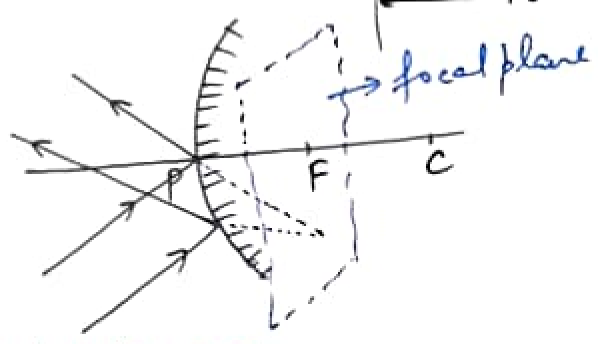
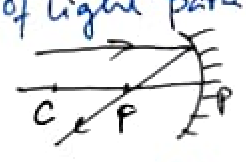
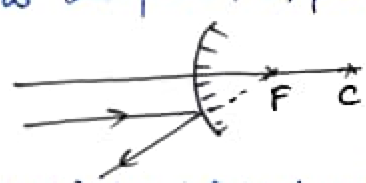


IMAGE FORMATION BY SPHERICAL MIRRORS :-

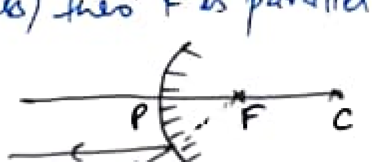
Rules

1. **Rule-1 :-** A Ray of light parallel to the pri axis, passes thro' the focus after reflection. (appear to pass)





2. **Rule-2 :-** A Ray of light passing (appear to pass) thro' F is parallel to the pri axis after Reflection.

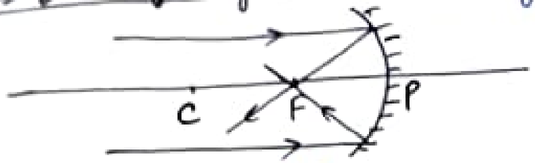


3. **Rule-3 :-** A ray of light passing thro' the centre of curvature is reflected back along the same path.

4. Rule - 4: A ray incident obliquely to the principle axis towards pole is reflected obliquely.

Ray Diagrams for the Image formation by Concave Mirror :-

1. Position of object: At infinity

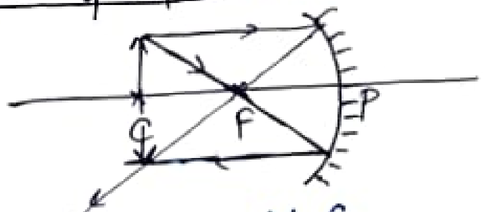


Position of Image: At F
Nature " " : Real & Inverted
Size " " : pt. sized

2. posn of object: Beyond C

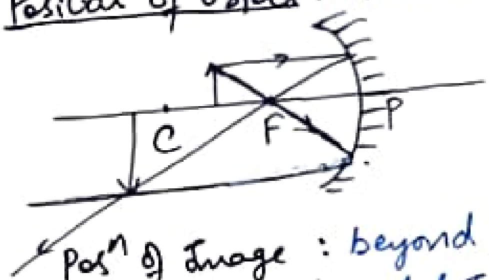
posn of Image : B/w F & C
Nature " " : Real & Inverted
Size " " : Smaller than the object

3. Position of object: At C



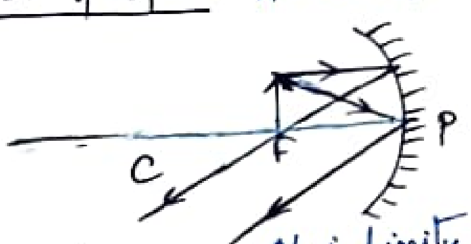
position of Image : At C
Nature of Image : Real & Inverted
Size of Image : Same size

4. Position of object: B/w F & C



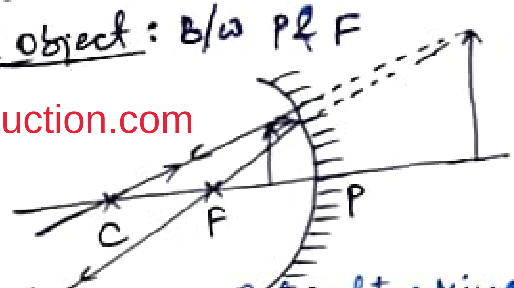
Posn of Image : beyond C
Nature " " : Real & Inverted
Size " " : enlarged

5. Posn of object: At Focus, F



Posn of Image : At infinity
Nature " " : Real & Inverted
Size " " : Highly enlarged

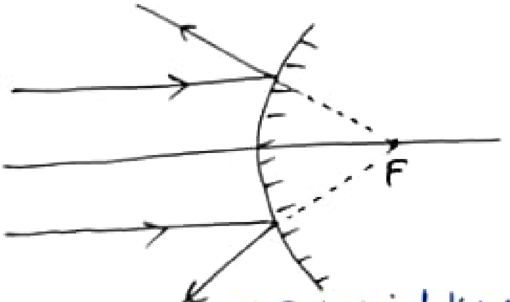
6. Posn of object: B/w P & F



Posn of Image: Behind the Mirror
Nature " " : Virtual & Erect
Size of " : Enlarged.

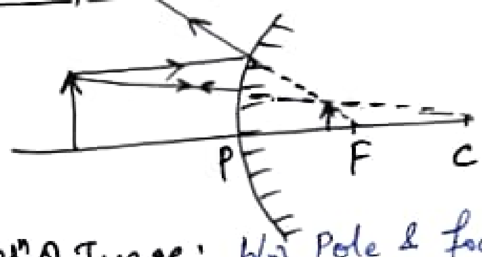
Ray Diagrams for the Image formation by Convex Mirror :-

1. Posn of object: At infinity



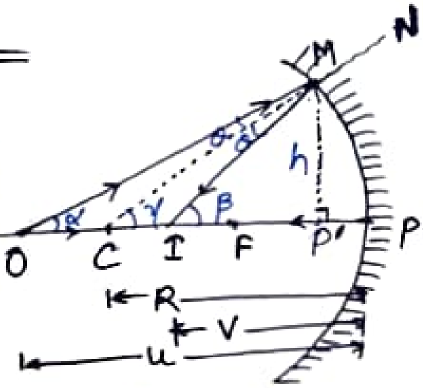
Posn of Image: At F, behind the mirror
Nature " " : Virtual and erect
Size of Image : Highly diminished, pt sized

2. Posn of Object b/w Pole & Infinity



Posn of Image: b/w Pole & focus (Behind the Mirror)
Nature of Image: Virtual & erect
Size of Image: Diminished.

MIRROR FORMULA :- $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}=\frac{2}{R}$



Concave Mirror :- O → Object, I → Image

$\angle OMC\,(i) = \angle IMC\,(r) = \theta$ (law of Reflection)

Draw $MP' \perp OP$, for mirrors of small Aperture P is close to P'

As P' tends to P ∴ $OP' = OP$. Let $MP' = h$

Let $\angle MOP'$ be α, $\angle MCP' = \gamma$, $\angle MIP' = \beta$

$\tan\alpha = \frac{h}{-u}$ (−u ∵ of sign convention) $\quad$ |||^{ly}, $\tan\gamma = \frac{h}{-R}$ (−R ∵ of sign conv.)

$\tan\beta = \frac{h}{-v}$ (−v ∵ " " ")

In ΔOMC : γ → exterior ∠ ∴ $\gamma = \alpha + \theta$ — ①

In ΔCMI : β → " " ∴ $\beta = \gamma + \theta$ — ②

① − ② gives : $\gamma - \beta = \alpha - \gamma \Rightarrow 2\gamma = \alpha + \beta$

for small Aperture : α, β, γ will be very small. ∴ $\tan\alpha \approx \alpha$, $\tan\beta \approx \beta$, $\tan\gamma \approx \gamma$.

As, $2\gamma = \alpha + \beta$

$$\therefore\ 2\left(\frac{h}{-R}\right) = \left(\frac{h}{-u}\right) + \left(\frac{h}{-v}\right)$$

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

$$\Rightarrow \frac{1}{R/2} = \frac{1}{u} + \frac{1}{v} \Rightarrow \boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$$

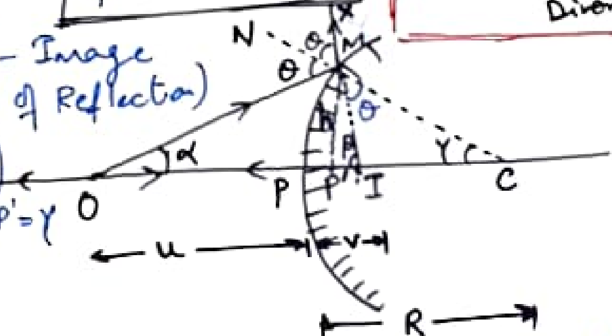
Power of a Mirror

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

for concave mirror : f = −ve
converging ⇒ P = +ve

for convex mirror : f = +ve
Diverging ⇒ P = −ve

Convex Mirror :- O → object, I − Image



$\angle OMN\,(i) = \angle NMX\,(r) = \theta$ (law of Reflection)

Draw $MP'(h) \perp OC$ $\quad$ P' → P (Small Apert.)

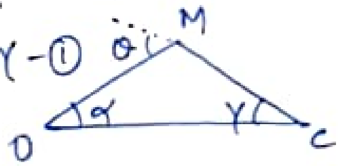
$\angle MOP' = \alpha$, $\angle MIP' = \beta$ & $\angle MCP' = \gamma$

$\tan\alpha = \frac{h}{-u}$ (−u ∵ Sign conv.)

$\tan\beta = \frac{h}{v}$ (+v ∵ " ")

$\tan\gamma = \frac{h}{R}$ (+R ∵ " ")

In ΔOMC : $\theta = \alpha + \gamma$ — ①



In ΔIMC :

$\beta = \theta + \gamma$
$\Rightarrow \theta = \beta - \gamma$ — ②

from ① & ② : $\alpha + \gamma = \beta - \gamma \Rightarrow 2\gamma = \beta - \alpha$

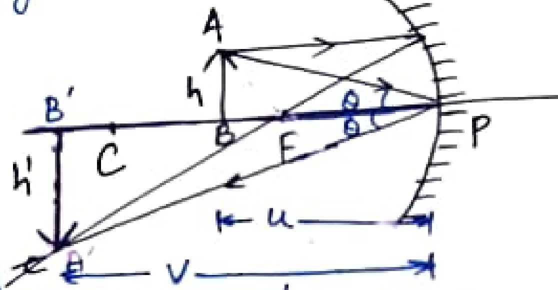
for small Apert : $\tan\alpha \approx \alpha$, $\tan\beta \approx \beta$, $\tan\gamma \approx \gamma$

As $2\gamma = \beta - \alpha$

$$\Rightarrow 2\left(\frac{h}{R}\right) = \left(\frac{h}{v}\right) - \left(\frac{h}{-u}\right) \Rightarrow \frac{2}{R} = \frac{1}{v} + \frac{1}{u} \Rightarrow \frac{1}{R/2} = \frac{1}{v} + \frac{1}{u} \Rightarrow \boxed{\frac{1}{f} = \frac{1}{v} + \frac{1}{u}}$$

MAGNIFICATION: also called as Linear / Transverse / Lateral Magnification
Magnification produced by spherical mirrors gives the relative extent to which the image of an object is magnified w.r.t the object size.
Mathematically, it's defined as the ratio of the size of image to the size of object. It's generally denoted by 'm'.

$$m = \frac{\text{Size of Image}}{\text{Size of Object}} = \frac{h'}{h}$$



Also, $m = -\frac{V}{u}$

Pf:- $\Delta ABP \sim \Delta A'B'P$ (AA similarity)

$\therefore \frac{A'B'}{AB} = \frac{B'P}{BP}$ (corresp. sides are proportional)

$\Rightarrow \frac{-h'}{h} = \frac{-V}{-u} \Rightarrow \underline{\frac{h'}{h} = \frac{-V}{u}}$

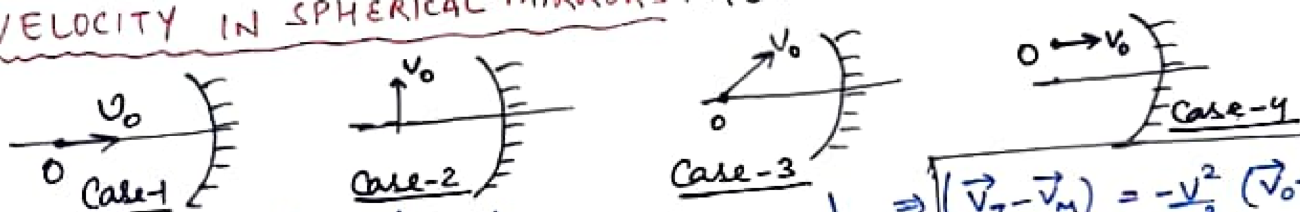
$\Rightarrow \boxed{m = \frac{h'}{h} = \frac{-V}{u}}$

If m = -ve	If m = +ve
Real Image	Virtual Image

If |m| > 1	If |m| < 1	If |m| = 1
Image is magnified	Image is reduced	Image is of same size as the object

COMBINATION OF MIRRORS:- Num Probs.

VELOCITY IN SPHERICAL MIRRORS: 4 cases:



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

$\Rightarrow f^{-1} = v^{-1} + u^{-1}$

By differentiating w.r.t t we get

$$0 = (-1)v^{-2}\frac{dv}{dt} + (-1)u^{-2}\frac{du}{dt}$$

$\vec{V}_I$ & $\vec{V}_O$ velocities w.r.t. mirror

$$\Rightarrow \frac{1}{v^2}\underbrace{\frac{dv}{dt}}_{V_{IM}} = \frac{-1}{u^2}\underbrace{\frac{du}{dt}}_{V_{OM}}$$

$$\Rightarrow \frac{dv}{dt} = \frac{-v^2}{u^2}\cdot\frac{du}{dt}$$

$$\Rightarrow \boxed{\vec{V}_{IM} = -\frac{v^2}{u^2}\vec{V}_{OM}}$$

along x-axis (Principal Axis)

$$\Rightarrow \boxed{(\vec{V}_I - \vec{V}_M) = -\frac{v^2}{u^2}(\vec{V}_O - \vec{V}_M)}$$

Case-2: u, v = constants

$\therefore \frac{du}{dt} = 0$ (V_O) & $\frac{dv}{dt} = 0$ (V_I)

h → changing

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

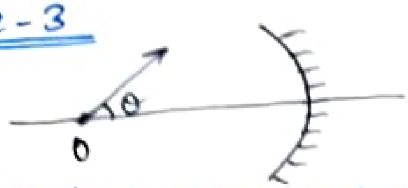
$\Rightarrow h' = -\frac{v}{u}h$

$$\Rightarrow \underbrace{\frac{dh'}{dt}}_{\text{velocity of the image along Y-axis}} = -\left(\frac{v}{u}\right)\underbrace{\frac{dh}{dt}}_{\text{velocity of object in Y-direc}^n}$$

$$\Rightarrow \boxed{\vec{V}_I = -\left(\frac{v}{u}\right)\vec{V}_O}$$

along Y-axis

Case - 3



u - changing, v - changing. Resolve - components

Along x-axis : $(v_I - v_M) = -\frac{v^2}{u^2}(v_O - v_M)$

h - changing, h' - changing

(for case - 2, u, v - constants)

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

$\Rightarrow h'u = -vh$

diff. w.r.t. t & by applying product Rule

$$\Rightarrow h'\underbrace{\frac{du}{dt}}_{0} + u\frac{dh'}{dt} = -h\underbrace{\frac{dv}{dt}}_{0} - v\frac{dh}{dt}$$

(initially h' & $h = 0$)

$$\therefore u\frac{dh'}{dt} = -v\frac{dh}{dt}$$

$$\Rightarrow uv_I = -vv_O$$

$$\Rightarrow v_I = \left(-\frac{v}{u}\right)v_O$$

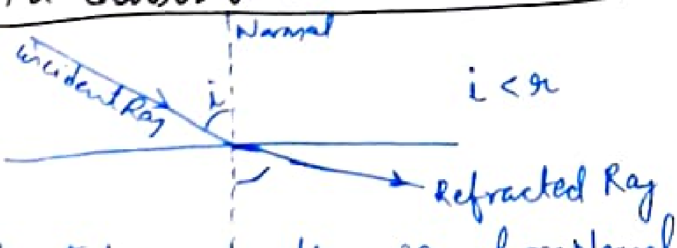
REFRACTION OF LIGHT:- It's the phenomenon of change in the path of light, when it goes from one medium to another. (with diff. optical density)

Optically denser medium – Medium in which light travels slower.

Optically rarer medium – Medium in which light travels faster.

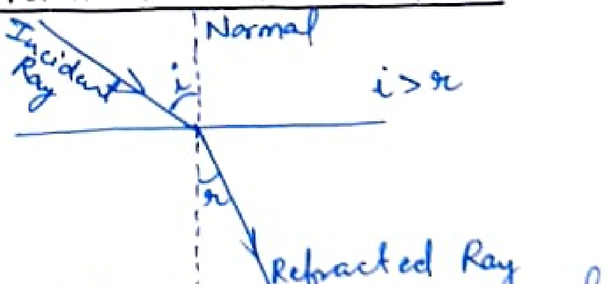
Cause of Refraction:- The refraction of light takes place because speed of light is different in different media.

Refraction of light when it goes from a denser to a rarer medium:



Refracted ray bends away from Normal

Refraction of light when it goes from a rarer to a denser medium:-

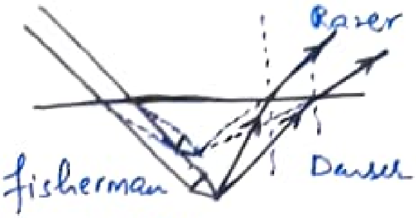


Refracted Ray bends towards normal.

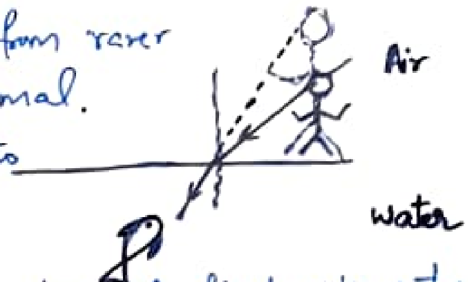
REFRACTION IN DAY-TO-DAY EXPERIENCES :-

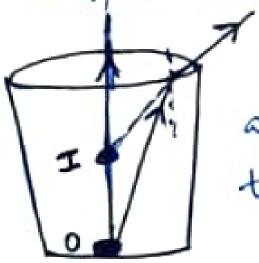
* when lemon is dipped in water, it appears bigger in size.

* When pencil is partly immersed in water in a glass tumbler, it appears to be displaced & short at the interface of air & water. Part of the pencil immersed in water appears to be thicker.



* To a fish under water viewing obliquely, a fisherman standing on the bank of the lake, the man looks taller. Since, the fisherman is in air, rays travel from rarer to denser medium. They bent towards the normal & appear to come from larger distance. So, to a fish under water, the man looks taller.





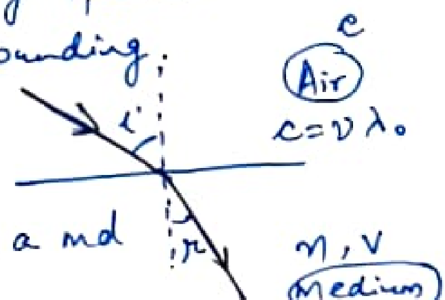
* Coin placed at the bottom of a bucket filled with water appears to be slightly raised above its actual position due to refraction of light.

Note : For Refracted light, frequency remains unchanged but wavelength & speed get changed.

REFRACTIVE INDEX :

* The Refractive Index of a medium gives the indication of light bending ability of that medium.

* It is defined as the extent of the change in the direct^n of light in a given pair of media.
* The value of refractive index for a given pair of media depends upon the speed of light in the two media.
* It has no units.
* Refractive Index depends upon the following factors:
  (a) Nature of the medium & nature of surrounding.
  (b) Physical cond^n e.g. Temperature.
  (c) wavelength, λ of light used.



Absolute Refractive Index:- Refractive Index of a md w.r.t air is called Absolute Refractive Index.

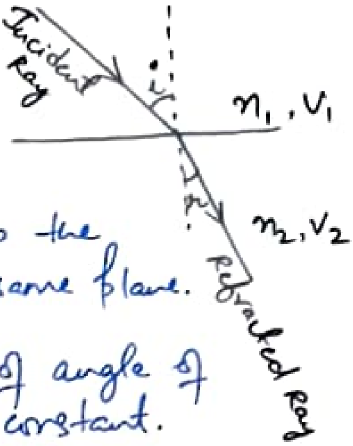
$\boxed{n = c/v}$ $\Rightarrow$ $\boxed{n = \frac{c}{v} = \frac{\nu\lambda_0}{\nu\lambda_m} = \frac{\lambda_0}{\lambda_m}}$ $\boxed{n > 1 \Rightarrow \lambda_m < \lambda_0}$.

Relative Refractive Index:- Relative Refractive Index is the Refractive index of a medium w.r.t another medium.

* n_{21} OR ${}_1n_2$: Ref. Index of md. 2 w.r.t 1

Ref. Index of md. 2 w.r.t 1 $= n_{21} = \frac{n_2}{n_1} = \frac{V_1}{V_2}$

Ref. Index of md. 1 w.r.t. 2 $= n_{12} = \frac{n_1}{n_2} = \frac{V_2}{V_1}$



LAWS OF REFRACTION :-

* The incident Ray, the refracted Ray & normal to the interface at the pt. of incidence, all lie in the same plane.
* **Snell's Law of Refraction :-** The ratio of sine of angle of incidence to the sine of angle of refraction is a constant.

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = n_{21} \ (\text{OR } {}^1n_2)$$

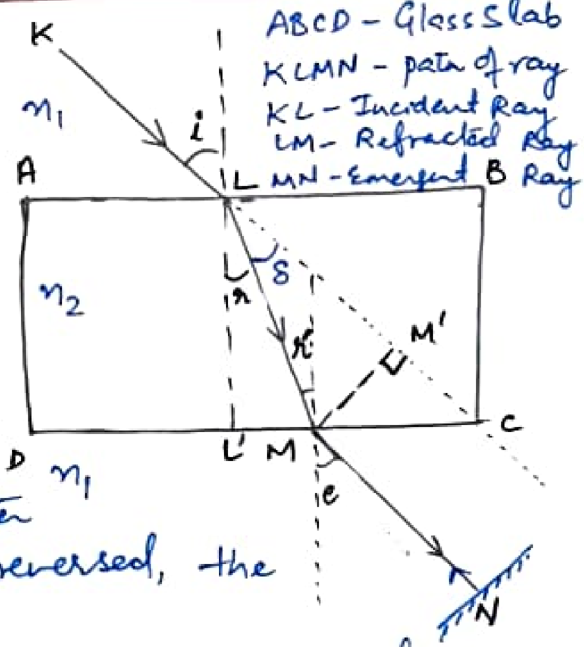
$\uparrow$ Ref. Index of medium 2 w.r.t. medium 1

$$\therefore \frac{\sin i}{\sin r} = \frac{n_2}{n_1} = n_{21} = \frac{1}{n_{21}} = \frac{V_1}{V_2} = \frac{\lambda_1}{\lambda_2} \quad \left[\because \begin{matrix} V_1 = \nu\lambda_1 \\ V_2 = \nu\lambda_2 \end{matrix}\right]$$

Also, $n_1 \sin i = n_2 \sin r$

* If $n_{21} > 1$, $r < i$ $\rightarrow$ optically denser md. 2
* If $n_{21} < 1$, $r > i$ $\rightarrow$ optically rarer : md 2.

REFRACTION OF LIGHT THROUGH A RECTANGULAR GLASS SLAB:



At L : $n_1 \sin i = n_2 \sin r$ [Snell's law]

$$\Rightarrow \frac{\sin i}{\sin r} = \frac{n_2}{n_1} = {}^1n_2 \quad \text{— (1)}$$

At M :- $n_2 \sin r' = n_1 \sin e$ [Snell's law]

$$\Rightarrow \frac{\sin r'}{\sin e} = \frac{n_1}{n_2} = {}^2n_1 \quad \text{— (2)}$$

Acc. to "principle of Reversibility of light", when final path of a ray of light after any no. of reflections & refractions is reversed, the ray retraces its entire path.

By placing a plane mirror at N, path MN is reversed.

For a reversed ray : $\frac{n_2}{n_1} = \frac{\sin e}{\sin r'} = {}^1n_2$ — (3)

from (2) & (3) $\quad {}^2n_1 = \frac{1}{{}^1n_2} \Rightarrow \underline{{}^2n_1 \times {}^1n_2 = 1}$

from (1) & (2) $\quad \frac{\sin i}{\sin r} = \frac{\sin e}{\sin r'}$

but $r = r'$ (alt. int $\angle$s) $\Rightarrow \boxed{i = e}$

Expression for Lateral displacement / shift :- Draw $MM' \perp KL$

Let $\angle MLM' = \delta$ = deviation on first refraction

In $\Delta LMM'$ $\quad \sin\delta = \frac{MM'}{LM} \Rightarrow MM' = LM\sin\delta$

In $\Delta LL'M$ $\quad \cos r = \frac{LL'}{LM} \Rightarrow LM = \frac{LL'}{\cos r} = \frac{t}{\cos r}$ ← thickness of the glass slab.

$$\therefore \boxed{MM' = \frac{t}{\cos r}\sin\delta = \frac{t\sin(i-r)}{\cos r}}$$

Lateral shift will be maximum, when

$\sin(i-r) = \max = 1 = \sin 90°$

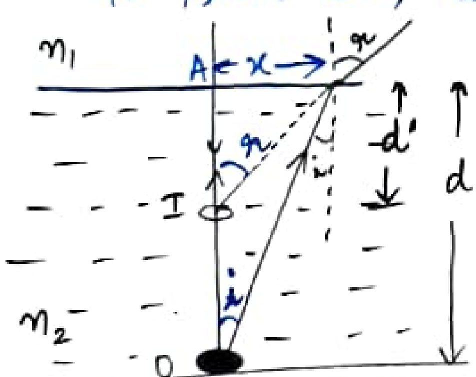
$\Rightarrow (i-r) = 90°$

If $r = 0$, $i = 90°$ $\therefore$ Max^m Lateral shift, $MM' = \frac{t \times 1}{1} = t$ ← thickness

REAL DEPTH AND APPARENT DEPTH OF A TANK :-

A water tank appears shallower. i.e., less deep than what it actually is. This is on account of Refraction of light.

To Prove this, let's put a coin in a container filled with water.



O → Actual pos^n of the coin

I → Apparent pos^n of the coin

d → Actual depth of the coin from the surface

d' → Apparent depth of the coin from the surface

$n_2 \sin i = n_1 \sin r$ — (1) [Snell's Law of Refraction]

considering the rays to be paraxial rays, therefore $\angle i$ & $\angle r$ are quite small

$\Rightarrow \sin i \approx i \approx \tan i$ [for small angle i]

^{lly} $\sin r \approx r \approx \tan r$ [" " " r]

$\therefore$ (1) b'comes : $n_2 \tan i = n_1 \tan r$

$$\Rightarrow n_2 \frac{x}{d} = n_1 \frac{x}{d'}$$

$$\boxed{n_{21} = \frac{n_2}{n_1} = \frac{d}{d'}}$$

$$\Rightarrow \frac{n_2}{n_1} = \frac{d}{d'}$$
d ← Real depth
d' ← Apparent Depth

for water, $n_{21} = 4/3$

$$\therefore d' = \frac{d}{n_{21}} = \frac{d}{4/3} = \frac{3}{4}d \text{ (for normal incidence)}$$

Normal shift in the posn, $IO = AO - AI = AO\left(1 - \frac{AI}{AO}\right)$

$$= d\left(1 - \frac{d'}{d}\right) = \boxed{d(1 - n_{21})}$$

ATMOSPHERIC REFRACTION :-

* Twinkling of stars
* Stars appear higher than they actually are.
* Oval shape of Sun at the time of sunrise & sunset.
* Sun is visible to us before actual sunrise & after actual sunset.
* Mirage
* Looming.

TOTAL INTERNAL REFLECTION (TIR) :-

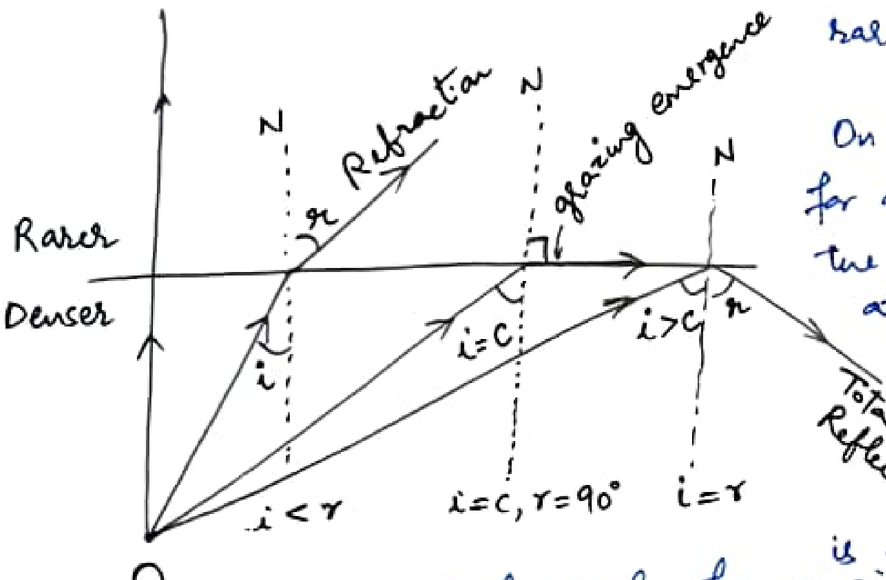
Consider incident rays travelling from a denser to a rarer medium.

For a given i, we get r

On increasing i, r also increases.

For a particular value of $i = c$ the incident ray is refracted at $r = 90°$ & goes grazingly along the interference

when $\angle i > c$, No portion of light is refracted. This phenomenon is called TIR.



Critical Angle :- Critical Angle for a given pair of media in contact as the angle of incidence in the denser medium corresponding to which angle of refraction in the rarer medium is 90°.

At. $\angle i = c$, $\angle r = 90°$

Value of c depends on the nature of media in contact.

Total Internal Reflection :- It's the phenomenon of reflection of light into a denser medium from an interface of this denser medium & a rarer medium.

Two essential condn for TIR :

(i) Light should travel from a denser medium to a rarer medium.

(ii) Angle of incidence in denser md. should be greater than the critical angle for a given pair of media in contact.

for $i > c$, Ray is totally reflected back into denser medium.

Rel^n b/w refractive Index & Critical Angle :-

$n_2 \sin i = n_1 \sin r$

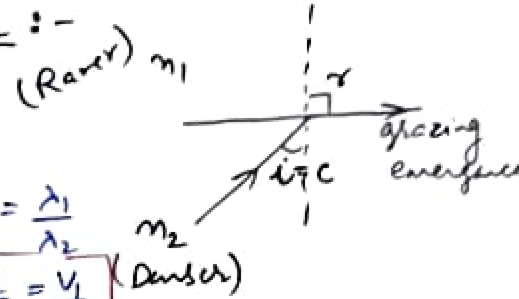
$\therefore n_2 \sin C = n_1 \sin 90°$

$\Rightarrow \boxed{\sin C = \frac{n_1}{n_2}}$

$\frac{1}{\sin C} = \frac{n_2}{n_1} = n_{21}$

As, $n_{21} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

$\therefore \boxed{\sin C = \frac{1}{n_{21}} = \frac{\lambda_2}{\lambda_1} = \frac{v_1}{v_2}}$

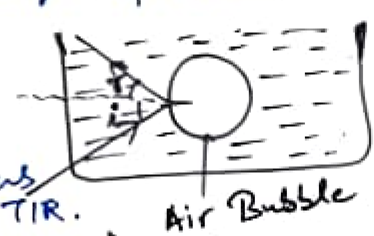


C for red colour will be greater than that of violet colour. ($\because \lambda_r > \lambda_v$)

Some Applications of TIR :-

(i) The brilliance of diamond: n for diamond is 2.42. The diamond is cut suitably so that light entering the diamond from any face falls at an angle greater than 24.4°. Therefore, it suffers multiple total internal reflections at various faces & remain within the diamond

(ii) Shining of an air bubble in water: Critical angle for water air interface is 48.75°. When light propagating from water (Denser md) falls on the surface of an air bubble at an angle greater than 48.75°, it suffers TIR.

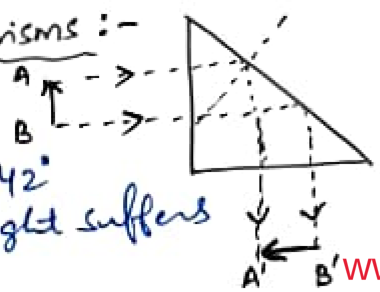


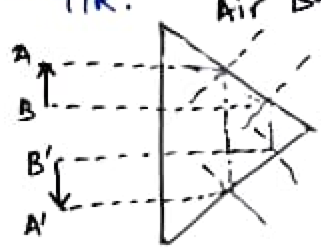
(iii) Totally reflecting glass prisms :-

n (glass) $= \frac{3}{2}$

C for glass - air interface = 42°

i is made 45° (i > C) $\therefore$ light suffers TIR.





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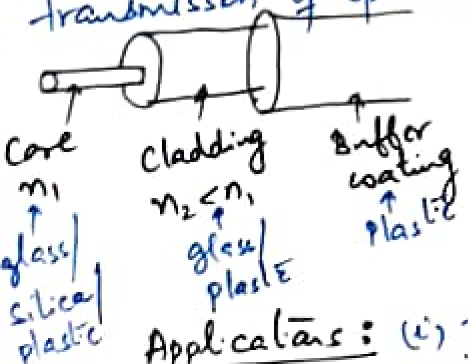
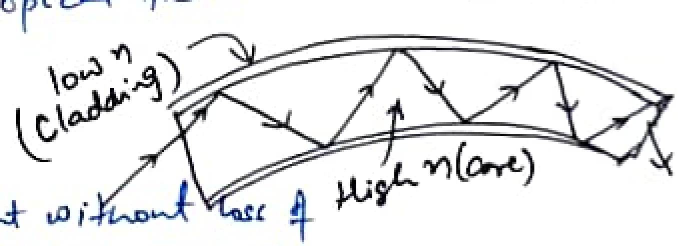
(iv) Optical fibres :- Optical fibres are used as guided medium for transmission of optical signals over long distances of several kms.

In typical optical fibre, $n_1 = 1.52$, $n_2 = 1.48$.

A bundle of optical fibres is called Light pipe.





Applications: (i) to transmit light without loss of intensity.

(ii) in the manufacture of medical instruments

(iii) in telecommunications.

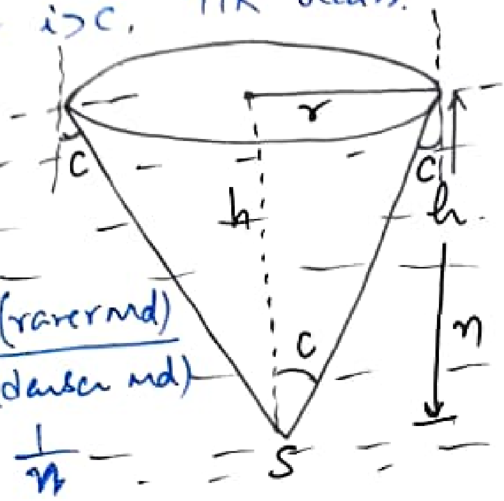
(iv) to measure n of liquids.

(v) in the form of photometric sensors, used in measuring the blood flow to the heart.

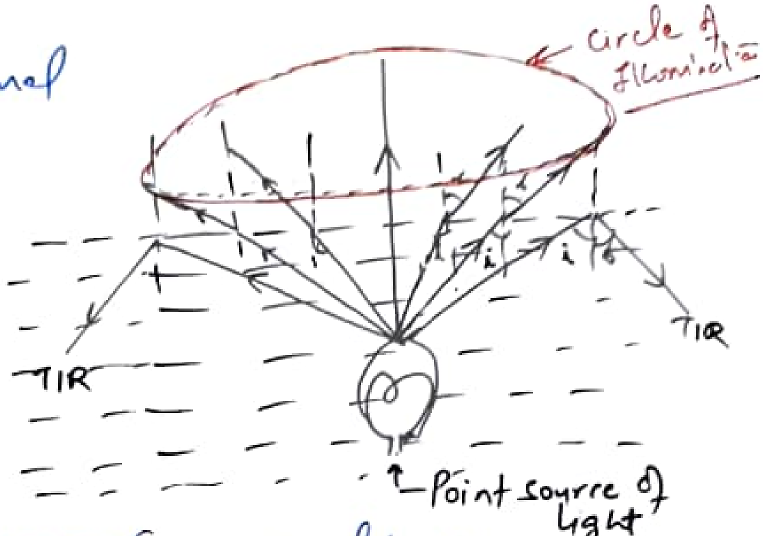
CIRCLE OF ILLUMINATION :-

Light will bend away from normal

for $i > C$, TIR occurs.

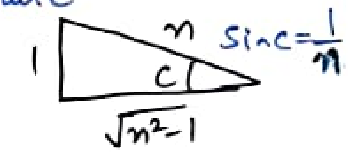


$\sin C = \dfrac{n(\text{rarer md})}{n(\text{denser md})} = \dfrac{1}{n}$



$\tan C = \dfrac{r}{h} \Rightarrow r = h\tan C$

$\therefore \tan C = \dfrac{1}{\sqrt{n^2-1}}$



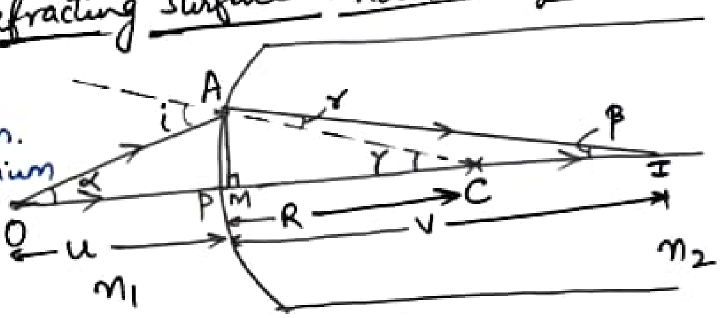
$\Rightarrow r = \dfrac{h}{\sqrt{n^2-1}}$

SPHERICAL REFRACTING SURFACES :-

- Convex spherical Refracting Surface
- Concave spherical Refracting surface

(1) Refraction from Rarer to Denser medium

(a) at a convex spherical Refracting surface : Real Image



O → Object I – Real Image

n_1 → Ref. Index of Rarer medium.

n_2 → Ref. Index of Denser medium

Draw $AM \perp OI$

for small Aperture : $PM \to 0$

Let $\angle AOM = \alpha$, $\angle AIM = \beta$, $\angle ACM = \gamma$

In ΔIAC : $\gamma = r + \beta \Rightarrow r = \gamma - \beta$

In ΔOAC : $i = \alpha + \gamma$

Snell's law : $n_1 \sin i = n_2 \sin r$

$\Rightarrow n_1 i = n_2 r$ (for small $\angle$s)

$\Rightarrow n_1(\alpha + \gamma) = n_2(\gamma - \beta)$

(α, β, γ – small $\angle$s, Using $\theta = l/r$ OR $\alpha \approx \tan\alpha$, $\beta \approx \tan\beta$, $\gamma \approx \tan\gamma$ for small $\angle$s)

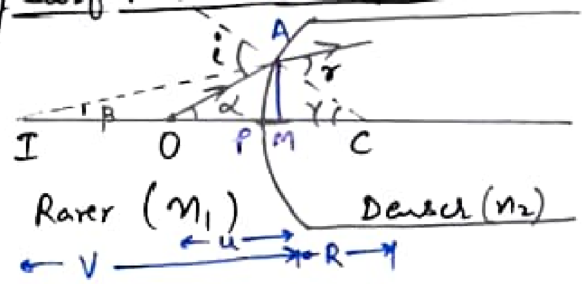
$\therefore n_1\left(\dfrac{AM}{OM} + \dfrac{AM}{CM}\right) = n_2\left(\dfrac{AM}{MC} - \dfrac{AM}{MI}\right)$

$\Rightarrow n_1\left(\dfrac{1}{OP} + \dfrac{1}{CP}\right) = n_2\left(\dfrac{1}{PC} - \dfrac{1}{PI}\right)$ [$\because$ M is close to P – Small Aperture]

$$n_1\left(\frac{1}{-u}+\frac{1}{R}\right) = n_2\left(\frac{1}{R}-\frac{1}{v}\right)$$

$$\Rightarrow \boxed{\frac{n_1}{-u}+\frac{n_2}{v} = \frac{n_2-n_1}{R}}$$

(b) at a convex spherical Refracting surf : Virtual Image



$n_1 i = n_2 r$

$i = \gamma + \alpha \quad , \quad r = \gamma + \beta$

$\Delta AOC \qquad \Delta AIC$

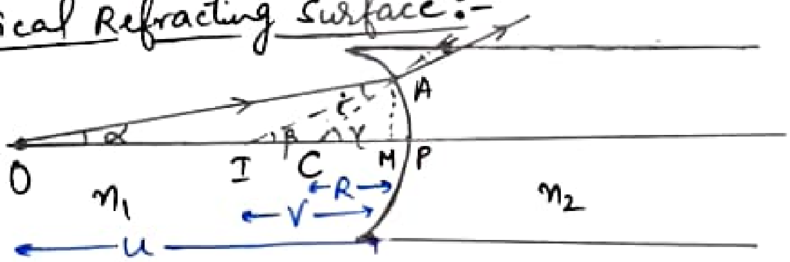
$\therefore n_1(\gamma+\alpha) = n_2(\gamma+\beta)$

$$\Rightarrow n_1\left(\frac{AM}{MC}+\frac{AM}{OM}\right) = n_2\left(\frac{AM}{MC}+\frac{AM}{MI}\right)$$

$$\Rightarrow n_1\left(\frac{1}{R}+\frac{1}{-u}\right) = n_2\left(\frac{1}{R}-\frac{1}{v}\right)$$

$$\Rightarrow \boxed{\frac{n_1}{-u}+\frac{n_2}{v} = \frac{n_2-n_1}{R}}$$

(c) at a concave spherical Refracting surface:-



$i = \gamma - \alpha, \quad r = \gamma - \beta$

$n_1 i = n_2 r$

$\Rightarrow n_1(\gamma-\alpha) = n_2(\gamma-\beta)$

$$\Rightarrow n_1\left(\frac{AM}{MC}-\frac{AM}{OM}\right) = n_2\left(\frac{AM}{MC}-\frac{AM}{MI}\right)$$

$$\Rightarrow n_1\left(\frac{1}{-R}-\frac{1}{-u}\right) = n_2\left(\frac{1}{-R}-\frac{1}{-v}\right)$$

$$\Rightarrow n_1\left(\frac{1}{-R}+\frac{1}{u}\right) = n_2\left(\frac{1}{-R}+\frac{1}{v}\right)$$

$$\Rightarrow \boxed{\frac{-n_1}{u}+\frac{n_2}{v} = \frac{n_2-n_1}{R}}$$

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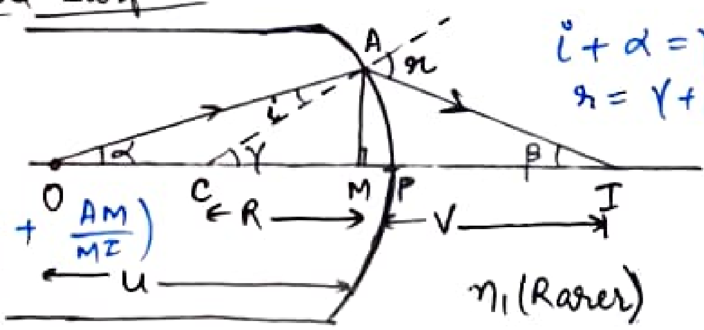
(2) Refraction from Denser to Rarer medium :-

(a) at a convex spherical surface :-



$i + \alpha = \gamma$

$r = \gamma + \beta$

$n_2 i = n_1 r$

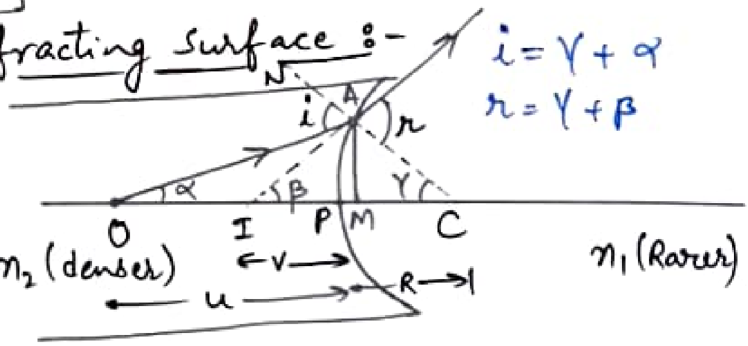
$\Rightarrow n_2(\gamma-\alpha) = n_1(\gamma+\beta)$

$$\Rightarrow n_2\left(\frac{AM}{MC}-\frac{AM}{OM}\right) = n_1\left(\frac{AM}{MC}+\frac{AM}{MI}\right)$$

$$n_2\left(\frac{1}{-R} - \frac{1}{-u}\right) = n_1\left(\frac{1}{-R} + \frac{1}{V}\right)$$

$$\Rightarrow \boxed{\frac{n_2}{-u} + \frac{n_1}{V} = \frac{n_2 - n_1}{-R} = \frac{n_1 - n_2}{R}}$$

(b) at a concave spherical Refracting surface :-



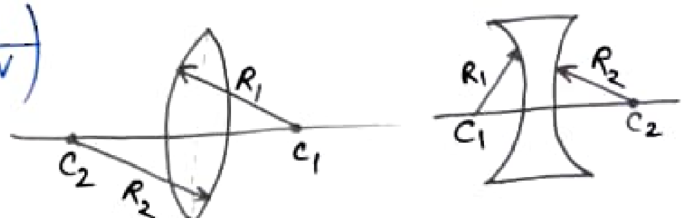
$$n_2 i = n_1 r$$

$$\Rightarrow n_2(\gamma + \alpha) = n_1(\gamma + \beta)$$

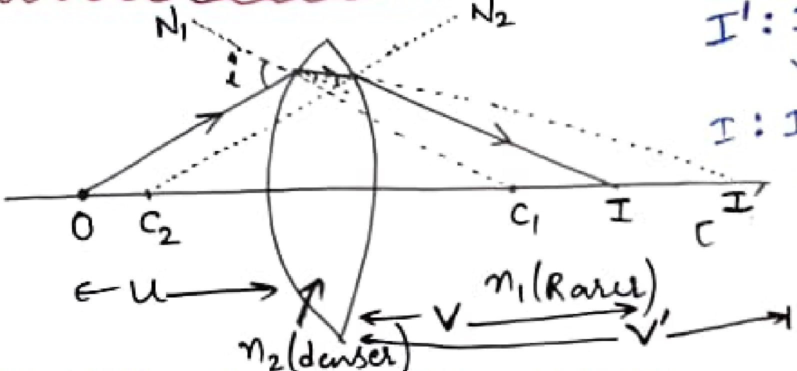
$$\Rightarrow n_2\left(\frac{AM}{MC} + \frac{AM}{OM}\right) = n_1\left(\frac{AM}{MC} + \frac{AM}{MI}\right)$$

$$\Rightarrow n_2\left(\frac{1}{+R} + \frac{1}{-u}\right) = n_1\left(\frac{1}{R} + \frac{1}{-V}\right)$$

$$\Rightarrow \boxed{\frac{n_2}{-u} + \frac{n_1}{V} = \frac{n_1 - n_2}{R}}$$



LENS MAKER'S FORMULA:-



I' : Image of object O, acts as virtual object

I : Image of I'

$$-\frac{n_1}{u} + \frac{n_2}{V} = \frac{n_2 - n_1}{R}$$

Ist surface: $\dfrac{n_2}{V'} - \dfrac{n_1}{u} = \dfrac{n_2 - n_1}{R_1}$ ------ (i)

IInd surface: $\dfrac{n_1}{V} - \dfrac{n_2}{V'} = \dfrac{n_1 - n_2}{R_2}$ ------ (ii)

(i) + (ii) gives:

$$-\frac{n_1}{u} + \frac{n_1}{V} = \frac{n_2 - n_1}{R_1} + \frac{n_1 - n_2}{R_2}$$

$$\Rightarrow -\frac{n_1}{u} + \frac{n_1}{V} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

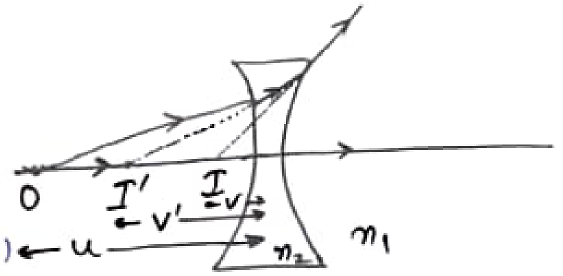
$$\Rightarrow \frac{-1}{u} + \frac{1}{V} = \frac{n_2 - n_1}{n_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\Rightarrow \boxed{\frac{1}{V} - \frac{1}{u} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)}$$

* If the object is at infinity, $u=\infty$ & $v=f$

$$\frac{1}{f}-\frac{1}{\infty}=(n_{21}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\Rightarrow \boxed{\frac{1}{f}=(n_{21}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)}$$



Rarer to Denser: $\frac{n_2}{v'}-\frac{n_1}{u}=\frac{n_2-n_1}{R_1}$ ---(i)

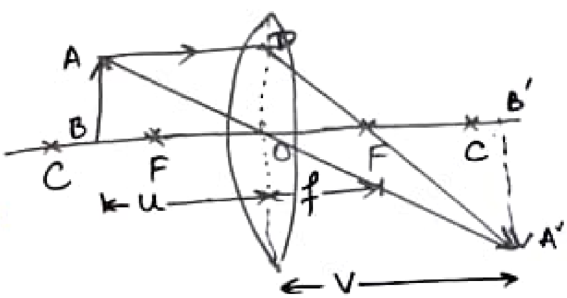
Denser to Rarer: $\frac{n_1}{v}-\frac{n_2}{v'}=\frac{n_1-n_2}{R_2}$ ......(ii)

(i) + (ii) gives: $\frac{n_1}{v}-\frac{n_1}{u}=(n_2-n_1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

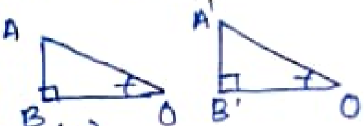
$$\Rightarrow\left(\frac{1}{v}-\frac{1}{u}\right)=(n_{21}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

* If the object is at infinity, $u=\infty$, & $v=f$

$$\therefore \boxed{\frac{1}{f}=(n_{21}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)}$$



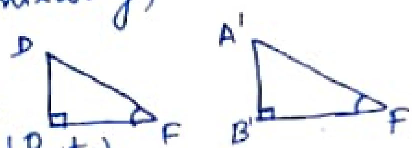
LENS FORMULA :-



Concider ΔABO & $\Delta A'B'O$

$\Delta ABO \sim \Delta A'B'O$ (AA similarity)

$\therefore \frac{A'B'}{AB}=\frac{OB'}{OB}$ —①



Consider $\Delta A'B'F$ & ΔDOF

$\Delta DOF \sim \Delta A'B'F$ (AA similarity)

$\therefore \frac{A'B'}{DO}=\frac{B'F}{OF}$

$\Rightarrow \frac{A'B'}{AB}=\frac{B'F}{OF}$ [$\because AB=DO$] —②

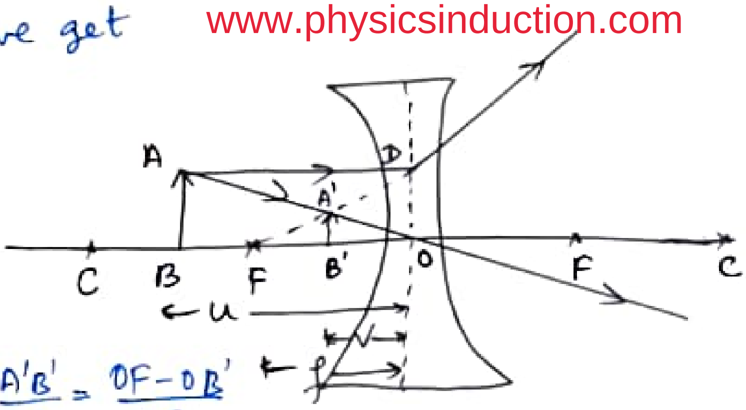
from ① & ②;

$\frac{OB'}{OB}=\frac{B'F}{OF}=\frac{OB'-OF}{OF} \Rightarrow \frac{v}{-u}=\frac{v-f}{f} \Rightarrow vf=-uv+uf$

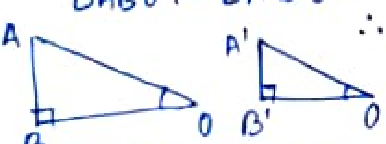
$\Rightarrow uv=uf-vf$

Dividing both sides by uvf, we get

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



$\Delta ABO \sim \Delta A'B'O$ (AA simil)



$\therefore \frac{A'B'}{AB}=\frac{OB'}{OB}$

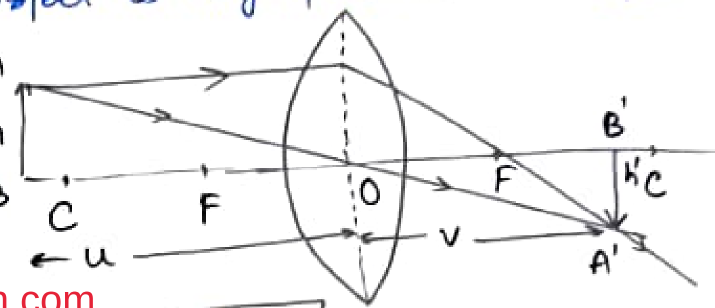
$\Delta A'B'F$ & ΔDOF $\frac{A'B'}{OD}=\frac{B'F}{OF} \Rightarrow \frac{A'B'}{AB}=\frac{OF-OB'}{OF}$

$\therefore \frac{OB'}{OB}=\frac{OF-OB'}{OF} \Rightarrow \frac{-v}{-u}=\frac{-f-(-v)}{-f} \Rightarrow \boxed{\frac{1}{v}-\frac{1}{u}=\frac{1}{f}}$

LINEAR MAGNIFICATION PRODUCED BY A LENS:-

* The Linear magnification produced by a lens is defined as the ratio of the size of the image (h') to the size of the object (h).
* Magnification produced by spherical lens gives the relative extent to which the image of an object is magnified w.r.t. the object size.

$m = \frac{A'B'}{AB} = \frac{h'}{h}$



$\triangle ABO \sim \triangle A'B'O$ (AA similarity)

$\frac{A'B'}{AB} = \frac{OB'}{OB}$ (sides are proportional)

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

$\Rightarrow \boxed{m = \frac{h'}{h} = \frac{+v}{u}}$

$m = -ve$ Real Image		$m = +ve$ Virtual Image
$\lvert m\rvert > 1$ Magnified I	$\lvert m\rvert = 1$ same size	$\lvert m\rvert < 1$ reduced Image

POWER OF A LENS:-

It's the ability of a lens to converge / diverge a beam of light rays of light falling on the lens. (Degree of convergence or divergence of light rays by the lens.)

It's measured as the reciprocal of focal length of the lens.

$\delta = \tan\delta = h/f = 1/f$ (for h=1)

i.e., $\boxed{P = \frac{1}{f}}$

Unit of Power: Dioptre, D.

1 Dioptre :- 1D is the power of a lens whose f is 1m. $\boxed{1D = 1m^{-1}}$

$P = \frac{1}{f(\text{in m})} = \frac{100}{f(\text{in cm})}$

Power of a convex lens : +ve (as f is +ve)

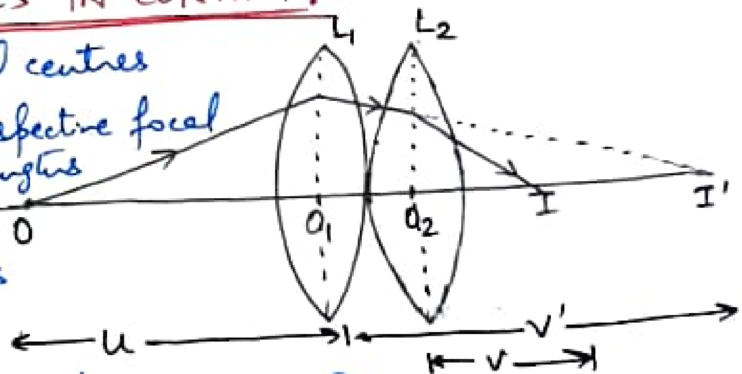
" " " concave " : -ve (as f is -ve)

COMBINATION OF THIN LENSES IN CONTACT:-

L_1 & L_2 → lens held co-axially in contact with each other

O_1 & O_2 → optical centres

f_1 & f_2 → Respective focal lengths

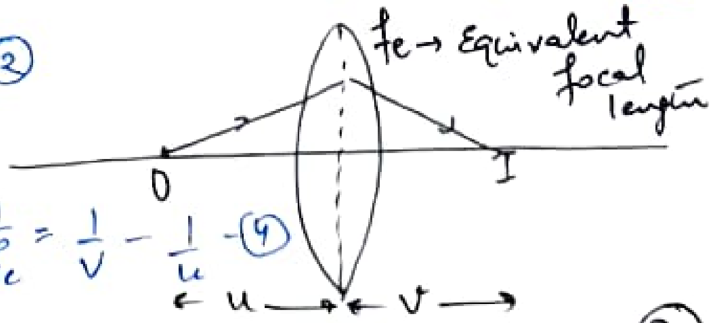


The lens L_1 alone would form its image at I'

$\therefore$ from lens formula: $\frac{1}{f_1} = \frac{1}{v'} - \frac{1}{u}$ —— (1)

For second lens, L_2: I' → acts as virtual object & final Image is formed at I

$\frac{1}{f_2} = \frac{1}{v} - \frac{1}{v'}$ —— (2)



(1) + (2) gives:

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$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{v} - \frac{1}{u}$ —(3) Also, $\frac{1}{f_e} = \frac{1}{v} - \frac{1}{u}$ —(4)

from (3) & (4): $\boxed{\frac{1}{f_e} = \frac{1}{f_1} + \frac{1}{f_2}}$

If one lens is convex & other is concave $\quad \frac{1}{f_e} = \frac{1}{f_1} + \frac{1}{(-f_2)}$

if $f_1 = f_2$, $f_e = \infty$: Comb^n would behave as a plane glass plate

if $f_1 > f_2$, $f_e = -ve$: comb^n would behave as a concave lens.

if $f_1 < f_2$, $f_e = +ve$: comb^n would behave as a convex lens.

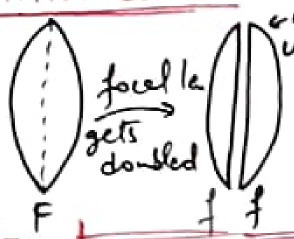
For several thin lenses of focal lengths $f_1, f_2, f_3 \ldots\ldots$ in contact :-

$$\frac{1}{f_e} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \text{------}$$

$\therefore$ Equivalent Power , $P_e = P_1 + P_2 + P_3 + \text{--------}$

CUTTING OF A THIN LENS

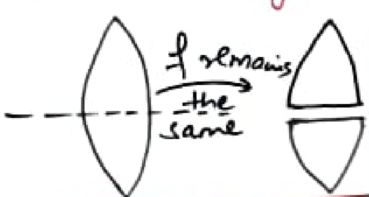
(i) Vertically :-



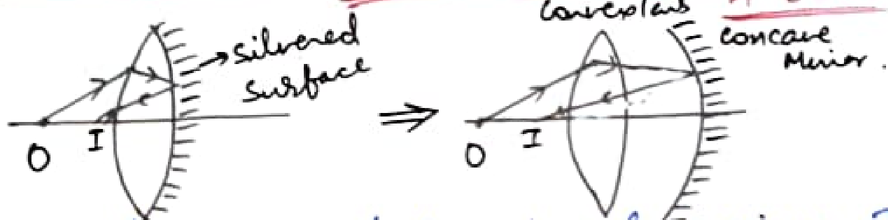
$\therefore \quad \frac{1}{F} = \frac{1}{f} + \frac{1}{f} = \frac{2}{f}$

$\Rightarrow F = f/2$ or $f = 2F$

(ii) Horizontally :-



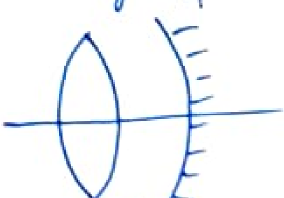
SILVERING OF ONE SURFACE OF A LENS



Suppose, we have a coaxial arrangement of a lens & a mirror. To study the nature of image formed by the comb^n, we proceed as follows:

(i) Using Refraction formulae, we can calculate the pos^n, size & nature of Image of the given object, formed by the lens alone. (as if mirror were not there)

(ii) The image so formed act as real or virtual object for the given mirror. Using mirror formula, we can calculate the pos^n, nature & size of image formed by the mirror.



Equivalent system behaves as a mirror

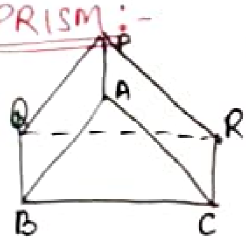
$$P_{equivalent} = P_L + P_M + P_L$$

$$-\frac{1}{f_E} = \frac{1}{f_L} - \frac{1}{f_M} + \frac{1}{f_L}$$

$$\left\{ \frac{1}{f_L} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad f_M = \frac{R_m}{2} \right\}$$

$$\frac{1}{f_E} = \frac{1}{V} - \frac{1}{u}$$

PRISM :-



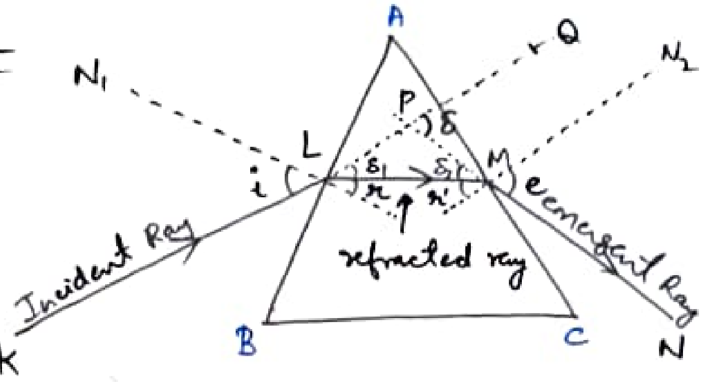
ABQP & ACRP → 2 Refracting faces

∠A → Refracting Angle / Angle of Prism.

AP → Refracting edge

ABC → Principal section of the prism

REFRACTION THROUGH A PRISM:-



path of ray : KL → LM → MN

1st Ref (KL → LM), 2nd Refraction (LM → MN)

dev : δ_1, δ_2

⇒ KL suffers two refractions & has turned thro' an $\angle QPN = \delta$ ← Angle of deviation

At the face AB : $\delta_1 = i - r$

" " " AC : $\delta_2 = e - r'$

And $\delta = \delta_1 + \delta_2$ (applying ext. ∠ thm in ΔPLM)

$\therefore \quad \delta = (i - r) + (e - r')$

$= (i + e) - (r + r')$ ——— (1)

Consider ΔALM:

$\angle A + \angle ALM + \angle AML = 180^\circ$ (sum of all the ∠s of a Δ)

$\Rightarrow \angle A + (90^\circ - r) + (90^\circ - r') = 180^\circ$

$\Rightarrow \angle A = (r + r')$ ——— (2)

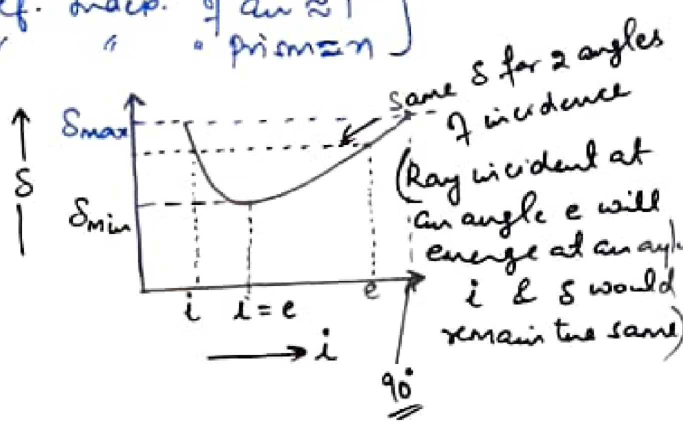
Substituting $(r + r')$ from (2) to (1), we get

∠ of dev. $\boxed{\delta = (i + e) - A}$

At L : $1 \times \sin i = n \times \sin r$ [ref. index of air ≈ 1, " " prism = n]

At M : $n \times \sin r' = 1 \times \sin e$

angle of minimum deviation :-



At the minimum deviation, there is only one angle of incidence.

At $\delta = \delta_{min}$ $\therefore$ $i = e$

As, $\sin i = n \sin r$
$\sin e = n \sin r'$ ⇒ $r = r' = r$ (say)

$\therefore \quad \delta_{min} = 2i - A \Rightarrow i = \dfrac{A + \delta_{min}}{2}$

(2) ⇒ $A = 2r$

As, $n = \dfrac{\sin i}{\sin r}$

$\therefore \quad \boxed{n = \dfrac{\sin\left(\dfrac{A + \delta_{min}}{2}\right)}{\sin \dfrac{A}{2}}}$ ← Prism formula

$\boxed{n_{21} = \dfrac{n_2}{n_1} = \dfrac{\sin\left(\dfrac{A + \delta_{min}}{2}\right)}{\sin \dfrac{A}{2}}}$

Thin Prism :- $\sin i \simeq i$, $\sin r \simeq r$, $\sin e \simeq e$, $\sin r' \simeq r'$

$\therefore i = nr$, $nr' = e$, $\delta = (i+e) - A = (nr + nr') - A = n(r+r') - A$
$= nA - A$

$\Rightarrow \boxed{\delta = (n-1)A}$ for small i, δ is ind. of i

i.e., all the rays (at small $\angle$s of incidence) undergo the same deviation on passing thro' the prism.

OPTICAL INSTRUMENTS :-

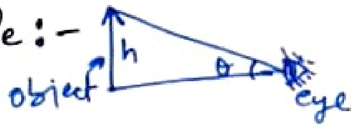
(1) THE MICROSCOPE — A simple Microscope / A Compound Microscope

magnifies object

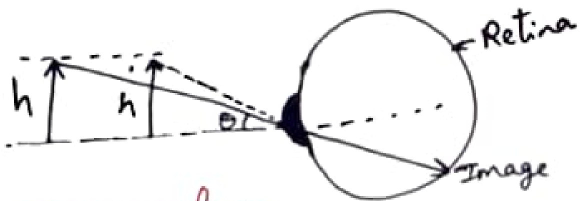
Accomodation – The ability of eye-lens to adjust its focal length.

Least dist of distinct vision – $D = 25$ cm (Near pt)

Visual Angle :-



Angle subtended by object at eye $\to h\uparrow \to \theta\uparrow$
$\Rightarrow h \propto \theta$

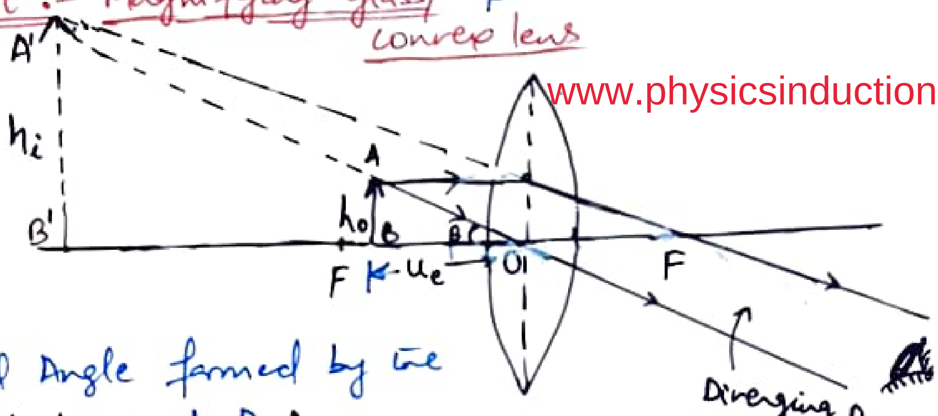


As the object is brought closer, it looks bigger in size & visual Angle increases.

Magnification of Microscope :-

$$M = \frac{\text{Visual Angle formed by final Image}}{\text{Visual Angle formed by object kept at } D} = \frac{\beta}{\alpha}$$

A SIMPLE MICROSCOPE :- Magnifying glass/ convex lens

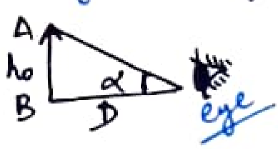


β – Visual Angle formed by final Image

$\beta \approx \tan\beta = \frac{h_o}{u_e}$

β is very small $\because h_o \to$ small

α – Visual Angle formed by the object kept at D



$\tan\alpha \approx \alpha = \frac{h_o}{D}$

As, $M = \frac{\beta}{\alpha} = \frac{\frac{h_o}{u_e}}{\frac{h_o}{D}} \Rightarrow \boxed{M = \frac{D}{u_e}}$

Case-1 :- for max^m magnification, final image should be formed at D(= 25 cm) - with microscope. {objects appear with max h at least dist of distinct vision & as moved away, appear smaller (strained eye)}

$u = -u_e$, $v = -D$

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

As, $M = \frac{D}{u_e} = D\left(\frac{1}{f} + \frac{1}{D}\right)$

$$\Rightarrow \boxed{m = \left(1 + \frac{D}{f}\right)}$$

max (at D)

Case-2 :- For Normal Adjustment → Relaxed eye (at infinity)

Final Image should be formed at infinity.

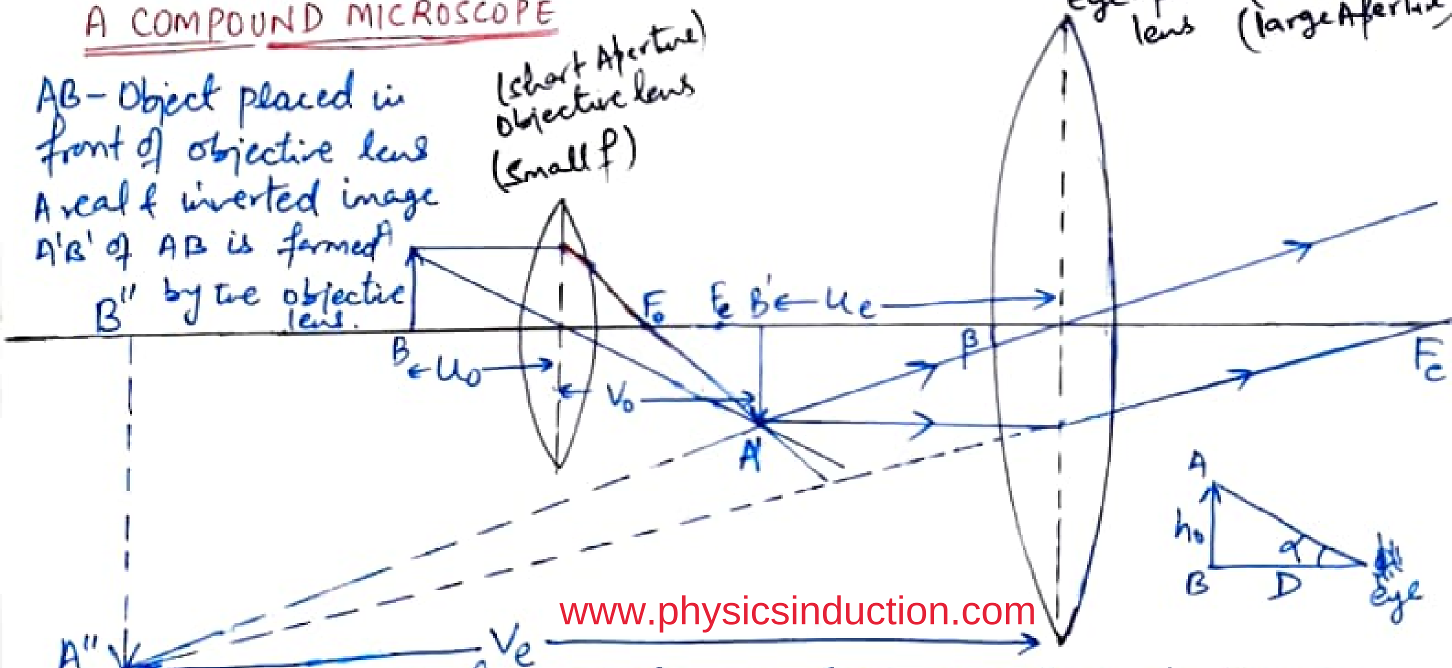
$u = -u_e$, $v = \infty$

$$\therefore \frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow \frac{1}{f} = \frac{1}{\infty} - \frac{1}{-u_e} \Rightarrow \frac{1}{u_e} = \frac{1}{f}$$

$$\therefore M = \frac{D}{u_e} \Rightarrow \boxed{m = \frac{D}{f}} \leftarrow \text{Min (at } \infty)$$

$$\frac{D}{f} \le M \le \left(1 + \frac{D}{f}\right)$$

A COMPOUND MICROSCOPE



A'B' acts as a virtual object for eye-lens. pos^n of eye-lens is so adjusted that A'B' lies b/w optical centre of F_e of eye-lens. A virtual & magnified image A''B'' is seen by the eye held close to eye-lens. The adjustments are so made that A''B'' is at least distance of distinct vision (D) from the eye.

$$\underline{V_e = D}$$

β - Visual Angle formed by image A''B''

$$\tan\beta \approx \beta = \frac{A'B'}{u_e}$$

As $\left(m = \frac{v}{u} = \frac{h'}{h}\right)$

$\therefore$ m of objective lens, $m_o = \frac{v_o}{-u_o} = -\frac{A'B'}{AB}$

$$\Rightarrow \frac{v_o}{u_o} = \frac{A'B'}{AB} \Rightarrow A'B' = \frac{v_o}{u_o}AB = \frac{v_o}{u_o} \times h_o$$

As, $\beta = \frac{A'B'}{u_e} = \frac{v_o}{u_o} \times \frac{h_o}{u_e}$

Magnification of Microscope, $m = \frac{\beta}{\alpha} = \frac{\frac{v_o}{u_o} \times \frac{h_o}{u_e}}{\frac{h_o}{D}} = \left(\frac{v_o}{u_o}\right)\left(\frac{D}{u_e}\right)$

$\boxed{M = m_o \times m_e}$

As m of eye piece, $m_e = \frac{v_e}{-u_e} = \frac{D}{-u_e}$

$\therefore$ Mag. of microscope, $m = \left(\frac{v_o}{u_o}\right)\left(\frac{D}{u_e}\right) = m_o \times m_e$

Case-1: Max magnification:- Final img should be at D by eye-piece.

$u = -u_e$

$v = -D$

$f = +f_e$

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

$$\Rightarrow \frac{1}{f_e} = \frac{1}{-D} - \frac{1}{-u_e}$$

$$\Rightarrow \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D} = \frac{1}{D}\left(\frac{D}{f_e} + 1\right)$$

$$\therefore m_e = \frac{D}{u_e} = \left(1 + \frac{D}{f_e}\right)$$

$$M = m_o \times m_e = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right)$$

Case-2: Min. magnification Final Image should be formed at ∞ by eye-piece. $\therefore u = -u_e$, $v = \infty$, $f = f_e$

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

$$\Rightarrow \frac{1}{f_e} = \frac{1}{\infty} - \frac{1}{-u_e}$$

$$\Rightarrow \frac{1}{u_e} = \frac{1}{f_e}$$

$$\therefore m_e = \frac{D}{u_e} = \frac{D}{f_e}$$

$$\therefore M = m_o \times m_e = \left(\frac{v_o}{u_o}\right)\left(\frac{D}{f_e}\right)$$

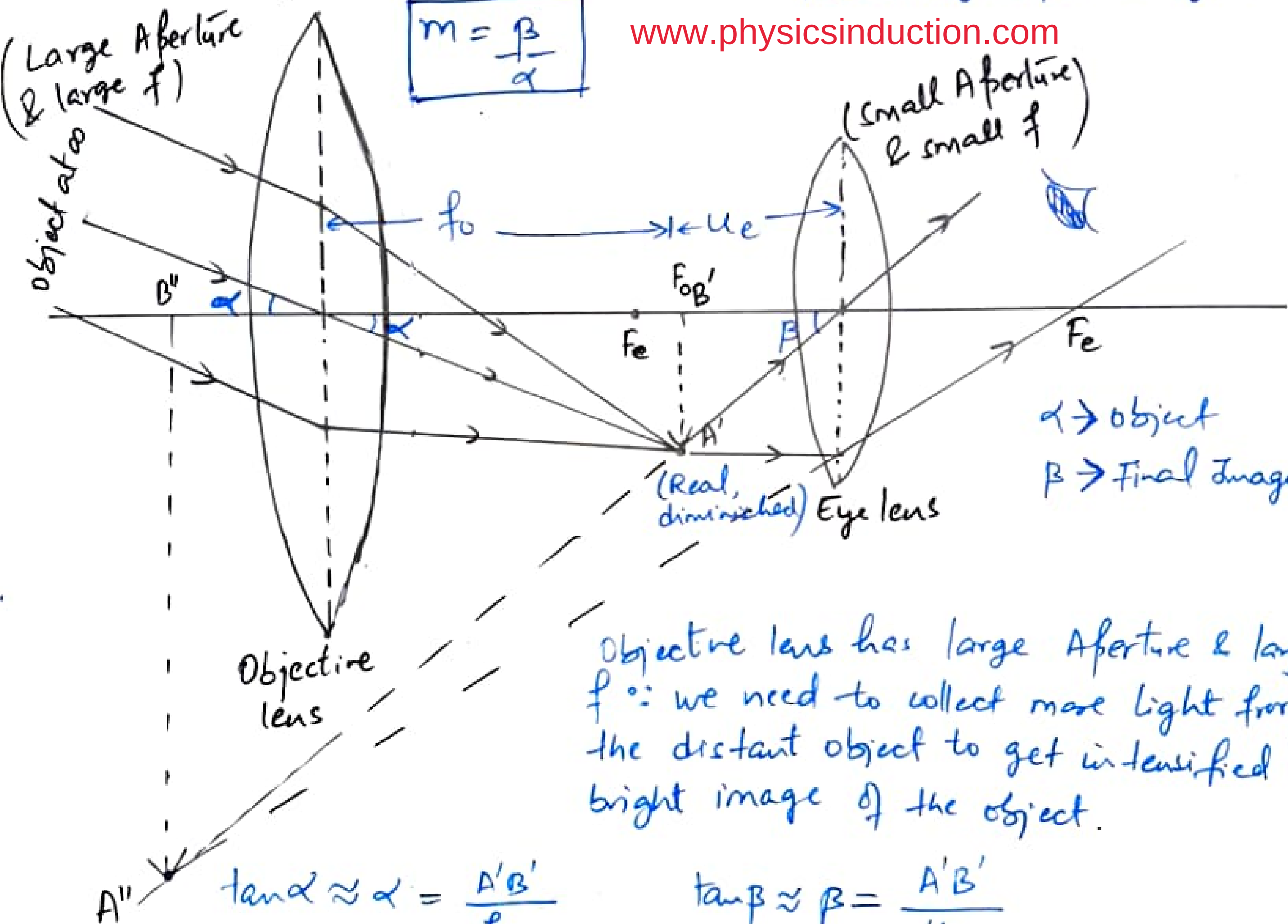
(2) THE TELESCOPE :- It's used for observing distinct images of distants object (heavenly bodies like stars, planets etc.)

2 types — Refracting type telescope
— Reflecting type telescope → Cassegrainian telescope.
→ Newtonian Reflecting type telescope

Refracting Telescope :- → Astronomical Telescope

Magnifying Power of Telescope, $m = \dfrac{\text{Visual Angle formed by final Img}}{\text{Visual Angle formed by object}}$

$$\boxed{m = \frac{\beta}{\alpha}}$$



α → object
β → Final Image

Objective lens has large Aperture & large f ∵ we need to collect more light from the distant object to get intensified & bright image of the object.

$$\tan\alpha \approx \alpha = \frac{A'B'}{f_o} \qquad \tan\beta \approx \beta = \frac{A'B'}{u_e}$$

Magnifying power, $M = \dfrac{\beta}{\alpha} = \dfrac{\frac{A'B'}{u_e}}{\frac{A'B'}{f_o}} = \boxed{\dfrac{f_o}{u_e}}$

Case-1 : Maximum Magnification ← strained Eye

final Image by eye-piece will be at D (least dist. of distinct vision)

$v = -D$, $u = -u_e$ $f = +f_e$ As, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$$\therefore \frac{1}{f_e} = \frac{1}{-D} - \frac{1}{-u_e} \Rightarrow \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D}$$

$$\therefore m = \frac{f_o}{u_e} = f_o\left(\frac{1}{f_e} + \frac{1}{D}\right) = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$

$$m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Case-2 :- Normal Adjustment (Relaxed Eye : final Image - ∞ by eye piece)

Minimum Magnification

$u = -u_e$, $V = \infty$, $f = +f_e$

As $\frac{1}{f} = \frac{1}{V} - \frac{1}{u} \Rightarrow \frac{1}{f_e} = \frac{1}{\infty} - \frac{1}{-u_e} \Rightarrow \frac{1}{f_e} = \frac{1}{u_e}$

$\therefore m = \frac{f_o}{u_e} = \frac{f_o}{f_e}$ $\quad$ $m = \frac{f_o}{f_e}$

Length of Telescope :- $l = |f_o| + |u_e|$

In case 2 : $l = |f_o| + |f_e|$ $\quad \because u_e = f_e$

Problems associated with large Objective lens :-

→ difficult to manufacture , → costly , → difficult to get placed mechanically

→ spherical Abbersation. (due to shape - lens & mirror)

→ chromatic Abberation