INTERFERENCE

Light is a form of energy which help us to see the objects or it is the form of energy which gives us the sensation of vision.

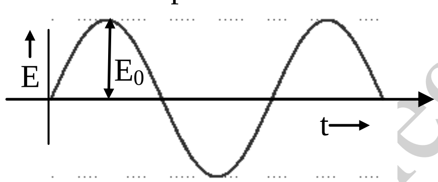
OPTICS:

Optics is the branch of Physics which deals with nature and properties of light.
Optics is broadly divided into Ray optics (geometrical optics), wave optics (physical optics) and quantum optics (photon optics).

In Ray optics, we consider light as extremely small (minute) particles called corpuscles travelling along straight lines with enormous speed.
Corpuscular theory of light is put forward by Isaac Newton. *According to this theory, a luminous body continuously emits tiny particles of light called corpuscles in all directions. These particles are massless, rigid, perfectly elastic, travel along straight lines with high speed and no material medium is required for their propagation. The corpuscles are different for different colours*. This theory was successful in explaining reflection, refraction, dispersion, scattering, etc. but failed to explain phenomena like interference, diffraction, polarization, etc.

In Wave Optics, we consider light as transverse waves. Later James Clerk Maxwell showed that light is an electromagnetic wave having electric and magnetic field vibrations. The wave theory could explain almost all phenomena like reflection, refraction, interference, diffraction, polarization etc. But it could not explain the phenomena like Photoelectric Effect, Compton Effect, Raman Effect etc. successfully.

Although light is a wave motion of both electric and magnetic fields, **electric field intensity alone is responsible for the optical phenomena**. So in wave optics, we **consider light as a function of the electric field alone** or the displacement variable at a point due to light is the electric field (E) at that point.



$E = E_0 \sin(\omega t + \phi)$, just like $y = y_0 \sin(\omega t + \phi)$ (general equation of an oscillation-SHM).

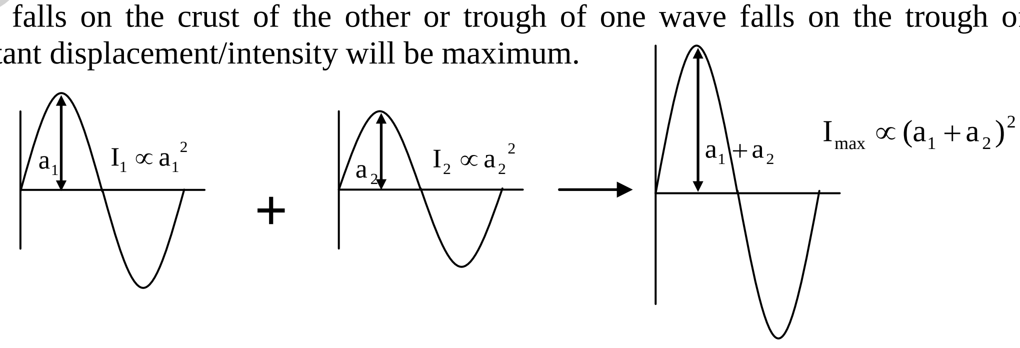
The intensity of light, $I \propto E_0^{\ 2}$, where E_0 is the amplitude of electric field vibration.

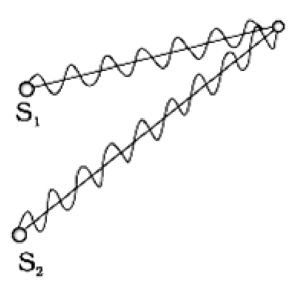
Superposition principle: According to superposition principle **when two or more light waves meet at a point in a continuous medium,** each wave produces its own displacement and **the resultant displacement produced is equal to the algebraic sum of the displacements produced by the individual waves.**
Let y_1 and y_2 are the displacements of the two superposing light waves, then the resultant displacement

$Y = y_1 + y_2$ Or here, $\vec{E} = \vec{E}_1 + \vec{E}_2$

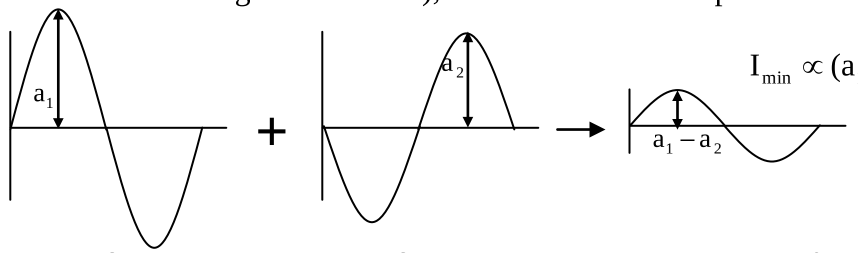
Note: Intensity of a wave is directly proportional to its amplitude. $I \propto A^2$.

Reinforcement (Constructive interference): The superposition of the waves resulting in maximum intensity is called Constructive interference. If the superposing waves are in the same phase (crust of one wave falls on the crust of the other or trough of one wave falls on the trough of the other), then the resultant displacement/intensity will be maximum.





Annulling (destructive interference): The superposition of waves resulting in minimum intensity is called destructive interference. If the superposing waves are out of phase or in opposite phase (crust of one wave falls on the trough of the other), then the resultant displacement/intensity will be minimum.



$I_{min} \propto (a_1 - a_2)^2$

$$\frac{I_{max}}{I_{min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2}$$

Condition for constructive interference: For constructive interference, the path difference between the interfering waves is an integral multiple of the wavelength λ.

$\delta = \lambda, 2\lambda, 3\lambda, ..., n\lambda$, Or $\boxed{\delta = n\lambda \;\; (n = 0,1,2,3,....)}$

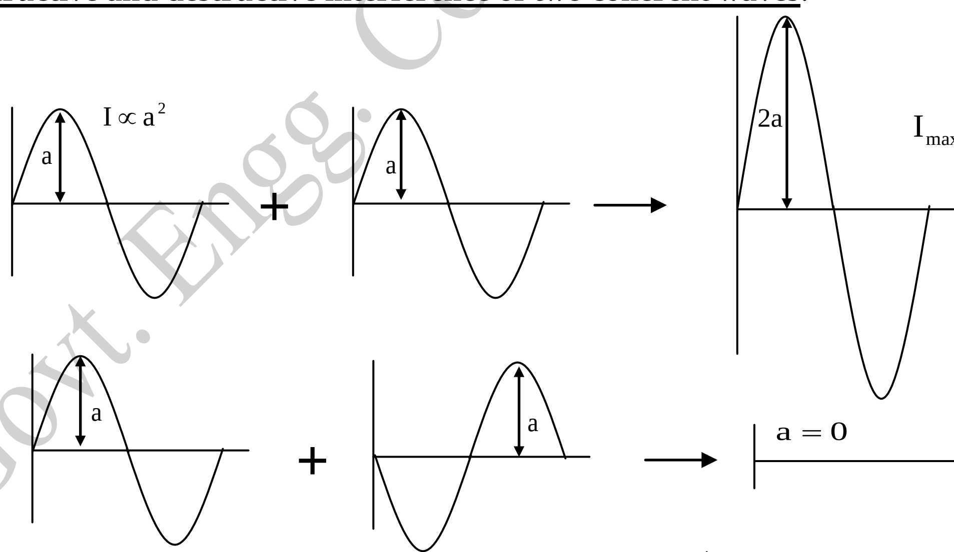
Condition for destructive interference: For destructive interference, the path difference between the interfering waves is an odd multiple of $\frac{\lambda}{2}$.

$\delta = \frac{\lambda}{2}, 3\frac{\lambda}{2}, 5\frac{\lambda}{2}, ..., (2n-1)\frac{\lambda}{2}$, Or $\boxed{\delta = (2n-1)\frac{\lambda}{2} \;\; (n = 1,2,3,....)}$

Coherent waves and coherent sources:

Light waves having the same amplitude, same frequency and with zero or constant phase difference is called coherent waves. Sources producing coherent waves are called coherent sources.
In actual practice, it is not possible to have two independent sources which are coherent. This is because, even if the two sources produce light waves of the same frequency and same amplitude, they may undergo random changes in their phases. The two coherent sources are to be produced or derived from the same parent source. Two slits illuminated by a monochromatic source of light (Young's double-slit method), a source of light and its reflected image (Lloyd's single mirror method), two refracted images of the same source (Fresnel's biprism method), etc are examples for coherent sources.

Constructive and destructive interference of two coherent waves:



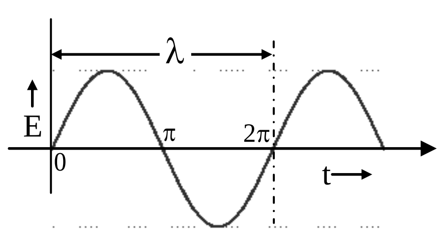
$I_{max} \propto (2a)^2 = 4a^2 = 4I$

$I_{min} = 0$

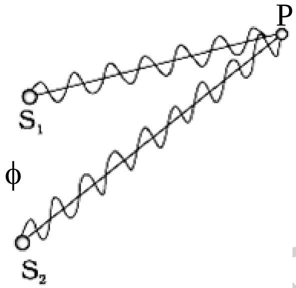
phase difference and path difference:

Phase difference, $\phi = \frac{2\pi}{\lambda} \times$ path difference.

Path difference is represented by the symbol δ.



Analytical treatment (based on two coherent waves):



Let the displacement of two light waves meeting at a point are represented as
$y_1 = a\sin\omega t$ and $y_2 = a\,\sin(\omega t + \phi)$.

Then the resultant displacement $y = y_1 + y_2 = a\sin\omega t + a\,\sin(\omega t + \phi)$

$$Y = a\sin\omega t + a\,\sin\omega t\cos\phi + a\,\cos\omega t\sin\phi = a\sin\omega t\,(1+\cos\phi) + a\,\cos\omega t\sin\phi$$

Since phase difference, $\phi = \frac{2\pi}{\lambda} \times \delta$

$$Y = a\sin\omega t\,(1+\cos\frac{2\pi}{\lambda}\times\delta) + a\,\cos\omega t\,\sin\frac{2\pi}{\lambda}\times\delta$$

Case1: When $\delta = 0, \lambda, 2\lambda, ..., n\lambda$ or $\delta = n\lambda$ $(n = 0,1,2,3,...)$, $\boxed{Y = 2a\sin\omega t}$

The resultant amplitude is **2a** and the resultant intensity $\boxed{I \propto 4a^2}$.

The resultant intensity is four times the intensity due to an individual wave. Thus for maximum intensity (constructive interference), the path difference between the interfering waves is an integral multiple of the wavelength λ.

Case II: When $\delta = \frac{\lambda}{2}, 3\frac{\lambda}{2}, 5\frac{\lambda}{2}, ..., (2n-1)\frac{\lambda}{2}$, or $\delta = (2n-1)\frac{\lambda}{2}$ $(n = 1,2,3,....)$ $\boxed{Y = 0 \text{ and } I = 0}$

The resultant amplitude and the resultant intensity are zero. Thus for minimum (zero) intensity (destructive interference), the path difference between the interfering waves is an odd multiple of $\frac{\lambda}{2}$.

Interference: **Interference is the phenomenon of redistribution (**remodification**) of energy** in a region **due to the superposition of two coherent waves** passing simultaneously through that medium.

Conditions for sustained interference:

1) The sources must be coherent.
2) The two coherent sources should be very close to each other.
3) The light waves from the sources should superimpose at the same time and the same place.

Two types of interference:

1) Interference produced by the division of wavefront: Here the incident wavefront is divided into two parts by reflection, refraction or total internal reflection. These two divided parts of wavefronts travel unequal distances through the medium and then combine to produce interference. A point source of light or very thin linear source (slit) is used for this interference. Young's double-slit experiment, Fresnel's biprism experiment, Lloyd's single mirror experiment, etc are the best examples for this type of interference.
2) Interference produced by the division of amplitude: Here the incident beam of light is divided into two parts by partial reflection or refraction. These two divided parts of light travel unequal distances through the medium and then combine to produce an interference pattern. Broad sources are enough to produce such interference. Newton's ring experiment, Air wedge, Michelson's interferometer, the colour of thin films, etc are some of the examples.

Optical path: optical path is the **equivalent distance in vacuum corresponding to the distance travelled by light through a medium for a particular interval of time**.

medium | Refractive index- μ | Speed of light - v
← d →

$$v = \frac{d}{t} \text{ or } t = \frac{d}{v}$$

vacuum | Refractive index- 1 | Speed of light - c
← Optical path →

$$c = \frac{O.P}{t} \quad \text{or} \quad t = \frac{O.P}{c}$$

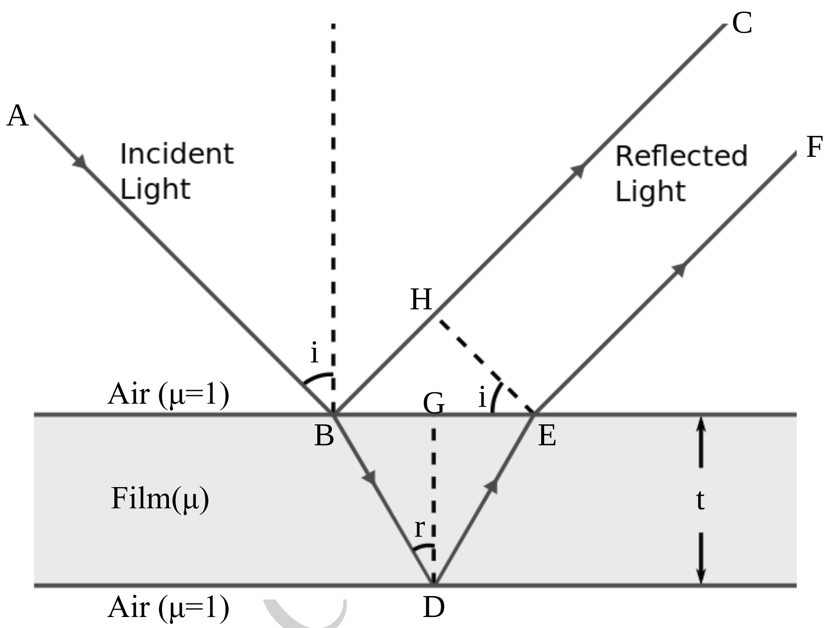
Comparing above two eqns. $\frac{O.P}{c} = \frac{d}{v}$, or $O.P = \frac{c}{v} d = \mu d$.

$\boxed{\text{Optical path} = \mu \times \text{distance in a medium}}$ $(O.P = \mu \times d)$

Path difference due to dissimilar reflection: Reflection on the surface of a denser medium produces an additional path difference of $\frac{\lambda}{2}$ as compared to reflection on the surface of a rarer medium.

Interference of light reflected from plane parallel thin films: when a beam of light falls on a thin transparent film, a part of the light is reflected from the top surface of the film and another part is reflected from the bottom surface. These two reflected rays interfere constructively or destructively, depending upon the path difference, to produce an interference pattern. If the incident light is white, the film appears beautifully coloured.

Consider the propagation of an incident beam of light through a thin film.



The Optical Path Difference (O.P.D) between the reflected rays

$$O.P.D = (BD + DE) \text{ in the film } - \left(BH \text{ in air } + \frac{\lambda}{2} \right)$$

Here $\frac{\lambda}{2}$ is added along with BH to include the additional path difference produced by reflection on the denser surface)

$$O.P.D = \mu(BD + DE) - BH - \frac{\lambda}{2} \quad ---(1)$$

From the figure, $BD = DE$ and consider ΔBDG

$$\cos r = \frac{DG}{BD} = \frac{t}{BD}, \quad BD = \frac{t}{\cos r} \quad ---(2)$$

From Δ BHE , $\sin i = \frac{BH}{BE}$, $BH = BE \sin i ---(3)$

From figure, $BE = BG + GE$ and $BG = GE$

Again consider ΔBDG , $\tan r = \frac{BG}{DG} = \frac{BG}{t}$, $BG = t \times \tan r$ or $BE = 2 \times t \times \tan r ---(4)$

Substituting eqn(4) in eqn(3) and then eqns (3) and (2) in eqn(1), we get

$$O.P.D = \mu\left(\frac{t}{\cos r}+\frac{t}{\cos r}\right) - 2\times t\times \tan r \times \sin i - \frac{\lambda}{2}$$

According to Snell's law $\frac{\sin i}{\sin r} = \mu$, $\sin i = \mu \sin r$. Substituting in the above equation and solving

$$O.P.D = \frac{2\mu t}{\cos r} - 2\times t\times \frac{\sin r}{\cos r}\times \mu \sin r - \frac{\lambda}{2} = \frac{2\mu t}{\cos r} - \frac{2\mu t}{\cos r}\sin^2 r - \frac{\lambda}{2} = \frac{2\mu t}{\cos r}\left(1-\sin^2 r\right) - \frac{\lambda}{2}$$

$$O.P.D = \frac{2\mu t}{\cos r}\times \cos^2 r - \frac{\lambda}{2} = 2\mu t \cos r - \frac{\lambda}{2} \quad \text{ie.} \quad \boxed{O.P.D = 2\mu t\cos r - \frac{\lambda}{2}}$$

Condition for maximum brightness (bright band):

$$2\mu t\cos r - \frac{\lambda}{2} = n\lambda \quad \text{where } n = 0,1,2,3....$$

$$2\mu t\cos r = n\lambda + \frac{\lambda}{2} = \left(n+\frac{1}{2}\right)\lambda = (2n+1)\frac{\lambda}{2}\ , \text{ where } n = 0,1,2,3....$$

$$\boxed{2\mu t\cos r = (2n+1)\frac{\lambda}{2}\ , \text{ where } n = 0,1,2,3....}$$

Condition for minimum brightness (dark band):

$$2\mu t\cos r - \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2} \quad \text{where } n = 1,2,3....$$

$$2\mu t\cos r = (2n-1)\frac{\lambda}{2} + \frac{\lambda}{2} = n\lambda\ , \text{ where } n = 1,2,3....$$

$$\boxed{2\mu t\cos r = n\lambda\ , \text{ where } n = 1,2,3....}$$

Note:

I) Interference of **light transmitted by a plane parallel thin film**:

For transmitted rays $\boxed{O.P.D = 2\mu t\cos r}$

Condition for maximum brightness (bright band):

$$\boxed{2\mu t\cos r = n\lambda \quad \text{where } n = 0,1,2,3....}$$

Condition for minimum brightness (dark band):

$$\boxed{2\mu t\cos r = (2n-1)\frac{\lambda}{2} \quad \text{where } n = 1,2,3....}$$

II) For an **air film produced between refracting media** (air film formed between two glass plates)

$$\boxed{O.P.D = 2\mu t\cos r + \frac{\lambda}{2}}\ , \quad \text{where } \mu = 1.$$

Condition for minimum brightness (dark band):

$$2\mu t\cos r + \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2} \quad \text{where } n = 1,2,3....$$

$$2\mu t\cos r = (2n-1)\frac{\lambda}{2} - \frac{\lambda}{2} = n\lambda - \lambda = (n-1)\lambda,\ \text{ where } n = 1,2,3....$$

Or $\boxed{2\mu t\cos r = n\lambda\ , \text{ where } n = 0,1,2,3....}$

<u>Condition for maximum brightness (bright band)</u>:

$$2\mu t\cos r + \frac{\lambda}{2} = n\lambda \quad \text{where } n = 1,2,3.... \qquad \text{(as the central band is dark)}$$

$$2\mu t\cos r = n\lambda - \frac{\lambda}{2} = \left(n - \frac{1}{2}\right)\lambda = (2n-1)\frac{\lambda}{2}, \quad \text{where } n = 1,2,3....$$

$$\boxed{2\mu t\cos r = (2n-1)\frac{\lambda}{2}, \quad \text{where } n = 1,2,3....}$$

<u>Colours of thin films</u>:

When a beam of light falls on a thin transparent film, a part of the light is reflected from the top surface of the film and another part is reflected from the bottom surface. These two reflected rays interfere constructively or destructively, depending upon the path difference, to produce interference bands. If the incident light is white, the film appears beautifully coloured. The condition for darkness is $2\mu t\cos r = n\lambda$. and this depends on the thickness of the film, refractive index, angle of incidence and the wavelength of light used. If a wavelength satisfies the condition for darkness at a point, that wavelength (colour) will be absent at that point and the film appears to have the combination of remaining colours.

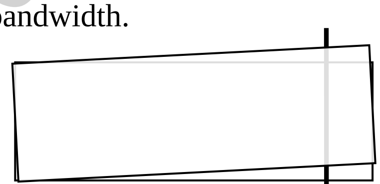
Ex: brilliant colours of peacock feathers, pigeon's neck, colours are seen on the oil spread on road, colours seen on soap bubbles, etc

Note:

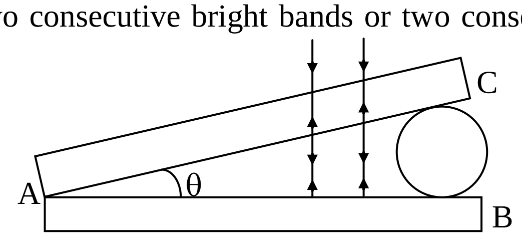
- In the case of spreading of oil on water or a draining soap film, the colour of the film changes because the thickness of the film is decreasing continuously.
- When we observe a thin film from different positions (angles) the colour of the film changes. As the angle of incidence changes the conditions for constructive and destructive interferences also change.
- If the thickness of the film is infinitesimally small, the path difference between the reflected rays becomes $\frac{\lambda}{2}$ (neglect $2\mu t\cos r$, as thickness is very very small), due to the reflection on the denser surface. This satisfies the condition for darkness and hence the film appears dark. In other words, the whole light is transmitted.
- If the thickness of the film is sufficiently large, almost all colours undergo some order of constructive interference and hence result in the formation of white light. Or in other words, interference is not observed.

<u>INTERFERENCE IN WEDGE SHAPED AIR FILM (AIR WEDGE):</u>

Air wedge consists of two optically plane glass plates placed one over the other in such a way that they are in contact at one end and separated by a small distance at the other end, using a thin metallic wire. A wedge-shaped air film is formed between the glass plates. The angle between the glass plates is called the angle of the wedge. When a beam of monochromatic light is incident normally on this setup, one part of the light is reflected from the top surface of the air film and another part is reflected from the bottom surface. These two reflected beams interfere constructively or destructively, depending upon their path difference, to produce an interference pattern. The pattern consists of equidistant, straight, parallel, dark and bright bands. The distance between two consecutive bright bands or two consecutive dark bands is called bandwidth.

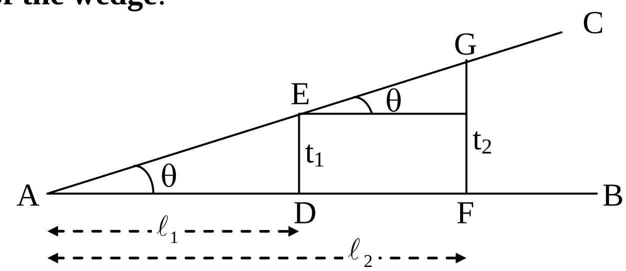


(Top view)



(Side view)

To find Angle of the wedge:



Let the n[th] dark band is formed at a distance of ℓ_1 from the point of contact, where the thickness of the film is t_1 and n+1[th] dark band is formed at a distance of ℓ_2, where the thickness of the film is t_2.

From the figure, $\tan\theta = \dfrac{t_2 - t_1}{\ell_2 - \ell_1}$.

Since θ is very very small, $\tan\theta \approx \theta$ and $\ell_2 - \ell_1 = \beta$, the bandwidth, the distance between two consecutive dark bands.

$$\therefore \quad \theta = \frac{t_2 - t_1}{\beta} \quad ---(1)$$

From the condition for the darkness of thin air film interference,

$$2\mu t\cos r = n\lambda, \text{ where } n = 0, 1, 2, 3, \ldots.$$

Here, $\mu = 1$ (air film) and $\cos r = 1$ (normal incidence)

$$2t = n\lambda, \text{ where } n = 0, 1, 2, 3\ldots.$$

Thus for the n[th] dark band, $2t_1 = n\lambda ---(2)$ and the (n+1)[th] dark band, $2t_2 = (n+1)\lambda ---(3)$

Or $2(t_2 - t_1) = (n+1)\lambda - n\lambda = \lambda$ and thus $t_2 - t_1 = \dfrac{\lambda}{2} ---(4)$

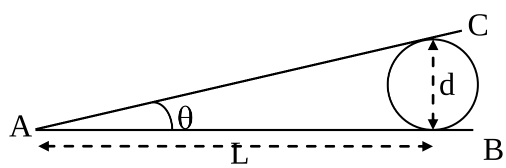
Substituting in eqn(1), we get $\boxed{\theta = \dfrac{\lambda}{2\beta}}$.

If the medium between the glass plates is filled with a medium having a refractive index μ,

then $\boxed{\theta = \dfrac{\lambda}{2\mu\beta}}$.

To find the diameter of a thin wire:

Based on the interference pattern formed



The angle of the wedge, $\theta = \dfrac{\lambda}{2\beta}$.

From the figure, $\theta = \dfrac{d}{L}$, where d is the diameter of the thin wire and L is the distance of the wire from the line of contact of the glass plates.

Then, $\dfrac{d}{L} = \dfrac{\lambda}{2\beta}$ or $\boxed{d = \dfrac{\lambda L}{2\beta}}$

<u>Practical application of an air wedge</u>:

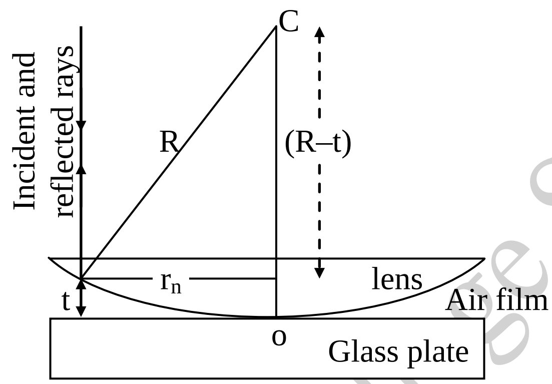
The Optical planeness (flatness) of a surface can be tested by observing the interference fringes obtained using air wedge method. In this method, an air wedge is formed by using the surface to be tested along with a standard optically plane glass plate. An interference pattern is produced by illuminating the system with a monochromatic light incident normally on it. If the fringes formed are straight, parallel and of equal thickness, the given surface is optically plane. If the fringes are irregular and distorted, then the surface is not a plane. The variation of the colour of the fringes also indicates the non-planeness of a surface. This method can be used to check the planeness of a surface up to $\frac{1}{10}^{th}$ of the wavelength of light used.

NEWTON'S RINGS:

Newton's ring arrangement consists of a plano-convex lens of large radius of curvature placed on an optically plane glass plate such that the convex surface is touching the glass plate. An air film of varying thickness is formed between the lens and the glass plate. The thickness of the air film is zero at the point of contact and gradually increases towards the edge of the lens. When a beam of monochromatic light is incident normally on this setup, one part of the light is reflected from the top surface of the air film and another part is reflected from the bottom surface. These two reflected beams interfere constructively or destructively, depending upon their path difference, to produce an interference pattern. As the thickness of the air film is increasing radially, alternate dark and bright rings of increasing radii are observed. These rings are concentric about the central point. As the radius increases (i.e. on moving towards the edge of the lens), the rings become thinner and closer. Since the thickness of the air film is zero at the centre (point of contact), the central spot becomes dark.

Determination of radius of the rings:

Let the radius of the nth ring (bright/dark) is r_n and is formed at a point where the thickness of the film is t.



From the figure, $(R-t)^2 + r_n{}^2 = R^2$, $R^2 - 2Rt + t^2 + r_n{}^2 = R^2$

Since the thickness t is very very small, t^2 is negligible.

$r_n{}^2 = 2Rt \; ----(1)$

Case I: **radius of the nth dark ring**:

From the condition for the darkness of thin air film interference,

$$2\mu t \cos r = n\lambda \text{ , where } n = 0, 1, 2, 3, ...$$

Here, $\mu = 1$ (air film) and $\cos r = 1$ (normal incidence)

$$2t = n\lambda \text{, where } n = 0,1,2,3....$$

Or $r_n{}^2 = Rn\lambda$ and $\boxed{r_n = \sqrt{Rn\lambda}} \; ----(2)$.

Case II: **radius of the nth bright ring**:

For the nth bright ring, $2t = (2n-1)\frac{\lambda}{2}$ Or $r_n{}^2 = R(2n-1)\frac{\lambda}{2}$ and $\boxed{r_n = \sqrt{R(2n-1)\frac{\lambda}{2}}} \; ----(3)$

Determination of wavelength of light:

The radius of the nth dark ring is given by the relation

$r_n{}^2 = Rn\lambda$, $\left(\frac{D_n}{2}\right)^2 = Rn\lambda$ or $D_n{}^2 = 4Rn\lambda \; ---(4)$, where D_n is the diameter of the nth dark ring.

Similarly, for the (n+k)th dark ring, $D_{n+k}{}^2 = 4R(n+k)\lambda \; ---(5)$

$$D_{n+k}^2 - D_n^2 = 4R(n+k)\lambda - 4Rn\lambda = 4Rk\lambda \;---(5)$$

Thus, $$\boxed{\lambda = \frac{D_{n+k}^2 - D_n^2}{4Rk}} \;---(6)$$

Determination of refractive index of a liquid:

Let a liquid of refractive index μ is introduced between the glass plate and the lens. The radius of the n^{th} dark ring becomes

$$r_n^2 = \frac{Rn\lambda}{\mu}, \quad \left(\frac{d_n}{2}\right)^2 = \frac{Rn\lambda}{\mu} \quad \text{or} \quad d_n^2 = \frac{4Rn\lambda}{\mu} \;---(7)$$, where d_n is the diameter of the n^{th} dark ring.

Similarly, for the $(n+k)^{th}$ dark ring, $$d_{n+k}^2 = \frac{4R(n+k)\lambda}{\mu} \;---(8)$$

$$d_{n+k}^2 - d_n^2 = \frac{4R(n+k)\lambda}{\mu} - \frac{4Rn\lambda}{\mu} = \frac{4Rk\lambda}{\mu} \;---(9)$$

For air as medium, we got $D_{n+k}^2 - D_n^2 = 4Rk\lambda \;---(10)$

Eqn(10)/(9) $$\frac{D_{n+k}^2 - D_n^2}{d_{n+k}^2 - d_n^2} = \frac{4Rk\lambda}{\frac{4Rk\lambda}{\mu}} = \mu$$ Thus, $$\boxed{\mu = \frac{D_{n+k}^2 - D_n^2}{d_{n+k}^2 - d_n^2}} \;---(11)$$

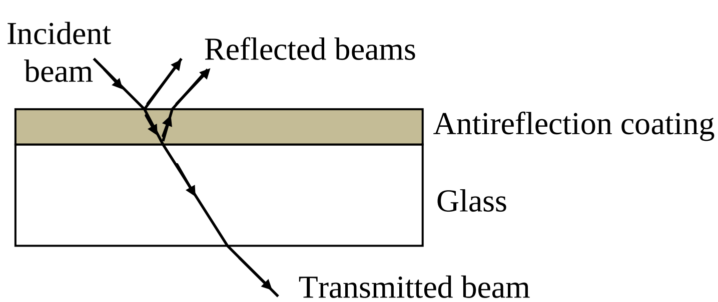
Note:

(1) In the interference pattern formed by reflected light the central spot becomes dark. The path difference between the reflected components from an air film is given $\delta = 2\mu t\cos r + \frac{\lambda}{2}$. As the thickness of the air film is zero at the centre (point of contact), the path difference between the reflected rays become $\frac{\lambda}{2}$ ($2\mu t\cos r = 0$) and it is the condition for destructive interference or dark band.

(2) In the interference pattern formed by transmitted light the central spot becomes bright.

<u>**Antireflection coating (non-reflecting coating)**</u>:

A thin transparent dielectric film coated on the surface of optical devices such as prisms, lenses, etc to suppress (reduce) surface reflections is called anti-reflection coating. It is an application of thin-film interference of reflected light. *In many optical instruments like telescopes, cameras, rangefinders, periscopes, etc. the incident light has to undergo reflections from many glass surfaces. This produces a considerable loss in the intensity of transmitted light. These reflection losses can be reduced by coating the glass surface with a suitable transparent dielectric material*. **The refractive index of the coating used is intermediate between air and glass**. The materials often used are calcium fluoride, magnesium fluoride, cryolite, etc and the process of such coating is known as blooming.



Incident light is reflected from the upper and lower surfaces of the film. Since both the rays are reflected under similar conditions (rarer to denser), the same path change $\frac{\lambda}{2}$ occurs in both reflection cases. Thus path difference between the reflected components becomes $\delta = 2\mu t \cos r$. If the thickness of the film is such that both the reflected rays are in opposite phase, they will cancel each other due to destructive interference. The intensity of the reflected light becomes zero (minimum) for wavelength λ satisfying the condition

$$\delta = 2\mu t \cos r = (2n-1)\frac{\lambda}{2}, \quad \text{where } n = 1,2,3.... \text{ (condition for destructive interference) .}$$

For normal incidence $\cos r = 1,\ 2\mu t = (2n-1)\frac{\lambda}{2}$ and

$2\mu t_{min} = \frac{\lambda}{2}$, where t_{min} is the minimum thickness of the film required. Then $\boxed{t_{min} = \frac{\lambda}{4\mu}}$

The above equation also shows that the minimum optical thickness of the anti-reflection coating should be one-quarter of a wavelength (optical thickness, $\mu t_{min} = \frac{\lambda}{4}$). *Any odd multiple of* $\frac{\lambda}{4\mu}$ *can also produce this type of destructive interference but as thickness increases the reflection of adjacent wavelengths also increases and hence the minimum thickness is always preferred. The above condition suggests that the thickness is suitable only for a particular wavelength. Hence the wavelength is selected from the yellow-green portion of the visible spectrum where the eye is most sensitive. Much wider coverage across the spectrum is possible with multiple coating, called multilayers. In practice, a three-layer coating is widely used and is highly effective over most of the visible spectrum.*

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