Unit-2 - Optics

Introduction :-

Optics is the branch of physics that deals with study of light. In this unit we are going to study wave optics.

(A) Interference of light -

The variation in the intensity due to overlapping of two or more waves is called as interference.

→ **Condition for constructive interference** -

optical path difference = OPD = $\Delta = n\lambda$, $n = 0, 1, 2 \ldots$

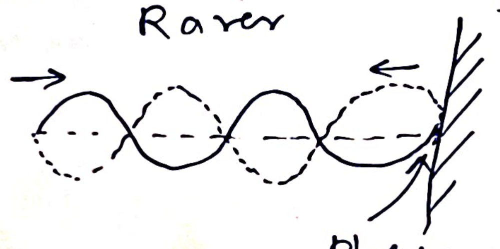
→ **Condition for destructive interference** -

optical path difference = OPD = $D = (2n \pm 1)\frac{\lambda}{2}$

→ If phase changes by '2π' rad then corresponding change in path difference is 'λ'.

→ **Stokes treatment** -

When light wave reflects from the boundary of denser medium then phase of wave changes by 'π' rad. So, the path difference changes by '$\frac{\lambda}{2}$'.



Thin film – An optical medium having thickness about one wavelength of visible light is called as thin film.

- An optical medium having thickness in the range of 0.5 μm to 10 μm.
- Eg. oil floating on water, soap bubble.

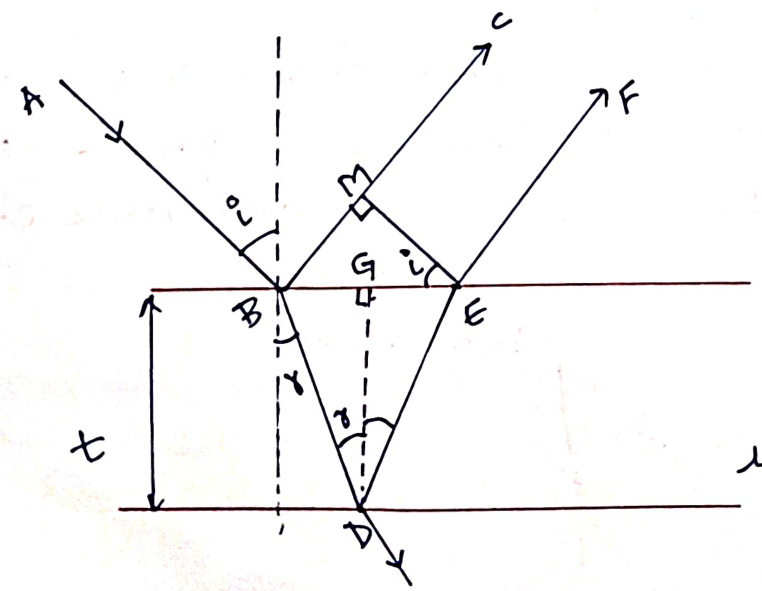
Interference in thin films –

(I) Interference in uniform thin film due to reflected light – [Uniform thin film – Constant thickness at each point]

(a) Consider a uniform thin film having refractive index 'μ'.

(b) A ray AB incident on the top surface of the film. Here, some part of ray 'AB' reflects in the same medium (BC) and some part of 'AB' refracts (transmits) in the film (BD ray).

(c) At point 'D' again reflection and transmission takes place. Also at point 'E', reflection & transmission takes place.



(d) let,

t = thickness of film
i = Angle of incidence
r = Angle of refraction
μ = Refractive index of film.

(e) Draw a ⊥ler 'EM' on ray 'BC'.

(E) The rays BC and EF are reflected rays. These rays meets at a point and interference pattern is formed.

Now, the optical path difference between BC + EF rays is,

$$OPD = \Delta = \mu(BD + DE) - BM$$

From figure, $BD = DE$

$$\therefore \quad \Delta = \mu(BD + BD) - BM$$

$$\therefore \quad \boxed{\Delta = 2\mu BD - BM} \quad \text{—(1)}$$

Now, we need to find 'BD' and 'BM'!

(i) <u>To find BD</u> –

(a) The triangle BDG is a right angled triangle.

so, $\cos r = \dfrac{DG}{BD} = \dfrac{t}{BD}$ $\quad (\because DG = t)$

$$\therefore \quad BD = \frac{t}{\cos r}$$

put in eq^n (1), so,

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

(ii) <u>To find BM</u> –

(a) Δ BEM is right angled triangle.

so, $\sin i = \dfrac{BM}{BE} = \dfrac{BM}{BG + GE}$

but $BG = GE$

$$\therefore \sin i = \frac{BM}{2BG}$$

$$\therefore BM = \sin i \times 2BG$$

Also, from Δ BDG, $\tan r = \dfrac{BG}{DG} = \dfrac{BG}{t}$

$$\therefore BG = t \times \tan r$$

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

put in eq^n (2),

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

from Snell's law, $\frac{\sin i}{\sin r} = \mu$

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

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

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

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

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

but at point 'B', phase changes by 'π' rad. so, path difference will change by $\frac{\lambda}{2}$!

$\therefore$ $\boxed{\Delta = 2\mu t \cos r \pm \frac{\lambda}{2}}$

Ⓐ Condition for constructive interference (Maxima or Bright)

we have, $\Delta = OPD = n\lambda$

put the value of 'Δ',

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

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

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

Ⓑ Condition for destructive interference (Minima / Dark)

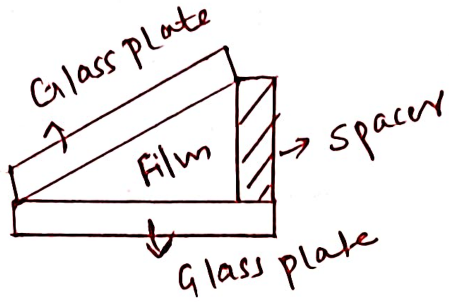
we have, $\Delta = OPD = (2n-1)\frac{\lambda}{2}$

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

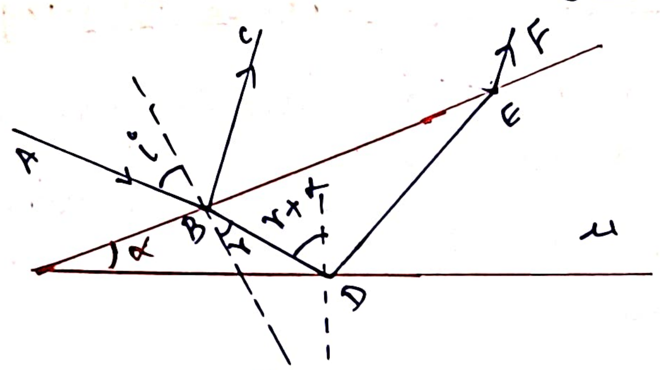
$\therefore$ $\boxed{2\mu t \cos r = n\lambda}$

(II) Interference in non-uniform thin film due to reflection
[Film of varying thickness]

(A) **Wedge-Shaped film** – Wedge shaped film can be formed by keeping two glass plates one over the other and by introducing a thin object at one end.



Interference in wedge-shaped film –



let,

α = wedge-angle

The rays BC & EF are reflected rays.

The optical path difference between BC & EF rays will be,

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

(A) Condition for constructive interference –

$$\Delta = n\lambda$$

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

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

(B) Condition for destructive interference

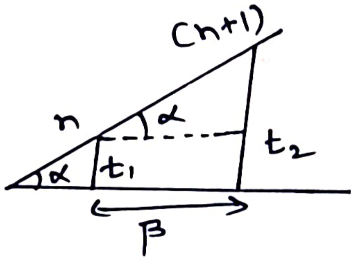
$$\Delta = (2n-1)\frac{\lambda}{2}$$

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

$$\therefore\ 2\mu t\cos(r+\alpha) = n\lambda$$

Note → In wedge-shaped film, the interference fringes are straight and of equal width.

Fringe-width (β) → The distance between the two successive bright fringes or dark fringes is called as fringe width.



$$\text{fringe width} = \beta = \frac{\lambda}{2\mu\alpha}$$

Testing of flatness of surface [surface testing]

(a) The surfaces of components may contain irregularities after production or machining & can be checked by interference.

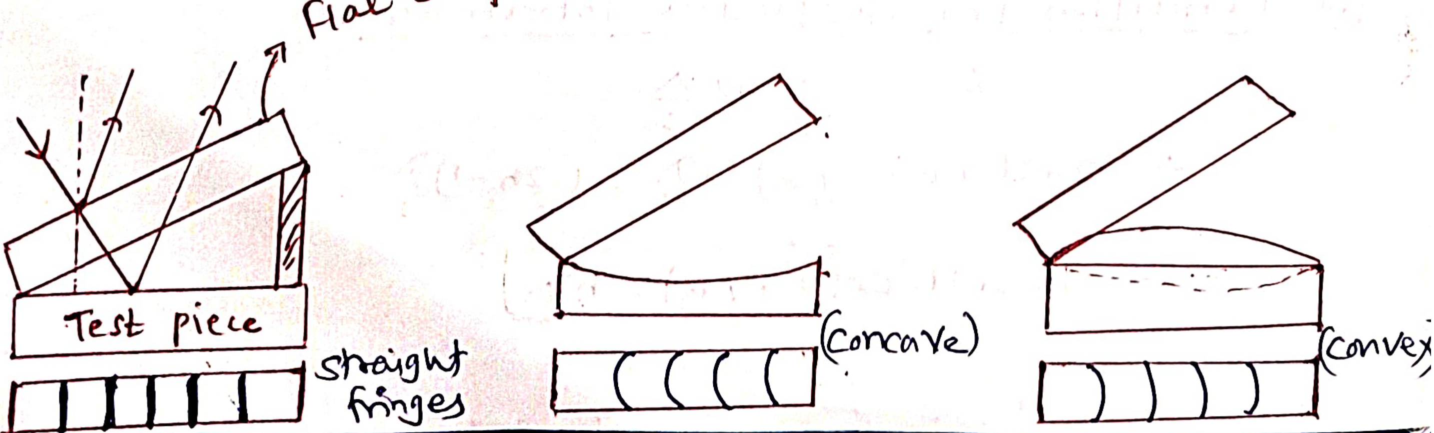
(b) An air-wedge film is formed between test piece and standard flat surface.

(c) Then this film is illuminated by monochromatic light and interference pattern is observed.

(d) If the interference fringes are straight and of equal width then test piece is optically flat.

(e) If the interference fringes are irregular then test piece is not optically flat.

(f) If fringes are irregular then test piece is polished and again tested till straight fringes are observed.



Anti-Reflection Coatings - (AR coating) -

ⓐ **Need of AR coatings -**

(I) Optical instruments like telescopes, cameras, binoculars consists of glass lenses. so, light reflects from these glass lenses. Thorfore image quality become poor due to reflection of light.

(II) so, to avoid reflection from the glass surface, we need anti-reflection coatings.

ⓑ **Use of AR-Coatings -**

(I) Anti-reflection coatings are used to reduce the intensity of reflected light by destructive interference and to enhance the transmission.

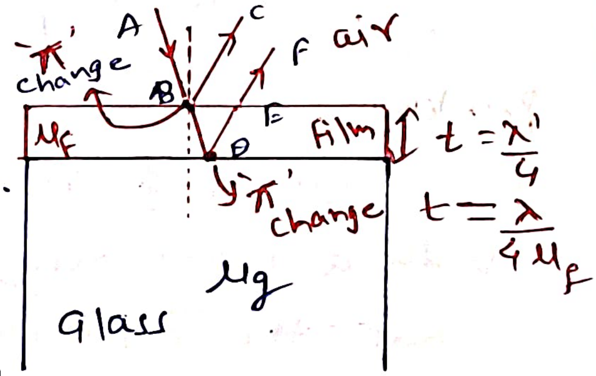
ⓒ **How to reduce the reflection?**

(I) Glass surface is coated with thin film (MgF_2) having refractive index less than the glass surface and having thickness $t = \frac{\lambda'}{4} = \frac{\lambda}{4\mu_f}$ [λ' = wavelength of light in thin film]

(II) let, λ = wavelength in air

$\mu_f = \mu$ = Refractive index of film

μ_g = Refractive index of glass.



(III) $\mu_f < \mu_g$ and $\mu_{air} = 1$

(III) for interference between BC & EF rays.

$OPD = \Delta = 2\mu_f t \cos r$

Here, for normal incidence, $r = 0$ & $\cos r = 1$

$\therefore OPD = 2\mu_f t$

(IV) Also, phase changes by 'π' rad at two points (B & D)

∴ Net change in phase = 0

∴ Net change in OPD (path difference) = 0
so, no need to add or substract $\frac{\lambda}{2}$!

$$\therefore \Delta = 2\mu_f t$$

but $t = \frac{\lambda'}{4}$

$$\therefore \Delta = 2\mu_f\left(\frac{\lambda'}{4}\right)$$

$$\therefore \Delta = \frac{\mu_f \lambda'}{2}$$

but. $\lambda' = \frac{\lambda}{\mu_f}$

$$\therefore \Delta = \frac{\mu_f}{2} \times \frac{\lambda}{\mu}$$

$$\therefore \boxed{\Delta = \frac{\lambda}{2}}$$

Now, optical path difference (Δ) is '$\frac{\lambda}{2}$', that means interference is destructive interference.
So, intensity of reflected light is reduced and intensity of transmission light enhanced.

Problem -

(I) A glass of refractive index 1.5 is to be coated with a transparent material of refractive index 1.2 so that the reflection of light of wavelength 6000 Å is eliminated by interference. What is the required thickness of the coating?

→ $\lambda = 6000$ Å,

$\mu = 1.2$

$$\therefore \lambda' = \frac{\lambda}{\mu} = \frac{6000}{1.2} = 5000 \text{ Å}$$

$$\therefore \quad t = \frac{\lambda'}{4} = \frac{5000}{4} = 1250\,\mathring{A}$$

$$\therefore \quad t = 1250 \times 10^{-10}\ m$$

$$\therefore \quad \boxed{t = 1.250 \times 10^{-7}\ m}$$