INSPIRE ACADEMY JAIPUR
LEADING INSTITUTE OF PHYSICS
INSTITUTE FOR CSIR-NET, GATE, JEST, TIFR, BARC, IIT-JAM, JNU, BHU, DU, CU, RU, M.Sc., B.Sc.
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B.Sc. & B.Sc. – B.Ed. 1st year

Physics

Optics

Class notes

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UNIT-I

Interference And Their related Experiment

Light :-

Light is a form of energy. That energy which works as visible is known as light.

Accⁿ to optics physics, Propagation of energy is in particle and waves in both form. Direction of wave propogation is of two types.

(a) Transverse Nature
(b) Longitudinal Nature.

(a) Transverse Nature :-

Accⁿ to wave mechanical, Nature of that wave in which vibration of particle is perpendicular to the dirⁿ of wave propagation is known as Transverse Nature of wave.

Ex- Electromagnetic wave, Pluent wave in stretched string. etc.

(b) Longitudinal Nature :-

Accⁿ to wave mechanics, Nature of that wave in which vibration of particle is parallel to the dirⁿ of wave propagation is known as longitudinal Nature of wave.

Ex- Pluent elastic wave in solid rod, Pluent wave in gas collum.

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Light source:-

That source of energy due to which energy is emit in the form of light known as light source.

Light source is of two types.

(i) Coherent light source.
(ii) Incoherent light source.

(i) Coherent light source:-

That light source in which phase diffⁿ b/w emitted light waves is constant known as coherent light source. with respect to time

This is the Necessary condition for proper Interference.

(ii) Incoherent light source:-

That light source in which phase diffⁿ b/w emitted light waves is changed with respect to time is known as Incoherent light source.

Interference:-

~~Def~~ Interference is a optical phenomenon of light. whose physical meaning is by "Superposition of Wave"

Accⁿ to concept of optical physics, "When two or more than two light waves are propagate in same dirⁿ and superposite then at some points intensity of light is observed maximum and at some points intensity of light is observed minimum. This physical incident is known as Interference.

Conditions for Proper Interference of light:-

i) Accⁿ to concept of optical physics, there are following conditions for proper interference.

(i) Amplitude of wave should be approx. equal.

(ii) light source should be coherent.

(iii) Frequency of wave should approximately equal.

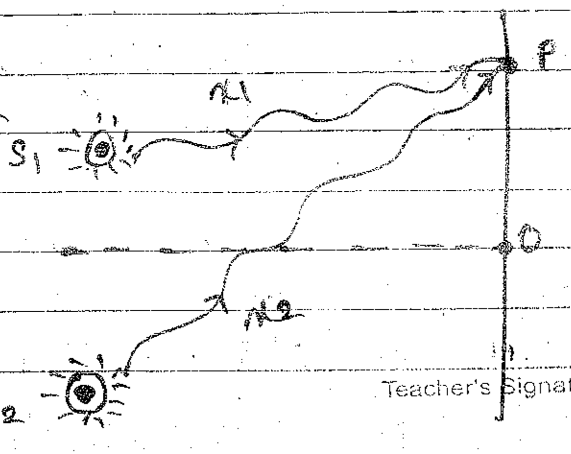
(iv) Path difference should be very small.

(v) propagation of wave should be in same direction.

(vi) Phase difference should be very small b/w wave.

(vii) Polarise wave should not be present and if there is polarise wave then polarisation plane should be same.

Mathematical Discussion:-



To Do the mathematical Analysis of Interference we image of two light source. let first light source is S_1 and second light source is S_2. from these light source their is emission of waves. let two waves of x_1 and x_2 path superpose on point P. Due to which maxima and minima of intensity of light waves is observed.

We know that from standard eq^n of wave

$$y = a \sin(\omega t - kx)$$

(i) Displacement eq^n for first wave.

$$y_1 = a_1 \sin(\omega t - kx_1)$$

(ii) Displacement eq^n for second wave.

$$y_2 = a_2 \sin(\omega t - kx_2)$$

By superposition principle.

$$y = y_1 + y_2$$

on putting values.

$$y = a_1 \sin(\omega t - kx_1) + a_2 \sin(\omega t - kx_2)$$

$$y = a_1[\sin\omega t \cos kx_1 - \cos\omega t \sin kx_1] + a_2[\sin\omega t \cos kx_2 - \cos\omega t \sin kx_2]$$

$$y = [a_1 \cos kx_1 + a_2 \cos kx_2]\sin\omega t - [a_1 \sin kx_1 + a_2 \sin kx_2]\cos\omega t$$

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$$R\cos\theta = a_1\cos kx_1 + a_2\cos kx_2 \quad \text{——} (1)$$

$$R\sin\theta = a_1\sin kx_1 + a_2\sin kx_2 \quad \text{——} (2)$$

$$y = R\cos\theta\sin\omega t - R\sin\theta\cos\omega t$$

$$y = R[\sin\omega t\cos\theta - \cos\omega t\sin\theta]$$

$$\boxed{y = R\sin(\omega t - \theta)} \quad \text{——} (3)$$

eq^n (3) is known as Displacement eq^n for resultant wave.

Calculation of Resultant Amplitude:

on squaring eq^n (1) and (2) and add.

$$R^2(\sin^2\theta + \cos^2\theta) = [a_1\cos kx_1 + a_2\cos kx_2]^2 + [a_1\sin kx_1 + a_2\sin kx_2]^2$$

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2[\cos kx_1\cos kx_2 + \sin kx_1\sin kx_2]$$

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos[kx_2 - kx_1]$$

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos k(x_2 - x_1)$$

$$\because \Delta = x_2 - x_1 \quad (\text{path diff}^n)$$

$$\boxed{R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\Delta k} \quad \text{——} (4)$$

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Eq^n (4) denotes the Resultant Amplitude. ΔK present in eq^n (4) is path difference. on this basis of path difference Interference is of two types.

(a) Constructive interference.
(b) Destructive Interference.

(a) <u>Constructive Interference</u> :-

Condition of that interference in which Resultant value of Amplitude is finds maximum. is known as Constructive Interference.

Value of path $diff^n$ for this Interference is

$$\boxed{\Delta = n\lambda} \quad \text{--- (5)}$$

$n = 0, 1, 2, 3, \text{------}$

<u>Now</u> $\cos K\Delta = \cos \frac{2\pi}{\lambda} \cdot n\lambda$

$\cos K\Delta = \cos 2n\pi$

$\cos 2n\pi = +1$

$$\boxed{\cos K\Delta = +1}$$

on putting in eq^n (4)

$$R^2_{max.} = a_1^2 + a_2^2 + 2a_1a_2(+1)$$

$$R^2_{max.} = (a_1+a_2)^2$$

$$\boxed{R_{max.} = (a_1+a_2)} \quad \text{--- (6)}$$

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(b) Destructive Interference:-

Condition of that interference in which resultant value of Amplitude is find minimum is known as Destructive interference. In this Dark fringes obtained.

Path diff^n for this interference is:-

$$\boxed{\Delta = (2n \pm 1)\frac{\lambda}{2}} \quad \text{---(7)}$$

$n = 0, 1, 2 \ldots$

Now $\cos k\Delta = \cos \frac{2\pi}{\lambda}(2n \pm 1)\frac{\lambda}{2}$

$\cos k\Delta = \cos (2n \pm 1)\pi$

$\because \cos(2n \pm 1)\pi = -1$

$\boxed{\cos k\Delta = -1}$

on putting in eq^n (4)

$R^2_{min} = a_1^2 + a_2^2 + 2a_1a_2(-1)$

$R^2_{min} = (a_1 - a_2)^2$

$$\boxed{R_{min} = (a_1 - a_2)} \quad \text{---(8)}$$

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Calculation OF Light Intensity:-

Acc^n to Concept of Optical physics, Intensity of light is directly proportional to the square of Amplitude.

$$I \propto R^2$$

$$\boxed{I = kR^2}$$

on putting value from eq^n (4)

$$I = k(a_1^2 + a_2^2 + 2a_1a_2 \cos k\Delta)$$
$$I = ka_1^2 + ka_2^2 + 2ka_1a_2 \cos k\Delta$$
$$I = ka_1^2 + ka_2^2 + 2\sqrt{ka_1^2 \cdot ka_2^2} \cdot \cos k\Delta$$

$$\because I_1 = ka_1^2$$
$$I_2 = ka_2^2$$

$$\boxed{I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos k\Delta} \quad \text{--- (9)}$$

eq^n (9) is called the mathematical formula of intensity of light. on the basis of Δ present in eq^n (9) interference is of two types.

(1) Constructive interference:-

Bright fringes obtained. Condition of that Interference in which resultant value of intensity finds maximum, is known as Constructive Interference.

Value of path difference for this is following:-

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$$\boxed{\Delta = n\lambda}$$

$n = 0, 1, 2 ---$

Now $\cos k\Delta = \cos \frac{2\pi}{\lambda} . n\lambda$

$\cos k\Delta = \cos 2\pi n$

$\because \cos 2\pi n = +1$

$$\boxed{\cos k\Delta = +1}$$

on putting in eqn (9)

$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos 2\pi n$

$I = I_1 + I_2 + 2\sqrt{I_1 I_2} (+1)$

$$\boxed{I_{max.} = (\sqrt{I_1} + \sqrt{I_2})^2}$$

$\Rightarrow$ If $I_1 = I_2 = I_0$

$$\boxed{I_{max} = 4 I_0}$$ Ans

(2) Destructive Interference :- Condition of that interference in which resultant value of intensity is find minimum is known as Destructive interference

In this Dark fringes obtained.

$\Delta = (2n \pm 1) \frac{\lambda}{2}$

Now $\cos k\Delta = \cos \frac{2\pi}{\lambda} . (2n \pm 1) \frac{\lambda}{2}$

$\cos K\Delta = \cos(2n\pm1)\pi$

$\because \cos(2n\pm1)\pi = -1$

$$\boxed{\cos K\Delta = -1}$$

on putting in eq^n (9)

$I_{min} = I_1 + I_2 + 2\sqrt{I_1 I_2}\,(-1)$

$I_{min} = I_1 + I_2 - 2\sqrt{I_1 I_2}$

$$\boxed{I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2}$$

$\Rightarrow$ if $I_1 = I_2 = I_0$

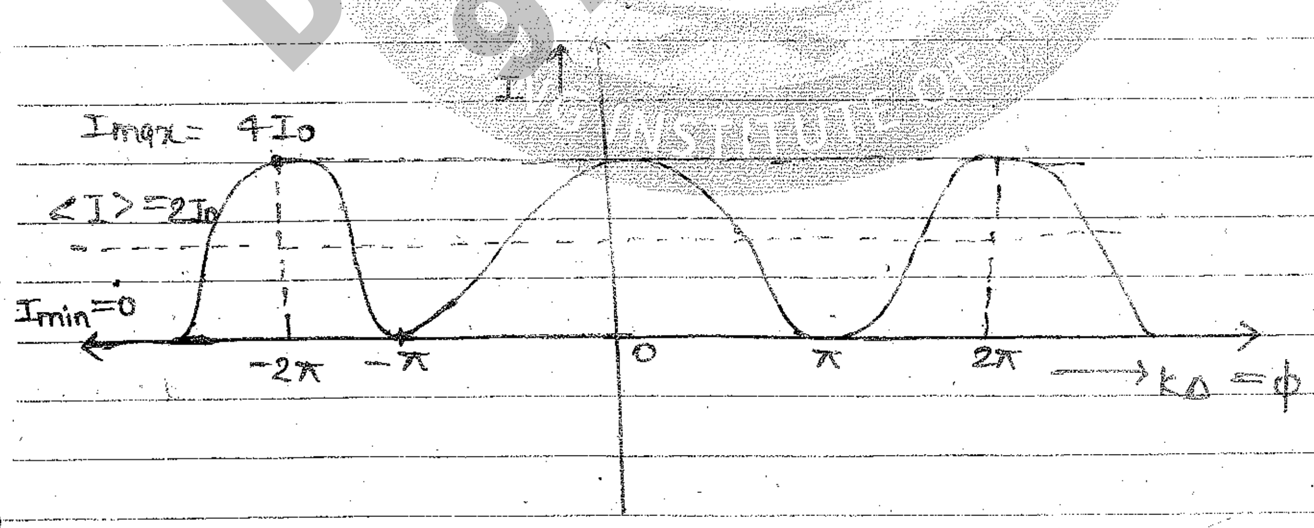
$I_{min} = (\sqrt{I_0} - \sqrt{I_0})^2$

$\boxed{I_{min} = 0}$ ~~##~~ dark.

Curve Of Interference :-

From eq^n (9)

$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos K\Delta$



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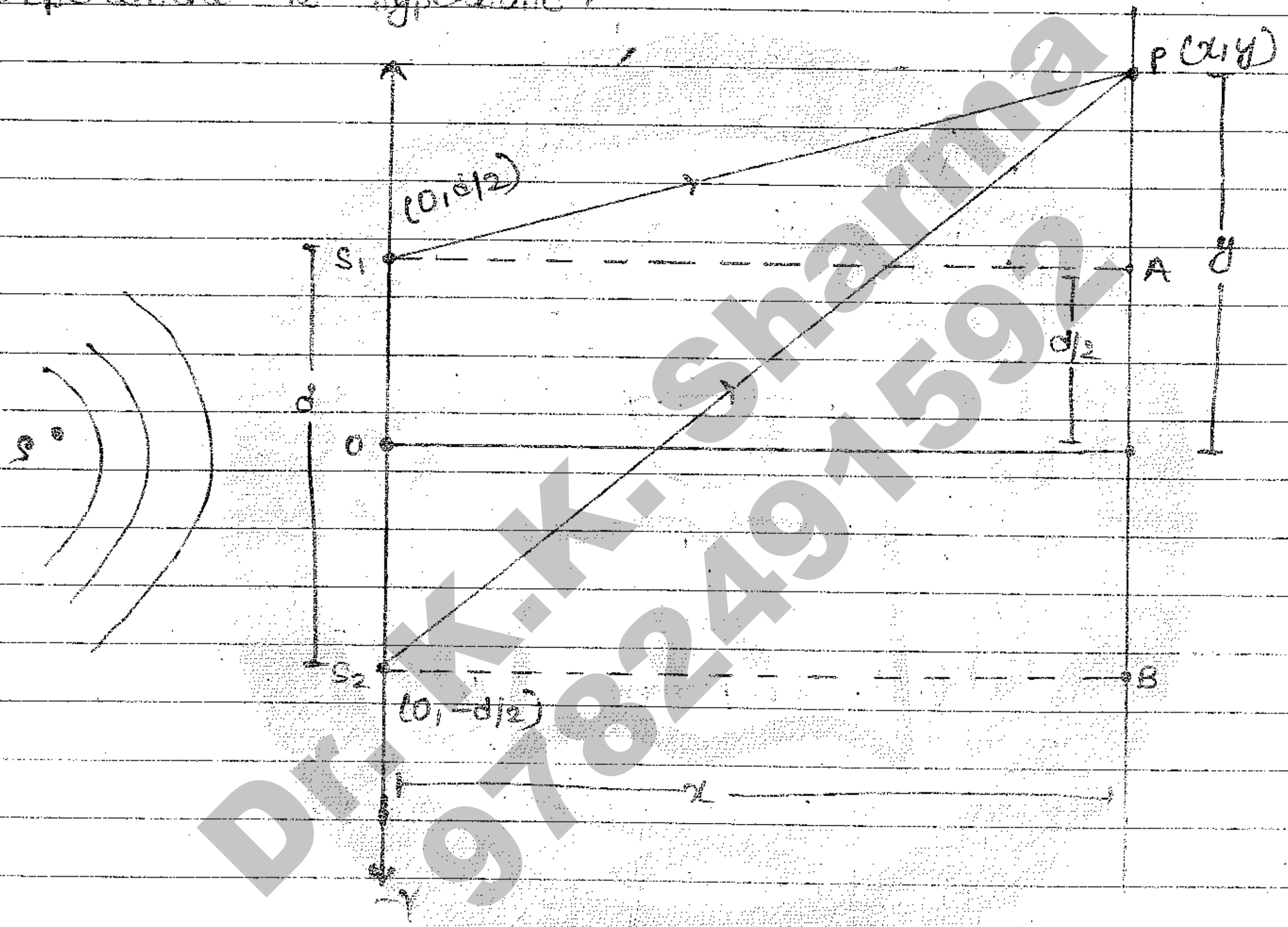
Hence it is clear from energy curve of interference that propagation of ~~eg~~ energy is from maximum to minimum point. This is the energy conservation law.

Q Prove that shape of fringe in Young's double slit experiment is hyperbolic?



In Young's double slit experiment, to study the shape of fringe we image of Cartesian co-ordinate system.

Let on Y-co-ordinate axis two slit S_1 and S_2 are present. The distance b/w these slit is d. These slit S_1 and S_2 behave as a secondary light source. Co-ordinate for slit S_1 is $(0, d/2)$ and co-ordinate for slit S_2 is $(0, -d/2)$. Let due to these slit fringes are observed at point P on screen. whose co-ordinates are (x,y)

Mathematical Verification :-

To do the mathematical verification, we calculate the path diffⁿ b/w secondary emitted wave front path diffⁿ b/w S_1 and S_2.

$$\Delta = S_2P - S_1P$$

$$\boxed{\Delta + S_1P = S_2P} \quad \text{---} (1)$$

(i) in ΔS_2BP, By pythagorous theorum.

$$(S_2P)^2 = (S_2B)^2 + (BP)^2$$

$$(S_2P)^2 = x^2 + (y+d/2)^2$$

$$S_2P = \sqrt{x^2 + (y+d/2)^2} \quad \text{---} (2)$$

(ii) in ΔS_1AP, By pythagorous theorum.

$$(S_1P)^2 = (S_1A)^2 + (AP)^2$$

$$(S_1P)^2 = x^2 + (y-d/2)^2$$

$$S_1P = \sqrt{x^2 + (y-d/2)^2} \quad \text{---} (3)$$

on putting value of eqⁿ (2) and (3) in eqⁿ (1)

$$\Delta + [x^2 + (y-d/2)^2]^{1/2} = [x^2 + (y+d/2)^2]^{1/2}$$

on squaring

$$\Delta^2 + [x^2 + (y-d/2)^2] + 2\Delta[x^2 + (y-d/2)^2]^{1/2} = x^2 + (y+d/2)^2$$

$$\Rightarrow \Delta^2 + x^2 + y^2 + \frac{d^2}{4} - \frac{2yd}{2} = x^2 + y^2 + \frac{d^2}{4} + \frac{2yd}{2} - 2\Delta[x^2 + (y-d/2)^2]^{1/2}$$

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$$\Rightarrow \quad \Delta^2 - 2yd = -2\Delta\left[x^2 + (y - d/2)^2\right]^{1/2}$$

on squaring

$$\Rightarrow \quad \Delta^4 + 4y^2d^2 - 4\Delta^2 yd = 4\Delta^2\left[x^2 + y^2 + \frac{d^2}{4} - 2y\frac{d}{2}\right]$$

$$\Rightarrow \quad \Delta^4 + 4y^2d^2 - 4\Delta^2 yd = 4\Delta^2x^2 + 4\Delta^2y^2 + \Delta^2d^2 - 4\Delta^2yd$$

$$\Rightarrow \quad \Delta^4 - \Delta^2d^2 = 4\Delta^2x^2 + 4y^2(\Delta^2 - d^2)$$

$$\Rightarrow \quad \Delta^2(\Delta^2 - d^2) = 4\Delta^2x^2 + 4y^2(\Delta^2 - d^2)$$

$$\frac{4\Delta^2x^2}{\Delta^2(\Delta^2 - d^2)} + \frac{4y^2(\Delta^2 - d^2)}{\Delta^2(\Delta^2 - d^2)} = 1$$

$$\boxed{\frac{x^2}{\left(\sqrt{\frac{\Delta^2 - d^2}{4}}\right)^2} + \frac{y^2}{\left(\sqrt{\frac{\Delta}{4}}\right)^2} = 1} \quad \text{—— (4)}$$

d shows the distance b/w slits and Δ define path diffⁿ. We know that for proper interference value of Δ is very small so,

$$\boxed{\frac{y^2}{\left(\frac{\Delta}{2}\right)^2} - \frac{x^2}{\left(\frac{d}{2}\right)^2} = 1} \quad \text{—— (5)}$$

$$\boxed{\frac{y^2}{\left(\frac{\Delta}{2}\right)^2} = 1 + \frac{x^2}{\left(\frac{d}{2}\right)^2}}$$

eqⁿ ⑤ satisfy the standard eqⁿ of hyperbola so, in young's double slit experiment, shape of fringe is hyperbolic.

If screen is present very far distance from slit then fringe in 'young's' Double slit experiment observed rectilinear.

$$x >>> 1 \quad \text{——⑥}$$

From eqⁿ ⑤

$$\frac{y^2}{\left(\frac{\Delta}{2}\right)^2} - \frac{x^2}{\left(\frac{d}{2}\right)^2} = 1$$

$$\frac{y^2}{\left(\frac{\Delta}{2}\right)^2} = 1 + \frac{x^2}{\left(\frac{d}{2}\right)^2} \quad \text{——⑦}$$

From eqⁿ ⑥ and ⑦

$$\frac{y^2}{\left(\frac{\Delta}{2}\right)^2} = \frac{x^2}{\left(\frac{d}{2}\right)^2}$$

taking square root

$$\frac{y}{\Delta/2} = \pm \frac{x}{d/2}$$

$$\frac{y}{\Delta} = \pm \frac{x}{d}$$

$$\boxed{y = \pm \frac{\Delta x}{d}} \quad \text{——⑧}$$

From straight line eqⁿ $y = mx + c$ ——⑨

eq^n (8) satisfy eq^n (9). Therefore in young's double slit experiment shape of fringe is rectilinear.

Method Of producing Coherent light Source:

The light source for which value of phase diff^n is constant with respect to time is known as coherent light source.

Monocromatic light source is known as coherent light source.

In optics physics, their are two methods of producing / finding coherent light source.

(i) By Wavefront Division method.
(ii) By Amplitude Division method.

(i) By Wavefront Division Method:

Wavefront division method is a process of finding coherent light source. In this process pointed light source is used. Wavefront are emit by pointed light source. This emitted wavefront division is done by reflection or refraction method. or we find secondary light source. these secondary light source is coherent light source.

Ex (a) Young's Double slit experiment.
(b) Fresnal biprism experiment.

(ii) By Amplitude Division Method:

Amplitude division is also an optical method. by which Coherent light source is found. In Amplitude division method broad or Narrow light source is used. By this light source, Amplitude division is either done by partial reflection or partial refraction process of emitted light.

Ex (a) Interference in thin film.
(b) Newton's ring experiment.
(c) Michelson Interferometer experiment.

Young's Double slit Experiment:

It is a method of finding coherent light source. This method is based on wavefront division method. This method is define by Hygen wavefront principle.

Theoritical Explanation:

To explain Theoritical explanation of Young's Double slit experiment we image a light source. This light source is called primary light source. Emission of light energy in the form of wavefront from primary light source. Take a rectangular board in young's double slit experiment and make two holes, these two holes are called S_1 and S_2. A screen is also used to observe Interference and observe bright or dark fringe.

From the light source of emitted wavefront is incident on rectangular board. incident wavefront is divided due to slit S_1 and S_2. This wavefront is called secondary wavefront. because

Acc^n to concept of Hygen's scientist slit S_1 and S_2 behaves as a secondary light source. By secondary light source emitted wavefront superposite in same phase then intensity of light finds maxima on screen. due to this bright fringe are observed & if wavefront emitted by slit S_1 and S_2 are superposite in opposite phase then intensity of light finds minima on screen. due to this dark fringes are observed on screen. but at central point O, always bright fringe are observed on screen. because at central point path diff^n become zero which is the condition of Constructive Interference. This is the theoritical explanation of Young's double slit experiment.

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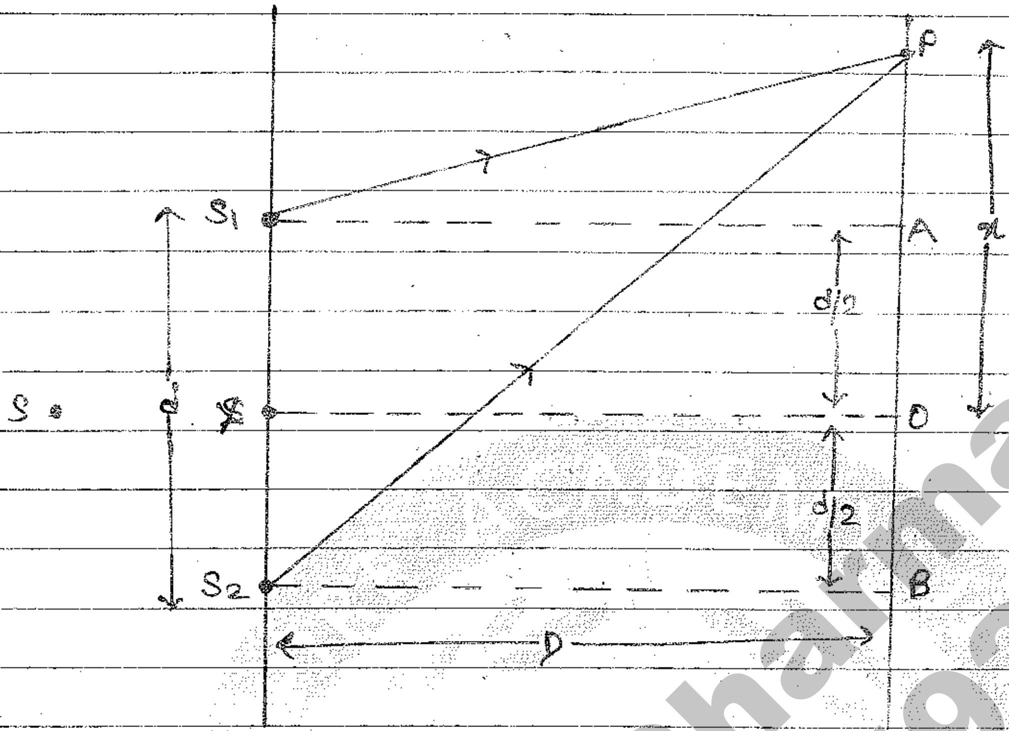
Mathematical Analysis:

To calculate Mathematical Analysis of Young's Double slit experiment we have to calculate the path diff^n.



To calculate the value of path difference, we define some parameter suppose D is parameter which define distance b/w slits and screen and d define distance b/w slits. suppose from central point O of screen at x distance a point P is present on that fringes are observe.

$$\Delta = S_2P - S_1P \quad \text{---} (1)$$

in ΔS_2BP, By pythagorous theorum.

$$(S_2P)^2 = (S_2B)^2 + (BP)^2$$

$$(S_2P)^2 = D^2 + (x + d/2)^2$$

$$(S_2P)^2 = D^2 \left[1 + \frac{(x + d/2)^2}{D^2}\right]$$

$$S_2P = D\left[1 + \frac{(x + d/2)^2}{D^2}\right]^{1/2}$$

$$\because (1+x)^n = 1 + nx$$

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$$S_2P = D + \frac{(x+d/2)^2}{2D} \quad \text{--- (2)}$$

in ΔS_1AP,

By pythagorous theorum:

$$(S_1P)^2 = (S_1A)^2 + (AP)^2$$

$$(S_1P)^2 = D^2 + (x-d/2)^2$$

$$(S_1P)^2 = D^2\left[1 + \frac{(x-d/2)^2}{D^2}\right]$$

$$(S_1P) = D\left[1 + \frac{(x-d/2)^2}{D^2}\right]^{1/2}$$

$$\because (1+x)^n = (1+nx)$$

$$(S_1P) = D\left[1 + \frac{1}{2}\frac{(x-d/2)^2}{D^2}\right]$$

$$S_1P = D + \frac{(x-d/2)^2}{2D} \quad \text{--- (3)}$$

put in value of eq^n (2) and (3) in eq^n (1)

$$\Delta = D + \left[\frac{(x+d/2)^2}{2D}\right] - D - \frac{(x-d/2)^2}{2D}$$

$$\Delta = \frac{1}{2D}\left[\left(x+\frac{d}{2}\right)^2 - \left(x-\frac{d}{2}\right)^2\right]$$

$$\Delta = \frac{1}{2D}\left[x^2+\frac{d^2}{4}+\frac{2xd}{2} - x^2 - \frac{d^2}{4} + \frac{2xd}{2}\right]$$

$$\Delta = \frac{1}{2D}\cdot 2xd$$

$$\boxed{\Delta = \frac{xd}{D}} \quad \text{--- (4)}$$

eqⁿ (4) defined path difference. on the basis of path diffⁿ interference is of two types.

<u>Constructive interference</u>:-

That Interference for which value of intensity of light finds maximum is known as Constructive interference.

Bright fringes are observe in this interference. for which value of path difference is:-

$$\boxed{\Delta = n\lambda}$$

From eqⁿ (4)

$$\frac{xd}{D} = n\lambda$$

$$\boxed{x = \frac{n d D}{d}}$$

For n^{th} fringe,

$$\boxed{x_n = \frac{n d D}{d}}$$

For $(n+1)^{th}$ fringe,

$$\boxed{x_{n+1} = \frac{(n+1) d D}{d}}$$

From mathematical formula of fringe width,

$$\beta = x_{n+1} - x_n$$

$$\beta = \frac{(n+1) d D}{d} - \frac{n d D}{d}$$

$$\beta = \frac{n d D}{d} + \frac{d D}{d} - \frac{n d D}{d}$$

$$\boxed{\beta = \frac{d D}{d}} \quad \text{--- (5)}$$

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It is clear from eqⁿ (5) that fringe width does not depends on n. therefore for all fringe, fringe width is equal.

② Destructive interference:-

That interference in which light intensity will be minimum. means finds minima is called Destructive interference.

from eqⁿ (4)

$$\frac{xd}{D} = \Delta$$

$$\Delta = (2n \pm 1)\frac{\lambda}{2} \quad \text{—— (6)}$$

from eqⁿ (4) and (6)

$$\frac{xd}{D} = (2n \pm 1)\frac{\lambda}{2}$$

$$x = (2n+1)\frac{\lambda D}{2d} \quad (+ve\ taking)$$

For n^{th}

$$x_n = (2n+1)\frac{\lambda D}{2d}$$

For $(n+1)^{th}$

$$x_{n+1} = (2n+3)\frac{\lambda D}{2d}$$

from mathematical formula of fringe width.

$$\beta = x_{n+1} - x_n$$

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$$\beta = \frac{(2n+3)\lambda D}{2d} - \frac{(2n+1)\lambda D}{2d}$$

$$\beta = [2n+3-2n-1] \cdot \frac{\lambda D}{2d}$$

$$\beta = \frac{2 \cdot \lambda D}{2d}$$

$$\boxed{\beta = \frac{\lambda D}{d}} \quad \text{——— (7)}$$

It is clear from eqn (7) ~~that~~ fringe width depends on following factors.

(i) Fringe width is directly proportional to wave length of light.

$\boxed{\beta \propto \lambda}$

(ii) Fringe width is inversely proportional to the distance b/w slits. $\boxed{\beta \propto \frac{1}{d}}$

(iii) Fringe width is directly proportional to the distance of light source to screen.

$\boxed{\beta \propto D}$

Interference in Thin film: Thin film interference is a optical method. By this optical method, Coherent light source is find. This method is based on amplitude division process. In this method, broad light source is used. By this broad light

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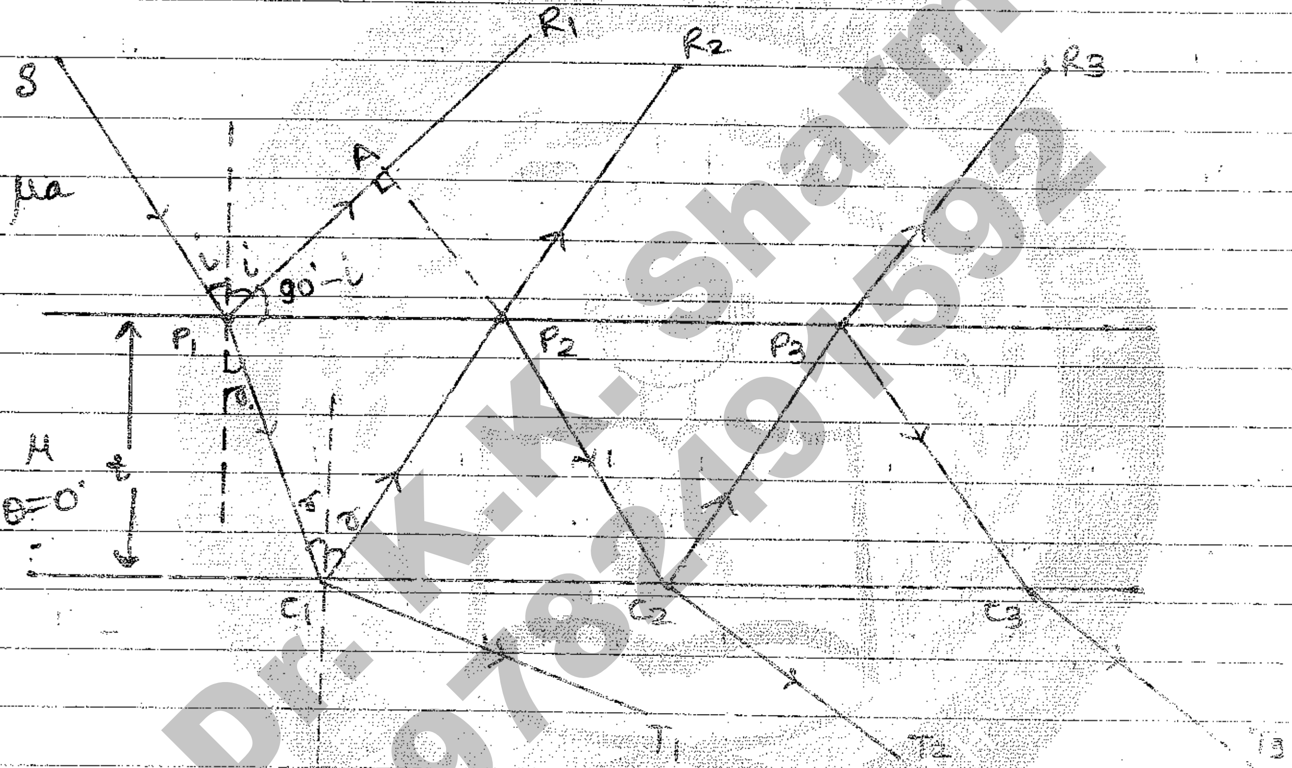
source, amplitude division is done by emitted waves of partial reflection and partial refraction.

That layer in which distance b/w upper surface and lower surface is very small is known as thin film. For thin film, both surface remain parallel, due to which we get $\theta = 0°$



Theoritical Explanation :-

In thin film interference, light ray incident from broad light source. By which some ~~ligt~~ part is reflected and some part is refracted. By this process, we observe two type of light in thin film.

① Reflected light ray that is get from upper surface.

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② transmitted light ray which get from lower surface.

Due to these light ray interference occur in both reflected and transmitted light ray. whose mathematical analysis is done ~~by~~ following:

ⓑ Mathematical Explanation:-

Mathematical Analysis of thin film is done by following two terms.

① Interference in Reflected light ray.
② Interference in transmitted light ray.

① Interference in Reflected light ray:-

Reflected light ray is denoted by P_1R_1, P_2R_2, P_3R_3 ----
So, path diff^n b/w ~~of~~ P_1R_1 and P_2R_2 reflected light ray.

path diff^n = μ (medium in distance) − μ_a (distance in air)

$$\Delta_1 = \mu(P_1C_1P_2) - \mu_a(P_1A)$$

$$\because \mu_a = 1$$

$$\boxed{\Delta_1 = \mu(P_1C_1 + C_1P_2) - P_1A} \quad \text{—— ①}$$

In ΔP_1C_1M

$$\cos r = \frac{C_1M}{P_1C_1}$$

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$$P_1C_1 = \frac{C_1M}{\cos r}$$

$\because C_1M = t$ width

$$\boxed{P_1C_1 = \frac{t}{\cos r}}$$

Similarly $\boxed{C_1P_2 = \frac{t}{\cos r}}$

Now $\tan r = \frac{P_1M}{C_1M}$

$P_1M = C_1M \tan r$

$P_1M = t \cdot \tan r$

Similarly

$MP_2 = t \tan r$

in $\triangle P_1P_2A$

$\sin i = \frac{P_1A}{P_1P_2}$

$P_1A = P_1P_2 \sin i$

$P_1A = (P_1M + MP_2) \sin i$

on putting values

$P_1A = (t \tan r + t \tan r) \sin i$

$\boxed{P_1A = 2t \cdot \tan r \cdot \sin i}$

on putting value in eq^n (1)

$$\Delta_1 = \mu\left(\frac{t}{\cos r} + \frac{t}{\cos r}\right) - 2t\,\tan r \cdot \sin i$$

$$\Delta_1 = \frac{2\mu t}{\cos r} - \frac{2t \cdot \sin r \cdot \sin i}{\cos r}$$

$$\Delta_1 = \frac{2\mu t}{\cos r}\left[1 - \frac{\sin r \cdot \sin i}{\mu}\right]$$

From Snell's law,

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

$$\Delta_1 = \frac{2\mu t}{\cos r}\left[1 - \frac{\sin r \cdot \sin i \cdot \sin r}{\sin i}\right]$$

$$\Delta_1 = \frac{2\mu t \cdot \cos^2 r}{\cos r}$$

$$\boxed{\Delta_1 = 2\mu t \cos r} \quad \text{---} (2)$$

eq^n (2) defines the path diff^n for reflected light ray. Acc^n to stoke scientist, extra path diff^n $\frac{\lambda}{2}$ is present for reflected light ray.

So, effective path difference,

$$\Delta = \Delta_1 - \frac{\lambda}{2}$$

on putting value from eq^n (2)

$$\boxed{\Delta = 2\mu t \cos r - \frac{\lambda}{2}} \quad \text{---} (3)$$

eq^n (3) is called the mathematical formula of effective path diff^n for reflected light ray.

On the basis of this path diff^n, interference is of two types.

(i) Constructive interference :-

In which value of intensity of light finds maximum that interference known as constructive interference.

In this bright fringe obtained. For which value of path diff^n is following :-

$$\boxed{\Delta = n\lambda} \quad \text{---} (4)$$

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

From eq^n (3) and (4)

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

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

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

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eqⁿ (5) is known as condition of bright fringe for Reflected light ray.

(2) ~~Destructive~~ Destructive interference
That interference in which value of intensity of light finds minimum, is known as ~~cons.~~ Destructive interference.

In this interference dark fringes obtained for which value of path diffⁿ is:-

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

$$\boxed{\Delta = (2n-1)\frac{\lambda}{2}} \quad (6)$$

$$n = 0, 1, 2 ---$$

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

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

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

eqⁿ (7) is called the dark fringe condition for Reflected light ray.

Interference in Transmitted light ray:-

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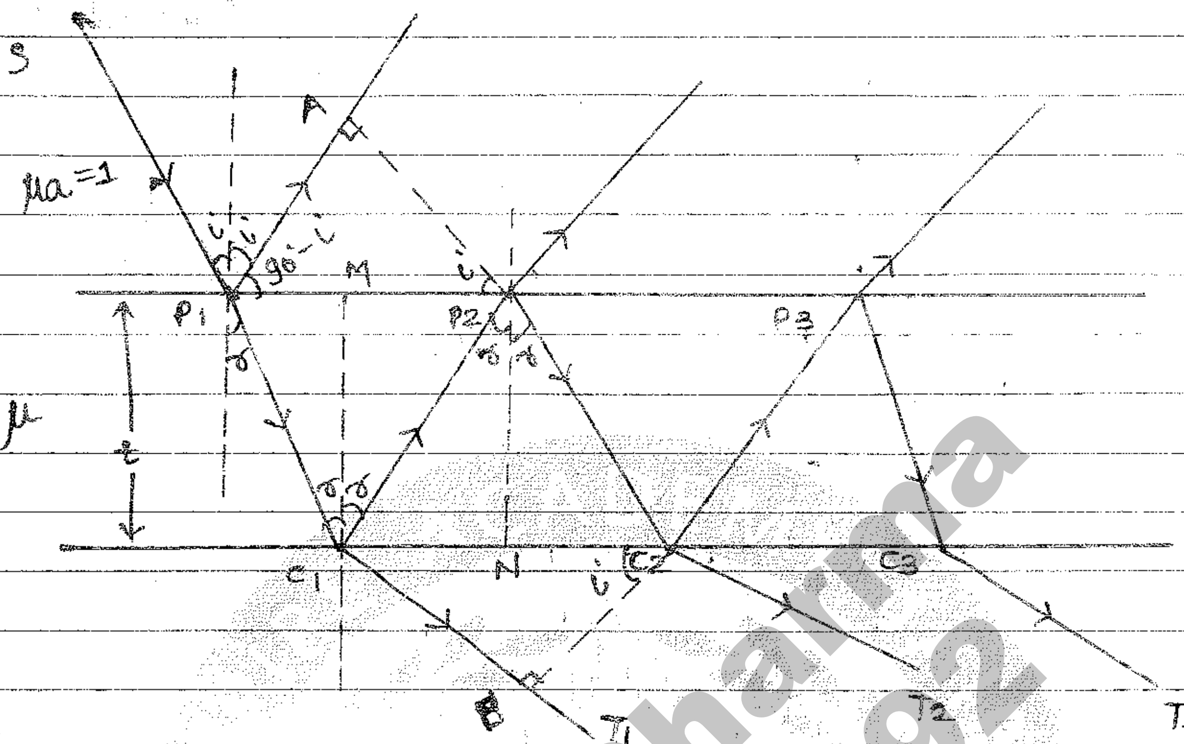

It is clear from thin film that transmitted light ray is found from lower surface. transmitted light ray are shown by C_1T_1, C_2T_2, C_3T_3 - - - -

Path diffⁿ b/w transmitted light ray C_1T_1 and C_2T_2 =

= μ (Distance in medium) − μa (Distance in air)

$\Delta = \mu(C_1P_2C_2) - \mu a\,(C_1B)$

$\mu a = 1$

$$\boxed{\Delta = \mu\,(C_1P_2 + P_2C_2) - C_1B} \text{ ——— (6)}$$

in ΔC_1P_2N

$$\cos r = \frac{NP_2}{C_1P_2}$$

$$C_1P_2 = \frac{NP_2}{\cos r}$$

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$\because$ $NP_2 = t$ (width of

$$\boxed{C_1P_2 = \frac{t}{\cos r}}$$

Similarly $$\boxed{C_2P_2 = \frac{t}{\cos r}}$$

Now $\tan r = \frac{C_1N}{NP_2}$

$$C_1N = NP_2 \tan r$$

$$\boxed{C_1N = t \tan r}$$

Similarly

$$\boxed{NC_2 = t \tan r}$$

in ΔC_1C_2B

$$\sin i = \frac{C_1B}{C_1C_2}$$

$$C_1B = C_1C_2 \sin i$$

$$C_1B = (C_1N + NC_2) \sin i$$

$$C_1B = (t \tan r + t \tan r) \cdot \sin i$$

$$\boxed{C_1B = 2t \tan r \cdot \sin i}$$

on putting values in eqn (5)

$$\Delta = \mu\left(\frac{t}{\cos r} + \frac{t}{\cos r}\right) - 2t \tan r \cdot \sin i$$

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

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

By snell's law

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

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

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

$$\boxed{\Delta = 2\mu t \cos r} \text{ ——— (9)}$$

eqn (9) defined the path diffn for transmitted light ray. On the basis of path diffn interference are of two types.

(1) Constructive interference:-

That interference in which value of intensity of light finds maximum is known as constructive interference.

In this bright fringes are obtained. For which value of path diffn is following:-

$$\boxed{\Delta = n\lambda} \text{ ——— (10)}$$

$n = 0, 1, 2 \ldots$

From eqⁿ (9) and (10)

$$\boxed{2\mu t \cos r = n\lambda} \quad \text{———} (11)$$

eqⁿ (11) is known as condition of bright for transmitted light ray.

② **Destructive Interference :-**

That interference for which value of intensity of light finds minimum is known as Destructive interference.

In this interference dark fringe is obtained for which value of path diffⁿ is:-

$$\Delta = (2n \pm 1)\frac{\lambda}{2}$$

$$\boxed{\Delta = (2n+1)\frac{\lambda}{2}} \quad \text{———} (12)$$

$n = 0, 1, 2 \dots$

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

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

$$\boxed{2\mu t \cos r = n\lambda + \frac{\lambda}{2}} \quad \text{———} (13)$$

eqⁿ (13) is called condition for dark fringe in transmitted light ray.

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Ques Prove that thin film interference is a complimentary interference?

Soln We know that, By mathematical Analysis of thin film interference, following results are find.

① For Reflected light ray:-

For reflected light ray, two conditions are find for interference.

(a) Condition of bright fringe:

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

$n = 0, 1, 2 ---$

(b) Condition of Dark fringe

$$\boxed{2\mu t \cos r = n\lambda} \quad \text{--- ②}$$

$n = 0, 1, 2 ---$

② For Transmitted light ray:-

For transmitted light ray, two conditions are find for interference

(a) Condition of bright fringe

$$\boxed{2\mu t \cos r = n\lambda} \quad \text{--- ③}$$

$n = 0, 1, 2 ---$

(b) Condition of Dark fringe

$$\boxed{2\mu t \cos r = (2n+1)\frac{\lambda}{2}} \quad \text{--- ④}$$

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$n = 0, 1, 2 ---$

It is clear from eq^n ① and ④ when their find condition of bright fringe for reflected ray then in this state, condition of dark fringe for transmitted ray is find, and vice versa.

When their find condition of dark fringe for reflected ray then in this state condition of bright fringe for transmitted ray is find. This mathematical conclusion satisfy the energy conservation law. This property is known as complementary interference. Now we can say that thin film interference is a complementary interference.

Interference due to Infinitely Thin film :

let a thin film. thickness of thin film(t) is very small. means $t \to 0$,

$$\left.\begin{array}{l} t \to 0 \\ t <<< \lambda \end{array}\right\} \text{——} ①$$

We know that from thin film interference following two conditions are find:

ⓐ Path diffⁿ for reflected light ray :

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

$$t \to 0 \qquad \text{from } ①$$
$$t <<< \lambda$$

$$\boxed{\Delta = -\frac{\lambda}{2}} \text{——} ②$$

(b) Path diff^n for transmitted light ray:-

$$\Delta = 2\mu t \cos r$$

$$t \to 0$$

$$t <<< \lambda \quad (from\ ①)$$

$$\boxed{\Delta = 0} \text{ --- } ③$$

Again we know that,

(i) Path diff^n for bright fringe:-

$$\Delta = n\lambda$$

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

$$n = 0$$

$$\boxed{\Delta = 0} \text{ --- } ④$$

(ii) path diff^n for dark fringe:-

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

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

$$\boxed{\Delta = \frac{\lambda}{2}} \text{ --- } ⑤$$

~~eq~~ it is clear from eq^n ③ and ④, value of light intensity finds maximum for transmitted ray, means bright ~~from~~ fringe are observed.

but it is clear from ② and eq^n ⑤, value of light intensity finds minimum for reflected light ray, means dark fringe are observed.

This conclusion is also said in this way, that infinitely thin film works as Non-reflecting surface

Ques

Interference Due to Thick film :-

Let a thick film whose width is t. $t >>> \lambda$ — ①

(a) Path diffⁿ for reflected light ray :-

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

$\because t >>> \lambda$ from eqⁿ ①

$$\boxed{\Delta = 2\mu t \cos r} \quad — ②$$

(b) Path diffⁿ for transmitted light ray :-

$$\boxed{\Delta = 2\mu t \cos r} \quad — ③$$

It is clear from eqⁿ ② and ③ value of path diffⁿ for thick film finds equal. So, becoz of both light ray same fringes are observed.

Haidinger Fringe / Equal Inclination :-

If light is incident from monochromatic light on thin film then focus point of fringe observed circular. At every point of drawn from tangent line design equal angle. these fringe are known as Equal inclination or Haidinger fringe.

But these fringes are defined in equal thickness in thin film.

Haidinger film are define in Michelson interferometer experiment. These fringes are observed by Telescope.

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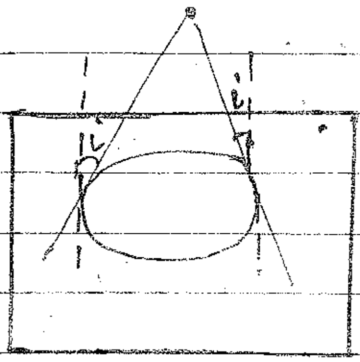


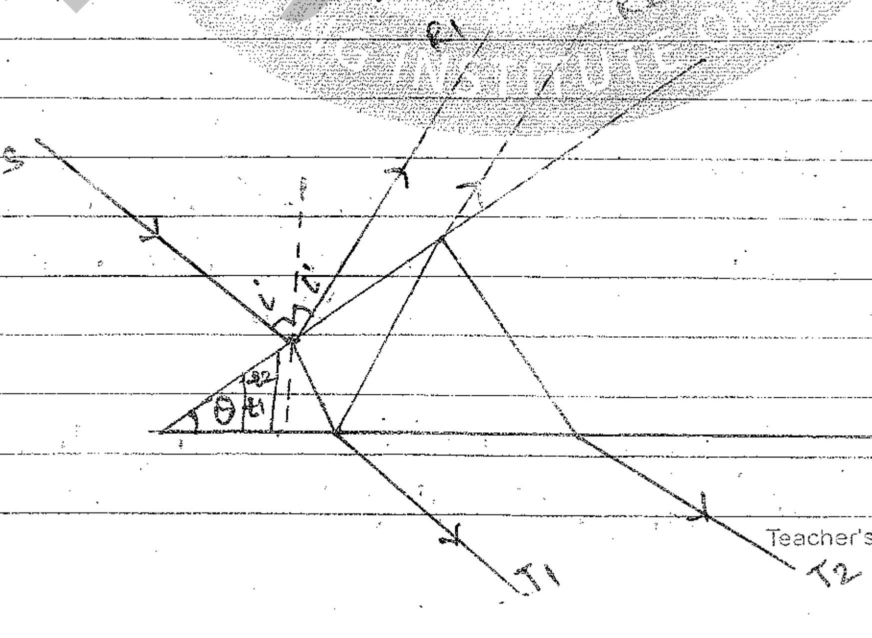
Interference Due to Wedge-shaped film:-

Acc^n to Optical physics, "That film in which $\angle$ is present b/w upper surface and lower surface is known as wedge shaped film.

Angle define in wedge-shaped film is known as wedge Angle. Wedge Angle is denoted by θ. Due to wedge Angle, width of wedge film is not equal. This film is defined in Newton's ring experiment.

Mathematical Analysis:-

Mathematical Analysis of wedge-shaped film is done on the basis of Concept of thin film interference.



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From wedge shaped film two type of light ray are find due to which interference model also finds two.

ⓐ Interference In Reflected light ray.

Accⁿ to Concept of thin film experiment, value of path diffⁿ for reflected light ray of wedge - shaped is following:-

$$\boxed{\Delta = 2\mu t \cos(\theta + r) - \frac{\lambda}{2}} \quad \text{——— (1)}$$

Value of $(\theta + r)$ in eqⁿ (1) is very small ~~maximum~~ for proper interference.

$$\theta + r \longrightarrow 0$$

$$\cos(\theta + r) \approx 1$$

$$\boxed{\Delta = 2\mu t - \frac{\lambda}{2}} \quad \text{——— (2)}$$

eqⁿ (2) defined the path diffⁿ for reflected light ray, on this basis of path diffⁿ two types of fringes are observed.

(i) Constructive interference:-

That interference for which value of light intensity finds maximum. is known as Constructive intensity.

Bright fringe are observed in this Interference for which value of path diffⁿ is:-

$$\boxed{\Delta = n\lambda} \text{ --- } (3)$$

From eq^n (2) and (3)

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

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

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

for n^{th} fringe,

$$\boxed{2\mu t_n = (2n+1)\frac{\lambda}{2}} \text{ --- } (4)$$

t_n = width of n^{th} fringe.

eq^n (4) is called the condition of bright fringe for reflected light ray for wedge shaped film.

(b) Interference in transmitted light ray:- Acc^n to concept of thin film

(ii) Destructive interference:-

That interference for which value of intensity of light finds minimum is known as destructive interference.

Dark fringe are observed in this interference for which value of path diff^n is:-

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

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$$\Delta = (2n-1)\frac{\lambda}{2} \quad \text{---} (5)$$

$n = 0, 1, 2 \ldots$

From eq^n (2) and (5)

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

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

$$2\mu t = n\lambda$$

For n^{th} fringe

$$\boxed{2\mu t_n = n\lambda} \quad \text{---} (6)$$

$n = 0, 1, 2 \ldots$

eq^n (6) is called the condition of dark fringe for reflected light ray for wedge-shaped film.

(b) <u>Interference in transmitted light ray</u>:- Acc^n to concept of thin film experiment, value of path diff^n for transmitted light ray for wedge shaped is following:-

$$\boxed{\Delta = 2\mu t \cos(\theta + r)} \quad \text{---} (7)$$

value of $(\theta + r)$ in eq^n (7) is very small for proper interference.

$$\theta + r \longrightarrow 0$$

$$\cos(\theta + r) \simeq 1$$

$$\boxed{\Delta = 2\mu t} \quad \text{---} (8)$$

eq^n ⑧ defines the path diff^n for transmitted light ray. On this basis of path diff^n two types of fringes are observed.

(i) Constructive Interference:-

That interference for which value of intensity of light finds maximum is known as Constructive Interference.

Bright fringes are observed in this interference for which path diff^n is following:-

$$\boxed{\Delta = n\lambda} \text{ --- } ⑨$$

From eq^n ⑧ and ⑨

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

For n^{th} fringe,

$$\boxed{2\mu t_n = n\lambda} \text{ --- } ⑩$$

t_n = width of n^{th} fringe.

eq^n ⑩ is called the condition of bright fringe for transmitted light ray for wedge shaped film.

Destructive interference:-

That interference for which value of intensity of light find minimum is known as Destructive interference.

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Dark fringes are observed in this interference for which path diffⁿ is following.

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

$$\boxed{\Delta = (2n+1)\frac{\lambda}{2}} \quad \text{--- (11)}$$

$n = 0, 1, 2 \ldots$

From eqⁿ (8) and (11)

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

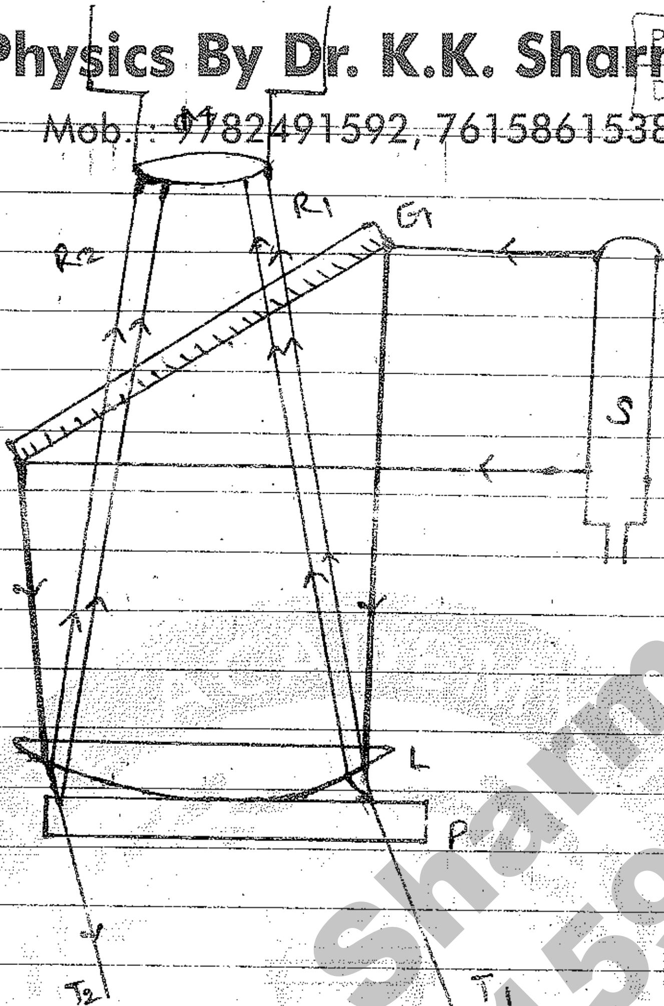
For n^{th} fringe.

$$\boxed{2\mu t_n = (2n+1)\frac{\lambda}{2}} \quad \text{--- (12)}$$

eqⁿ (12) is called the Condition of dark fringe for transmitted light ray for wedge-shaped film.

Newton's Ring Experiment:

Newton's ring experiment is an optical method. by this experiment coherent light source is find. This experiment is based on amplitude division method. In this experiment, broad light source (S) is used.



Dn = Diameter of n^{th} film.

Dn+1 = Diameter of $(n+1)^{th}$ film

Theoretical Explanation:-

To explain the Newton's ring experiment in theoritical form, broad light source is used, light ray are emit from this broad light source. to reach these light ray to wedge shaped film, one plate is also used, these are half - silvered plate that works as reflected light. This plate is kept at an 45° Angle. From this plate or light ray reflect and reach to wedge shape film. In "wedge shaped film," there is partial reflection and partial refraction of light ray. due to which, reflected light ray is find from upper surface. and transmitted light ray are find from lower surface. due to these light rays two models are obtained for interference. in interference model, frinzes are observed as Concentric ring. These Concentric rings are known as newtons ring.

In Newton's ring experiment, to obtain the wedge - shaped film, a plano-convex lens and transparent glass is used. Plano-convex lens(L) is kept on the glass P, due to which air film is obtained. This air film is known as wedge shaped film. on the central point of wedge shaped film, always dark fringe are observed.

In Newton's ring experiment dark fringe are obtained. This is the theoritical explaination of Newton's ring experiment.

Mathematical Explanation:-

Mathematical Analysis of newton's ring experiment, are done by two Concept.

(1) Interference in Reflected light ray:-

We know that in Newton's ring experiment wedge-shape film are desired. From the upper surface of wedge-shape film reflected light ray are find.

Value of path diffⁿ for reflected light ray is:-

$$\boxed{\Delta = 2\mu t \cos(\theta + r) - \frac{\lambda}{2}} \quad \text{——} (1)$$

Value of $(\theta + r)$ in eqⁿ (1) is very small for proper Interference.

$$\theta + r \rightarrow 0$$

$$\cos(\theta + r) \approx 1$$

$$\boxed{\Delta = 2\mu t - \frac{\lambda}{2}} \quad \text{——} (2)$$

eqⁿ (2) defines the path diffⁿ for reflected light ray. On this basis path diffⁿ two types of fringes are observed.

(a) Constructive interference:-

That interference for which value of intensity of light finds maximum, is known as Constructive interference.

Bright fringes are observed in this interference. For which value of path diffⁿ is:-

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$$\boxed{\Delta = n\lambda} \quad \text{--- (3)}$$

From eq^n (2) and (3)

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

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

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

For n^{th} fringe.

$$\boxed{2\mu t_n = (2n+1)\frac{\lambda}{2}} \quad \text{--- (4)}$$

t_n = width of n^{th} fringe.

eq^n (4) is called the condition of bright fringe for reflected light for wedge-shaped film.

(b) Destructive Interference :-
That Interference for which value of intensity of ~~the~~ light finds minimum is known as Destructive interference.

Dark fringes are observed in this interference. for which value of path diff^n is

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

Teacher's Signature..........

$$\Delta = (2n-1)\frac{\lambda}{2} \quad \text{—— (5)}$$

$n = 0, 1, 2 \ldots$

From eqⁿ (2) and (5)

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

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

$$2\mu t = n\lambda$$

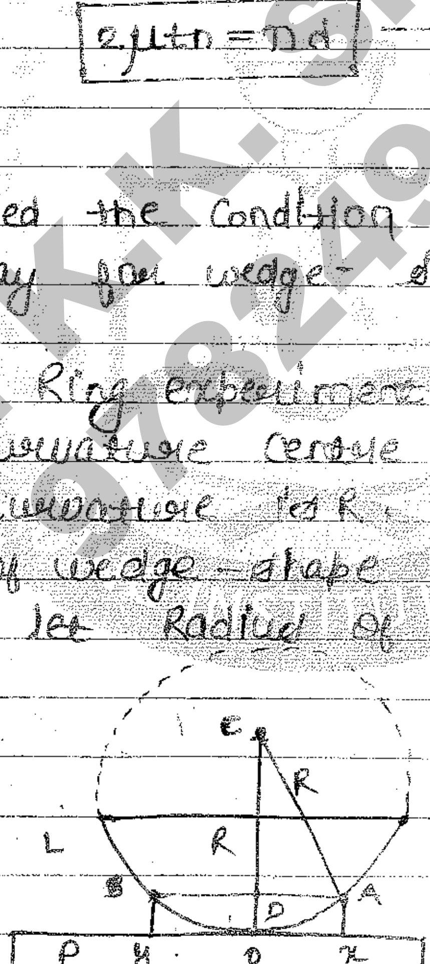
For n^{th} fringe

$$\boxed{2\mu t_n = n\lambda} \quad \text{—— (6)}$$

$n = 0, 1, 2 \ldots$

eqⁿ (6) is called the condition of dark fringe for reflected light ray for wedge-shaped film.

In Newton's Ring experiment, plano convex lens is used. Let curvature centre of this lens is C and radius of curvature is R. For n^{th} fringe, thickness/width of wedge-shape film is t_n, that is very small. Let Radius of n^{th} Newton's Ring is r_n.



In $\triangle ADC$, By phythagorous theorum.

$$(AC)^2 = (CD)^2 + (AD)^2$$
$$(AD)^2 = (AC)^2 - (CD)^2$$

$\because AC = R$ (Radius of curvature)
$AD = r_n$ (radius of Newton's Ring)

$$r_n^2 = R^2 - (CD)^2$$
$$\because CD = OC - OD$$
$$CD = R - t_n$$
$$r_n^2 = R^2 - (R - t_n)^2$$
$$r_n^2 = R^2 - R^2 - t_n^2 + 2Rt_n$$
$$r_n^2 = 2Rt_n - t_n^2$$
$$R >> t_n^2$$
$$r_n^2 = 2Rt_n$$
$$r_n = \sqrt{2Rt_n}$$

We know that

$$D_n = 2r_n$$
$$D_n = 2\sqrt{2Rt_n}$$
$$\boxed{D_n = \sqrt{8Rt_n}} \quad (7)$$

From eqn (7) Diameter of Newton's Ring can be calculate.

(4) Diameter Of Bright Fringe:-

We know that, following Conditions are find for bright fringe.

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

$$t_n = \frac{(2n+1)\lambda}{4\mu}$$

from eq^n (7)

$$D_n = \sqrt{\frac{8R\cdot(2n+1)\lambda}{4\mu}}$$

$$D_n = \sqrt{\frac{2R\lambda(2n+1)}{\mu}}$$

For air film.

$\mu = \mu_a = 1$

$$\boxed{D_n = \sqrt{2R\lambda(2n+1)}} \quad (8)$$

eq^n (8) defines the Diameter of bright fringe for Reflected light ray.

For $(n+1)^{th}$ Newton's Ring.

$$\boxed{D_{n+1} = \sqrt{2R\lambda(2n+3)}}$$

From mathematical formula of fringe width:-

$$\beta = r_{n+1} - r_n$$

$$\beta = \frac{1}{2}\left[D_{n+1} - D_n\right]$$

on putting values

$$\beta = \frac{1}{2}\left[\sqrt{2R\lambda(2n+3)} - \sqrt{2R\lambda(2n+1)}\right]$$

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$$\beta = \frac{1}{2}\sqrt{2R\lambda}\left[\sqrt{2n+3} - \sqrt{2n+1}\right]$$

$$\boxed{\beta = \sqrt{\frac{R\lambda}{2}}\left[\sqrt{2n+3} - \sqrt{2n+1}\right]} \quad \text{--- (9)}$$

eqn (9) is known as mathematical formula of fringe width.

Diameter of Dark Fringe:-

We know that following conditions are find for Dark fringe.

$$2\mu t_n = n\lambda$$

$$t_n = \frac{n\lambda}{2\mu}$$

From eqn (7)

$$D_n = \sqrt{8R\frac{n\lambda}{2\mu}}$$

$$D_n = 2\sqrt{\frac{Rn\lambda}{\mu}}$$

For air film

$$\mu = \mu_a = 1$$

$$\boxed{D_n = 2\sqrt{Rn\lambda}} \quad \text{--- (10)}$$

eqn (10) defined the diameter of dark fringe for reflected light Ray.

For $(n+1)^{th}$ Newton's Ring.

$$\boxed{D_{n+1} = 2\sqrt{R(n+1)d}}$$

From mathematical formula of fringe width.

$$\beta = r_{n+1} - r_n$$

$$\beta = \frac{1}{2}\left[D_{n+1} - D_n\right]$$

on putting values.

$$\beta = \frac{1}{2}\left[2\sqrt{R(n+1)d} - 2\sqrt{Rnd}\right]$$

$$\beta = \sqrt{R(n+1)d} - \sqrt{Rnd}$$

$$\boxed{\beta = \sqrt{Rd}\left[\sqrt{n+1} - \sqrt{n}\right]} \quad \text{—— (11)}$$

eqn (11) is known as mathematical formula of fringe width.

(2) Interference in Transmitted light Ray:-

In Newton's Ring experiment, wedge-shape film are designed. Transmitted light ray are find from lower surface of wedge-shape film. For which value of path diff^n is following:-

$$\Delta = 2\mu t \cos(\theta + r)$$

∵ $(\theta + r)$ is very small.

$$\theta + r \rightarrow 0$$

$$\cos(\theta + r) \approx 1$$

$$\boxed{\Delta = 2\mu t} \quad \text{--- (1)}$$

eq^n (1) defined the path diff^n for transmitted light ray. on this basis newton's ring are observed two types.

<u>Constructive interference</u> :-

That interference for which value of Intensity of light finds maximum is known as constructive interference.

Bright fringes are observed in this for which value of path diff^n is:-

$$\boxed{\Delta = n\lambda} \quad \text{--- (2)}$$

From eq^n (1) and (2).

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

For n^{th} fringe

$$\boxed{2\mu t_n = n\lambda} \quad \text{--- (3)}$$

t_n = width of n^{th} fringe

eqⁿ ③ is called the condition of bright fringe for transmitted ray for wedge-shaped film.

Destructive interference:-

That interference for which value of Intensity of light finds minimum is known as Destructive interference.

Dark fringes are observed in this interference. on this basis path diffⁿ is:-

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

$$\boxed{\Delta = (2n+1)\frac{\lambda}{2}} \quad \text{—— (4)}$$

$n = 0, 1, 2 \ldots$

From eqⁿ ① and ④

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

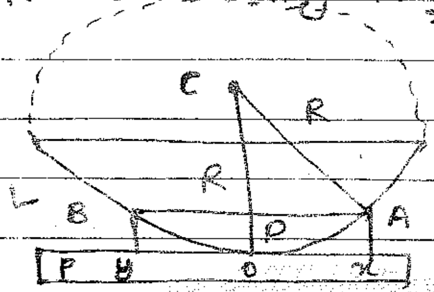
For n^{th} fringe

$$\boxed{2\mu t_n = (2n+1)\frac{\lambda}{2}} \quad \text{—— (5)}$$

eqⁿ ⑤ is called the condition of dark fringe for transmitted rays for wedge-shaped film.

In Newton's ring experiment, plano convex lens is used. let curvature center of this lens is C_0

and radius of curvature is R. For n^{th} fringe width of wedge-shaped film is t_n. this is very small. Let radius of n^{th} Newton's ring is r_n.



in $\triangle ADC$, By pythagorous theorum.

$$(AC)^2 = (CD)^2 + (AD)^2$$
$$(AD)^2 = (AC)^2 - (CD)^2$$
$\because AC = R$ (Radius of curvature)
$AD = r_n$ (radius of Newton's Ring)

$$r_n^2 = R^2 - (CD)^2$$
$\because CD = OC - OD$
$$CD = R - t_n$$

$$r_n^2 = R^2 - (R - t_n)^2$$
$$r_n^2 = R^2 - R^2 - t_n^2 + 2t_n R$$
$$r_n^2 = 2Rt_n - t_n^2$$
$$R >>> t_n^2$$
$$r_n^2 = 2Rt_n$$
$$r_n = \sqrt{2Rt_n}$$
We know that
$$D_n = 2r_n$$
$$D_n = 2\sqrt{2Rt_n}$$
$$\boxed{D_n = \sqrt{8Rt_n}}$$

From eq^n (6) Diameter of Newton's ring can be calculate.

We know that following conditions are find for bright fringe.

$$2\mu t_n = n\lambda$$

$$t_n = \frac{n\lambda}{2\mu}$$

From eq^n (6)

$$D_n = \sqrt{8Rt_n}$$

$$D_n = \sqrt{\frac{8Rn\lambda}{2\mu}}$$

For air film.

$$\mu = \mu_a = 1$$

$$D_n = \sqrt{\frac{8Rn\lambda}{2}}$$

$$\boxed{D_n = 2\sqrt{Rn\lambda}} \quad \text{---} (7)$$

eq^n (7) defined the Diameter of bright fringe for R transmitted light ray.

For $(n+1)^{th}$ Newton's Ring.

$$\boxed{D_{n+1} = 2\sqrt{R(n+1)\lambda}}$$

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From mathematical formula of fringe width:-

$$\beta = r_{n+1} - r_n$$

$$\beta = \frac{1}{2}\left[D_{n+1} - D_n\right]$$

$$\beta = \frac{1}{2}\left[2\sqrt{R(n+1)\lambda} - 2\sqrt{Rn\lambda}\right]$$

$$\boxed{\beta = \sqrt{R\lambda}\left[\sqrt{n+1} - \sqrt{n}\right]} \quad \text{—} (8)$$

eqn (8) is the mathematical formula of fringe width.

We know that following conditions are find for dark fringe.

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

$$t_n = \frac{(2n+1)\lambda}{4\mu}$$

from eqn (6)

$$D_n = \sqrt{8Rt_n}$$

$$D_n = \sqrt{\frac{8R(2n+1)\lambda}{4\mu}}$$

$$\because \mu = \mu_a = 1$$

$$\boxed{D_n = \sqrt{2R(2n+1)\lambda}} \quad \text{—} (9)$$

eqn (9) defined the Diameter of Dark fringe for airfilm.

For $(n+1)^{th}$ ~~film~~ fringe

$$\boxed{D_{n+1} = \sqrt{2R(2n+3)d}}$$

From mathematical formula of fringe width

$$\beta = r_{n+1} - r_n$$

$$\beta = \frac{1}{2}\left[D_{n+1} - D_n\right]$$

$$\beta = \frac{1}{2}\left[\sqrt{2R(2n+3)d} - \sqrt{2R(2n+1)d}\right]$$

$$\boxed{\beta = \frac{1}{2}\sqrt{2Rd}\left[\sqrt{2n+3} - \sqrt{2n+1}\right]} \quad \text{--- (10)}$$

eqn (10) defined the condition of Dark fringe for transmitted light ray.

And eqn (10) defines the mathematical formula of fringe width.

Applications of Newton's Ring experiment:-

By the Newton's Ring experiment in optical physics, following mathematical calculations are done. These mathematical calculations are known as Applications of Newton's Ring experiment.

(i) Determination of Wavelength of light:-
(ii) Determination of Refractive index of transparent liquid.

(i) Determination of Wavelength of light:-

By Newton's Ring experiment, calculation of light wavelength λ is done by following:-

We know that, diameter for n^{th} Newton's Ring is:-

$$D_n = \sqrt{\frac{4Rn\lambda}{\mu}}$$

On squaring

$$D_n^2 = \frac{4Rn\lambda}{\mu} \quad \text{---} (1)$$

For $(n+p)^{th}$ fringe:

$$D^2_{n+p} = \frac{4R(n+p)\lambda}{\mu} \quad \text{---} (2)$$

on subtracting ① from ②

$$D^2_{n+p} - D^2_n = \frac{4R(n+p)d}{\mu} - \frac{4Rnd}{\mu}$$

$$D^2_{n+p} - D^2_n = \frac{4Rnd}{\mu} + \frac{4Rpd}{\mu} - \frac{4Rnd}{\mu}$$

$$\boxed{D^2_{n+p} - D^2_n = \frac{4Rpd}{\mu}} \quad \text{—— ③}$$

If their is air film then,
$\mu = \mu_a = 1$
From eqn ⑤

$$D^2_{n+p} - D^2_n = 4Rpd \quad \text{—— ④}$$

$$\boxed{d = \frac{D^2_{n+p} - D^2_n}{4Rp}} \quad \text{—— ⑤}$$

eqn ⑤ is known as mathematical formula of wavelength of light.

(ii) Determination of Refractive Index of transparent liquid :-

By Newton's Ring experiment, Calculation of refractive index is done following :-

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We know that Diameter of n^{th} Newton's Ring

$$D_n = \sqrt{\frac{4Rn\lambda}{\mu}}$$

on squaring

$$D_n^2 = \frac{4Rn\lambda}{\mu} \quad \text{--- (1)}$$

for $(n+p)^{th}$ fringe.

$$D_{n+p}^2 = \frac{4R(n+p)\lambda}{\mu} \quad \text{--- (2)}$$

on subtracting (1) from (2)

$$D_{n+p}^2 - D_n^2 = \frac{4R(n+p)\lambda}{\mu} - \frac{4Rn\lambda}{\mu}$$

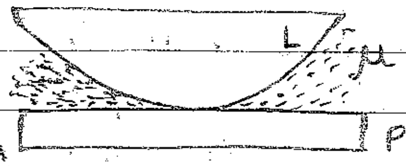
$$D_{n+p}^2 - D_n^2 = \frac{4Rn\lambda}{\mu} + \frac{4Rp\lambda}{\mu} - \frac{4Rn\lambda}{\mu}$$

$$\boxed{D_{n+p}^2 - D_n^2 = \frac{4Rp\lambda}{\mu}} \quad \text{--- (3)}$$

if there is air film, then,

$$\mu = \mu_a = 1$$

$$\boxed{D_{n+p}^2 - D_n^2 = 4Rp\lambda} \quad \text{--- (4)}$$



We know that wedge-shape film is generate in Newton's Ring experiment. This wedge-shape film is produce b/w lens L and glass P. Now we fill transparent liquid in wedge-shaped film due to which Diamter of Newton's ring experiment is changed

$$\boxed{D'^2_{n+p} - D'^2_n = \frac{4RPd}{\mu}} \quad \text{--- (5)}$$

on dividing eq^n (4) and (5)

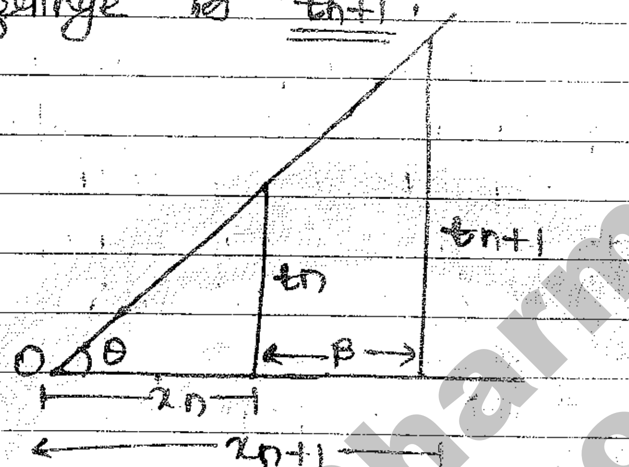
$$\frac{D^2_{n+p} - D^2_n}{D'^2_{n+p} - D'^2_n} = \frac{4RPd}{\frac{4RPd}{\mu}}$$

$$\boxed{\frac{D^2_{n+p} - D^2_n}{D'^2_{n+p} - D'^2_n} = \mu} \quad \text{--- (6)}$$

eq^n (6) is known as mathematical formula of refractive index.

Ques Prove that fringe width for wedge shaped film $\beta = \frac{\lambda}{2\mu\theta}$?

Proof let a wedge-shaped film in which θ b/w upper surface and lower surface is θ. film thickness for n^{th} fringe is t_n and fringe width for $(n+1)^{th}$ fringe is t_{n+1}.



$$\boxed{\beta = x_{n+1} - x_n} \quad \text{--- (1)}$$

$$\tan\theta = \frac{t_n}{x_n}$$

$$\boxed{t_n = x_n \tan\theta} \quad \text{--- (2)}$$

For $(n+1)^{th}$ fringe

$$\boxed{t_{n+1} = x_{n+1} \tan\theta} \quad \text{--- (3)}$$

Now eq^n (3) $-$ eq^n (2)

$$t_{n+1} - t_n = x_{n+1}\tan\theta - x_n \tan\theta$$

$$t_{n+1} - t_n = (x_{n+1} - x_n)\tan\theta$$

From eq^n (1)

$$\boxed{t_{n+1} - t_n = \beta \tan\theta} \quad \text{——} (4)$$

Condition for n^{th} bright fringe.

$$2\mu t_n \cos(\theta+\gamma) = (2n+1)\frac{\lambda}{2} \quad \text{——} (5)$$

$$2\mu t_{n+1} \cos(\theta+\gamma) = (2n+3)\frac{\lambda}{2} \quad \text{——} (6)$$

if light ray is incident normal. then,

$$i = \gamma = 0$$

on putting value in eq^n (5) and (6)

$$2\mu t_n \cos\theta = (2n+1)\frac{\lambda}{2}$$

$$2\mu t_{n+1}\cos\theta = (2n+3)\frac{\lambda}{2}$$

eq^n (8) $-$ eq^n (7)

$$2\mu t_{n+1}\cos\theta - 2\mu t_n \cos\theta = [2n+3-2n-1]\frac{\lambda}{2}$$

$$2\mu \cos\theta (t_{n+1} - t_n) = \lambda$$

From eq^n (4)

$$2\mu \cos\theta \cdot \beta \cdot \tan\theta = \lambda$$

$$2\mu \cos\theta \cdot \beta \cdot \frac{\sin\theta}{\cos\theta} = \lambda$$

$$2\mu\beta \sin\theta = \lambda$$

$\sin\theta = \theta$ (for proper interference)

$$\therefore 2\mu\beta\theta = \lambda$$

$$\boxed{\beta = \frac{\lambda}{2\mu\theta}}$$

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Difference b/w Newton's Ring experiment and Michelson interferometer experiment :-

Newtons Ring Experiment	Michelson interferometer
⇒ In Newton's Ring experiment plano convex lens (L) is used to define film.	⇒ In Michelson interferometer experiment, Compensate plate (C) is used ~~for~~ to define film and to describe the value of path diff^n.
⇒ In Newton's Ring experiment, width of film is different because in this wedge-shaped film are generate.	⇒ In Michelson interferometer experiment, equal film width are design.
⇒ In this Air film is real.	⇒ In this, Air film is fictious or pseudo.
⇒ In this ~~Hadinger~~ design film are known as figau film or Newton's film / fringe.	⇒ In this, design film are known as Michelson fringe or Hadinger fringe.
⇒ For central Newton's Ring value of $n=0$	⇒ In this, For central fringe $n =$ infinite (∞)
⇒ In this, when value of n increases then radius of newton's ring also increased.	⇒ In this, when serial no of n increased then radius of michelson decreased.

⇒ In Newton's Ring experiment, fringes are observed by microscope.	⇒ In ~~this~~, fringes are observed by telescope.

Michelson Interferometer Experiment:-

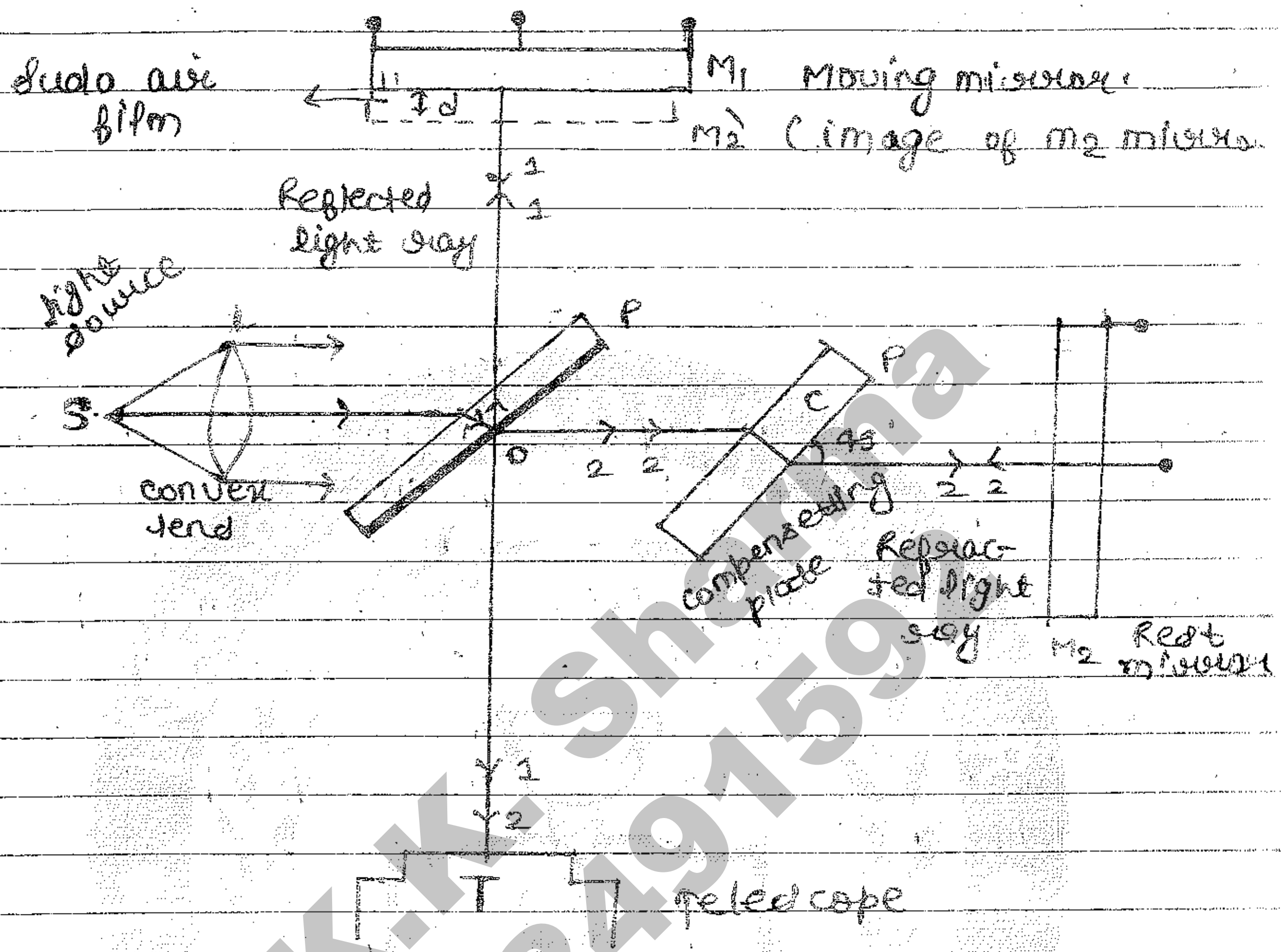
Michelson interferometer experiment is an optical method to find Coherent light source. In this experiment broad light source is used. Emitted waves from broad light source is partial reflected and partial refracted and amplitude division is done. due to which we get two types of rays - reflected and transmitted. Due to the superposition of light ray, two models are find for interference.

(A) Interference in Reflected light ray.
(B) Interference in Transmitted light ray.

This is the principal of Michelson interferometer experiment.

Experimental Arrangement:-

In Michelson interferometer experiment a broad light source is used. By broad light source, light rays are emit. To ll the emitted light rays a Convex lens (L) is used. These parallel light rays are incident on plate P. Glass plate P is Half-silvered, due to which it works ~~in~~ for reflection in partial form.



Accn to concept of amplitude division process. At point O two types of rays are define i.e. reflected and refracted. It means, by half-silvered plate P incident light is partially reflected and partially refracted. These reflected and refracted light ray reach to mirror M_1 and M_2. By mirror, light ray are reflected due to which they again approach at point O. Due to superposition, intensity of light finds maximum and minimum. Due to which Michelson fringes are observed.

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Working on compensating plate C :-

In Michelson interferometer experiment, reflected and refracted light rays light ray are define on point D. Reflected light ray is reach to M_1 mirror from plate P. and after that, light ray is refracted by mirror M_2. due to which this light ray is ~~are~~ went two times. while refracted light ray does not do this work one times. By condition of proper interference, path diffn should be very small b/w light rays. To decrease the value of path diffn, an another transparent glass plate is kept. Refracted light is went to times. due to which path diffn become equal of reflected and refracted light ray. This transparent glass plate is known as compensating plate (C).

Design of Fringe:-

In Michelson interferometer experiment, two mirror M_1 and M_2 are used. M_2 mirror is kept in rest state while M_1 mirror is kept in moving state with the help of screw. In Michelson experiment, image of M_2 mirror, i.e. M_2' make near M_1. by this d air film width is form. In air film, reflected light ray approach 2D distance. Due to this air film, Michelson fringes are formed.

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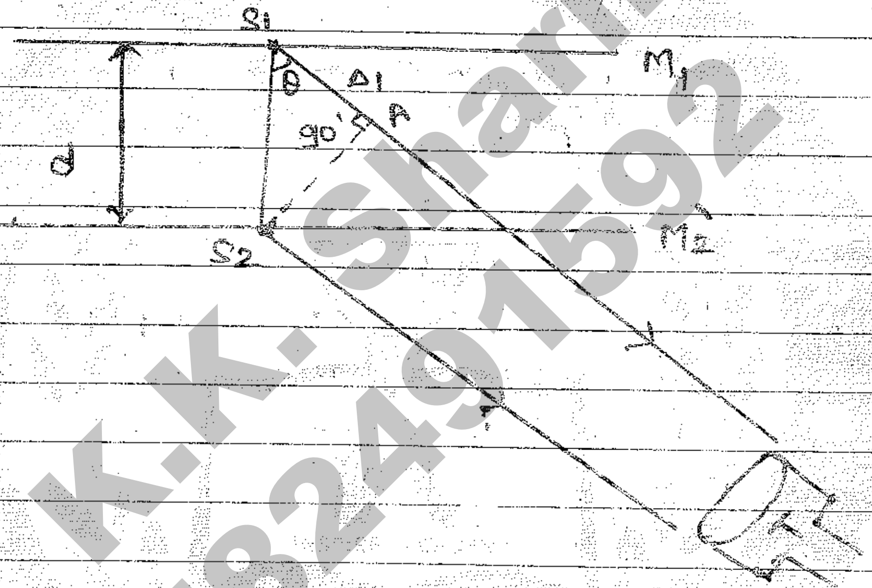
Mathematical Calculation :-

We know that mirror behaves as a secondary light source. Let mirror M_1 works as a S_1 light source, and mirror M_2 works as a S_2 secondary light source.



$$\cos\theta = \frac{S_1A}{S_1S_2}$$

$$S_1A = S_1S_2 \cos\theta$$

$$\because S_1S_2 = 2d$$

$$\because S_1A = \Delta_1$$

$$\Delta_1 = 2d\cos\theta$$

By Stoke's curl theorem.

$$\Delta = \Delta_1 - \frac{d}{2}$$

$$\boxed{\Delta = 2d\cos\theta - \frac{d}{2}} \quad \text{--- (1)}$$

eqn (1), defines the path diffn for reflected light light. Accn to this path diffn, Michelson fringe observe two types.

(a) Constructive interference
(b) Destructive interference.

(a) <u>Constructive interference</u>:-
Those interference for which value of ~~interference~~ light intensity finds maximum is known as Constructive interference.

in this, Bright fringes are observed for which value of path diffn is:-

$$\boxed{\Delta = n\lambda} \quad \text{—(2)}$$

$n = 0, 1, 2 ---$

from eqn (1) and (2)

$$2d\cos\theta - \frac{\lambda}{2} = n\lambda$$

$$2d\cos\theta = n\lambda + \frac{\lambda}{2}$$

$$\boxed{2d\cos\theta = (2n+1)\frac{\lambda}{2}} \quad \text{—(3)}$$

eqn (3) is the condition of Bright fringe for michelson interferometer experiment.

for nth fringe

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$$2d\cos\theta_n = (2n+1)\frac{\lambda}{2}$$

$$\boxed{\cos\theta_n = \frac{(2n+1)\lambda}{4d}} \quad \text{--- (4)}$$

Destructive interference:- That interference for which value of intensity of light finds minimum is known as destructive interference.

Dark fringes are observed for which value of path diffⁿ is:-

$$\Delta = (2n\pm1)\frac{\lambda}{2}$$

$$\boxed{\Delta = (2n-1)\frac{\lambda}{2}} \quad \text{--- (5)}$$

From eqⁿ (1) and (5)

$$2d\cos\theta - \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2}$$

$$2d\cos\theta - \frac{\lambda}{2} = \frac{2n\lambda}{2} - \frac{\lambda}{2}$$

$$\boxed{2d\cos\theta = n\lambda} \quad \text{--- (6)}$$

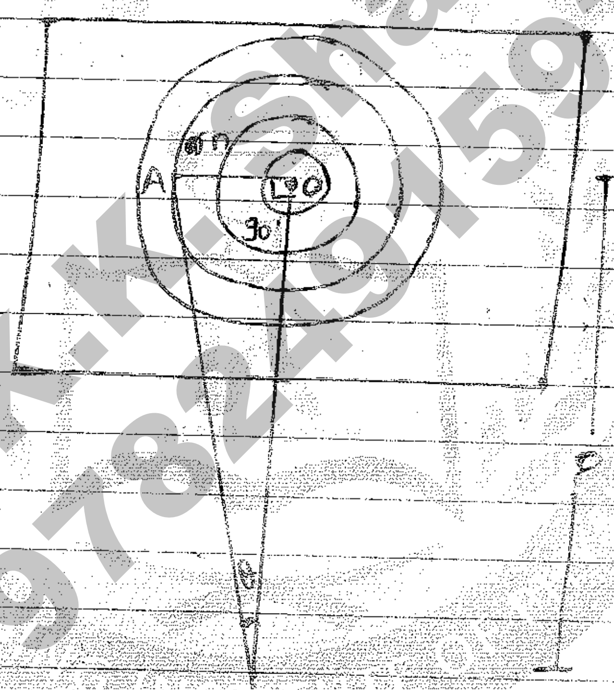
eqⁿ (6) is the condition of dark fringe for Michelson interferometer experiment.

For n^{th} fringe

$$\boxed{\cos\theta_n = \frac{n\lambda}{2d}} \quad \text{——} (7)$$

Radius Of Michelson Fringe:-

To calculate the radius of fringe, we take a model of fringe in michelson, interferometer experiment. let distance of model from Telescopy is D and radius of n^{th} fringe is r_n.



$$\tan\theta_n = \frac{r_n}{D}$$

$$r_n = D\tan\theta_n$$

$$r_n = D\sqrt{\sec^2\theta_n - 1}$$

$$\boxed{r_n = D\sqrt{\frac{1}{\cos^2\theta_n} - 1}} \quad \text{——} (8)$$

(a) Radius for Bright fringe:- on putting value of (4) in eq^n (8)

$$r_n = D\sqrt{\frac{1}{\frac{(2n+1)^2 d^2}{16d^2}} - 1}$$

$$\boxed{r_n = D\sqrt{\frac{16d^2}{(2n+1)^2 d^2} - 1}} \quad \text{--- (9)}$$

Eq^n (9) is the radius for Bright fringe.

(b) Radius for Dark fringe:-

on putting value of eq^n (5) in eq^n (8)

$$r_n = D\sqrt{\frac{1}{\cos^2\theta_n} - 1}$$

$$r_n = D\sqrt{\frac{1}{\frac{n^2 d^2}{4d^2}} - 1}$$

$$\boxed{r_n = D\sqrt{\frac{4d^2}{n^2 d^2} - 1}} \quad \text{--- (10)}$$

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Ques Calculate the value of wavelength of light for Michelson interferometer experiment ?

Proof We know that, condition for dark fringe. By mathematical conclusion in Michelson experiment

$$2d\cos\theta = n\lambda$$

$$\theta = 0^\circ$$

$$\boxed{2d = n\lambda} \quad \text{—— (1)}$$

In eqn (1), d is the film width,

By eqn (1)

$$2(d+x) = (n+N)\lambda \quad \text{—— (2)}$$

eqn (2) − eqn (1)

$$2(d+x) - 2d = (n+N)\lambda - n\lambda$$

$$2d + 2x - 2d = n\lambda + N\lambda - n\lambda$$

$$2x = N\lambda$$

$$\boxed{\lambda = \frac{2x}{N}}$$

By this we can calculate the value of wavelength.

Ques Prove that $\dfrac{I_{max} - I_{min}}{I_{max} + I_{min}} = \dfrac{2\sqrt{\beta}}{1+\beta}$

where β is intensity ratio $\left(\dfrac{I_1}{I_2}\right)$

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Sol^n We know that from mathematical analysis of interference.

$$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$$
$$I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$$

LHS

$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{(\sqrt{I_1} + \sqrt{I_2})^2 - (\sqrt{I_1} - \sqrt{I_2})^2}{(\sqrt{I_1} + \sqrt{I_2})^2 + (\sqrt{I_1} - \sqrt{I_2})^2}$$

$$= \frac{I_1 + I_2 + 2\sqrt{I_1 I_2} - I_1 - I_2 + 2\sqrt{I_1 I_2}}{I_1 + I_2 + 2\sqrt{I_1 I_2} + I_1 + I_2 - 2\sqrt{I_1 I_2}}$$

$$= \frac{4\sqrt{I_1 I_2}}{2I_1 + 2I_2}$$

$$= \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}$$

$$= \frac{2\sqrt{I_1 I_2}}{I_2\left(1 + \frac{I_1}{I_2}\right)}$$

$$= \frac{2\sqrt{\frac{I_1 I_2}{I_2^2}}}{\left(1 + \frac{I_1}{I_2}\right)} \quad \because \frac{I_1}{I_2} = \beta$$

$$= \frac{2\sqrt{\beta}}{1+\beta}$$

Ques-1 Write down conditions for obtaining sustained interference?

Ques-2 Define two methods of producing coherent sources?

Ques-3 Compare zone plate with a convex lens?

Ques-4 Explain the interference in thin film. Derive the conditions for constructive and destructive interference in reflected rays?

Ques-5 Derive the construction and working of a Michelson interferometer. Using this find out wave length of a monocromatic light?

Ques-6 Two coherent sources of light whose intensities ratio is 81:1 produce interference fringes. Find the ratio of maximum and minimum intensities of fringes?

Ques-7 Define coherence length and coherence time?

Ques-8 Explain the formation of Newton's Rings. How can you determine the refractive index of liquid with the help of Newton's Rings?

Ques-9 The Refractive index of a thin film is 1.40. Sodium light of wavelength 5900Å is incident on this film. Find the minimum thickness of this film for destructive interference in reflected light?

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Ques-10 On Newton's ring experiment the diameter of 4^{th} and 12^{th} dark rings are 0.40 cm and 0.70 cm resp. Deduce the diameter of 20^{th} dark ring?

Ques-11 Explain the interference due to thin wedge shaped film and obtain an expression for fringe width?

Ques-12 What are fringes of equal inclination and Haidinger fringes?

Ques-13 What is diffⁿ b/w division of wavefront and division of amplitude?

Ques-14 Show that there is no violation of the law of conservation of energy in the phenomenon of interference?

Ques-15 Prove that the shape of interference fringe is a hyperbola?

Ques-16 In a double slit experiment 6000Å light is used. The slit are 1mm apart and the screen is 1m away. Calculate fringe width and angular position of 10^{th} bright fringe?

Ques-17 Hundred fringes are found shifted from vision region when moving mirror of Michelson's interferometer is moved by a distance 0.03 mm. Calculate the wavelength of light used.

$$\lambda = \frac{2x}{N}$$

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Optical Fibre :-

Optical fibre is the co-axial cable which is used to propagate optical signal without lose. It is based on the principle of total internal Reflection.

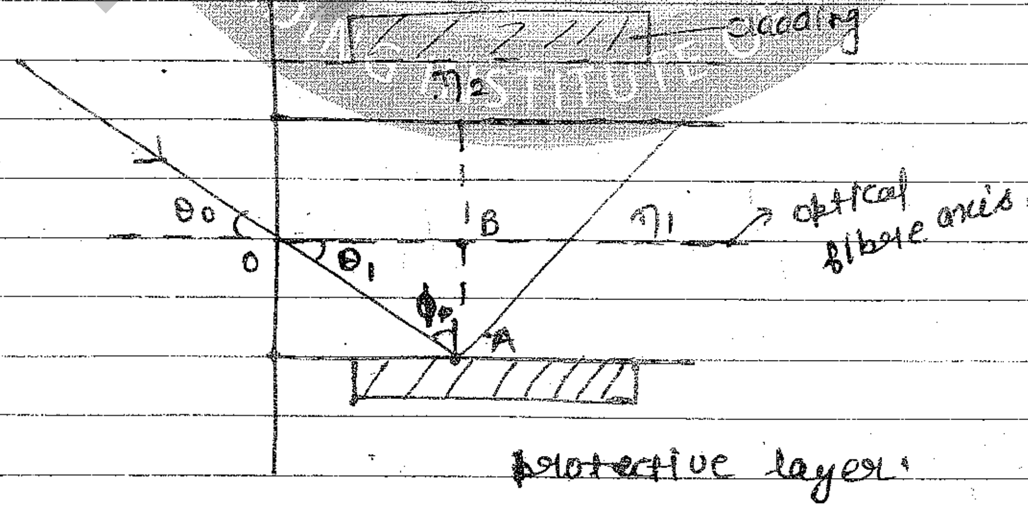
Optical fibre had two part :-
The inner part is core made up with Glass or Plastic (insulator) of high refractive index η_1. The core is surrounded by cladding which has refractive index less than core. The refractive index of cladding is η_2.

where $\eta_1 > \eta_2$.

Further more the cladding is covered by a secured layer which protect optical fibre from mechanical damage.

Calculation of Numerical aperature in optical fibre:-

Numerical aperature is measured of the ability of optical fibre to propogate the electromagnetic signal wave.



Let us consider an electromagnetic wave is incident from air to core which is making an incident ∠ θ_0 with normal and the refracted wave making ∠ θ_1 with normal.

From Snell's law

$$\eta_0 \sin\theta_0 = \eta_1 \sin\theta_1 \quad \text{--- (1)}$$

in ΔOAB,

$$\phi + \theta + \pi/2 = 180°$$

$$\phi = \frac{\pi}{2} - \theta$$

or

$$\theta = \frac{\pi}{2} - \phi$$

Putting value of θ in eq^n (1)

$$\eta_0 \sin\theta_0 = \eta_1 \sin(\pi/2 - \phi)$$

$$\eta_0 \sin\theta_0 = \eta_1 \cos\phi \quad \text{--- (2)}$$

We know that

$$\cos^2\phi + \sin^2\phi = 1$$

$$\cos^2\phi = 1 - \sin^2\phi$$

$$\cos\phi = \sqrt{1-\sin^2\phi} \quad \text{--- (3)}$$

Putting value of $\cos\phi$ in eq^n (2)

$$\eta_0 \sin\theta_0 = \eta_1 \sqrt{1-\sin^2\phi}$$

For optical signal to propagate without lose the incident ∠ θ_0 should such that the refracted wave make internal reflection,

So, at $\theta_0 = \theta_a$

$\phi = \theta_c$

here θ_c = critical Angle.

using eqⁿ (2)

$$\eta_0 \sin\theta_a = \eta_1 \sqrt{1-\sin^2\theta_c} \qquad \left[\sin\theta_c = \frac{\eta_2}{\eta_1}\right]$$

$$\eta_0 \sin\theta_a = \eta_1 \sqrt{1-\frac{\eta_2^2}{\eta_1^2}}$$

$$\eta_0 \sin\theta_a = \eta_1 \sqrt{\frac{\eta_1^2-\eta_2^2}{\eta_1^2}}$$

$$\eta_0 \sin\theta_a = \sqrt{\eta_1^2-\eta_2^2}$$

For air $\eta_0 = 1$

$$NA = \sin\theta_a = \sqrt{\eta_1^2-\eta_2^2}$$

$$\boxed{\theta_a = \sin^{-1} NA = \sin^{-1}\sqrt{\eta_1^2-\eta_2^2}}$$

where θ_a is the ∠ of Acceptance.

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Laser And Holography:-

Laser:-

(i) Absorption :-

Absorption probability depends on the density of radiation at the frequency corresponding to the energy separation of the two levels. hence transitional probability of absorption process per atom in mth state can be written as:-

$$P_{mn} \propto u(\nu)$$

$$\text{or} \quad P_{mn} = B_{mn}\, u(\nu)$$

Here, B_{mn} = Einstein absorption cofficient.

(ii) Spontaneous Emission:-

The probability per unit time of spontaneous emission will of course depends only on the two energy levels b/w which the atom makes a transition but it will be independent of the energy density of radiation field. Thus, Accⁿ to einstein the transition probability per second of spontaneous emission only depends on the density of atom in the exited state. (n)

Einstein represents this rate by A_{nm}.

So, rate of transitional probability for spontaneous emission is:-

$$P_{nm} \propto N_n$$

$$P_{nm} = A_{nm} N_n$$

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(iii) Stimulated Emission :-

(interaction of radiation with matter) due to this process the intensity of proper radiations of frequency ν passing through the atom gets amplified.

$$P_{nm} \propto N_n u(\nu)$$

$$(P_{nm})_{st} = B_{nm} N_n u(\nu) \quad \text{—③}$$

$$A^* + h\nu \longrightarrow A + 2h\nu$$

B_{nm} = Einstein cofficient for stimulated emission.

Relation Among Einstein's Cofficients:-

Let us consider an assembly of atom in thermal equilibrium at T temperature, with radiation frequency ν energy density $u(\nu)$. Let N_m = No. of atoms in m^{th} state. and N_n = No. of atoms in n^{th} state, at any instant.

The no. of atoms that absorb a photon and rise to n^{th} state per unit time,

$$R_{mn} = N_m P_{mn}$$

$$R_{mn} = N_m B_{mn} u(\nu) \quad \text{—①}$$

Conversely the no. of atom in state n that drops to m, either spontaneously or under stimulation, emitted photon per unit time.

$$R_{nm} = N_n (A_{nm} + B_{nm} u(\nu)) \quad \text{—②}$$

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From eqn, the absorption and emission must occur equally.

thus, $R_{mn} = R_{nm}$

$$B_{mn} N_m u(\nu) = A_{nm} N_n + B_{nm} N_n u(\nu)$$

$$\Rightarrow (B_{mn} N_m - B_{nm} N_n) u(\nu) = A_{nm} N_n$$

$$u(\nu) = \left(\frac{N_n A_{nm}}{N_m B_{mn} - N_n B_{nm}} \right)$$

$$u(\nu) = \frac{(N_n/N_n)(A_{nm}/B_{nm})}{\left[\left(\frac{N_m}{N_n}\right)\left(\frac{B_{mn}}{B_{nm}}\right) - 1\right]}$$

From from maxwell boltzmann statiets :-

$$N \propto e^{-E/KT} \quad \text{and} \quad \nu = \frac{E_n - E_m}{h}$$

$$N_m \propto e^{-E_m/KT}$$

$$N_n \propto e^{-E_n/KT}$$

$$\frac{N_m}{N_n} = e^{-E_m + E_n/KT}$$

$$\frac{N_m}{N_n} = e^{\Delta E/KT}$$

$$\frac{N_m}{N_n} = e^{h\nu/KT}$$

on putting value.

$$u(\nu) = \frac{(A_{nm}/B_{nm})}{\left(e^{h\nu/KT} - 1\right)} \quad \text{--- (3)}$$

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From Plank's ~~constant~~ radiation formula:-

$$u(\nu) = \frac{8\pi h\nu^3}{c^3 (e^{h\nu/KT} - 1)} \quad \text{--- (4)}$$

on comparing

$$\frac{A_{nm}}{B_{nm}} = \frac{8\pi h\nu^3}{c^3}$$

$$\boxed{\frac{A_{nm}}{B_{nm}} \propto \nu^3} \quad \text{--- (5)}$$

and $\frac{B_{mn}}{B_{nm}} = 1$

$$\boxed{B_{mn} = B_{nm}} \quad \text{--- (6)}$$

<u>Conclusions Drawn By Einstein:-</u>

(i) $B_{nm} \neq 0$ that means stimulated emission is possible from atom by the mutual interaction of external photons.

(ii) $B_{nm} = B_{mn}$, hence stimulated emission are known as Negative absorption.

(iii) $\frac{A_{nm}}{B_{nm}} \propto \nu^3$ $\Rightarrow$ probability of spontaneous emission is dominant over induced emission more and more as the energy diffⁿ b/w the two states increases.

Metastable state :-

There are certain energy states whose life time are much longer (10^{-3} sec) than the life time of usual short ~~time~~ lived exited state ($\sim 10^{-8}$ sec). Due to relatively long lived state are called **Metastable state** (temporarily state). Due to longer life time. Tc of the metastable state the einstein cofficient of spontaneous emission is comparitively small. Thus spontenous emission from metastable state are forbidden to some degree. However their is no restriction for induced transition from metastable state to lower state. Thus in lasers, transition from metastable state to ground state are chosen for stemi.

Principle OF Laser :-

For laser action two conditions must be satisfied.

(i) R_{nm} (sti) > R_{nm} (spon) $\Rightarrow$ $A_{nm} << B_{nm}\, u(\nu)$

(ii) Rate of emission > absorption rate.

$$\Rightarrow \quad A_{nm} << B_{nm}\, u(\nu) \quad \text{---} (1)$$

$$\frac{R_{nm}}{R_{mn}} = \frac{A_{nm} + B_{nm}\, u(\nu)}{B_{mn}\, u(\nu)} \frac{N_n}{N_m}$$

but $B_{nm} = B_{mn}$

$$\frac{R_{nm}}{R_{mn}} = \left[1 + \frac{A_{nm}}{B_{mn}\, u(\nu)}\right] \frac{N_n}{N_m}$$

From (1) condition :-

$$\frac{R_{nm}}{R_{mn}} = [1 + (\text{very small})]\frac{N_n}{N_m} \simeq \frac{N_n}{N_m}$$

From Max. Bolt distribution law :-

$$\frac{N_n}{N_m} = e^{-h\nu/KT}$$

$$\boxed{\frac{R_{nm}}{R_{mn}} = e^{-h\nu/KT}} \quad \text{— (1)}$$

At Normal circumstances, $N_n << N_m$ and incident photon of proper frequency. ~~so~~ the main contribution of absorption transition and emission transition is Neglected.

(i) Population Inversion :-

By some means a larger no. of atoms are made available in the higher energy state, in comparision of no. of atoms in lower state i.e. $N_n >> N_m$ and hence stimulated emission can be enhanced. The situation in which the number of atom in higher energy state exceeds than that in lower energy state is known as population inversion.

$$\frac{N_n}{N_m} = e^{-h\nu/KT}$$

$$\log \frac{N_n}{N_m} = \frac{-h\nu}{KT}$$

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$$T = \frac{-(E_n - E_m)}{k \log (N_n/N_m)}$$

000 0000 00000
00000000 00000 0000 000

(a) $T = 0K$, $N_n = 0$
(b) $T > 0K$, $N_n < N_m$ $(E_m < E_n)$
(c) $T = \infty K$, $N_n = N_m$
(d) $T < 0K$, $N_n > N_m$ $(E_m < E_n)$

⇒ Thus, Negative temperature state of the system is known as Population inversion.

⇒ The Medium which produce population inversion is known as active medium.

⇒ The Population inversion can be achieved by exciting the medium with suitable form of energy, this process is called Pumping.

(iii) Condition of laser action:- (under which the stimulated emission can be made very large in comparison to the other processes).

(a) $N_n > N_m$ This state is known as Population inversion.

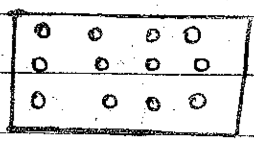
(b) The spectral energy density of incident radiation must be made very large i.e. $u(\nu)$ must be very large. To do so, the emitted radiations are reflected coherently again and again b/w two parallel mirror facing each other in a cavity containing active medium.

(c) Anm/Bnm should be minimised i.e. Anm < Bnm, to do so, metastable state is chosen which allow stimulated emission rather than spontaneous emission.

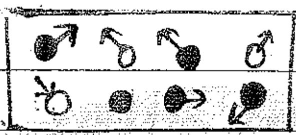
(iii) Light Amplification:-

In a laser the active system is enclosed in an optical cavity, usually made in the form of rod or a tube. The ends of a laser material are closed by accurately parallel reflectors one of which is a perfect ~~reflection~~ reflector and the other has 90% reflectivity (or 10% transmission). The cavity makes the energy energy density large, when stimulated emission dominants over spontaneous emission. The multiple reflection also makes the stimulated emission more coherent. This process is called light Amplification. This process is explained below:-

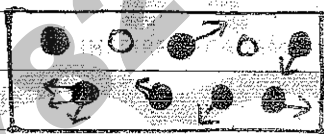
(i) Almost all atoms are initially in the unexited state. An outside agent (such as electric discharge for example) exites atom inside the laser. The hollow circles here represent the unexited atoms.



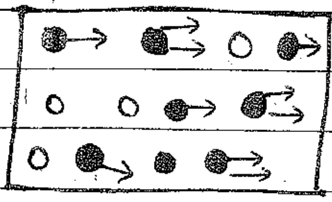
(ii) When the Pumping radiation falls on the active material the atoms are exited (the population inversion not yet reached) black dots less than hollow circle). Black dots ⟶ exited atoms.



(iii) Pumping radiation ~~contains~~ continues the majority of certain atoms in the active material are exited to the metastable state. In which the exited atoms remain for an appreciable time. Population inversion is reached at this stage. The dominant radiation initially are the spontenous ones. Two cases of ~~spontenous~~ coherent emission are shown. (multiple lines are ow) are along the axis, and another at a slant angle.



(iv) One exited atom falls to a lower state and emits a photon. This photon waves travels past the other exited atoms and triggers them to fall to the lower state. In doing so they emit photons with wave in step with the original photon waves. The beam travels back and forth again and again due to multiple reflection on the end faces. On each ~~step~~, strip, it causes more exited atom to emit waves in phase with it. Spontenous component of emission still not negligible.

(iv) 

(v) Only those waves that travels accurately along the axis of the tube will remain in the tube after many trips up and down it. Since the beam is almost entirely compound of waves going in exactly the same direction. Its rays are accurately parallel. Thus radiations that are mutually coherent go on becoming dominant at successive stages. Spontaneous component of emission is now very weak.

Ruby laser :-

⇒ Maximann was the I^{st} who constructed Ruby laser in 1960.

⇒ This device is a solid state laser and is a three level laser system.

⇒ Optical pumping is used for Population inversion.

Construct :-

Ruby crystal is an oxide of Aluminium oxide (Al_2O_3) with small percentage of Chromium ion (Cr^{+3}) which are responsible for the characteristic pink colour of Ruby. Replace some of Al^{+3} ions and absorb a broad band of green and yellow light.

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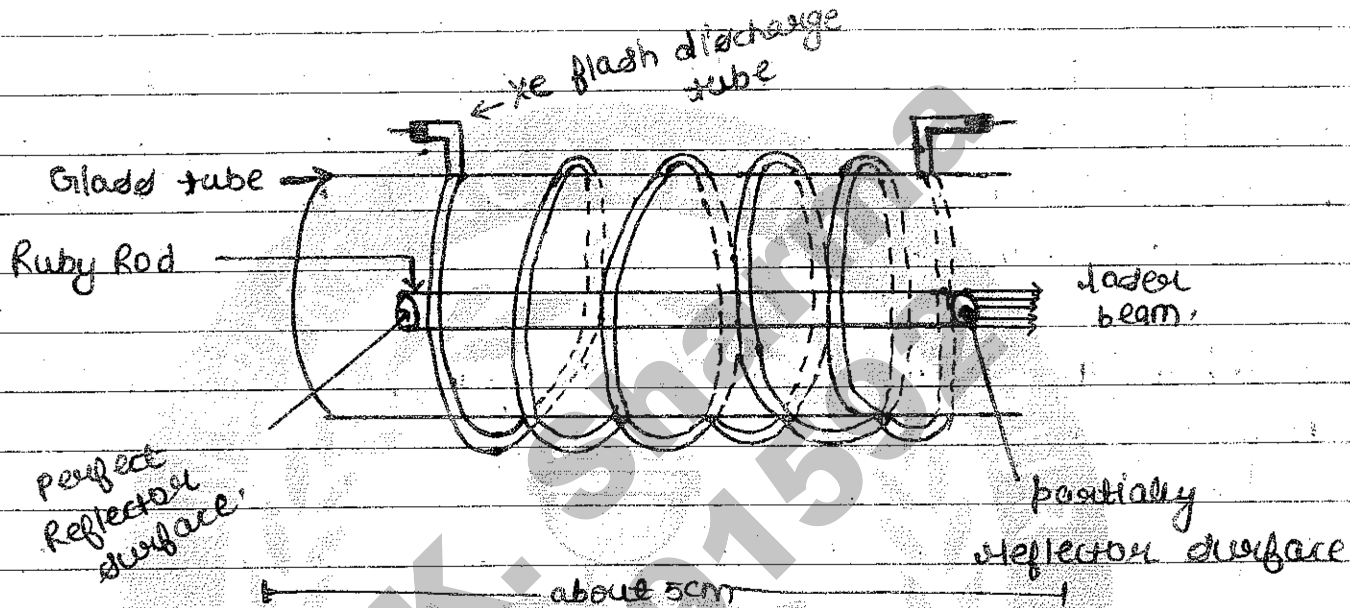
⇒ It consist of pink ruby cyclindrical rod.

⇒ Ends of rod made perfectly parallel and optically same and are silver polished.



⇒ Length of Ruby ray is made equal to an interegal no of $\frac{1}{2}$ of λ of laser light. This type of Ruby ray acts as an active medium of optical resonator cavity for laser action.

⇒ Ruby ray placed inside a cyclindrical glass tube upon which a Xenon gas discharge tube in the form of helix is wound. It is connected to a suitable power supply and flash made repeadly with a time interval of few mili second in order to pump the atoms of cromium atoms to the exited state.

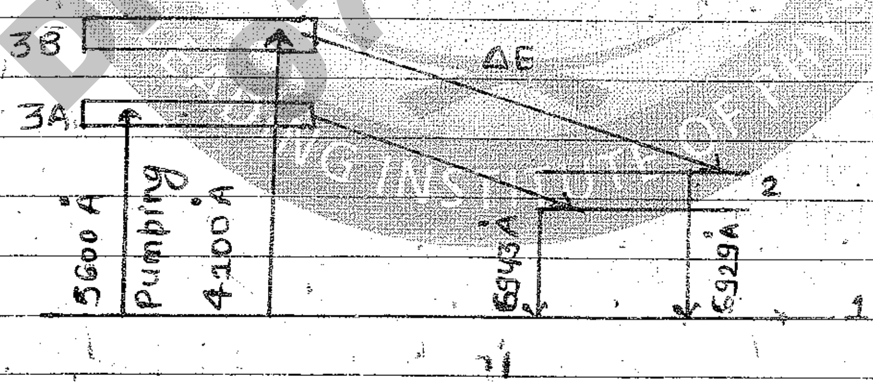
⇒ The cylindrical ~~gas~~ glass tube is also surrounded by another glass tube through which water is circulated to keep ruby ray cool.

Working :-

For laser action in Ruby crystal there must be ~~atleast~~ three energy level of the active medium in which one of them should be metastable level is b/w the atomic level.

⇒ Cromium atom have certain energy level which contain three level scheme for laser action.

⇒ The chromium ion has two broad energy level i.e 3A and 3B above its ground level 1. and a metastable 2 consisting of two energy levels slightly below 3A.



⇒ When a flash light (which last only for a millisecond) from Xenon flash tube falls on a ruby rod. The green and yellow light photons are absorbed by Cr^{+3} ions and transition takes place to any one of the exited state 3A or 3B. These transition are known as ~~Pumping~~ Transition.

⇒ life time $\approx 10^{-8}$ sec.

⇒ spontaneous transition from 3A and 3B make the atom to go over 2.

⇒ These transition are Non-radiative in nature.

⇒ Meta-stable state have large life time so the population density at this level grows till it exceeds the population density of state 1.

⇒ At this state of triggering beam of light of $\lambda = 6943\,Å$ or $6929\,Å$ will emit from laser action.

⇒ If even one photon out of the photons produced by Induced emission moves parallel to axis of Ruby crystal, it undergoes multiple reflections b/w the parallel mirrors.

⇒ When this photon interacts with an exited atom in state 2, it induces the exited atom to emit a fresh photon in phase with the stimulated photon.

⇒ The process is repeated again and again and thus photons having same phase multiply.

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The regenerative action continues and a part of beam comes out as a red colour laser beam from the semi-transparent end of ruby crystal.

⇒ In the original ~~step~~ set-up the Xenon flash lamp was connected to a capacitor which was charged to a few kilovolts.

⇒ The energy stored in the capacitor was discharged through Xenon lamp in a few milliseconds. Thus a power of a few megawatts is released and a part of this energy is absorbed for lasing.

⇒ The laser output is 10-20 KW in the form of pulses.

He-Ne Gas Laser:-

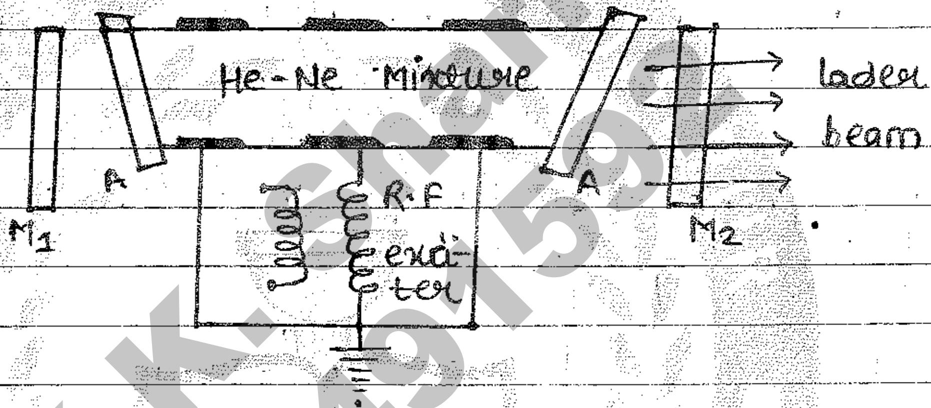
⇒ The Helium-Neon laser uses a mixture of He and Ne in ratio 10:1 with the total pressure of approximately 1 Torr (1mm of mercury).

⇒ The mixture is kept in a thin pyrex glass tube. (internal diameter about 2mm and length 40cm)

⇒ The Reflector M_1, M_2 are two dielectric ~~optically~~ coated spherical mirror having a very high reflectivity at 6328 Å. M_1 is perfect reflector and M_2 - partially transparent for emergence of laser light.

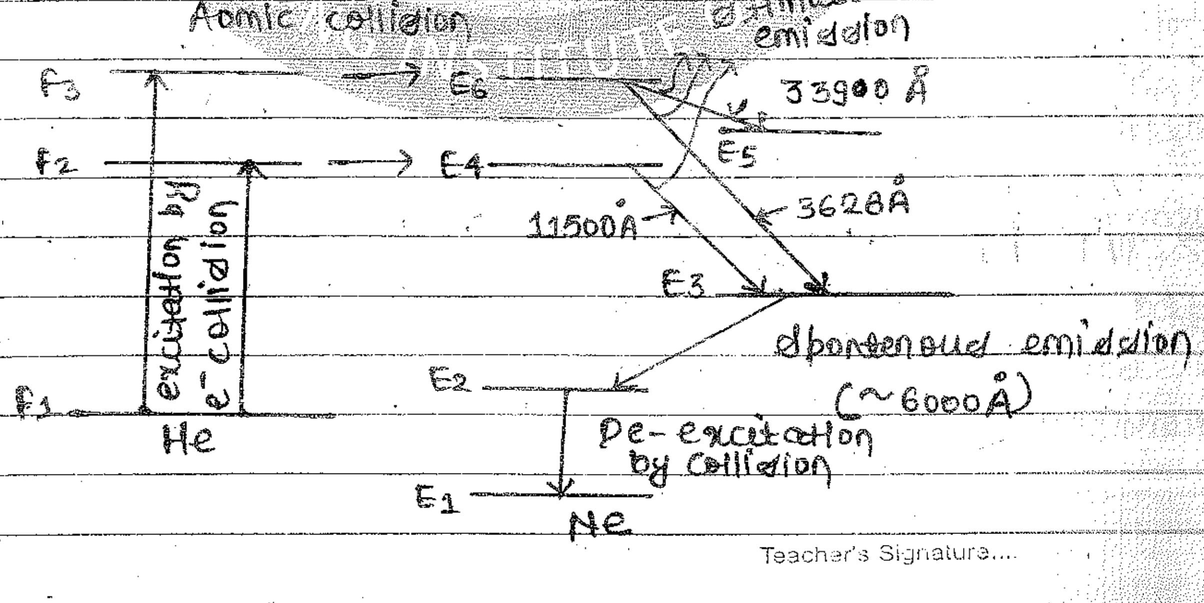
⇒ The spacing of the mirror is equal to an integral multiple of half wavelength of the laser light.

⇒ Pumping is achieved by an electrical discharge produced in the gas by means of electrodes outside the tube and connected to a source of high frequency alternating current.



Working :-

⇒ Ne atom has metastable energy levels E4 and E6 very close to a energy state F2 and F3 of He atom.



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⇒ When an electric discharge is produced in He-Ne mixture by means of RF exciter collision b/w the metastable state He atoms and unexcited Ne atoms have a high probability of energy transfer to the Neon atoms.

⇒ Some of the excited He atoms transfer their energy to excited state of Ne atom by collision. to level E_4 and E_6 which have near by same energy as the levels F_2 and F_3 of He.

⇒ Thus population density in excited ~~state~~ level of Ne will increases.

⇒ When the population in E_4 and E_6 become much more than the population in lower level E_3 and E_5. population inversion is achieved.

⇒ The purpose of He atoms is thus to achieve a population inversion in Ne atoms.

⇒ These transition of Ne atom from E_6 and E_4 to E_5 and E_3 are coherent in nature.

⇒ Another photon of wavelength ~6000Å is spontaneously emitted in a transition from E_3 and E_5 to a lower metastable state E_2. Thus transition yet yield only in coherent light.

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⇒ The remaining energy of atoms is lost in the deexcitation process by collision with the tube and atoms reach to ground state.

⇒ The high directivity of a laser beam is achieved by the parallel mirror fixed at the end of the tube and a resonator cavity made by them.

⇒ The stimulated emission is a resonant process.

⇒ The absence of effects such as crystalline imperfect, thermal distortion and scattering which are present in solid-state laser, result in getting a laser beam of wavelength $\lambda = 6328\ \text{Å}$ has an extremely narrow band width (highly monocromatic)

(However power output is much smaller → 1-50 mw, input → 5 to 10 W).

Special property of Laser Beam:-

(i) Highly intense
(ii) Extremely directional
(iii) Monocromatic
(iv) Spatial and time Coherent.

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Ques-9 ~~It~~ is given the center of sphere is $O(0,0,0)$ and tangent line of sphere.

$$2(x+1) = (2-y) = (z+3)$$

$$(x+1) = \frac{2-y}{2} = \frac{z+3}{2}$$

$$\frac{x+1}{1} = \frac{y-2}{-2} = \frac{z+3}{2} = r \text{ (let)} \quad \text{---(1)}$$

A point lie on this line

$$P(r-1, -2r+2, 2r-3)$$

let this point is point of contact.

Dir^n Ratio of line $OP = (r-1)-0, (-2r+2)-0, (2r-3)-0$

$$r-1, -2r+2, 2r-3$$

Dir^n Ratio's of tangent line (1) $= 1, -2, 2.$

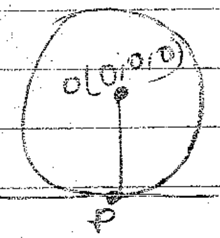
$$OP \perp (1)$$

$$(1)(r-1) + (-2)(-2r+2) + 2(2r-3) = 0$$

$$r-1+4r-4+4r-6 = 0$$

$$9r-11 = 0$$

$$\boxed{r = 11/9}$$



Hence $P\left(\frac{11}{9}-1, \frac{-22}{9}+2, \frac{22}{9}-3\right)$

$$P\left(\frac{2}{9}, \frac{-4}{9}, \frac{-5}{9}\right)$$

Hence Radius of sphere OP =

$$= \sqrt{\left(\frac{2}{9}-0\right)^2+\left(\frac{-4}{9}-0\right)^2+\left(\frac{-5}{9}-0\right)^2}$$

$$= \sqrt{\frac{4}{81}+\frac{16}{81}+\frac{25}{81}}$$

$$= \sqrt{\frac{45}{81}} = \sqrt{\frac{5}{9}}$$

Hence eqn of sphere is

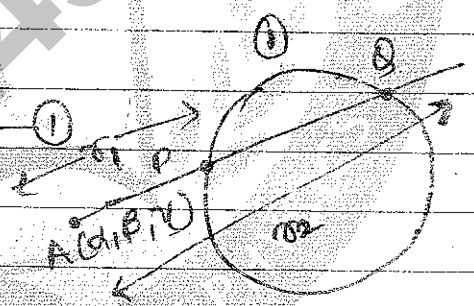
$$(x-0)^2+(y-0)^2+(z-0)^2 = \left(\sqrt{\frac{5}{9}}\right)^2$$

$$\boxed{x^2+y^2+z^2 = \frac{5}{9}}$$

Ques-14

Eq. of sphere:-

$$x^2+y^2+z^2 = a^2 \quad \text{--- (1)}$$



eqn of line :-

$$\frac{x-\alpha}{l} = \frac{y-\beta}{m} = \frac{z-\gamma}{n} = r \text{ (let)} \quad \text{--- (2)}$$

A point lie on line (2) (now if this point is intersecting point of sphere and line then it lie on sphere also--)

$(lr+\alpha,\ mr+\beta,\ nr+\gamma)$

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By eqn (1) $(lr+\alpha)^2 + (mr+\beta)^2 + (nr+\gamma)^2 = a^2$

$(l^2+m^2+n^2)r^2 + 2(l\alpha+m\beta+n\gamma)r + (\alpha^2+\beta^2+\gamma^2-a^2) = 0$

$= r^2 + 2(l\alpha+m\beta+n\gamma)r + (\alpha^2+\beta^2+\gamma^2-a^2) = 0$ —— (3)

Since eqn (3) is Quadratic eqn in r. Hence, let two roots of eqn (3) are r_1 and r_2.

$$r_1 + r_2 = \frac{-B}{A} = \frac{-2(l\alpha+m\beta+n\gamma)}{1}$$

$$r_1 \cdot r_2 = \frac{C}{A} = \frac{(\alpha^2+\beta^2+\gamma^2-a^2)}{1}$$

length of Chord $PQ = r_2 - r_1$

$= \sqrt{(r_1+r_2)^2 - 4r_1r_2}$

$= \sqrt{4(l\alpha+m\beta+n\gamma)^2 - 4(\alpha^2+\beta^2+\gamma^2-a^2}$

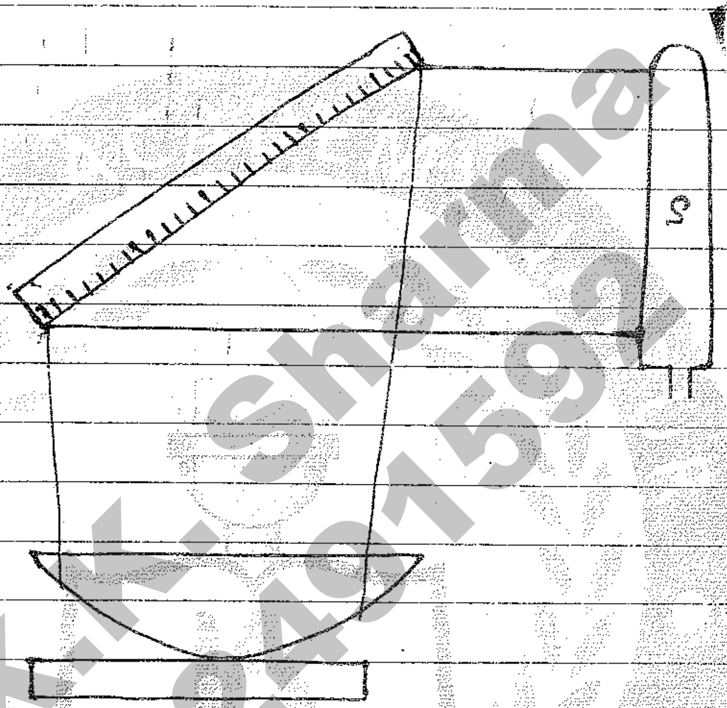
$\Longleftrightarrow$

Teacher's Signature........

Ques Explain Newton's Ring experiment with diagram?

Ans

Newton's Ring experiment is an optical phenomenon. It is use to find the coherent light source. This method is done by Amplitude division method.



$$E_0 = \frac{E_0}{r} \sin(\omega t - kr - \phi)$$ M_2

[redacted] M_1

$$E_0 = a_0(x,y)\cos(\omega t + \phi)$$

$$E_r = a_r \cos(\omega t - \vec{k}\cdot\vec{r})$$

$$E_r = a_r \cos(\omega t - k_x \cdot x)$$

$$E_r = a_r \cos(\omega t - \alpha x)$$ M_3

$$E = E_r + E_0$$

$$E = a_0 \cos(\omega t + \phi) + a_r \cos(\omega t - \alpha x)$$

$$I = \langle E^2 \rangle = a_0^2 \langle \cos^2(\omega t + \phi)\rangle + a_r^2 \langle \cos^2(\omega t - \alpha x)\rangle$$
$$+ 2a_0 a_r \langle \cos(\omega t + \phi)\rangle \langle \cos(\omega t - \alpha x)\rangle$$

$$I = \frac{a_0^2}{2} + \frac{a_r^2}{2} + 2a_0 a_r \cos(\alpha x - \phi)$$

$$I = \frac{a_0^2}{2} + \frac{a_r^2}{2} + a_0 a_r \cos(\alpha x - \phi)$$

$$\boxed{T = \beta I}$$

$$= \beta\left(\frac{a_0^2 + a_r^2}{2}\right) + \beta a_0 a_r \cos(\alpha x - \phi)$$

$$= \beta_0 + \beta a_0 a_r \cos(\alpha x - \phi)$$

$$E_t = T E_r$$

$$E_t = \left[\frac{\beta}{2}(a_0^2 + a_r^2) + \beta a_0 a_r \cos(\alpha x - \phi)\right]\left[a_r \cos(\omega t - \alpha x)\right]$$

$$E_t = \frac{\beta}{2}(a_0^2 + a_r^2)\, a_r \cos(\omega t - \alpha x) + \beta a_0 a_r^2 \cos(\alpha x - \phi)\cos(\omega t - \alpha x)$$

$$+ \beta a_0 a_r^2 \left[\cos(\omega t - \phi) + \cos(2\alpha x - \omega t - \phi)\right]$$

$$\boxed{E_t = \frac{\beta}{2}(a_0^2 + a_r^2)\, a_r \cos(\omega t - \alpha x) + \frac{\beta a_0 a_r^2}{2}\cos(\omega t - \phi) + \frac{\beta a_0 a_r^2}{2}\cos(2\alpha x - \omega t - \phi)}$$

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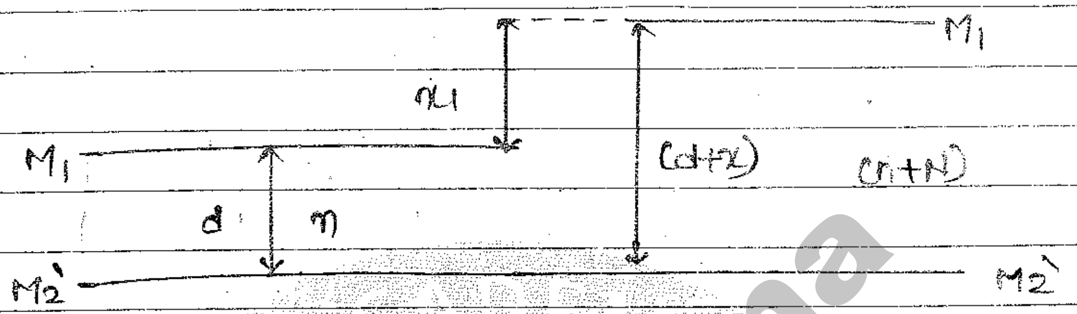

$$2(d+x) = (n+N)\lambda \quad \text{— ②}$$

Subtracting eq^n ① from ②

$$2(d+x) - 2d = (n+N)\lambda - n\lambda$$

$$2d + 2x - 2d = n\lambda + N\lambda - n\lambda$$

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$\boxed{\sqrt{R\lambda(n+1)} - \sqrt{n\lambda}}$

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