Engineering Physics

UNIT-I: WAVE OPTICS

Interference

Principle of Superposition:

When two or more waves overlap, the resultant displacement at a point equal to the algebraic sum of the individual displacement at that point. This is the principle of superposition.

Thus, if $y_1(x, t)$ and $y_2(x, t)$ are the wave functions characterizing two waves traveling in space, their resultant is given by

$$Y(x, t) = y_1(x, t) + y_2(x, t)$$

Coherent waves:

If two waves possess the same frequency and phase, then they are known as coherent waves.

Examples:

(1) Two pin holes illuminated by the same light, and

(2) Two point sources on the surface of an electric bulb.

Coherence is of two types: Namely
Temporal coherence
Spatial coherence

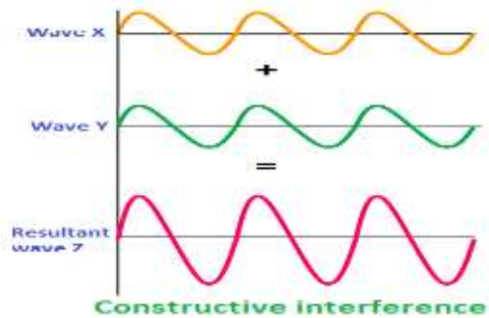
Temporal Coherence:

"If it is possible to predict the phase relation at a point on the wave W.R.T another point on the same wave then the wave has temporal coherence." It is also called longitudinal coherence.

Spatial Coherence:

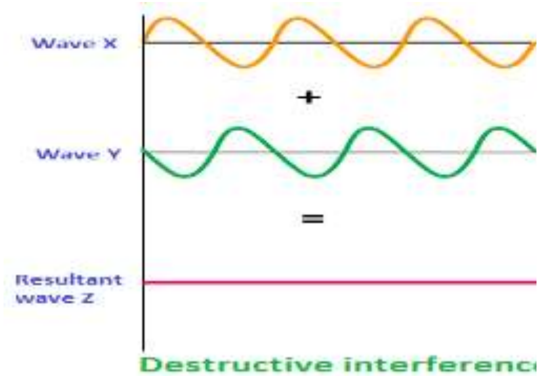
"If it is possible to predict the phase relation at a point on the wave W.R.T another point on another wave then the wave has spatial coherence." It is also called transfer coherence.

Note: The constructive and destructive interferences represent the maximum and minimum intensity positions, respectively



- The bright fringes are more intense and they are due to **constructive interference**, where the resultant amplitude is equal to the sum of the amplitudes due to individual waves.

The Resultant **constructive interference** $Y=Y_1+Y_2$



- The dark fringes are completely dark and they are due to **destructive interference**, where the resultant amplitude is equal to the difference of the amplitudes due to individual waves.

The Resultant **destructive interference** $Y=Y_1-Y_2$

Conditions for the interference of light:

The two light sources should be coherent.
The two sources must emit continuous waves of same wavelength and frequency

To observe the fringes :

The separation between the two sources should be small
The distance between the two sources and the screen should be large.
The background should be dark.

For good contrast:

The amplitude of the light waves should be equal or nearly equal
The sources should be narrow i.e. They must extremely small.
The sources should be monochromatic.

1.2. Interference of light:

The modification in light intensity in the region of superposition of two or more coherent waves is known as "interference of light".

**Types of Interference:

The phenomenon of interference requires two wave fronts to interact. These wavefronts can be obtained in two different ways, resulting two different type of interference, namely

i) Division of wavefront type of interference:

In this type of interference, the incident wave front is divided into two parts using the phenomenon of reflection, refraction or diffraction. The two parts of the wavefronts are then made to travel unequal distances before reuniting at same angle leading to the produce interference pattern.

Examples: 1) Young's double slit experiment and

2) Fresnel's Biprism.

ii) Division of amplitude type of interference:

In this type of interference, the amplitude of the incoming wave divided into number of parts through the process of reflection (or) refraction. These two parts are then travel along different optical paths and finally superimpose to produce interference pattern.

To produce this type of interference pattern, point (or) narrow line source is not essential. However, the broad light sources can be employed to yield bright interference bands.

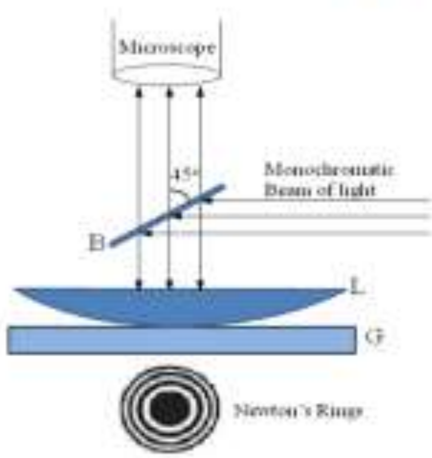
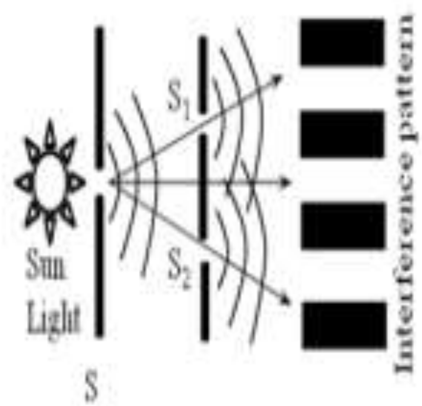
Examples: 1) Thin films interference and

2) Newton's Rings.

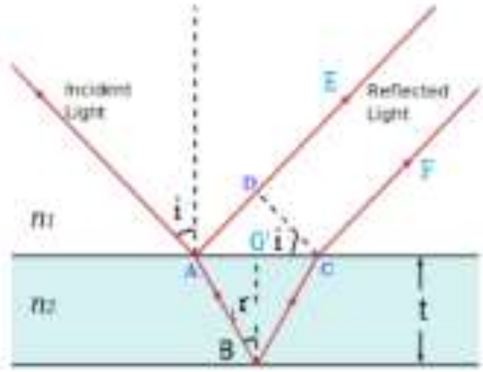
Q1: Can Young's double slit experiment prove the particle nature of light?

- From the interference phenomenon, it is clear that the combination of dark and bright bands is the evidence for interference and it is due to the wave nature of light.
- Suppose the light has particle nature, when passing through the slits, the particles gather in clumps on the screen without producing any intensity modification.
- We can't understand the interference phenomenon.
- The **interference pattern** was the evidence Young needed to determine that light was a wave and not a particle as Newton had suggested.
- Therefore, Young's double slit experiment disproves the particle nature of light.

1.3. Difference between interference due to amplitude division and wavefront division:

Interference due to amplitude division		Interference due to wavefront division	
1	Two coherent sources have been obtained by dividing the amplitude of a beam originated from a common source. So, coherent sources are produced by division of amplitude.	1	Two coherent sources have been obtained by dividing the wavefront of a beam originated from a common source. So, coherent sources are produced by division of wavefront.
2	Coherent sources are obtained either partial reflection or refraction.	2	Coherent sources are obtained due to lenses or mirrors
3	Light beams travel along different paths and finally brought together to produce interference.	3	Light beams travel along the same path and they are brought together to produce interference.
4	Light beams travel in different media.	4	Light beams travel in one medium only.
5		5	
6	Example: Interference in Thin films, Newton Rings, and Michelson's interferometer	6	Example: Young's double slit experiment, Fresnel's Biprism, Lloyd's mirror method, etc.

1.4. Interference in Uniform Thin films by Reflection



Consider a thin film of thickness 't' and refractive index μ. Let a ray of light is incident at a point A with angle of incidence 'i'. This ray partly reflected along AE and partly refracts along AB and incident at B with an angle 'r'. Finally, this ray of light along CF.

The reflected rays AE and CF are parallel to each other and constitute reflected system to produce interference pattern. To study the interference phenomenon, we have to calculate the effective path difference between AE and CF. From the figure,

Path difference = Path (AB+BC) in film – Path AD in air

$= \mu_{film}.(AB+BC) - \mu_{air}.AD$

$= \mu(AB+BC) - AD$ (since $\mu_{film} = \mu$ and $\mu_{air} = 1$)

From Figure we have, $AB = BC = \dfrac{t}{\cos r}$ and $AD = 2\mu t\dfrac{\sin^2 r}{\cos r}$

Substituting the values of AB, BC and AD, we get

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

Since the ray of light reflects from the denser medium, it undergoes a phase difference of 'π'

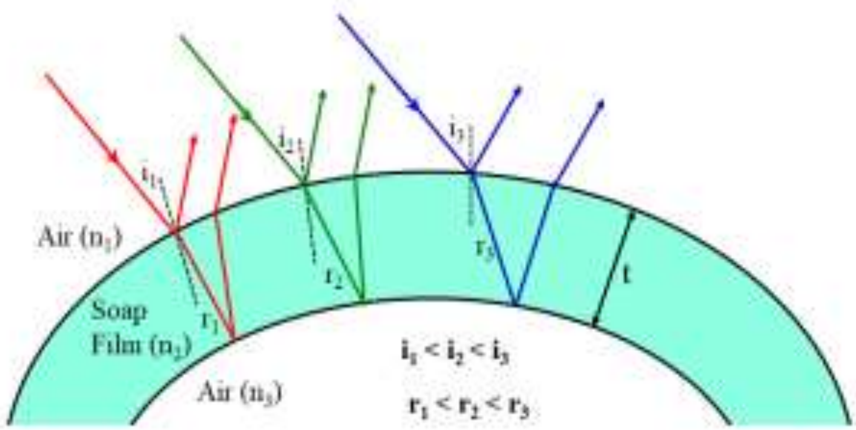
Therefore, **effective path difference = $2\mu t \cos r + \lambda/2$**

Condition for bright fringe, $2\mu t \cos r + \lambda/2 = n\lambda$

(or) $2\mu t \cos r = (2n-1)\lambda/2$, n = 1,2,3, …..

1.4.1. Multi-colour in soap bubble

- In case of soap bubble, the thickness (t) of film is constant.
- And the refractive index (μ) and the angle of refraction (r) are variables.
- Since, the Sun light is composed of different colours or different wavelength (λ) values, the refractive index (μ) of the film also varies with λ.
- Due to the curved nature of bubble, even if parallel rays are incident, the angle of incidence (i) varies for different points on the bubble and hence the angle of refraction (r) varies as shown in figure.



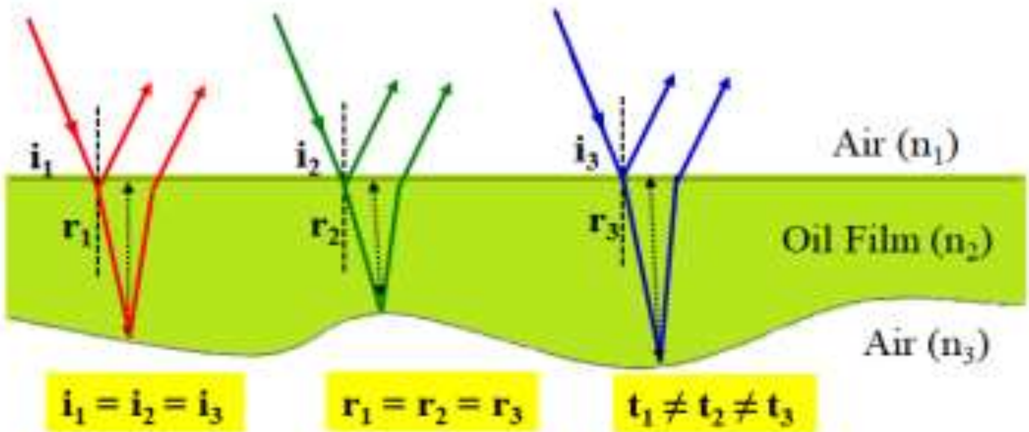
- The condition for bright band is given as

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

- The varying values of μ and r can satisfy the condition of constructive interference for a particular wavelength (say λ_{red}) only. Accordingly, that point will appear in that colour (red).
- For other neighbouring wavelengths, the condition of destructive interference is satisfied.
- In a similar way, different points different points satisfy the condition of constructive interference for different wavelengths (or) colours producing multi-colours.

1.4.2. Multi-colour in Oil film

- Let us consider a thin layer of oil film floating on road/water.
- Though the film is perfectly flat on upper surface, its lower surface is not uniform as shown in figure.



- In this case, the thickness 't' of the film is not constant throughout it.
- When a beam of parallel rays such as Sun light is incident, the angle of incidence (i) and hence angle of refraction (r) will remain constant.
- Since the refractive index is a wavelength dependent, it varies for different values of λ.
- Hence, different points on the film satisfy the condition of constructive interference for different colours (or wavelengths) depending up on the values of μ and t.
- Thus, the oil film appears with multi-colours.

1.4.3. Applications of Thin Film technology or thin films

- Thin film technology is used for defrosting aircraft windshields.
- Thin film technology is used in cellular functions in the human body.
- Thin films are used for protecting the surface of many optical elements.
- Thin-film cells convert solar energy into electricity through the photovoltaic effect.

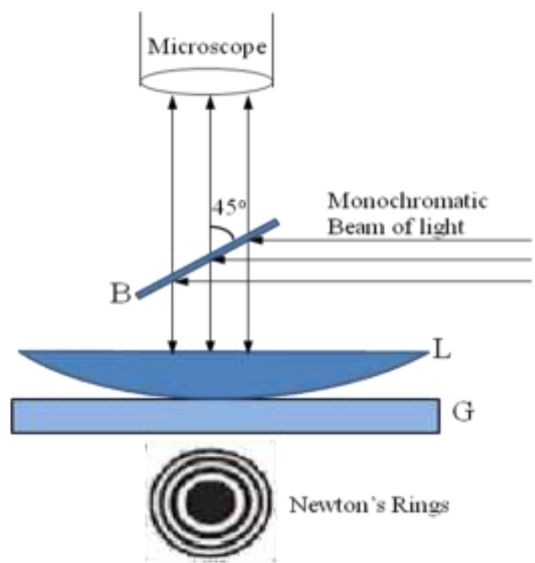
Newton's Rings (Interference in Non-uniform Thin films)

Definition: When Plano-convex lens with its convex surface placed on a glass plate is illuminated normally with a monochromatic light a circular concentric rings pattern is observed. These rings are known as Newton's rings.

Experimental arrangement of Newton's Rings

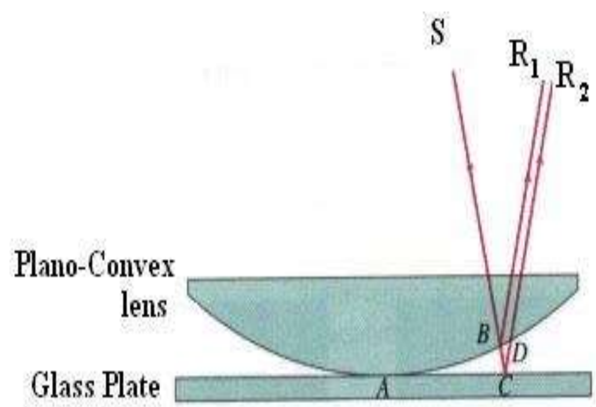
The experimental arrangement to observer the Newton's rings is shown in figure.

In figure, 'L' is a Plano–convex lens of large radius of curvature and is placed on an optically that glass plate G. A beam of monochromatic light is allowed to fall on a partially silvered glass plate B which is inclined at an angle of 45^0 with the vertical. The glass plate B reflects a part of incident light towards the air film enclosed by the lens – glass plate system. The reflected beam from the air film can be viewed with microscope M. Due to the interference of the light rays reflected from the lower surface of the lens and the upper surface of the glass plate, a circular concentric dark and bright fringes are produced as shown in figure.



Formation of Newton's Rings – Theoretical explanation:

The formation of Newton's Rings can be explained using the following figure.
Consider a Plano – convex lens (L) of radius of curvature R, placed on a glass plate P. Let a monochromatic ray of light AB is Incident on the lens. Glass plate system with angle of incidence 'i '



A part of the light is reflected at ‘C’ (glass-air boundary), which goes out in the form of ray-1 without any phase change.

→ The other part is reflected along CD.

→ At point D, the light ray again reflected and goes out in the form ray-2 with a phase change of π ((or) path difference $\frac{\lambda}{2}$)

→ The reflected rays 1& 2 are superposed to form interference pattern

→ As the interference pattern is observed in the reflected light,

Effective path difference = $2\mu t\ Cos\ (i+r) + \frac{\lambda}{2}$ ------------------→ (1)

Where i is the angle of incidence, r is the angle of reflection, t is the thickness of the air film and μ is the refractive index of air.

→ We know that, for air film, μ = 1 and for normal incidence r = 0. The angle of incidence i is very small, hence, Cos i can be neglected.

∴ Effective path difference = $2t + \frac{\lambda}{2}$ ------------------→ (2)

At the point of contact of lens and glass plate:

At this point, t = 0

∴ Effective path difference = $\frac{\lambda}{2}$

This is the condition for minimum intensity. Thus a dark fringe is formed at the centre with a monochromatic light waves.

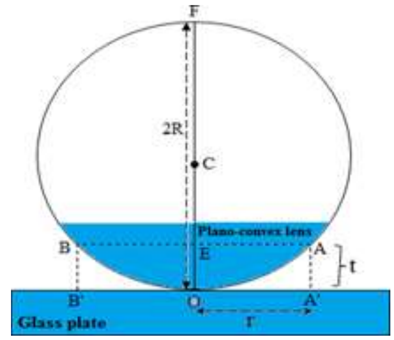
<u>Condition for nth minimum</u>: $2t + \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$, n= 0, 1, 2, 3…

∴ $2t = n\lambda$, n = 0, 1, 2, 3… ------------------→ (3a)

Condition for n^{th} maximum: $2t + \frac{\lambda}{2} = n\ \lambda$, n = 1, 2, 3……………

∴ $2t = (2n-1)\frac{\lambda}{2}$, n = 1, 2, 3... ------------------→ (3b)

Theory of Newton's Rings (OR) Expression for diameter of Dark and Bright Rings:



Consider a plano-convex lens of radius of curvature R placed on a plane glass plate as shown in figure.

Let us imagine a dark ring of radius 'r'. Let the thickness of air film is t (say) for the dark ring which is under consideration.

According to principle of circles,

AE×BE = OE×EF

$\Rightarrow r \times r = t(2R - t)$ $\Rightarrow r2 = t(2R - t)$

$\Rightarrow r^2 \approx 2Rt$ (Since t is small, t^2 can be neglected)

$$\Rightarrow 2t = \frac{r^2}{R} \longrightarrow \quad (1)$$

This is the path difference b/n. the light rays reflected from the top & bottom surfaces of air film.

Case-I: Condition for a Dark Ring:

$$\Rightarrow 2t = n\lambda \longrightarrow \quad (2)$$

From Eqs. 1& 2, we obtain, $r^2/R = n\lambda$

$$\Rightarrow r = \sqrt{n\lambda R}$$

But radius $r = \dfrac{Diameter(D)}{2}$

$$D = \sqrt{4n\lambda R} \quad \text{(or)} \quad D_n = \sqrt{4n\lambda R} \longrightarrow (3)$$

This is the expression for diameter of n^{th} dark ring.

Case-II: Condition for a Bright Ring:

$$2t = (2n-1)\lambda/2 \longrightarrow \quad (4)$$

$$\Rightarrow 2t = \frac{r^2}{R}$$

From. Eqs. 1& 4, we obtain, $\frac{r2}{R} = (2n-1)\frac{\lambda}{2}$

$$r^2 = (2n-1)\frac{\lambda R}{2} \text{ (or) } D^2 = (2n-1)2\lambda R$$

$$D = \sqrt{(2n-1)2\lambda R} \quad (\text{Here } \sqrt{2\lambda R} \text{ constant})$$

$$D \alpha \sqrt{(2n-1)} \longrightarrow (5)$$

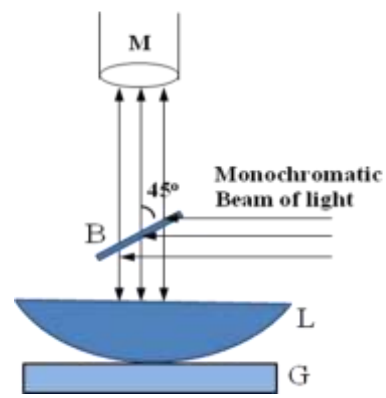
This is the expression for diameter of n^{th} bright ring.
With increase in the order (n), the rings get closer and the fringe width decreases

Applications of Newton's Rings:

1. Wavelength (λ) of a monochromatic light can be determined.
2. Radius of curvature (R) of a curved surface can be determined.
3. Refractive index (μ) of a transparent liquid can be determined.

To determine the wavelength (λ) of a monochromatic light:

The wavelength of given monochromatic light source can be determined by measuring the diameters of various rings formed. For this purpose, Newton's Rings have been formed as shown in figure using a plano-convex lens of known radius of curvature (R) with the given monochromatic source of light of wavelength (λ).



Let Dm and Dn are the diameters of m^{th} and n^{th} dark rings, respectively.

We know that the $D_n = \sqrt{4n\lambda R}$

For n^{th} ring Diameter

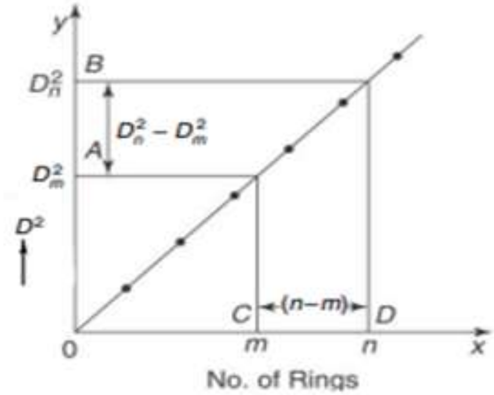
$$D_n^2 = 4n\lambda R \longrightarrow (1)$$

For m^{th} ring Diameter

$$D_m^2 = 4m\lambda R \longrightarrow (2)$$

From equations (1)-(2) will get

$$D_n^2 - D_m^2 = 4(n-m)\lambda R \longrightarrow (3)$$

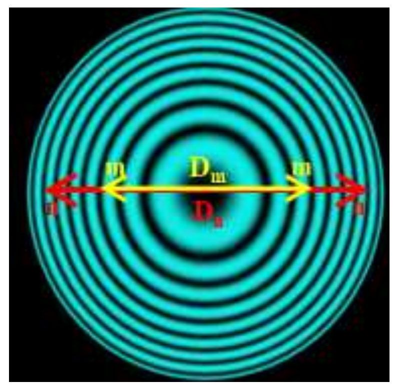


Plot of D^2 w.r.t. the number of rings

$$\lambda = \frac{D_n^2 - D_m^2}{4(n-m)R}$$

Using the above formula, the wavelength (λ) of a monochromatic light can be calculated.

Experimental

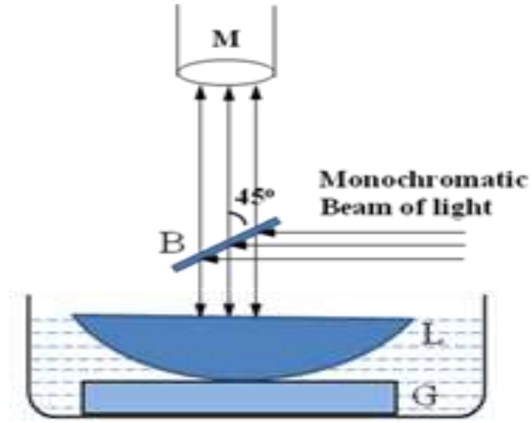


Experimental arrangements are made as given in Figure. After forming the Newton's rings, the microscope is adjusted so that the centre of the crosswire is adjusted at the central dark spot of the ring pattern. By counting the number of rings, the microscope is moved to the extreme left of the pattern and the cross wire is adjusted tangentially in the middle of the nth (21st) dark ring. The reading of the microscope is noted. Now the microscope is moved to the right and its readings are noted successively at $(n-3)^{th}$ (18^{th}), $(n-6)^{th}$ (15^{th}) … rings, etc., with a difference of three rings up to the central dark spot. Again crossing the central dark spot in the same direction, the readings corresponding to $(n-6)^{th}$ (15^{th}), $(n-3)^{th}$ (18^{th}) and n^{th} (21^{st}) rings are noted. The difference between the left and right reading gives the diameter of the particular ring. A graph is plotted between the number of the rings and the square of the corresponding diameter.

From the graph,

$$\frac{D_n^2 - D_m^2}{n-m} = \frac{AB}{CD}$$

The radius R of the plano convex lens can be obtained with the help of a spherometer. Substituting these values in the formula, the wavelength of the light source can be known



To determine the radius of curvature (R) of a curved surface:

The radius of curvature (R) of a curved surface can also be determined by measuring the diameters of various rings formed. For this purpose, Newton's Rings have been formed as shown in figure using the given curved surface of radius of curvature (R) with the monochromatic source of light of wavelength (λ). The value of R can be determined using the following formula.

We know that the $D_n = \sqrt{4n\lambda R}$

For n^th ring Diameter

$$D_n^2 = 4n\lambda R \longrightarrow \quad (1)$$

For m^th ring Diameter

$$D_m^2 = 4m\lambda R \longrightarrow \quad (2)$$

From equations (1)-(2) will get

$$D_n^2 - D_m^2 = 4(n-m)\lambda R \longrightarrow \quad (3)$$

$$R = \frac{D_n^2 - D_m^2}{4(n-m)\lambda}\,\text{Cm}$$

Using the above formula, the wavelength (R) radius of a curvature can be calculated.

To determine the refractive index (μ) of a transparent liquid:

The refractive index of a transparent liquid can be obtained by measuring the diameters of any two dark rings, in air and in the given liquid.

Newton's Rings have been formed by illuminating the lens and glass plate system placed in air with monochromatic source of light. Let Dm and Dn are the diameters of m^{th} and n^{th} dark rings, respectively.

We know that the

$$D_n = \sqrt{4n\lambda R}$$

For n^th ring Diameter

$$D_n^2 = 4n\lambda R \longrightarrow \quad (1)$$

For m^th ring Diameter

$$D_m^2 = 4m\lambda R \longrightarrow \quad (2)$$

From equations (1)-(2) will get

$$D_n^2 - D_m^2 = 4(n-m)\lambda R \longrightarrow \quad (3)$$

Now, the air film has been replaced with the liquid whose μ has to be determined without disturbing the lens-glass plate arrangement as shown in the figure.

Then we have $$\Rightarrow D_n^{2'} - D_m^{2'} = \frac{4(n-m)\lambda R}{\mu} \longrightarrow \quad (4)$$

From Eqs. (3) and (4), we obtain

$$\mu = \frac{D_n^2 - D_m^2}{D_n^{2'} - D_m^{2'}}$$

Using the above formula μ can be calculated.

1. Newton's rings are observed in the reflected light of wavelength 5900 Å. The diameter of 10th dark ring is 0.5 cm. Find the radius of curvature of the lens.

Given:

Wavelength of light used, $\lambda = 5900\ \text{Å} = 5900\times10^{-8}$ cm

Let Number of dark ring, n = 10

Diameter of 10th dark ring, $D_n = 0.5$ cm

Radius of curvature of the lens, R =?

Diameter of nth dark ring, $D_n = \sqrt{4n\lambda R}$

$$\Rightarrow D_n^2 = 4n\lambda R$$

$$\Rightarrow R = \frac{D_n^2}{4n\lambda}$$

$$\Rightarrow R = \frac{0.5^2}{4\times10\times5900\times10^{-8}}$$

$\therefore R = 105.9\ cm$

2. In a Newton's rings experiment, the diameter of 15th ring was found to be 0.59 cm and that of 5th ring is 0.336 cm. If the radius of curvature of lens is 100 cm, find the wave length of light.

Given:

Let Number of dark rings, n = 15 and m = 5

Diameter of 15th dark ring, $D_n = 0.59$ cm

Diameter of 5th dark ring, $D_m = 0.336$ cm

Radius of curvature of the lens, R = 100 cm

Wavelength of light used, λ =?

Wavelength of light, $\lambda = \dfrac{D_n^2 - D_m^2}{4(n-m)R}$

$$\Rightarrow \lambda = \frac{0.59^2 - 0.336^2}{4\times(15-5)\times100}$$

$\therefore \lambda = 5.88\times10^{-5}\ cm$

3. Calculate the thickness of air film at 10th dark ring in a Newton's rings system viewed normally by a reflected light of wavelength 500 nm. The diameter of 10th dark ring is 2mm.

Given:

Let Number of dark ring, n = 10

Wavelength of light used, λ = 500 nm

Diameter of 10th dark ring, D_n = 2 mm

In case of Newton's rings, the condition for dark ring is given as

$$2t = n\lambda \qquad \Rightarrow t = \frac{n\lambda}{2}$$

$$\Rightarrow t = \frac{10\times500\ nm}{2}$$

$\therefore t = 2500\ nm$

4. If the diameter of 20th dark ring has changed from 1.55 cm to 1.33 cm when a transparent liquid is introduced between the plano-convex lens and plane glass plate, find the refractive index of the liquid.

Given:

Let Number of dark ring, n = 20

Diameter of the ring in air, D_1 = 1.55 cm

Diameter of the ring in liquid, D_2 = 1.33 cm

Refractive index of liquid, μ =?

Diameter of dark ring, $D_n^2 = \dfrac{4n\lambda R}{\mu}$

With air medium, $D_1^2 = \dfrac{4n\lambda R}{1}$ $(\because\ for\ air\ \mu=1)$

With liquid medium, $D_2^2 = \dfrac{4n\lambda R}{\mu}$

$$\mu = \frac{D_1^2}{D_2^2} = \frac{1.55^2}{1.33^2}$$

$\therefore \mu = 1.358$

General questions:

1. What happens' the ring system, when air film is replaced with liquid film? Since $\mu_{air} < \mu_{liquid}$, the diameter of rings decreases.
2. Can we use polychromatic (white) light in Newton's Rings experiment?

   No. Because, a ring system with multiple colours is formed and there is distinction between bright and dark rings.
3. What happens' the ring system, when the lens is lifted upwards slowly? The ring system disappears due to increased thickness of air film.
4. What will happen to Newton's Rings if a plane glass plate is replaced by a plane mirror?

   No rings are formed. But uniform illumination will result. If the plane glass plate is replaced by a plane mirror, the transmitted light rays before will be reflected now. Due to the superposition between reflected and transmitted (now reflected) rays, uniform illumination will result.
5. What will happen to Newton's Rings if a plane glass plate is replaced by another plano- convex lens?

   More compressed rings will form. If the glass plate is replaced with another plano-convex lens, the optical paths changes more rapidly resulting rings to form more compressed rings.
6. Newton's Rings are circular. Why?

   Since the lens is symmetric along its axis, the thickness is constant along the circumference of a ring of given radius. Thus, Newton's rings are circular.
7. Why an extended source of light is required for the formation of Newton's rings?

   An extended source of light is a collection of large number of point sources and each point gives a beam of parallel rays. All the parallel rays from one point correspond to one Newton ring. Thus, an extended source of light is required for the formation of Newton's rings.
8. Newton's rings are not evenly spaced. Why?

   Since the diameter of the ring does not increase in the same proportion as the order of ring, they do not spaced evenly.