Physics (PH- 1007)

Interference due to division of amplitude

:- Newton's ring -:

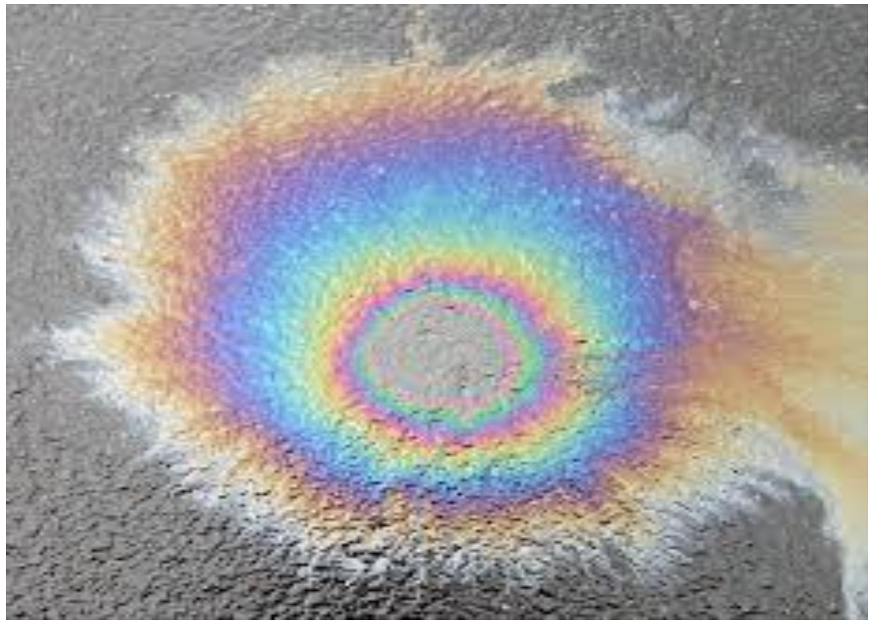
Department of Physics
School of Applied Sciences
E-LEARNING DIVISION
https://ksas.kiit.ac.in/

Topics to be covered

- ❖ Introduction
  - ❖ Colours in thin films (pictorial)
  - ❖ Path difference calculation
    - ❖ Stoke's treatment
    - ❖ Parallel thin film
    - ❖ Wedge shaped thin film
  - ❖ Fringes
    - ❖ Fringes of equal thickness
    - ❖ Fringes of equal inclination
    - ❖ Point source and Extended source
- ❖ Newton's ring
  - ❖ Experimental Set-up and formation of Newton's ring
  - ❖ Constructive and destructive interference
    - ❖ Calculation of path difference for bright and dark rings
    - ❖ Calculation of diameter for bright and dark rings
- ❖ Application of Newton's ring
  - ❖ Determination of 'λ' of an unknown monochromatic light
  - ❖ Determination of refractive index 'μ' of an unknown liquid

Colours in thin films

Soap Bubbles

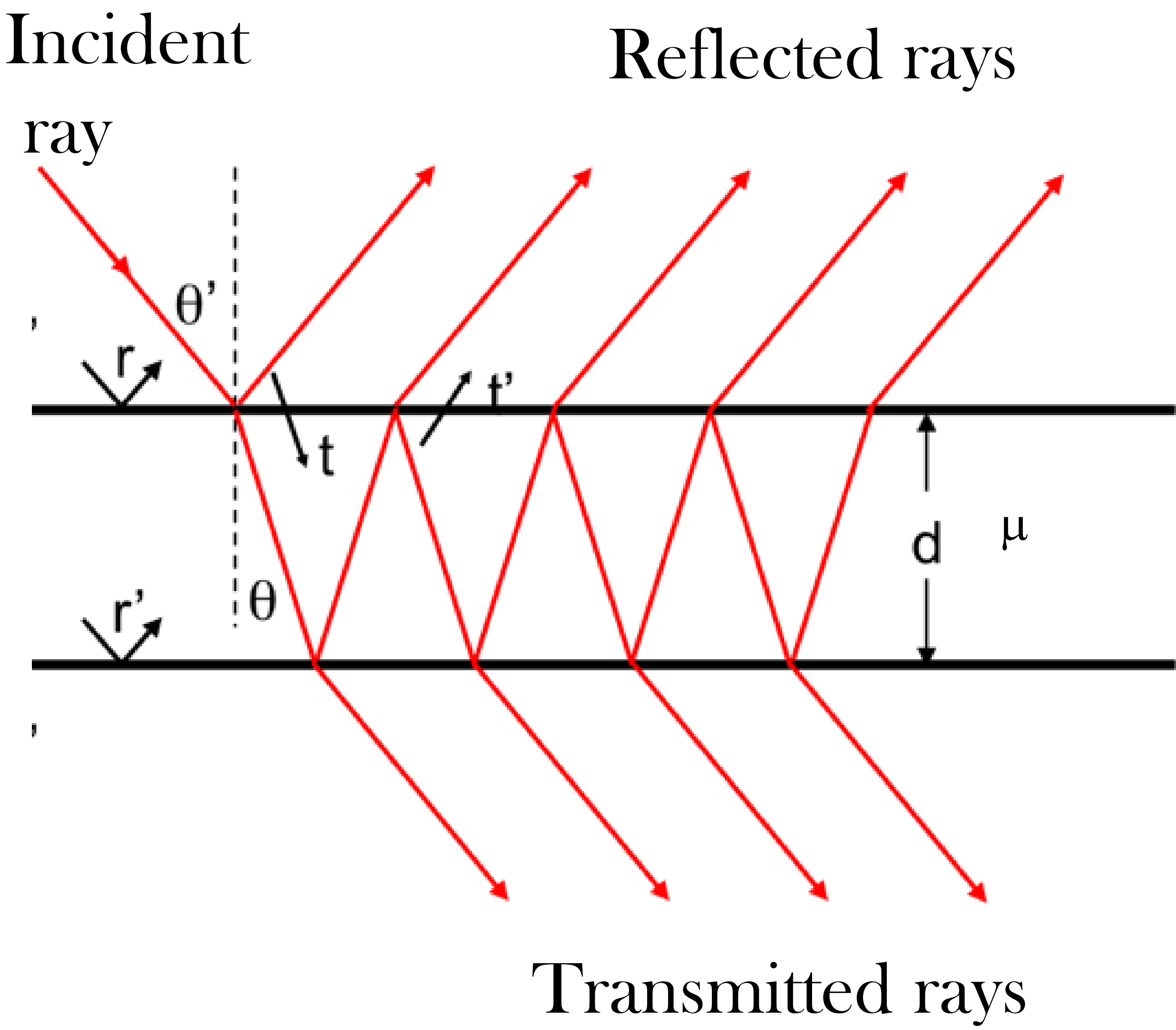


Oil Films

Peacock Feather

Butterflies

Principle



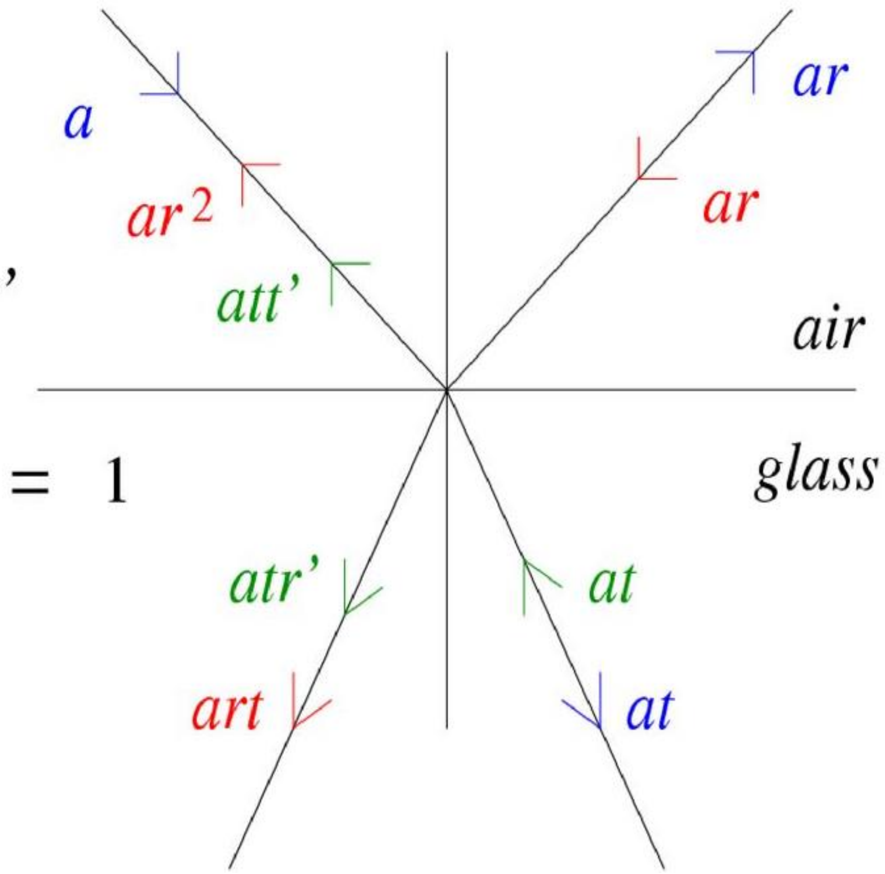
❖ The thickness of the film should be of the order of the wave length of incident light

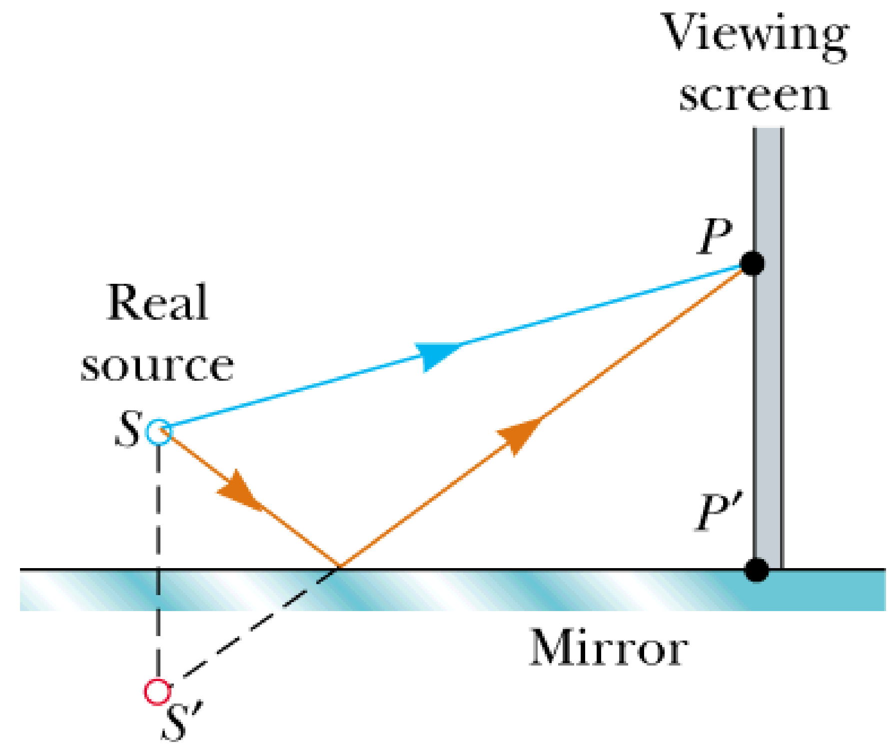
Stokes' relations

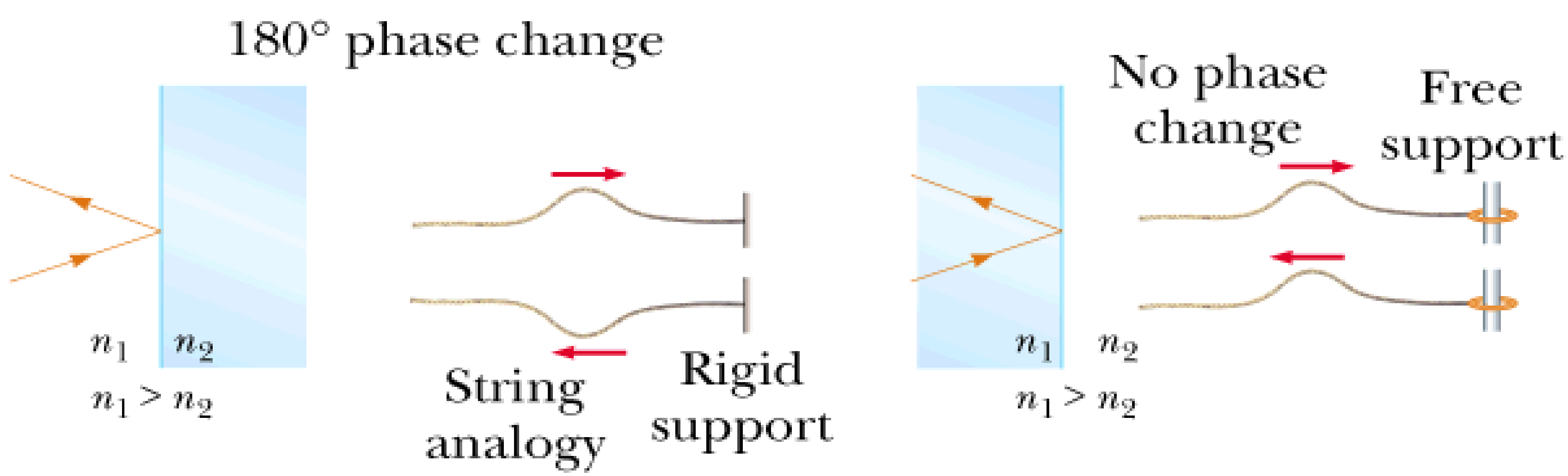
When the light is reflected from an interface backed by a denser medium, then the reflected light travels an additional phase of π or an extra path of $\lambda/2$

$$r = -r'$$

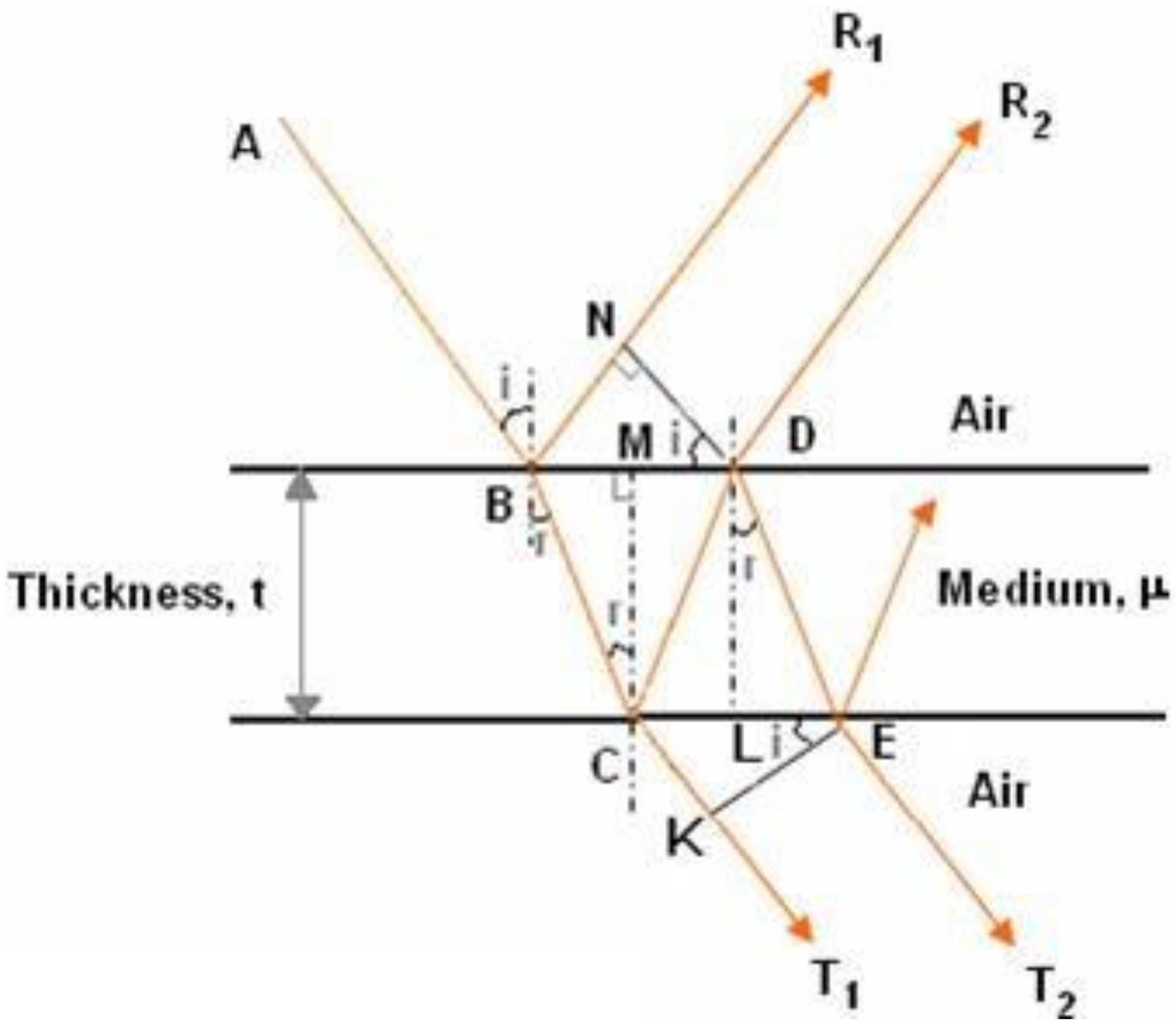
$$r^2 + tt' = 1$$







Parallel Thin Film



The optical path difference between the two reflected rays

$$\Delta = \mu(BC + CD) - BN$$

(In ΔBDN, $\sin i = BN / BD$ and $BC = CD$ as ΔBMC ≡ ΔMCD)

$$\Rightarrow \Delta = 2\mu BC - BD\sin i$$

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

In ΔBMC, $\cos r = t / BC$

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

In ΔBMC, $\tan r = BM / t$

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

Snell's law : $\mu = \dfrac{\sin i}{\sin r}$

$$\Rightarrow \Delta = \frac{2\mu t}{\cos r} - 2\mu t(\tan r)\sin r$$

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

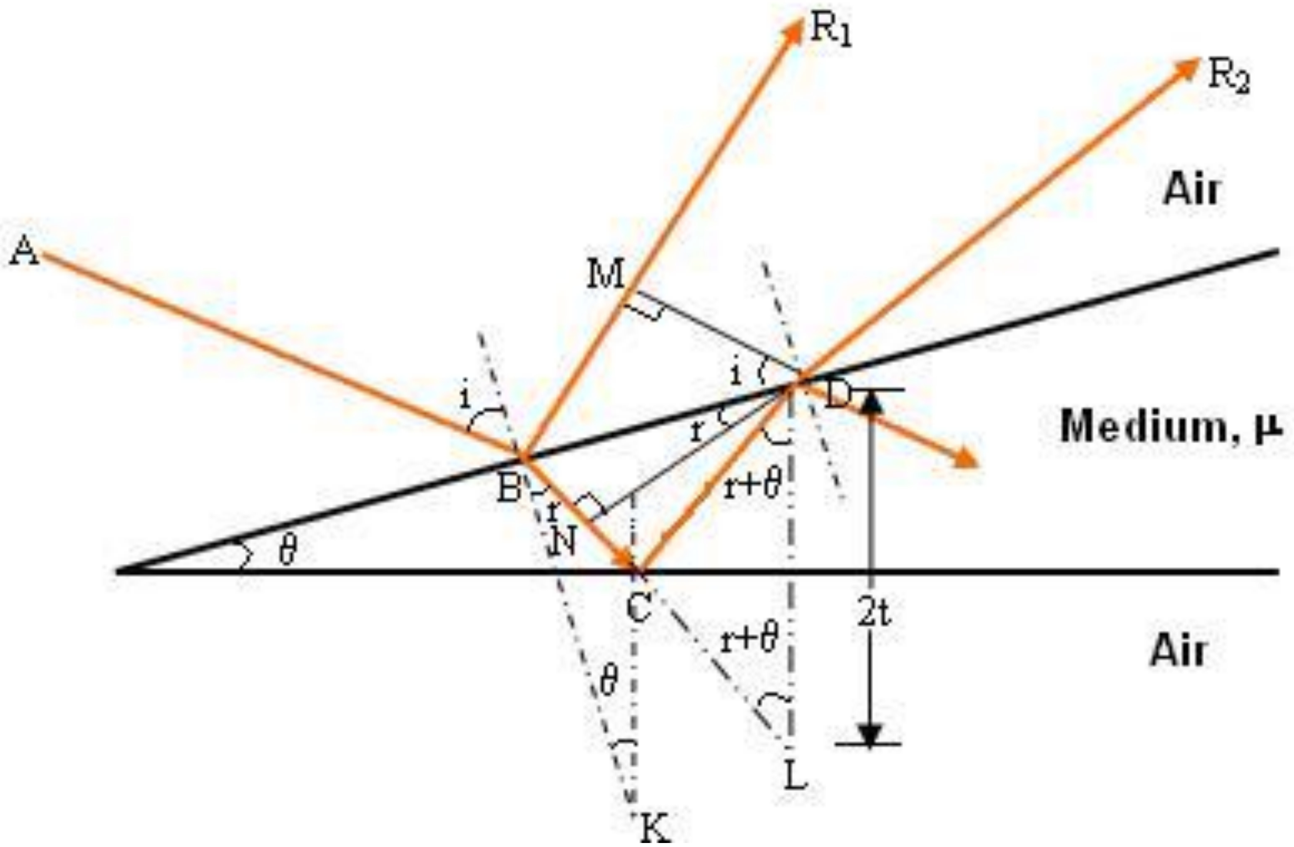
$$\Rightarrow \Delta = \frac{2\mu t}{\cos r}(1 - \sin^2 r) \quad \Rightarrow \Delta = \frac{2\mu t}{\cos r}\cos^2 r \quad \Rightarrow \Delta = 2\mu t\cos r$$

$\Rightarrow$ The effective path difference $\boxed{\Delta = 2\mu t\cos r + \frac{\lambda}{2}}$ (As per Stoke's relation)

\# Condition of Maxima (Bright Fringe), $\Delta = n\lambda \Rightarrow \boxed{2\mu t\cos r + \frac{\lambda}{2} = n\lambda}$

\# Condition for Minima (Dark Fringe) $\Delta = \dfrac{(2n+1)\lambda}{2} \Rightarrow \boxed{2\mu t\cos r + \frac{\lambda}{2} = \frac{(2n+1)\lambda}{2}}$

Wedge Shaped Thin Film



The optical path difference between the two reflected rays R_1 and R_2 will be

$$\Delta = \mu(BC + CD) - BM \quad \Rightarrow \Delta = \mu(BN + NC + CD) - BM$$

[From the geometry: ΔBMD and ΔBND]

$$sin\mathbf{i} = \frac{BM}{BD} \quad sin\mathbf{r} = \frac{BN}{BD} \quad \mu = \frac{sin\mathbf{i}}{sin\mathbf{r}} = \frac{BM/BD}{BN/BD} = \frac{BM}{BN}$$

$$\Rightarrow \quad BM = \mu BN$$

[Snell's Law]

$$\Rightarrow \quad \Delta = \mu(NC + CD)$$

$$\Rightarrow \quad \Delta = \mu(NC + CL)$$

$$\Rightarrow \quad \Delta = \mu NL$$

[ΔNDL]

Again,

$$cos(r + \theta) = \frac{NL}{2t}$$

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

The effective path difference between the two reflected rays R_1 and R_2 will be

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

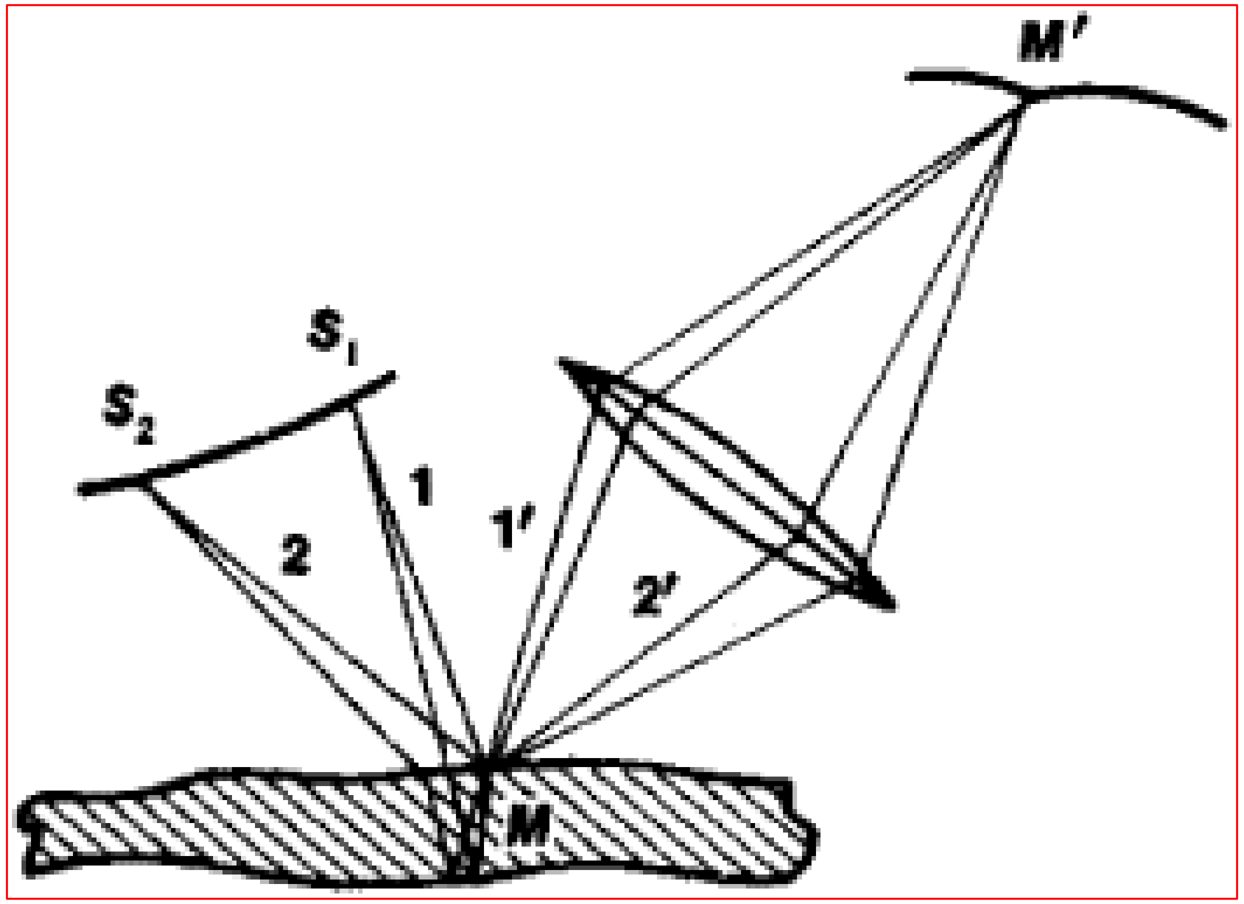
#Condition of Maxima (Bright Fringe)

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

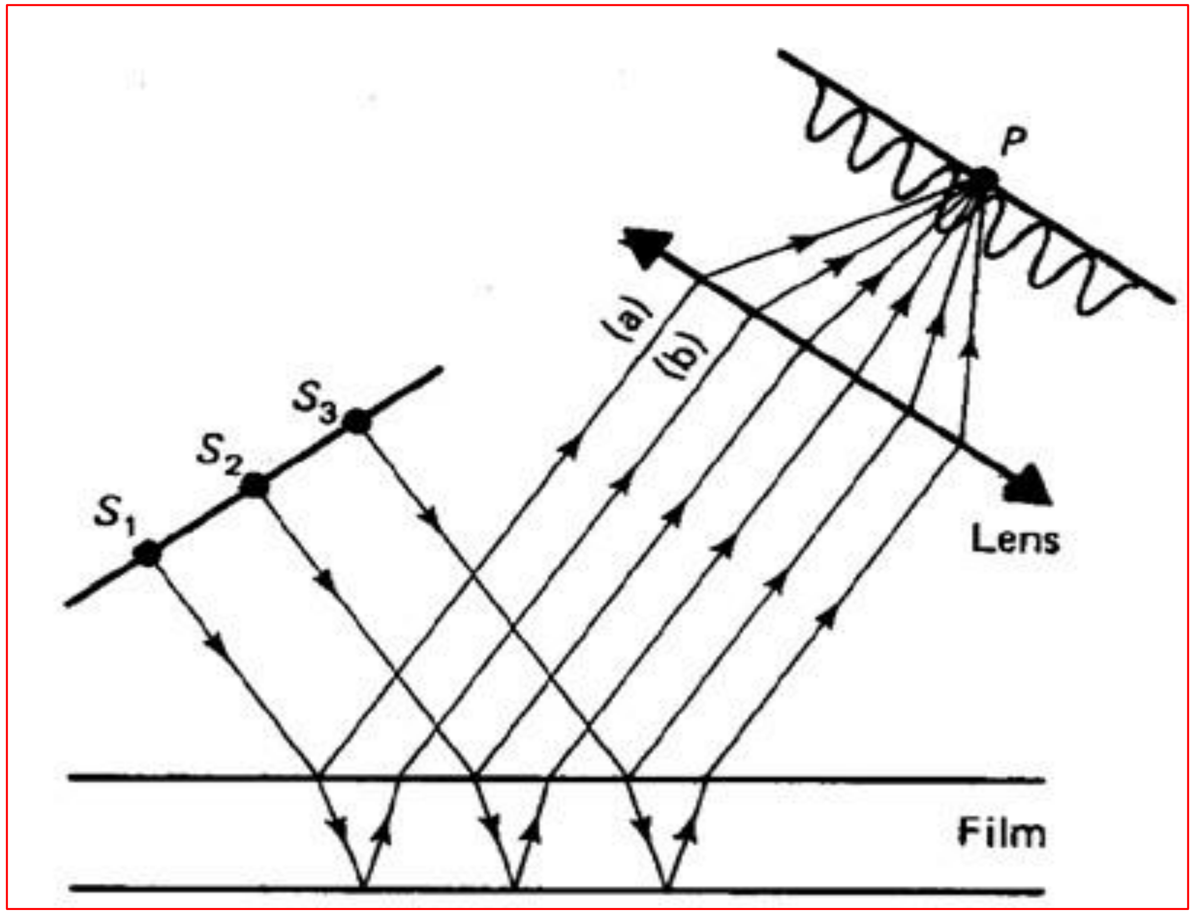
#Condition of Minima (Dark Fringe)

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

Fringes of equal thickness and inclination



Fringes of equal thickness :-Newton's ring



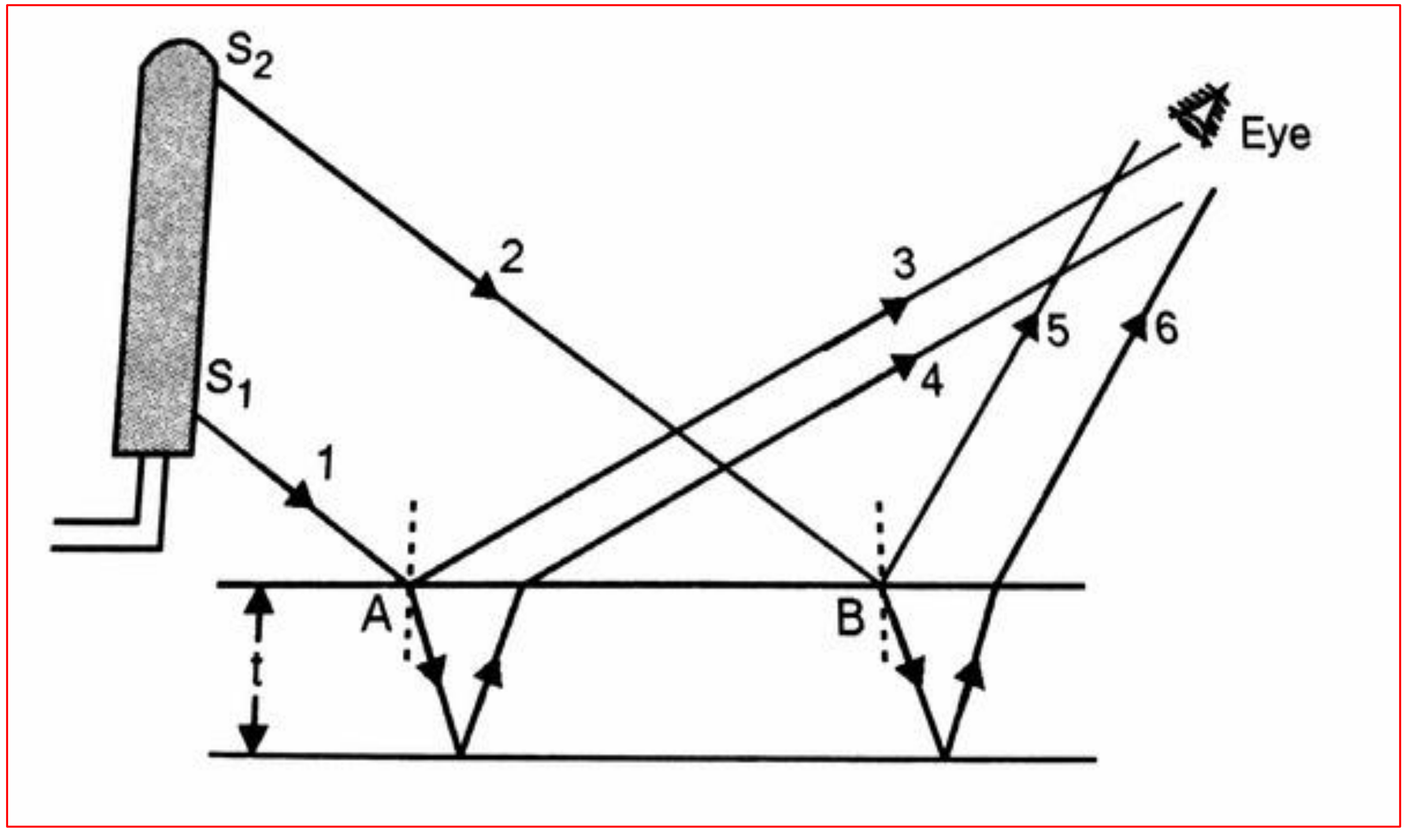
Fringes of equal inclination:-Michelson's interferometer

The occurrence of the alternate maxima and minima is due to variation in the thickness of the film and each maximum and minimum is a locus of constant film thickness.

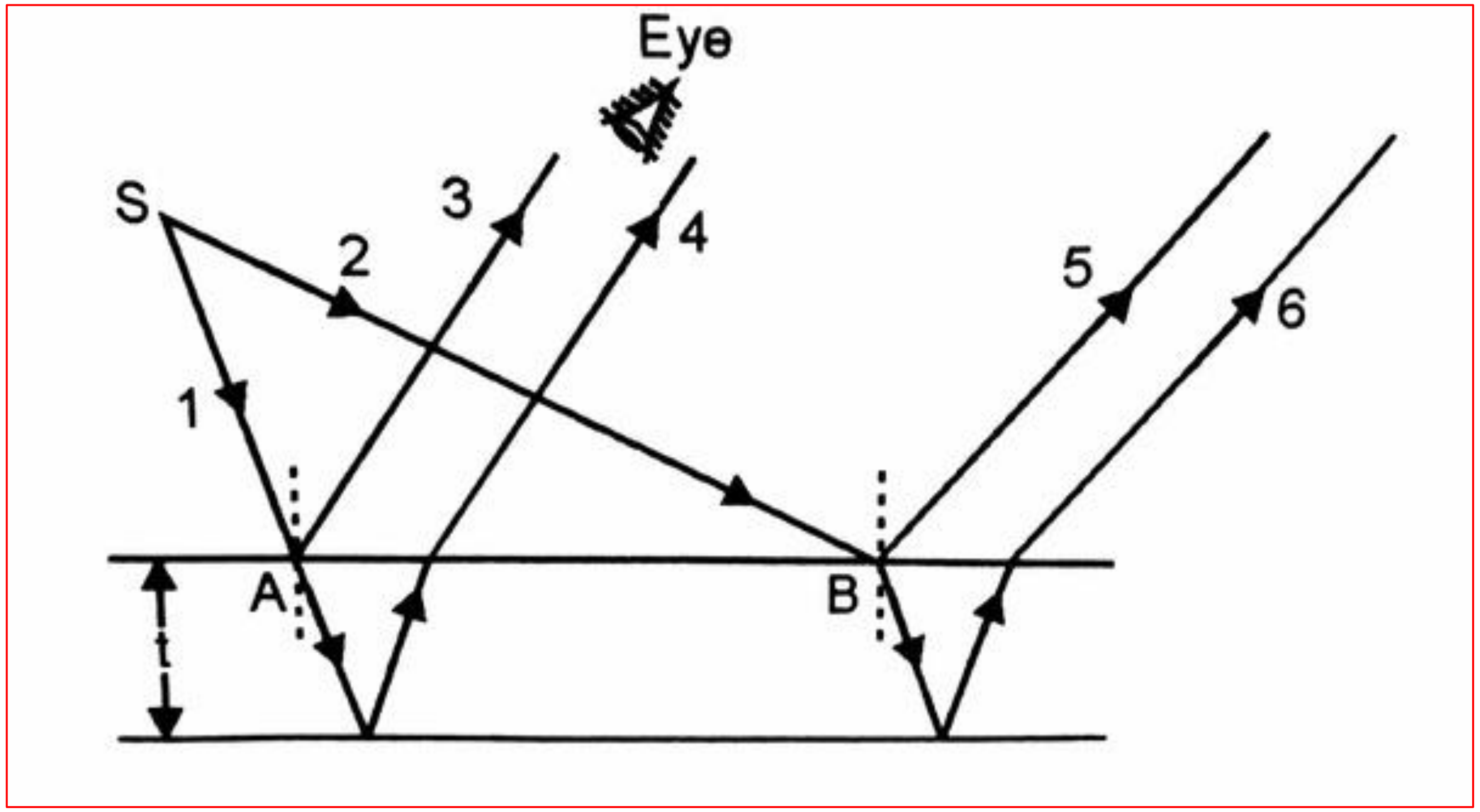
If the thickness of the film is uniform, then the path difference $2\mu t\cos\theta$ between coherent rays can change only with inclination.

In this case one can get wide cones of light, and each fringe corresponds to a particular value of θ.

Point Source Vs Broad Source



Extended/Broad Source



Point Source

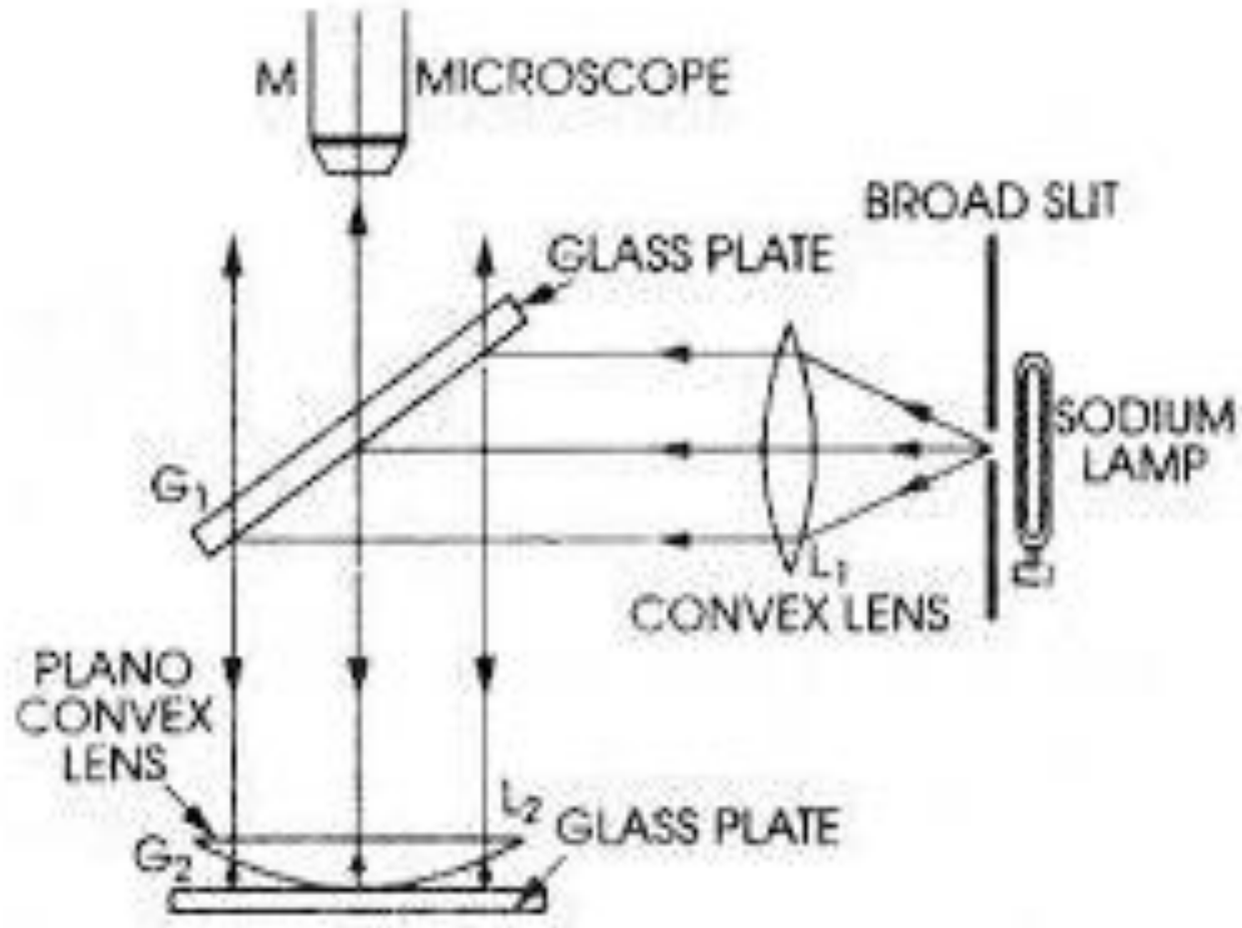
Necessity of broad source:

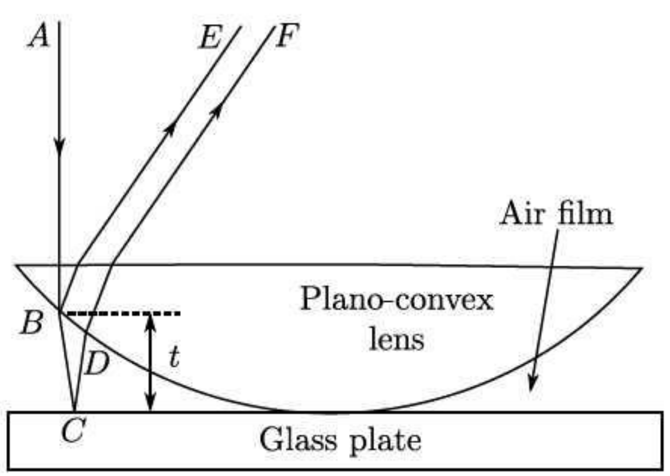
- ❖ When point source is used only a small portion of the film can be seen through eye and as a result the whole interference pattern cannot be seen.

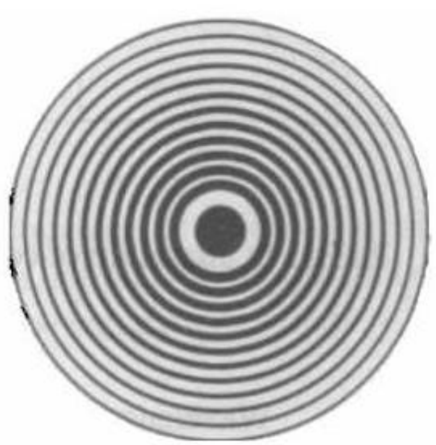
- ❖ But when a broad source is used rays of light are incident at different angles and reflected parallel beam reach the eye and whole beam and complete pattern is visible.

Newton's Ring

Formation of Newton's Ring





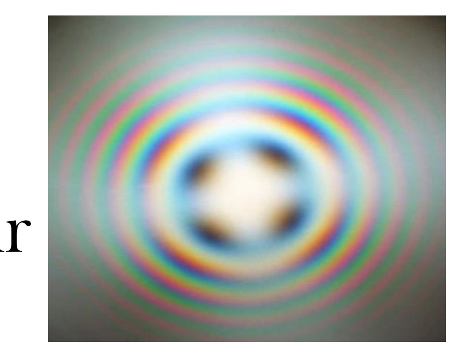


When a plano-convex lens is placed on a plane glass surface with it's convex surface facing the glass, an wedge shaped air film of increasing thickness is formed between the lower surface of the lens and upper surface of the glass surface. The thickness of film at the point of contact is zero.

When a beam of monochromatic light is allowed to fall normally on the upper surface of the lens, it is reflected as well as refracted.

The reflected rays from the top and bottom surface of the air film interfere with each other to form concentric bright and dark circular rings.

When viewed by white light, concentric ring pattern of rainbow colors is observed because the different wavelengths of light interfere at different thicknesses of the air between the surfaces.



Contd……… Conditions for Bright and Dark Rings

For wedge shaped film, the effective path difference between two reflected rays is :

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

[r ⟶ angle of refraction,
θ ⟶ angle of wedge,
t ⟶ thickness of the film,
μ ⟶ refractive index of the film]

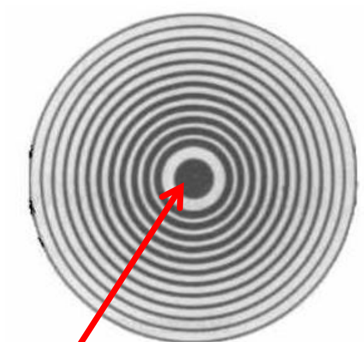
In Newton's ring,

- For normal incidence, r = 0

$$\Rightarrow \Delta = 2\mu t\cos\theta + \frac{\lambda}{2} \quad \text{..................(2)}$$

- Since, the radius of curvature is very large, the angle of the wedge is very small, i.e., $\theta \approx 0^\circ$

$$\Rightarrow \Delta = 2\mu t + \frac{\lambda}{2} \quad \text{..................(3)}$$



- At point of contact t=0, therefore the effective path difference,

$$\Rightarrow \boxed{\Delta = \frac{\lambda}{2}} \quad \text{..................(4)}$$

which is an odd multiple of $\frac{\lambda}{2}$,therefore the Central fringe is dark.

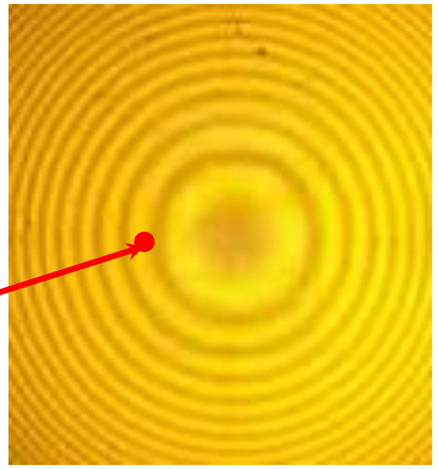
Contd……… Conditions for Bright and Dark Rings

- For Maxima (Bright ring), the effective path difference

$$\Delta=\pm n\lambda \quad \text{………………(5)}$$

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

$$\Rightarrow \boxed{2\mu t=\pm\frac{(2n-1)\lambda}{2}} \quad \text{………………(6)}$$



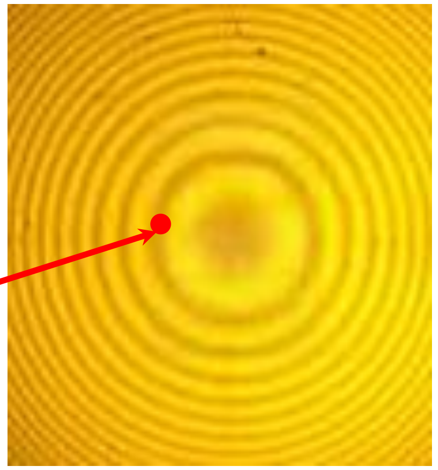
This is the condition for constructive interference.

- For minima (Dark rings), the effective path difference

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

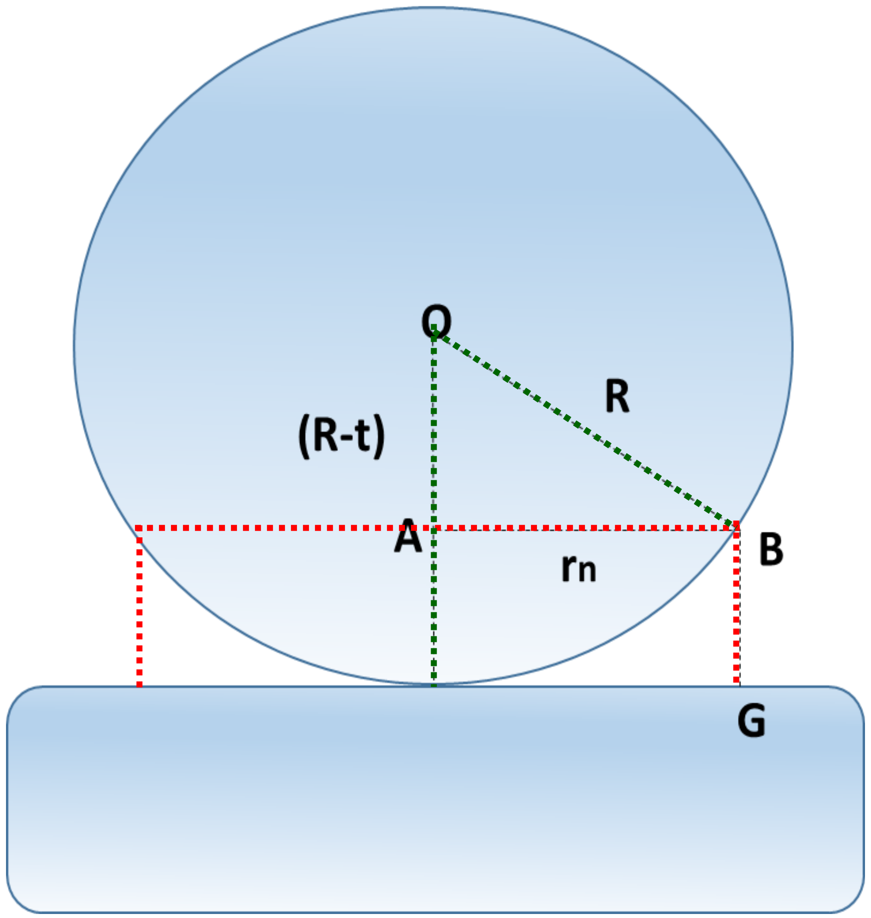
$$\Rightarrow 2\mu t+\frac{\lambda}{2}=\pm\frac{(2n+1)\lambda}{2}$$

$$\Rightarrow \boxed{2\mu t=\pm n\lambda} \quad \text{………………(8)}$$



This is the condition for destructive interference.

Contd……… Diameter of Bright and Dark Rings



Let $R \rightarrow$ radius of curvature of lens

$O \rightarrow$ is the center of curvature

$BG = t$ be the thickness of air filling at point G

$AB = r_n$ be the radius of the n^{th} ring with respect to the thickness t

- Now from the ΔOAB,

$$R^2=(R-t)^2+r_n^2 \quad \text{..................(9)}$$

$$\Rightarrow R^2=R^2+t^2-2Rt+r_n^2$$

As $t << R$; neglecting t^2 (small value)

$$2Rt=r_n^2$$

$$\Rightarrow t=\frac{r_n^2}{2R} \quad \text{..................(10)}$$

where, $n = 0, 1, 2, 3$.......

Diameter of Bright Rings

For constructive interference, $2\mu t= \dfrac{(2n-1)\lambda}{2}$

$$\Rightarrow 2\mu.\frac{r_n^2}{2R} = \frac{(2n-1)\lambda}{2}$$

$$\Rightarrow \boxed{r_n^2 = \frac{(2n-1)\lambda R}{2\mu}} \quad ....(11)$$

As $D_n=2r_n$, $$D_n^2 = 4r_n^2 \quad ....(12)$$

$$\Rightarrow \boxed{D_n^2 = \frac{2(2n-1)\lambda R}{\mu}} \quad ....(13)$$

$$\Rightarrow D_n = \sqrt{\frac{2(2n-1)\lambda R}{\mu}} \quad ....(14)$$

The medium enclosed between the lens and glass plate is if air therefore, $\mu= 1$. The diameter of n^{th} order bright fringe will be

$$\boxed{D_n = \sqrt{2(2n-1)\lambda R}} \quad ....(15)$$

$$\Rightarrow D_n \propto \sqrt{(2n-1)}, \; n=0,1,2,3,\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

Diameter of dark rings

For destructive interference, $2\mu t = n\lambda$

$$\Rightarrow 2\mu . \frac{r_n^2}{2R} = n\lambda$$

$$\Rightarrow \boxed{r_n^2 = \frac{n\lambda R}{\mu}} \qquad \text{..................(17)}$$

As $D_n^2 = 4r_n^2$

$$\Rightarrow \boxed{D_n^2 = \frac{4n\lambda R}{\mu}} \qquad \text{..................(18)}$$

$$\Rightarrow D_n = \sqrt{\frac{4n\lambda R}{\mu}} \qquad \text{..................(19)}$$

The medium enclosed between the lens and glass plate is if air therefore, $\mu=1$. The diameter of nth order dark fringe will be

$$\boxed{D_n = \sqrt{4n\lambda R}} \qquad \text{..................(20)}$$

$$\Rightarrow D_n \propto \sqrt{n}, \; n=0, 1, 2, 3, \ldots\ldots \qquad \text{..................(21)}$$

Contd.........

Spacing Between Fringes

- The Newton's rings are not equally spaced because the diameter of ring doesn't increase in the same proportion as the order of ring and rings get closer and closer as 'n' increases.
- For example the diameter of dark ring is given by, $D_n = \sqrt{4n\lambda R}$ where n= 0, 1, 2, 3,4.........

$D_5 - D_4 = 2\sqrt{5\lambda R} - 2\sqrt{4n\lambda R} = 2(0.236)\sqrt{\lambda R}$

$D_{15} - D_{14} = 2\sqrt{15\lambda R} - 2\sqrt{14n\lambda R} = 2(0.131)\sqrt{\lambda R}$

$D_{25} - D_{24} = 2\sqrt{25\lambda R} - 2\sqrt{24n\lambda R} = 2(0.101)\sqrt{\lambda R}$

From above, we conclude that the fringe width reduces with increase in **n** & the rings gradually becomes narrower as their radii increase.

Applications : Wavelength of an Unknown Monochromatic Light

We know that the square of diameter of nth dark ring is

$$D_n^2 = 4n\lambda R \qquad \text{..................(22)}$$

Therefore the square of diameter of (n+p)th ring is

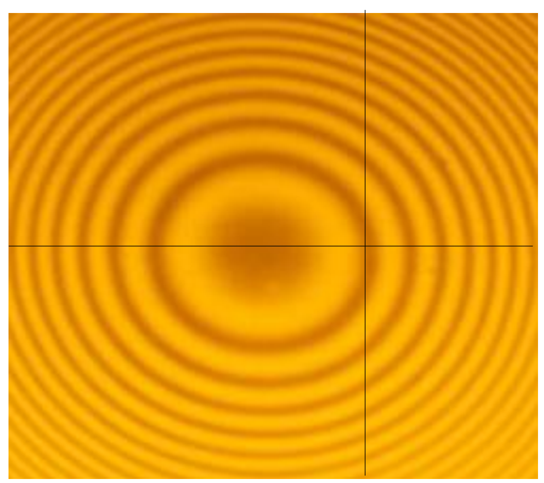
$$D_{n+p}^2 = 4(n+p)\lambda R \qquad \text{..................(23)}$$

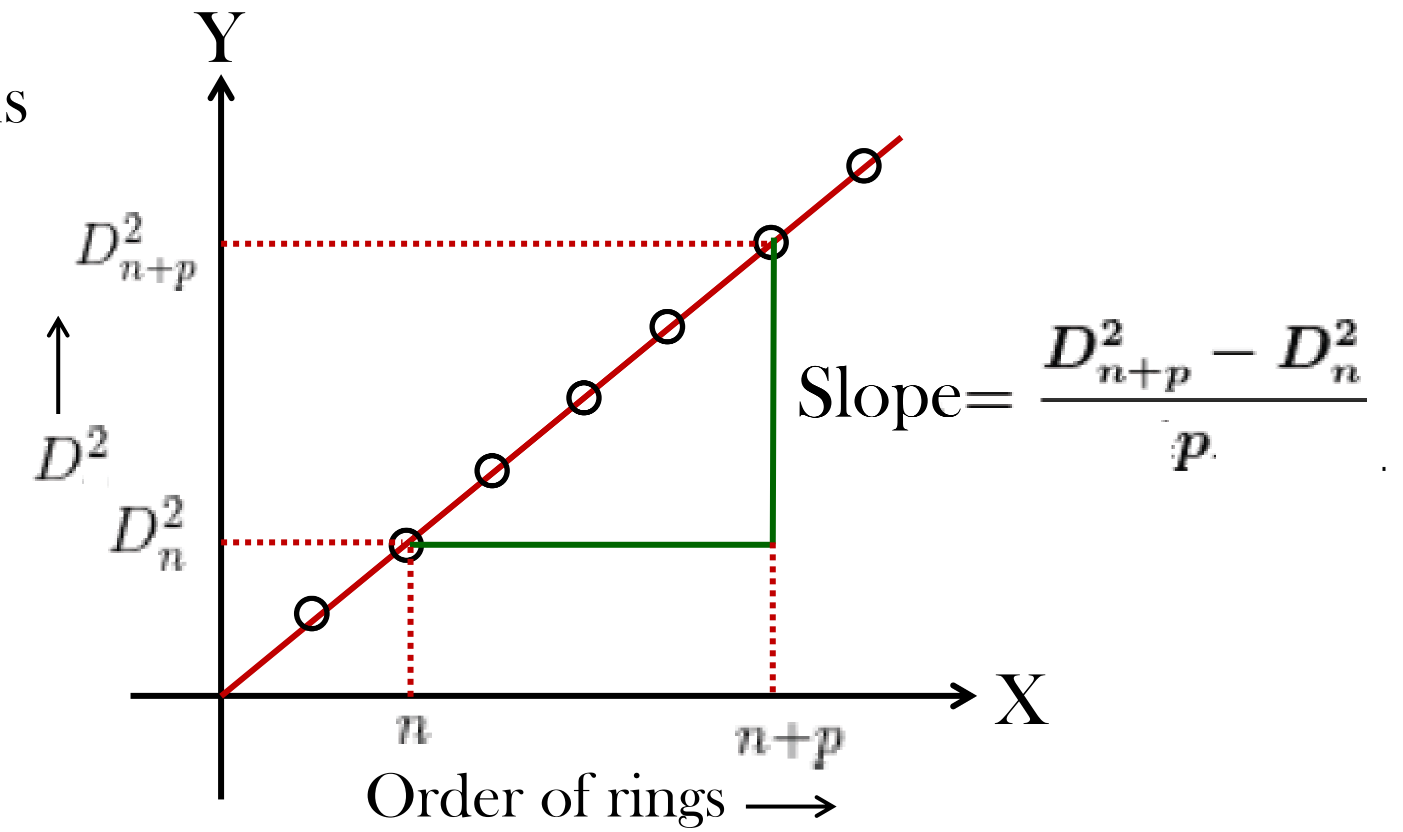
Subtracting both the above equation

$$D_{n+p}^2 - D_n^2 = 4(n+p)\lambda R - 4n\lambda R \qquad \text{......(24)}$$

Therefore

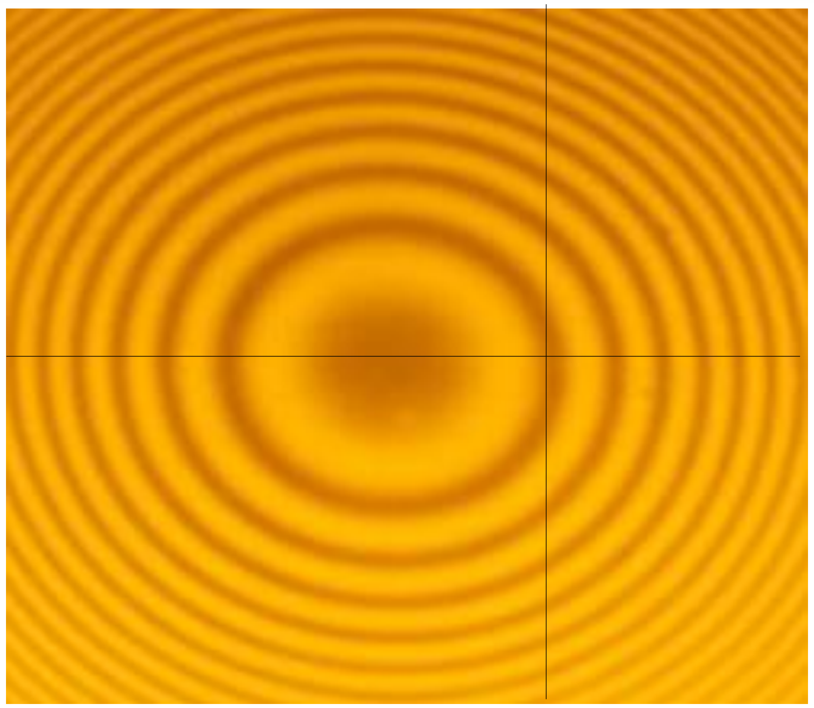
$$\boxed{\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}} \qquad \text{..................(25)}$$





- ❖ Measure the diameter of different orders of rings using experimental set up
- ❖ Plot a graph between square of diameter, D^2 Vs. order of rings.
- ❖ Calculate the slope of the straight line from the graph
- ❖ Using the working formula, calculate the wavelength of the unknown light

Applications : Refractive Index of an Unknown Liquid



- Perform the Newton's ring experiment for the air medium and determine the difference in the square of the diameter of $(n+p)^{th}$ and n^{th} dark ring :

$$\boxed{(D_{n+p}^2 - D_n^2)_{air} = 4p\lambda R} \quad \text{..................(26)}$$

- Put few drops of liquid of refractive index μ in between the glass plate and the plano-convex lens resulting a liquid film formed between the lens and the plate.
- Repeat the experiment and determine the difference in the square of the diameter of $(n+p)^{th}$ and n^{th} dark ring in the same manner for the liquid medium :

$$\boxed{(D_{n+p}^2 - D_n^2)_{liquid} = \frac{4p\lambda R}{\mu}} \quad \text{..................(27)}$$

- From the above two equations, calculate the refractive index :

$$\boxed{\mu = \frac{(D_{n+p}^2 - D_n^2)_{air}}{(D_{n+p}^2 - D_n^2)_{liquid}}} \quad \text{..................(28)}$$

Summary

- ❖ We learn the concept "colours in thin films"
- ❖ We learn to calculate the optical and effective path difference between reflected rays for both parallel and wedge shaped film. We have also discuss briefly about fringes of equal thickness and fringes of equal inclination . The need of extended source has also been explained.
- ❖ We have discussed " Newton's ring experimental set up and the formation of rings" followed by the discussion on " why central ring is dark, condition of bright and dark fringes, calculation of diameters of bright and dark rings, fringe width etc."
- ❖ Finally, the applications of Newton's ring experiment were discussed "how to determine the wavelength of an unknown monochromatic light and refractive index of an unknown liquid".