DATE :
PAGE NO. :

12

OPTICS

[Unit - 1]

INTERFERENCE

- interference → The superposition of two or more waves which results in a new wave pattern.

- Concept of waves & Huygen's Principle.

A wave is a disturbance that propagates through space & time, usually with the transference of energy from one point to another without any particle of the medium being permanently displaced.

* if the oscillation of the particles are in the direction of wave propagation then the wave is called longitudnal wave.

* if oscillation takes place in perpendicular direction in the direction of wave propagation, the wave is said to be transverse in nature.

Huygens Principle.

↳ wave theory of the light was proposed in 1678 by Huygens.

↳ He explained the phenomena of reflection & refraction.

→ Pricipie was based on the following assumptions.

Each point on the given wavefront acts as a source of secondary wavelets.

DATE :
PAGE NO. :

2. The secondary wavelets from each point travel through space ~~it~~ in all direction with the velocity of light.

3. A surface touching the secondary wavelets tangentially in the forward direction at any given time constructs the new wavefront at that instant. This is known as secondary wavefront.

* PHASE DIFFERENCE

Two waves have same frequencies & different phase are known to have a phase Difference.

→ if the two interfering waves meet at a point where they are in antiphase, then the destructive interference occurs.

→ if these two waves meet at a point where they are in same phase, then the constructive interference occurs.

* PATH DIFFERENCE.

The two wave crests are travelling a different distance from their sources they meet at a point P such that ~~they~~ a crest meets a crests.
For this particular location on the pattern, The difference in distance travelled is known as PATH DIFFERENCE.

* Relation b/w Phase Difference & Path Difference.

Phase difference → $\frac{2\pi}{\lambda}$ × Path difference (δ)

DATE :
PAGE NO. :

* COHERENCE.

1. Coherence is a property of waves that helps in getting stationary interference. i.e, the interference which is temporally & spatially constant.

2. During interference waves add constructively & substract destructively, depending on their ~~the~~ relative phases.

3. Two waves are said to be coherent if they have same relative phase which also means ~~they~~ also have same frequency.

4. Actually, The coherence is the measure of correlation exists b/w the phases of the wave measured at different points.

5. The coherence of the wave depends on the characteristics of its source.

1. TEMPORAL COHERENCE.

→ Temporal Coherence is also known as ~~log~~ longitudinal coherence.

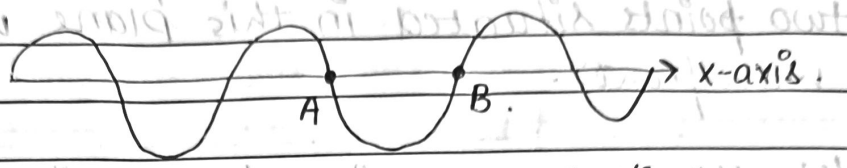
a) → Temporal coherence is a measure of correlation b/w the phases of wave (light) at different point in the direction of wave propagation.

b) if the phase difference of the wave crossing the two points lying in the direction of wave propagation is independent of time, then the wave is said to have Temporal Coherence

DATE :
PAGE NO. :

c) This tells us how monochromatic a source is.

d) Example →



in fig. a wave is travelling along x-axis is shown, where two points A & B are lying on x-axis.

Let the phase diff. of these waves at any instant t be ϕ_A & ϕ_B. & at later time t' be ϕ'_A & ϕ'_B.

under this situation the phase diff. $\phi_B - \phi_A = \phi'_B - \phi'_A$, then the wave is said to have temporal coherence

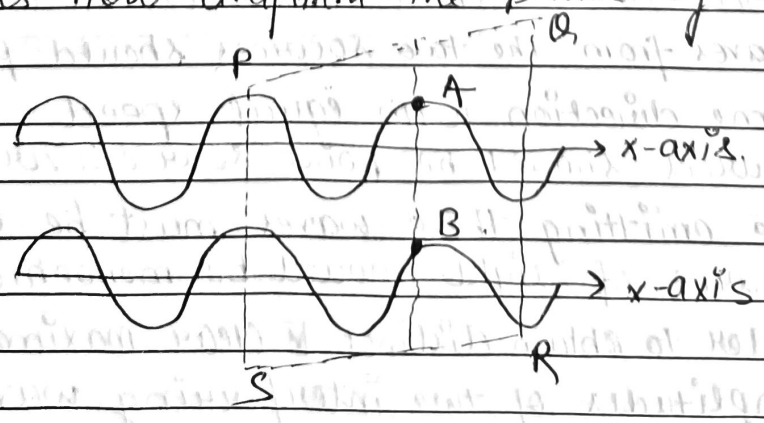
2. SPATIAL COHERENCE.

a) Spatial Coherence is the measure of correlation b/w the phase of a wave (light) at a different points transverse to the direction of propagation.

b) If the phase difference of the waves crossing the two points lying on a plane perpendicular to the direction of wave propagation is independent of time, then the wave is said to have spatial coherence.

c) This tells us how uniform the phase of wavefront is.

d) Example →



in fig. a wave is travelling in +ve x direction shown. where, PQRS is a transverse plane & A and B are two points situated in this plane within the wavefront.

Let the waves crossing these points at any time t have the same phase ϕ & at a later time t' the phases of wave are again same but equal to ϕ.

Under this condition the wave is said to have spatial coherence

* COHERENT SOURCES.

Two sources of light are said to be coherent if they emit waves of same frequency (or wavelength) nearly a same amplitude & maintain a constant phase difference between them.

→ Laser is a good example of coherent source

→ But practically it is not possible to have two independent sources which are coherent.

* CONDITIONS FOR SUSTAINED INTERFERENCE

1] The waves from the two sources should propagate through the same direction with equal speed

→ The sources should be point source & very close to each other.

2] Source emitting these waves must be coherent.

→ Two source of light should be monochromate.

3]. In order to obtain distinct & clear maxima & minima, the amplitudes of two interferring waves must be equal or nearly equal.

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→ INTERFERENCE BY DIVISION OF WAVEFRONT.

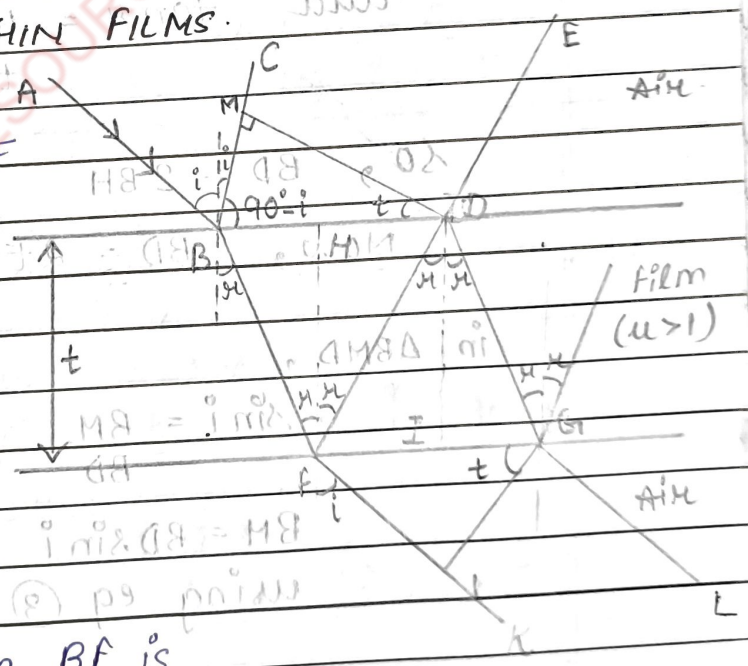
1) Fresnel's Biprism.

Fresnel's Biprism is a device by which we can obtain two virtual coherent sources of light to produce sustaied interference.

→ INTERFERENCE BY DIVISION OF AMPLITUDE

method which is used to produce two coherent sources from a common source is called division of Amplitude.

★★• INTERFERENCE DUE TO THIN FILMS.



Consider a uniform transparent film having thickness t & a refractive index μ.
A ray of light AB incident at an angle i on the upper layer of film is partly reflected along BC & partly refracted along BF at an angle r.
At point F again the wave BF is partly reflected from the second surface along FD & partly emerges out along FK. & so on.

In this situation the interference occurs b/w reflected waves BC & DE & also b/w the transmitted waves FK & GL.

The Path difference b/w the refracted rays.

$$\Delta = (BF + FD) - BM.$$

$$\Delta = \mu(BF + \cancel{BD}\ FD) - BM.$$

$$\Delta = \mu(2BF) - BM \qquad [\text{since, } BF = \cancel{BD}\ FD]$$

$$\Delta = 2\mu BF - BM \quad \text{--- (1)}$$

in rigth angled ΔBFH,

$$\cancel{\cos r = \frac{t}{BH}} \qquad \cos r = \frac{t}{BF} \quad \text{--- (2)}$$

and $\tan r = \dfrac{BH}{t}$

So, $BD = 2BH$

Now, $BD = 2t \tan r$ --- (3)

in ΔBMD,

$$\sin i = \frac{BM}{BD}$$

$$BM = BD \sin i$$

using eq (3)

$$BM = 2t \tan r \sin i \quad \text{--- (4)}$$

Now, from eq. (1), (2) & (4)

$$\Delta = 2\mu \frac{t}{\cos r} - 2t \tan r \sin i \quad \text{--- (5)}$$

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DATE :
PAGE NO. :

According to Snell's law,

$$\mu = \frac{\sin i}{\sin r} \rightarrow \boxed{\sin i = \mu \sin r}$$

Putting in eq (5).

$$\Delta = \frac{2\mu t}{\cos r} - \frac{2t \sin r}{\cos r} \mu \sin r$$

$$\Delta = \frac{2\mu t}{\cos r} - \frac{2t \mu \sin^2 r}{\cos r}$$

$$\Delta = \frac{2\mu t}{\cos r} \left[1 - \sin^2 r\right]$$

$$\boxed{\Delta = 2\mu t \cos r.}$$ Ans

Now, this is only the apparent path difference & does not represent the effective total path difference. when a light is reflected from an optically denser med. the surface of in case of rad BC, a phase change of π a equivalent to path difference $\lambda/2$ is introduced.

$\therefore$ Total path difference $\rightarrow \boxed{2\mu t \cos r + \frac{\lambda}{2}}$

Condition for Maxima.	* Condition for Minima.
$2\mu t \cos r = (2n-1)\frac{\lambda}{2}$	$2\mu t \cos r = (2n+1)\frac{\lambda}{2}$

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DATE :
PAGE NO. :

* DIFFRACTION

Diffraction of light is defined as the bending of light around corners such that it spreads out & illuminates areas where a shadow is expected.

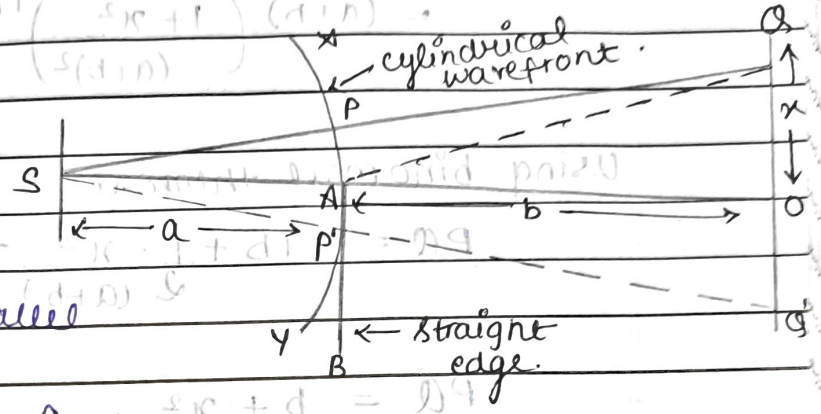
→ Diffraction & interference both occurs together.

→ DIFFERENCE B/W DIFFRACTION & INTERFERENCE

	Interference	Diffraction
1.	It is due to the interaction of light coming from two different wavefront from two coherent sources.	1. It is due to the interaction of light from different parts of the same wavelength.
2.	Fringes width will be same.	2. Fringes are always of varrying width.
3.	The fringes of min. intensity are perfectly dark.	3. The fringes of min. intensity are not perfectly dark.
4.	The Bright fringes are of same intensity.	4. Bright fringes are of varrying intensity.
5.	Condition for maxima & Minima. • Path diff. = $n\lambda$ (max.) • Path diff. = $(2n+1)\frac{\lambda}{2}$ (min)	5. Condition for maxima & minima • Path diff. = $(2n+1)\frac{\lambda}{2}$ (max) • Path diff = $n\lambda$ (min).

DATE :
PAGE NO. :

FRESNEL DIFFRACTION AT STRAIGHT EDGE.



Let S be a narrow slit illuminated by a source of monochromatic light of wavelength λ.
The length of edge is parallel to length of slit.
XY is the cylindrical wavefront.
Below O is geometrical shadow & above is illuminated portion, with respect to O, divide wavefront into number of half period zones.
A is the pole of wavefront & AM_1, M_1M_2, M_2M_3, -- are the thickness of 1, 2, 3 -- are the half period zones.

Let Q be the point in the illuminated system & the intensity at Q depends upon no. of half period zones AB.

no. of half period elements contained in PA = no. of half wavelengths in path diff. (AQ − PQ).

$$AQ = \sqrt{AO^2 + OQ^2}$$

$$AQ = \sqrt{b^2 + x^2}$$

$$= b^2\left(1 + \frac{x^2}{b^2}\right)^{1/2}$$

By applying binomial theorem & neglecting the terms higher than x^2,

we get, $AQ = b + \frac{1}{2}\frac{x^2}{b}$

DATE :
PAGE NO. :

Now, $PQ = SQ - SP$

$$= \sqrt{(a+b)^2 + x^2} - a$$

$$= (a+b)\left(1 + \frac{x^2}{(a+b)^2}\right)^{1/2} - a.$$

Using binomial theorem

$$PQ = a+b+\frac{1}{2}\cdot\frac{x^2}{(a+b)} - a.$$

$$PQ = b + \frac{x^2}{2(a+b)}$$

Path diff $= AQ - PQ$

$$= \left(b + \frac{x^2}{2b}\right) - \left(b + \frac{x^2}{2(a+b)}\right)$$

$$= \frac{x^2}{2}\left(\frac{1}{b} - \frac{1}{(a+b)}\right) = \frac{ax^2}{2b(a+b)}$$

$$\boxed{\text{Path diff.} = \frac{ax^2}{2b(a+b)}.}$$

For max. at Q, this path diff. should be equal to odd multiple of $\frac{\lambda}{2}$.

For brightness : $\frac{ax^2}{2b(a+b)} = (2n+1)\frac{\lambda}{2}$

$$x^2 = \frac{(2n+1)(a+b)\,b\lambda}{a}$$

$$x_n = \sqrt{\frac{b(a+b)(2n+1)\lambda}{a}}$$

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For min. at Q, path diff. should be equal to even multiple of $\frac{\lambda}{2}$.

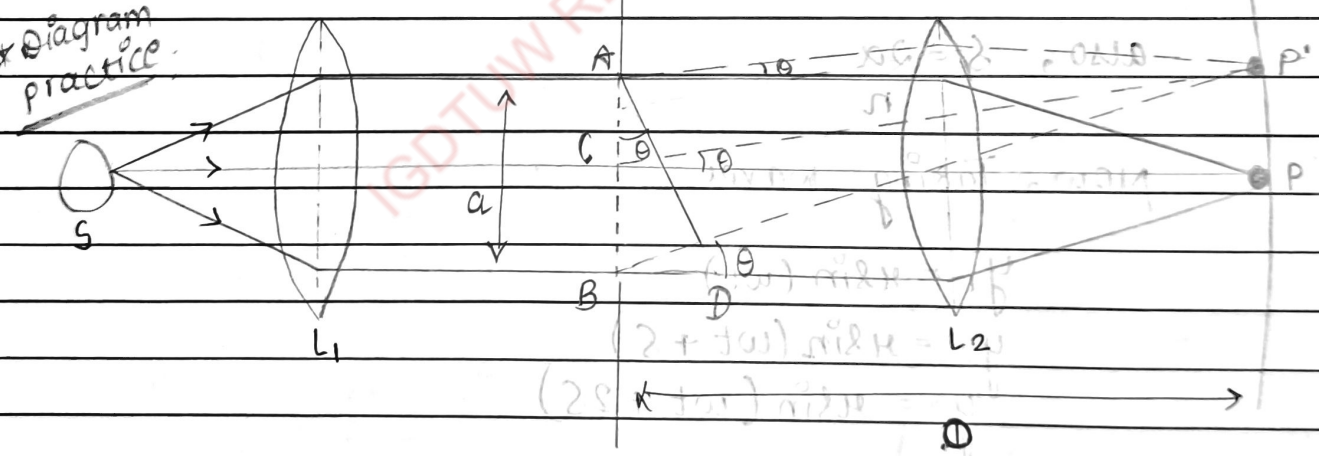
Thus, $\frac{ax^2}{2b(a+b)} = \frac{2n \cdot \lambda}{2}$

$$x_n = \sqrt{\frac{2b(a+b)n\lambda}{a}}$$

* For bright bands, $x \propto \sqrt{2n+1}$
* For dark bands, $x \propto \sqrt{2n}$.

** FRAUNHOFER DIFFRACTION DUE TO SINGLE SLIT.

* Diagram practice



S is a monochromatic source of light held at the focus of a convex lens L. The parallel beam of light from L_1 is made to fall on single slit AB, of width 'a' comparable to wavelength of light. After passing through the slit the diffraction pattern is focused on screen XY placed at distance 'D' from single slit with help of another lens L_2.

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Path diff ΔABD

$BD = AB\sin\theta$

$= a\sin\theta = n\lambda$ (minima)

$n = 1, 2, \ldots$

and $a\sin\theta = (2n-1)\frac{\lambda}{2}$ (maxima)

$\Rightarrow$ Phase diff $\rightarrow$ $2\alpha = \frac{2\pi}{\lambda}$ (P.D)

$2\alpha = \frac{2\pi}{\lambda} \times a\sin\theta$

$$\boxed{\alpha = \frac{\pi}{\lambda}(a\sin\theta)}$$

also, $\delta = \frac{2\alpha}{n}$

Now, Taking waves

$y_1 = r\sin(\omega t)$

$y_2 = r\sin(\omega t + \delta)$

$y_3 = r\sin(\omega t + 2\delta)$

$\vdots$

$y_n = r\sin(\omega t + (n-1)\delta)$

$\therefore y = y_1 + y_2 + y_3 + \ldots + y_n$

$$y = r\left[\sin(\omega t) + \sin(\omega t + \delta) + \sin(\omega t + 2\delta) + \ldots \sin(\omega t + (n-1)\delta)\right]$$

$$y = \frac{r \sin \frac{n\delta}{2}}{\sin \frac{\delta}{2}} \sin\left[\omega t + (n-1)\frac{\delta}{2}\right]$$

Now, we know, $I \propto A^2$

$$I = \left[\frac{r \sin \frac{n\delta}{2}}{\sin \frac{\delta}{2}}\right]^2$$

$$I = \left[\frac{r \sin \frac{2n\alpha}{2n}}{\sin \frac{2\alpha}{2n}}\right]^2$$

$$I = \left[\frac{r \sin\alpha}{\sin \frac{\alpha}{n}}\right]^2$$

So, $A = \left[\frac{r \sin\alpha}{\sin \frac{\alpha}{n}}\right]$

$$I = \left[nr \frac{\sin\alpha}{\alpha}\right]^2$$

$$A = \left[\frac{r \sin\alpha}{\frac{\alpha}{n}}\right]$$

$$I = A_0^2 \left[\frac{\sin\alpha}{\alpha}\right]^2$$

$$A = \left[nr \frac{\sin\alpha}{\alpha}\right] ***$$

$$\boxed{I = \frac{A_0^2 \sin^2\alpha}{\alpha^2}} \#$$

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DATE :
PAGE NO. :

* DIFFRACTION GRATING.

An optical component with a periodic structure that splits the light into various beams that travel in different directions.

→ it is an alternate way to observe spectra other than a prism.

Diffraction grating = $\lambda_n = d \sin\theta_n$.

* Grating element → No. of lines per cm.

$N = \frac{2.54\ cm}{}$

→ Application of Diffraction Grating

1. Determination of wavelength of light.
2. Resolving power of an optical instrument.

* ABSENT SPECTRA.

$(a+b)\sin\theta_n = n\lambda$ — (1)

$a\sin\theta_m = m\lambda$ — (2)

Diving eq. (2) by (1).

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$\frac{a+b}{a} = \frac{n}{m}$	a = Trans * b = Opaque *

if $a=b$,

$n = 2m \longrightarrow n = 2, 4, 6, 8 \ldots$

These spectra are missing.

DATE :
PAGE NO. :

* RESOLVING POWER OF GRATING

Ability of an optical instrument or type of film to separate or distinguish small or closely adjacent images.

$$P - (b+d)\sin\theta = n\lambda$$

$$P' - (b+d)\sin(\theta + d\theta) = n(\lambda + d\lambda)$$

$$N(b+d)\sin(\theta_n + d\theta_n) = (nN+1)\lambda$$

$$(b+d)\sin(\theta + d\theta) = \frac{(nN+1)\lambda}{N}$$

$$n(\lambda + d\lambda) = \frac{(nN+1)\lambda}{N}$$

$$\cancel{n\lambda} + n\,d\lambda = \cancel{n\lambda} + \frac{\lambda}{N}$$

$$\boxed{\frac{\lambda}{d\lambda} = nN}$$ Ans.

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* DISPERSIVE POWER OF DIFFRACTION GRATING

The dispersive power of a grating is defined the ratio of the difference in angle of diffraction of any two neighbouring spectral lines to the diffraction in the wavelength b/w the two spectral lines.

Expressed in $d\theta/d\lambda$.

$$(a+b)\sin\theta = n\lambda \quad [\text{differentiate w.r.t } \lambda]$$

$$\boxed{\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta}}$$ Ans

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DATE :
PAGE NO. :

* POLARIZATION.

The phenomena of restricting the vibration of light in a particular direction perpendicular to the direction of wave motion is called Polarization.

* DIFFERENT BETWEEN POLARISED & UNPOLARISED LIGHT.

	Polarised light.	Unpolarised light.
1.	When unpolarised light is passed through a tourmaline crystals with its face parallel, then only those waves get passed whose plane of vibration is parallel to face of crystal & the emergent light is said to be plane polarised light	1. The ordinary light consist of many waves whose plane of vibration are randomly oriented about the direction of propagation, such light waves are said to be unpolarised light.

* MALUS LAW.

Acc. to this law when a beam of light (plane polarized) is incident on an Analyzer the resultant intensity of light transmitted from analyzer varries directly as the square of cosine of angle θ, b/w the plane of transmission of analyzer and polarizer.

$$I \propto \cos^2\theta$$

$$I \propto (A)^2$$

$$I \propto (a\cos\theta)^2 \longrightarrow I = K(a\cos\theta)^2$$

$$I = Ka^2\cos^2\theta$$

[$Ka^2 = I_0$, intensity of unpolarised light]

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

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DATE :
PAGE NO. :

* BREWSTER LAW.

According, to this law when unpolarised light is incident on polarising angle (i_p) on the interface of rarer & denser medium, the light will be fully polarised.

$$\tan i_p = \mu$$

with the help of snell's law.

$$r + i_p = 90^\circ$$

$$\mu = \frac{\sin i_p}{\sin r} = \tan i_p = \frac{\sin i_p}{\cos i_p}$$

$$\sin r = \cos i_p$$

$$\sin r = \sin(90 - i_p)$$

$$r = 90 - i_p$$

$$\boxed{r + i_p = 90}$$

Hence, proved.

DOUBLE ~~REF~~ REFRACTION.

Double refraction is an optical property in which a single ray of unpolarised light when passes through a uniaxial crystal gets split into two refracted rays, each propagates in different direction.

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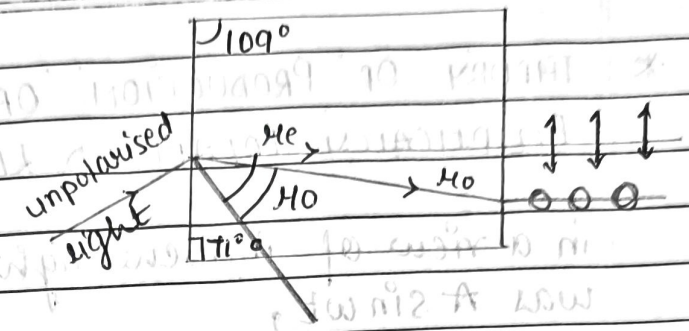
$$\mu_o = \frac{\sin i}{\sin r_o}$$

$$\mu_e = \frac{\sin(i)}{\sin r_e}$$



* NICOL PRISM.

Nicol prism is made of calcite crystal & is widely used for producing & detecting Polarised light.

The μ of calcite is 1·66

→ Construction :-

The face of calcite crystal which has angles of 72° and 108°, is cut into two halves along the diagonals AB & then cemented together (Canada Balsam).

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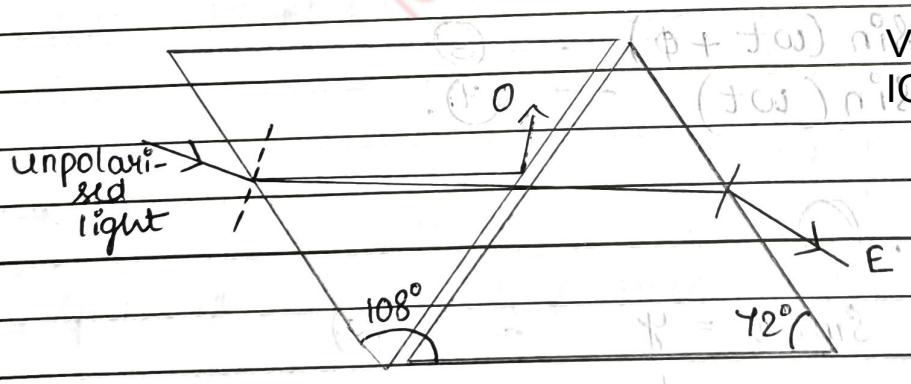

O → ordinary light.

E → extra ordinary light

* CANADA BALSAM → Ref index – 1·55.
→ has some optical properties.

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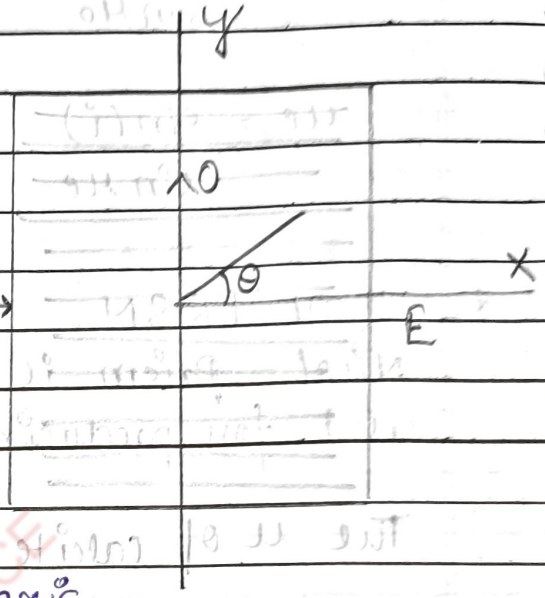
DATE :
PAGE NO. :

* THEORY OF PRODUCTION OF PLANE, CIRCULARLY AND ELLIPTICALLY POLARISED LIGHT.

in a view of incident light was $A \sin \omega t$,
we can represent the E-ray along the optic axis as



$$x = A\cos\theta \sin(\omega t + \phi) \quad \text{— (1)}$$

similarly, the O-ray along y-axis

$$y = A\sin\theta \sin \omega t \quad \text{— (2)}$$

let, $A\cos\theta = a$
$A\sin\theta = b$.

$$x = a \sin(\omega t + \phi) \quad \text{— (3)}$$
$$y = b \sin(\omega t) \quad \text{— (4)}.$$

from eq. (4).

$$\sin \omega t = \frac{y}{b} \quad \text{— (5)}$$

and,

$$\cos \omega t = \sqrt{1 - \frac{y^2}{b^2}} \quad \text{— (6)}$$

Now, from eq. (3).

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$$\frac{x}{a} = \sin\omega t \cos\phi + \cos\omega t \sin\phi \quad \text{--- (7)}$$

Putting the values of $\sin\omega t$ & $\cos\omega t$ from eq. (5) & (6) in above eq.

$$\frac{x}{a} = \frac{y}{b}\cos\phi + \sqrt{1-\frac{y^2}{b^2}}\sin\phi.$$

$$\frac{x}{a} - \frac{y}{b}\cos\phi = \sqrt{1-\frac{y^2}{b^2}}\sin\phi \quad \text{--- (8)}$$

Squaring eq. (8) on both sides

$$\left[\frac{x}{a} - \frac{y}{b}\cos\phi\right]^2 = \left[1-\frac{y^2}{b^2}\right]\sin^2\phi.$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cos\phi = \left[1-\frac{y^2}{b^2}\right]\sin^2\phi.$$

$$\boxed{\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cos\phi = \sin^2\phi.}$$

General ~~eth~~ eq. of ellipse.

→ Different Cases.

1. If $\phi = 0$, straight line (even) $[\sin\phi = 0, \cos\phi = 1]$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab} = 0$$

$$\left[\frac{x}{a} - \frac{y}{b}\right]^2 \longrightarrow \boxed{y = \frac{b}{a}x}$$

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DATE :
PAGE NO. :

2. If $\phi = \pi$, straight line (odd). $[\sin\phi = 0, \cos\phi = -1]$

$$\left[\frac{x}{a} + \frac{y}{b}\right]^2 \Rightarrow \boxed{y = \frac{-b}{a}x}$$

3. If $\phi = \frac{\pi}{2}$, std. ellipse $[\sin\phi = 1, \cos\phi = 0]$

$$\boxed{\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1}$$

4. If $a = b$, std. circle

$$\boxed{x^2 + y^2 = a^2}$$

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DIFFERENCE BETWEEN FRESNEL & FRAUNHOFER.

	FRESNEL DIFFRACTION	FRAUNHOFER DIFFRACTION
1.	The source of light & screen is kept at a finite distance.	1. The source of light & screen is at ~~a~~ infinite distance.
2.	Sperical or cylindrical wavefronts are considered.	2. Only plane wavefronts are considered.
3.	It is observed in straight edge, narrow slit etc.	3. It is observed in the single slit, double slit, etc.
4.	Lens are not used	4. Convex lens are used.

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