PHYSICS

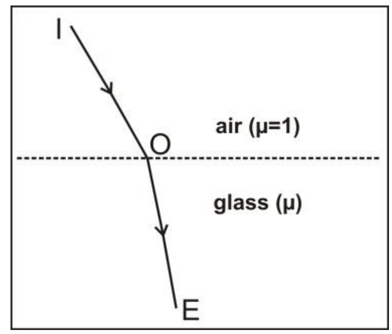
UNIT - 1

Chapter 1 : INTERFERENCE OF LIGHT

Geometric path (L) and Optical path (Δ)

The shortest physical distance between two points between which light travels is known as the geometric path (L). The geometric path is independent of the medium in which light travels.

Since light travels in different media with different velocities, the optical path travelled by light between two points will be different for different media.



Optical path = Geometric path x refractive index of medium

i.e. $\Delta = \mu L$

Eg: Geometric path from I to E, L = IO + OE

Optical path from I to E, $\Delta = \mu_{air} \times IO + \mu_{glass} \times OE$

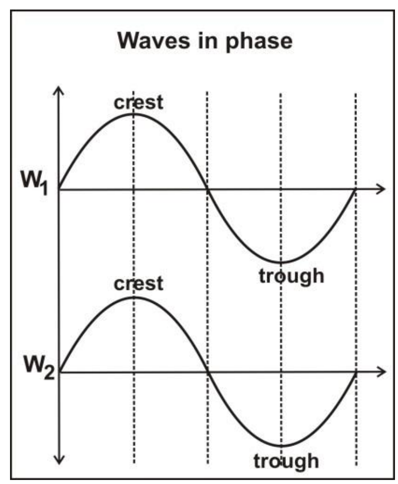
$= IO + \mu \cdot OE$ (since $\mu_{air} = 1$)

Optical Path difference (Δ)

The optical path difference between two rays of light is the difference in the optical paths travelled by the two rays.

Phase difference (δ)

The relative difference in phase of two waves is called the phase difference between them.



Waves completely in phase

Two waves are said to completely in phase with each other when the crests and troughs of one wave come exactly over the crests and troughs of the other wave.

For two waves to be in phase, the phase difference between them must be zero or even integral multiple of π.

i.e. **for waves in phase, $\delta = 2n\pi$** eqn.1

where n = 0, 1, 2, 3……

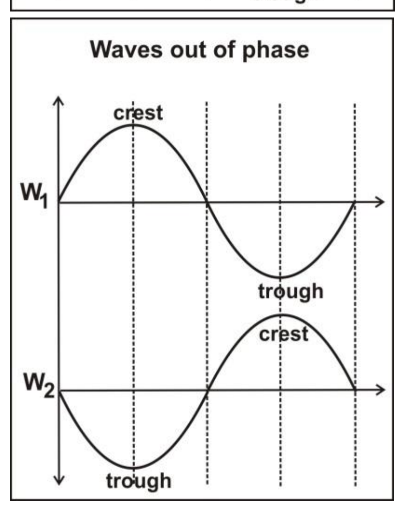
Waves completely out of phase

Two waves are said to completely out of phase with each other when the crest of one wave comes exactly over the trough of the other wave and vice versa.

For two waves to be out of phase, the phase difference between them must be an odd integral multiple of π.

i.e. **for waves out of phase, $\delta = (2n+1)\pi$** eqn.2

where n = 0, 1, 2, 3……



Relation between phase difference (δ) and path difference (Δ)

$$\delta = \frac{2\pi}{\lambda}\Delta \qquad ......eqn.3$$

where λ = wavelength of light

Using the values of δ from eqn.1 & eqn.2 in eqn.3 we get,

For waves in phase, $\Delta = n\lambda$ **where n = 0, 1, 2, 3……**

i.e. the path difference between them is an integral multiple of the wavelength.

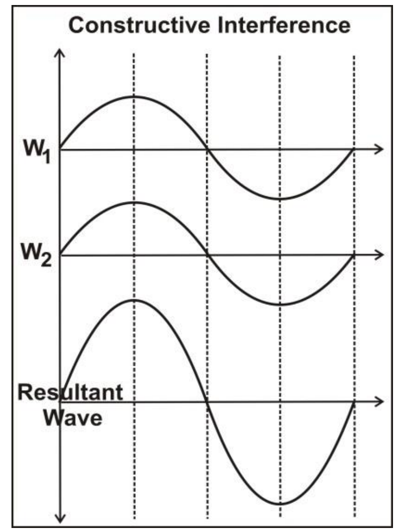
Similarly, **for waves out of phase, Δ = (2n+1) λ/2** **where n = 0, 1, 2, 3……**
i.e. the path difference between is an odd integral multiple of half wavelength.

Change of phase on reflection

When a light wave is reflected at the surface of an optically denser medium, it suffers a phase change of π or a path change of λ/2.

Interference of light

When two light waves superimpose then the resultant amplitude or intensity in the region of superposition in different from the amplitude of the individual waves. This modification in the amplitude in the region of superposition is called interference of light.

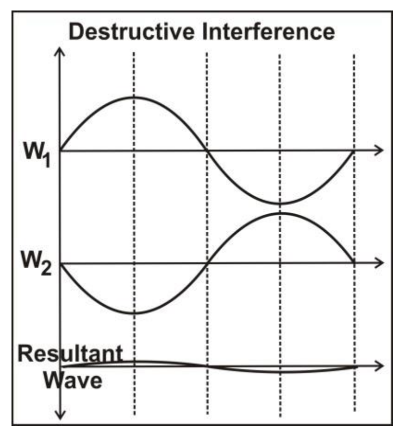


a) Constructive Interference

When the two waves arrive at a point in phase, the amplitudes add up to get larger amplitude (**bright spot or maxima**). This is called constructive interference.

Thus for constructive interference, waves must be in phase.

i.e. **Phase difference, δ = 2nπ OR**
Path difference, Δ = n λ
where n = 0, 1, 2, 3……



b) Destructive Interference

When the two waves arrive at a point out of phase, the amplitudes cancel each other to get zero or almost zero amplitude (**dark spot or minima**). This is called destructive interference.

Thus for destructive interference, waves must be out of phase.

i.e. **Phase difference, δ = (2n+1)π OR**
Path difference, Δ = (2n+1) λ/2
where n = 0, 1, 2, 3……

Condition to get Steady Interference Pattern

To get a steady interference pattern (pattern which does not change with time), the two interfering sources of light must be coherent. i.e. the phase difference or path difference between them must remain constant.

Note: Two separate sources of light cannot be coherent, since, they being independent of each other, changes taking place in one source may not simultaneously take place in the other source. Hence the phase or path difference between them will not remain constant.

Coherent sources can be obtained by spitting a single source into two or more sources. This can be done by various methods.

Types of Interference

Depending upon the method by which coherent sources are obtained, interference is classified into two categories: (i) Interference by division of wavefront, and (ii) Interference by division of amplitude

(i) Interference by division of wave front

Here the wave is physically divided into two coherent sources by the use of a double slit, a mirror, or a biprism.

A narrow or point source is required for this method, hence, the interference pattern is not bright.

Eg: Young's Double Slit, Lloyd's Mirror, Fresnel's Biprism

(ii) Interference by division of amplitude

Here the amplitude of the incoming beam is divided into two parts either by parallel reflection or parallel refraction using thin films.

A broad light source can be used resulting in a brighter interference pattern.

Eg: Newton's Rings, Interference in Thin Air Wedge, Michelson's Interferometer.

Thin Films

A film is said to be thin when its thickness is of the order of the wavelength of visible light (about 5500 Å)

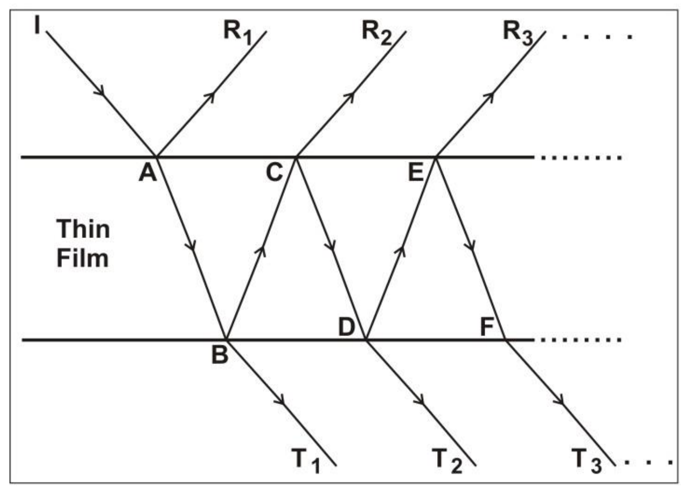
Eg: i) a thin sheet of transparent material like glass, mica

ii) an air film enclosed between two transparent sheets

iii) soap bubble

iv) oil slick on water

Interference based on division of amplitude (using thin films)



When light is incident on a thin film, a small part of it gets reflected along AR_1 from the upper surface, and a major portion gets transmitted into the film along AB. Again, a small part of the transmitted component AB is reflected back into the film along BC by the lower surface of the film, and the rest of it emerges out of the film along BT_1. A small portion of the light thus gets partially reflected several times within the film giving rise to a set of rays R1, R2, R3,…. on the upper side of the film (called as reflected rays), and a set of rays T1, T2, T3,……. on the lower side of the film (called as transmitted rays) as shown in the figure. All these rays are coherent, since they are all derived from the single ray IA. At each reflection, the incident amplitude is divided into a reflected component and a transmitted component. Hence interference produced by this method using thin films is called interference by division of amplitude.

Interference in Parallel Thin Film (due to reflected light)

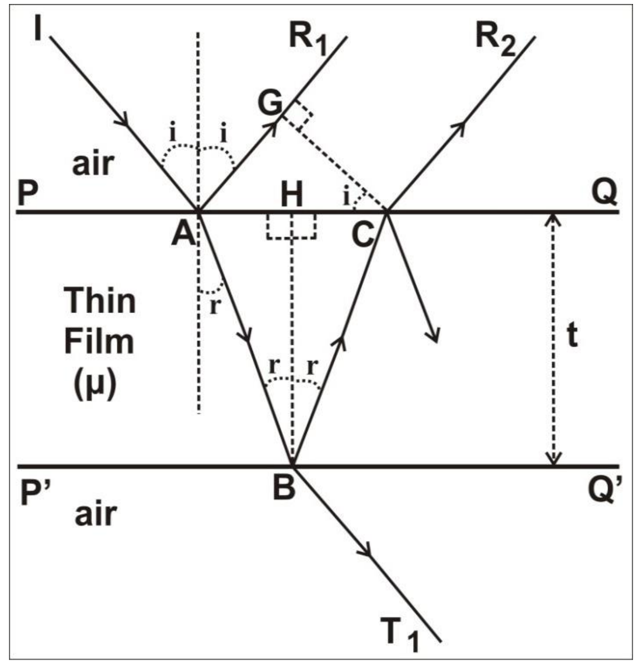
Let PQ and P'Q' be the two surfaces of a transparent thin film of uniform thickness 't' and refractive index μ. Let the film be surrounded by air on both sides. Consider a ray IA of monochromatic light of wavelength λ incident on the top surface of the film at point A making an angle of incidence 'i' with the normal. The ray is partly reflected along AR_1 and partly transmitted into the film along AB making an angle of refraction 'r' with the normal. The ray AB is again partly reflected and transmitted several times within the film giving rise to reflected rays R_1 and R_2 as shown in the figure. The rays R_1 and R_2 are parallel and coherent. Thus they will produce steady interference pattern if they are made to converge using a lens or eye.

The optical path difference between the rays R_1 and R_2 is:

Δ = (AB + BC) in film – AG in air

$= \mu\,(AB + BC) - (AG + \lambda/2)$ …….eqn.1

The additional factor λ/2 is to take into account the phase change π (or path change λ/2) of the ray R_1 due to reflection at a denser surface at point A.



ΔAHB is congruent to ΔCHB (ASA rule)

$\Rightarrow AB = BC$

$\Rightarrow AB + BC = 2AB$ eqn.2

From ΔAHB, we have

$\cos r = \frac{HB}{AB}$

$\Rightarrow AB = \frac{HB}{\cos r} = \frac{t}{cos r}$ eqn.3

Substituting eqn. 3 in eqn. 2 we get,

$AB + BC = 2AB = \frac{2t}{\cos r}$ eqn.4

From ΔAGC,

$\sin i = \frac{AG}{AC}$

$\Rightarrow AG = AC \sin i$ eqn.5

Since ΔAHB is congruent to ΔCHB,

$AH = HC$

Therefore, $AC = AH + HC = 2AH$ eqn.6

From ΔAHB,

$\tan r = \frac{AH}{HB}$

$\Rightarrow AH = HB \tan r = t \tan r$ eqn.7

Substituting eqn. 7 in eqn. 6 we get,

$AC = 2\, t \tan r$ eqn.8

Substituting eqn. 8 in eqn. 5 we get,

$AG = 2\, t \tan r \, sin i$ eqn.9

From Snell's Law,

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

$\Rightarrow \sin i = \mu \sin r$ eqn.10

Substituting eqn. 10 in eqn. 9 we get

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

$= 2\, \mu\, t\, \frac{sin^2 r}{cos r}$ eqn.11

Substituting eqn.4 and eqn.11 in eqn.1 we get,

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

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

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

Thus we have path difference between the rays R_1 and R_2 is:

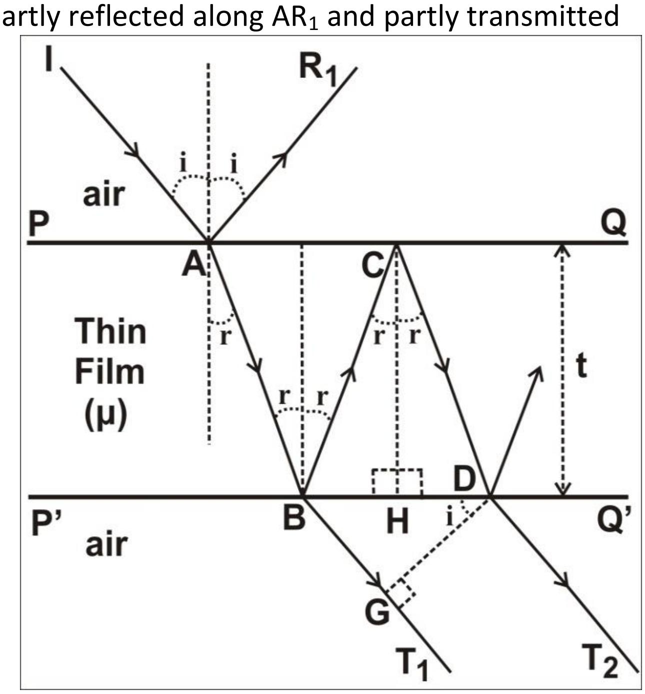
$\Delta = 2\,\mu\,t\cos r - \frac{\lambda}{2}$ eqn.12

<u>Condition for maxima (brightness)</u>
If the optical path difference is an integral multiple of full wavelength then the two rays BC and DE undergo constructive interference.
i.e for constructive interference (maxima), $\Delta = n\lambda$ n = 0, 1, 2......
Using this in eqn.5 and simplifying we get,
$2\,\mu\,t\cos r = (2n+1)\frac{\lambda}{2}$ ....Condition for maxima in parallel thin film due to reflected light
n = 0,1,2.......

<u>Condition for minima (darkness)</u>
If the optical path difference is an odd integral multiple of half wavelength then the two rays BC and DE undergo destructive interference.
i.e for destructive interference (minima), $\Delta = (2n+1)\,\lambda/2$ n = 0, 1, 2......
Using this in eqn.5 and simplifying we get,
$2\,\mu\,t\cos r = (n+1)\,\lambda$

If n is an integer, n+1 is also an integer. Thus replacing n+1 with n we get
$2\,\mu\,t\cos r = n\,\lambda$ ....Condition for minima in parallel thin film due to reflected light
n = 0,1,2.......

<u>Interference in Parallel Thin Film (due to transmitted light)</u>
Let PQ and P'Q' be the two surfaces of a transparent thin film of uniform thickness 't' and refractive index μ. Let the film be surrounded by air on both sides. Consider a ray IA of monochromatic light of wavelength λ incident on the top surface of the film at point A making an angle of incidence 'i' with the normal. The ray is partly reflected along AR_1 and partly transmitted into the film along AB making an angle of refraction 'r' with the normal. The ray AB is again partly reflected and transmitted several times within the film giving rise to transmitted rays T_1 and T_2 as shown in the figure. The rays T_1 and T_2 are parallel and coherent. Thus they will produce steady interference pattern if they are made to converge using a lens or eye.



The optical path difference between the rays T_1 and T_2 is:
Δ = (BC + CD) in film – BG in air

= μ (BC + CD) – BG eqn.1

[Here there is no additional factor λ/2 because the ray T_2 arises from reflection at point B aand C at a rarer medium.]
ΔBHC is congruent to ΔDHC (ASA rule)

$\Rightarrow BC = CD$

$\Rightarrow BC + CD = 2BC$ eqn.2

From ΔBHC, we have
$\cos r = \frac{HC}{BC}$

$\Rightarrow BC = \frac{HC}{\cos r} = \frac{t}{\cos r}$ eqn.3

Substituting eqn. 3 in eqn. 2 we get,

$BC + CD = 2BC = \frac{2t}{\cos r}$ eqn.4

From ΔBGD,

$\sin i = \frac{BG}{BD}$

$\Rightarrow BG = BD \sin i$ eqn.5

Since ΔBHC is congruent to ΔDHC,

$BH = HD$

Therefore, $BD = BH + HD = 2BH$ eqn.6

From ΔBHC,

$\tan r = \frac{BH}{HC}$

$\Rightarrow BH = HC \tan r = t \tan r$ eqn.7

Substituting eqn. 7 in eqn. 6 we get,

$BD = 2\, t \tan r$ eqn.8

Substituting eqn. 8 in eqn. 5 we get,

$BG = 2\, t \tan r\, sini$ eqn.9

From Snell's Law,

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

$\Rightarrow \sin i = \mu \sin r$ eqn.10

Substituting eqn. 10 in eqn. 9 we get

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

$$= 2\, \mu\, t\, \frac{sin^2 r}{cosr}$$ eqn.11

Substituting eqn.4 and eqn.11 in eqn.1 we get,

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

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

$$= 2\, \mu\, t \cos r$$ eqn.12

At point B and C, the reflection occurs at an optically rarer medium (air), hence, there is no phase change of π.

Therefore, the correct expression for path difference is:

$\Delta = 2\, \mu\, t \cos r$ eqn.12

<u>Condition for maxima (brightness)</u>

If the optical path difference is an integral multiple of full wavelength then the two rays CT_1 and ET_2 undergo constructive interference.

i.e for constructive interference (maxima), Δ = nλ n = 0, 1, 2......

Using this in eqn.12 we get,

$2\, \mu\, t \cos r = n\, \lambda$ ....Condition for maxima in thin film due to transmitted light n = 0,1,2…….

Condition for minima (darkness)

If the optical path difference is an odd integral multiple of half wavelength then the two rays CT_1 and ET_2 undergo destructive interference.

i.e for destructive interference (minima), $\Delta = (2n+1)\,\lambda/2$ n = 0, 1, 2……

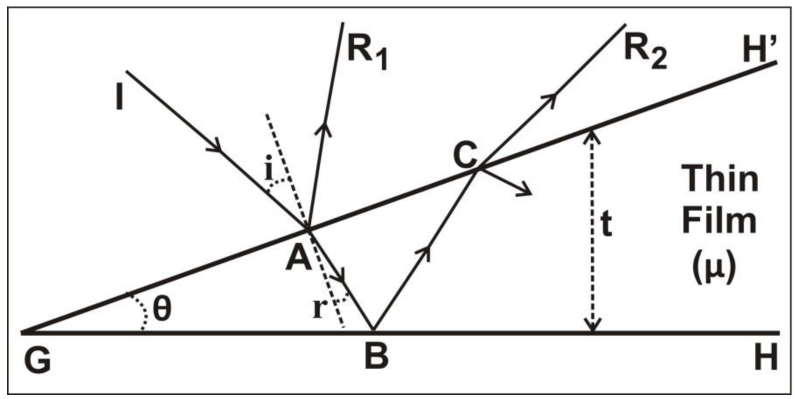
Using this in eqn.12 we get,

$2\,\mu\,t\cos r = (2n+1)\frac{\lambda}{2}$ ………Condition for minima in thin film due to transmitted light

n = 0,1,2…….

Interference in Wedge-shaped Film

Consider two plane surfaces GH and GH' inclined at an angle θ and enclosing a wedge-shaped film of refractive index μ. The thickness of the film is zero at G and keeps on increasing towards H.



A ray IA of monochromatic light of wavelength λ incident at point A partly undergoes reflection at the top surface of the film along AR_1 and partly gets transmitted along AB to be reflected again along BC and finally coming out along CR_2.

The two rays R_1 and R_2 are coherent and therefore on interference they will produce a steady interference pattern depending upon the path difference between them.

Applying the theory of thin film interference for reflected light, we know that the rays R_1 and R_2 will interfere destructively and produce a minima when,

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

where t is the thickness of the film,
r is the angle of refraction, and
n = 0,1,2,3…….

Similarly, the rays R_1 and R_2 will interfere constructively and produce a maxima when,

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

For normal incidence, i = r = 0 and cos r =1

Thus we have,

$2\,\mu\,t = n\lambda$ ……for minimas, and

$2\,\mu\,t = (2n+1)\frac{\lambda}{2}$ ……for maximas

Position of Minimas (Dark)

Putting n = 0,1,2,3,…… in the minima condition will give the position of minimas in the wedge-shaped film.

When n = 0, $t = 0$

n = 1, $t = \frac{\lambda}{2\mu}$

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

……..and so on…

Position of Maximas (Bright)

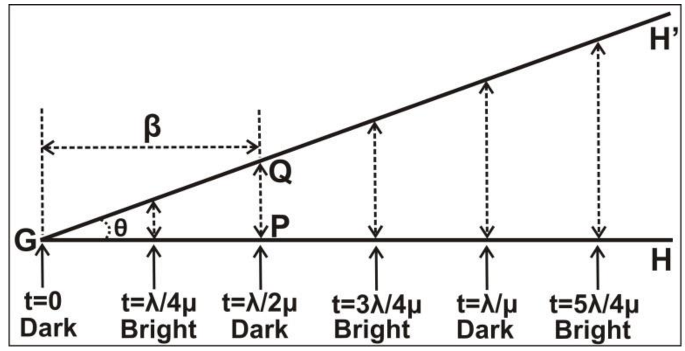
Putting n = 0,1,2,3,…… in the maxima condition will give the position of maximas in the wedge-shaped film.

When n = 0, $t = \frac{\lambda}{4\mu}$

n = 1, $t = \frac{3\lambda}{4\mu}$

n = 2, $t = \frac{5\lambda}{4\mu}$

……..and so on…



The positions of the minimas and maximas are shown in the figure.

Since the thickness 't' of the film remains constant in a direction parallel to the contact edge of the wedge, equidistant alternate dark and bright fringes are obtained along the length of the film as shown in the figure.

Expression for Fringe Width (β)

The distance between any two consecutive dark or bright fringes is called the fringe width.

From the figure, we have

$$tan\theta = \frac{PQ}{GP}$$

$$= \frac{\lambda/2\mu}{\beta}$$

Thus, $\beta = \frac{\lambda}{2\ \mu\ tan\theta}$

For small values of θ, $tan\theta \approx \theta$

Thus, $\beta = \frac{\lambda}{2\ \mu\ \theta}$ …….expression for fringe width

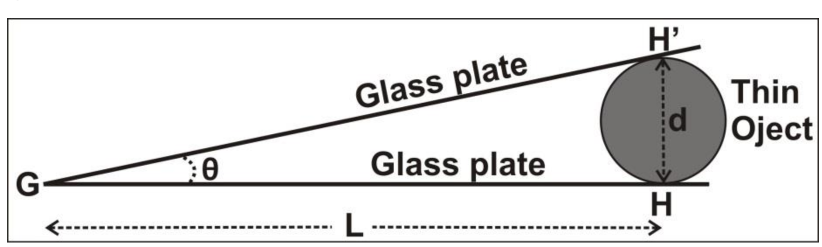
For air film, μ = 1,

Thus, $\beta = \frac{\lambda}{2\theta}$ …….expression for fringe width for air film

To find thickness of small object using wedge-shaped film

If the wedge is formed by placing a thin object (like a hair) of thickness 'd' between the two plane glass plates as shown in the figure, then

$$tan\theta = \frac{HH'}{GH} = \frac{d}{L}$$



where L is the length of the wedge.

For small object, θ is small,

and $tan\theta \approx \theta$

Hence we have, $\theta = \frac{d}{L}$

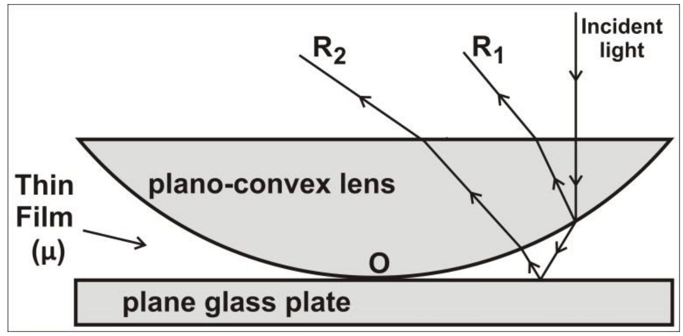
Using this in the expression for fringe width, we get

$$\beta = \frac{\lambda}{2{\cdot}d/L}$$

$$\Rightarrow d = \frac{\lambda L}{2\beta}$$

Thus by measuring the fringe width (β) and the length of the wedge (L), and by knowing the wavelength (λ) of the light used, the thickness (d) of the very small object can be found.

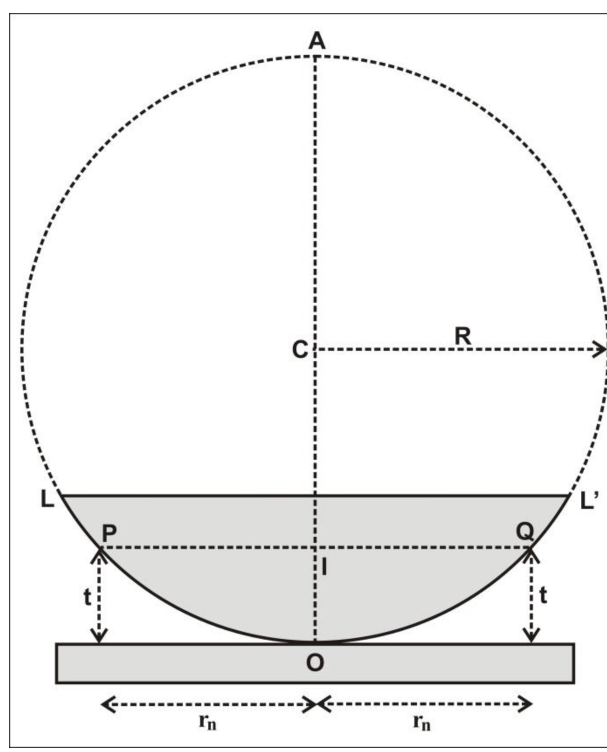
Newton's Rings



When a plano-convex lens is placed, with its convex surface facing downwards, on a plane glass-plate, a thin film (of refractive index μ) is formed between the two as shown in the figure. The thickness of the film is zero at the point of contact O, and keeps on increasing radially outwards.
If monochromatic light is allowed to fall normally onto the film the light reflected from it is viewed using a microscope, alternate dark and bright concentric rings with the point of contact O as the centre are seen. These are the Newton's Rings.

Theory (How Newton's Rings are formed)
Newton's Rings are formed due to interference between the rays R_1 and R_2 reflected from the top and bottom surfaces of the air film as shown in the figure.
In this system of lens and glass plate, the thickness 't' of the air film remains constant along a circle with centre as the point of contact. Thus as we go from centre (point of contact) outwards, alternate dark and bright rings will be formed depending upon whether the rays R_1 and R_2 interfere constructively or destructively.

Calculation of Diameter of the Rings



Let 'R' be the radius of curvature of the plano-convex lens and 'r_n' be the radius of the n^{th} ring (dark or bright).
From the figure, by using the Theorem of Intersecting Chords for the chords AO and PQ, we have

$$PI \times IQ = AI \times IO$$

$$r_n \times r_n = (2R - t) \times t \qquad \text{(since AI = AO – IO)}$$

where 't' is the thickness of the air film at the position of the n^{th} ring.

Thus, $r_n^2 = 2\,R\,t - t^2$

As the film is thin, the thickness t is very small. Thus the term t^2 can be neglected.

Thus we have, $r_n^2 = 2\,R\,t$ ……….eqn.1

We have, $r_n = \frac{D_n}{2}$

where D_n is the diameter of the n^{th} ring

Thus, $r_n^2 = \frac{D_n^2}{4}$ ……..eqn.2

Substituting eqn.2 in eqn.1, we get

$D_n^2 = 8\,R\,t$ eqn.3

The above equation gives the diameter of the n^th dark or bright Newton's Ring.

A) Newton's Rings due to reflected light

Applying the theory of interference in thin films for reflected light, we know that the rays R_1 and R_2 will interfere constructively to produce maximas when:

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

and interfere destructively to produce mimimas when:

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

where μ is the refractive index of the film
t is the thickness of the film
r is the angle of refraction
n = 0,1,2,........

For normal incidence, i = r = 0, and cos r = 1. Thus we have,

$2\,\mu\,t = (2n+1)\frac{\lambda}{2}$ ....for maximas

$2\,\mu\,t = n\,\lambda$ ....for minimas

a) Dark Rings

From condition for minimas we have,

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

Substituting this in eqn.3 we get,

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

$\Rightarrow \quad D_n^2 = \frac{4\,n\,\lambda\,R}{\mu}$ ....for dark rings due to reflected light

$\Rightarrow \quad D_n = 2\sqrt{\frac{\lambda\,R}{\mu}} \cdot \sqrt{n}$

$\Rightarrow \quad D_n \propto \sqrt{n}$ (since $2\sqrt{\frac{\lambda\,R}{\mu}}$ is a constant)

Thus, the diameters of dark rings due to reflected light are directly proportional to the square root of natural numbers.

b) Bright rings

From condition for maximas we have,

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

Substituting this in eqn.3 we get,

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

$\Rightarrow \quad D_n^2 = \frac{2\,(2n+1)\,\lambda\,R}{\mu}$ ....for bright rings due to reflected light

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

$\Rightarrow \quad D_n \propto \sqrt{(2n+1)}$ (since $\sqrt{\frac{2\,\lambda\,R}{\mu}}$ is a constant)

Thus, the diameters of bright rings due to reflected light are directly proportional to the square root of odd natural numbers.

Note: In the formula for diameter of dark rings, if we put n = 0, we get, $D_n = 0$. Thus in the **Newton's Rings due to reflected light**, the **centre is dark**.

Also, **for the p^{th} dark ring, n = p.**

For the p^{th} bright ring, n = p – 1

B) Newton's Rings due to transmitted light

Applying the theory of interference in thin films for reflected light, we know that the rays R_1 and R_2 will interfere constructively to produce maximas when:

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

and interfere destructively to produce mimimas when:

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

where μ is the refractive index of the film

t is the thickness of the film

r is the angle of refraction

n = 0,1,2,……..

For normal incidence, i = r = 0, and cos r = 1. Thus we have,

$$2\,\mu\,t = n\,\lambda \qquad \text{..........for maximas}$$

$$2\,\mu\,t = (2n+1)\frac{\lambda}{2} \qquad \text{..........for minimas}$$

a) Dark Rings

From condition for minimas we have,

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

Substituting this in eqn.3 we get,

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

$$\Rightarrow \quad D_n^2 = \frac{2\,(2n+1)\,\lambda\,R}{\mu} \qquad \text{...........for dark rings due to transmitted light}$$

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

$$\Rightarrow \quad D_n \propto \sqrt{(2n+1)} \qquad \left(\text{since } \sqrt{\frac{2\,\lambda\,R}{\mu}} \text{ is a constant}\right)$$

Thus, the diameters of dark rings due to transmitted light are directly proportional to the square root of odd natural numbers.

b) Bright rings

From condition for maximas we have,

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

Substituting this in eqn.3 we get,

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

$$\Rightarrow \quad D_n^2 = \frac{4\,n\,\lambda\,R}{\mu} \qquad \text{..........for bright rings due to transmitted light}$$

$$\Rightarrow \quad D_n = 2\sqrt{\frac{\lambda R}{\mu}} \cdot \sqrt{n}$$

$$\Rightarrow \quad D_n \propto \sqrt{n} \qquad \text{(since } 2\sqrt{\frac{\lambda R}{\mu}} \text{ is a constant)}$$

Thus, the diameters of bright rings due to transmitted light are directly proportional to the square root of natural numbers.

Note: In the formula for diameter of bright rings, if we put n = 0, we get, D_n = 0. Thus **in the Newton's Rings due to transmitted light, the centre is bright.**

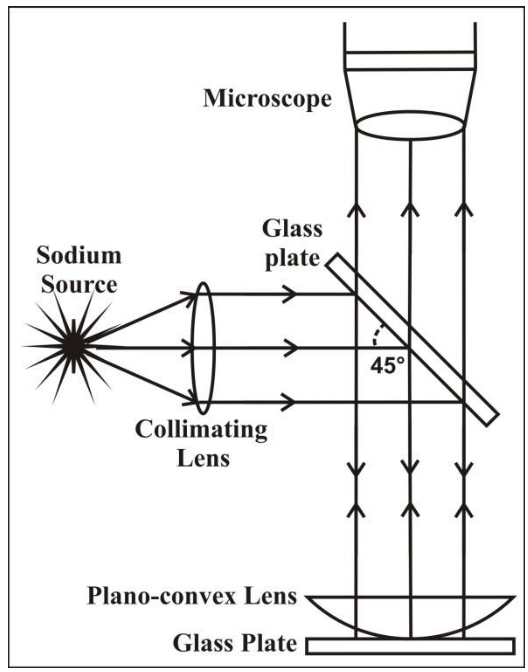
Also, **for the pth dark ring, n = p – 1**

For the pth bright ring, n = p

Applications of Newton's Rings

i) Determination of wavelength of monochromatic light using Newton's Rings

Let 'R' be the radius of curvature of the plano-convex lens, 'λ' be the wavelength of light used and D_n and D_{n+p} be the diameters of the nth and (n+p)th dark rings respectively for the reflected light system.



Then for air film (μ = 1) we have,

$$D_n^2 = 4\,n\,\lambda\,R \qquad \text{.....eqn.1}$$

and, $$D_{n+p}^2 = 4\,(n+p)\,\lambda\,R \qquad \text{.....eqn.2}$$

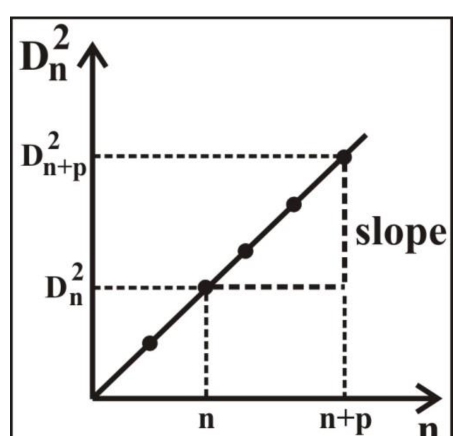
Subtracting eqn.1 from eqn.2 we get,

$$D_{n+p}^2 - D_n^2 = 4\,p\,\lambda\,R$$

$$\Rightarrow \quad \lambda = \frac{D_{n+p}^2 - D_n^2}{4\,p\,R} \qquad \text{.....eqn.3}$$

Thus, using this formula, the wavelength 'λ' of monochromatic light can be found.

In practice, the diameters of successive dark rings are measured using a travelling microscope and a graph of D_n^2 versus ring number 'n' is plotted as shown in the figure.



The slope of this graph gives,

$$slope = \frac{D_{n+p}^2 - D_n^2}{(n+p)-n} = \frac{D_{n+p}^2 - D_n^2}{p}$$

Using this in eqn.3 we get,

$$\lambda = \frac{slope}{4\,R}$$

ii) Determination of radius of curvature of plano-convex lens using Newton's Rings

Let 'R' be the radius of curvature of the plano-convex lens, 'λ' be the wavelength of light used and D_n and D_{n+p} be the diameters of the nth and (n+p)th dark rings respectively for the reflected light system.

Then for air film (μ = 1) we have,

$$D_n^2 = 4\,n\,\lambda\,R \qquad \text{.....eqn.1}$$

and, $$D_{n+p}^2 = 4\,(n+p)\,\lambda\,R \qquad \text{.....eqn.2}$$

Subtracting eqn.1 from eqn.2 we get,

$$D_{n+p}^2 - D_n^2 = 4\,p\,\lambda\,R$$

$$\Rightarrow \quad R = \frac{D_{n+p}^2 - D_n^2}{4\,p\,\lambda} \qquad \text{.....eqn.3}$$

Thus, using this formula, the radius of curvature 'R' of the plano-convex lens can be found.
In practice, the diameters of successive dark rings are measured using a travelling microscope and a graph of D_n^2 versus ring number 'n' is plotted as shown in the figure.
The slope of this graph gives,

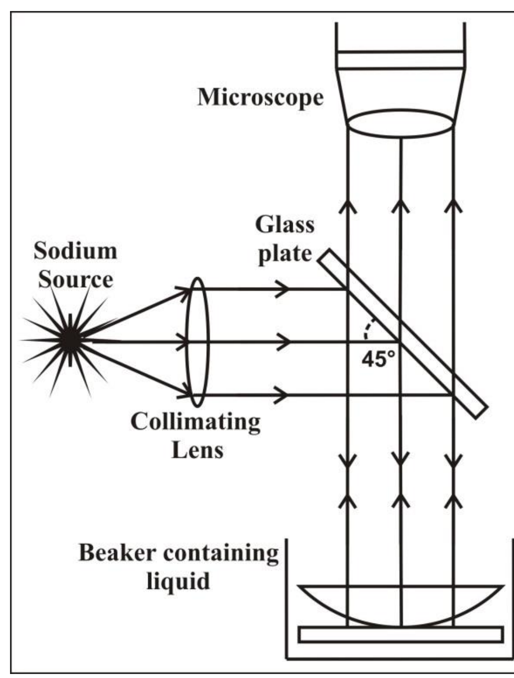
$$slope = \frac{D_{n+p}^2 - D_n^2}{(n+p)-n} = \frac{D_{n+p}^2 - D_n^2}{p}$$

Using this in eqn.3 we get,

$$R = \frac{slope}{4\,\lambda}$$

{Note: Above diagrams (ray diagram & graph) are common for applcations (i) and (ii)}

iii) Determination of Refractive Index of a liquid using Newton's Rings



Let 'R' be the radius of curvature of the plano-convex lens, 'λ' be the wavelength of light used, and 'μ' be the refractive index of the liquid.
First, the experiment is performed when there is air film between the plano-convex lens and the glass plate.
Let D_n and D_{n+p} be the diameters of the nth and (n+p)th dark rings respectively for the reflected light system. Then for air film (μ = 1), we have,

$$D_n^2 = 4\,n\,\lambda\,R \qquad \text{.....eqn.1}$$

and, $$D_{n+p}^2 = 4\,(n+p)\,\lambda\,R \qquad \text{.....eqn.2}$$

Subtracting eqn.1 from eqn.2 we get,

$$D_{n+p}^2 - D_n^2 = 4\,p\,\lambda\,R \qquad \text{.....eqn.3}$$

Next, the lens and glass plate system are placed in a container and the liquid whose refractive index is to be found is poured into it so that there is a liquid film between the lens and glass plate.
The Newton's Rings pattern will remain the same, except that the diameters of the rings will be smaller.
Let D_n' and D_{n+p}' be the diameters of the nth and (n+p)th dark rings respectively for the reflected light system.
Then we have,

$$D_n'^{\,2} = \frac{4\,n\,\lambda\,R}{\mu} \qquad \text{.....eqn.4}$$

and, $$D_{n+p}'^{\,2} = \frac{4\,(n+p)\,\lambda\,R}{\mu} \qquad \text{.....eqn.5}$$

Subtracting eqn.4 from eqn.5 we get,

$$D_{n+p}'^{\,2} - D_n'^{\,2} = \frac{4\,p\,\lambda\,R}{\mu} \qquad \text{.....eqn.6}$$

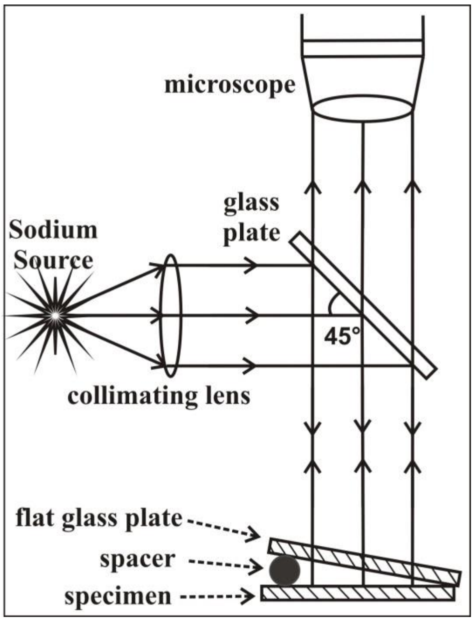
Dividing eqn.3 by eqn.6 we get,

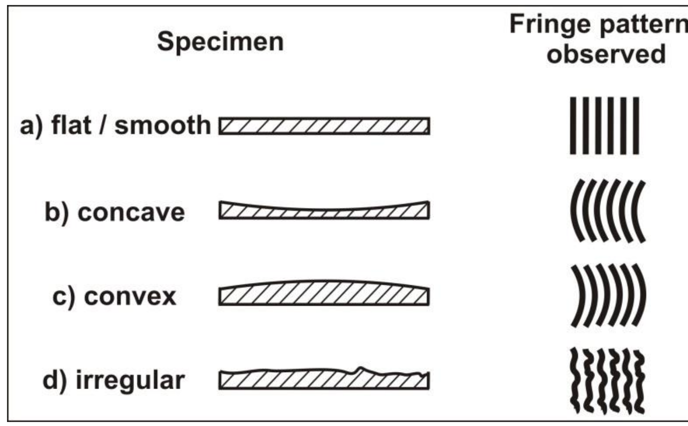
$$\mu = \frac{D_{n+p}^2 - D_n^2}{{D'_{n+p}}^2 - {D'_n}^2}$$

Using this formula, the refractive index of the liquid can be found.

Applications of Interference

i) Optical Flatness/Smoothness: Testing of surface finish





The smoothness/flatness of a surface can be inspected using interference in wedge-shaped film. For this, an optically flat glass plate is kept on the specimen whose smoothness is to be tested. A thin spacer is placed between the two so that an air film is formed between them. The system is illuminated using a monochromatic light, and the fringe pattern formed is viewed using a microscope.

If the specimen is perfectly smooth (flat), then straight and equidistant fringes are seen (fig. a). If the fringes are curved towards the contact edge, then the surface is concave (fig. b). If the fringes are curved away from the contact edge, the surface is convex (fig. c). If the surface is irregular, then an irregular fringe pattern is observed (fig. d).

Thus by observing the fringe pattern, the smoothness of the surface can be verified.

Some questions from previous year's papers (not covered above)

- Explain the importance of an extended source of light while observing interference in thin films.

Ans: Light from a point source is incident on different parts of the film at different angles of incidence (fig. a). This gives rises to different pairs of parallel rays which are oriented at different angles. Thus in order to view different parts of the film, the orientation of the eye will have to be constantly changed as shown in fig. a.

An extended source can be thought to be made up of large number of point sources S_1, S_2, S_3… (fig. b). Light from an extended source illuminates different parts of the film at the same angle of incidence, giving rise to pairs of rays which are all oriented at the same angle. Thus by placing the eye at a single suitable position, the entire film can be viewed.

Thus an extended source is used for viewing thin films.

- Explain the appearance of colours in thin films when illuminated by an extended source of light.

Ans: In parallel thin films, using reflected light, the condition for constructive interference (maxima) is:

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

When an extended source is used, refractive index of the film μ, thickness of the film t, and angle of refraction r, are constants.

Thus if an extended source of white light is incident on the film, the optical path difference will vary from one colour to another, because λ is different for different colours. Accordingly, the film will appear to be coloured, the colour at any point being that of the rays which satisfy the above eqn.1. Also the colour of the film will change as the inclination of the film is changed (in this case angle of refraction r will change).

- Show that the interference patterns due to reflected and transmitted light are complementary to each other.

In reflected light system, the condition for maxima is:

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

and condition for minima is:

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

In transmitted light system, the condition for maxima is:

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

and the condition for minima is:

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

It can be seen that, the condition for maxima in reflected light is the condition for minima in transmitted light and vice versa. That is, what appears as bright in reflected light appears as dark in transmitted light and vice versa. **Therefore the reflected and transmitted light interference patterns are said to be complimentary to each other.**