5th week

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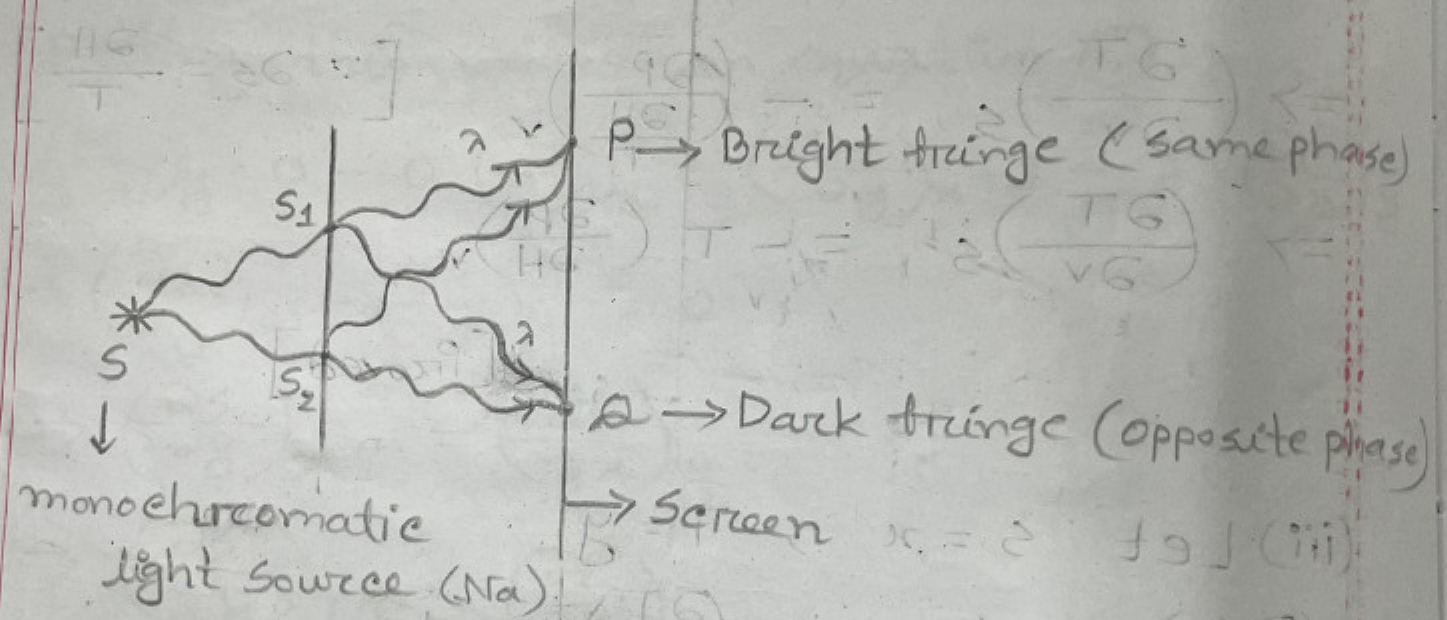
4. (Optics)

- **Interference** :-

Interference is the phenomenon in which two or more coherent waves of the same frequency and wavelength overlap on each other, resulting in a redistribution of energy and the formation of alternating bright and dark fringes.



Conditions :

(i) The light must be monochromatic

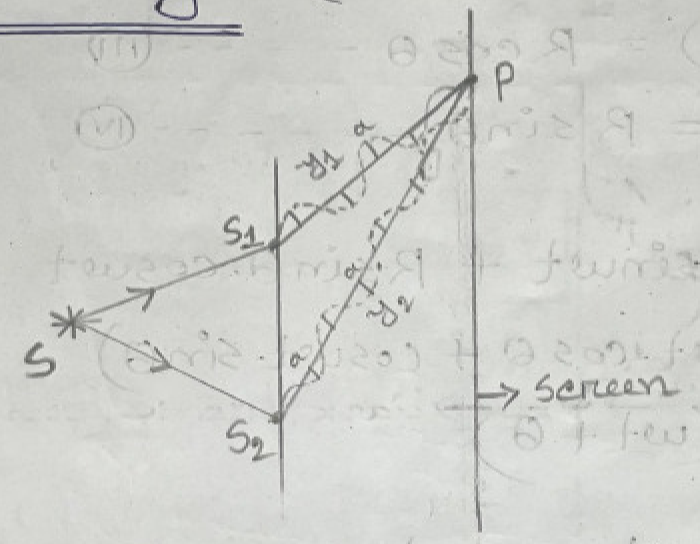
(ii) The sources must be coherent.

(iii) Same frequency and wavelength.

(iv) Amplitudes should be nearly equal.

- Coherent Source – A Light source that produces wave of the same frequency and constant phase difference is called a Coherent Source. (S_1, S_2)

- Intensity – (Intensity of interference)



We consider a monochromatic light source, the light passing through two slits produces bright and dark fringes on the screen. Here, two displacement are y_1 and y_2. The amplitude are same.

Therefore,

$$y_1 = a \sin \omega t \quad \text{------ (1)}$$

$$y_2 = a \sin(\omega t + \delta) \quad \text{---- (11)}$$

$$\therefore y = y_1 + y_2$$

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$\Rightarrow y = a\sin\omega t + a(\sin\omega t.\cos\delta + \cos\omega t\cdot\sin\delta)$

$\Rightarrow y = a\sin\omega t + a\sin\omega t.\cos\delta + a\cos\omega t.\sin\delta$

$\Rightarrow y = a\sin\omega t(1+\cos\delta) + a\cos\omega t\cdot\sin\delta$

Let,

$a(1+\cos\delta) = R\cos\theta$ ---- (III)

$a\sin\delta = R\sin\theta$ ------ (IV)

$\Rightarrow y = R\cos\theta.\sin\omega t + R\sin\theta.\cos\omega t$

$\Rightarrow y = R(\sin\omega t.\cos\theta + \cos\omega t.\sin\theta)$

$\Rightarrow y = R\sin(\omega t+\theta)$

Here,

y is the displacement

Squaring (III) and (IV),

$a^2(1+\cos\delta)^2 = R^2\cos^2\theta$ ----- (V)

$a^2\sin^2\delta = R^2\sin^2\theta$ ------ (VI)

(V) + (VI) $\Rightarrow$

$a^2(1+2\cos\delta+\cos^2\delta) - R^2\cos^2\theta + a^2\sin^2\delta - R^2\sin^2\theta = 0$

$\Rightarrow a^2 + 2a^2\cos\delta + a^2\cos^2\delta - R^2\cos^2\theta + a^2\sin^2\delta - R^2\sin^2\theta = 0$

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$$\Rightarrow a^2(\sin^2\delta + \cos^2\delta) - R^2(\sin^2\theta + \cos^2\theta) + a^2 + 2a^2\cos\delta = 0$$

$$\Rightarrow a^2 - R^2 + a^2 + 2a^2\cos\delta = 0 \qquad [\because \cos^2\theta + \sin^2\theta = 1]$$

$$\Rightarrow R^2 = 2a^2 + 2a^2\cos\delta$$

$$\Rightarrow I = 2a^2(1+\cos\delta) \qquad [\because I = R^2]$$

$$\Rightarrow I = 2a^2\left(1 + \cos 2\cdot\frac{\delta}{2}\right)$$

$$\Rightarrow I = 2a^2\cdot\cancel{2}\cos^2\frac{\delta}{2} \qquad [\because 2\cos^2 A = 1 + \cos 2A]$$

$$\boxed{\therefore I = 4a^2\cos^2\frac{\delta}{2}}$$

Energy distribution diagram:

if $\delta = 0$

$$I = 4a^2\cos^2\left(\frac{0}{2}\right)$$
$$= 4a^2 \quad (max)$$

if $\delta = \pi$

$$I = 4a^2\cos^2\left(\frac{\pi}{2}\right)$$
$$= 0 \quad (min)$$

if $\delta = -\pi$

$$I = 4a^2\cos^2\left(-\frac{\pi}{2}\right)$$
$$= 0 \quad (min)$$

if $\delta = 2\pi$

$$I = 4a^2\cos^2\left(\frac{2\pi}{2}\right)$$

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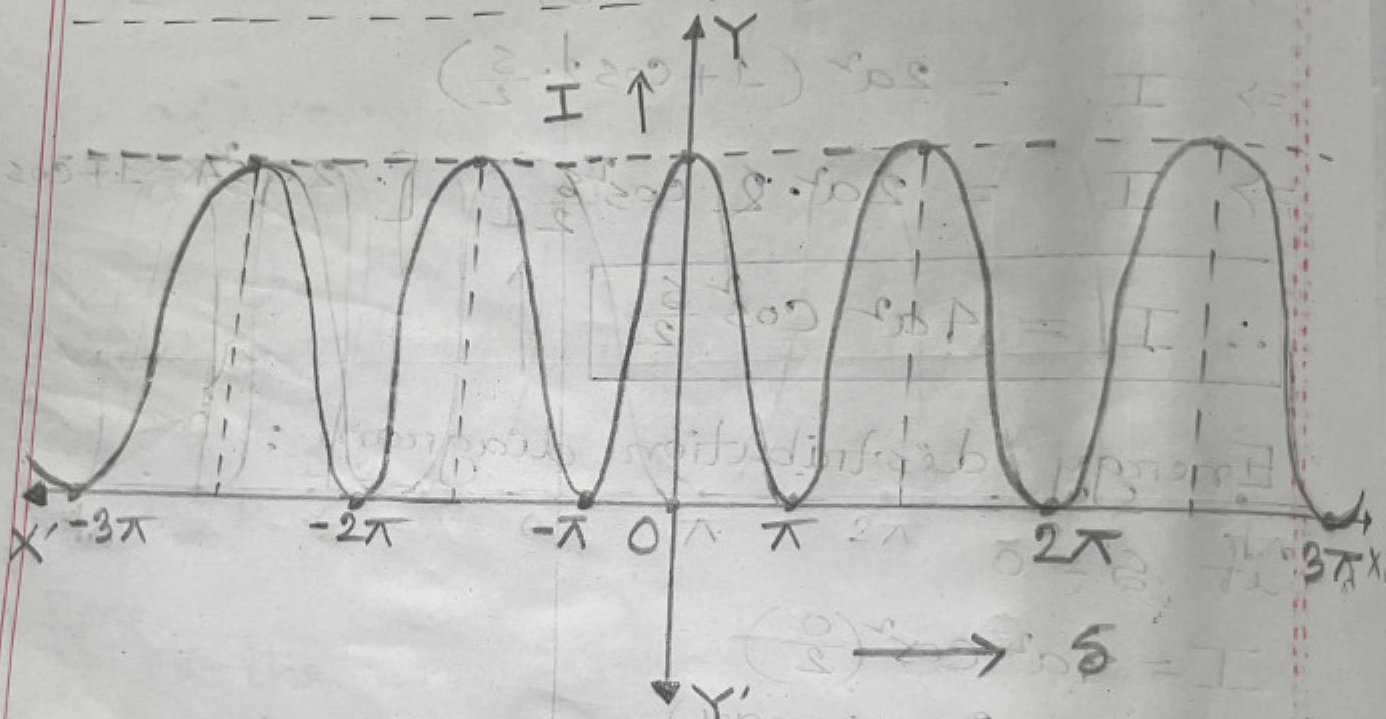
$= 4a^2$

if $\delta = -2\pi$

$I = 4a^2 \cos^2\left(\frac{-2\pi}{2}\right)$

$= 4a^2$



- Physical optics –

Refractive index: The refractive index of a medium is the ratio of the velocity of light in vacuum to the velocity of light in that medium.

$\mu = \frac{c}{v} = \text{constant}$ or, $\mu = \frac{\lambda_0}{\lambda_m}$ $\left[\begin{array}{l} v = f\lambda_m \\ c = f\lambda_0 \end{array}\right.$

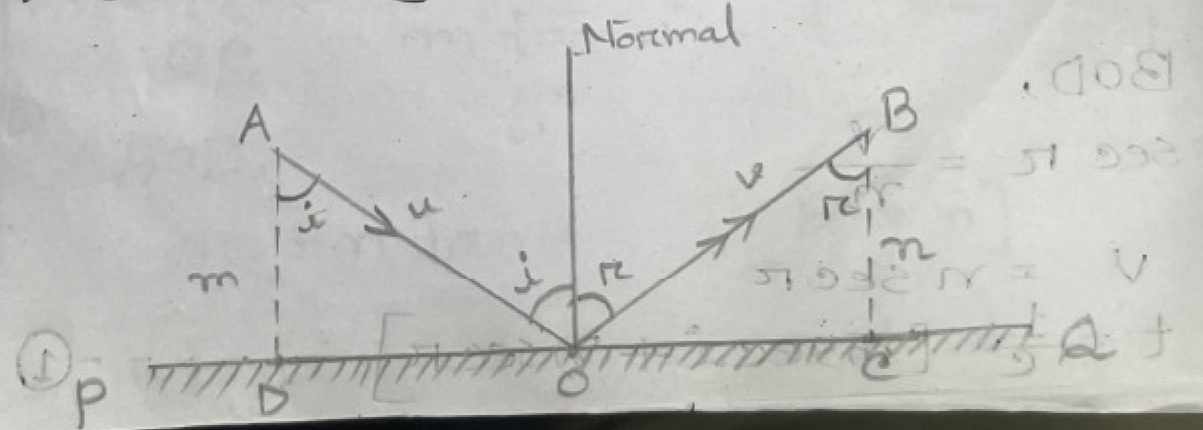
where,

c = velocity of light in vaccum
v = velocity of light in any medium

μ depends on Wavelength of light.
It is usually debendend by μ.

- <u>Derivation of laws of reflection</u> –

According to Farmet Principal –
The path taken by a light ray from one point to another point represents the path of least time.
Sometimes it is prove that time does not define as minimum. So, it may be minimum or maximum.
Therefore the modified form of Farmet Principle – is the path taken by a light ray from one to another point represents the path of minimum or maximum time.
It is also known as Farmet's Principle of stationary time.



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We consider a plane surface PQ and a light ray from A is incident at plane surface PQ on point O at angle i along path AO. Reflected along path OB at angle r.

Let,

$AO = u$, $OB = v$

$AC = m$, $BD = n$

Here,

AOB path $\Rightarrow AO + OB \Rightarrow u+v$

time for path AOB, $t = \frac{u+v}{c}$ $\left[t = \frac{s}{v}\right]$

From ΔAOC,

$\cos i = \frac{m}{u}$

$\Rightarrow \frac{1}{\cos i} = \frac{u}{m}$

$\Rightarrow \sec i = \frac{u}{m}$

$\Rightarrow u = m \sec i$

Δ BOD,

$\sec r = \frac{v}{n}$

$\Rightarrow v = n \sec r$

$\therefore t = \frac{1}{c} [m \sec i + n \sec r]$ ------ (1)

if O is slidely shifted towards D then i and r are slidely changed.

Therefore,

differentiating equation ①

$$\therefore dt = \frac{1}{c}\left[m\sec i\cdot\tan i\cdot di + n\sec r\cdot\tan r\, dr\right]$$

for minimum time,

$dt = 0$

$$\Rightarrow \frac{1}{c}\left[m\sec i\cdot\tan i\, di + n\sec r\cdot\tan r\cdot dr\right] = 0$$

$$\Rightarrow m\sec i\cdot\tan i\, di = -n\sec r\cdot\tan r\cdot dr \quad \text{---} ②$$

Whatever the position of O

$CD = CO + OD = \text{constant}$

Now from,

ΔAOC,

$$\tan i = \frac{OC}{AC}$$

$$\Rightarrow OC = m\tan i \quad [\because AC = m]$$

ΔBOD,

$$OD = n\tan i \quad [\because BD = n]$$

$$\therefore m\tan i + n\tan i = \text{constant}$$

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Differentiating,

$$m\sec^2 i \cdot di + n\sec^2 r \cdot dr = 0$$

$$\Rightarrow m\sec^2 i\, di = -n\sec^2 r \cdot dr \quad \text{--- (3)}$$

(3) ÷ (2)

$$\frac{m\sec^2 i\, di}{m\sec i \cdot \tan i\, di} = \frac{-n\sec^2 r \cdot dr}{-n\sec r \cdot \tan r \cdot dr}$$

$$\Rightarrow \frac{\sec i}{\tan i} = \frac{\sec r}{\tan r}$$

$$\Rightarrow \frac{1}{\cos i} \times \frac{\cos i}{\sin i} = \frac{1}{\cos r} \times \frac{\cos r}{\sin r}$$

$$\Rightarrow \frac{1}{\sin i} = \frac{1}{\sin r}$$

$$\Rightarrow \sin i = \sin r$$

$$\therefore i = r$$

Therefore,
Incident angle is equal to reflected angle and also incident ray, reflected ray and normal are at the same plane surface.

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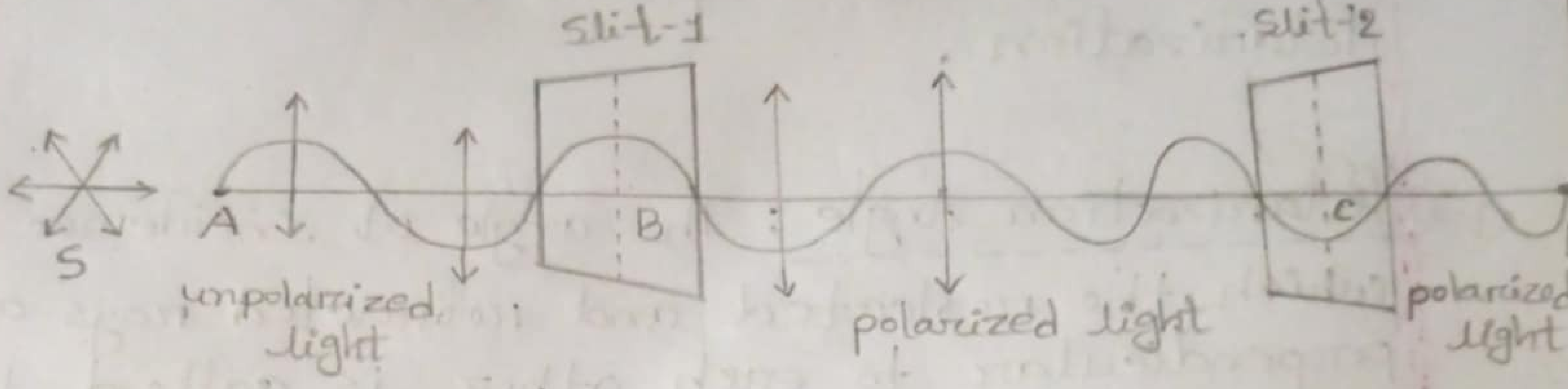
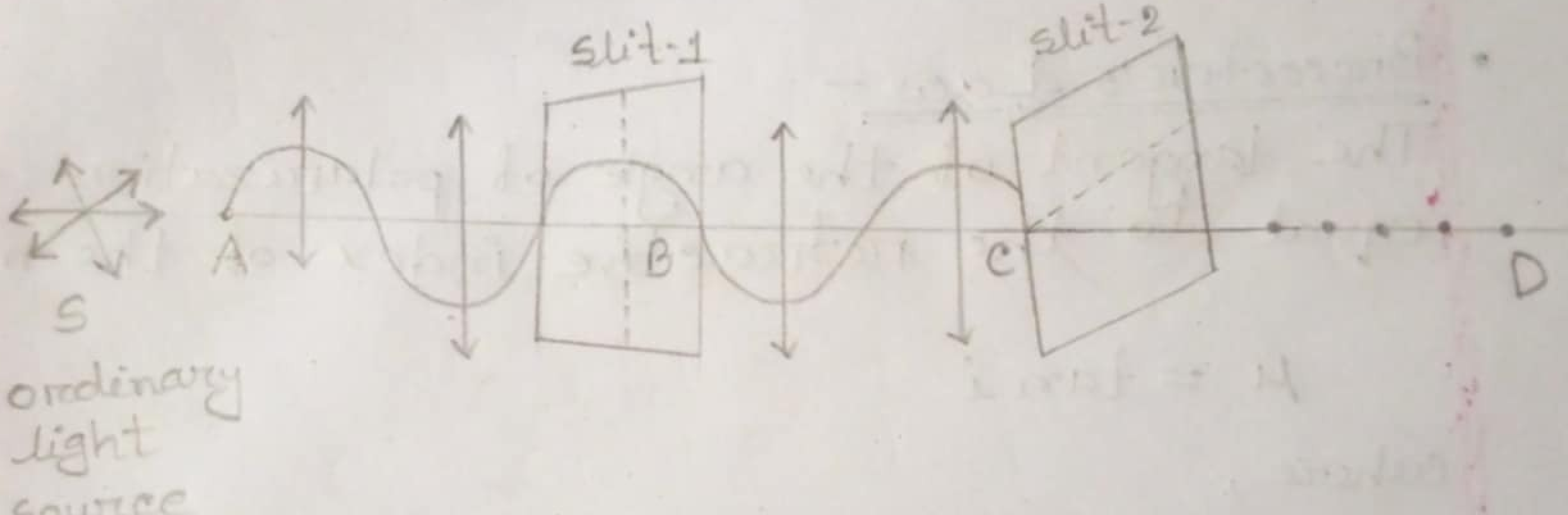
- Polarization of light –



(Figure-1.)



(Figure-2)

In figure-1, two slit are in parallel to the direction of light source and light ray pass through this slits from ordinary light source and polarized light is observed. In figure-2, slit S_1 allows only those light vibrations which are parallel to the direction of light to pass through it, but slit S_2 being perpendicular to that direction does not allow the polarized light t

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pass through it. Thus plane polarized light is observed. This phenomenon is called Polarization.

Polarization Angle: The angle of incidence at which the reflected and refracted rays are perpendicular to each other is called the Polarization angle.

- Brewster's Law -

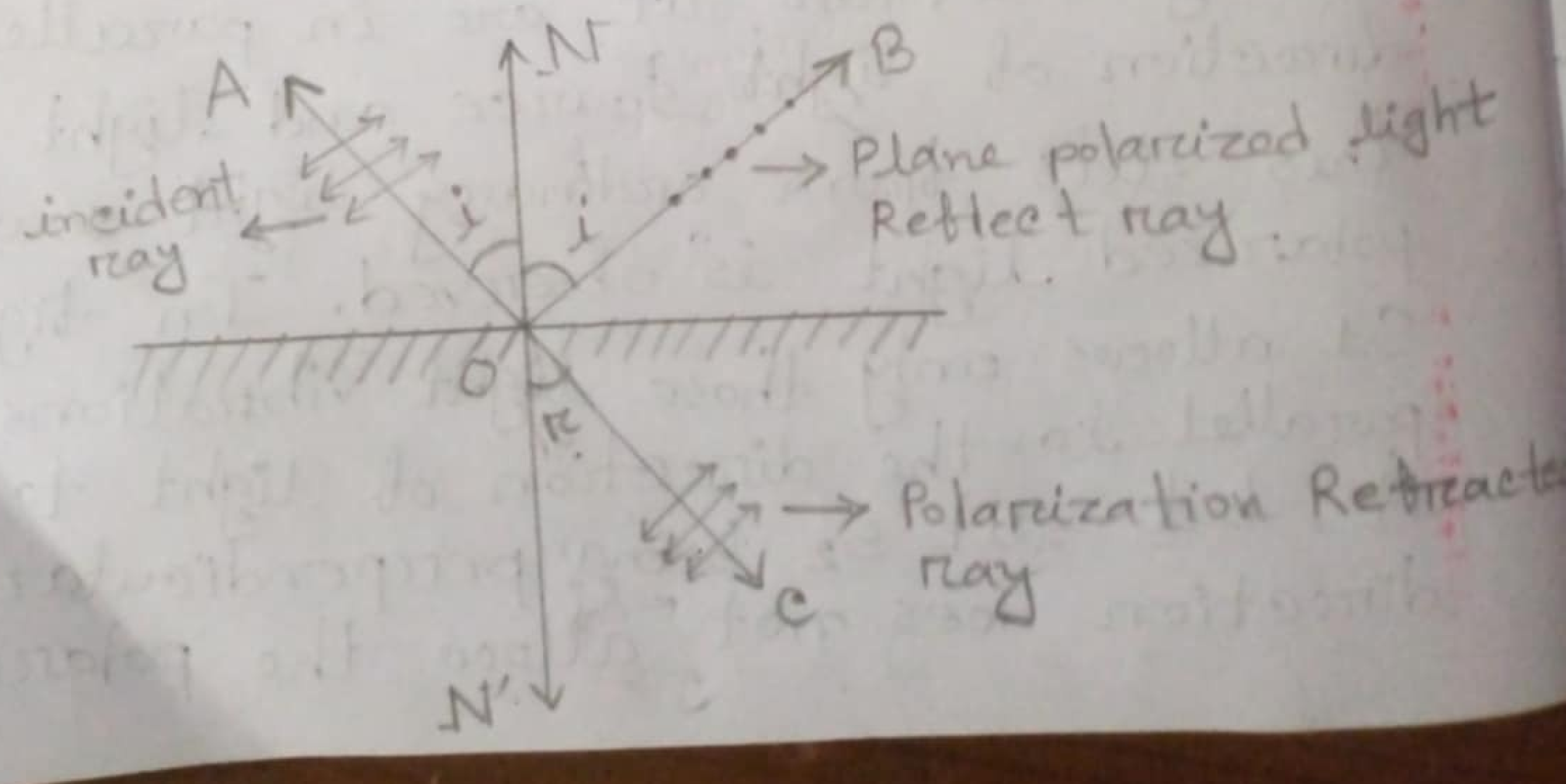
The tangent of the angle of polarization is equal to the refractive index of the medium

$$\mu = \tan i$$

where,

$i \rightarrow$ angle of polarization

$\mu \rightarrow$ refractive index of the medium



According to Snell's law,

$$\mu = \frac{\sin i}{\sin r} \text{ ------ } (1)$$

According to Brewster's law,

$$\mu = \tan i \text{ --------- } (2)$$

from equation (1) and (2),

$$\tan i = \frac{\sin i}{\sin r}$$

$$\Rightarrow \frac{\sin i}{\cos i} = \frac{\sin i}{\sin r}$$

$$\Rightarrow \cos i = \sin r$$

$$\Rightarrow \cos i = \cos(\pi/2 - r)$$

$$\Rightarrow i = \frac{\pi}{2} - r$$

$$\Rightarrow i + r = \frac{\pi}{2}$$

from figure,

$$\angle BON + \angle CON' = \frac{\pi}{2}$$

$$\therefore \angle BOC = \frac{\pi}{2}$$

$$\boxed{\therefore OB \perp OC}$$