Optics {concept}

100 Inspiring Years

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BECAUSE YOU ARE ONE OF A KIND

Lake Como, *the third largest and one of the most beautiful lakes in Italy, has been famously described as 'the looking glass of Venus'. The sprawling lake covers an area of 146 square kilometres.*

Notebook

I N D E X

NAME: Aditya STD.: XII SEC.: A ROLL NO.: 01 SUB.: Physics {optics}

S. No.	Date	Title	Page No.	Teacher's Sign / Remarks
		Optics {Syllabi}		
		→ Rectilinear propagation of light		
		→ Reflection and Refraction at plane and Spherical Surface		
		→ Total Internal reflection		
		→ Deviation and dispersion of light by a prism		
		→ Thin lenses		
		→ Combination of mirror and thin lenses		
		→ Magnification		

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Geometrical Optics

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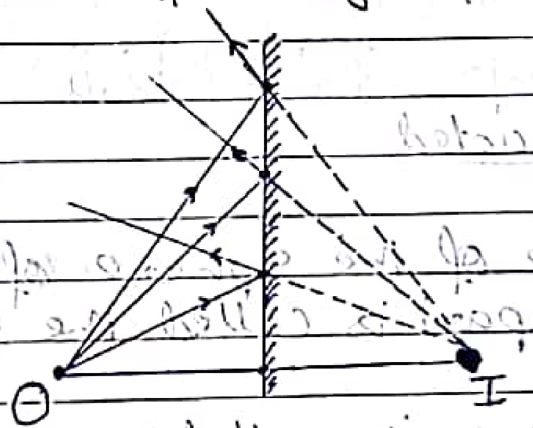
⇒ Laws of reflection

ⓐ The angle of incidence is equal to the angle of reflection.

ⓑ The incident ray, the reflected ray and the normal to the reflecting surface are coplanar.

* Formation of Image



→ All reflected ray meet at I when produced behind the mirror.

→ An eye receiving the reflected rays feels that the rays are diverging from the point I.

→ The point I is called Image of Object O.

⇄ Spherical mirrors

→ A spherical mirror is a part cut from a hollow sphere with one surface silvered.

→ If reflection takes place at the convex surface, it is called a convex mirror. and if reflection takes place at the concave surface, it is called a concave mirror.

* Terms associated

→ The centre of the sphere of which the mirror is a part is called the centre of curvature

→ The r of sphere is called the radius of curvature.

→ The point on the mirror at the middle of the surface is called its pole.

→ The line joining the pole and the centre of curvature is called the principal axis.

* Focus ⇒ The point where reflected rays converge is called the focus of the mirror.

* focal plane ⇒ A plane through focus and perpendicular to principle axis is focal plane.

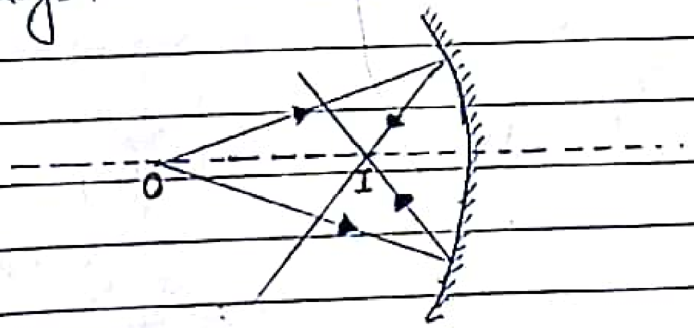
* focal length ⇒ Distance between focus and pole is focal length.

* Paraxial Rays ⇒ A ray close to the principle axis is called

* Image tracing

→ Draw Incident rays and ~~divergent~~ reflected rays.

→ The point of intersection of the incident rays is called the object & the point of intersection of the corresponding reflected rays is called its image.

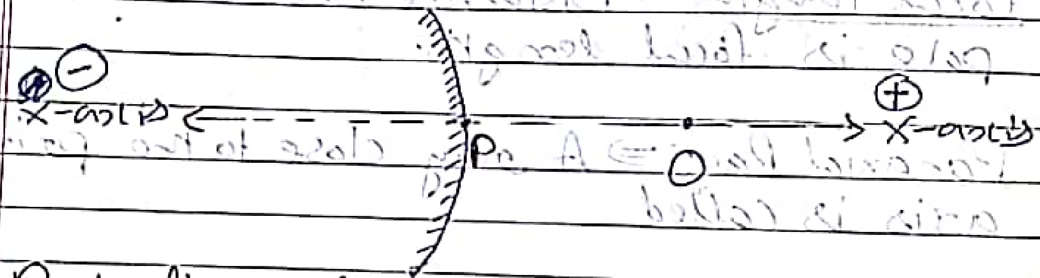


* Sign Convension

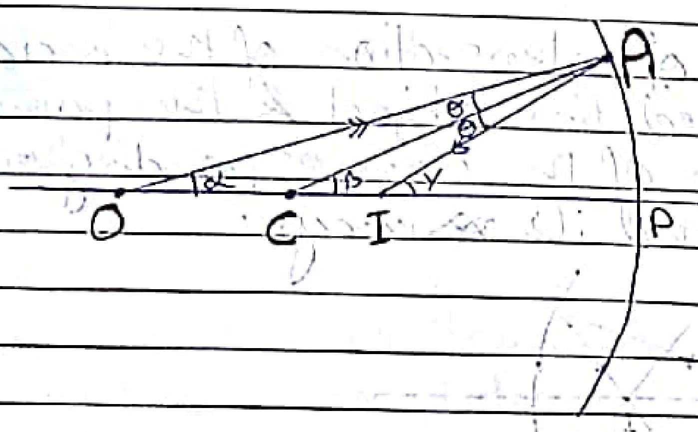
⇒ Pole is taken to be origin.

⇒ Principle axis is taken as X-axis.

⇒ The positive Side of X-axis is taken along the direction of ~~incident rays~~ Object to mirror.



⇒ Relation Between u, v & R for Spherical mirrors



$\beta = \alpha + \theta$ {In a exterior angle equals the sum
$\gamma = \alpha + 2\theta$ of two opposit interior angle}

$\Rightarrow 2\beta = \alpha + \gamma$ {from above} —— ①

$\Rightarrow \alpha \approx \frac{AP}{OP}$ $\beta = \frac{AP}{CP}$ $\gamma \approx \frac{AP}{PI}$ {form $\theta = \frac{l}{r}$}

$\Rightarrow 2\frac{AP}{CP} = \frac{AP}{PO} + \frac{AP}{PI}$ {from relation ①}

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

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

* Relation between focal length and radius of Curvature

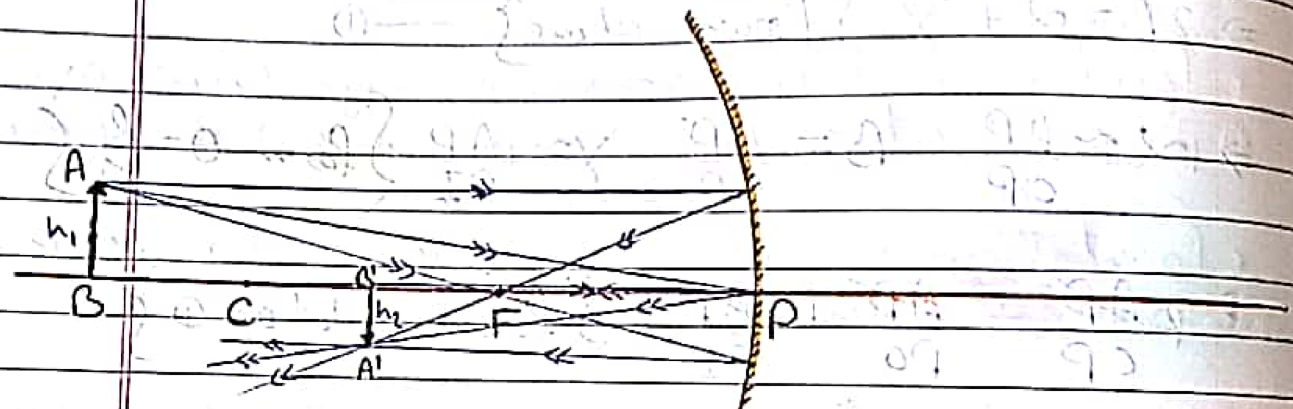
→ If Object O is taken at infinity, the ray coming from O become // to principle axis.

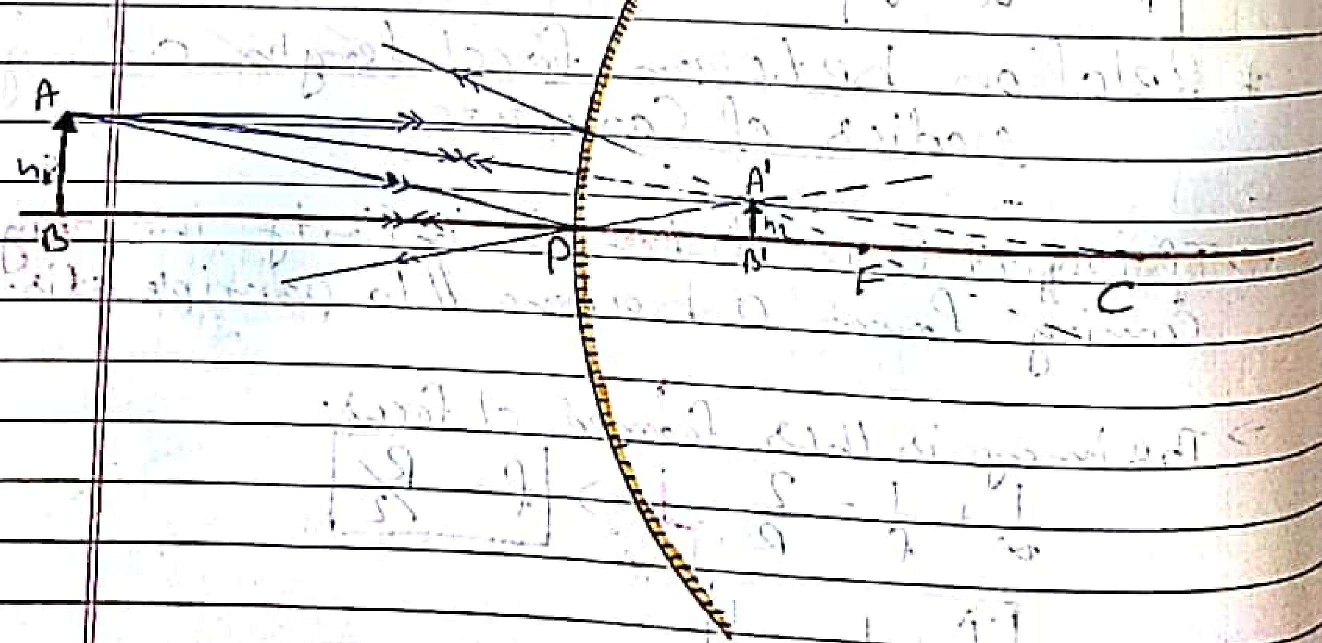
→ The image is thus formed at focus.

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

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

Extended object & Magnification





* Lateral magnification ⇒ The ratio $\frac{\text{height of image}}{\text{height of object}}$ is called lateral or transverse magnification.

⇒ Let h_1 & h_2 be height of object and image respectively.

$$\frac{h_1}{h_2} = \frac{-u}{v} \quad \{\text{as } \triangle ABP \sim \triangle A'B'P\} \quad \text{—} (1)$$

$$\boxed{m = \frac{h_2}{h_1} = \frac{-v}{u}} \quad \{\text{from } (1)\}$$

⇒ Refraction at Plane Surface

When a light ray is incident on a surface separating two transparent media, the ray bends at the time of changing the medium. The angle of incidence i and angle of refraction r follow Snell's law:

$$\boxed{\frac{\sin i}{\sin r} = \frac{V_1}{V_2} = \frac{\mu_2}{\mu_1}}$$

→ speed

{Where V_1 & V_2 are ~~velocities~~ speed of light in medium 1 & 2 and μ_1 & μ_2 are refractive index of medium 1 & 2 respectively.}

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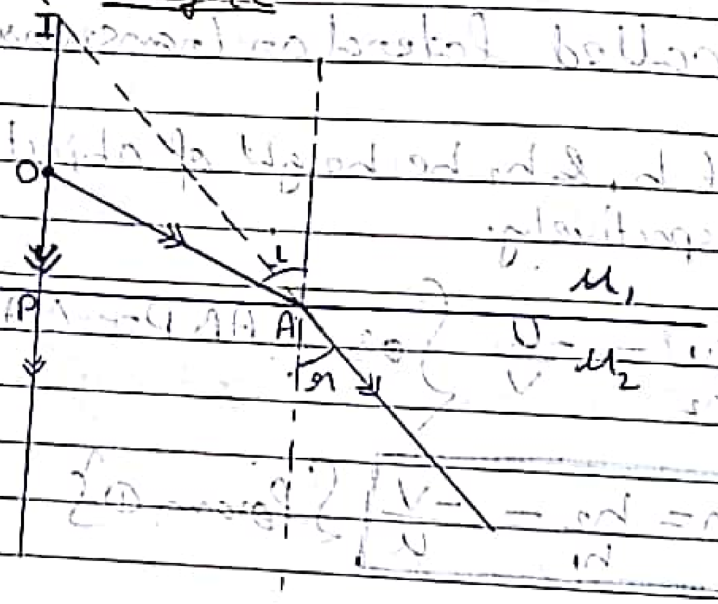
* Image due to Refraction at a Plane Surface *



for small i & r

$\sin i \approx \tan i = \frac{PA}{PO}$

& $\sin r \approx \tan r = \frac{PA}{PI}$

$\Rightarrow \boxed{\frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r} = \frac{PI}{PO} = \frac{t}{t_0}}$

t = apparent depth
t_0 = real depth

for $\mu_2 = 1$ & $\mu_1 = \mu$

$\frac{1}{\mu} = \frac{t}{t_0} \Rightarrow \mu = \frac{t_0}{t}$

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$$\boxed{\Delta t = t_0 - t = \left(1-\frac{1}{\mu}\right)t_0}$$ $\left\{\Delta t = \text{apparent shift}\right\}$

⇒ Critical angle $\{\theta_c\}$

For a particular refraction, the angle of incident at which angle of refraction become 90° is Critical angle.

$$\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$

μ_1 = RI of medium from where light is coming

μ_2 = RI of medium where light is going

// For light coming from a medium to air:

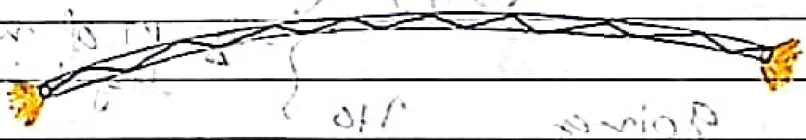
$$\theta_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$

* Total internal reflection ⇒ It is a phenomenon that happens when a propagating wave strikes a medium boundary at an angle larger than Critical angle. The wave cannot pass through and is entirely reflected.

Optical Fibre

→ An optical fiber is a flexible, transparent fiber made of high quality extruded glass or plastic {slightly thicker than a human hair}

→ It can function as "light pipe" to transmit light between the two ends of the ~~fiber~~ fiber.

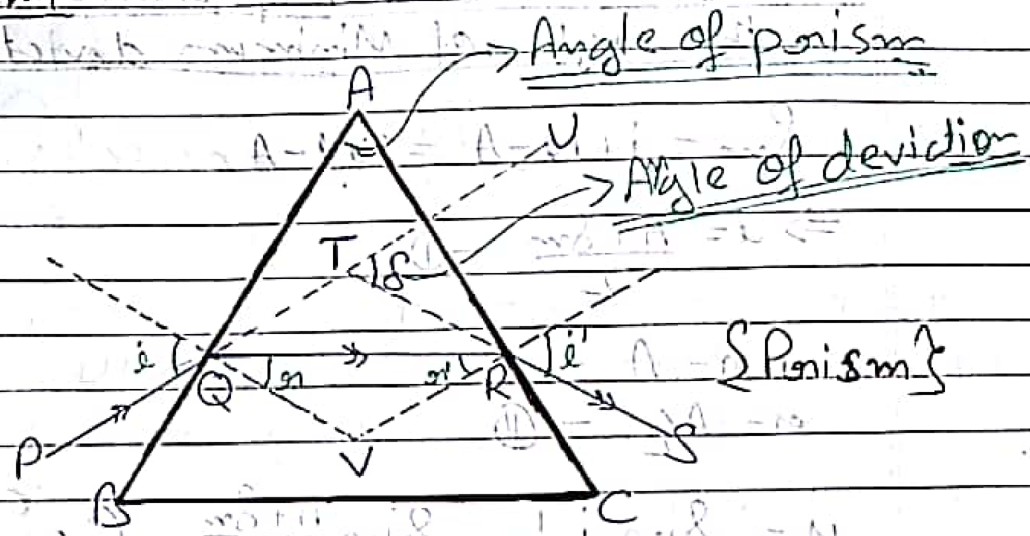


→ Because of the small radius of the fibre, light going into it makes a nearly glancing incidence on the wall.

$\boxed{i > \theta_c}$

• Hence total internal reflection takes place

⇒ Prism



$$\delta = (i - r) + (i' - r') = (i + i') - (r + r') \quad \text{—} \; (1)$$

$$A = \pi - (\bar{r} + \bar{r'})$$

$$A = \pi - \frac{\pi}{2} + r - \frac{\pi}{2} + r' = r + r' \quad \text{—} \; (11)$$

using (1) and (11) we get :-

$$\Rightarrow \delta = i + i' - A$$

$$\boxed{\delta = i - A + \sin^{-1}\left[\sin\left\{A - \sin^{-1}\left(\frac{1}{\mu}\sin i\right)\right\}\mu\right]}$$

→ for angle of minimum deviation :-

$\boxed{i = i'}$ ⟹ $\boxed{r = r'}$

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* Relation between Refractive Index and the angle of Minimum deviation

$\delta m = i + i - A = 2i - A$

$\Rightarrow i = \frac{A + \delta m}{2}$ — ①

$\Rightarrow r + r = A$

$r = A/2$ — ②

$\mu = \frac{\sin i}{\sin r} = \frac{\sin \frac{A + \delta m}{2}}{\sin A/2}$ {from ① & ②}

$\mu = \frac{A + \delta m}{2} \Big/ \frac{A}{2}$ {for small δm & A}

$\boxed{\delta m = (\mu - 1) A}$

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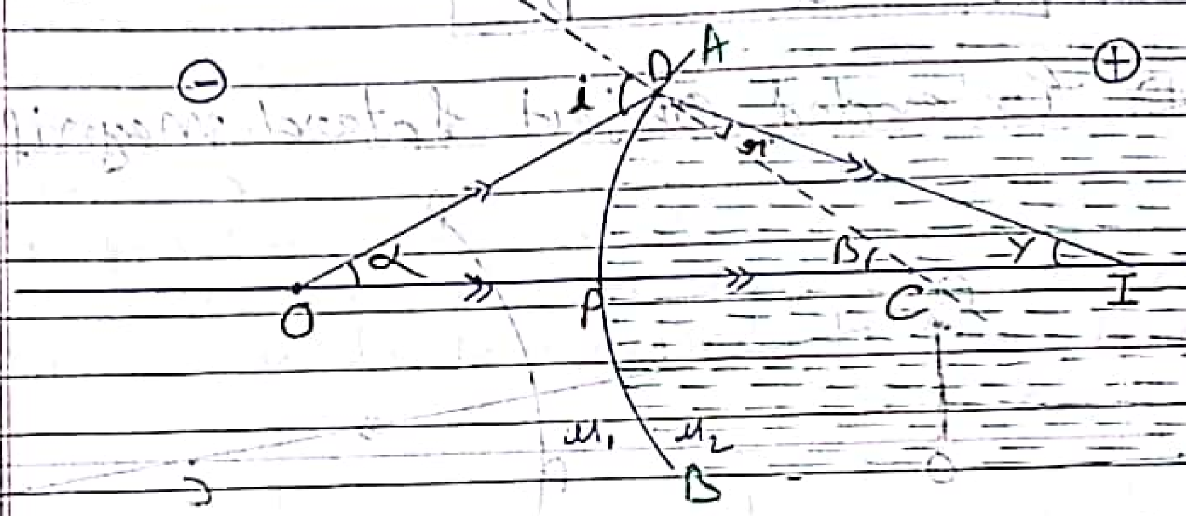
⇒ Refraction at Spherical Surface



* Relation between u v and R

$i = \alpha + \beta$ —— (I)

$\beta = \gamma + r$ —— (II)

$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} = \frac{i}{r}$ {for small i & r} —— (III)

// using (I) (II) and (III) we get :-

$\mu_1 \alpha + \mu_1 \gamma = (\mu_2 - \mu_1)\beta$ —— (a)

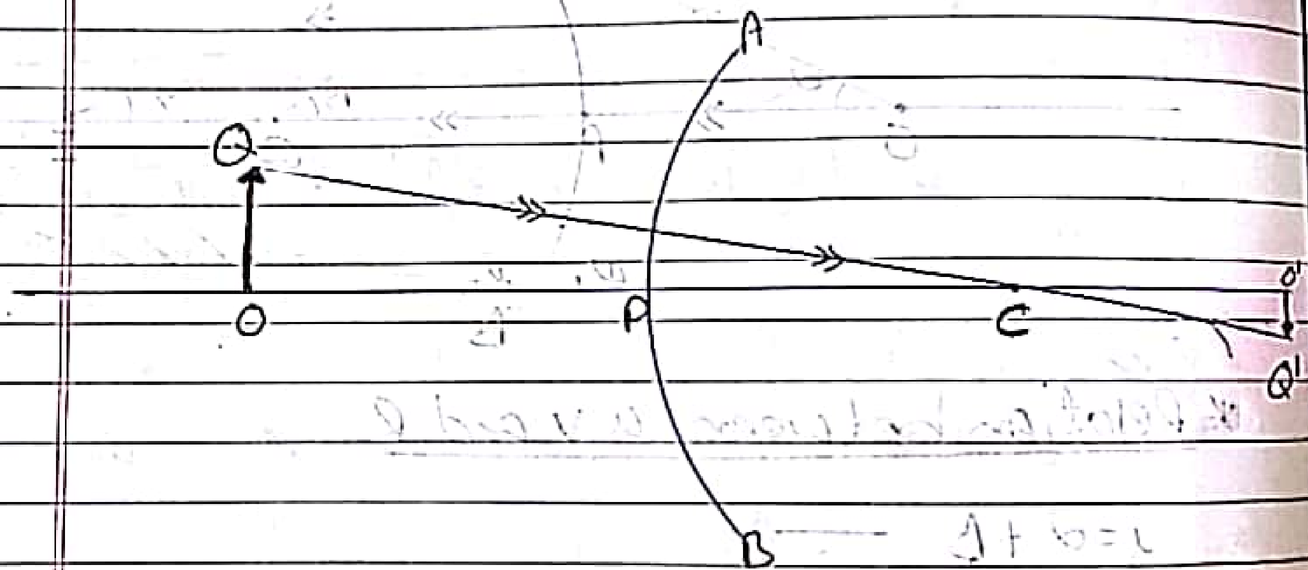
// $\alpha \approx \frac{DP}{PO}$ $\beta = \frac{DP}{PC}$ $\gamma \approx \frac{DP}{PI}$ —— (b)

// using (a) & (b) we get :-

$$\Rightarrow \mu_1\left(\frac{DP}{PO}\right) + \mu_2\left(\frac{DP}{PI}\right) = (\mu_2 - \mu_1)\left(\frac{DP}{PC}\right)$$

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

⇒ Extended Object Lateral magnification



* Lateral magnification, $m = \frac{\text{height of Image}}{\text{height of object}}$

$$m = -\frac{O'Q'}{OQ} = -\frac{PO' - PC}{PO' + PC} = -\frac{u - R}{-u + R}$$

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

$$\boxed{m = \frac{\mu_1 v}{\mu_2 u}}$$

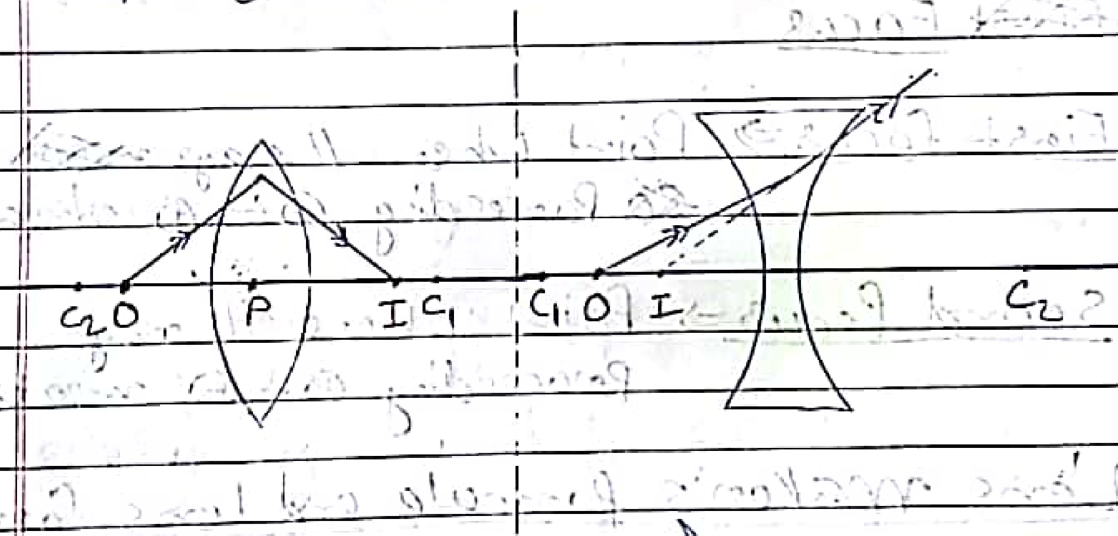
{Eleminating R from Relation

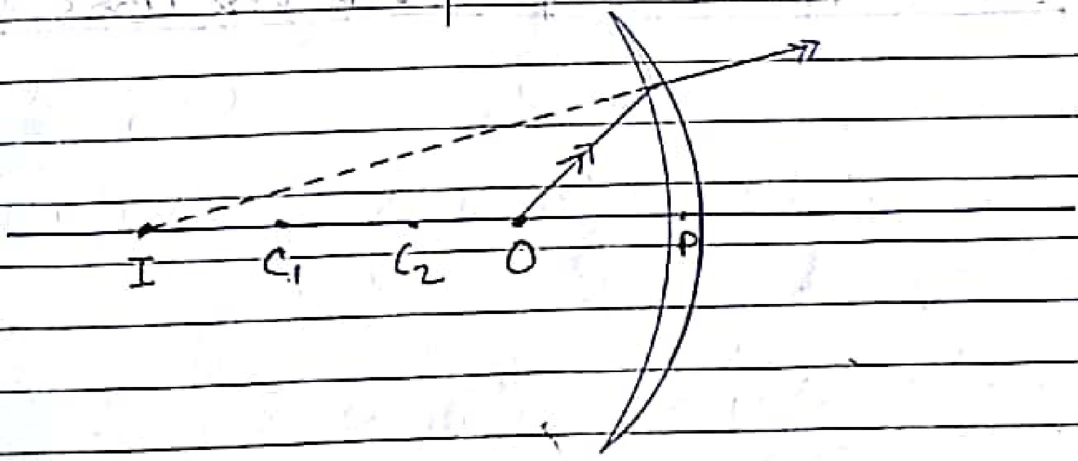
$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$
}

⇒ Refraction through thin lenses

→ A lens is made of a transparent material bounded by two spherical surfaces.

→ When the thickness of the lens is small compared to the other dimensions like object distance etc. we call it a thin lens.





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* **Principal axis** ⇒ line joining C_1 & C_2 is called principle axis.

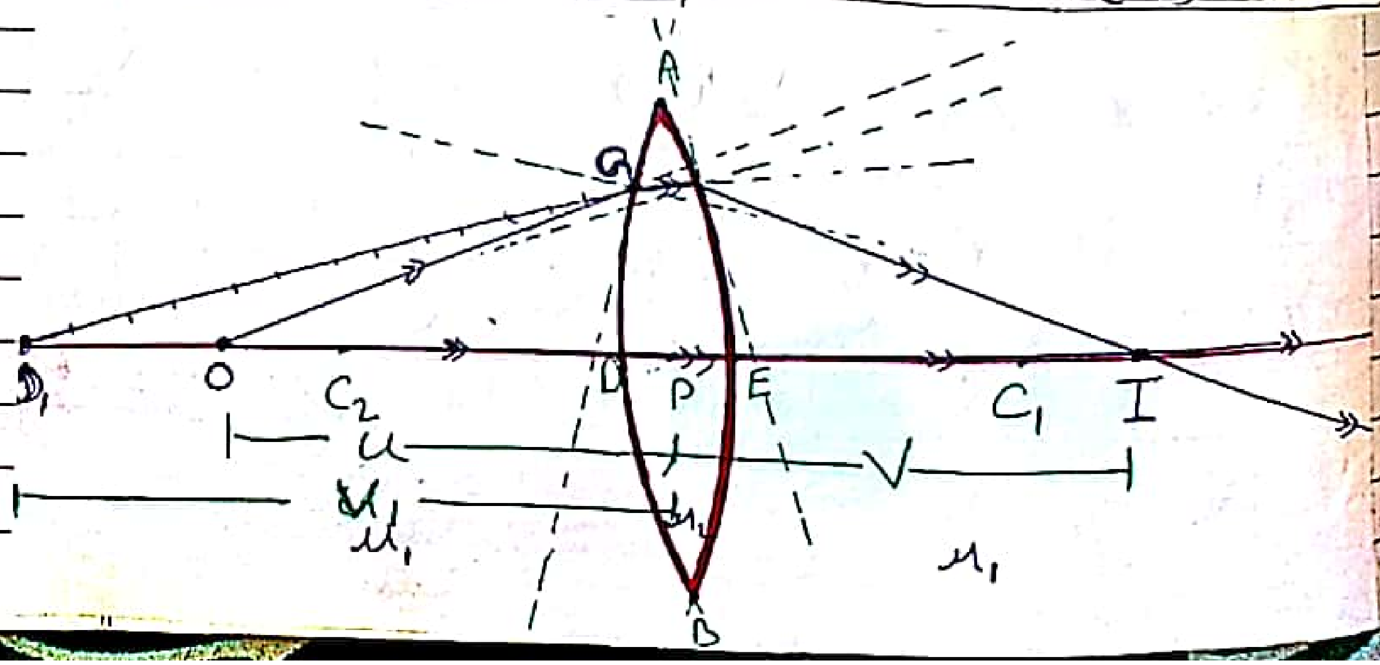
* **Optical Centre** ⇒ The centre P of the thin lens which lies on the principal axis is called the optical centre.

→ ~~First~~ **Focus**

* **First focus** ⇒ Point where ∥ rays proceeding ⊖ → ⊕ meets

* **Second focus** ⇒ Point where ∥ rays proceeding ⊕ → ⊖ meets.

⇌ **Lens maker's formula and lens formula**



// General equation for refraction at a Spherical Surface is :-

$$\boxed{\frac{\mu_2}{V} - \frac{\mu_1}{u} = \frac{\mu_2-\mu_1}{R}}$$ {Verified Earlier}

⇒ For refraction at surface (ADB) :-

$$\frac{\mu_2}{V_1} - \frac{\mu_1}{u} = \frac{\mu_2-\mu_1}{R_1} \quad \text{— (I)}$$

⇒ For refraction at surface (AEB) :-

$$\frac{\mu_1}{V} - \frac{\mu_2}{V_1} = \left(\frac{\mu_1-\mu_2}{R_2}\right) \quad \text{— (II)}$$

≈ adding Eq. (I) & (II) we get :-

$$\frac{1}{V} - \frac{1}{u} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{— (III)}$$

// Considering Ideal Condition

$V = \infty$ {far away}
$u = f$ {focus}
$\mu_2 = \mu$ {RI of lence}
$\mu_1 = 1$ {Ideal air}

$$\boxed{\frac{1}{f} = (\mu-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)} \quad \text{— (IV)}$$

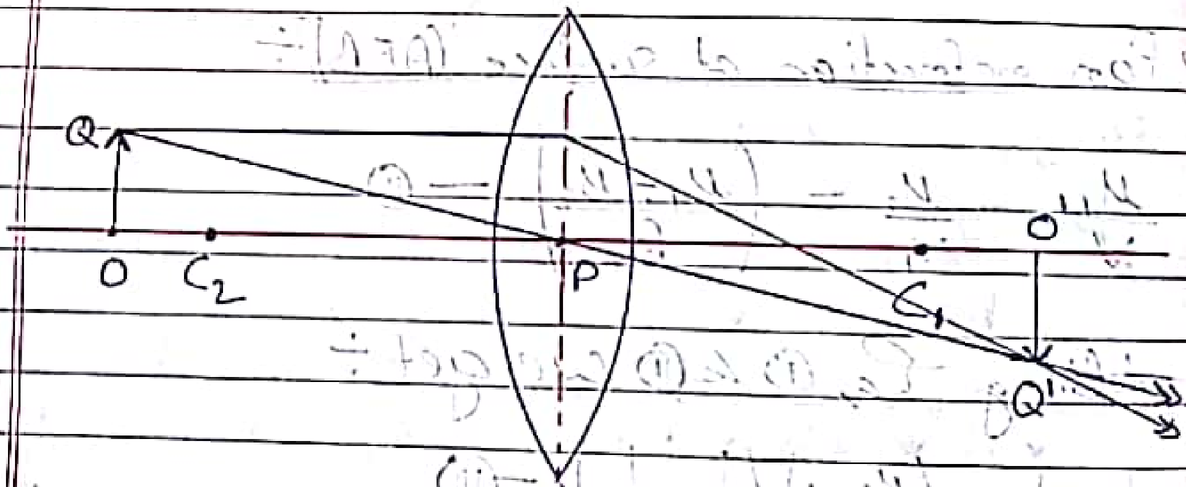
* This is called lence makers formula.

⇒ Comparing e_n (iii) & (iv) we get

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

*This is known as lence formula.

⇒ Extended Objects : Lateral magnification



$m = \frac{h_2}{h_1} = \frac{-Q'O'}{QO} = \frac{-PO'}{PO}$ {as $\Delta QOP \simeq \Delta Q'O'P$}

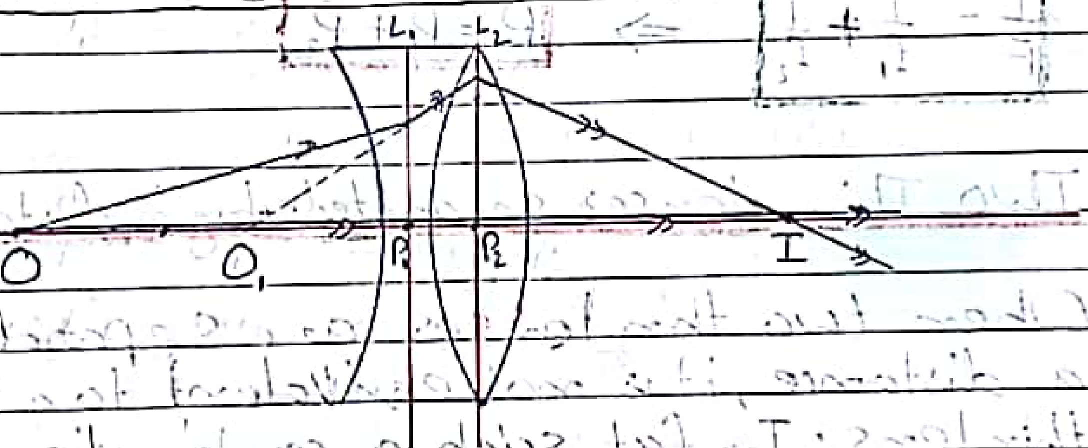
$m = \frac{-v}{-u} \Rightarrow \boxed{m = \frac{v}{u}}$

⇒ Power of lens (P)

$\boxed{P = \frac{1}{f}}$ {defination, where f = focal length}

→ SI unit of power of a lens is diopter.

⇒ Thin lenses in Contact



⇒ Let, u = object distance for the first lense
V = final image distance for the second lens.
V_1 = image distance of the first image O_1 for the first lence

* $\frac{1}{V_1} - \frac{1}{u} = \frac{1}{f_1}$ {for first lense} — (I)

* $\frac{1}{V} - \frac{1}{V_1} = \frac{1}{f_2}$ {for Second lens} — (II)

// Adding (I) & (II) we get :-

$\boxed{\frac{1}{V} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2}}$ — (III)

⇒ If the combination is replaced by a single lens of focal length F such that it form the image of O at the same position I.

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{F} \quad \text{—— (iv)}$$

// Comparing (iii) & (iv) we get :-

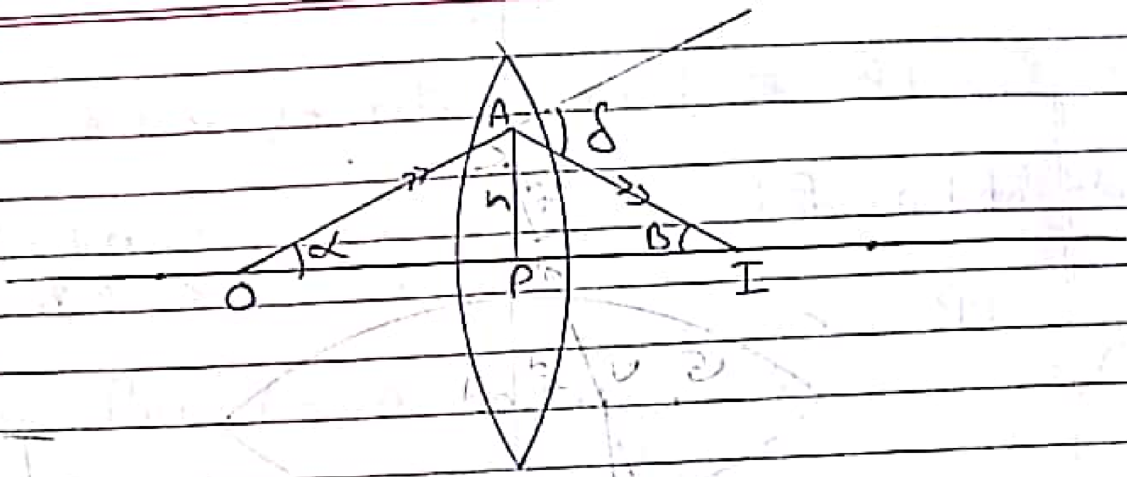
$$\boxed{\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}} \Rightarrow \boxed{P = P_1 + P_2}$$

⇒ **Two Thin lenses separated by a distance**

⇒ When two thin lenses are separated by a distance, it is not equivalent to a single thin lens. In fact such a combination can only be equivalent to a thick lens.

⇒ In a special case when the object is placed at infinity, the combination may be replaced by a single thin lens.

// Expression for angle of deviation



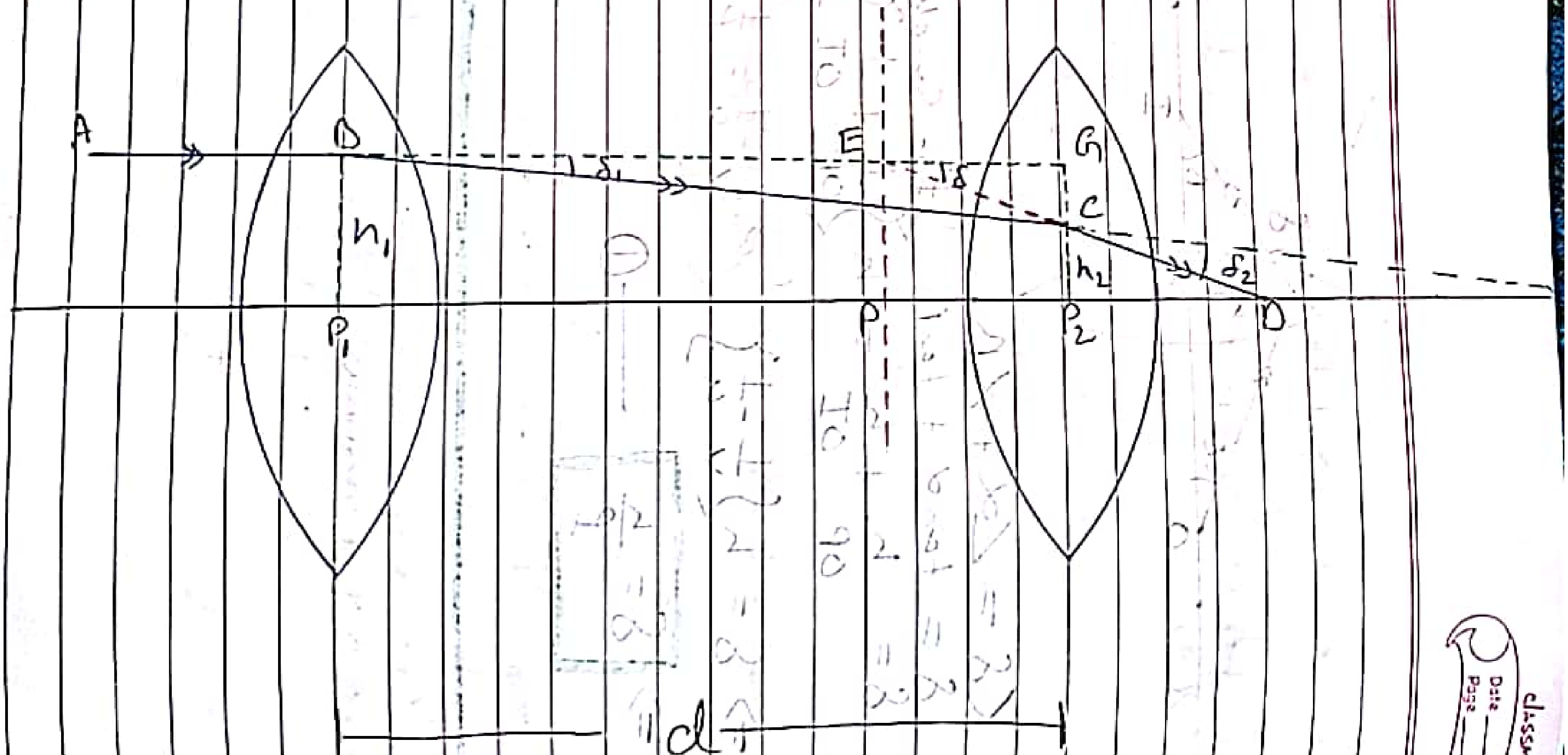
$\Rightarrow \angle\delta = \angle\alpha + \angle\beta$

$\Rightarrow \delta = \tan\alpha + \tan\beta$ {for small α & β}

$\Rightarrow \delta = \dfrac{h}{OP} + \dfrac{h}{OI} = h\left\{\dfrac{1}{OP} + \dfrac{1}{OI}\right\}$

$\Rightarrow \delta = h\left\{\dfrac{1}{v} - \dfrac{1}{u}\right\}$ $\left\{\text{as } \dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f}\right\}$

$\Rightarrow \boxed{\delta = \dfrac{h}{f}}$ —— (1)



A
B
E
G
C
D
δ1
δ
δ2
h1
h2
P1
P
P2
d

$\Rightarrow \delta = \delta_1 + \delta_2 \left\{ \text{from } \triangle BEC \right\}$ — (a)

$\Rightarrow$ Equivalent thin lense should be placed along EP with its pole at P.

$\Rightarrow$ The focal length of the equivalent lens, $F = PD$.

$$\delta_1 = \frac{h_1}{f_1} \;\&\; \delta_2 = \frac{h_2}{f_2} \;\&\; \delta = \frac{h_1}{F} \left\{ \text{from eq } (1) \right\}$$

$$\Rightarrow \delta = \delta_1 + \delta_2$$

$$\Rightarrow \frac{h_1}{F} = \frac{h_1}{f_1} + \frac{h_2}{f_2} \quad \text{— (b)}$$

$$h_1 - h_2 = GC = BG \tan \delta_1 = d \tan \delta_1 = \frac{d h_1}{f_1}$$

$$h_2 = h_1 - \frac{d h_1}{f_1} \quad \text{— (c)}$$

Using (c) & (b) we get:

$$\boxed{\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}} \quad \text{— (d)}$$

Position of Equivalent lens.

$PP_2 = EG = GC \cot\delta = \frac{h_1 - h_2}{\tan\delta} = \frac{h_1 - h_2}{\delta}$

$PP_2 = \frac{h_1 - h_2}{\delta}$ — (8)

using eq (6), (1) & $\{\delta = \frac{h_1}{F}\}$ we get :-

$PP_2 = \left(\frac{dh_1}{f_1}\right)\left(\frac{F}{h_1}\right)$

$$\boxed{PP_2 = \frac{dF}{f_1}}$$

---

* Chromatic aberration ⇒ It is a type of distortion in which there is a failure of a lens to focus all colours to the same convergence point.

⇒ Defects of Image

➔ The simple theory of image formation developed for mirrors and lenses suffers from various approximations.

* As a result, the actual images formed contains several defects.

Defects of Image

- Monochromatic Aberration
  - Spherical Aberration — defect due to which ‖ ray dose not meet at a point.
  - Coma — defect due to which ‖ ray dose not meet at a point
  - Astigmatism — defect due to which Point object image spread on principle axis
  - Curvature — defect due to which Perfect image is obtaind on curved surface not plane
  - Distortion — defect due to which magnification of extended object are different at different portion.
- Chromatic Aberration

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Wave Optics

⇒ Huygen's Principle

⇒ Huygen's considered light to be a mechanical wave moving in a hypothetical medium which was named as ether.

⇒ Huygen's principle may be stated in its most general form as follows ÷

"Various points of an arbitrary surface, when reached by a wavefront, become secondary sources of light emitting secondary wavelets. The disturbance beyond the surface results from the superposition of these secondary wavelets"

* Huygens' Construction

"Various points of an arbitrary surface, as they are reached by a wavefront, becomes the sources of secondary wavelets. The geometrical envelope of these wavelets at any given later instant represents the new position of the wavefront at that instant"

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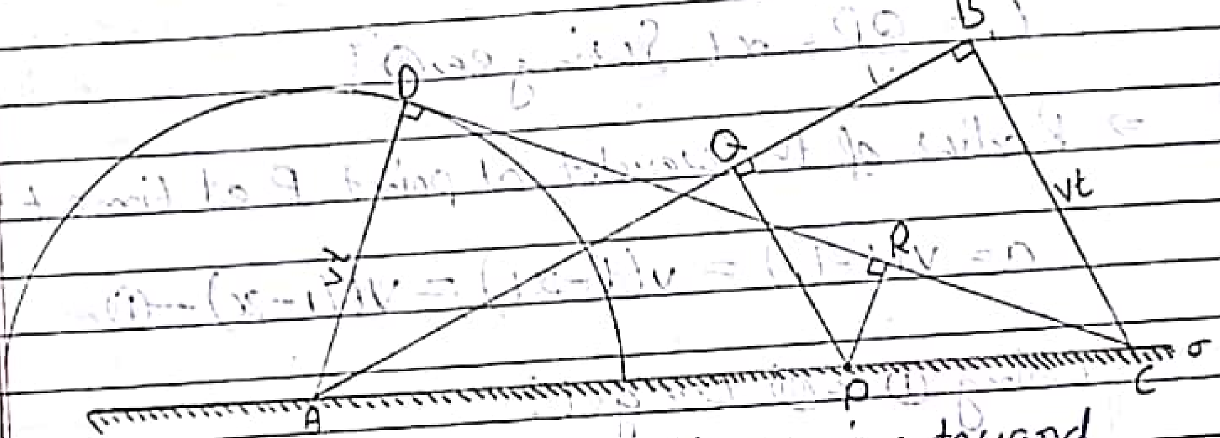
* Reflection of Light



⇒ Let us concider a wavelet AB moving toward reflecting surface σ ~~xxxxxx~~. Let at time t point B come in contact with σ at point C.

⇒ Let P be an point of σ between $\overline{AC}$.

$$\Rightarrow \frac{PR}{AD} = \frac{PC}{AC} = \frac{AC-AP}{AC} = 1 - \frac{AP}{AC} = 1 - x \quad \left\{ \text{let } x = \frac{AP}{AC} \right\}$$

$$\{\Delta ACD \sim \Delta PCR\}$$

$$\Rightarrow PR = AD(1-x) = vt(1-x) \quad \text{--- (I)}$$

also $$\Rightarrow \frac{QP}{BC} = \frac{AP}{AC} = x \quad \{\text{as } \Delta APQ \sim \Delta ACB\}$$

$$\Rightarrow QP = BCx = xvt \quad \text{--- (II)}$$

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⇒ Let t_1 be the time taken by wavefront to reach point P.

$$t_1 = \frac{QP}{V} = xt \text{ \{using eq (II)\}}$$

⇒ Radius of the wavelet at point P at time t:

$$a = v(t - t_1) = v(t - xt) = Vt(1 - x) \quad \text{— (III)}$$

⇒ Using (I) & (III) we get:

⇒ $a = PR$

* CD is tagent to ~~every~~ wavelet at point at time t.

* As P is an arbitrary point, Hence ~~at every~~ CD ~~point~~ is tagent to every wavelet formed from point within AC.

* Hence CD is new wave front at time t.

⇒ Hence incident ray is ⊥ to AC & reflected ray is ⊥ to CD.

$\angle i = \angle BAC$ & $\angle r = \angle ACD$

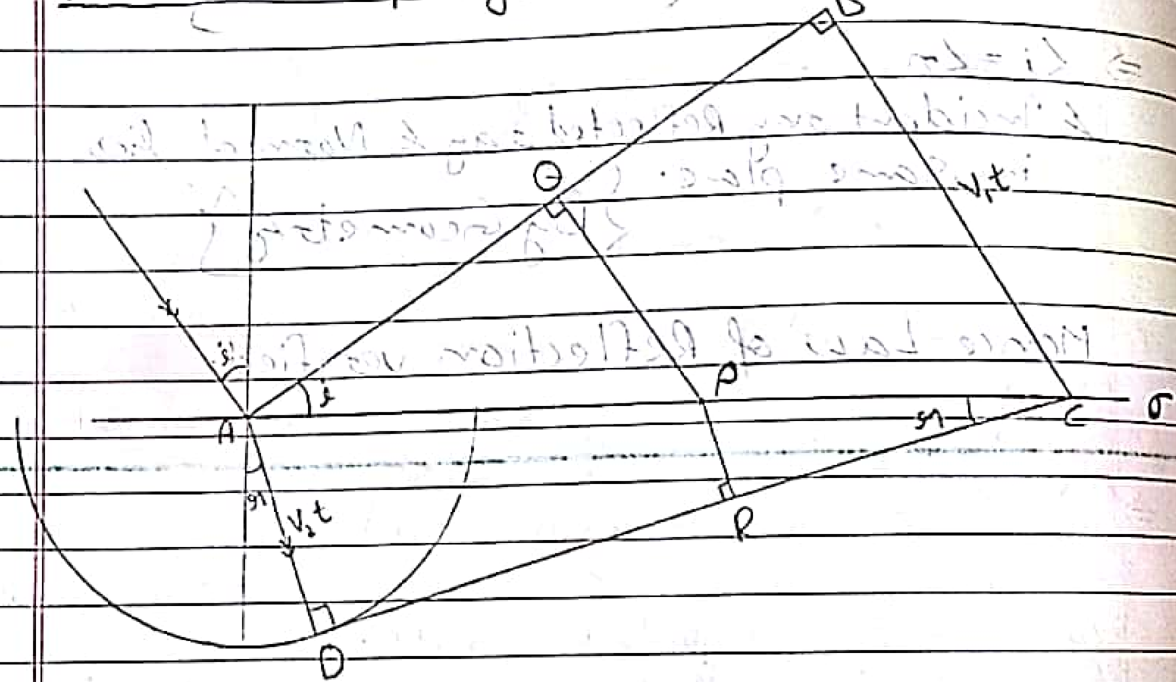
$\Rightarrow \angle BAC = \angle ACD$ {as $\triangle ACD \cong \triangle ABC$}

$\Rightarrow \angle i = \angle r$

& Incident ray, Reflected ray & Normal lies in same plane. {By Geometry}

Hence Law of Reflection verified.

* Refraction of light



$$\Rightarrow \frac{PR}{AD} = \frac{PC}{AC} = \frac{AC-AP}{AC} = 1-\frac{AP}{AC} = 1-x \left\{ \text{let } x = \frac{AP}{AC} \right\}$$

$$\Rightarrow PR = (AP)(1-x) = v_2 t(1-x) \quad \text{—(1)}$$

Also $\Rightarrow \frac{PQ}{BC} = \frac{AP}{AC} = x \Rightarrow PQ = (BC)x = v_1 t x$ —(ii)

// Let t_1 be the time taken by the wave front to reach point P.

$$t_1 = \frac{PQ}{v_1} = xt \{\text{using (ii)}\}$$

Let a be the radius of wavelet originated at point p.

$$a = V_2(t - t_1) = V_2 t(1 - x) \quad \text{---} (III)$$

Using eq. (I) & (III) we get :-

$\Rightarrow \quad a = PR$

Hence CD is the new wave front at time t.

$$\sin i = \frac{V_1 t}{AC} \quad \& \quad \sin r = \frac{V_2 t}{AC}$$

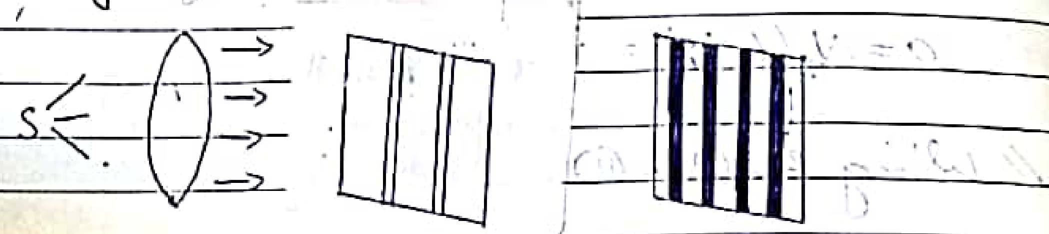
$\Rightarrow \boxed{\frac{\sin i}{\sin r} = \frac{V_1}{V_2}}$ Hence Snell's Law & Law of refraction is verified.

$\Rightarrow$ The ratio V_1/V_2 is called refractive index of medium 2 with respect to medium 1 and is denoted by μ_{21}.

$\Rightarrow$ If the medium 1 is vacuum, μ_{21} is simply the refractive index of the medium 2 and is denoted by μ_2.

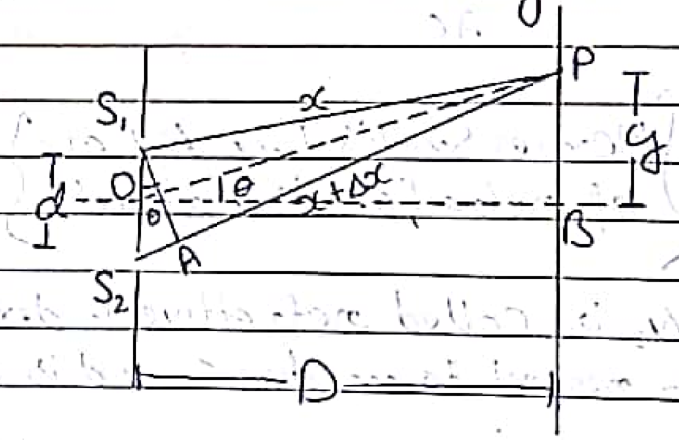
$$\Rightarrow \boxed{\mu_{21} = \frac{V_1}{V_2} = \frac{C/V_2}{C/V_1} = \frac{\mu_2}{\mu_1}}$$

⇒ Young's double Slit Experiment



Source   Slits   Fringes on Screen

* Fringes ⇒ Series of dark and bright Strips obtained on screen is called fringes.



$\{D \gg d\}$

Let us consider two wave one from S_1 & another from S_2 Interfare at a general point P.

$S_1P = x$; $S_2P = x + \Delta x$

* $E_1 = E_{01} \sin(kx - \omega t)$ $\left\{ \text{Electric field at point P due to } S_1 \right\}$

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* $E_2 = E_{02} \sin[k(x+\Delta x) - \omega t]$

$\Rightarrow E_{02} \sin[kx - \omega t + \delta]$ { Electric field at point P due to S_1 }

$\{ \delta = k\Delta x = \frac{2\pi}{\lambda} \Delta x \}$

$E = E_0 \sin(kx - \omega t + \varepsilon)$ { Resultant electric field at point P }

{ Where, $E_0^2 = E_{01}^2 + E_{02}^2 + 2E_{01}E_{02}\cos\delta$

$\tan\varepsilon = \frac{E_{02}\sin\delta}{E_{01} + E_{02}\cos\delta}$ }

The condition for constructive & destructive Interferences:-

(i) $\delta = 2\pi n$
$\Delta x = n\lambda$ for bright fringes
$\forall n \in$ Integer

(ii) $\delta = (2n+1)\pi$ for dark fringes
$\Delta x = (n+\frac{1}{2})\lambda$

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* Intensity Variation :

If the two slits are identical $E_{01} = E_{02} = E_0'$

$E_0^2 = 2E'^2(1+\cos\delta)$

$\Rightarrow I = 2I'(1+\cos\delta) = 4I'\cos^2\frac{\delta}{2}$

Note

→ Intencity is proportional to Square of Amplitude.

→ I = Resultant Intensity

→ I' = Intensity due to Single Slit

* $I = 4I'$ for Constructive Interferance

* $I = 0$ for ~~des~~ distructive Interferace.

* Fringe-width and determination of wavelength

* Fringe-width ⇒ The Separation on the screen between the centres of the two consecutive bright fringes or two consecutive dark fringes is called the fringe-width.

⇒ S_1P & S_2P are nearly $\parallel$ and hence S_1A is very nearly $\perp$ to S_1P, S_2P & OP.

$\{as\ D \gg d\}$

$\Rightarrow \angle S_2S_1A = \angle POB = \theta$

$\Rightarrow \Delta x = PS_2 - PS_1 \approx PS_2 - PA = S_2A$

$\Rightarrow d\sin\theta \approx d\tan\theta$ {for small θ}

$\Delta x = \dfrac{dy}{D}$

// for bright fringes

$\Delta x = d\dfrac{y}{D} = n\lambda$

$\Rightarrow \boxed{y = \dfrac{nD\lambda}{d}}$

// for dark fringes

$\Delta x = \left(n + \dfrac{1}{2}\right)\lambda$

$\Rightarrow \boxed{y = \left(n + \dfrac{1}{2}\right)\dfrac{D\lambda}{d}}$

Hence fringe-width is :-

$\boxed{\omega = \dfrac{D\lambda}{d}}$

Optical Path

⇒ Let us consider a light wave travelling in a medium of refractive index μ.

Its equation may be written as ÷

$$E = E_0 \sin \omega (t - x/v)$$

$$E = E_0 \sin \omega (t - \mu x/c)$$

⇒ In the light wave travels a distance Δx, the phase changes by:

$$\delta_1 = \mu \frac{\omega}{c} \Delta x \quad \text{—(I)}$$

⇒ If the light travels through a distance $\mu \Delta x$ in vacume then phase changes by ÷

$$\delta_2 = \mu \frac{\omega}{c} \Delta x \quad \text{—(II)}$$

By (I) & (II), we see that a wave travelling through a distance Δx in a medium of refractive index μ suffers the same phase change as when it travels a distance $\mu \Delta x$ In vacuum.

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⇒ The quantity $\mu \Delta x$ is called the optical path of the light.

Note

→ The geometrical path and the optical path are equal only when light travels in vacume or in air where the refractive index is close to 1.

⇒ The concept of optical path may also be introduced in terms of change in wavelength as the wave changes its medium.

⇒ If the wavelength of light in vacum is λ_0 and that in the medium is λ_n then :-

$$\lambda_0 = \frac{c}{f}$$

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

$$\Rightarrow \boxed{\lambda_n = \frac{\lambda_0}{\mu}}$$

Hence the Path λ_n in a medium is equivalent to path $\lambda_0 = \mu \lambda_n$ in vacume.

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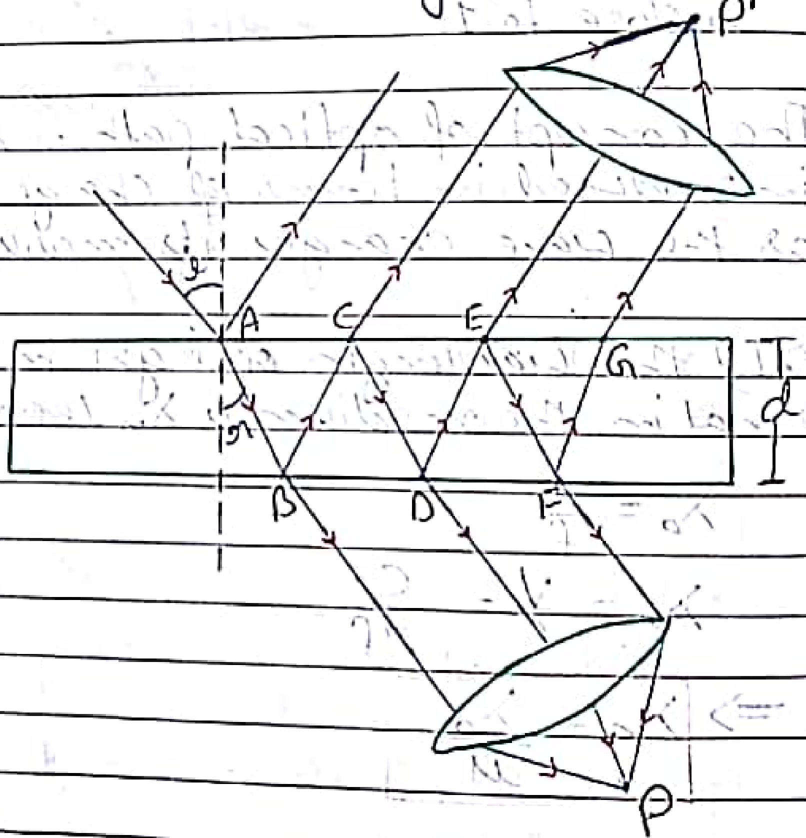
⇌ Interference from thin films

Consider a thin film made of a transparent material with plane parallel faces separated by a distance d.

⇒ Suppose a ∥ beam of light is incident on the film at an angle i as shown.



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⇒ The amplitude of the individual transmitted wave is different for different waves, it gradually decreases as more reflection's are involved.

// Let us consider the phase difference between BP & DP through a special case when $i=0$.

⇒ Geometrical path difference $= 2d$

⇒ Optical path difference $= 2\mu d$

⇒ $\Delta x = 2\mu d$ ⇒ $\boxed{\delta = \frac{2\pi}{\lambda}\Delta x = \frac{2\pi}{\lambda} \times 2\mu d}$

⇒ All these waves are in phase if

$\delta = 2n\pi$

⇒ $\frac{2\pi}{\lambda} \times 2\mu d = 2n\pi$

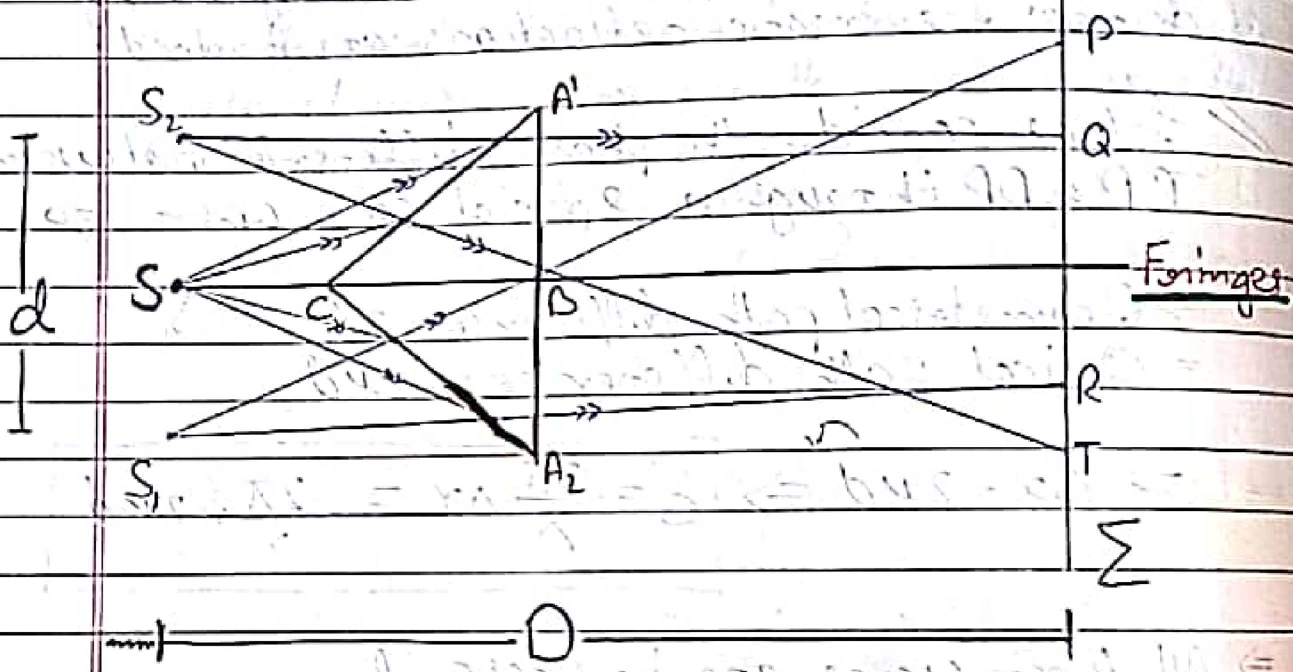
⇒ $\boxed{2\mu d = n\lambda}$ { Condition for maximum illumination in refraction }

⇒ All these waves are out phase if

$\delta = (2n+1)\pi$

$\boxed{2\mu d = \left(n+\frac{1}{2}\right)\lambda}$ { Condition for minimum illumination in ~~refraction~~ refraction }

⇒ Fresnel's Biprism



⇒ One can treat the points S_1 & S_2 as two coherent sources sending light to the screen.

⇒ The arrangement is then equivalent to a Young's double slit experiment with S_1 & S_2 acting as the two slits.

⇒ The fringe-width obtained on the screen is :-

$$\boxed{\omega = \frac{D\lambda}{d}}$$

⇌ Coherent & Incoherent sources

* Coherent sources ⇒ Two sources of light waves are said to be coherent if initial phase difference δ_0 between the waves remains constant in time.

* Incoherent Sources ⇒ Two Sources of light waves are Said to be Incoherent if initial phase difference δ_0 ~~ab~~ between the waves Changes randomly with time.

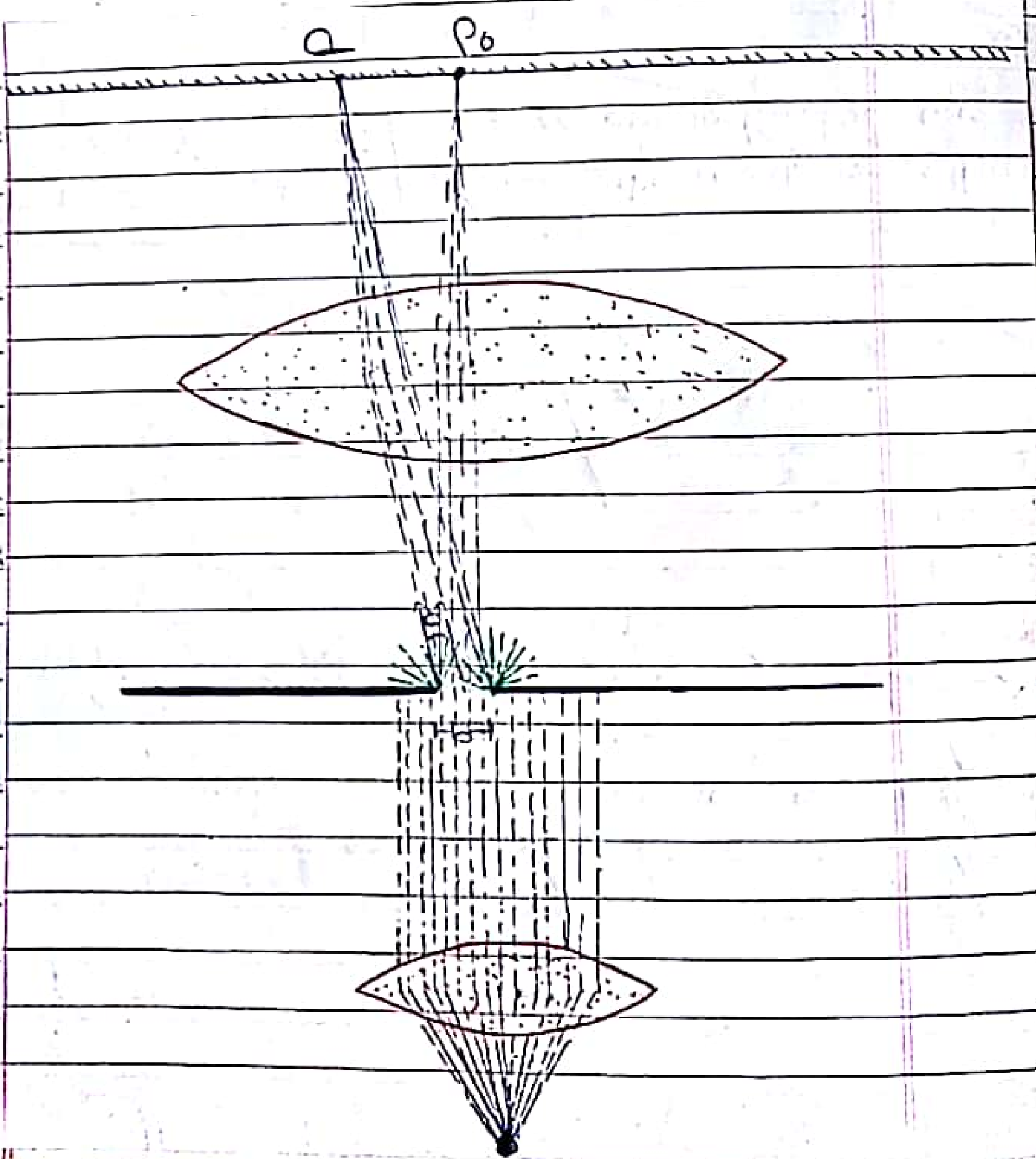
⇌ Diffraction of Light

* Diffraction ⇒ When a wave is obstructed by an obstacle, the rays bend round the corner. This phenomenon is Known as diffraction.

→ Fraunhofer diffraction ⇒ It deals with the limiting cases where the light approaching the diffracting object is parallel and monochromatic and where the image plane is at a distance large compared to the size of the diffracting object.

* **Fresnel diffraction** ⇒ Fresnel diffraction is a general form of Fraunhofer diffraction in which all the restrictions are relaxed.

⇒ **Fraunhofer diffraction by a Single Slit**



⇒ Suppose a parallel beam of light is incident normally on a slit of width b.

⇒ The light is received by a screen placed at a large distance. In practice, this condition is achieved by placing the screen at the focal plane of a converging lens placed just after the slit.

⇒ Let us consider a point P which collects the waves originating from different points of the slit at an angle θ.

⇒ The optical path difference between the waves sent by the upper edge A of the slit and the wave sent by the centre of the slit is $\frac{b}{2}\sin\theta$.

⇒ Consider the angle for which $\frac{b}{2}\sin\theta = \lambda/2$

$$\Rightarrow \delta = \frac{2\pi}{\lambda} \times \frac{\lambda}{2} = \pi$$

⇒ The two wave will cancel each other.

⇒ The whole slit can be divided into such pairs and hence, the intensity at P will be zero.

⇒ Condition for minima, $\boxed{b\sin\theta = n\lambda}$ {dark fringe}

Condition for maxima,

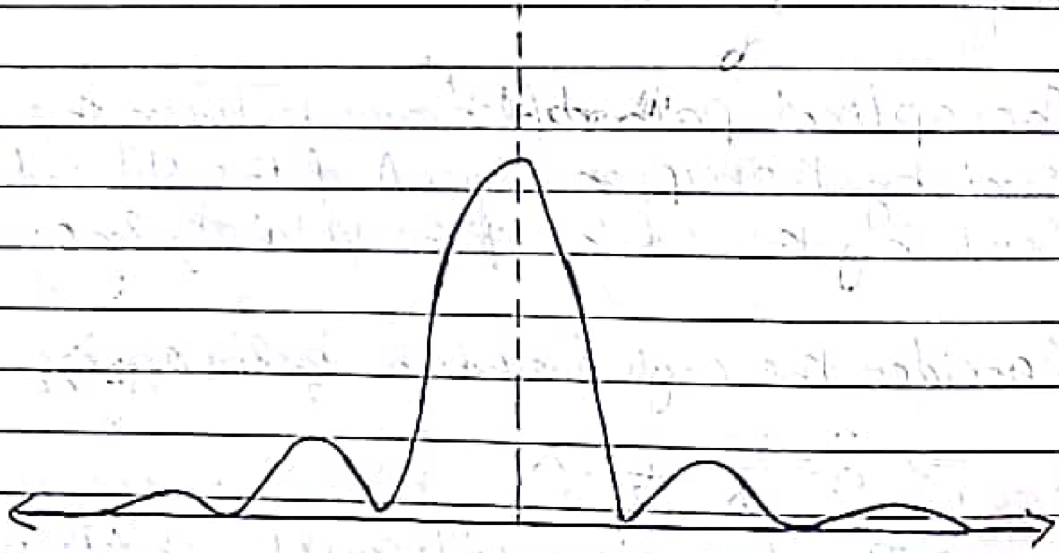
$$b \sin\theta = (n+\tfrac{1}{2})\lambda \quad \{n \to 1, 2 \cdot$$

⇒ A detailed mathematical analysis shows that the amplitude E_0' of the electric field at a general point P is :-

$$\boxed{E_0' = E_0 \frac{\sin\beta}{\beta}} \quad \left\{ \beta = \frac{1}{2}\frac{\omega}{v} b\sin\theta = \frac{\pi}{\lambda} b\sin\theta \right\}$$

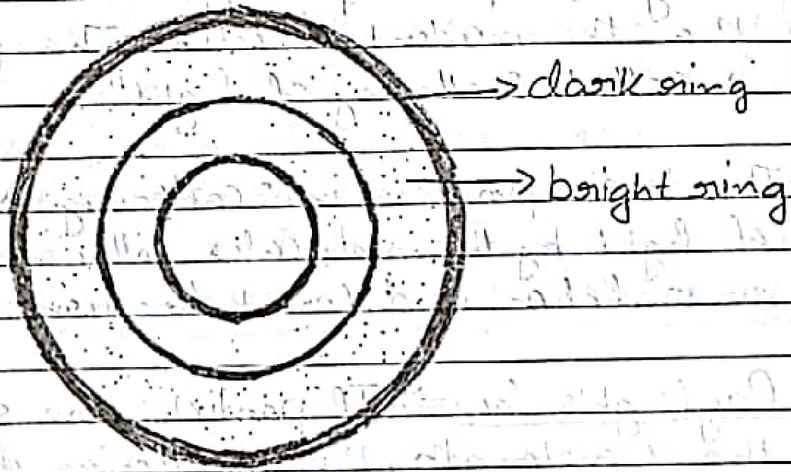
$$\boxed{I = I_0 \frac{\sin^2\beta}{\beta^2}}$$

{Intensity is proportional to the square of the amplitude}

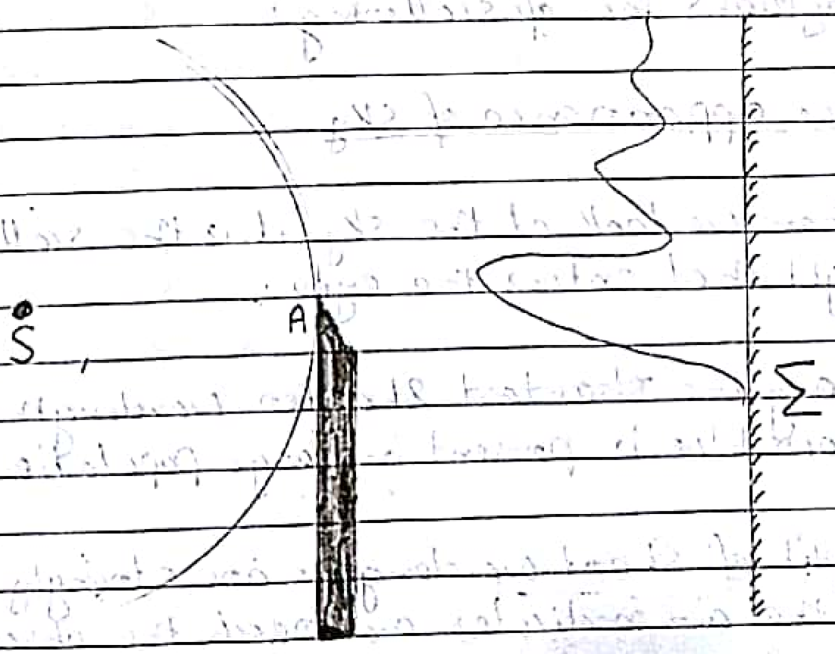


Rough Intensity variation

⇒ Fraunhofer diffraction by a Circular aperture



⇒ Fresnel diffraction at a straight edge



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⇒ Scattering of light

"When a parallel beam of light passes through a gas, a part of it appears in directions other than the incident direction. This phenomenon is called scattering of light"

⇒ The basic process in scattering is absorption of light by the molecules followed by its re-radiation in different direction.

* Rayleigh's law ⇒ If particle are smaller than the wavelength, the scattering of light is proportional to $1/\lambda^4$. ~~This~~ This is known as Rayleigh's law of scattering.

* Blue appearance of sky

⇒ When we look at the sky, it is the scattered light that enters the eyes.

⇒ Among the ~~shortest~~ shorter wavelengths, the colour blue is present in large population in sunlight

⇒ Light of short wavelengths are strongly scattered by the air molecules and reach the observer

⇒ This explains blue colour of sky.

* Red appearance of sun at the sunset and at the sunrise.

⇒ At these time, the sunlight has to travel a large distance through the atmosphere. The blue and neighbouring colours are scattered away in the path and the light reaching the observer is predominantly red.

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⇒ Polarization of light

* Plane polarized light ⇒ If electric field at a point always remains parallel to a fixed direction as time passes, the light is called linearly polarized along that direction. Also called plane polarized light.

* Unpolarized light ⇒ If electric field at a point changes direction randomly, then the light is called unpolarized light.

⇒ Suppose an unpolarized light wave travels along the x-axis. The electric field at any instant is in the Y-Z plane, ~~and~~ we can break the field into its components E_y & E_z.

⇒ The fact that the resultant electric field changes its direction randomly may be mathematically expressed by saying that E_y and E_z have a phase difference δ that changes randomly with time.

$$E_y = E_1 \sin(\omega t - kx + \delta)$$
$$E_z = E_2 \sin(\omega t - kx)$$

$\Rightarrow$ If $\delta = \pi/2$ and $E_1 = E_2$ then,

$$\tan\theta = \frac{E_z}{E_y} = \frac{E_2 \sin(\omega t - kx)}{E_1 \sin(\omega t - kx + \pi/2)} = \tan(\omega t - kx)$$

$$\Rightarrow \theta = \omega t - kx$$

$$\& \quad E^2 = E_y^2 + E_z^2 = E_1^2 = E_2^2$$

$\Rightarrow$ The tip of the electric field thus, goes in a circle at a uniform angular speed. Such light is called Circularly polarized light.

$\Rightarrow$ If $\delta = \pi/2$ but $E_1 \neq E_2$, the tip of electric field traces out an ellipse. Such a light wave is called elliptically polarized light.

★ Polaroids

$\Rightarrow$ Plane sheets in the shape of circular discs called polaroids are commercially available which transmit light with E-vector parallel to a special direction in the sheet.

$\Rightarrow$ These polaroids have long chain of hydrocarbon which becom conducting at optical frequencies.

⇒ When light falls perpendicularly on the sheet, the electric field parallel to the chains is absorbed in setting up electric currents in the chains but the field perpendicular to the chain gets transmitted.

⇒ The direction perpendicular to the chains is called the transmission axis of the polaroid.

★ Polarization by Reflection and Refraction.

⇒ If the light is incident on the surface with an angle of incidence i such that:-

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

⇒ The reflected light is completly polarized with the electric field along the z-direction.

⇒ The refracted ray is never completely polarized.

⇒ The angle i is called Brewster's angle and equation itself is known as the Brewster's Law.

★ Polarization by Scattering

⇒ When unpolarized light is scattered by small particles, the scattered light is partially polarized.

"Austrian Novel Laureate Karl Von Frisch performed experiments for several years on bees and concluded that the bees can not only distinguish unpolarized light from polarized light but can also determine the direction of polarization"

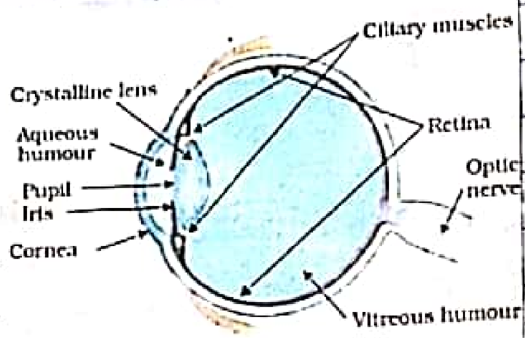
★ Malus law

⇒ If the E-Vector is at an angle θ with the transmission axis, light is partially transmitted. The intensity of the transmitted light is :-

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

3
Optical Instruments

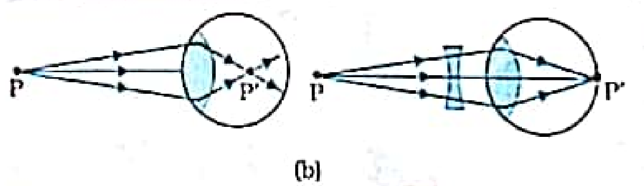
★ EYE



* Accomodation ⇒ Accomodation is the process by which the vertebrate eye changes optical power to maintain a clear image.

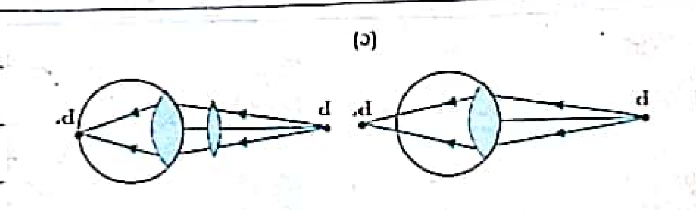
* Presbyopia ⇒ Presbyopia is a condition where with age, the eye exhibits a progressively diminished ability to focus on near object.

* Miopia {nearsightedness} ⇒ Myopia is a condition of the eye where the light that comes in does not directly focus on the retina but in front of it.

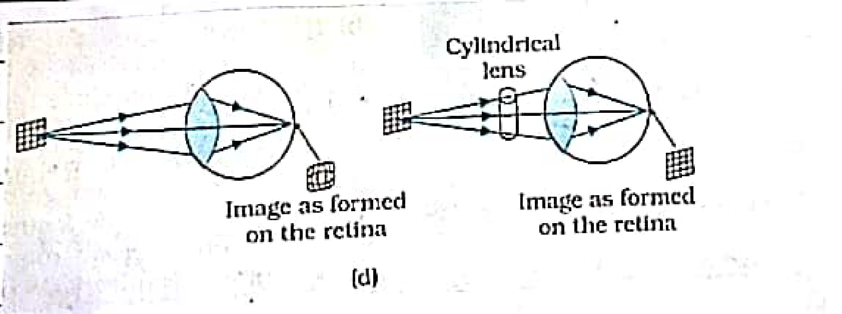


(b)

* Hypermetropia {farsightness} ⇒ Hypermetropia is a condition of the eye where the light that comes in does not directly focus on the retina but away from it.

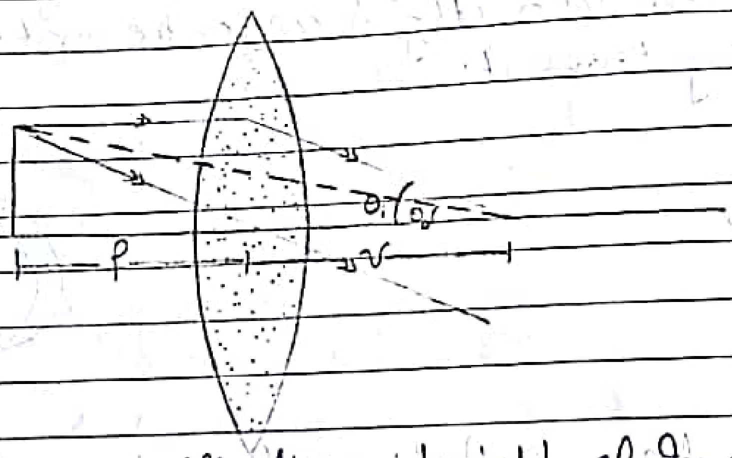


* Astigmatism ⇒ Astigmatism is an optical defect in which vision is blurred due to the inability of the optics of the eye to focus a point object into a sharp focused image on the retina.



(d)

★ MICROSCOPE



* linear magnification = $\frac{\text{height of Image}}{\text{height of object}}$

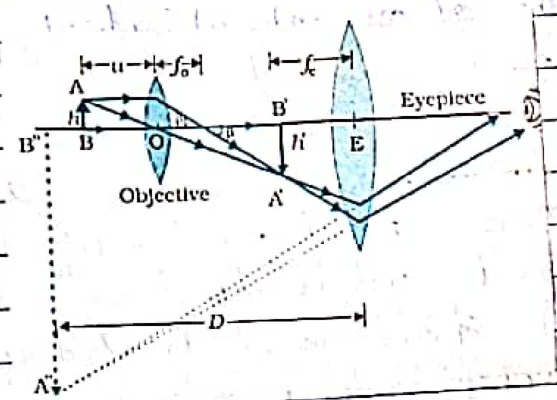
* Angular magnification = $\frac{\theta_i}{\theta_o}$

⇒ linear magnification = $\frac{v}{u} = \left(1 + \frac{D}{f}\right)$

⇒ Angular magnification = D/f

⇒ A Simple microscope has a limited maximum magnification (<9).

* Compound microscope ⇒ Light microscope that uses two converging lens system : the objective and the eyepiece.



$$m_o = \frac{h'}{h} = \frac{L}{f_o} \quad ; \quad m_e = 1 + \frac{D}{f_e}$$

$$\Rightarrow m = m_o m_e = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$$ {m = Total magnification}

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

★ TELESCOPE

"Telescope is an instrument that aids in the observation of remote objects by collecting electromagnetic radiation"

⇒ Magnifying power of a telescope is the ratio of the angle β subtended at the eye by the image to the angle α subtended at the eye by the object.

$$m = \frac{\beta}{\alpha} = \frac{f_o}{f_e}$$

Where, f_o and f_e are the focal length of the objective and ~~the~~ eyepiece respectively.

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★ Doppler Effect

"Doppler effect is change in frequency of wave for an observer moving relative to its source".

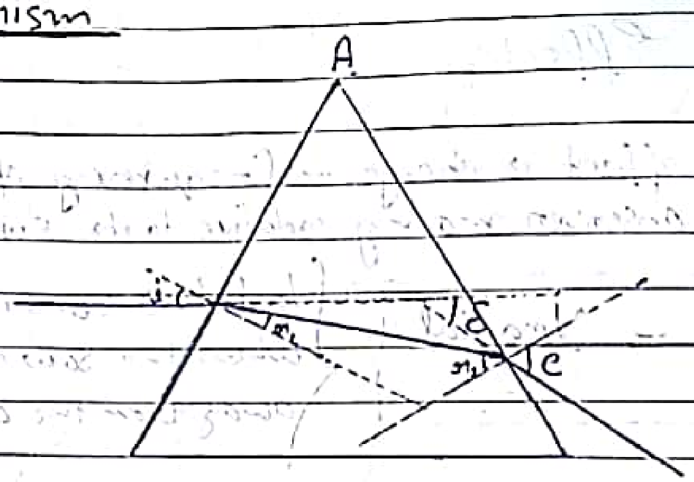
$$\boxed{\frac{\Delta f}{f_0} = \frac{V_{radial}}{C}}$$

{ V_{radial} is concidered positive when the source moves away from the observer }

* Red Shift ⇒ Source moving away from observer results in Redshift.

* Blue Shift ⇒ Source moving toward observer results in Blueshift.

Prism



$\angle A$ = Angle of prism
$\angle i$ = Angle of incidence
$\angle e$ = Angle of emergence

$$A + (90 - r_1) + (90 - r_2) = 180$$

$$\Rightarrow A = r_1 + r_2 \quad \text{—(1)}$$

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

$$\Rightarrow \delta = i + e - (r_1 + r_2)$$

$$\Rightarrow \delta = i + e - A \quad \{\text{from equation 1}\}$$

for minimum deviation $i = e$. $\cancel{r_1 = r_2}$

Hence, $r_1 = r_2$ {from Symmetry}

$\Rightarrow \delta = 2i - A \Rightarrow i = \frac{\delta + A}{2}$ — (a)

$\Rightarrow r_1 + r_2 = A$

$\Rightarrow 2r_1 = A \; \{as\; r_1 = r_2\}$

$\Rightarrow r_1 = A/2$ — (b)

$$\mu = \frac{\sin i}{\sin r_1} = \frac{\sin\left(\frac{\delta + A}{2}\right)}{\sin (A/2)} \quad \{\text{from eq (a) \& (b)}\}$$

$$\Rightarrow \boxed{\mu = \frac{\sin\left(\frac{\delta + A}{2}\right)}{\sin(A/2)}}$$

Experimental Result

$$\boxed{\mu = \mu_0 + \frac{A}{\lambda^2}}$$ {Law of dispersion}

N	V	I	B	G	Y	O	R	~

400nm — 700nm

Understanding Concepts

★ Simple Microscope

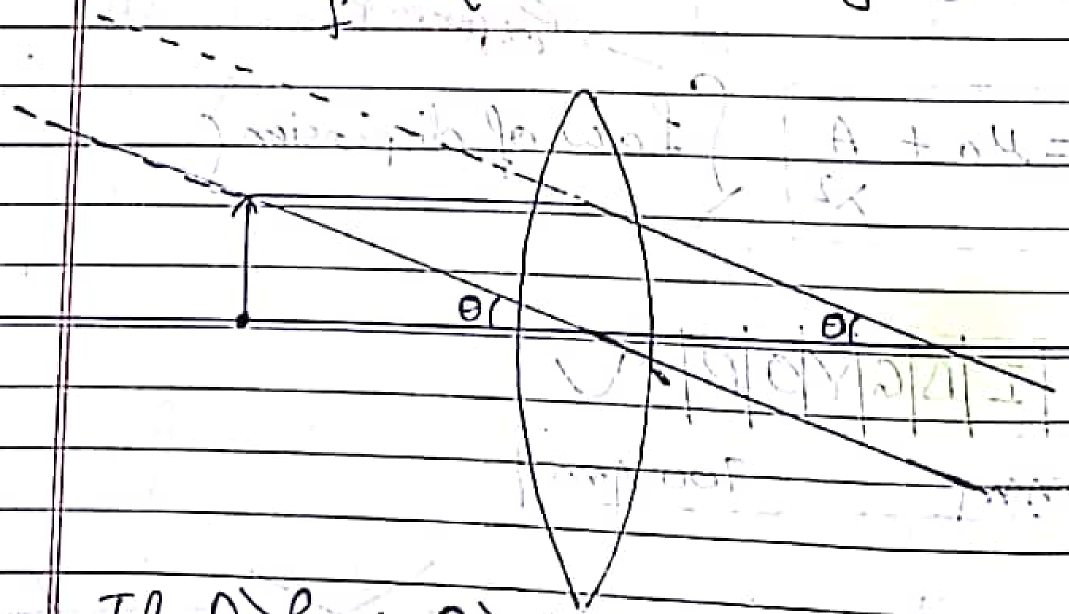
⇒ When we view an object with naked eyes, the object must be placed somewhere between infinity and the near point.

⇒ Maximum angle is subtended on the eye when the object is placed at the near point.

$$\theta_0 = \frac{h}{D} \quad \left\{ \begin{array}{l} h = \text{Size of object} \\ D = \text{least distance} \end{array} \right\}$$

// Suppose, the lens has a focal length f; $D > f$

$$\theta = \frac{h}{f} \quad \{ f = \text{focal length} \}$$



If $D > f$; $\theta > \theta_0$

Hence, the eye ~~per~~ perceives a larger image than it could have had ~~with~~ without the microscope.

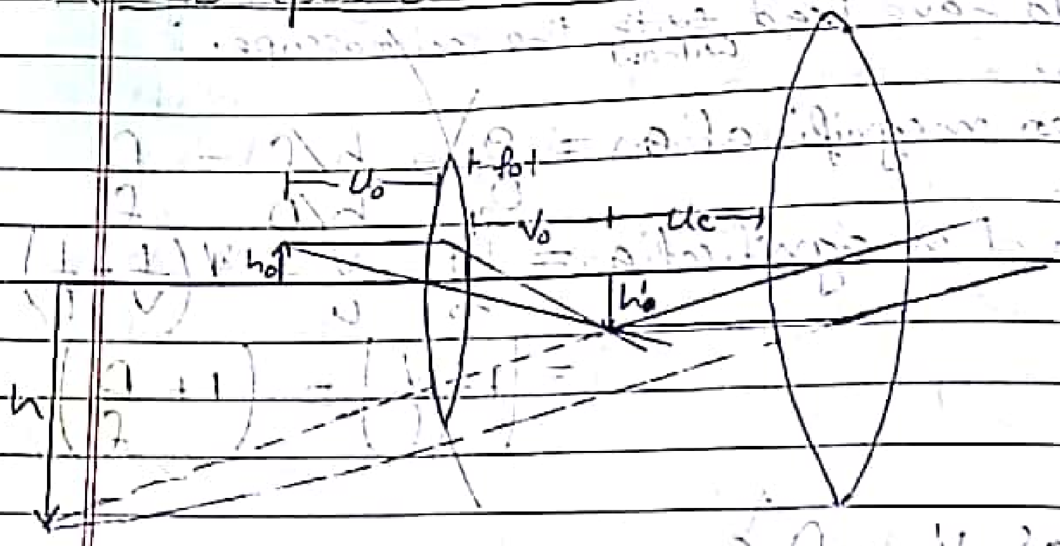
$$\text{Angular magnification} = \frac{\theta}{\theta_0} = \frac{h/f}{h/D} = \frac{D}{f}$$

$$\text{Lateral magnification} = \frac{h_i}{h_o} = \frac{v}{u} = v\left(\frac{1}{v} - \frac{1}{f}\right)$$

$$= \left(1 - \frac{v}{f}\right) = \left(1 + \frac{D}{f}\right)$$

$\{$as $v = -D\}$

★ Compound microscope



⇒ Magnification by compound microscope is in two steps :-

① In first step the objective produces a magnified image of the given object.

② In second step the eyepiece produces an angular magnification

$$\theta_o = h/D \quad — ①$$

⇒ When compound microscope is used, the final image subtend an angle θ' on the eye piece

$$\theta' = \frac{h'}{u_e} \quad — ①$$

$\Rightarrow$ Magnifying power of the compound microscope is therefore :-

$$m = \frac{\theta'}{\theta_0} = \cancel{\frac{h}{D}} \times \cancel{\frac{u_e}{h'}} \frac{h'}{u_e} \times \frac{D}{h}$$

$$\Rightarrow \left(\frac{h'}{h}\right)\left(\frac{D}{u_e}\right)$$

$$\Rightarrow \frac{v}{u}\left(\frac{D}{f_e}\right) \cancel{= \left(1+\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)}$$

$$\Rightarrow \left(\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)$$

Hence, $\boxed{m = \left(\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)}$

★ **Limit of Resolution**

The fact that a lens forms a disc image of a point source, puts a limit on resolving two neighbouring points imaged by lens.

⇒ A detailed analysis shows that the radius of the central bright region is approximately given by :-

$$\boxed{r_0 \simeq \frac{0.61 \lambda f}{b}}$$

$\left\{ \begin{array}{l} b = \text{radius of lense} \\ f = \text{focal length} \end{array} \right\}$

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★ Validity of Ray Optics

Ray optics is good ~~appo~~ approximation at a distance Z_F where :-

$$\boxed{Z_F = \frac{a^2}{\lambda}}$$

a = Size of ~~opp~~ aperture
aperture ⇒ {Slit or hole}
λ = Wave-length

The quantity Z_F is called Fresnel distance.

Huygens principle

According to huygens principle, each point of the wavefront is the source of secondard disturbance. Wavelet emerging from these points spreads out in all direction with speed of the wave. A common tangent to all these wavelet, gives the new position of the wavefront at a later time.

Electromagnetic ~~wate~~ wave

Type	Wavelength Range	
① Radio	$> 0.1 m$	
② Microwave	$0.1 m - 1 mm$	
③ Infrared	$1 mm - 700 nm$	
④ Light	$700 nm - 400 nm$	$1.7 eV \longleftrightarrow 3 eV$
⑤ Ultraviolet	$400 nm - 1 nm$	
⑥ X-rays	$1 nm - 10^{-3} nm$	
⑦ Gama-rays	$< 10^{-3} nm$	

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Optics Revision

① Rectilinear propagation of light.

"In a medium whose refractive index in not changing, light ~~travels~~ travels in straight path indipendent of any other parameter"
{Classical prospective}

Note
⇒ In relativestic prospective light bends in a medium with constant refractive index in presence of gravity field. But that deviation is insignificat relative to classical prospective"

② Reflection and Refraction at Plane and Spherical Surface

Ⓐ Reflection at Plane Surface

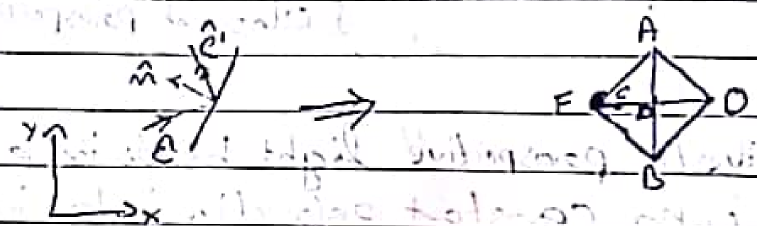
[I] Newton Law of Reflection

ⓐ The angle of incidence is equal to the angle of reflection.

ⓑ The incident ray, the reflected ray and the normal to the reflecting surface are coplaner.

[II] Newton Law of reflection in vector form

Let us consider $\hat{e}$, $\hat{e}'$ and $\hat{n}$ be unit vectors parallel to incident ray, reflected ray and normal to the plane



BO $\Rightarrow \hat{e}$

OA $\Rightarrow \hat{e}'$

OC $\Rightarrow \hat{n}$

$$|\vec{BO}\cdot\vec{OC}| = |\vec{BD}|$$

$\Rightarrow$ AD = DB $\Rightarrow$ {∠AOC = ∠BOC}

$$|\vec{AB}| = 2|\vec{BD}| = 2|\vec{BO}\cdot\vec{OC}|$$

$$\cancel{\vec{BO}+\vec{OA}=\vec{BA}}$$

$$\vec{OB}+\vec{OA}=\vec{OE}$$

$$|\vec{OE}| = |\vec{AB}|$$ {as AOBE is Square}

$$\Rightarrow \vec{OE} = 2|\vec{BO}\cdot\vec{OC}|\vec{OC}$$

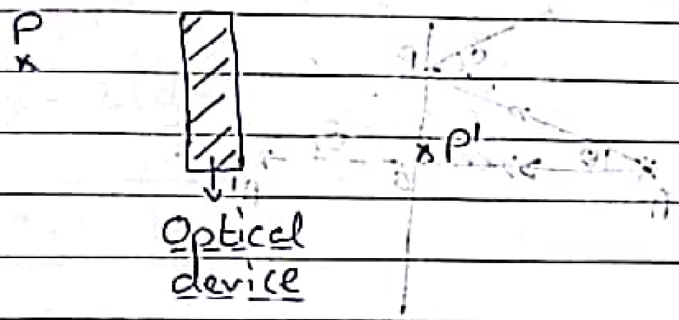
$$\Rightarrow \vec{OB}+\vec{OA} = 2|\vec{BO}\cdot\vec{OC}|\vec{OC}$$

$$\Rightarrow -\hat{e}+\hat{e}' = 2(\hat{n}\hat{e})\hat{n}$$

$$\cancel{\Rightarrow e' = \hat{e} - 2(\hat{e}\hat{n}}$$

$$\boxed{e' = e - 2(en)n}$$

[III] Image



→ A point is visible if light comes from it or spreads from it or seems to spread from it in all direction.

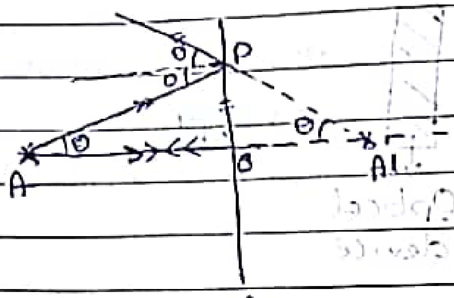
→ The point P' is the image of point P if light rays from P intersect at P'.

→ Intensity or Brightness of Image will be proportional to amount of light intersect at point P'.

★ Real Image ⇒ Image in which light ray comming from object actualy Intersect.

★ Virtual Image ⇒ Image in which light ray comming from object only seems to Intersect but not intersect actualy.

[IV] Image formation due to plane mirror



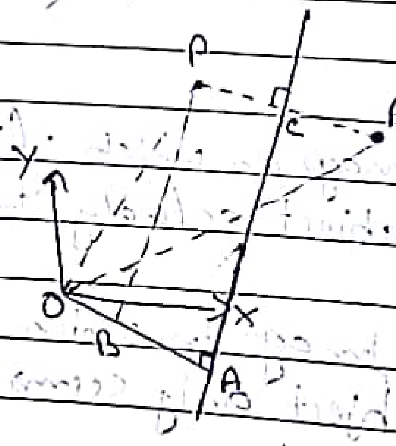
$\Delta APO \sim \Delta A'PO$ {as $\angle PAO = \angle PA'O$ & $\angle POA = \angle POA' = 90$}

$\Rightarrow OA = OA'$ {independent of θ}

[V] Image formation due to plane mirror in vector form

Let $\vec{r}_o$ and $\vec{r}_i$ be the position vector of point object and its image.

Let $\vec{r}\cdot\hat{n} = d$ be the equation of plane mirror



$\Rightarrow OA \perp PC$

$|\vec{OA}| = d$

$|\hat{OA}\cdot\vec{OP}| = |\vec{OB}|$

$|\vec{BA}| = |\vec{PC}| = |\vec{OA}| - |\vec{OB}|$

$|\vec{PP'}| = 2|\vec{PC}|$

$= 2\{|\vec{OA}| - |\hat{OA}\cdot\vec{OP}|\}$

$$\vec{OP'} + \vec{P'P} = \vec{OP}$$

$$\vec{OP'} = \vec{OP} - \vec{P'P}$$

$$\vec{r_i} = \vec{r_o} - 2(d - (rn))\hat{n}$$

$$\Rightarrow \boxed{r_i = r_o - 2[d - (rn)]\hat{n}}$$

(B) Reflection at curved surface

[I] Mirror formula

$$\boxed{\frac{1}{V} + \frac{1}{u} = \frac{2}{R} = \frac{1}{f}}$$

{Mirror formula is symmetric about Image & Object}

$$\boxed{m = -\frac{V}{u}}$$

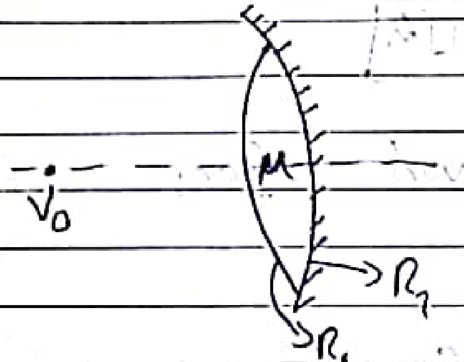
[II] Coordinate of Image with given Coordinate of object with pole at origin and mirror and principle axis oriented along y- & x- axis respectively

$$[u_x, u_y] \Longrightarrow \cancel{\left[\frac{u_x f}{-f+u_x}, \frac{-u_y f}{-f+u_x}\right]}$$

$$\Rightarrow \left[\frac{u_x f}{u_x - f}, \frac{-u_y f}{u_x - f}\right]$$

~~Ⓒ Refraction at plane Surface~~

Thin lences Combined With Mirror



$(-1)\times \quad \frac{\mu}{v_1} - \frac{1}{v_0} = \frac{\mu-1}{R_1}$

$\mu \times (+) \quad \frac{1}{v_2} + \frac{1}{v_1} = \frac{2}{R_2}$

$\frac{1}{v_3} - \frac{\mu}{v_2} = \frac{1-\mu}{R_1}$

$(+) \quad \frac{1}{v_3} + \frac{1}{v_0} = \frac{2\mu}{R_2} + \frac{2(1-\mu)}{R_1} = -2(\mu-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] + \frac{2}{R_2}$

$\Rightarrow \frac{1}{v_3} + \frac{1}{v_0} = \frac{1}{f_m} - \frac{2}{f_l}$

⇒ So above combination of mirror and lense can be thought as mirror of focal length f.

$\boxed{\frac{1}{f} = \frac{1}{f_m} - \frac{2}{f_l}}$

// Appendix : formula Optics

① Spherical mirror

$\Rightarrow \dfrac{1}{u} + \dfrac{1}{v} = \dfrac{1}{f}$ {Mirror formula}

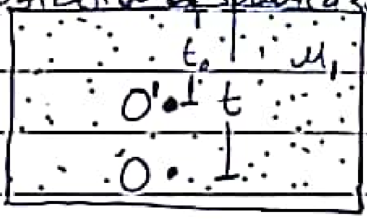
$\Rightarrow f = R/2$

$\Rightarrow m = -v/u$

② Apparent depth

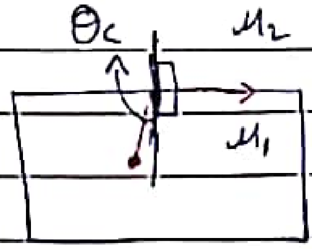
$$\left\{ \boxed{\Delta t = \left(1 - \frac{1}{\mu_2}\right) t} \right\}$$

$\ast$ $\dfrac{\text{Real depth}}{\text{Apparent depth}} = \dfrac{\mu_1}{\mu_2}$ {Can be worked out from refraction at spherical surface}



$\Rightarrow \dfrac{t}{t_0} = \dfrac{\mu_1}{\mu_2}$ {Shift formula}

③ Critical angle



$\Rightarrow \theta_c = \sin^{-1}\left(\dfrac{\mu_2}{\mu_1}\right)$

④ Prism

$$\Rightarrow \mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin(A/2)}$$ {δ_m = angle of minimum deviation}

⑤ Refraction at spherical surface

$\Rightarrow \dfrac{\mu_2}{v} - \dfrac{\mu_1}{u} = \dfrac{\mu_2 - \mu_1}{R}$ {Refraction formula}

$$\Rightarrow m = \frac{R-V}{R-u} = \frac{\mu_1 V}{\mu_2 u} = \frac{V/\mu_2}{u/\mu_1}$$

⑥ Refraction through lenses

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

$$\Rightarrow \frac{1}{f} = \frac{1}{V} - \frac{1}{u}$$ {lenses formula}

$$\Rightarrow m = \frac{V}{u}$$

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

⑦ Thin lenses in contact

$$\Rightarrow P_{eff} = \sum P$$

⑨ Dispersion through Prism

$$\boxed{\mu = \mu_0 + \frac{A}{\lambda^2}}$$

⑧ Two thin lenses separated by a distance

$$\Rightarrow \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$ {Effective focal length}

$$\Rightarrow S_2 = \frac{dF}{f_1}$$ {distance from second lenses}