Physics

By

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Class:10+2

Unit:VI

Topic: Ray Optics

Chapter-6: Ray Optics and Optical Instruments

Ray Optics: Reflection of light, spherical mirrors, mirror formula. Refraction of light, Total internal reflection and its applications, optical fibres, Refraction at spherical surfaces, lenses, thin lens formula, lensmaker's formula. Magnification, power of a lens, combination of thin lenses in contact, combination of a lens and a mirror. Refraction and dispersion of light through a prism.

Scattering of light - Blue colour of sky and reddish appearance of the sun at sunrise and sunset.

Optical instruments: Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.

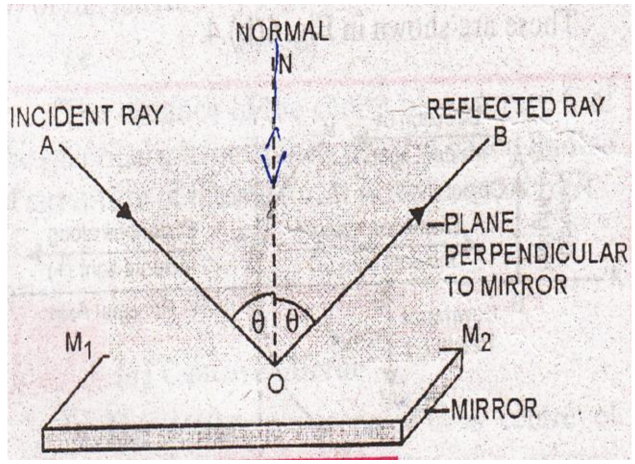
Ray optics (Reflection)

Q1. (a) What are laws of reflection?

(b) An object of height 3 cm is at 5 cm from a plane mirror, find its image and comment regarding size, orientation etc.

Ans: (a) 1. ∠i = ∠r

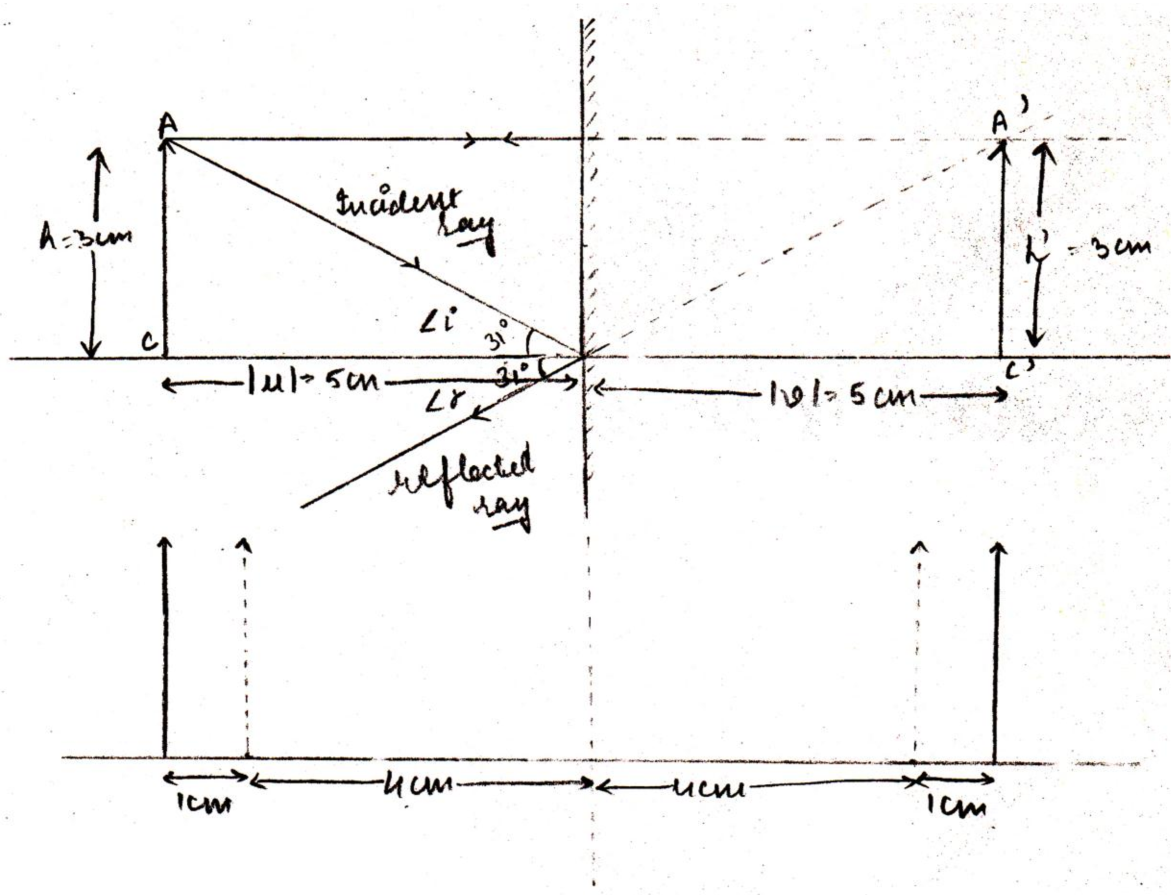
2. Incident ray, Normal and Reflected ray all lie in a same plane .



(b) <u>Given:</u>

Object distance = 5cm

Height of object = 3cm



Practical	**Theory**
u = - 5 cm	$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$
v =? = +5 cm	$\frac{1}{v} + \frac{1}{-5} = \frac{1}{\infty}$
h = + 3 cm	$\boxed{v = 5 \text{ cm}}$
h' = ? = + 3cm	

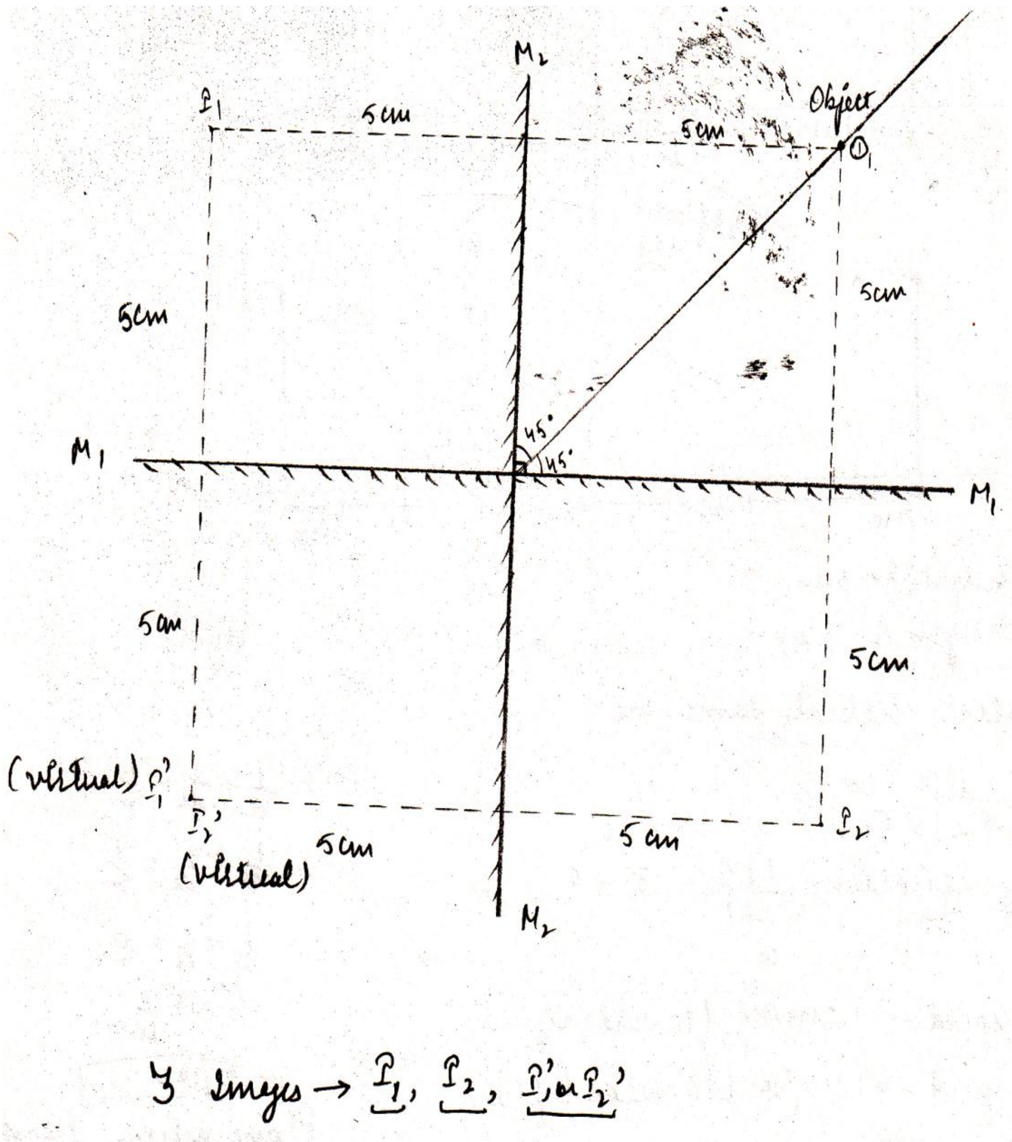
$$|m| = \frac{|h'|}{|h|} = \frac{|v|}{|u|} = \frac{5}{5} = 1$$

$$\boxed{|m| = +1}$$

Nature:-
Image formed is Erect, virtual and of low intensity i.e diminished.

Q2. An object is placed at 5 cm from two right angled mirrors placed in a corner. Find number of images formed. How many of the images are free from left right problem.

Ans: **<u>Practical</u>**



No of images formed = 3

<u>Theory</u>

$$\frac{360°}{\theta°} = \frac{360°}{90°} = 4$$

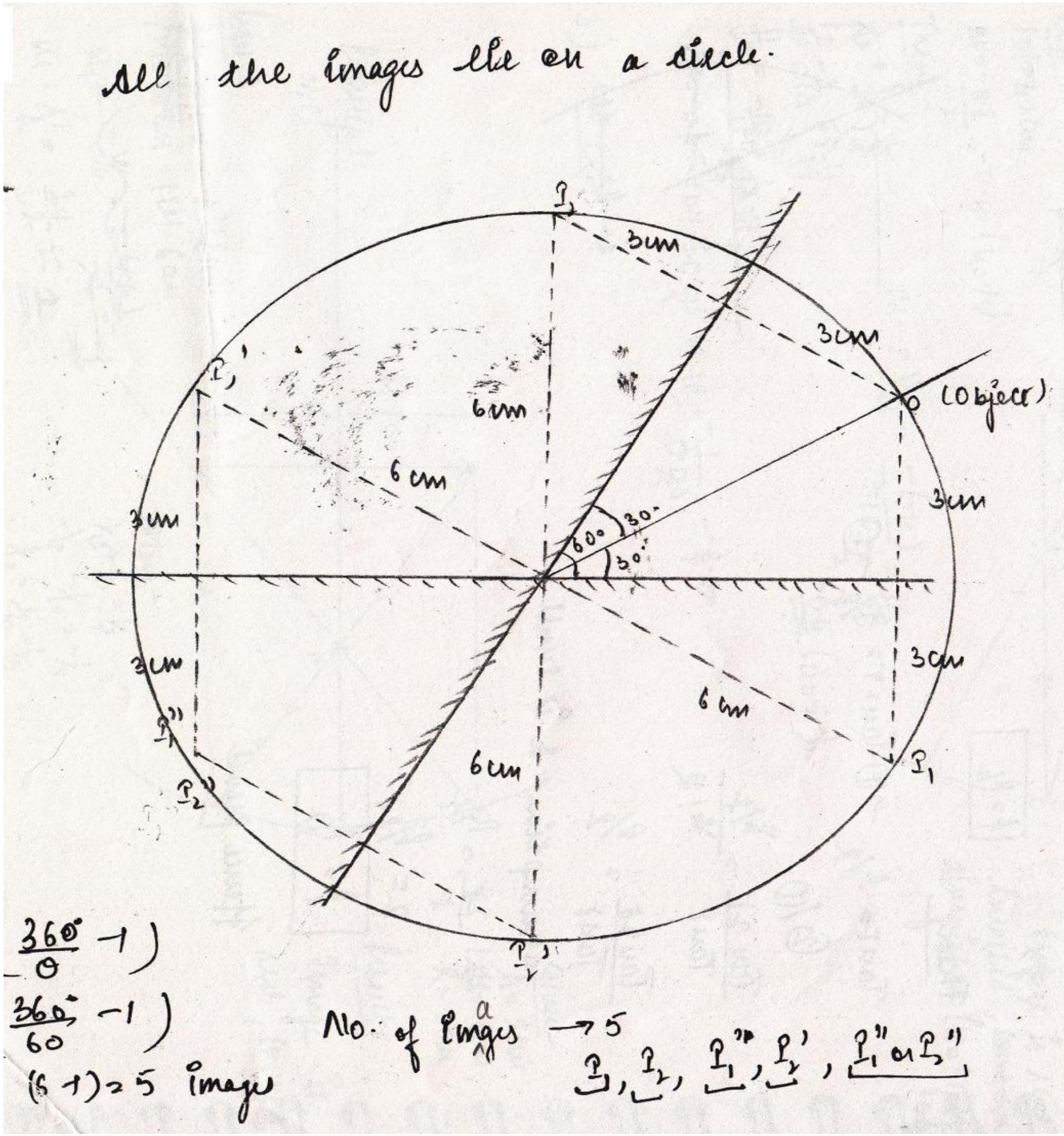
No of images = 4 -1 =3

Object and images lie on “circle”.

Image I_3 is free from left right problem.

Q3. An object is placed symmetrically in between two mirrors inclined at 60° to each other object distance is 5 cm from cross- section of mirrors. Find the number of images formed?

Ans: **<u>Practical</u>**



No of images = 5

<u>Theory</u>

$$\text{No of images} = \left(\frac{360}{\theta} - 1\right)$$

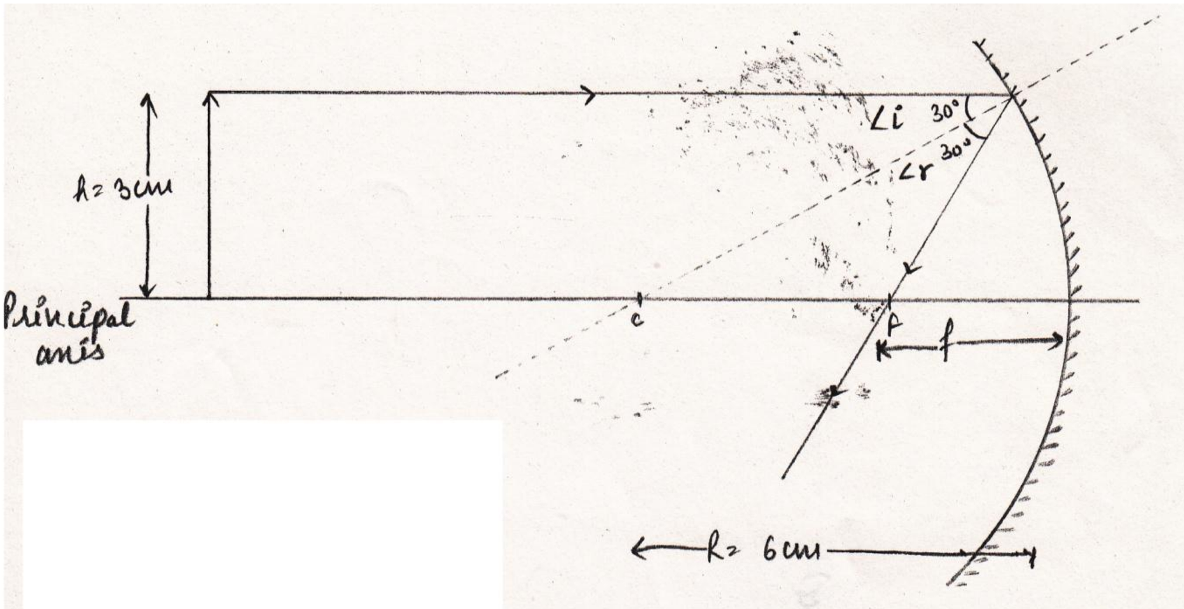
$$= \frac{360}{60} - 1$$

$$= 6-1 = 5$$

Object and images lies on "circle".

Q4. Prove $f = \frac{R}{2}$ for concave mirror?

Ans: **Practical**



R = 6 cm

f (Measure) = 2.6 cm

For small angle
of incidence

$f \simeq 3\text{ cm} \simeq \frac{R}{2}$

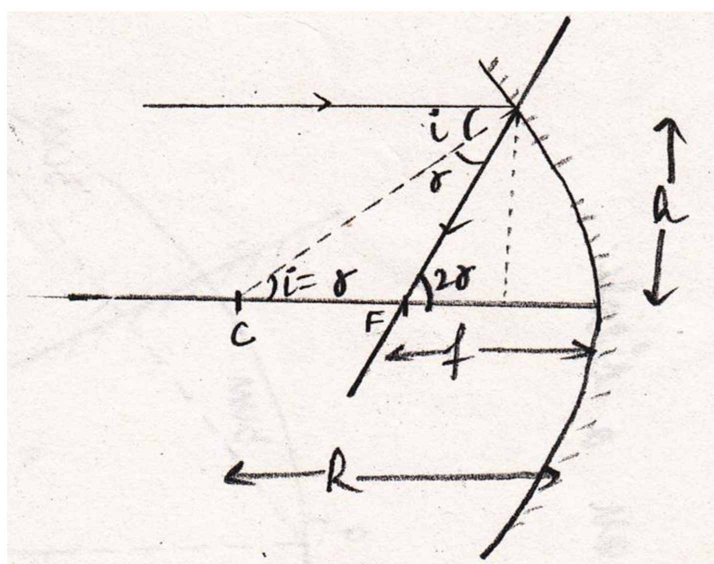
Theory

1. e = 2i
2. If e and i are small $\begin{bmatrix} Tan\ i = i \\ Tan\ e = e \end{bmatrix}$

Tan e = 2 Tan i

$\frac{PM}{f} = 2\left(\frac{PM}{R}\right)$

$\boxed{f = \frac{R}{2}}$



Q5. a) Prove mirror equation.

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

b) Magnification, m = $\frac{-v}{u}$ = $|m|$ = $\frac{|v|}{|u|}$

Ans: Practical:

Given $u = -10$

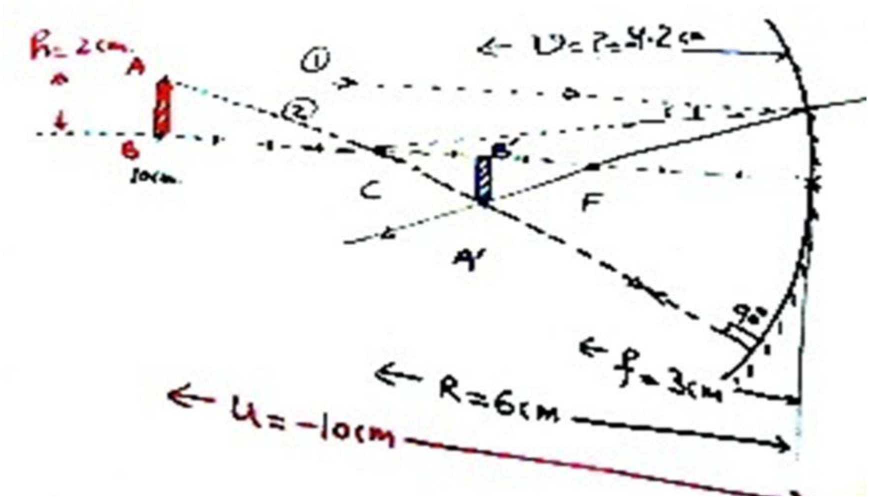
$h = 2\ cm$

By measurement

V = - 4.2 cm

$|m|$ = $\frac{|h'|}{|h|}$= $\frac{1cm}{2\ cm}$ =0.5

m = - 0.5



Formula

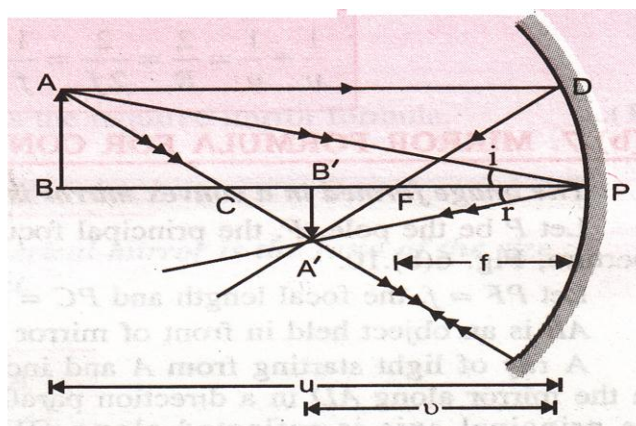
$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$\frac{1}{v}+\frac{1}{-10}=\frac{1}{-3}$$

v = - 4.2 cm

m = $\frac{-v}{u}$ = $\frac{-4.2}{10}$ = - 0.42

Theory



Step-1: Δ ABC & Δ $A'B'C$

Tan θ = $\frac{h}{u-R}$ = $\frac{h'}{R-v}$ ———— (1)

Step-2: Tan i = $\frac{h}{u}$ = $\frac{h'}{v}$ ———— (2)

Step-3: $\frac{h}{h'}$ = $\boxed{\frac{u-R}{R-v}=\frac{u}{v}}$

$$uv - Rv = Ru - uv$$

$$2uv = Ru + Rv$$

Step-4: Divide both sides by uv

$$\frac{2uv}{uv}=\frac{Ru}{uv}+\frac{Rv}{uv}$$

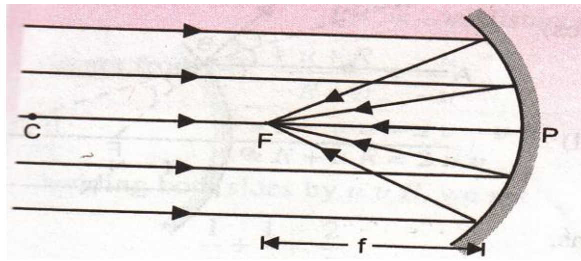
$$2=\frac{R}{v}+\frac{R}{u} \Rightarrow \frac{2}{R}=\frac{1}{v}+\frac{1}{u}$$

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

Step-5: $\frac{h}{h'}=\frac{u-R}{R-v}=\frac{u}{v}$, $|m|=\frac{|h'|}{|h|}=\frac{|v|}{|u|}$

Q6. Find image position, size etc for a concave mirror of R = 6cm for following positions. (Object size = 2 cm)

Ans: **Case I:** **object is at ∞**



$u = -\infty$

$v = ?$

Theory: $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

$\frac{1}{v} + 0 = \frac{1}{f}$

$\boxed{v = f}$

$m = \frac{|v|}{\infty} = 0$

Case II: **Object is between ∞ and C.**

u = - 10 cm

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

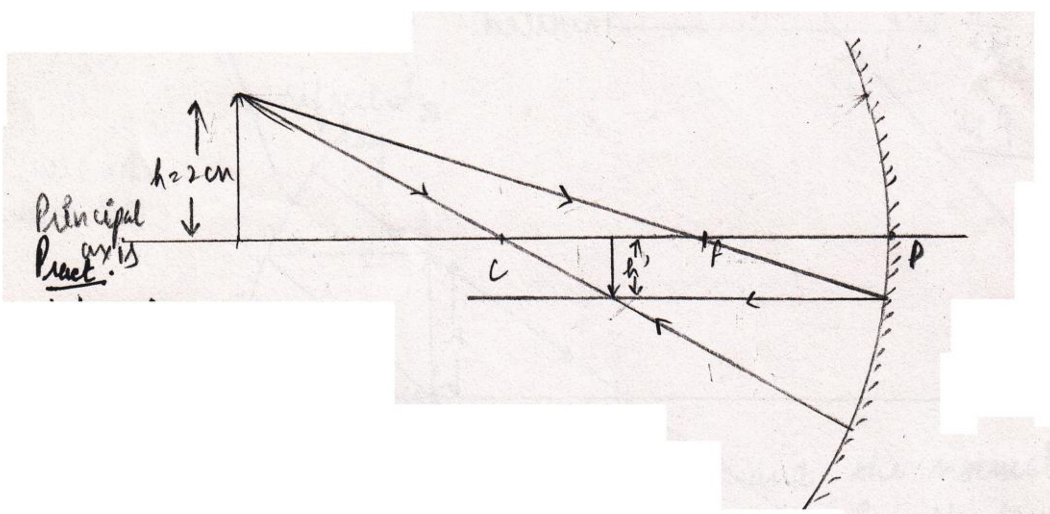
$\frac{1}{v} + \frac{1}{-10} = \frac{1}{-3}$

$\boxed{v = -4.2}$

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

$= \frac{4.2}{10} = 0.42$

m = - 0.42



<u>Case III:</u> Object at C

u = -6 cm

v = ?

<u>Theory</u> $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

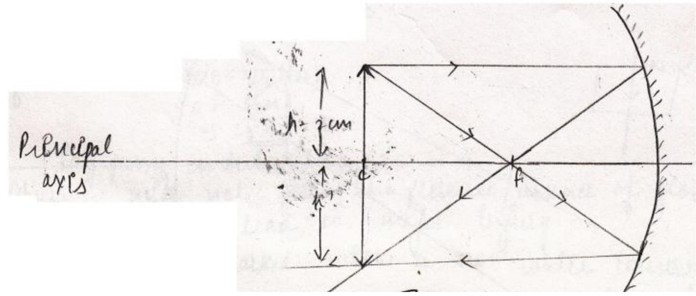
$\frac{1}{v} - \frac{1}{6} = \frac{1}{-3}$

$\boxed{v = -6 \text{ cm}}$

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

$= \frac{6}{6} = 1$

$\boxed{m = -1}$



<u>Case IV</u>: Object is between C and F

u = -5 cm

v = ?

<u>Theory</u>: $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

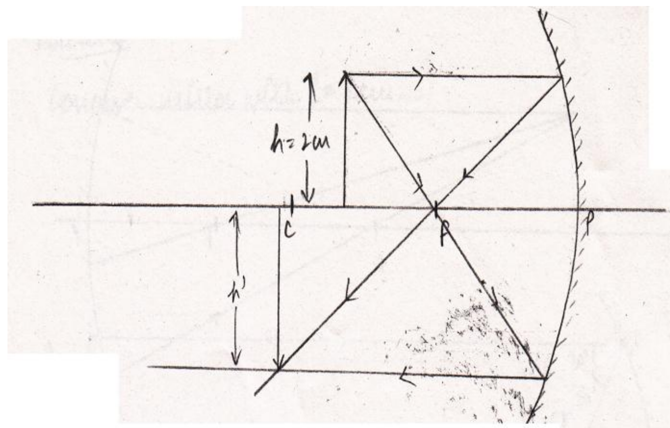
$\frac{1}{v} + \frac{1}{-5} = \frac{1}{-3}$

$\boxed{v = -7.5}$

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

$= \frac{7.5}{5} = 1.5$

$\boxed{m = -1.5}$



<u>Case V:</u> Object is at F

u = -3 cm

v =?

<u>Theory:</u> $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

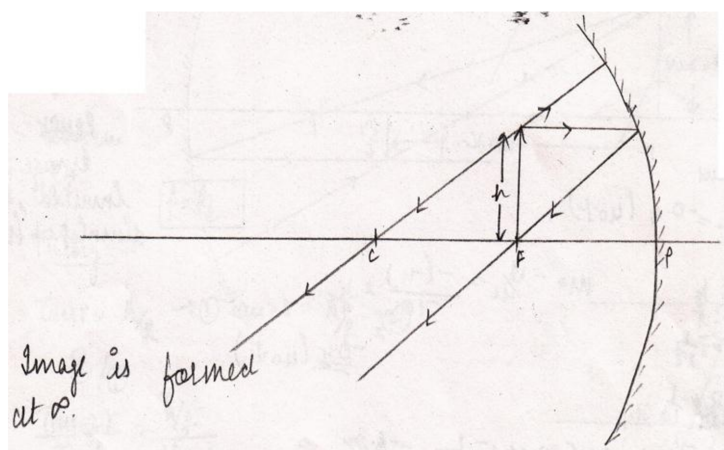
$\frac{1}{v} + \frac{1}{-3} = \frac{1}{-3}$

$\boxed{V = -\infty}$

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

$= \frac{\infty}{3}$

$m = \infty$



Case VI: Object is between F and P

h = 2 cm

u = - 2.3 cm

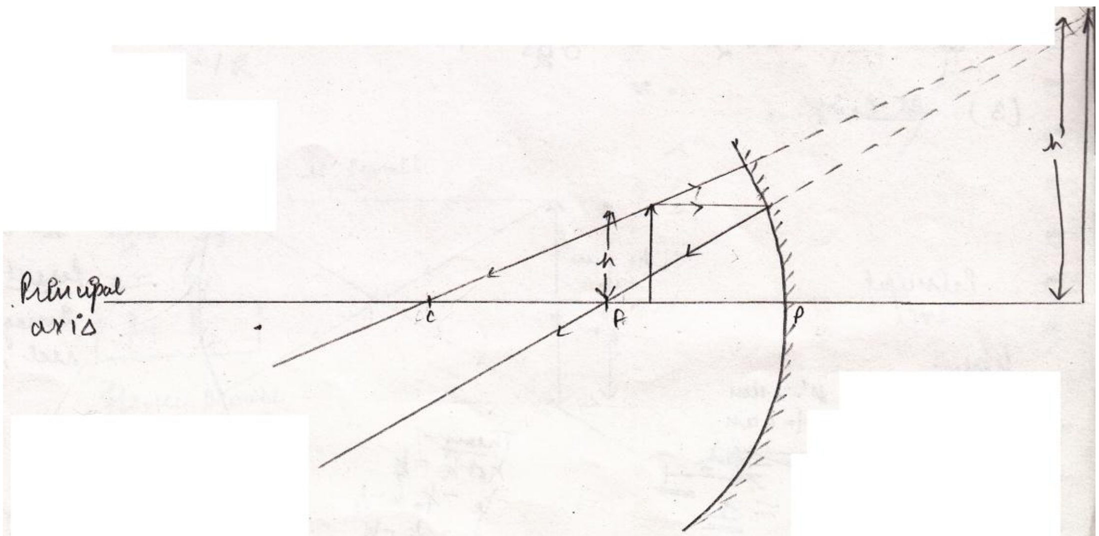
Practical

h' = 6 cm

m = $\frac{h'}{h}$ = $\frac{6}{2}$ =3

$|v|$ = 5.6 cm

Image formed is virtual, erect and magnified.



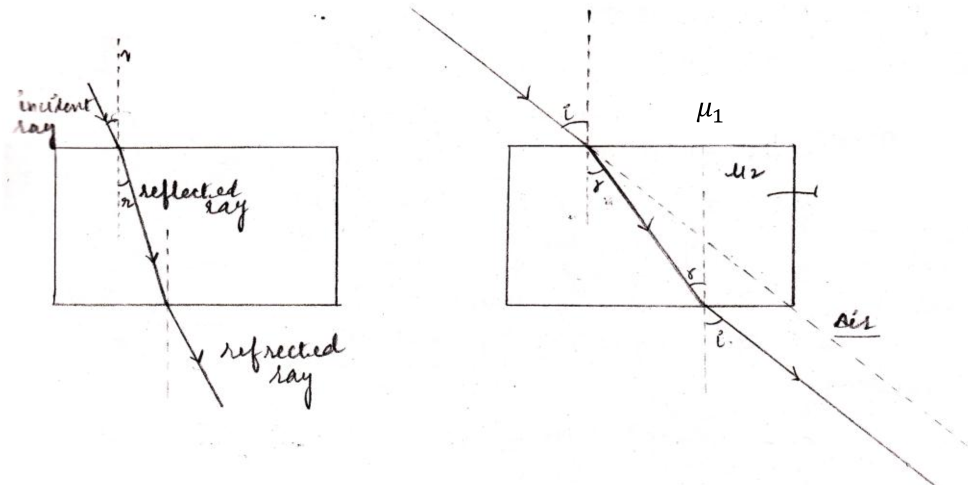
Refraction At Plane Surface

Q7. a) What is Refraction?
b) State laws of Refraction.

Ans: a) Bending of a ray as it moves from one medium to another ($i \neq 0$)

or

Direction of propagation of an obliquely incident ray of light that enters the other medium, changes at the interface of the 2 media, this phenomenon is known as refraction of light.



b) **Laws of refraction:-**

1. The incident ray, the refracted ray and the normal to the interface at the point of incidence, all lie in the same plane .
2. The ratio of the sine of the angle of incidence to the sine of angle of refraction is constant .

$$\boxed{\mu_1 \sin i = \mu_2 \sin r}$$

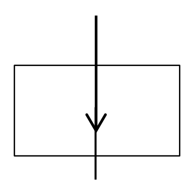
or $\mu \sin i$ = constant

Discussion:-

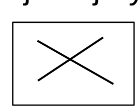
If $i = 0 \Rightarrow \mu_1 \sin 0 = \mu_2 \sin r$

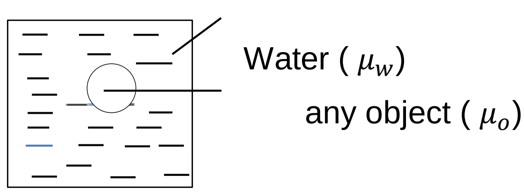
$0 = \sin r$

$\Rightarrow \angle r = 0$



Ray passes undeviated. Observer will not feel the presence / absence of glass & will move as such & so can lead to major injury. So, glass are marked with cross while construction.





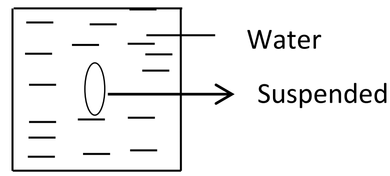
If $\mu_w = \mu_o$ then this object Will be invisible in water.

Q8. What do you mean by Mechanical density, Optical density and accoustic density?

Ans: a) <u>Mechanical Density</u> :-

$$\rho_{Mechanical} = \frac{Mass}{Volume}$$

$$\rho_{water} = 1\ kg\ /ltr$$
$$\rho_{iron} = \rho_{water} \times 6$$
$$\rho_{ice} = P_{water} \times 0.9$$



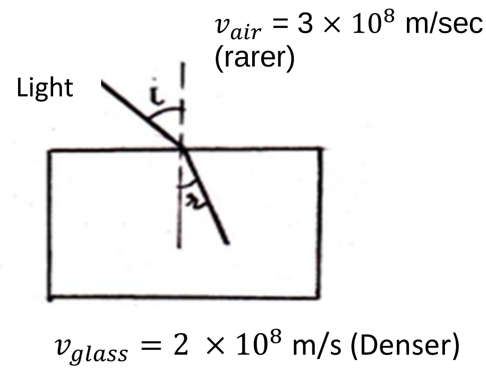
b) <u>Optical Density:-</u>

$$\boxed{\mu = \frac{c}{v}}$$

Where $\mu \rightarrow$ refractive Index of material

c $\rightarrow$ speed of light in vacuum (free sp

v $\rightarrow$ speed of light in the material



<u>For glass:-</u>

$$1.5 = \frac{3 \times 10^8}{v}$$

$$c = 3 \times 10^8 \text{ m/s}$$

$$v_{\text{glass}} = 2 \times 10^8 \text{ m/s}$$

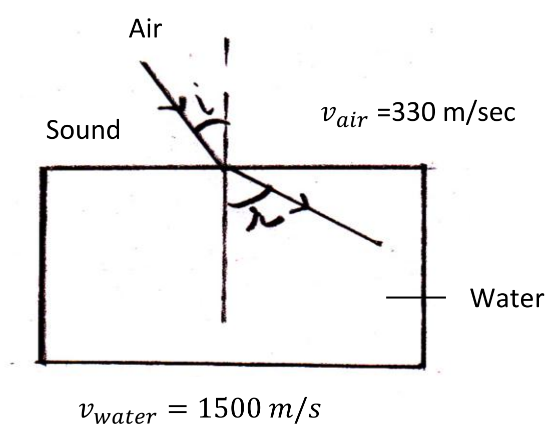
$$v_{glass} < v_{air}$$

Optical density of glass is more then optical density of air.

c) <u>Accoustic Density:-</u> Speed of sound is more for water i.e

$$v_{air} < v_{water}$$

Air is denser than water (accoustic)



Q9. A ray of light hits a glass plate of thickness 6 cm at incident angle 45°. Find lateral shift. what about deviation produced?

Ans: **Practical:**

Given: t = 6cm, i = 45°, μ_g = 1.4

Step I: Draw AB with i = 45°

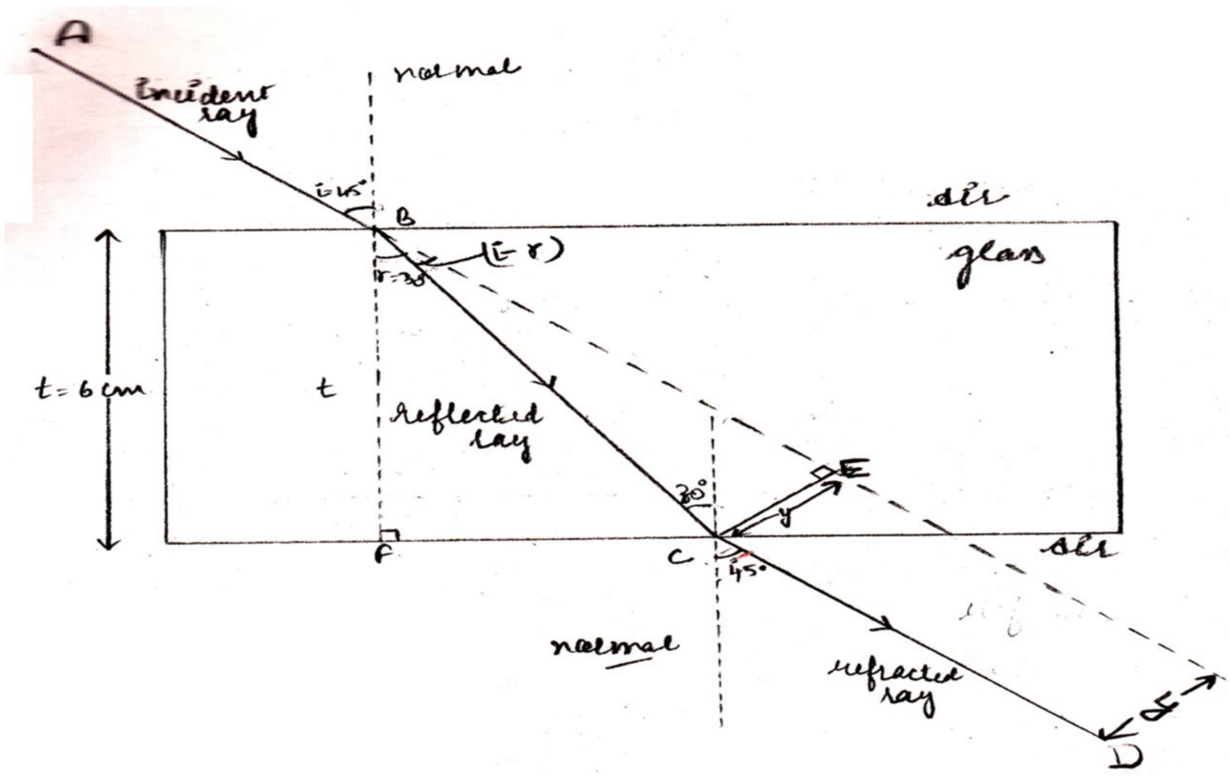
Step II: μ_{air} Sin i = $\mu_g \, sin\, r$

1× Sin 45° = 1.4 sin r

$\frac{1}{\sqrt{2}} = \sqrt{2}$ sin r

Sin r = $\frac{1}{2}$

r = 30°



Step III: Refraction at C

Step IV: Measure y = 1.8 cm

Theory: -

In Δ BCE,

Sin $(i - r)$ = $\frac{CE}{BC}$

$\Rightarrow$ BC = $\frac{CE}{\sin(i-r)}$

BC = $\frac{y}{\sin(i-r)} \rightarrow (1)$

In Δ BFC

cos r = $\frac{BF}{BC}$

cos r = $\frac{t}{BC}$

$\Rightarrow$ BC = $\frac{t}{\cos r} \rightarrow (2)$

From (1) and (2)

$$\frac{y}{\sin(i-r)} = \frac{t}{\cos r}$$

$$\Rightarrow \boxed{y = \frac{\sin(i-r)t}{\cos r}}$$ where $y \rightarrow$ lateral shift, t $\rightarrow$ thickness

Confirmation :-

$$y = \frac{\sin(45° - 30°)\ 6}{\cos 30°}$$

$$y = \frac{\sin 15° \times 6}{\cos 30°}$$

$$y = \frac{0.26 \times 6 \times 2}{\sqrt{3}}$$

$$y = \frac{26 \times 6 \times 2 \times 100}{100 \times 1.72} = 1.8 \text{ cm}$$

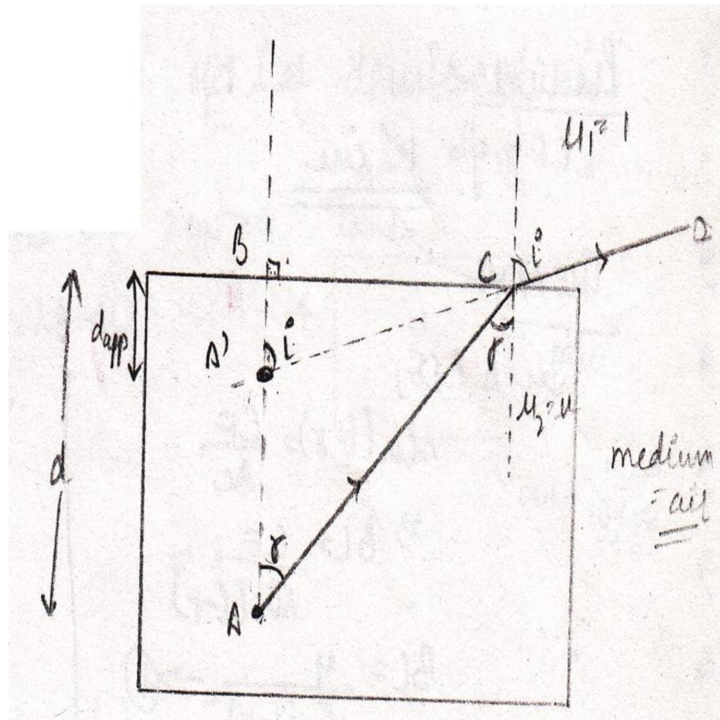
Q10. Derive expression for apparent depth (d_{app}).

Or

Prove $\boxed{d_{app} = \frac{d}{\mu}}$

Ans: **<u>Step I:</u>** In $\Delta\, ABC$

$$Tan\, r = \frac{BC}{AB} \quad \text{———————} \quad (1)$$



<u>Step II</u> In $\Delta\, A'BC$

$$Tan\, i = \frac{BC}{A'B}$$

$$Tan\, i = \frac{BC}{d_{app}} \quad \text{———————} \quad (2)$$

<u>Step III</u>: Divide (1) by (2)

$$\frac{Tan\, r}{Tan\, i} = \frac{d_{app}}{d}$$

$$d_{app} = d \times \left(\frac{Tan\, r}{Tan\, i}\right)$$

$$\simeq d \left(\frac{\sin r}{\sin i}\right) \qquad \left[\begin{array}{c} \because For\ small\ i, r \\ sin\ i \approx Tan\ i \\ \sin r \approx Tan\ r \end{array}\right]$$

$$d_{app} = \frac{d}{\mu} \qquad [\because\ \mu \sin r = 1 \sin i]$$

<u>Error</u> = d - d_{app} = d - $\frac{d}{\mu}$

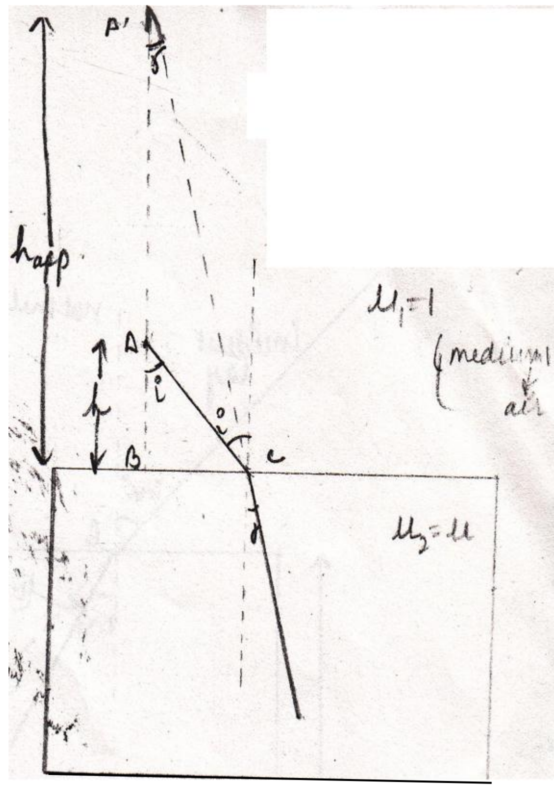
Q11. Derive expression for apparent height. (h_{app}).

Or

Prove $\boxed{h_{app} = \mu \text{ h}}$

Ans. **Step I:** In Δ ABC

$$Tan\ i = \frac{BC}{h} \text{ ———— (1)}$$



Step II: In Δ $A'BC$

$$Tan\, r = \frac{BC}{h_{app}} \text{ ———— (2)}$$

Step III: Divide (1) by (2)

$$\frac{Tani}{Tan\, r} = \frac{h_{app}}{h}$$

$$h_{app} = \text{h} \left(\frac{Tan\ i}{\text{Tan}\, r}\right)$$

$$h_{app} = \text{h} \left(\frac{sin\ i}{\sin r}\right) \quad \left[\begin{array}{c} \because For\ small\ i, r \\ \sin i = Tani \\ \sin r \approx Tan\, r \\ \mu \sin r = 1 \sin i \end{array}\right]$$

$$\boxed{h_{app} = h\mu}$$

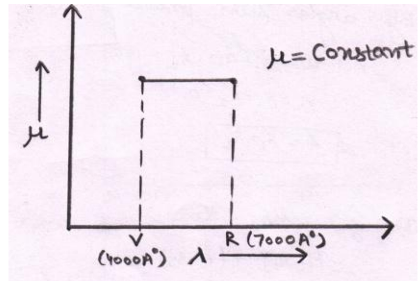
Error = $\mu h - h = (\mu - 1)h$

Q12. Discuss variation of μ with λ

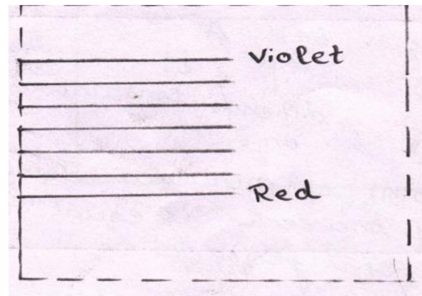
Ans: 1) <u>Non dispersive media:</u>

$$\mu = \frac{c}{v}$$

$$v = \frac{c}{\mu}$$



For Non- dispersive media all colours cover same distance because they have same speed.



2) <u>Dispersive Media:</u>

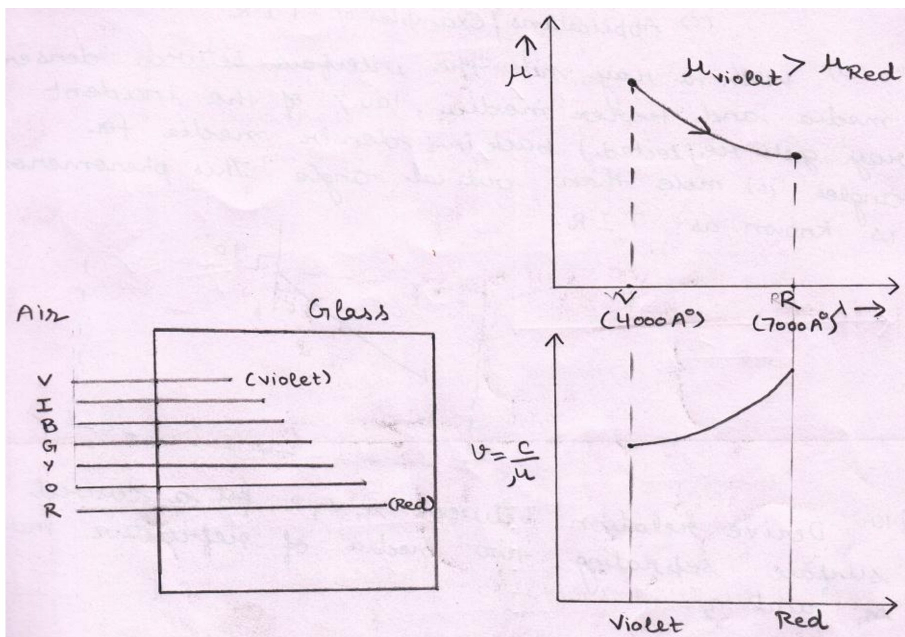
$$\mu = \frac{c}{v} \Rightarrow v = \frac{c}{\mu}$$

1. $V_{violet} = \dfrac{c}{\mu_{violet}}$

2. $V_{red} = \dfrac{c}{\mu_{red}}$

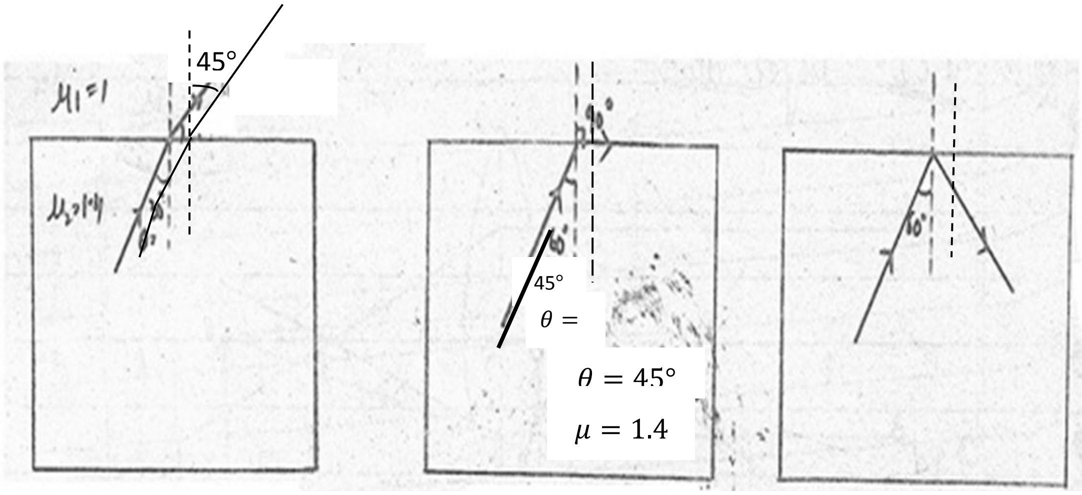
$\mu_{violet} > \mu_{red}$

$v_{violet} < v_{red}$



Q13. a) What is Total Internal Reflection or (T.I.R) and critical angle (θ_c).
b) Discuss its Examples/ Applications.

Ans: When a ray hits the interface b/w denser media and rarer media, 100% of the incident ray gets reflected back in denser media for angle (i) more than critical angle. This phenomenon is known as total internal reflection (T.I.R.)



$\mu_1 \sin i = \mu_2 \sin \theta$

(1) $\text{Sin } i = 1.4 \sin 30^\circ$

$\text{Sin } i = \sqrt{2} \times \frac{1}{2}$

$\text{Sin } i = \frac{1}{\sqrt{2}}$

$\Rightarrow \boxed{i = 45^\circ}$

1) $\sin i = 1.4 \sin 45^\circ$

$\sin i = \sqrt{2} \times \frac{1}{\sqrt{2}}$

$\sin i = 1$

$\Rightarrow \boxed{i = 90^\circ}$

For angles more than 45°, TIR is observed

Conditions for T.I.R:

1. Light should travel from denser medium to rarer medium.
2. Angle of incidence should be greater than critical angle.

Critical angle (θ_c):

It is defined as the angle of incidence in the denser medium corresponding to which angle of refraction in the rarer medium is 90°.

Relation between Refractive index and Critical angle (θ_c):

$$\mu \sin \theta_c = (1).\sin 90^\circ$$

$$\mu \sin \theta_c = 1$$

$$\boxed{\sin \theta_c = \frac{1}{\mu}}$$

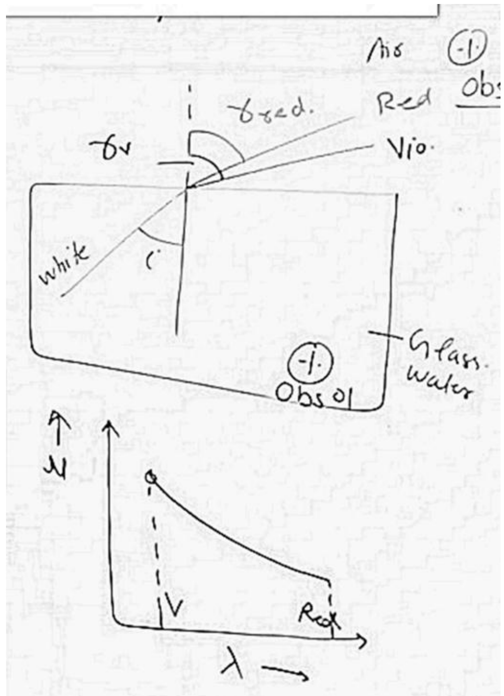
Applications

1) Different colours suffers different T.I.R:

$\mu \ \sin i = 1 \sin r$

$\mu \propto \sin r$

$r_{violet} > r_{red}$

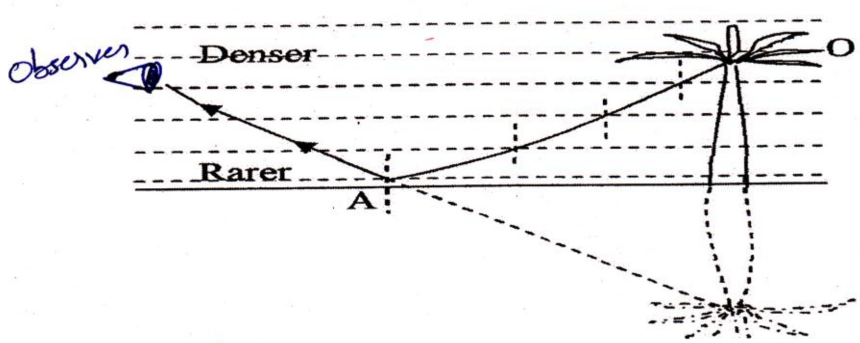


Conclusion:-

[Observer 1 will observe T.I. R of Violet First and Red last]

[Observer 2 will miss T.I.R of the violet colour first and Red last.

2) Mirage (Desert Area): A ray of light from the top O of a tree goes from denser to rarer medium bending away from normal. At a particular layer, when angle of incidence becomes greater than the critical angle, total internal reflection occurs, and the totally reflected ray reaches the observer along AE, appearing to come from I, the mirror image of O.

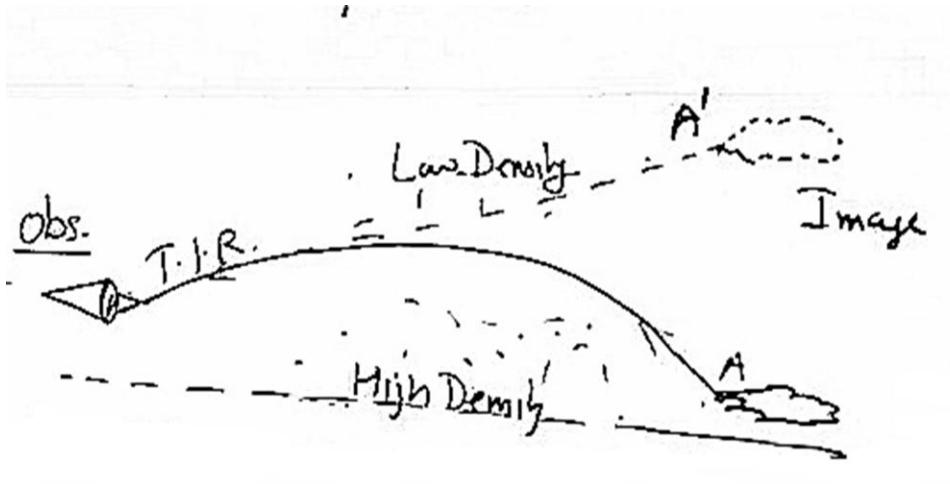


OR

$$\begin{bmatrix} Near\ surface \rightarrow \ Temperature\ is\ high, Density\ is\ low\ (Rarer) \\ Above\ surface \rightarrow Temperature\ is\ low, Density\ is\ high\ (Denser) \end{bmatrix}$$

3) <u>Looming (Polar Area):</u>

$$\begin{bmatrix} \textit{Near surface} \rightarrow \textit{Temp low} \rightarrow \textit{Density High (Denser)} \\ \textbf{Above surface} \rightarrow \textbf{Temp high} \rightarrow \textbf{Density Low (Rarer)} \end{bmatrix}$$



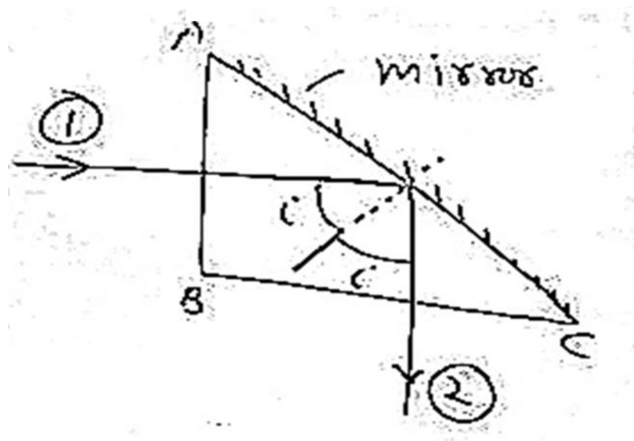
4) <u>Deviation by 90°:</u>

If $i > \theta_c$

If $i = 45^\circ$

$$\boxed{2\,i = 90^\circ}$$

Ray turns by 90°

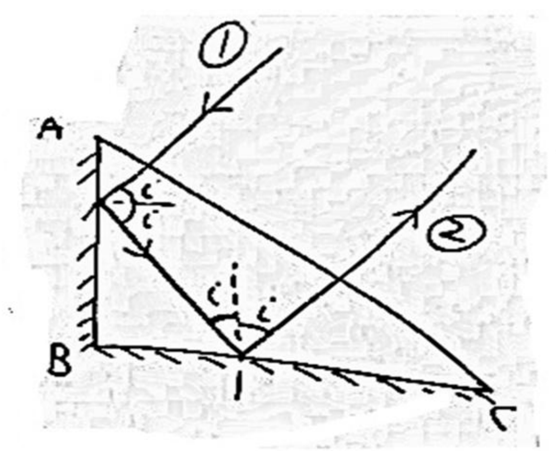


5) <u>Deviation by 180°</u>

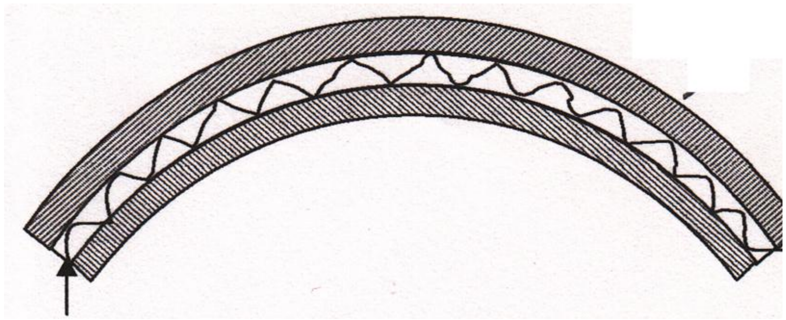
If $i > \theta_c$

T. I.R takes place at face AB and B

Turns by 180°.



6) Fibre optic: The diameter of each fibre is of the order of 10^{-4} cm with refractive index of material being of the order of 1.7.



Applications of optical fibres:

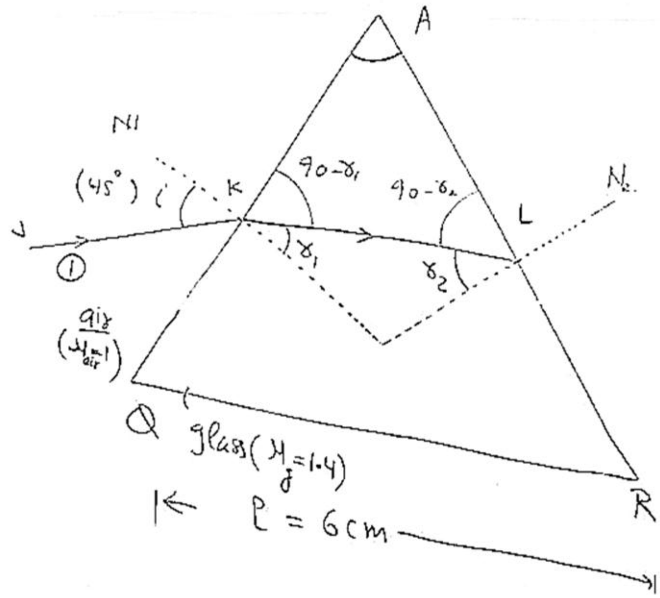
1. Used in medical and optical examination of even the inaccessible parts of an equipment or of human body.

2. Used in transmission and reception of electrical signals.

3. Used in telephone and other transmitting cables.

Q14. What is Prism? Discuss important points related to it.

Ans: 1) Relation between i and r_1:-



μ_{air} sin i = μ_g $sin\, r_1$

1 sin i = μ sin r_1

Example

Sin 45° = 1.4 sin r_1

$\frac{1}{\sqrt{2}} = \sqrt{2}$ sin r_1

sin $r_1 = \frac{1}{2}$

$r_1 = 30^\circ$

2) **Relation between r_1 and r_2:-**

In Δ AKL

$\angle A + \left(\angle 90^\circ - r_1\right) + \left(\angle 90^\circ - r_2\right) = 180$

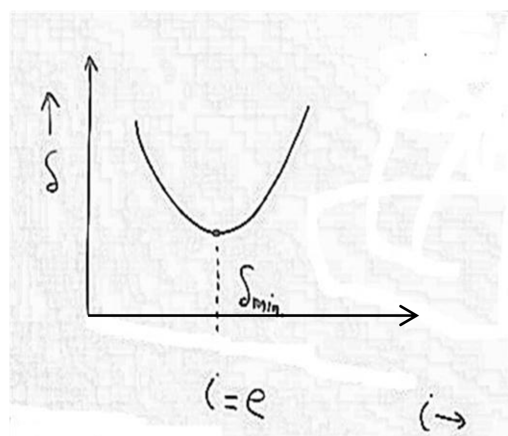
A + $180^\circ - r_1 - r_2 = 180^\circ$

$\boxed{r_1 + r_2 = A}$

Example: $30^\circ + r_2 = 60^\circ$

$r_2 = 30^\circ$

3) **Total Deviation δ:**



$\delta = \delta_1 + \delta_2$

$= (i - r_1) + (e - r_2)$

$= i + e - (r_1 + r_2)$

$\boxed{\delta = i + e - A}$

↓

function of "i"

Minimum deviation δ_m when $\boxed{i = e}$ $\boxed{r_1 = r_2}$

Ray (KL) is parallel to base QR

4) **Deviation for small angles:**

$\delta = i + e - A$

$= (\mu r_1) + (\mu r_2) - A$

$= \mu\ (r_1 + r_2) - A$

$= \mu\ A - A$

$\boxed{\boldsymbol{\delta = (\mu - 1)\ A}}$ For small angles

5) **Refractive Index (μ):**

Experiment → For minimum deviation

Step –I: $\delta_m = \delta_1 + \delta_2$

$= (i - r_1) + (e - r_2)$

$= 2i - (r_1 + r_2)$

$= 2i - A$

$$\boxed{i = \frac{\delta_m + A}{2}}$$

Step-2: $\sin i = \mu \sin r_1$

$$\mu = \frac{sini}{sinr_1}$$

$$\boxed{\boldsymbol{\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}}}$$

Example: $\mu = \dfrac{\sin\left(\frac{60^\circ + 30^\circ}{2}\right)}{\sin\frac{60^\circ}{2}}$

$= \dfrac{\sin\ 45^\circ}{\sin 30^\circ} = \sqrt{2} = 1.4$

Q15. What do you mean by Angular Dispersion and Dispersive power of a Prism?

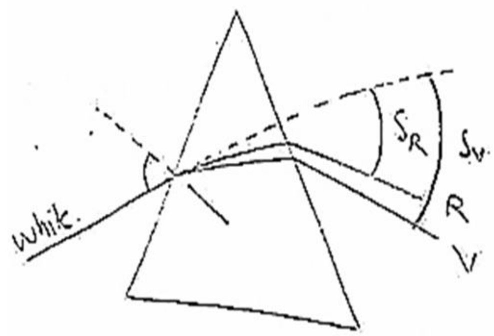
Ans: a) <u>Angular Dispersion (δ)</u> :- Difference of deviation of violet and Red colour

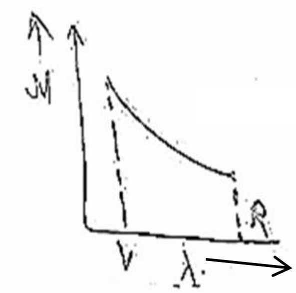
Angular Dispersion = δ_v - δ_R

$= (\mu_{v-1})\, A - (\mu_{R-1})\, A$

$\left\{ \because\ \delta = (\mu - 1)\, A \text{ for small angles} \right\}$

Angular Dispersion = $(\mu_v - \mu_R)\, A$





b) <u>Dispersive Power (ω)</u>:- Dispersive power of a prism is defined as the ratio of angular dispersion to the mean deviation produced by the prism. It is represented by ω.

Mean deviation produced by the prism,

$$\delta = (\mu - 1)\, A$$

Angular dispersion produced by the prism is

$$\delta_v - \delta_R = (\mu_v - \mu_R)\, A$$

Where, $\delta_v \rightarrow$ deviation in violet

$\delta_R \rightarrow$ deviation in red

$\mu_v \rightarrow$ refractive index of violet

$\mu_R \rightarrow$ refractive index of red.

$$\boxed{\textbf{Dispersive power} = \frac{\textbf{angular dispersion}}{\textbf{mean deviation}}}$$

$$\therefore \quad \boxed{\omega = \frac{\delta_v - \delta_R}{\delta}}$$

$$\omega = \frac{(\mu_v - 1)\, A - (\mu_r - 1)\, A}{(\mu - 1)\, A}$$

$$\omega = \frac{A[\mu_v - 1 - \mu_r + 1]}{(\mu - 1)\, A}$$

$$\boxed{\omega = \frac{\mu_v - \mu_r}{\mu - 1}}$$

$$\boxed{\omega = \frac{\mu_v - \mu_r}{\mu - 1} = \frac{d\mu}{\mu - 1}}$$

ω depends only on nature of material of the prism. But angular dispersion and mean deviation both depend on angle of prism in addition to the nature of material of the prism.

Q16. Refraction from Rarer to Denser medium at convex spherical surfaces.

Ans. **Step I:** Refraction at A

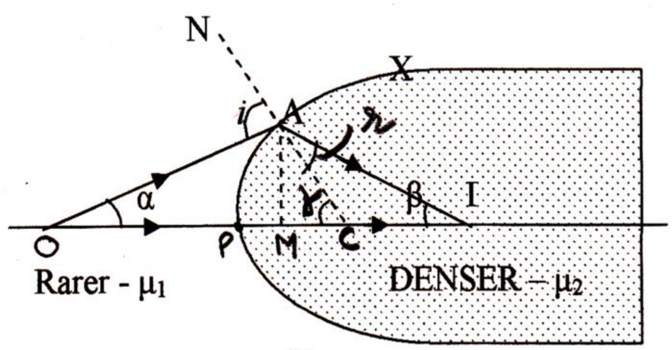
$$\mu_1 \sin i = \mu_2 \sin r$$

$$\mu_1\, i = \mu_2\, r \text{ ——————— (1)}$$

Step II: $\mu_1\,(\alpha + \gamma) = \mu\,(\gamma - \beta)$

$$\mu_1\,\alpha + \mu_2\,\beta = \mu_2\,\gamma - \mu_1\,\gamma$$

$$\mu_1\,\alpha + \mu_2\,\beta = (\mu_2 - \mu_1)\gamma \text{ ——————— (2)}$$



Step III: $\mu_1\, Tan\,\alpha + \mu_2\, Tan\,\beta = (\mu_2 - \mu_1)\, Tan\,\gamma$

$$\mu_1 \left(\frac{AM}{OM}\right) + \mu_2 \left(\frac{AM}{MI}\right) = (\mu_2 - \mu_1) \left(\frac{AM}{MC}\right)$$

$$\frac{\mu_1}{OM} + \frac{\mu_2}{MI} = \frac{\mu_2 - \mu_1}{MC}$$

$$\boxed{\frac{\mu_1}{-u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}}$$

Q17. Derive expression for Lens maker's Formula.

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

Ans: **Lens Maker's Formula:** Lens Maker's formula is a relation that connects focal length of a lens to radii of curvature of the two surfaces of the lens and refractive index of the material of the lens.

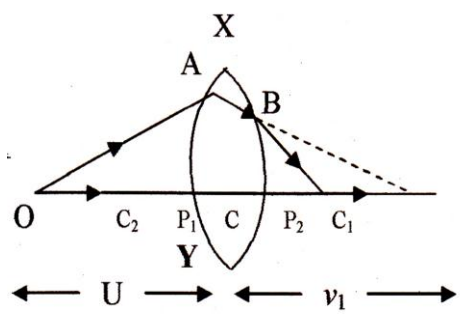
New Cartesian sign conventions:

1. Distance are measured from the optical centre of the lens.
2. Distance measured in the direction of incidence of light are taken as Positive,
3. Convex lens – f is positive. Concave lens – f is negative,

The assumptions made in the derivation are:

1. Lens is thin
2. Aperture of the lens is small.
3. Object consists only of a point
4. The incident ray and refracted ray make small angles with the principal axis of the lens.

For Convex Lens. $\frac{\mu_1}{-u} + \frac{\mu_2}{v_1} = \frac{\mu_2 - \mu_1}{R_1}$



$$\frac{-\mu_2}{v_1} + \frac{\mu_1}{u} = \frac{\mu_1 - \mu_2}{R_2} = \frac{\mu_2 - \mu_1}{-R_2}$$

Adding, we get:

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

When $u = \infty, v = f$ = focal length of the lens.

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

Or

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

Q18. What do you mean by Power of lens? Discuss Power of combination of lenses.

Ans: <u>Power of a lens</u>:-

Power of a lens is defined as the ability of the lens to converge a beam of light falling on the lens. It is measured as the reciprocal of focal length of the lens (expressed in metres)

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

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

For a converging lens, power is taken as positive and for a diverging lens, power is taken as negative

The **S.I. unit** of power is **dioptre (D)**

When f = 1 m, P = $\frac{1}{f} = \frac{1}{1}$ = 1 dioptre

Hence one dipotre is the power of a lens f focal length one metre.

<u>Combination of thin lenses in contact</u>

Two or more lenses are combined to

1. Increase the magnification of the image,
2. Make the final image erect w.r.t. the object,
3. Reduce certain aberrations (i.e defects of images by single lens)

<u>Combination of thin lenses in contact</u>

a) Both the lenses are convex

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

b) One lens is convex and the other is concave

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{-f_2} = \frac{1}{f_1} - \frac{1}{-f_2}$$

Three cases arise

a) If $f_1 = f_2$, then F = ∞ The combination would behave like a plane glass plate.

b) If $f_1 > f_2$, then F is negative. Therefore, the combination would behave as concave lens.

c) If $f_1 < f_2$, then F is positive therefore the combination would behave as a convex lens.

<u>Note</u>:-

1. Total Magnification of the Lens combination is the product of the magnifications produced by individual lenses i.e.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

In terms of power: $\mathbf{P = P_1 + P_2}$

2. If the lenses of focal lengths f_1 and f_2 are separated by a finite distance d, the focal length F of the equivalent lens is given by

$$\boldsymbol{\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}}$$

Q19. a) Explain uses of Lens formula.
b) Prove Lens formula.

Ans: $\boxed{\frac{1}{v} - \frac{1}{u} = \frac{1}{f}}$ $\boxed{|m| = \frac{|v|}{|u|}}$

<u>Case I</u>:

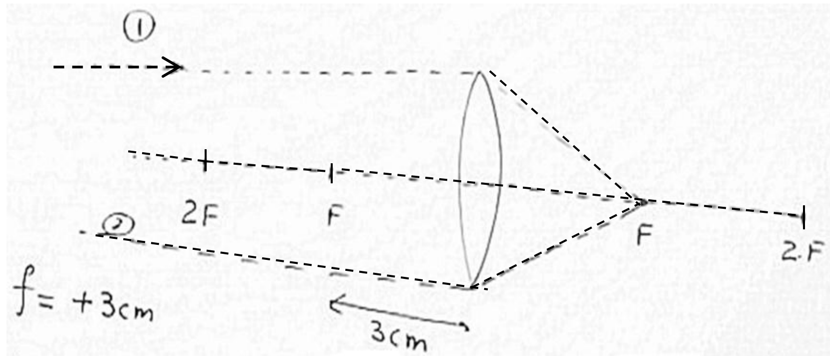
Object at ∞

<u>Practical:</u>

f = +3 cm

u = - ∞

V = ? = f = +3 cm



<u>Theory:</u>

$$\frac{1}{v} - \frac{1}{-\infty} = \frac{1}{+3}$$

$\Rightarrow v$ = + 3cm

$$|m| = \frac{|v|}{|u|} = \frac{3}{\infty} = 0$$

<u>Case II:</u>

[$-\infty$ < Object < 2F]

<u>Practical:</u>

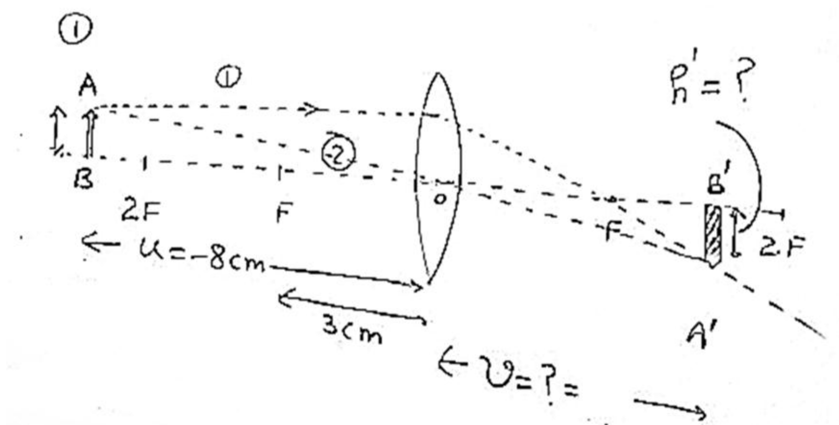
h= +2 cm

f = + 3 cm

u = - 8 cm

v_1 =? =+ 4.5 (Practically)

h' =? = −1.2 (Practically)



<u>Theory:</u>

$$\frac{1}{v} - \frac{1}{-8} = \frac{1}{+3}$$

$$\boxed{v = +4.8}$$

$$|m| = \frac{|v|}{|u|} = \frac{|h'|}{|h|}$$

$$|m| = \frac{4.8}{8} = \frac{|h'|}{|h|} = 0.6 \Rightarrow h' = -1.2$$

Case III:

(Object at 2F)

Practical:

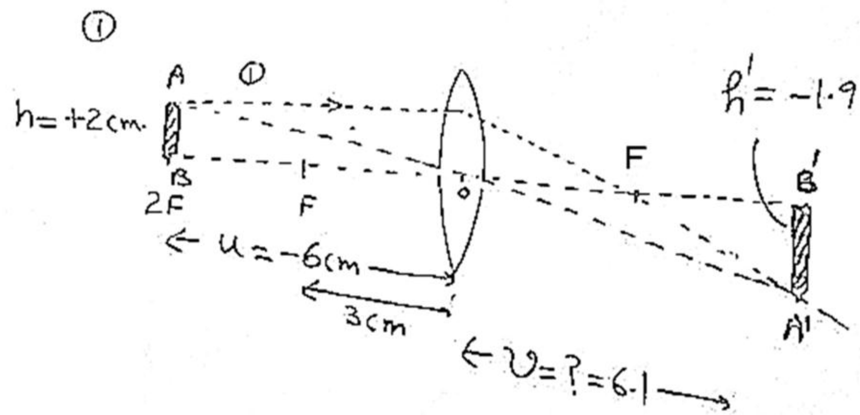
h = + 2cm

f = + 3cm

u = - 6 cm

v =? = + 6.1 (Practically)

h' = ? = – 1.9 (Practically)



$|m| = \frac{|h'|}{|h|} = \frac{1.9}{2}$ = .95

$\boxed{m = -0.95}$

Theory:

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

$$\frac{1}{v} - \frac{1}{(-6)} = \frac{1}{+3}$$

$$\boxed{v = +6 \text{ cm}}$$

$$|m| = \frac{|h'|}{|h|} = \frac{|v|}{|u|} = \frac{6}{6} = 1$$

$$1 = \frac{|h'|}{|h|} \Rightarrow |h'| = |h| = 2\text{cm}$$

Case IV:

[2F < object < F]

Practical:

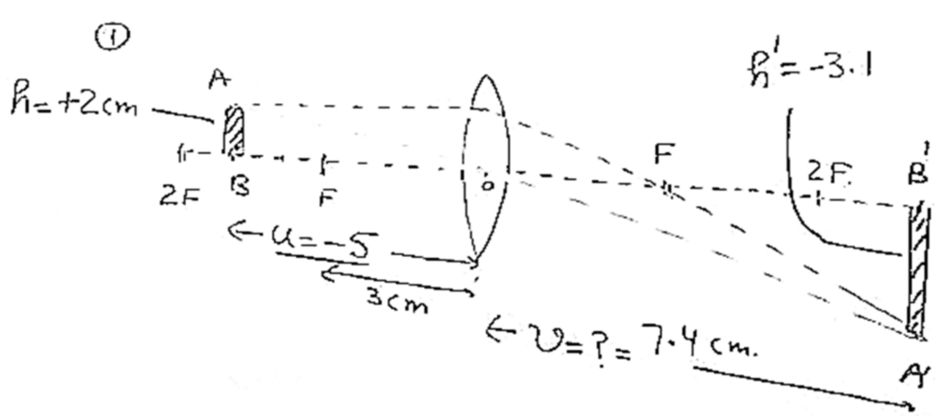
h = + 2cm

f = + 3 cm

v = -5 cm

v =? = 7.4

h' =? = - 3.1



$|m| = \frac{|h'|}{|h|} = \frac{3.1}{2.0}$ =1.55 $\Rightarrow$ $\boxed{m = -1.55}$

Theory:

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

$\frac{1}{v} - \frac{1}{-5} = \frac{1}{+3}$

$\boxed{v = 7.5 \text{ cm}}$

$|m| = \frac{|h'|}{|h|} = \frac{|v|}{|u|} = \frac{7.5}{5}$

$|m| = 1.5$

$\boxed{m = -1.5}$

$h' = 2 \times (-1.5)$

$= -3.0$ cm

Case V:

Object at F

Practical:

h = + 2 cm

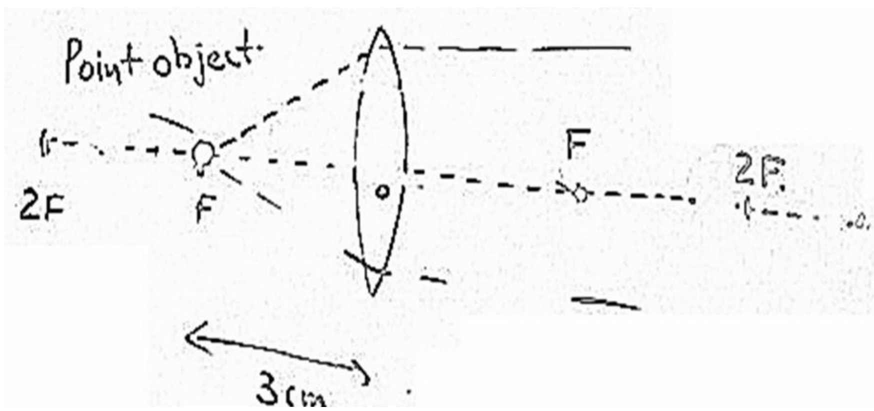
f = + 3 cm

u = -3 cm

v =? = ∞

h' = ? =

$|m| = \frac{|h'|}{|h|} = \frac{|v|}{|u|} = \infty$



Theory:

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

$\frac{1}{v} - \frac{1}{-3} = \frac{1}{+3}$

$\frac{1}{v} = 0$, $\boxed{v = \infty}$

$|m| = \frac{|h'|}{|h|} = \frac{|v|}{|u|} = \frac{\infty}{3} = \infty$

Case VI:

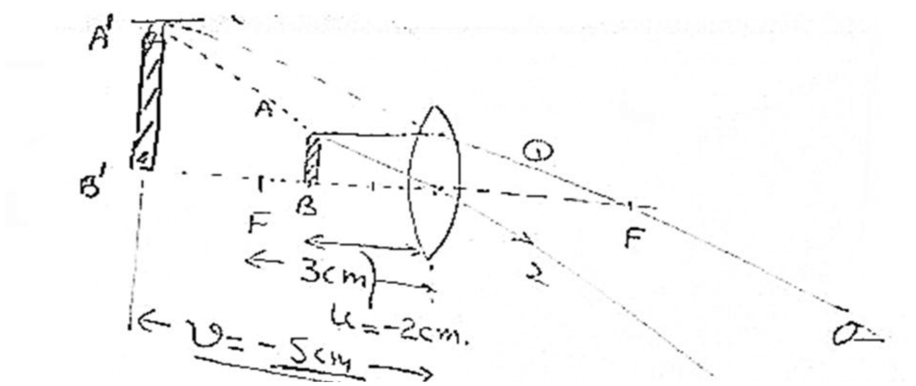
[F < Object < lens]

Practical:

h = + 2 cm

f = + 3 cm

u = - 2 cm



$\boxed{v = ? = -5 \text{ cm}}$

$h' = ? = +4.3$

$|m| = \frac{|h'|}{|h|} = \frac{4.3}{2} = \boxed{+2.15}$

Theory:

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

$\frac{1}{v} - \frac{1}{-2} = \frac{1}{+3}$

$\Rightarrow \boxed{v = -6}$

$|m| = \frac{|h'|}{|h|} = \frac{|v|}{|u|}$

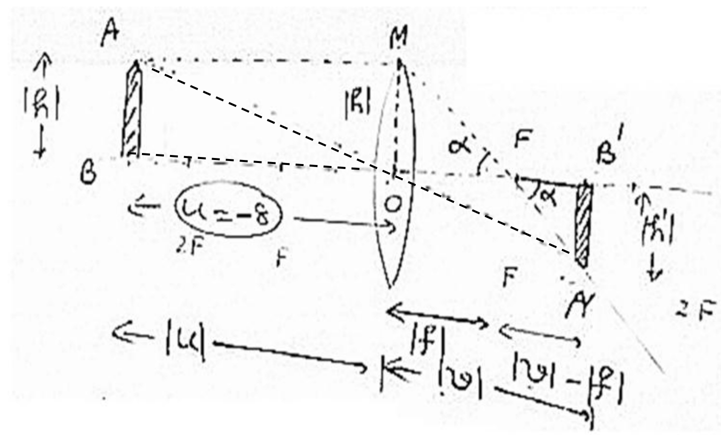
$= \frac{|6|}{|2|} = 3$

b) Proof of Lens Formula:-

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

$$\boxed{|m| = \frac{|v|}{|u|}}$$

Step I: Draw Diagram



Step II: In Δ MOF, Tan $\alpha = \frac{|MO|}{|OF|}$ ———— (1)

In Δ A' B' F, Tan $\alpha = \frac{|A'B'|}{|B'\ F|}$ ———— (2)

$$\frac{|h|}{|f|} = \frac{|h'|}{|v| - |f|}$$

$$\boxed{\frac{|h'|}{|h|} = \frac{|v| - |f|}{|f|}} \quad \text{———— (3)}$$

Step III:

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

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

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

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

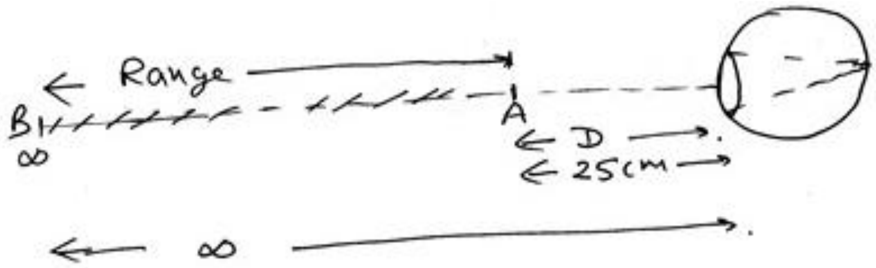
$$\frac{1}{|v|} + \frac{1}{|u|} = \frac{1}{|f|}$$

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

Q20. Discuss Important Points about eye. Explain working, Defects and Remedies of eye.

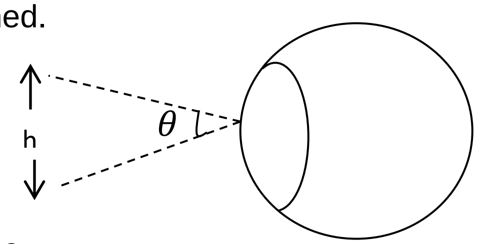
Ans: <u>Important points regarding eye:-</u>

1) <u>Range of vision</u>



Near point is at 25 cm. (A) – Relaxed Eye
Far point is at ∞   (B) – Maximum strained.

2) <u>Limit of Resolution:-</u>



$$\theta_{min} = 1' = \left(\frac{1}{60}\right) \text{ degree}$$

$$\boxed{\theta_{min} = \frac{1}{60} \times \frac{\pi}{180} \text{ rad}}$$

<u>Example</u>:- Two objects are at distance 11 km from eye. What should be the distance between the two objects to be resolved.

$$\text{Tan}\,\theta = \frac{h}{x}$$

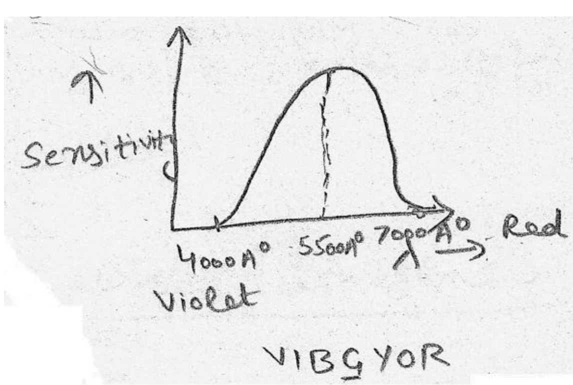
$$\theta = \frac{h}{x}$$

$$h = x\,\theta$$

$$h = 11 \times 10^3 \times \frac{1}{60} \times \frac{\pi}{180}$$

$$h = 3.2 \text{ m}$$

3) <u>Sensitivity:</u> Human eye is Maximum sensitive at 5500 A° (Yellow green)



4) Working of Eye:

For a normal eye, F lies at infinity. If the object is too close to the eye, the lens cannot curve enough to focus the image on the retina. The closest distance for which the lens can focus light on the retina is the least distance of distinct vision.

5) Defects of Eye:-

a) Myopia (Short Sightedness)

Myopia is the defect of human eye by virtue of which, the eye can see clearly the objects lying near it, but the far off objects cannot be seen distinctly, i.e, objects lying beyond a particular distance cannot be seen clearly by the eye. In this case, the far point shifts towards the eye. It is no longer at ∞. It is at F.

The two possible causes of this defect are:-

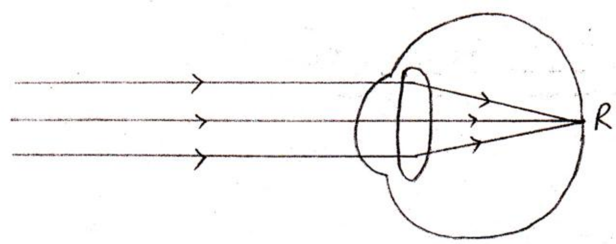
i) Increase in the size of the eye ball, i.e, distance of retina from the eye lens increases.

ii) Decrease in focal length of the eye lens, when the eye is fully relaxed.

To correct a myopic eye, the person has to use spectacles with a concave lens of suitable focal length.

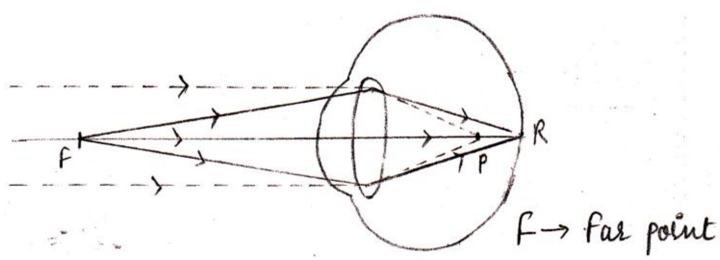
Normal Eye:-

Sharp image of object kept at infinity is formed at the retina of the eye.



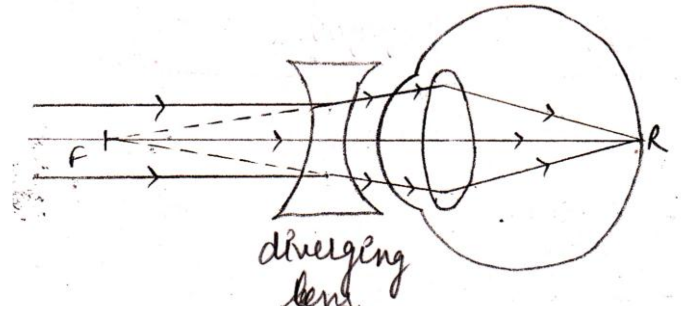
Myopic Eye:-

Blurred image of object kept at infinity is formed at point P, before the retina.



Corrected Myopic Eye:-

Person suffering from this defect has to use spectacles with a concave lens of suitable focal length. So that the sharp image of object kept at infinity is again formed on the retina of the eye.



b) Hypermetropia (Long Sightedness):-

Hypermetropia is that defect of human eye, by virtue of which the eye can see clearly the far off objects, but the nearby objects cannot be seen clearly i.e objects which are lying nearer than a certain distance cannot be seen by the eye. For a hypermetropic eye, the near point shifts away from the eye. It is no longer at 25 cm. In this defect, the image of the object is formed beyond the retina of the eye.

The two possible causes of this defect are:-

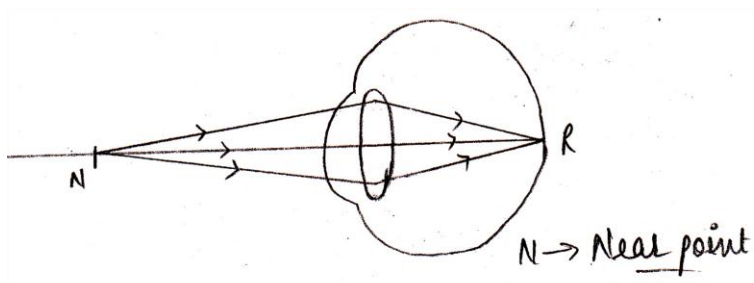
1) Contraction in the size of the eye ball, i.e, the distance of retina from the eye lens has decreased.

2) Increase in focal length of the eye lens, when the eye is fully relaxed.

To correct a hypermetropic eye, the person has to use spectacles with a convex lens of suitable focal length.

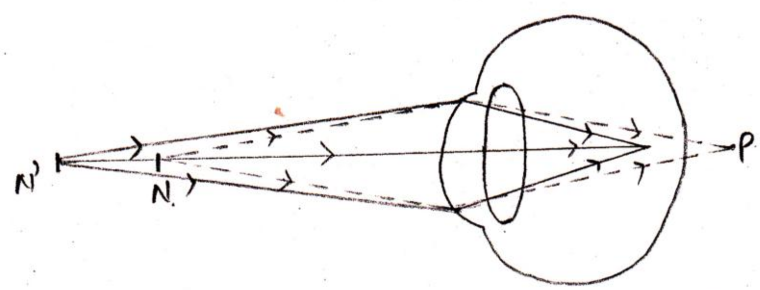
Normal Eye:-

Sharp image of object kept on the near pt. (N) is formed on the retina of the eye.



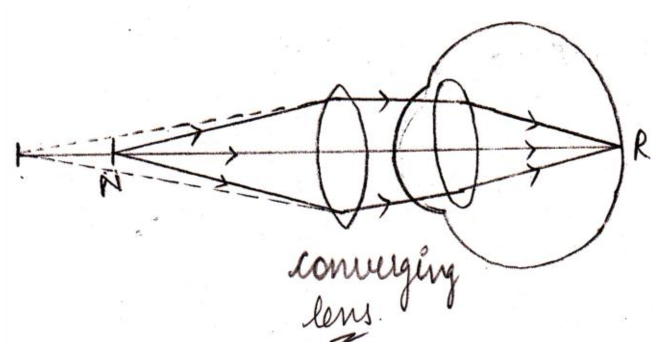
Hypermetropic Eye:-

Blurred image of object kept at N is formed beyond the retina of the eye.



Corrected Hypermetropic Eye:-

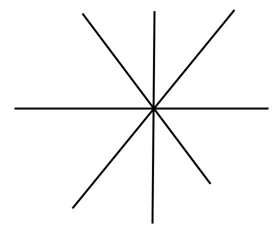
People suffering from this defect has to use spectacles with a convex lens of suitable focal length so that the sharp image of object kept at N is formed again on the retina of the eye.



c) <u>Presbyopia (old Sight):-</u>

With increasing age, the ciliary muscles holding the eye lens weaker and the lens loses some of its elasticity. Hence, power of accomodation of the eye decreases with age. This defect is called presbyopia. To remove this defect, the person is normally prescribed bifocal specs. The upper half of each lens is diverging and corrects the myopia, when the wearer is looking ahead at distant objects. The lower half of each lens is convex and corrects the defect when the wearer looks through this part while reading.

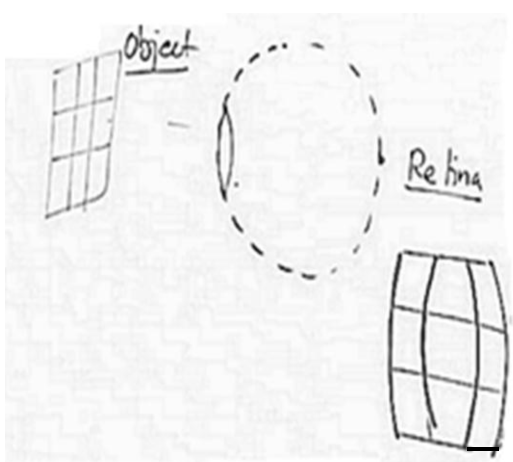
d) <u>Astigmatism:-</u>



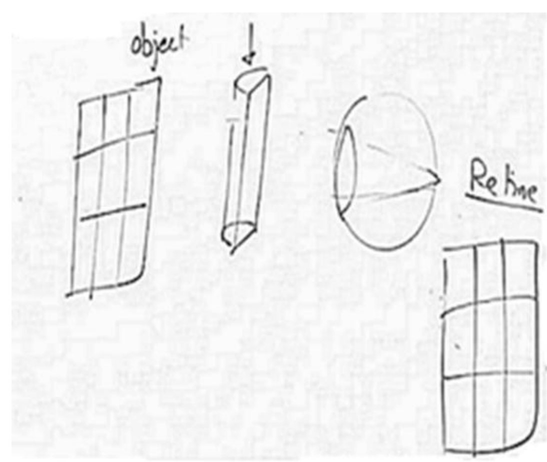
To a normal eye, all the lines drawn in figure look equally black. But an astigmatic eye will find variation in the intensity of different lines. This defect arises when cornea has unequal curvature in different directions. This defect is corrected by using a cylindrical lens of suitable radius of curvature and suitable axis. To correct this defect only, one surface of each lens will be flat and the other surface of each lens will be a section of circular cylinder as shown in figure given below.

This defect can occur along with myopia or hypermetropia.

<u>Defective eye</u>



<u>Corrected eye</u>

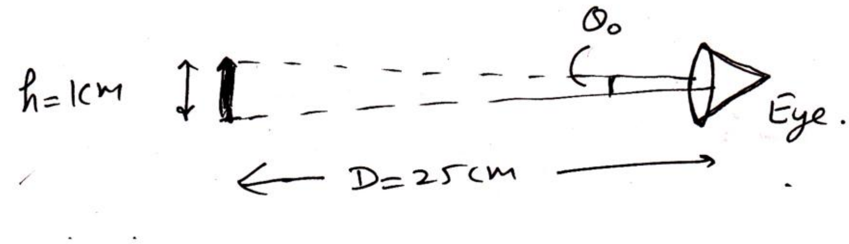


Q21. a) What is simple microscope? Explain its working.
b) Magnifying power of simple microscope?

Ans: a) Simple Microscope is a device which is used to see magnified image of small objects.

Working of simple Microscope:- Normal eye can see details of objects clearly if angle subtended by object on eye is large. But we can't place an object at distance less than 25 cm (Near point).

Suppose we place an object at 25 cm from eye and object size is 1 cm.



1) Normal Eye:

Object subtends angle θ_0 at eye (Unaided).

Tan $\theta_0 = \frac{h}{D}$

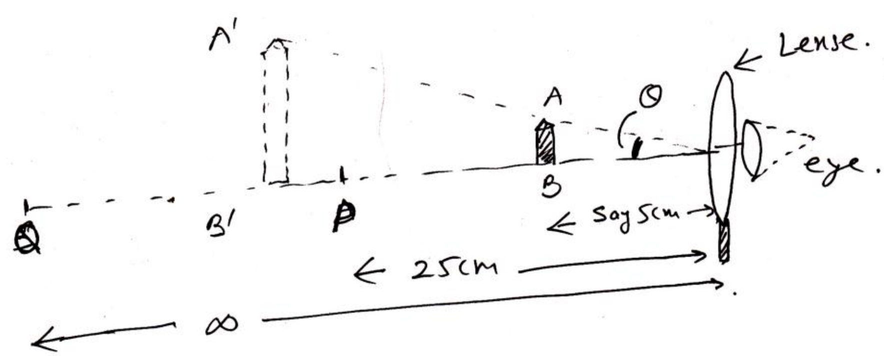
Tan $\theta_0 = \frac{1cm}{25cm} \Rightarrow$ Tan $\theta_0 \approx \theta_0$ = .04 rad

= (.04) $\left(\frac{180}{\pi}\right)$ degree

= $\boxed{\theta_0 \simeq 2^0}$

So, we can't place the object at distance less than 25 cm. So we can't have θ_0 more than 2^0 for unaided eye for an object of 1 cm height.

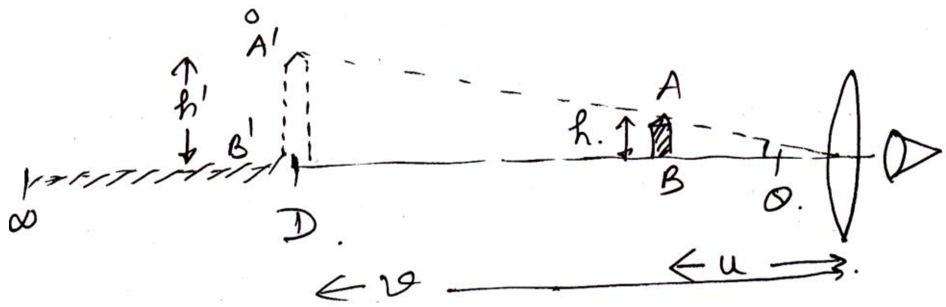
2) Use of microscope (simple)



By using simple converging lens, one can place object AB at distance less than 25 cm (here 5 cm) and can get image between 25 cm and ∞. So, angle (θ) will become more than θ_0 (here 2^0).

b) Magnifying Power of simple Microscope:

Case I: Image is at 25 cm.



Example: Given a lens of focal length f (say 5 cm). Find distance of object (u =?) so that image is formed at D = 25 cm. (Near point).

Ans:

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

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

$$\boxed{u = -\left(\frac{D.f}{D+f}\right)}$$

$$\begin{bmatrix} \boldsymbol{In\ eg}: & \mathbf{D = 25\ cm.} \\ & \boldsymbol{f = 5\ cm.} \\ \boldsymbol{u = ? =} & \boldsymbol{-4.16\ cm.} \end{bmatrix}$$

Magnification:

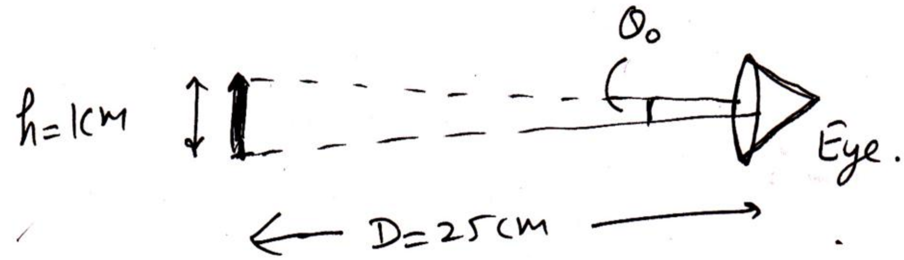
$$m = \frac{h'}{h.}$$

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

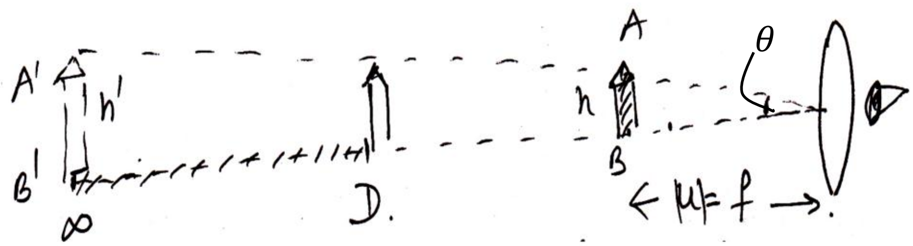
$$\boxed{m = \left(\frac{D}{f} + 1\right)}$$

$$\begin{bmatrix} \boldsymbol{In\ eg}: & \boldsymbol{D = 25\ cm.} \\ & \boldsymbol{f = 5\ cm.} \\ \boldsymbol{m =} & \boldsymbol{\frac{25}{5} + 1 = 6.} \end{bmatrix}$$

Unaided eye:-



Case II: **Image is at ∞.**



Example: Given a lens of focal length f (say 5 cm). Find u =? So that image is formed at infinity (Far point).

Ans: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{\infty} - \frac{1}{u} = \frac{1}{f} \Rightarrow$ $\boxed{u = -f}$

Magnification $m = \frac{\theta}{\theta_0} = \frac{Tan\theta}{Tan\theta_0}$ $\left[\begin{matrix} Where\ \theta_0\ is\ the\ angle \\ subtended\ by\ objet \\ at\ unaided\ eye\ and\ \theta \\ with\ the\ aided\ eye. \end{matrix}\right]$

$$\boxed{m = \frac{h/f}{h/D} = D/f}$$

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

$\frac{D}{f}$ ↓ Image at Infinity

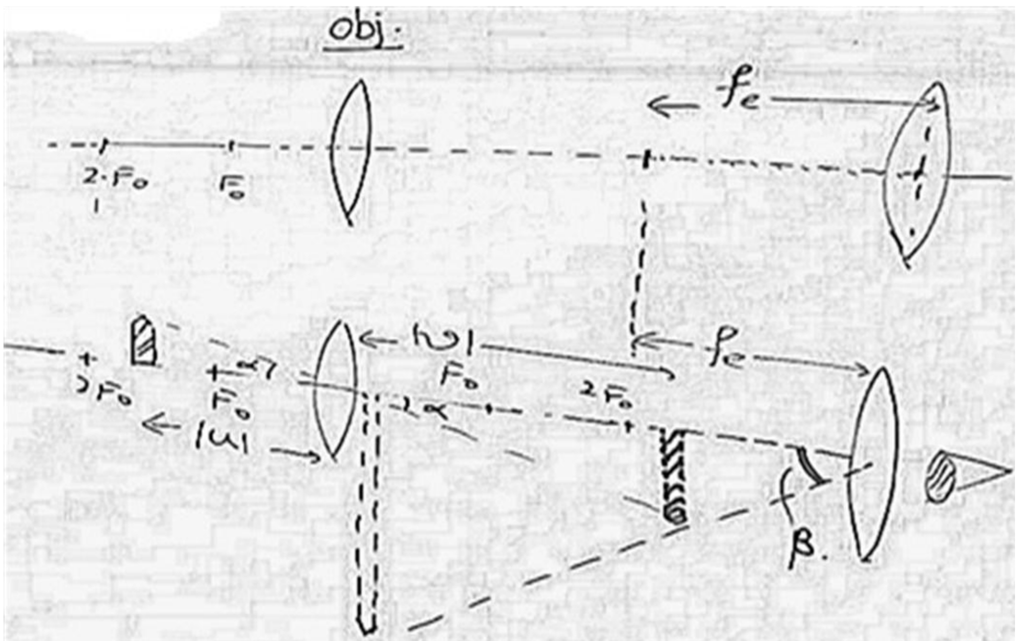
$\left(\frac{D}{f} + 1\right)$ ↓ Image at D

Q22. What is compound microscope? Explain its construction, working and magnifying power.

Ans: **Compound microscope:-** A compound microscope is an optical instrument used for observing highly magnified images of tiny objects.

Construction:- A compound microscope consists of two converging lenses; an objective lens O of very small focal length and short aperture and an eye piece E of moderate focal length and large aperture.

Working and Magnifying Power :-



1) Object is placed between F_0 and $2F_0$

So that $(\text{M.P})_{object} > 1$.

$$\boxed{(\text{M.P})_{object} = \frac{-|v_0|}{|u_0|}}$$

2) First image is to be placed within f_e for eye piece.

3) $(\text{M.P})_{eye}$ = ?

$$\left(\frac{D}{f_e}\right) \leq (\text{M.P})_{eye} \leq \left(\frac{D}{f_e} + 1\right)$$

4) Total Magnifying power:

$$(\mathrm{M.P})_{Total} = (\mathrm{M.P})_{object} \times (\mathrm{M.P})_{eye}$$

$$(\mathrm{M.P})_{Total} = \left[\frac{-|v_0|}{|u_0|}\right] \times \left[\left(\frac{D}{f_e}\right) \leq (\mathrm{M.P})_{eye} \leq \left(\frac{D}{f_e} + 1\right)\right]$$

Practical Example:-

M.P = $(\mathrm{M.P})_{object} \times (\mathrm{M.P})_{eye}$

= (-2) × (6)

= - 12

5) Approximate Method:

$$|\mathrm{M.P}| = \left(\frac{L}{f_o}\right) \left(\frac{D}{f_e}\right)$$

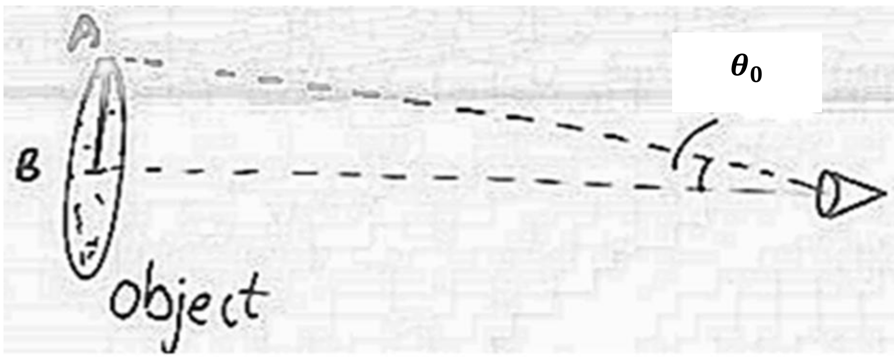
$$\boxed{|\boldsymbol{M.P}| = \frac{\boldsymbol{LD}}{\boldsymbol{f_o . f_e}}}$$

Q23. a) What is Astronomical Telescope? Explain Construction, Working and magnifying power of a Telescope.

Ans: 1) <u>Astronomical Telescope</u>:- It is a device which used to see distant objects like stars, Moon etc.

2) <u>Construction</u>: It consists of two lenses (or lens systems), the objective lens O, which is of large focal length and large aperture and the eye piece E, which has a small focal length and small aperture.

3) <u>Normal eye (unaided eye)</u>:- Angle subtended by AB on eye is θ_0.



4) <u>Object is at ∞ then Image</u> = ?

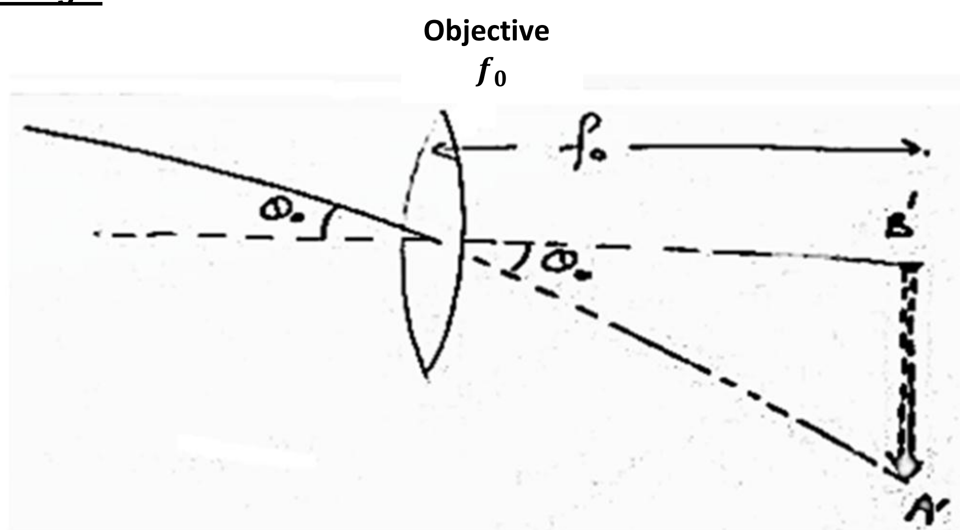
$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$u = \infty, f = f_0$$

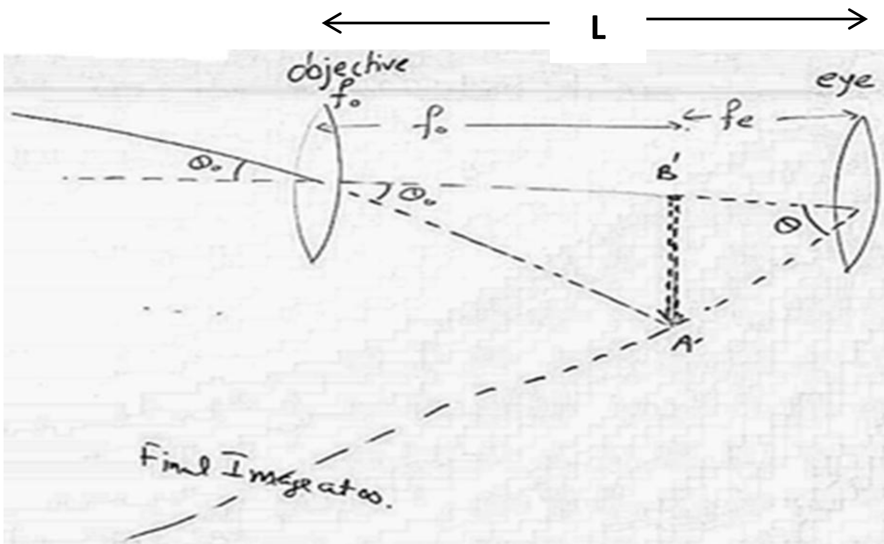
$$\frac{1}{v} - \frac{1}{\infty} = \frac{1}{f_0}$$

$$\frac{1}{v} - 0 = \frac{1}{f_0}$$

$$\boxed{v = f_0}$$



5) **Object is at infinity then final image is at ∞**



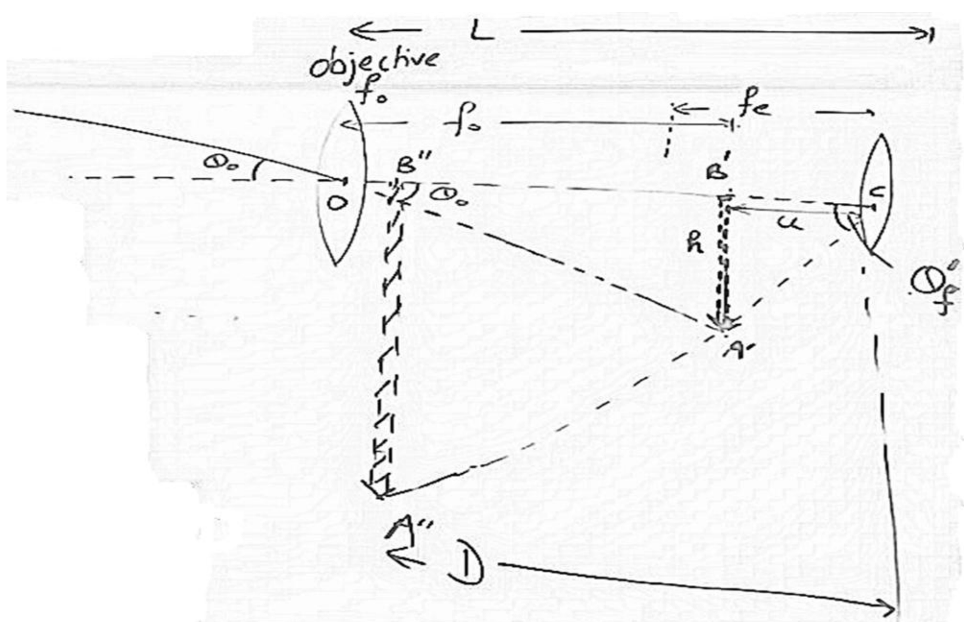
Magnifying Power:-

$$|m| = \frac{\theta}{\theta_0}$$

$$= \frac{Tan\,\theta}{Tan\,\theta_0} = \frac{h/f_e}{h/f_o} \qquad \Rightarrow |m| = \frac{f_o}{f_e}$$

6) L = $f_o + f_e$ $\qquad \begin{bmatrix} When\ object \rightarrow \infty \\ Final\ image \rightarrow \infty \end{bmatrix}$

7) **When object at ∞ then final image is at D:**



Step-I: **Magnifying Power-**

$$|m| = \frac{\theta'_f}{\theta_0} = \frac{Tan\theta'_f}{Tan\theta_0}$$

$$= \frac{\frac{h}{u}}{h/f_o}$$

$$\boxed{|m| = \frac{f_o}{u}} \text{——— (1)}$$

Step-II: Find u → ?

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

$$\frac{1}{-D} - \frac{1}{u} = \frac{1}{f_e}$$

$$\boxed{u = -\left(\frac{D.f_e}{D + f_e}\right)} \text{——— (2)}$$

Step-III: From equation (1) & (2)

$$|m| = \frac{|f_0|}{|u|}$$

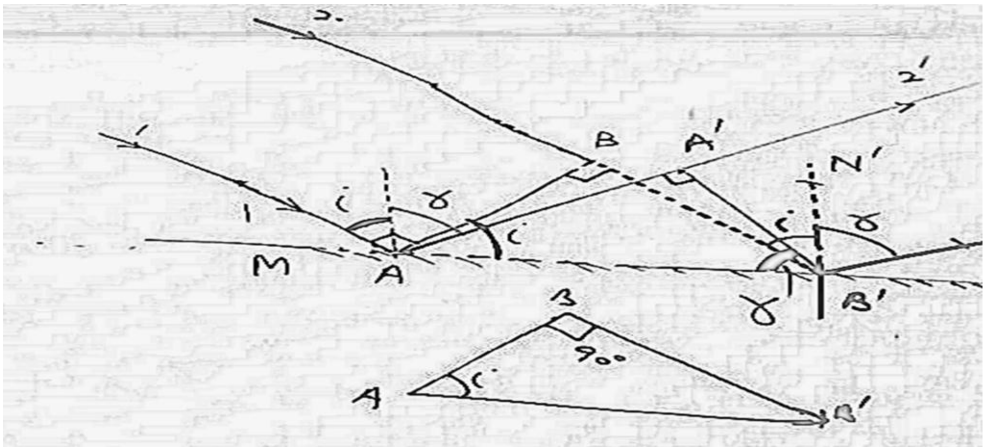
$$= \frac{f_o}{\frac{D.f_e}{D + f_e}}$$

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

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

7) $$\underset{\begin{bmatrix}\text{Image}\\ \text{at } \infty\end{bmatrix}}{\frac{f_o}{f_e}} < |M.P| < \underset{\begin{bmatrix}\text{Image}\\ \text{is at } D\end{bmatrix}}{\frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)}$$

Q24. a) Prove laws of reflection ($i = r$) using wave theory.
b) Prove laws of refraction by using wave theory.



Ans: a) Step I: In $\Delta A BB'$, Sin $i = \frac{BB'}{AB'}$ ———— (1)

Step-II: In $\Delta A A'B'$, sin $r = \frac{AA'}{AB'}$ ———— (2)

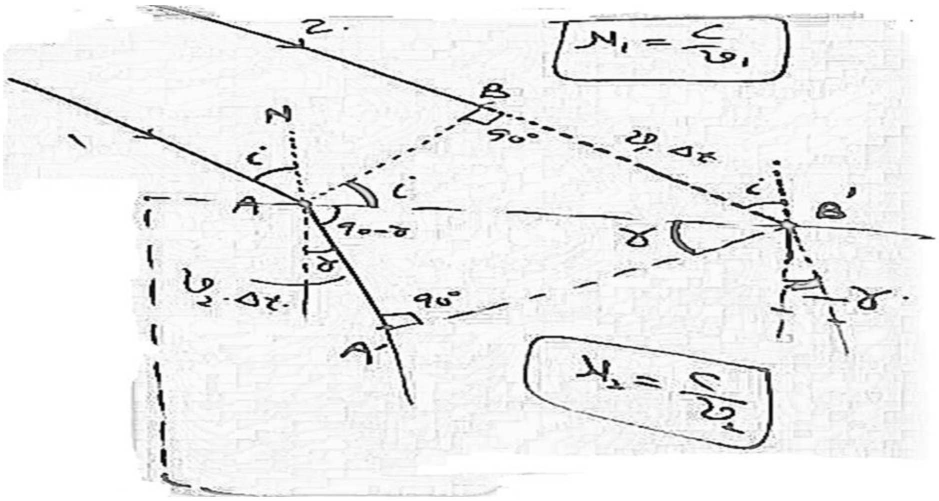
Step-III: Divide (1) by (2)

$$\frac{\sin i}{\sin r} = \frac{BB'}{AA'} = \frac{ct}{ct} = 1$$

$$\sin i = \sin r$$

$$\boxed{i = r}$$

b) Laws of Refraction using wave theory:-



Step-I:- In $\Delta\, ABB'$, sin i = $\frac{BB'}{AB'}$ = $\frac{v_1\, \Delta t}{AB'}$ ———— (1)

Step-II: In $\Delta\, AA'B$, sin r = $\frac{AA'}{AB'}$ = $\frac{v_2\, \Delta t}{AB'}$ ———— (2)

Step-III: Divide (1) by (2)

$$\frac{\sin i}{\sin r} = \frac{v_1\, \Delta T}{v_2\ \ \Delta T} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$$

$$\Rightarrow \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

$$\boxed{\mu_1 \sin i = \mu_2 \sin r}$$

Physics

By

Lalit Sharma

Class:10+2
Unit:VI
Topic: Wave Optics

Chapter-6: Wave Optics

Wave optics: Wave front and Huygen's principle, relection and refraction of plane wave at a plane surface using wave fronts. Proof of laws of reflection and refraction using Huygen's principle. Interference Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light. Diffraction due to a single slit, width of central maximum. Resolving power of microscopes and astronomical telescopes. Polarisation, plane polarised light Brewster's law, uses of plane polarised light and Polaroids.

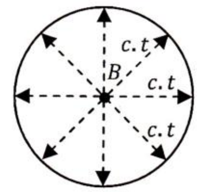
Q. No.	Topic/ Question	Page No.
	Chapter:VI (Wave Optics)	
1.	What is wave front? Draw diagram for i) Spherical wave front. ii) Cylindrical wave front. iii) Plane wave front.	6/50
2.	Explain Huygen's wave front theory? Explain reflection and refraction on the basis of same.	6/51
3.	a) What is Interference of Light? b) Explain formation of Bright and dark fringes in Young's double slit experiment.	6/51
4.	Derive conditions for "Constructive" and "Destructive interference of two waves having a phase difference of ϕ.	6/52
5.	Derive an expression for fringe width in interference pattern.	6/53
6.	Formation of bright and dark fringes in interference pattern is violation of law of conservation of Energy comment?	6/54
7.	What are coherent sources of light? Write conditions for obtaining coherent sources of light.	6/54
	Wave Optics- Diffraction and Polarisation	
1.	a) Explain Diffraction. Effect of window size. b) Explain Diffraction of "sound" and "light". Comparison?	6/55
2.	Explain Diffraction of light at single slit. Explain conditions for minima.	6/57
3.	a) Explain Resolving power. Explain Rayleigh conditions. b) Resolving power of Microscope and Telescope.	6/58
4.	Polarisation a) Mechanical waves (Transverse). b) Light	6/59
5.	a) Explain Law of Malus. b) Prove "Polarizer reduces the intensity to 50%".	6/60
6.	Use of plane polarized light and polaroids?	6/60
7.	Various methods for "Polarisation". a) Reflection. b) Scattering. c) Refraction.	6/61

Wave Optics- Interference

Q1. What is wave front?
Draw diagram for
i) Spherical wave front.
ii) Cylindrical wave front.
iii) Plane wave front.

Ans. A wave front is defined as the continuous locus of all the particles of a medium, which are vibrating in the same phase.

1**. Spherical wave front:**



Point source: e.g. Bulb

Distance covered = C.t (same in all directions)

All points on such a sphere are oscillating in phase because they are at the same distance from the source.

Num: A 100 watt red colour bulb is placed at 100m from a window. Dimensions of the window (1 × 1m). Find the no.of photons crossing the window per second.

Solution: $\frac{100J}{sec}$

No. of packets coming out per sec

$$= \frac{100J}{Energy\ of\ one\ packet\ i.e. 1.8\ ev}$$

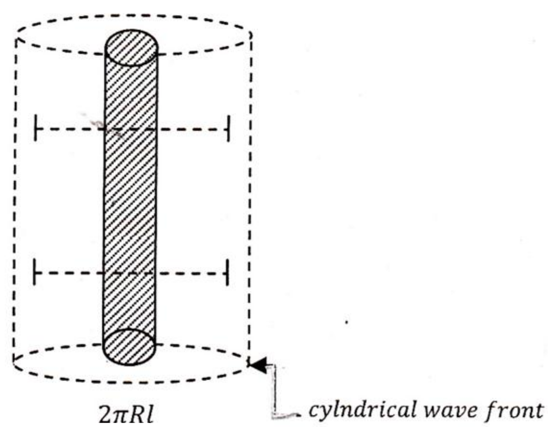
$$= \frac{100}{1.8 \times 1.6 \times 10^{-19}}$$

$$= 3.4 \times 10^{20}\ \frac{1}{sec}$$

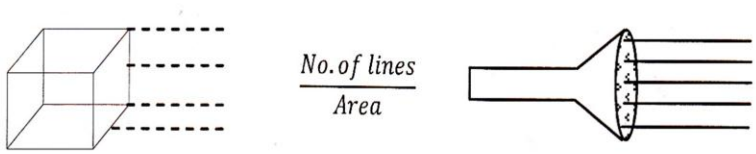
No. of packets crossing the window = $\frac{3.4 \times 10^{20}}{4\pi\ (100)^2} \cdot \left(\frac{No.}{m^2}\right)(1m^2)$

2. **Cylindrical wave front:**

Line source: e.g. Tube light

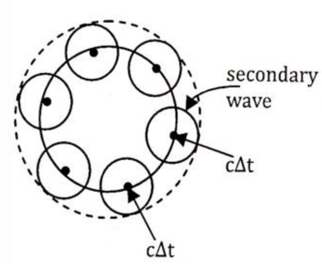


3. **Plane wave front**:



Q2. Explain Huygen's wave front theory? Explain reflection and refraction on the basis of same.

Ans. **<u>Huygen's Principle</u>:**

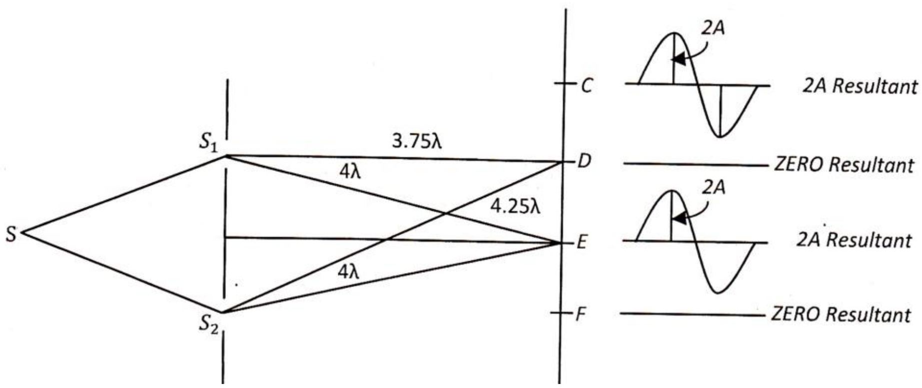


1. Every point on the given wave front (called primary wave front) acts as a fresh source of new disturbance, called secondary wavelets, which travel in all directions with the velocity of light in the medium.
2. A surface touching these secondary wavelets, tangentially in the forward direction, at any instant gives the new wave front at that instant. This is called secondary wave front.

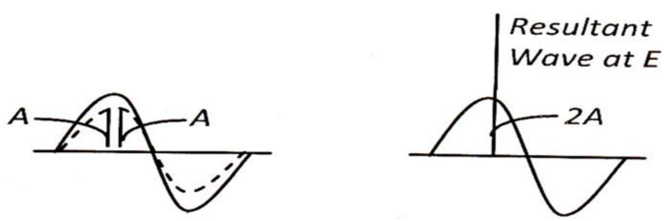
Q3. a) What is Interference of Light?
b) Explain formation of Bright and dark fringes in Young's double slit experiment.

Ans. a) Interference of light is phenomenon of redistribution of light energy in a medium on account of superposition of light waves from two coherent sources.

b)



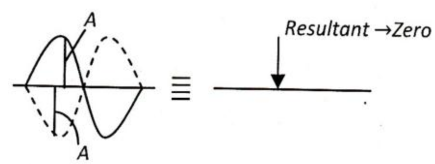
E = S_1 E = S_2 E = 4 λ (say)
Two waves, will reach in phase from S_1 and S_2



Resultant wave at E is having amplitude (2A) such interference is called "Constructive" and fringe formed is "Bright".

D = S_2 D = S_1 D = 0.5 λ (say)

Phase difference = π



Resultant amplitude and hence intensity of light is minimum. These Bright & Dark fringes are placed alternately and they are equally spaced. These bands are called interference fringes.

Q4. Derive conditions for "*Constructive*" and *"Destructive"* interference of two waves having a phase difference of ϕ.

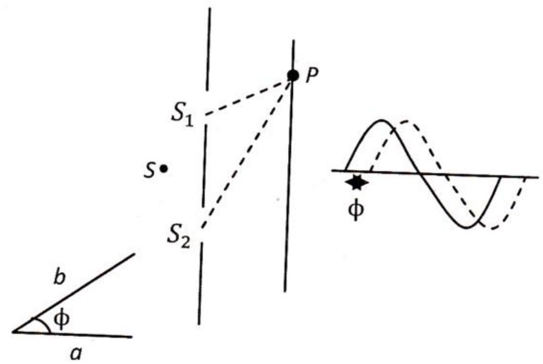
Ans. If two waves reaching P are

y_1 = a sin wt

y_2 = b sin (wt + ϕ)

$y = y_1 + y_2$

= a sin wt + b sin (wt + ϕ)



R $= \sqrt{a^2 + b^2 + 2ab\cos\phi}$

<u>**Condition for Maxima:**</u>

$R_{max} = \sqrt{a^2 + b^2 + 2ab\ (1)}$

ϕ is the phase difference when ϕ = 0

Cos ϕ =1

ϕ = 0,2π, 4π, ………………….. 2 nπ

[Relation between phase difference and path difference]

$2\pi = \lambda$

Phase difference, $\phi = \left(\frac{2\pi}{\lambda}\right)\Delta x$ ($\Delta x \rightarrow$ Path difference)

Phase difference, ϕ

= 0, 2π, 4π, …………………., 2nπ

$\frac{2\pi}{\lambda}.\ \Delta x$ = 0, 2π, 4π, ……………, $2n\pi$

Path difference,

Δx = 0, 1λ, 2λ, …………………, nλ

<u>**Condition for Minima**</u>**:**

Phase difference, ϕ

= 1π, 3π, ………………….., (2n -1) π

Path difference,

$\Delta x = \frac{\lambda}{2}, \frac{3\lambda}{2}$, ………………….., (2n -1) $\frac{\lambda}{2}$

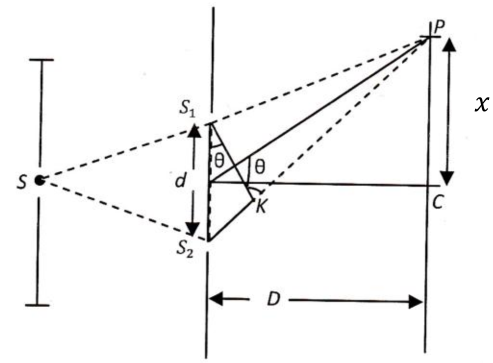
<u>**Conclusion**</u>:
Condition for Maxima:
Path difference, Δx = 0, 1λ, 2λ, ………………, nλ for n[th] maxima
<u>Condition for Minima</u>:
Path difference, Δx = 1. $\frac{\lambda}{2}$, 3. $\frac{\lambda}{2}$, ………………, (2n -1). $\frac{\lambda}{2}$ for nth minima

Q5. Derive an expression for fringe width in interference pattern.

Ans: S creates two coherent sources S_1 and S_2

Interference pattern is observed on screen at distance D.
Wave from S_1 covers distance S_1 P.

Wave from S_2 covers distance S_2 P.



1. Path difference $= S_2$ K

$= d \sin\theta$

$= d \tan\theta$

$= d \cdot \frac{x}{D}$

2. Path difference → 0, 1λ, 2λ, ………………..nλ, then it is a n[th] bright fringe.

$d \cdot \frac{x}{D} = 0\lambda, 1\lambda, 2\lambda, \ldots, n\lambda,$

$$\boxed{x = 0, \frac{D\lambda}{d}, \frac{2D\lambda}{d}, \ldots\ldots, \frac{nD\lambda}{d}}$$

Distance between two consecutive bright fringes $\boxed{\boldsymbol{\beta_{bright} = \frac{D}{d}\lambda}}$

3. **For Dark Fringes**:

Path difference → $\frac{1\lambda}{2}, \frac{3\lambda}{2}, \ldots\ldots, (2n-1)\frac{\lambda}{2}$

$$d. \frac{x}{D} = \frac{\lambda}{2}, \frac{3\lambda}{2}, \ldots\ldots, (2n-1)\frac{\lambda}{2}$$

$$\boxed{x = \frac{D}{d}.\frac{\lambda}{2}, \frac{3D}{d}.\frac{\lambda}{2}, \ldots\ldots, (2n-1)\frac{D}{d}.\frac{\lambda}{2}}$$

Distance between two consecutive dark fringes $\boxed{\boldsymbol{\beta_{dark} = \frac{D}{d}\lambda}}$

Discussion:

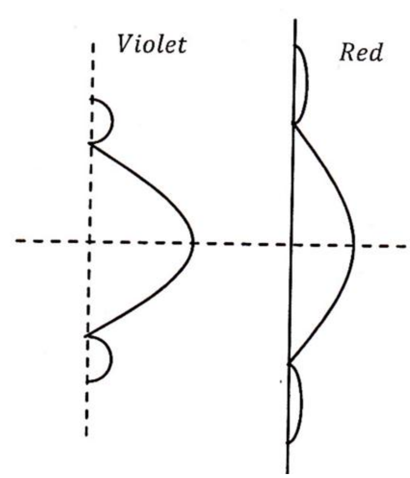
1. d – decreases, β – increases **(Reason: $\boldsymbol{\beta = D\lambda/d}$)**
2. If the whole interference apparatus is shifted from air to water fringe width

   $\beta_w = \frac{D}{d} \cdot \lambda_{water}$ $\qquad \beta_{air} = \frac{D}{d} \cdot \lambda_{air}$

   $\frac{\beta_w}{\beta_a} = \frac{\lambda_w}{\lambda_{air}} < 1$ $\qquad \boxed{\text{So, } \boldsymbol{\beta_{water} < \beta_{air}}}$

3. Monochromatic light is replaced by "White" light. Maxima of all colours is at central point C so central fringe is bright and white colour. $\boxed{\boldsymbol{\beta \propto \lambda}}$

   So violet fringe width is less than red colour. As you move away from C on the screen, colour sequence is Violet, Indigo, Blue, Green, Yellow, Orange, Red. After covering some distance general illumination is their due to mixing of colours.



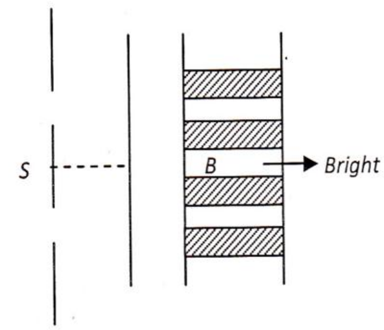
Q6. Formation of bright and dark fringes in interference pattern is violation of law of conservation of Energy comment?

Ans. 1. $I_1 = a^2$

2. $I_2 = b^2$ without interference, $I_{total} = a^2 + b^2$

3. $I_{av} = \frac{I_{max} + I_{min}}{2} = \frac{(a+b)^2 + (a-b)^2}{2}$

$I_{av} = a^2 + b^2$



Q7. What are coherent sources of light? Write conditions for obtaining coherent sources of light.

Ans. The sources of light, which emit continuous light waves of the same wavelength, same frequency and in same phase are called coherent sources.

Conditions for obtaining coherent sources of light are:

1. Coherent sources of light should be obtained from a single sources by some device.

   The coherent sources can be obtained either by

   i) The sources and its virtual image or

   ii) The two virtual images of the same sources

   iii) Two real images of the same source.

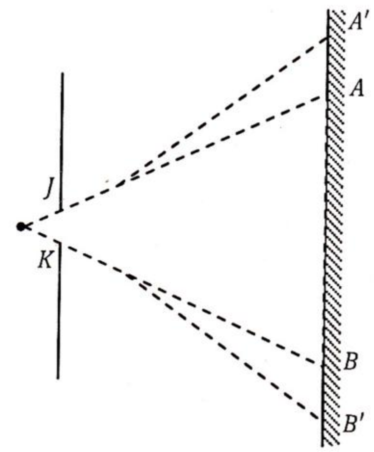
2. The two sources should give monochromatic light.

3. The path difference between light waves from two sources should be small.

Wave Optics- Diffraction and Polarisation

Q1. a) Explain Diffraction. Effect of window size.
b) Explain Diffraction of "sound" and "light". Comparison?

Ans: a) <u>Effect of window size</u>:



As per ray optics light is available only in part AB of the screen. Part AC and BD are dark areas because no light can reach straight.

But practical observation is light available in areas AA' and BB'. This is due to bending of light around corner JK.

This phenomenon of bending of waves around corners is known as diffraction.

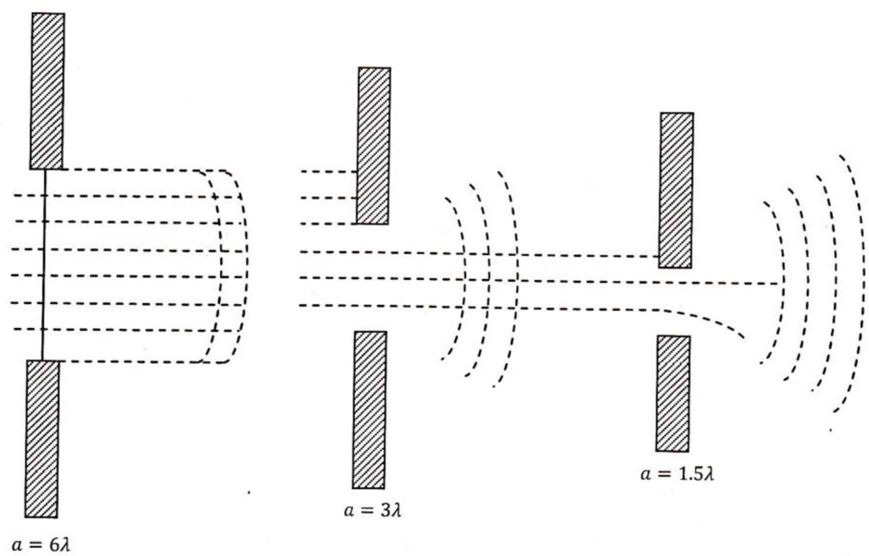


Fig. I　　Fig. II　　Fig. III

When window size is very large in comparison to wavelength, diffraction effect is very small as shown in Fig I. As window size decreases, diffraction effect increases as shown in Fig.II, Fig.III.

b) Normal window size is of the order of metre $\simeq$ 1m.

Sound

20 Hz < freq <20KHz

f = 330 Hz

$\lambda = \frac{v}{f}$

$= \frac{300\ m/sec}{300\ 1/sec}$

$\boxed{\boldsymbol{\lambda_{sound}} = \mathbf{1\ m}}$

$\lambda_{sound} \simeq$ window size

Wavelength of sound is comparable to window size

Light

λ = 5000Å

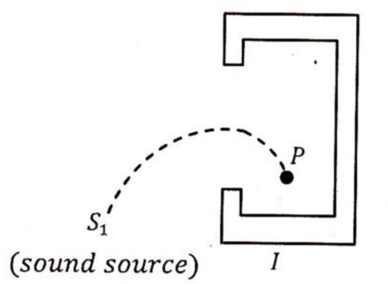
$\boxed{\boldsymbol{\lambda_{light}} = \mathbf{5 \times 10^{-7}\ m}}$

λ_{light} << window size

Wavelength of light is very very small in comparison to window size.

So, diffraction takes place for "sound" and not for "light" in given case.

Example:



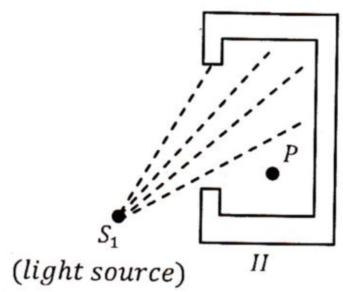


Figure I represents sound, S_1 is the source of sound. Person P will listen due to bending of sound waves. Diffraction is sufficient.

Figure II represents light, S_1 is the source of light. Person P cannot see the source of light. Diffraction is negligible.

Q2. Explain Diffraction of light at single slit. Explain conditions for minima.

Ans. A wave hits window AB as shown in the figure. AB is made up of two equal parts AC and BC. Wave from centre of AC comes in phase with wave from centre of BC, when these wave reach O.

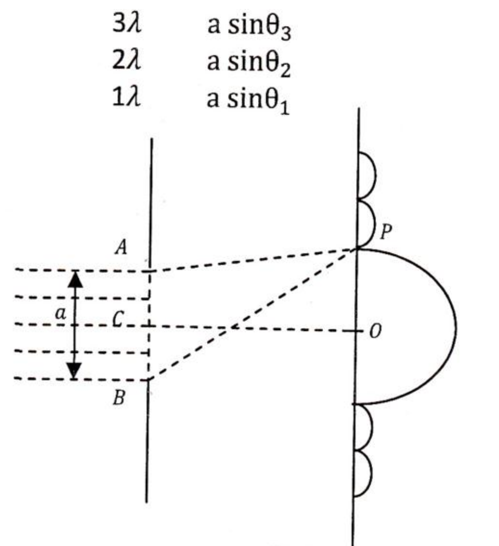


Fig.*I*

Wave from centre of AC travel to point P. Another wave from centre of BC travel towards point P.

Minima:

If waves reaching

P have path difference = $\frac{\lambda}{2}$,

P is a point of minima

$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$ (as given in Fig.II)

a $\sin\theta = \lambda$ is condition for 1st minima

a $\sin\theta = 2\lambda$ is condition for 2nd minima

⋮

a $\sin\theta = n\lambda$ is condition for n^{th} minima

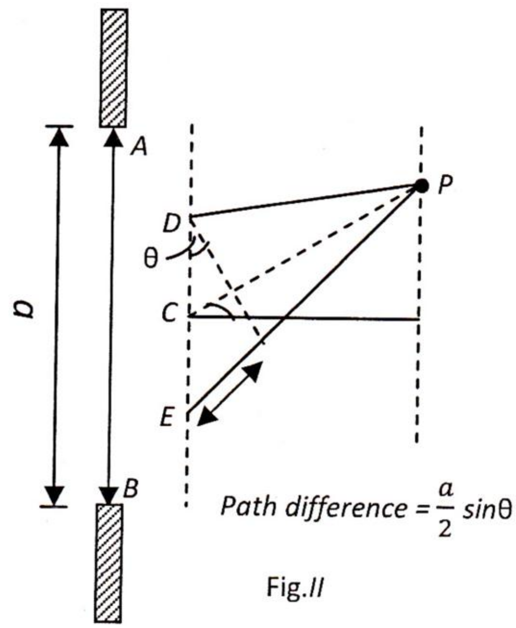


Fig.*II*

Maxima: (Approx.)

1st sec. max, a. $\sin\theta = 1.5\lambda$ $\left[\frac{1\lambda + 2\lambda}{2} = 1.5\lambda\right]$

2nd sec. max, a. $\sin\theta = 2.5\lambda$ $\left[\frac{2\lambda + 3\lambda}{2} = 2.5\lambda\right]$

3rd sec. max, a. $\sin\theta = 3.5\lambda$ $\left[\frac{3\lambda + 4\lambda}{2} = 3.5\lambda\right]$

nth sec. max, a. $\sin\theta = (n + 0.5)\lambda$

Conclusion: Diffraction

Minima:

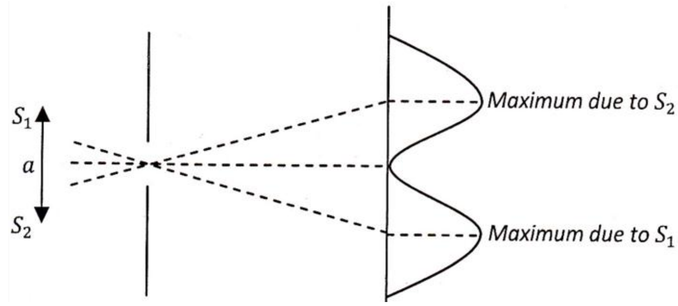
a.$\sin\theta$ = 1λ for 1st minima
= 2λ for 2nd minima
= $n\lambda$ for nth minima

Maxima:

a.$\sin\theta$ = 1.5λ for 1st sec. maxima
= 2.5λ for 2nd sec. maxima
= $(n + 0.5)\lambda$ for n^{th} sec maxima

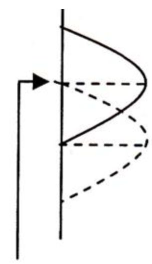
Q3. a) Explain Resolving power. Explain Rayleigh conditions.
b) Resolving power of Microscope and Telescope.

Ans: a) Resolving power of an optical instrument is the power or ability of the instrument to produce distinctly separate images of two close objects, i.e. it is the ability of the instrument to resolve or to see as separate the images of two close objects.



The minimum distance between two objects which can just be seen as separate by the optical instrument is called the limit of resolution of the instrument. Smaller the limit of resolution of the optical instrument, greater is its resolving power.

Condition for first minima ($d\ sin\theta \propto \lambda$)



maxima due to one coincides with minima due to others

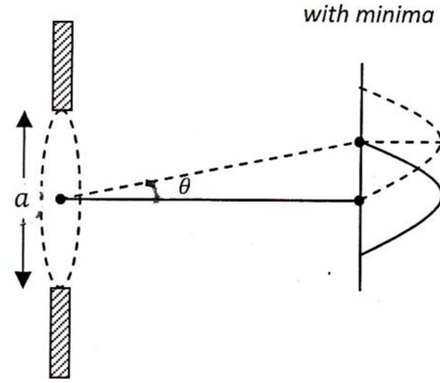
Rayleigh Criterion:
Rayleigh suggested a quantitive criterion for resolution of two close objects. Two images are called just resolved if maxima due to one object falls on minima of the other.

b) Resolving power of Microscope:

1. a. Sinθ $= \frac{\lambda}{2}$
2. If surrounding material is μ (say water)

a sinθ $= \frac{\lambda'}{2}$ $= \frac{\lambda/\mu}{2}$ $\boxed{\boldsymbol{a}.\ \textbf{Sin}\boldsymbol{\theta} = \frac{\boldsymbol{\lambda}}{\boldsymbol{2.\mu}}}$

'a' size of window
OR
for microscope,
'a' dia of object to be seen



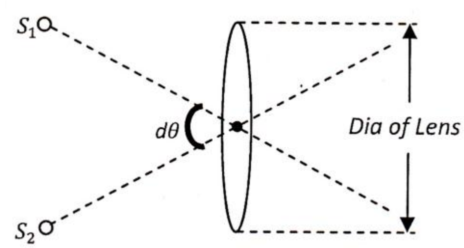
$\boxed{\boldsymbol{a} = \frac{\boldsymbol{\lambda}}{\boldsymbol{2.\mu\ .sin\theta}}}$

Conclusion:
Resolving Power $= \frac{\mathbf{1}}{\textbf{Limit of resolution } (\boldsymbol{a})}$
$= \frac{\boldsymbol{2.\mu.sin\theta}}{\boldsymbol{\lambda}}$

Resolving power of Telescope:

Resolving power $\propto$ Dia of Lens [More dia means more light]
$\propto \frac{1}{\lambda}$ [smaller the λ, better the power]

Combining above two factors:
Resolving power $\propto \frac{D}{\lambda}$
Resolving power $\propto \frac{D}{1.22\ \lambda}$ [factor 1.22 on the basis of Geometrical factors]



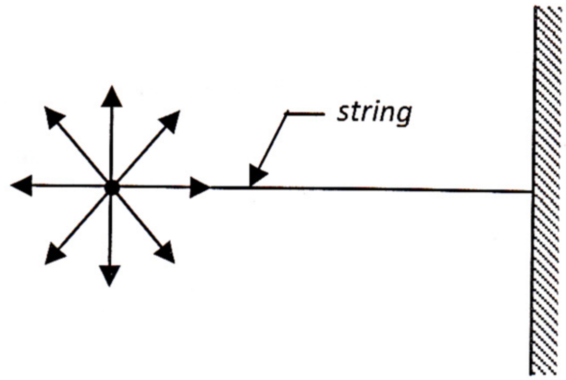
Conclusions:
Resolving Power $= \frac{\mathbf{1}}{\textbf{Limit of resolution } (\boldsymbol{d\theta})}$
$= \frac{\boldsymbol{D}}{\mathbf{1.22}\ \boldsymbol{\lambda}}$

Q4. Polarisation

a) Mechanical waves (Transverse).

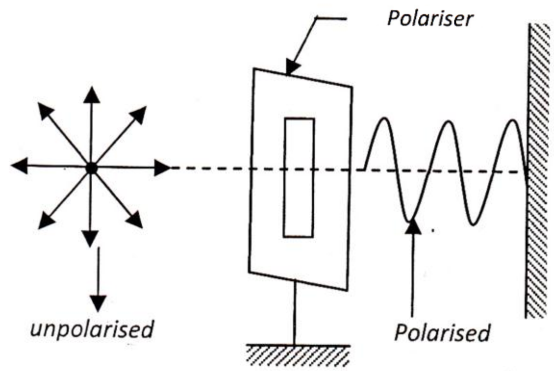
b) Light.

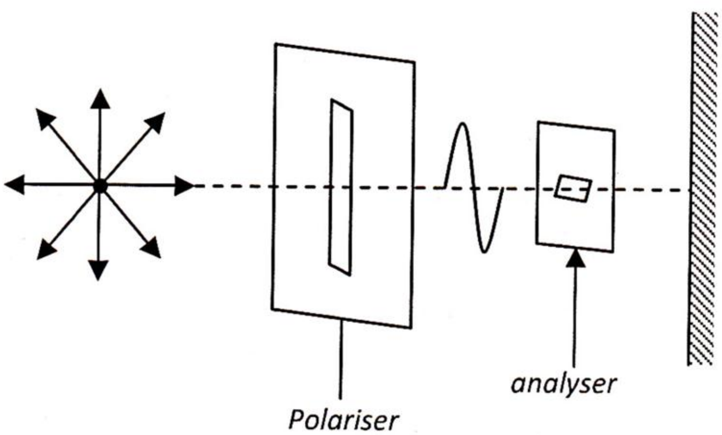
Ans. a) Mechanical wave:



b) Light:

"The phenomenon of restricting the vibrations of light in a particular direction, perpendicular to the direction of wave motion is called polarization of light".



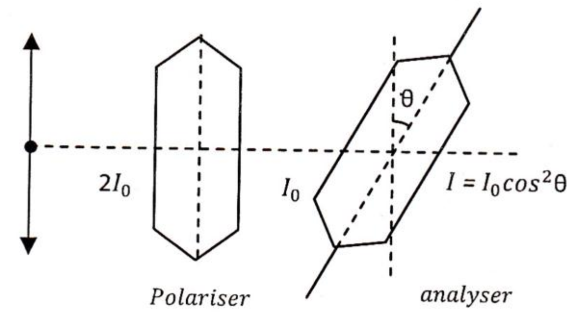


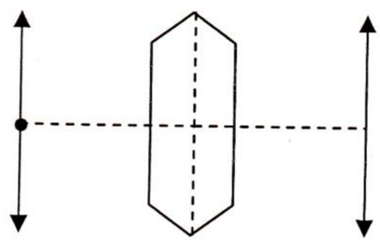
Q5. a) Explain Law of Malus.
b) Prove "Polarizer reduces the intensity to 50%".

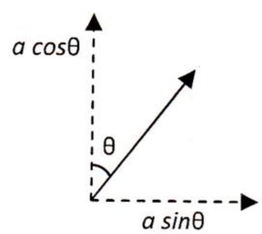
Ans. a) **<u>Law of Malus</u>:**

When a beam of completely plane polarized light is incident on an analyzer, the resultant intensity of light (I) transmitted from analyzer varies directly as the square of the cosine of angle between plane of transmission of analyzer.

$$\boxed{I = I_0 \cos^2 \theta}$$







b) i) $I \propto (a\cos\theta)^2$ for all waves

$\propto a^2 \cos^2 \theta$ for all waves

ii) $(\cos^2\theta)_{avg}$ = ?

$$= \int_0^{2\pi} \frac{\cos^2\theta \, d\theta}{2\pi - 0}$$

$$= \frac{1}{2}$$

So, $\quad I = (a^2)\,(\cos^2\theta)_{avg}$

$$= (a^2)\left(\frac{1}{2}\right)$$

$$I = \frac{1}{2}.\, a^2$$

Here $I_0 = \frac{1}{2}\,.\,(2.I_0)$

$= \frac{1}{2}$ (Intensity before polarizer)

Q6. Use of plane polarized light and polaroids?

Ans: **<u>Applications and uses of Polarisation</u>:**

1. By determining the polarizing angle and using Brewster's law, i.e., $\mu = \tan\theta_p$, refractive index of dark transparent substance can be determined.
2. It is used to reduce glare (which is due to horizontal polrisation of light by reflection from ground or water, etc.) by wearing Polaroid sunglass with vertical transmission axis.
3. In calculators and watches, numbers and letters are formed by liquid crystals through polarization of light called liquid crystal display (L.C.D).
4. In CD player polarized laser beam acts as needle for producing sound from compact disc which is an encoded digital format.
5. It has also been used in recording and reproducing three – dimensional pictures.
6. Polarisation of scattered sunlight is used for navigation in solar- compass in polar regions (where magnetic compass becomes inoperative).
7. Polarised light is used in optical stress analysis known as *'photoelasticity'*.
8. Polarisation is also used to study asymmetries in molecules and crystals through the phenomenon of *'optical activity'*.

Q7. Various methods for "Polarisation".

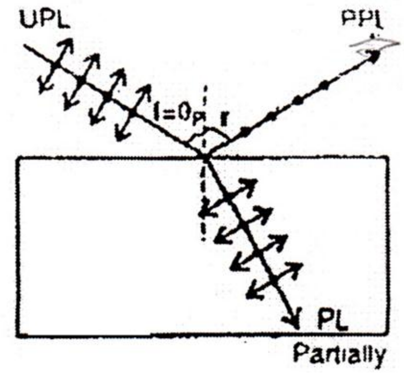
a) Reflection.

b) Scattering.

c) Refraction.

Ans.

a) <u>Reflection</u>:



Reflected light is polarized when "Reflected light" ⊥ T
o refracted light.

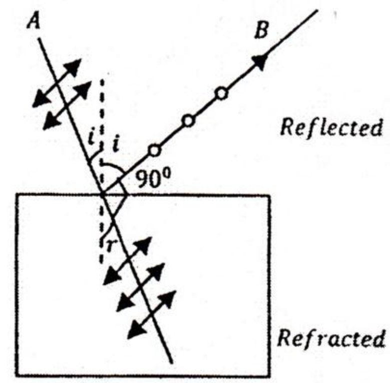
i) $i + r = 90°$ ——————— (1)

ii) $1 \sin i = \mu \sin r$ ——————— (2)

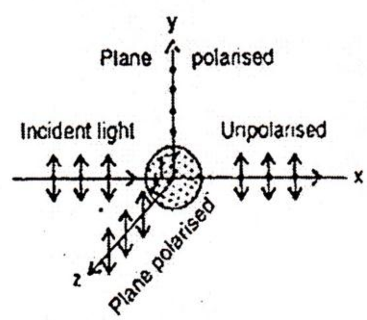
$= \mu \sin(90 - i)$

$\sin i = \mu \cos i$

$$\boxed{\tan i = \mu}$$

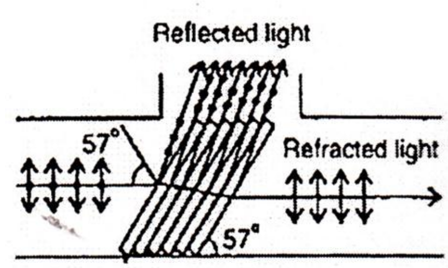


b) <u>Scattering</u>:



When light is incident on atoms and molecules, the electrons absorb the incident light and reradiate it in all directions, This process is called scattering. It is found that scattered light in directions perpendicular to the direction of incident light is completely plane polaised while transmitted light is unpolarised. Light in all other directions is partially polarized.

c) <u>Refraction</u>:



In this method, a pile of glass plates is formed by taking 20 to 30 microscopic slides and light is made to be incident at polarising angle (57°). In accordance with Brewster's law, the reflected light will be plane polarized with vibration perpendicular to the plane of incidence (which is here plane of paper) and the transmitted light will be partially polarized. Since, in one reflection about 15% of the light with vibration perpendicular to plane of paper is reflected, therefore after passing through a number of plates as shown in Fig., emerging light will become plane polarized with vibrations in the plane of paper.