Unit - 4
Interference

Interference

The modification in the distribution of light intensity over a region due to the superposition of light waves coming from two closely located sources emitting light waves of identical wavelength and amplitude is called interference.

It is a special phenomenon reflecting the wave nature of light.

Types of Interference

There are two types of interference.

a) Constructive interference.

b) Destructive interference

Constructive interference

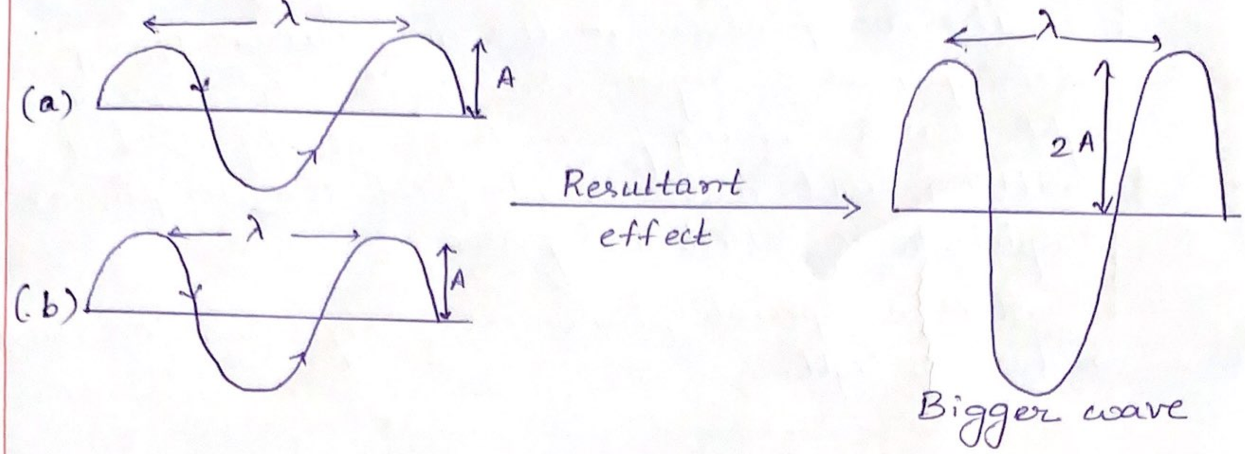
The points at which light waves of same amplitude & wavelength from two sources arrive with a phase difference of $0, 2\pi ----- 2n\pi$ or path difference of $\lambda, 2\lambda ----n\lambda$, undergo an addition of amplitude. Such an interference causes brightness & hence referred as constructive interference.

Destructive interference

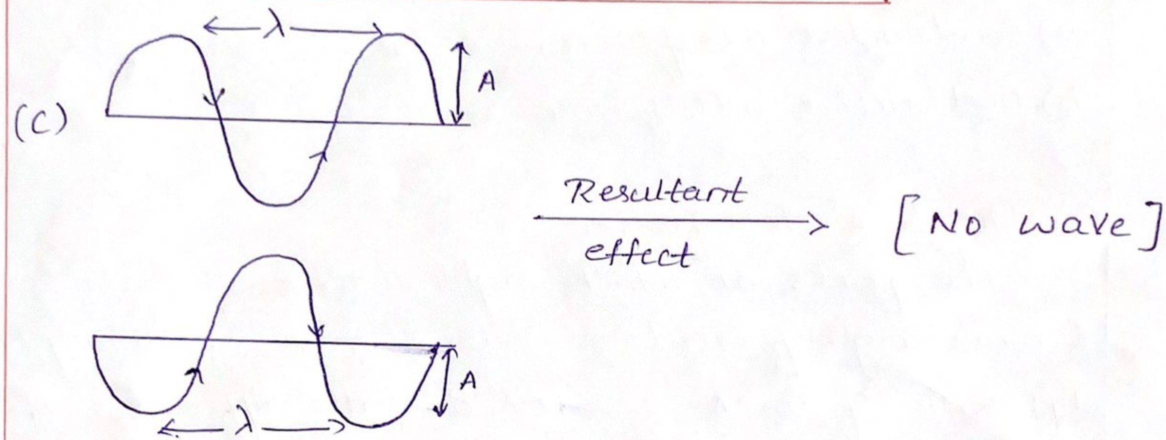
The points at which light waves of equal amplitude and wavelength arrive with a phase difference of $\pi, 3\pi, ----(2n+1)\pi$ or path difference of $\lambda/2, 3\lambda/2 --- (2n+1)\frac{\lambda}{2}$ undergo cancellation which leads to darkness and hence referred as destructive interference.

Principle of Superposition

The superposition principle states that, when two or more waves overlap in space, the resultant disturbance is equal to the algebraic sum of the individual.



CONSTRUCTIVE INTERFERENCE



DESTRUCTIVE INTERFERENCE

Conditions for Interference of light

The conditions to achieve interference of light are as follows:

a) The light waves participating in the interfence must originate from two identical coherent sources.

b) The two waves must be of equal amplitudes without which the regions where destructive interfer-ence occurs will also have illumination depending upon the difference in amplitude.

c) The coherent sources must be closely located.

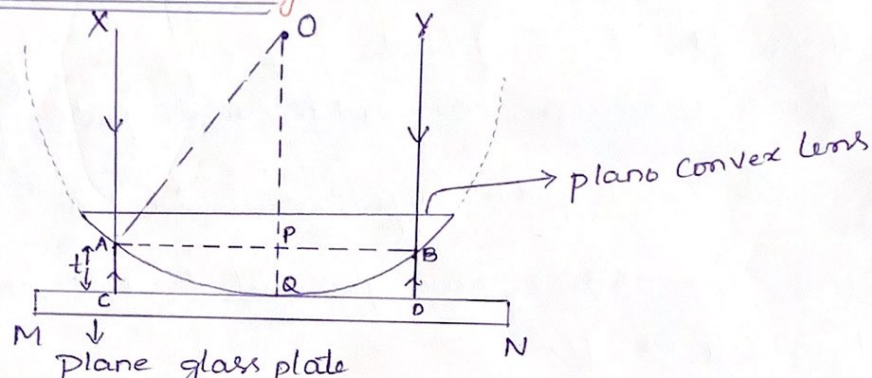
d) The light waves must be continuously emitted by two coherent sources.

e) The two coherent sources must be extremely small in size.

Newton's Rings

A fringe pattern of alternate bright & dark concentric rings that are formed due to interference effects obtained when a plano convex lens placed on a plane glass plate are called Newton's rings.

Theory of Newton's Rings



Let a plano convex lens of large radius of curvature 'R' be resting on a glass plate. The lens can be imagined to be part of a sphere of radius 'R' whose centre is 'O'. Let the thickness of the air film be 't' at the point AC, ie $AC = t$.

Let a parallel beam of monochromatic light of wavelength 'λ' fall normally on the lens. Consider a ray of light incident along XA which emerges into the air film at A, after traversing through the lens, because of the change in media, the ray suffers partial reflection & transmission. The transmitted part which travels along get reflected by the plane glass plate MN and re enters the lens, where it interfere with the part of the ray which is being reflected at A.

As per the theory of interference at thin films, the path difference b/n the two rays at 'A' is given by,

$$\delta = 2\mu t \cos r \longrightarrow (1)$$

$\mu = 1$ [Refractive index of air which is surrounding medium]

$r = 0$ [angle of refraction]

$\therefore \cos 0 = 1$

$$\therefore \delta = 2t \rightarrow (2)$$

Since the transmitted ray suffers reflection at a denser medium, an additional path of $\lambda/2$ is introduced.

$$\therefore \text{Total path difference} = 2t + \frac{\lambda}{2} \longrightarrow (3)$$

The line AB drawn parallel to MN intersects the line OQ at P.

From the triangle OAP,

$$OA^2 = OP^2 + AP^2$$

$$OA^2 = (OQ - PQ)^2 + AP^2$$

$OA = OQ = R$, $PQ = AC = t$

Let $AP = CQ = r$

$$\therefore R^2 = (R-t)^2 + r^2 \qquad (a-b)^2 = a^2 + b^2 - 2ab$$

$$\cancel{R^2} = \cancel{R^2} + t^2 - 2Rt + r^2$$

Since $t << R$, t^2 is negligible

$$\therefore r^2 - 2Rt = 0 \Rightarrow \boxed{2t = \frac{r^2}{R}} \longrightarrow (4)$$

Formation of Bright rings

From the diagram, the interference at A is Constructive if the path difference b/n the rays is $n\lambda$.

$\therefore$ There will be brightness if,

$$2t + \frac{\lambda}{2} = n\lambda \rightarrow (5)$$

Since 't' is small for all points lying on a circle of radius $r = AP = CQ$, it leads to the formation of a bright ring of radius r.

From eqns (4) & (5),

$$\frac{r^2}{R} + \frac{\lambda}{2} = n\lambda$$

$$r^2 = R(2n-1)\frac{\lambda}{2}$$

$$\boxed{r = \sqrt{R(2n-1)\frac{\lambda}{2}}}$$

where $n = 1, 2, 3$ ... Corresponds to 1^{st}, 2^{nd}, 3^{rd} .... rings.

Formation of Dark rings

The interference at 'A' will be destructive, if the path difference is $(2n+1)\frac{\lambda}{2}$.

$\therefore$ There will be darkness if,

$$2t + \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$$

$$2t = n\lambda \rightarrow (6)$$

From eqns (4) & (6)

$$\frac{r^2}{R} = n\lambda$$

$$\boxed{r = \sqrt{Rn\lambda}} \rightarrow (7)$$ Radius of the dark rings.

Expression for radius of curvature

If d is the diameter of the given dark ring,

$$d = 2r = 2\sqrt{Rn\lambda}$$

If d_m & d_n are the diameters of m^{th} & n^{th} dark rings,

$$d_m = 2\sqrt{Rm\lambda} \implies d_m^2 = 4Rm\lambda$$

$$\text{II}^{ly} \quad d_n = 2\sqrt{Rn\lambda} \implies d_n^2 = 4Rn\lambda$$

$$\therefore (d_m^2 - d_n^2) = 4R(m-n)\lambda$$

$$\therefore \boxed{R = \frac{(d_m^2 - d_n^2)}{4(m-n)\lambda}}$$

Applications of Newton's Rings

a) To determine the wavelength of a monochromatic light.

b) To determine the refractive index of the liquid.

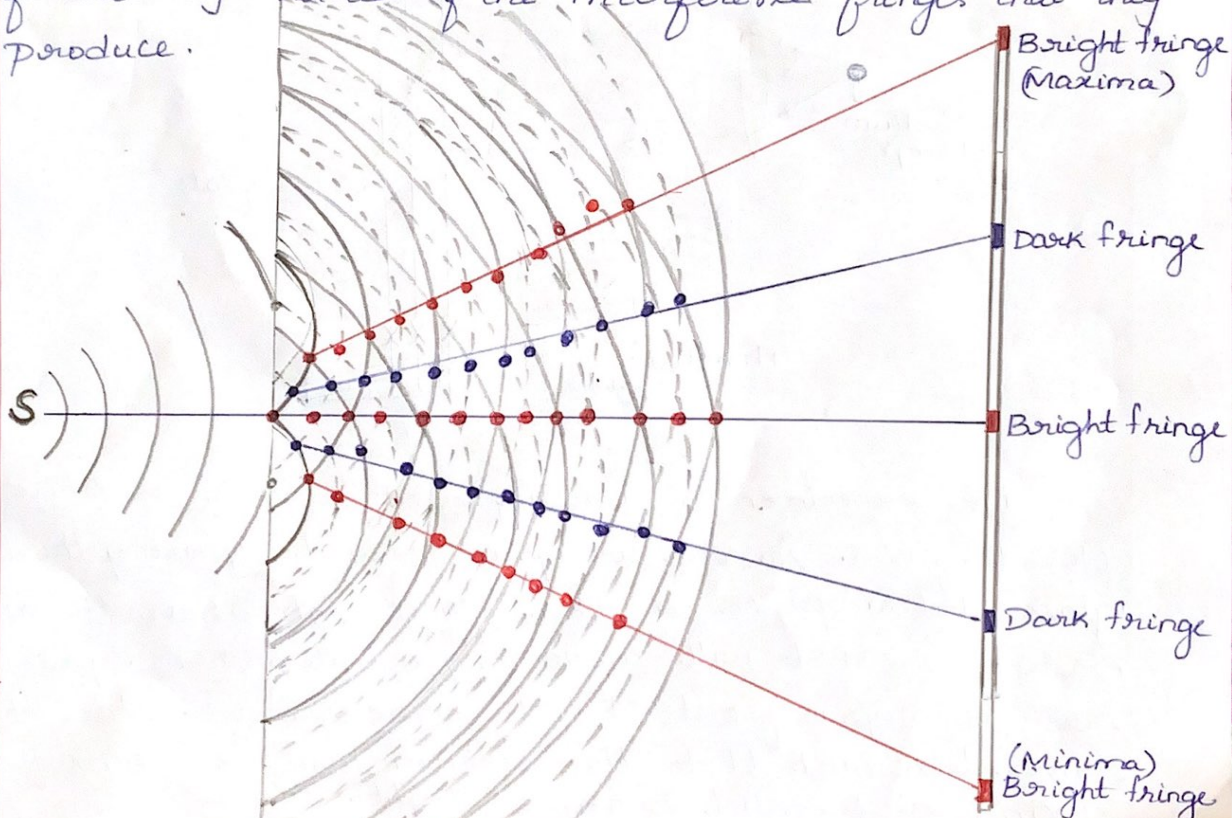
c) To determine the radius of curvature of a plano convex lens.

Interference in Thin Films

Theory of Interference Fringes

Interference fringe is a bright or dark band caused by beams of light that are in phase or out of phase with one another. Light waves and similar wave propagation when superimposed will add their crests if they meet in the same phase; or the troughs will cancel the crests if they are out of phase; these phenomena are called constructive and destructive interference, respectively.

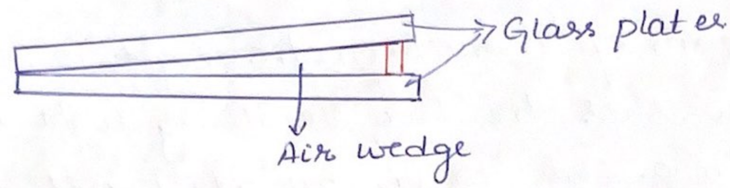
If a beam of monochromatic light is passed through two narrow slits, the two resulting light beams can be directed to a flat screen on which instead of forming two patches of overlapping light, they will form interference fringes, a pattern of evenly spaced alternating bright and dark bands. All optical interferometers function by virtue of the interference fringes that they produce.



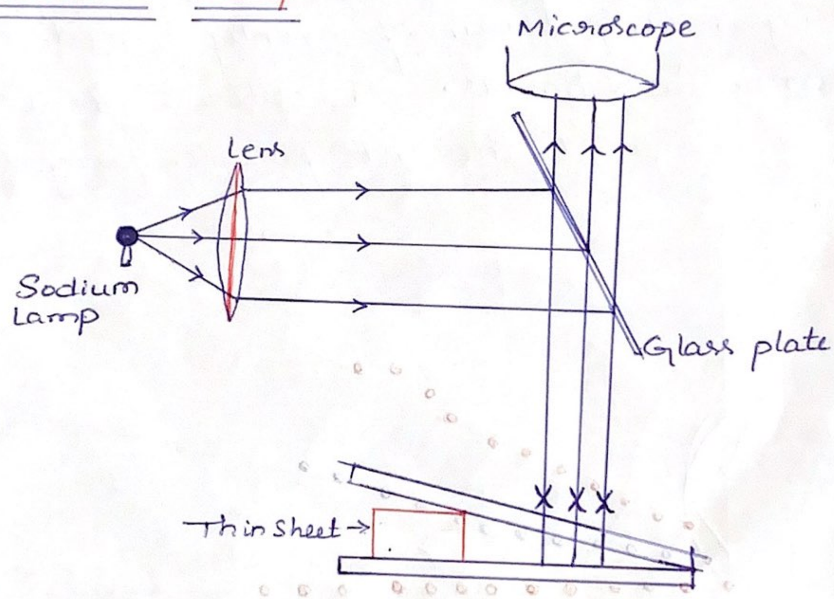
Determination of the thickness of a thin paper strip using air wedge.

Formation of air wedge

Consider two glass plates held together at one end with a rubber band. place a piece of paper in between them, on the other end and thus an air wedge is created. Now this is the air wedge that is created.



Experimental Set up



The experimental arrangement is made as shown in the diagram. An air wedge is created by using the two glass plates. place a thin glass slab above the air wedge, so that will work as partial mirror. place the sodium lamp in front of this arrangement. place the convex lens such that the sodium lamp is at its focus giving a parallel beam of light.

place a travelling microscope above the $45°$ glass slab to see the interference.

working

When the light from the lamp travels through the glass plate it gets refracted. Then the light passes through the air wedge into other glass plate. After the reflection from the bottom of the other glass plate, the light follows the same route back up. Due to these reflections and refractions the light is out of phase with the one getting partially refracted from the top surface. These lights in different phases cause interference & form fringes.

* The fringes are alternately dark and bright based on the path difference.

* The fringes are formed as the superposition of waves occur.

* Depending On the path difference, the waves in different phases overlap.

Condition for maxima is given by,

$$\boxed{2\mu t + \lambda/2 = n\lambda}$$

Condition for minima is given by,

$$\boxed{2\mu t + \lambda/2 = (2n+1)\lambda/2}$$

Fringe width, $\boxed{\beta = \lambda/2\mu\theta}$

Thickness of paper, $\boxed{t = \lambda l/2\beta}$

Where, $\lambda \rightarrow$ wavelength of light, $\theta \rightarrow$ Angle b/n glass plates
$t \rightarrow$ Thickness of paper
$L \rightarrow$ Length of air wedge
$\beta \rightarrow$ Fringe width

Diffraction

Diffraction

Diffraction is the bending of light waves around the corners of an obstacle or through an aperture into the region of geometrical shadow of the aperture.

In other words, diffraction is the slight bending of light as it passes around the edge of an object. The amount of bending depends on the relative size of the wavelength of light to the size of the opening. If the opening is much larger than the light's wavelength, the bending will be almost unnoticeable. However if the two are closer in size or equal, the amount of bending is considerable & easily seen with the naked eye.

Condition for Diffraction

The essential condition for diffraction of light is,

a) The wavelength of the light should always be comparable to the size of the object.

b) In certain cases, it may occur is the size of the object is less than the wavelength of light.

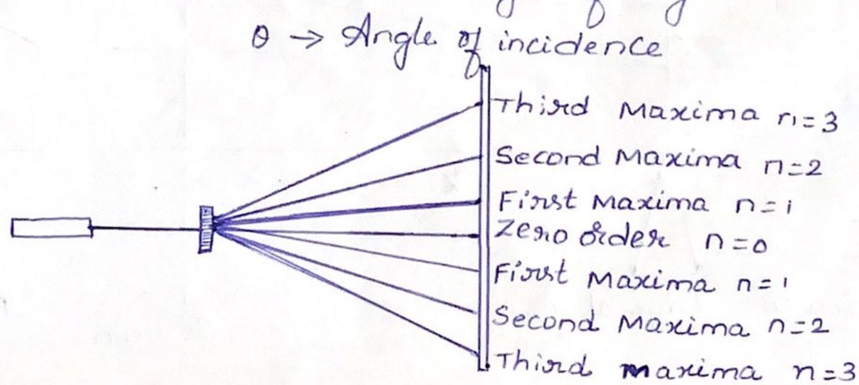
condition for maximum is,

$$d \sin\theta = n\lambda \quad \text{[Bragg's Law]}$$

where $n \rightarrow$ order of diffraction

$\lambda \rightarrow$ wavelength of light

$\theta \rightarrow$ Angle of incidence



Types of Diffraction

There are two types of diffraction.

a) Fresnel diffraction

b) Fraunhofer diffraction

Fresnel diffraction

when the source of light and the screen are at a finite distance from the inside obstacle, then the diffraction observed due to the obstacle is called Fresnel diffraction.

In Fresnel diffraction;

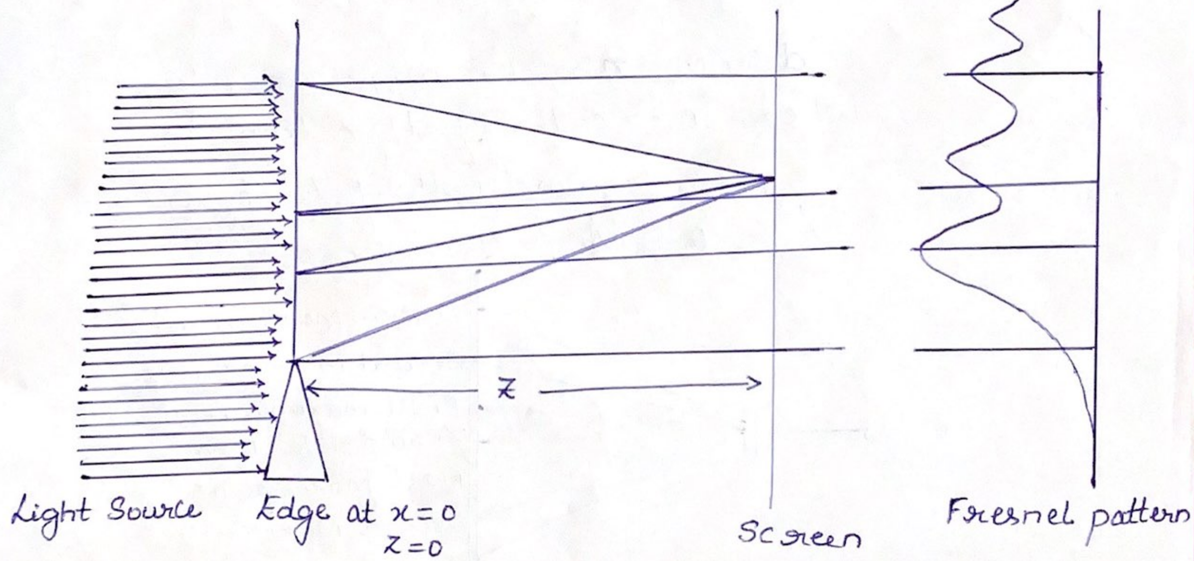
a) Source and screen are not far away from each other.

b) Incident wavefronts are spherical.

c) wavefronts leaving the obstacles are also spherical.

d) A convex lens is not needed to converge the spherical wavefronts.

This type of diffraction occurs on the straight edge, fine wire and narrow slit.



Fraunhofer Diffraction

- When the source of light and screen are effectively at an infinite distance from the obstacle or aperture causing diffraction, then the type of diffraction is called Fraunhofer diffraction.

In Fraunhofer diffraction;

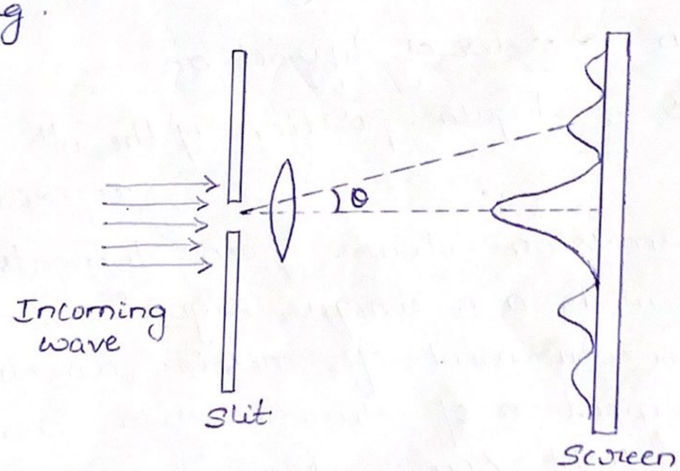
a) Source and the screen are far away from each other.

b) Incident wavefronts on the diffracting obstacle are plane.

c) Diffraction obstacle gives rise to wavefronts which are also plane.

d) plane diffracting wavefronts are converged by means of a convex lens to produce a diffraction pattern.

In this type of diffraction, wavefront incident on the obstacle or aperture is a plane. In order to produce this type of diffraction, a convex lens is placed in front of the lens in such a way as parallel rays come out of it. This diffraction is produced by single slit, double slits and grating.



Difference between Interference and Diffraction

Interference	Diffraction
Interference is a phenomenon of light which takes place due to the meeting of two light waves as they travel along the same medium.	Diffraction is a phenomenon of bending of light waves around the corners of an obstacle.
It occurs due to the light waves superposition that is from two sources.	It occurs because of the secondary wavelengths superposition.
Fringe width is equal.	Fringe width is unequal.
Same fringe intensity for all the friengs.	Not same fringe intensity for all the fringes.
obstacle is not required.	obstacle is required.
The contract b/n maxima and minima is good.	The contract b/n maxima and minima is poor.

15/12/23

Interference of Light

* Condition for Interference

* The light wave is participating in interferencere must have equal amplitude ~~and~~ with identical wavelength & constant or zero phase difference

* The wave amplitudes are equal, without which, the destructive interference accurs where the illumination of light, has the difference in the amplitude

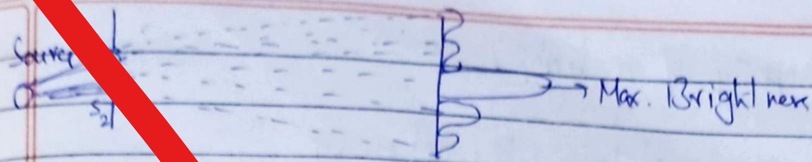
* The two light waves are kept very close to each other to avoid overlapping of the fringe pattern

* The two light waves must be emitting continuosly, If one of the light waves fails to emit the light waves fails to emit the light wave, Interference will be absent

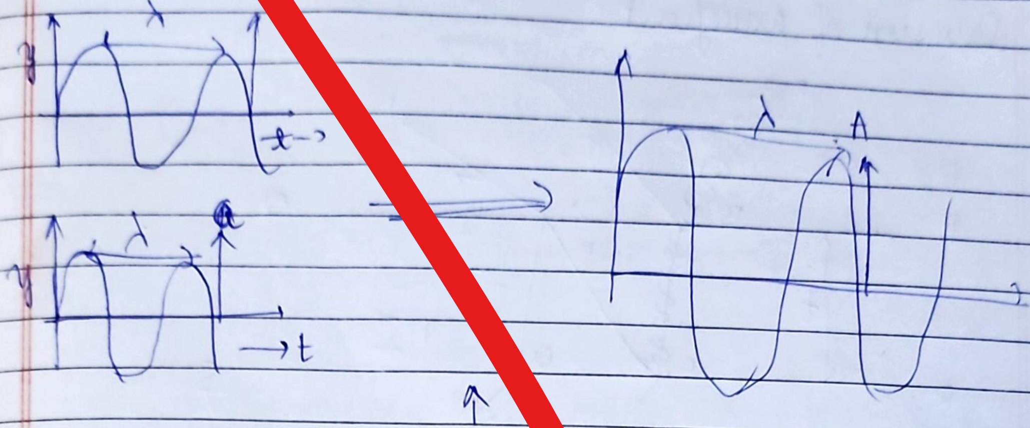
* If the two light waves dimensions are longer, the light comming from the are longer, the light coming from same source from different parts will not produce the interference of light

(waves - light waves dimensions is small)

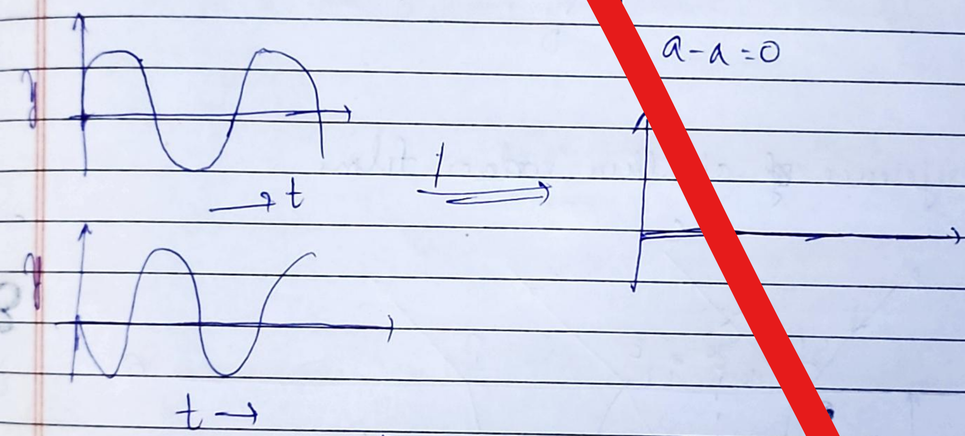
* The phase difference of the two light waves are bright $n\pi$ If the phase difference two waves are dark $= \frac{n\pi}{2}$



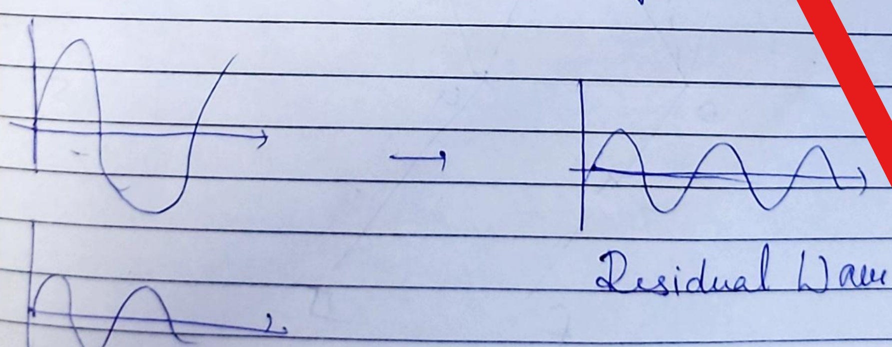
* Superposition Theorem of two waves:



Constructive Interference



Destructive Interference

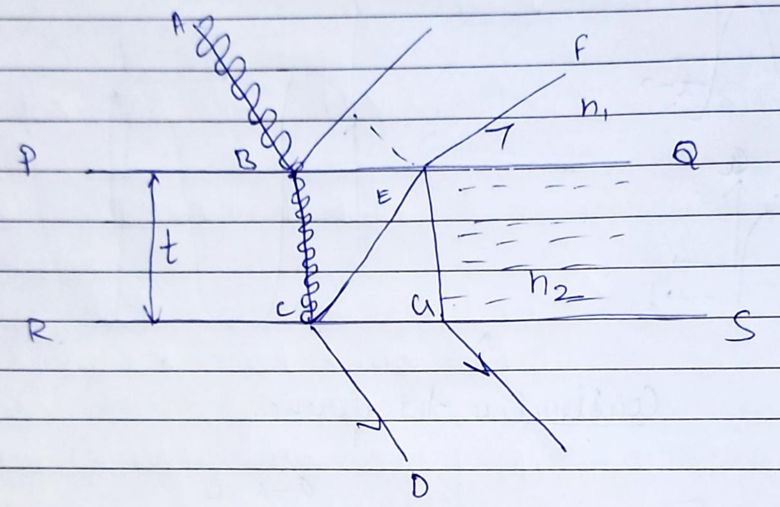


Residual Wave

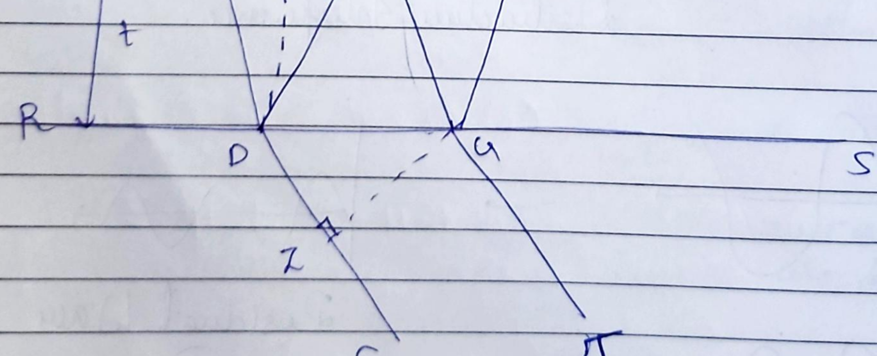
* Coherence Property of a light:

Techniques to obtain the cohensy

(i) Division of Amplitude
(ii) Division of Wavefront



* Interference ~~of~~ at thin various films



Consider a thin film of transparent medium of refractive index n, let it be uniform thickness of whose upper surface PQ & lower surface RS. Let ray of light AB of the monochromatic light of wavelength travelling in ~~air~~ ~~air~~ be incident on the surface PQ at an angle of incidence I.

Due to change of medium the rays suffers partial reflection & transmission (division of amplitude) at B. The reflected path travels along BC in air. The transmitted path reflected ~~ray~~ at D medium angle of reflection r.

Further it encounters again a change of medium at medium at D at which point it is partly reflected along DE ~~med~~ within the medium & partly refracted along ~~DE~~ EF emerging into air.

Partial reflection & transmission occur at points E G.

Let EX ~~&~~ EY be perpendicular drawn ~~points~~ to BC & BE respectively. Now assume beyond a point EX, the component ray pair XE & EX will cover same path length ~~aft~~ upto point of focus such as retina of observer's eye.

Since they incorporated in the ray AB, they can be assumed to have to cover the same path length upto point B. B/w these 2 stages the transmitted ray covers an optical path length

~~Optical~~

Transmitted ray covers an optical length $= \mu(BD + DE)$

Reflected ray covers a path length $= BX$

The path difference δ b/w the component rays XE & E~~H~~ $= \mu(BD + DE) - BX$ $\rightarrow$ (1)

But $BD = DE = \frac{DY}{\cos r} = \frac{t}{\cos r}$

$$BX = BE \sin i = (BY + EY) \sin i \rightarrow (2)$$

$$BY = EY = t \tan r$$

$$BX = (t \tan r + t \tan r) \sin i$$

$$BX = 2t \tan r \sin i$$

By Snell's Law $\frac{\sin i}{\sin r} = \mu$ or $\sin i = \mu \sin r$

$$\cancel{BX} = 2t \frac{\sin r}{\cos r} \sin i$$

$$BX = 2t \tan r \, \mu \sin r$$

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

$$= 2t \frac{\sin^2 r}{\cos r} \rightarrow (3)$$

Using (2) & (3) in eq^n (1)

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

$$\therefore \frac{2\mu t}{\cos r}\left(1 - \frac{\sin^2 r}{\cancel{\cos r}}\right)$$

SPARK

Date ______ Page ______

$$\delta = 2\mu t \frac{\cos^2 r}{\cos r}$$

$$\boxed{\delta = 2\mu t \cos r} \rightarrow (4)$$

∵ Since the part of the ray reflection at a denser medium, an additional path diff of $\lambda/2$ must be considered for Bx in eq^n (1).

∴ Total path diff $= \mu(BD+DE) - (Bx + \lambda/2)$

$$\boxed{\text{Total path} = 2\mu t \cos r - \frac{\lambda}{2}} \longrightarrow (5)$$

(i) Condition for Brightness:-

If the thin film appears bright when the two component ray pairs undergo constructive interference, which is possible when the total path difference is

$$2\mu t \cos r - \frac{\lambda}{2} = n\lambda$$

$$2\mu t \cos r = n\lambda + \frac{\lambda}{2}$$

$$\boxed{2\mu t \cos r = (2n+1)\frac{\lambda}{2}} \rightarrow (5)$$

Where $(n = 0, 1, 2 \ldots)$

(ii) Condition of ~~Brightness~~ Darkness

$$\text{Total path diff} = (2n+1)\frac{\lambda}{2}$$

$$2\mu t \cos r - \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$$

$$2\mu t \cos r = (2n+1)\frac{\lambda}{2} + \frac{\lambda}{2}$$

$$= (2n+1+1)\lambda$$

$$= (2n+2)\frac{\lambda}{2}$$

$$= \cancel{2}(n+1)\frac{\lambda}{\cancel{2}}$$

$$\boxed{2\mu t \cos r = (n+1)\lambda} \rightarrow (7)$$

$n = 0, 1, 2, 3, \ldots$

(iii) Interference effects observed in transmitted system:

We have to consider the interference b/w transmitted rays DF & GJ, If GZ is drawn normal to the ray DF, then the path diff (δ) b/w the component rays ZA & GJ in the similar way.

$\cancel{\mu(BD+DE)}$

$$\delta = \mu(DE + EG) - DZ$$

$$\boxed{\delta = 2\mu t \cos r} \rightarrow (8)$$

(a) Condition for Brightness

If film appear bright

$$\delta = 2\mu t \cos r = n\lambda$$

Also film thickness $t << \lambda$, $2\mu t \cos r = 0$

$\boxed{\delta = 0} \rightarrow (9)$. The thickness is negligible w.r.t 'λ'

SPARK

Date ______ Page ______

(ii) Condition for Darkness

$$\delta = 2\mu t \cos r = (2n+1)\frac{\lambda}{2} \longrightarrow (10)$$

Note: The complementary nature of reflected & transmitted system, by comparing (6) & (10), the condition of brightness in reflected system, the same one holds for darkness in transmitted system & vice-versa
∴ The light being comprising of rays of different wavelengths in which it is appearing bright in reflecting system will undergo extension in transmitted system & vice-versa. These two system consists of lights of wavelength which are present one & absent in another & vice-verse. But on whole they mutual complete the lights of wavelength present in incident light. Hence the reflected & transmitted system are said to complementary to the system

classmate

Date
Page

Q) Calculate the thickness of the air film at a distance of 2 cm, 3 cm respectively from the line of contact of glass plate of wedge setup, if the fringe width is 0.1 mm and if the illuminating light has a wavelength of 600 nm

ans) Given :

First line of Contact = $x_1 = 2\,cm$

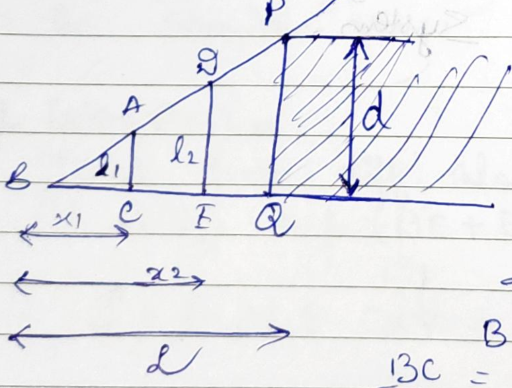
Dist. of 2^{nd} line of Contact $= x_2 = 3\,cm$

fringe width $\beta = 0.1\,mm$

$\lambda = 600 \times 10^{-9}\,m$

To find : The thickness t_1 & t_2 of the air film at distances x_1 & x_2 from the line of Contact.

$$\omega = \frac{\lambda l}{2d}$$



from fig : The simmilar Δ's BAC, BQE, BPQ

$$\frac{BC}{AC} = \frac{BE}{QE} = \frac{BQ}{PQ}$$

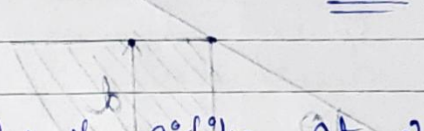
$$\frac{x_1}{l_1} = \frac{x_2}{l_2} = \frac{L}{d}$$

$$w = \frac{\lambda}{2} \times \frac{x_1}{l_1} = \frac{600\times10^{-9}}{2} \times \frac{2}{l_1} = \beta \Rightarrow 600\ nm \qquad l_1 \Rightarrow 6\times10^{-5}$$

$$\Rightarrow l_1 = 1w = \lambda/2 \times \frac{x_2}{l_2} = \frac{600\times10^{-9}}{2} \times \frac{3}{l_2} = \cancel{600\times10^{-9}}\ 0.1\times10^{-3}$$

$$\Rightarrow l_2 = 9\times10^{-5}$$

~~Wt~~ =



∴ the thickness value of airfilm at 2cm and 3cm from line of contact are 6×10^{-5} & 9×10^{-5} resp.

Calculate the thickness of airfilm at 5cm & 10cm respectively from the line of contact of glass shape wedge shape, if the fringe width is 1mm and the wavelength of source used is $\lambda = 635\ nm$

ans

$x_1 = 5\ cm = 5\times10^{-2}\ m$

$x_2 = 10\ cm = 10\times10^{-2}\ m$

$\beta = 1mm = 10^{-3}\ m$

$\lambda = 635\ nm = 653\times10^{-9}\ m$

$$w = \frac{\lambda}{2} \times \frac{x_1}{l_1}$$

$$10^{-3} = \frac{653\times10^{-9}}{2} \times \frac{5\times10^{-2}}{l_1}$$

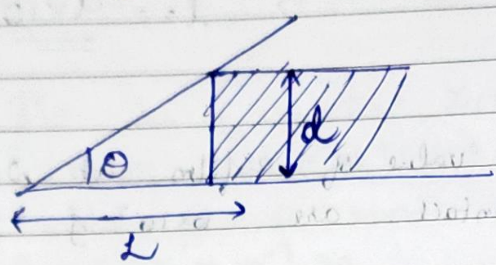
$$l_1 = 1587\times10^{-8}\ m$$

$$w = \frac{\lambda}{2} \times \frac{x_2}{l_2}$$

$$10^{-3} = \frac{635\times10^{-9}}{2}\ \frac{10\times10^{-2}}{l_2}$$

$$l_2 = 3175\times10^{-8}\ m$$

Q) A monochromatic light is incident normally on a wedge shaped air film having an angle 10' at its apex. If the fringe system formed due to interference as a fringe width of 0.1×10^{-3} m. Calculate the wavelength of incident light.



Apex angle of wedge $= 10' = \frac{10}{60} \times \frac{\pi}{180} \Rightarrow \pi/1080$

Fringe width $= \omega = 0.1 \times 10^{-3}$ m

Wavelength $= \lambda = ?$

$\therefore \quad \omega = \frac{\lambda l}{2d}$

l is length of wedge and d is the thickness of the seperating two optical ~~fib~~ flat. But since the angle 'θ' the apex of the wedge shape film is small.

$$\theta = \frac{d}{l}$$

$$\omega = \frac{\lambda}{2\theta}$$

$$\lambda = 2\theta\omega$$

$$\Rightarrow 2 \times \frac{\pi}{1080} \times 0.1 \times 10^{-3}$$

$$\Rightarrow \underline{5.81 \times 10^{-7} \text{ m}}$$

Q) In an interference ~~of~~ of an air wedge expt. Conducted by using sodium lamp source the wavelength is found to be fringe of 10^{-2} m. Calculate the thickness of specimen of two optical flask if length of air wedge is 4×10^{-3} m ($\lambda_{Na} = 5893 \times 10^{-10}$ m).

$W = 0.1 \times 10^{-3}$
$\lambda = 5893 \times 10^{-3}$
$l = 4 \times 10^{-3}$

$$W = \frac{\lambda l}{2d}$$

$$0.1 \times 10^{-3} = \frac{5893 \times 10^{-10} \times 4 \times 10^{-3}}{2 d}$$

$$d = 1.18 \times 10^{-5} \text{ m}$$

Q) Calculate the dist. at which the 100th dark fringe and the 200th bright fringe are formed from the line of Contact of the Glass plates in an air wedge expt. if the thickness of the object is 60 μ length of the wedge is 5 cm & the wavelength of light used is 600×10^{-10} m

(ans)

classmate

Date
Page

Q) The diameter of the 10^{th} dark ring in a newton's ring system, veiwed normally by a reflected light is 0.4 cm. Calculate the thickness of the air film at 10^{th} ring and the radius of curvature of the lens surface

Data: Ordinal no. of the ring = ?
diameter of the ring $d_n = 0.4$ cm
Wavelength of light $\lambda = 5893 \times 10^{-10}$ m

To find = Thickness of airfilm at 10^{th} dark ring
$t = ?$
Radius of curvature of lens = $R = ?$

Soln)
Eqn for Dark fringe ⇒ $2t = n\lambda$

$$t = \frac{n\lambda}{2} = \frac{10 \times 5893 \times 10^{-10}}{2}$$

$$t = 2.95 \times 10^{-6}$$

For dark fringe = $\frac{d_n^2}{4R} = n\lambda$

$$R = \frac{d_n^2}{4n\lambda} \Rightarrow 0.679 \text{ m}$$

Imt Q) In a newton's ring System if the dia of the 8^{th} dark ring is 3.35×10^{-3} m and the dia of 12^{th} " " " 4.103×10^{-3} m. Calculate the radius of curvature of the plano convex lens given the wavelength is 5893 Å.

(ans) $R = \dfrac{dn^2}{4(m-n)\lambda}$

$\Rightarrow \cancel{\dfrac{}{4(4.103 \times 10^{-3}}}$

For 8th Ring

$\Rightarrow \dfrac{dm^2 - dn^2}{4\lambda(m-n)}$

$\Rightarrow \dfrac{(4.103 \times 10^{-3})^2 - (3.305 \times 10^{-3})^2}{4 \times 5893 \times 10^{-3} \times (12-8)}$

$\Rightarrow 0.595\ m$