Interference of light

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the phenomema of modification in intensity of light due to superimposing of two or more light waves is called Interference of Light

Constructive Interference

$$E = E_1 + E_2$$

Destructive Interference

$$E = E_1 - E_2$$

Phase difference $\phi = \frac{2\pi}{\lambda}$

For construct ive interference

$$\phi = 2n\pi$$

Path difference $= n\lambda$

For destructive interference

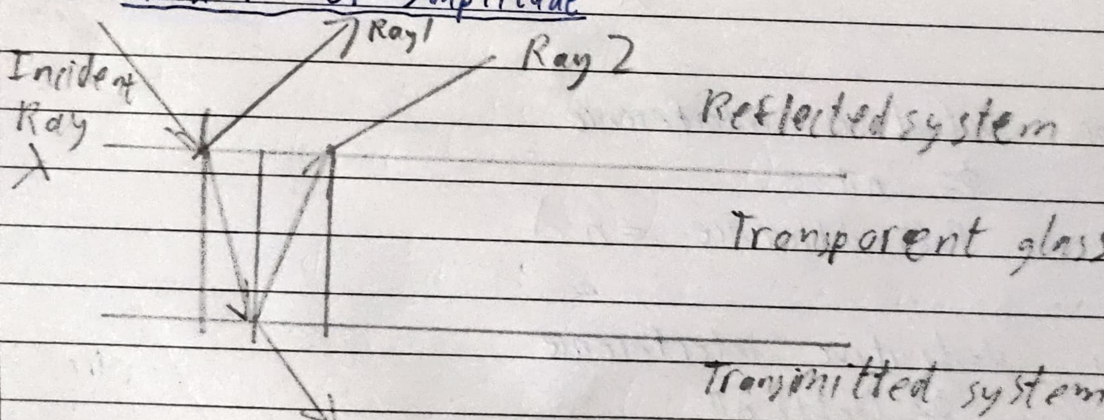
$$\phi = (2n \pm 1) n\pi$$

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

Sustained Interference

i) The two source must be coherent
ii) Source must be monochromatic
iii) Same amplitude or intensity
iv) Distance between two source must be small
v) The perpendicular distance of screen from two source must be large
vi) Sources must be narrow
vii) Two interfering waves must have the same plane of polarization.

Division of Amplitude



Reflected lights will have less amplitude than incident After multiple reflection, the waves would interfer which ~~would~~ is called division of ~~amplitud~~ amplitude.

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$I, \mu_1 \rightarrow \mu_2, I_R$

$$I_R = \left(\frac{\mu_2 - \mu_1}{\mu_2 + \mu_1}\right)$$

$\mu_1 = 1$
$\mu_2 = 1.5$

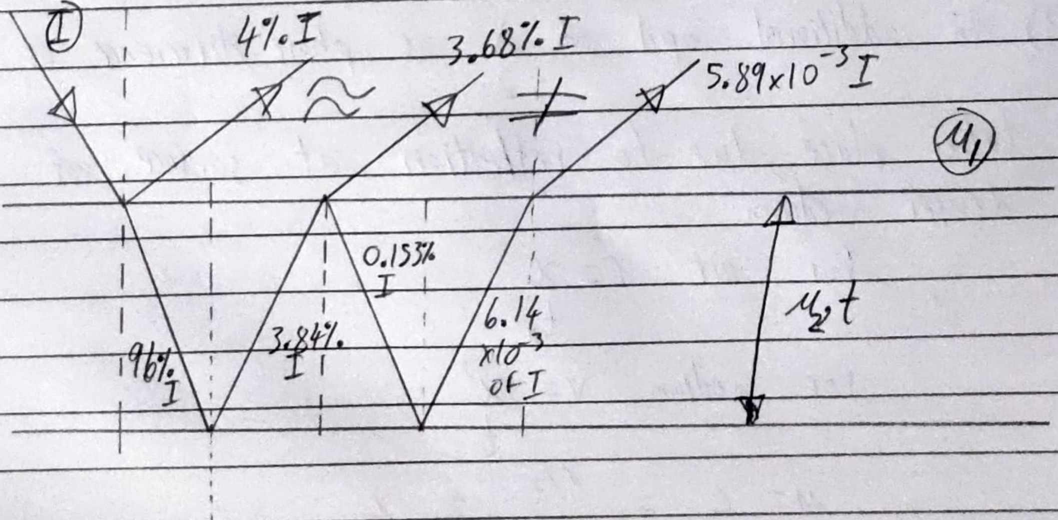
$$I_R = I\left(\frac{0.5}{2.5}\right) = I\left(\frac{1}{5}\right)^2 = I(0.2)^2$$

$I_R = 0.04\, I_r = 4\%\, I$

$I = I_R + I_T$

$I = \cancel{0.04 I_R}\ 4\%\, I + I_T$

$I_T = 96\%\, I$



Reflected Rays 1 and 2 will cause interference as intensities are very close to each other. But no Interference will happen with 3 as the Intensity is very small compared to 1 and 2

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Thickness of thin film

$t \rightarrow$ thickness of film

if t is large coherence will be lost

else if t is very small division amplitude will not happen.

From experiment, it is found that If

$\lambda =$ wavelength of incident light

$t = 0.1\lambda$ to 10λ

1000λ is thick film

Important results

1) when a ray of light travels a distance x' in medium of RI μ then its effective path $= \mu x'$

2) Phase difference $\delta = \left(\frac{2\pi}{\lambda}\right)(opd)$

3) An additional opd of $\frac{\lambda}{2}$ or phase difference of π takes place, due to reflection at surface of denser medium

for air $c = \frac{x}{t}$

for medium $v = \frac{x'}{t}$

$$\mu = \frac{c}{v} = \frac{x/t}{x'/t} = \frac{x}{x'}$$

$$x = \mu x'$$

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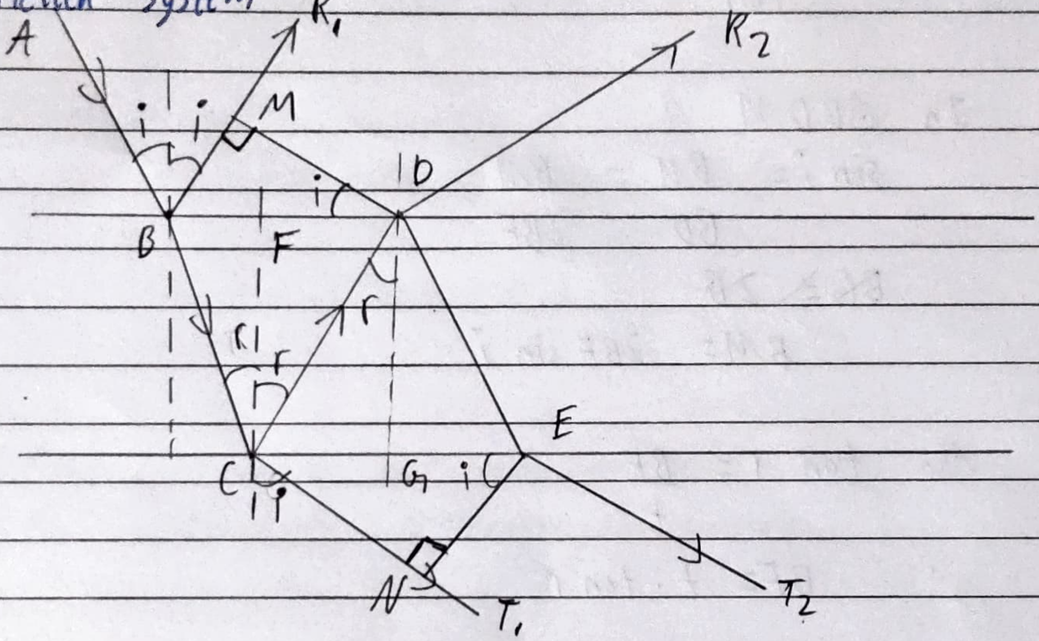
Interference in thin film

a) Reflected system



i) Ray of light AB incident on transparent medium of RI μ and thickness t.

ii) Ray AB is reflected along BR and refracted along BC multiple reflections and refractions take place.

iii) BR_1 and DR_2 interfere with each other.

After M there is no path difference

opd = path BCD in film − path BM in air

opd $= (BC + CD)\mu - BM$

As $BC = CD$

opd $= 2(BC)\mu - BM$

iv) In Δ BCF

$$\cos r = \frac{t}{BC}$$

$$BC = \frac{t}{\cos r}$$

$$opd = 2 \times \frac{t}{\cos r} \times \mu - BM$$

In ΔBDM

$$\sin i = \frac{BM}{BD} = \frac{BM}{2BF}$$

$$\cancel{BD = 2B}$$

$$BM = 2BF \sin i$$

Also $\tan r = \frac{BE}{t}$

$$BE = t \cdot \tan r$$

$$BM = 2 \times t \times \tan r \times \sin i$$

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

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

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

$$\sin i = \mu \sin r$$

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

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

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Now, due to reflection of light at surface of denser medium an additional phase difference of $\frac{\lambda}{2}$ takes place.

$\therefore$ Effective opd

$$\delta = \cancel{opd}\ opd \pm \frac{\lambda}{2}$$

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

Conditions for maxima and minima

1) for constructive interference or maxima

$$\delta = n\lambda$$

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

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

2) For destructive interference or minima

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

Taking $\pm$ve sign

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

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

Transmitted system -

$$Opd = \mu(CD + ED) - CN$$

As $CD = ED$

$$opd = 2\mu CD - CN \quad - (A)$$

In ΔDCG

$$\cos r = \frac{t}{CD}$$

$$CD = \frac{t}{\cos r} \quad - (1)$$

In ΔCEN

$$\sin i = \frac{CN}{CE} = \frac{CN}{2CG} \quad - (2)$$

In ΔDGC

$$\tan r = \frac{CG}{t}$$

$$t \cdot \tan r = CG \quad - (3)$$

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Dasit Using ②

$$\sin i = \frac{CN}{2CG}$$

$$CN = 2CG \sin i$$

Using ③

$$CN = 2 \times \tan r \times t \times \sin i \quad - ④$$

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

$$\sin i = \sin r \times \mu \quad - ⑤$$

Using ⑤ in ④

$$CN = 2\mu t \times \tan r \times \sin r$$

$$= \frac{2\mu t \times \sin^2 r}{\cos r} \quad - ⑥$$

Using ① and ⑥ in ④

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

$$= \frac{2\mu t (1 - \sin^2 r)}{\cos r}$$

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

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

Effective opd is same as it travels to rarer medium.

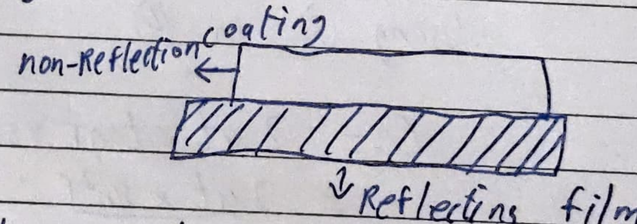
For maxima and minima

1) $2\mu t \cos r = n\lambda$ for maxima

2) $\delta = \frac{(2n \pm 1)\lambda}{2}$ for minima

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

Anti Reflecting coating



- This is also called highly refractive coating
- Used in telescopes as less light is lost due to reflection thus providing better contrast.

Applications-
Reflex free sight glasses
Contrast ~~eh~~ enhancement
Laser scanner windows
~~Anti~~ Anti reflection coating on mobile screens.

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Working

The coating should satisfy condition for destructive interference

μ_f = refractive index of the film

t = thickness of film

'n' → order of reflection

μ_g → RI of glass

The condition for destructive interference

$$\cos r \; 2\mu_f t_f = \frac{(2n+1)\lambda}{2}$$

$$t_f = \frac{(2n\pm1)\lambda}{4\mu_f \cos r}$$

For normal incidence $r=0$ min(order) = 1

$$t_f = \frac{\lambda}{4\mu_f}$$

Amplitude condition

$I \rightarrow \mu_a \rightarrow \mu_f \rightarrow I_1$

$$I_1 = I\left(\frac{\mu_f - \mu_a}{\mu_f + \mu_a}\right)^2$$

$I \rightarrow \mu_f \rightarrow \mu_g \rightarrow I_2$

$$I_2 = I\left(\frac{\mu_g - \mu_f}{\mu_g + \mu_f}\right)^2$$

for interference $I_1 = I_2$

$$I\left(\frac{\mu_f - \mu_a}{\mu_f + \mu_a}\right)^2 = I\left(\frac{\mu_g - \mu_f}{\mu_g + \mu_f}\right)$$

$$\frac{\mu_f - 1}{\mu_f + 1} = \frac{\mu_g - \mu_f}{\mu_g + \mu_f}$$

$$\mu_f^2 = \mu_g$$

$$\mu_f = \sqrt{\mu_g}$$

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