DETAILS OF THE TOPIC

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DETAILS OF THE TEACHER

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UNIT – II INTERFERENCE

SUPERPOSITION OF WAVES

When two or more wave trains act simultaneously on any particle in a medium, the displacement of the particle at any instant is due to the superposition of all the wave trains. Also, after the superposition, at the region of cross over, the wave trains emerge as if they have not intersected at all. Each wave train retains its individual characteristics. Each wave train behaves as if others are absent.

According to the principle of superposition, ***"When two or more waves overlap, the resultant displacement at any point and at any instant may be found by adding the instantaneous displacements that would be produced at the point by the individual waves if each were present alone."***

The phenomenon of interference of light is due to the superposition of two wave trains within the region of cross over. Interference is an important consequence of superposition of coherent waves. The phenomenon of interference of light has proved the validity of the wave theory of light.

INTERFERENCE

If two or more light waves of the same frequency overlap at a point, the resultant effect depends on the phases of the waves as well as their amplitudes. The resultant wave at any point at any instant of time is governed by the principle of superposition. The combined effect at each point of the region of superposition is obtained by adding algebraically the amplitudes of the individual waves. Let us assume here that the component waves are of the same amplitude.

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Fig. 1. Constructive interference

At certain points, the two waves may be in **phase**. The amplitude of the resultant wave will then be equal to sum of the amplitudes of the two waves (see Figure). Thus, the amplitude of the resultant wave

$$a_{\text{resultant}} = a + a = 2a$$

Hence, the intensity of the resultant wave is

$$I_{\text{resultant}} \propto (a_{\text{resultant}})^2 = (2a)^2 = 4a^2$$

It is obvious that the resultant intensity is greater than the sum of the intensities due to individual waves.

$$I_{\text{resultant}} > I + I = 2I$$

Therefore, the interference produced at these points is known as **constructive interference**. A **stationary bright band** of light is observed at points of constructive interference.

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Fig. 2. Destructive interference

At certain other points, the two waves may be in **opposite phase**. The amplitude of the resultant wave will then be equal to sum of the amplitudes of the two waves (see Figure). Thus, the amplitude of the resultant wave

$$a_{\text{resultant}} = a - a = 2a$$

Hence, the intensity of the resultant wave is

$$I_{\text{resultant}} \propto (a_{\text{resultant}})^2 = (0)^2 = 0$$

It is obvious that the resultant intensity is less than the sum of the intensities due to individual waves.

$$I_{\text{resultant}} < 2I$$

Therefore, the interference produced at these points is known as **destructive interference**. A **stationary dark band** of light is observed at points of destructive interference. Thus, we seen that a redistribution of energy took place in the region.

Thus, we can define interference as:

"The modification in the distribution of light energy obtained by the superposition of the two waves of equal frequency and constant phase difference in the region of superposition is called interference".

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OR

"The phenomenon of redistribution of light energy due to superposition of light waves from two or more coherent sources is known as interference."

COHERENT SOURCES

"Two sources are said to be coherent if they emit light waves of the same frequency, nearly the same amplitude and are always in phase with each other. It means that the two sources must emit radiations of the same colour (wavelength). "

In actual practice it is not possible to have two independent sources which are coherent. But for experimental purposes, two virtual sources formed from a single source can act as coherent sources. Methods have been devised where (i) interference of light takes place between the waves from the real source and a virtual source (ii) interference of light takes place between waves from two sources formed due to a single source. In all such cases, the two sources will act, as if they are perfectly similar in all respects.

Since the wavelength of light waves is extremely small (of the order of $10^{-5}\ cm$), the two sources must be narrow and must also be close to each other. Maximum intensity is observed at a point where the phase difference between the two waves reaching the point is a whole number multiple of 2π or the path difference between the two waves is a whole number multiple of wavelength.

For minimum intensity at a point, the phase difference between the two waves reaching the point should be an odd number multiple of π or the path difference between the two waves should be an odd number multiple of half wavelength.

CONDITIONS FOR INTERFERENCE

In order to obtain sustained or continuous interference of light waves at a place, the following conditions must be satisfied.

1. The two sources should be continuously emit waves of the **same wave-length or frequency**; otherwise the maxima, minima will change with time.
2. The two sets of wave trains from the two sources **should either have the same phase or a constant difference in phase,** *i.e.* **the two sources must be coherent.**
3. If the interfering waves are polarized, **their state of polarization must be the same.**
4. The separation between two coherent sources must be small, *i.e.* **they should be very close to each other,** otherwise, the path difference between the interfering waves will be large and the interference bands will be very close to each other, may even overlap. The maxima, minima will not appear as separate.
5. **The distance between the sources and screen should be reasonable.** Too large distance of the screen reduces the intensity. At too close distance the maxima, minima are quite close.
6. **The background must be dark.**
7. **The amplitudes of two waves must be equal or nearly equal.** In this case the cancellation of amplitudes will give zero. While the addition will make the amplitude double and the intensity four times. Thus, maxima and minima will be seen distinctly.
8. **The coherent sources must be narrow.** Otherwise a single source will act as a multi-source. It will, thus, result in a number of interference patterns and general illumination results.
9. **The sources should be monochromatic.** The fringe width will be constant and good intensity fringes will be observed.

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PHASE DIFFERENCE AND PATH DIFFERENCE

If the path difference between the two waves is λ, the phase difference $= 2\pi$. Suppose for a path difference x, the phase difference is δ. For a path difference λ, the path difference $= 2\pi$.

Therefore, for a path difference x, the phase difference $= \frac{2\pi x}{\lambda}$.

Therefore, phase difference,

$$\boldsymbol{\delta = \frac{2\pi x}{\lambda} = \frac{2\pi}{\lambda} \times (\text{Path Difference})}$$

Types of Interference

There are two methods of obtaining interference bands or fringes giving rise to two different classes of interference fringes.

(a) **Division of wave front:** The incident wavefront is divided into two parts, either by reflection or refraction. These two parts of the same wave front travel un equal distance and reunite at small angle to produce interference bands. **Youngs's double slit experiment, Fresnel's Biprism, Fresnel's double Mirror and Lloyd's Single Mirror are used to obtain interference by division of wavefront.**

(b) **Division of amplitude:** The amplitude of the incoming beam is divided into two, either by partial reflection or refraction. These divided parts reunite after traversing different paths and interfere constructively or destructively. In such cases broad sources are used. **Michelson interferometer, Newton's rings and parallel and wedge-shaped films are examples of this class of interference**.

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YOUNG DOUBLE SLIT EXPERIMENT

In the year 1982, Young demonstrated the experiment on the interference of light. He allowed sunlight to fall on a pinhole S and then at some distance away on two pinholes A and B. A and B are equidistant from S and are close to each other. Spherical waves spread out from S. Spherical waves also spread out from A and B. These waves are of the same amplitude and wavelength. On the screen interference bands are produced which are alternatively dark and bright. The points such as E are bright because the crest due to one wave coincides with the crest due to other and therefore, they reinforce with each other. The points such as F are dark because the crest of one falls on the trough of the other and they neutralize the effect of each other. Points, similar to E, where the trough of one falls on the trough of the other, are also bright because the two waves interfere.

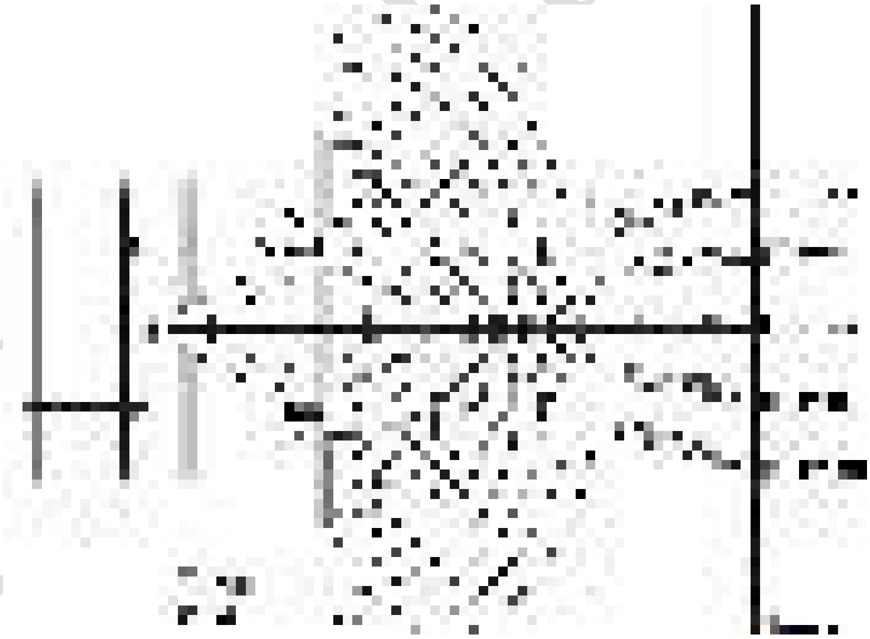

Fig. 3. Young's double slit experiment

It is not possible to show interference due to two independent sources of light, because a large number of difficulties are involved. The two sources may emit light waves of largely

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different amplitude and wavelength and the phase difference between the two may change with time.

INTENSITY DISTRIBUTION OF TWO INTERFERRING WAVES
(DOUBLE SLIT INTERFERENCE)

Consider a monochromatic source of light S emitting waves of wavelength λ and two narrow pinholes A and B. A and B are equidistant from S and act as two virtual coherent sources. Let a be the amplitude of the waves. The phase difference between the two waves reaching the point P, at any instant, is δ.

If y_1 and y_2 are the displacements,

$$y_1 = a \sin \omega t$$

$$y_2 = a \sin(\omega t + \delta)$$

$$\therefore \quad y = y_1 + y_2 = a \sin \omega t + a \sin(\omega t + \delta)$$

$$y = a \sin \omega t + a \sin \omega t \cos \delta + a \cos \omega t \sin \delta$$

$$y = a\,(1 + \cos \delta) \sin \omega t + a \sin \delta \cos \omega t.$$

Taking $\quad a(1 + \cos \delta) = R \cos \theta \quad \ldots(1)$

and $\quad a \sin \delta = R \sin \theta \quad \ldots(2)$

$$\Rightarrow \quad y = R \cos \theta \sin \omega t + R \sin \theta \cos \omega t$$

$$\Rightarrow \quad y = R \sin(\omega t + \theta) \quad \ldots(3)$$

which represents the equation of simple harmonic vibration of amplitude R.

Squaring (i) and (ii) and adding,

$$R^2 \sin^2\theta + R^2 \cos^2\theta = a^2 \sin^2\delta + a^2(1 + \cos \delta)^2 \quad \ldots(4)$$

$$\Rightarrow \quad R^2 = a^2 \sin^2\delta + a^2 + a^2 \cos^2\delta + 2a^2 \cos \delta$$

$$\Rightarrow \quad R^2 = 2a^2 + 2a^2 \cos \delta = 2a^2(1 + \cos \delta)$$

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$$\Rightarrow \qquad R^2 = 2a^2\left[1+\left\{2\cos^2\left(\frac{\delta}{2}\right)-1\right\}\right]$$

$$\Rightarrow \qquad \boxed{R^2 = 4a^2\cos^2\left(\frac{\delta}{2}\right)}$$

Special cases: (i) When the phase difference $\delta = 0, 2\pi, 2(2\pi), 3(2\pi), \ldots\ldots, n(2\pi)$, or the path difference $x = 0, \lambda, 2\lambda, 3\lambda, \ldots\ldots\ldots, n\lambda$.

$$\boxed{I = 4a^2} \qquad \ldots(5)$$

Intensity is maximum when the phase difference is a whole number multiple of 2π or the path difference is a whole number multiple of wavelength.

(ii) When the phase difference, $\delta = \pi, 3\pi, 5\pi, \ldots\ldots, (2n+1)\pi$, or the path difference, $x = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots\ldots, \frac{(2n+1)\lambda}{2}$.

$$\boxed{I = 0} \qquad \ldots(6)$$

Intensity is minimum when the path difference is an odd number multiple of half wavelength.

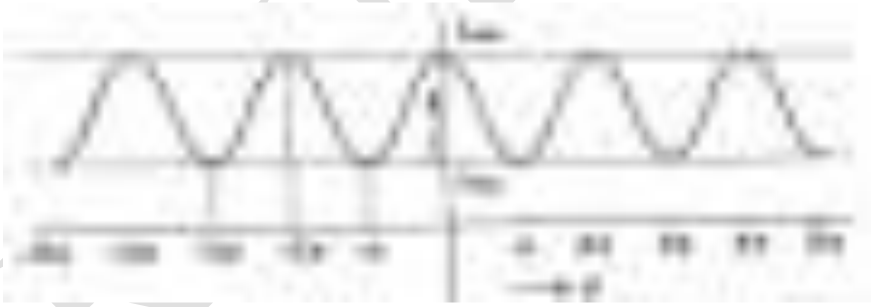

Fig. 4. Intensity variation with phase difference

Energy distribution: From equation (iv), it is found that the intensity at bright points is $4a^2$ and dark points it is zero. According to the law of conservation of energy, the energy cannot be destroyed. Here also the energy is not destroyed but only transferred from one points of minimum intensity to the maximum intensity. For, at bright points, the intensity due to the two waves should be $2a^2$ but actually it is $4a^2$. As shown in above Figure, the intensity varies from 0 to $4a^2$, and the average is still $2a^2$. It is equal to the uniform intensity $2a^2$ which will be

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present in the absence of the interference phenomenon due to the two waves. Therefore, the formation of interference fringes is in accordance with the law of conservation of energy.

THEORY OF INTERFERENCE FRINGES

Consider a narrow monochromatic source S and two pinholes A and B, equidistant from S. A and B act as two coherent sources separated by a distance d. Let a screen be placed at a distance D from the coherent sources. The point C on the screen is equidistant from A and B. Therefore, the path difference between the two waves is zero. Thus, the point C has maximum intensity.

Fig. 5. Optical path of interfering beams

Consider a point P at a distance x from C. The waves reach at point P from A and B.

Here, $$PQ = x - \frac{d}{2}, \quad PR = x + \frac{d}{2}$$

$$\therefore \quad (BP)^2 - (AP)^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right]$$

$$\Rightarrow \quad (BP)^2 - (AP)^2 = 2xd$$

$$\Rightarrow \quad (BP - AP)(BP + AP) = 2xd$$

$$\Rightarrow \quad (BP - AP) = \frac{2xd}{(BP + AP)}$$

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But $AP = D$ and $AP = D$ (approximately).

Therefore, **Path-difference =** $(\boldsymbol{BP - AP}) = \dfrac{\boldsymbol{2xd}}{\boldsymbol{2D}} = \dfrac{\boldsymbol{xd}}{\boldsymbol{D}}$ …(1)

and **Phase difference** $= \dfrac{\boldsymbol{2\pi}}{\boldsymbol{\lambda}}\left(\dfrac{\boldsymbol{xd}}{\boldsymbol{D}}\right)$ …(2)

$(\boldsymbol{i})$ **Bright fringes:** If the phase difference is a whole number multiple of wavelength λ, the point P is bright.

$$\therefore \qquad \frac{xd}{D} = n\lambda$$

where $n = 0, 1, 2, 3,$………..

$$\Rightarrow \qquad x = \frac{n\lambda D}{d} \qquad \dots(3)$$

This equation gives the distances of the bright fringes from the point C. At C, the path difference is zero and a bright fringe is formed.

When $n = 1, \quad x_1 = \dfrac{\lambda D}{d}$

$$n = 2, \quad x_2 = \frac{2\lambda D}{d}$$

$$n = 3, \quad x_3 = \frac{3\lambda D}{d}$$

$$n = 4, \quad x_2 = \frac{4\lambda D}{d}$$

$$\dots\dots\dots \quad x_n = \frac{n\lambda D}{d}$$

Therefore, the distance between any two consecutive bright fringes,

$$\boldsymbol{x_2 - x_1 = \frac{2\lambda D}{d} - \frac{\lambda D}{d} = \frac{\lambda D}{d}} \qquad \dots(4)$$

$(\boldsymbol{ii})$ **Dark fringes:** If the path difference is an odd number multiple of half wavelength, the point P is dark.

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$$\therefore \qquad \frac{xd}{D} = (2n + 1)\frac{\lambda}{2}$$

where $n = 0, 1, 2, 3, \ldots\ldots\ldots\ldots$

$$\Longrightarrow \qquad x = (2n + 1)\frac{\lambda D}{2d} \qquad \ldots(5)$$

This equation gives the distances of the dark fringes from the point C.

When $\qquad n = 0, \quad x_0 = \frac{\lambda D}{2d}$

$$n = 1, \quad x_1 = \frac{3\lambda D}{2d}$$

$$n = 2, \quad x_2 = \frac{5\lambda D}{2d}$$

$$n = 3, \quad x_2 = \frac{7\lambda D}{d}$$

$$\ldots\ldots\ldots \quad x_n = (2n + 1)\frac{\lambda D}{2d}$$

The distance between any two consecutive dark fringes,

$$\boxed{\boldsymbol{x_2 - x_1 = \frac{5\lambda D}{2d} - \frac{3\lambda D}{2d} = \frac{\lambda D}{d}}} \qquad \ldots(6)$$

The distance between any two consecutive bright or dark fringes is known as fringe width. Therefore, alternatively bright and dark parallel fringes are formed. The fringes are formed on both sides of C. Moreover, from equations (5) and (6), it is clear that the width of the bright fringe is equal to the width of the dark fringe. All the fringes are equal in width and are independent of the order of the fringe. The breadth of a bright or a dark fringe is, however, equal to half the fringe width and is equal to $\frac{\lambda D}{2d}$.

Thus, the fringe width

$$\boxed{\boldsymbol{\beta = \frac{\lambda D}{d}}} \qquad \ldots(7)$$

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Therefore, (i) the width of the fringe is directly proportional to the wavelength of light, $\beta \propto \lambda$, (ii) the width of the fringe is directly proportional to the distance of the screen from the two sources, $\beta \propto D$, (iii) the width of the fringe is inversely proportional to the distance between the two sources, $\beta \propto \frac{1}{d}$. Thus, the width of the fringe increases (a) with increase in wavelength (b) with increase in the distance D and (c) by bringing the two sources A and B close to each other.

INTERFERENCE BY DIVISION OF AMPLITUDE

In this type of interference, the incident amplitude is almost equally divided into two parts either by partial reflection or refraction. These divided amplitudes reunite to produce interference effects. Such effects are observed by illuminating thin films by a broad source of light. The colours of oil films in white light is well known example. If a soap film is observed in white light it appears coloured.

These interesting phenomena could be explained on the basis of interference (a) between light reflected from the top and bottom surface of a thin film (b) between the transmitted portion of the light.

INTERFERENCE DUE TO REFLECTION FROM PARALLEL THIN FILMS
(COLOUR OF THIN FILMS)

When a thin film, like that of oil, soap bubbles etc. are illuminated by white light, the brilliant colours are seen. These beautiful colours arise from the interference of light reflected between the two surfaces of thin films of transparent materials. In order to understand clearly how these interference effects are produced, consider a thin film of thickness 't' and refractive index μ. A monochromatic light wave of wavelength λ and amplitude 'a' from an extended source S is incident on the surface of film at A at an angle i. At A the light is partly reflected along AP and partly refracted along AE making angle of refraction 'r'. At E, part of the refracted light is again reflected along EB inside the film and a part is refracted out of the medium toward P_1 so that EP_1 is parallel to SA. At B the ray EB is again divided, partly reflected along BQ and partly reflected parallel to AE. Such reflections and refractions occur continuously. If two successive parallel and refracted rays are allowed to interfere, then interference patterns are observed, because of path difference between interfering rays.

To find the path difference between a pair of successive rays AP and BQ, first of all draw BN perpendicular to AP.

Fig. 6. Path difference in reflected light

The optical path difference between the two rays AP and BQ

$$= \mu(AE + EB) - AN$$

$$= \mu(GE + EB) - AN$$

$$= \mu(GB) - AN$$

$$= \mu(GM + MB) - AN$$

$$= \mu\, GM + \mu\, MB - AN$$

But $$\mu = \frac{\sin i}{\sin r} = \frac{AN/AB}{MB/AB} = \frac{AN}{MB}$$

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$$\Rightarrow \quad AN = \mu\, MB$$

$$\therefore \quad \text{Path difference} = \mu\, GM + \mu\, MB - \mu\, MB$$

$$= \mu\, GM$$

$$= \mu\, AG\, \cos r$$

$$= \mu\,(2\, AL)\, \cos r \quad (\because AG = 2\, AL)$$

$$\Rightarrow \quad \boxed{\textbf{Path difference} = 2\mu t \cos r} \quad (\because AL = t)$$

Since the ray AP suffers reflection at A, on the surface of a denser medium, it undergoes a path difference of $\lambda/2$ on reflection, while the ray BQ does not, since it is reflected at E, the surface of a rarer medium. The correct path difference between the two rays AP and BQ.

$$\therefore \quad \boxed{\text{Path difference} = 2\mu t \cos r \pm \frac{\lambda}{2}} \quad \ldots(1)$$

Now (i) the film appears bright if the path difference

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

$$\Rightarrow \quad \boxed{\mathbf{2\mu t \cos r = (2n \pm 1)\frac{\lambda}{2}}} \quad \ldots(2)$$

It is a condition for maximum.

Here second ray will be in phase with the first, but third, fifth and seventh etc. will be out of phase with second, fourth, sixth etc. Since the second ray is more intense than other rays, these pairs cannot cancel each other. These rays combine with the first, which is the strongest of all and give a maximum intensity.

(ii) the film appears dark if the path difference

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

$$\Rightarrow \quad \boxed{\mathbf{2\mu t \cos r = n\lambda}} \quad \ldots(3)$$

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

$\Rightarrow$ $$\boldsymbol{2\mu t\cos r = (n+1)\lambda} \quad \ldots(4)$$

Equations (3) and (4) represent the condition for a minimum.

Here second ray is out of phase with the first, but first is much stronger than the second so that the two will not completely annal each other. The addition of the third, fourth and fifth etc. which are all in phase with the second will be sufficient to produce complete darkness at the minimum.

INTERFERENCE DUE TO TRANSMITTED LIGHT FROM PARALLEL THIN FILM

Consider a thin film of thickness 't' and refractive index μ. A monochromatic light wave of wavelength λ and amplitude 'a' from an extended source S is incident on the surface of film at A at an angle i. At A the light is partly reflected along AP and partly refracted along AE making angle of refraction 'r'. Inside the film reflections and reflections occur continuously. The transmitted rays emerging from the lower side of the film are allowed to interfere. Thus causing interfere patterns due to path difference between interfering rays. The path difference between the two transmitted rays EP_1 and FQ_1 is given by

$$= \mu(AE + EB + BF - AE) - EN$$

$$= \mu(EB + BG) - EN$$

$$= \mu(EG) - EN$$

But $$\mu = \frac{\sin i}{\sin r} = \frac{EN/EF}{EM/EF} = \frac{EN}{EF}$$

$\Rightarrow$ $$EN = \mu\, EM$$

$\therefore$ $$\text{Path difference} = \mu\, EG - \mu\, EM$$

$$= \mu\, MG$$

$$= \mu\, FG\ \cos r$$

$$= \mu\,(2\, FL)\ \cos r \quad (\because FG = 2\, FL)$$

$$\Rightarrow \quad \boxed{\textbf{Path difference} \ = 2\mu t \cos r} \quad (\because FL = t) \qquad \ldots(1)$$

Since here reflection always takes place on the surface of rarer medium so that there is no extra path difference introduced on its account.

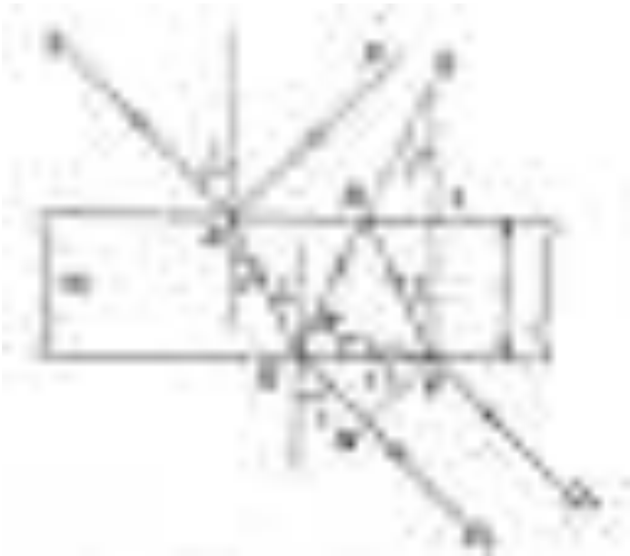

Fig. 7. Path difference in transmitted light

The film appears bright if

$$\therefore \quad \boxed{2\mu t \cos r \ = n\lambda} \qquad \ldots(2)$$

It is a condition for maximum.

and **it appears dark if**

$$\therefore \quad \boxed{2\mu t \cos r \ = (2n+1)\frac{\lambda}{2}} \qquad \ldots(3)$$

where $n = 0, 1, 2, 3, \ldots\ldots\ldots$,etc.

The conditions (2) and (3) for transmitted light are obviously opposite to those obtained with reflected light. A bright band in the reflected system will be a dark band in the transmitted system for the same path difference. **Thus, the two systems are complementary.**

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EXPLANATION FOR COLOUR PRODUCTION IN THIN FILM

When the film is exposed to white light, brilliant colours are seen due to following reasons:

1. The path difference between the rays reflected from the top and bottom of the film, $2\mu t\cos r$, depends upon μ, t and r. If t and r are kept constant the path difference would change with μ or the wavelength of light used. Since white light is composed of different colours, the path difference will be different for difference colours, so that with white light the film shows various colours from violet to red.
2. Since the path difference varies with the thickness of the film so that it passes through various colours for the same angle of incidence when seen in white light.
3. Since the path difference changes with the angle r and angle r changes with angle i so the film assumes various colours when viewed from different directions with white light.

NEED OF AN EXTENDED SOURCE

Interference fringes obtained in the case of Young's double slit experiment were produced by two coherent sources. The source used is narrow. These fringes can be obtained on the screen or can be viewed with an eye-piece. In the case of interference in thin films, the narrow source limits the visibility of the film.

Fig. 8. Illumination of film by (a) point source (b) extended source

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Consider a thin film and a narrow source of light S [Fig. 7(a)]. The ray 1 produces interference fringes because 3 and 4 reach the eye whereas the ray 2 meets the surface at some different angle and is reflected along 5 and 6. Here 5 and 6 do not reach the eye. Similarly, we can take other rays incident at different angles on the film surface which do not reach the eye. Therefore, portion A of the film is visible and not the rest. If an extended source of light is used [Fig. 7(b)], the ray 1 after reflection from the upper and the lower surface of the film emerges as 3 and 4 which reach the eye. Also ray 2 from some other point of the source after reflection from the upper and the lower surfaces of the film emerges as 5 and 6 which also reach the eye. Therefore, in the case of such source of light, the rays incident at different angles on the film are accommodated by the eye and the field of view is large. Due to this reason, to observe interference phenomenon in thin films, a broad source of light is required. Hence the colours due to whole film will be visible.

INTERFERENCE BY WEDGE-SHAPED FILM

If two thin plane surfaces, OA and OB, of glass are slightly inclined to each other at an angle θ and enclose a liquid or some other material of refractive index μ, are said to form wedge shaped film. Let the wedge be illuminated by a monochromatic light from a slit held parallel to the edges of the wedge in contact. Interference occurs between the rays reflected at the surfaces above and below the film respectively and the parallel interference bands result [see Fig. 8(a)]. The effect is best observed when angle of incidence is small.

If t is the thickness of the film at a distance x from the edge, the path difference between the two reflected rays producing interference will be $2\mu t\cos r \pm \lambda/2$.

The condition for brightness is $$2\mu t\cos r - \frac{\lambda}{2} = n\lambda$$

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

And condition for darkness is $\quad 2\mu t\cos r = n\lambda \quad$ where, $n = 0, 1, 2, 3, \ldots\ldots$

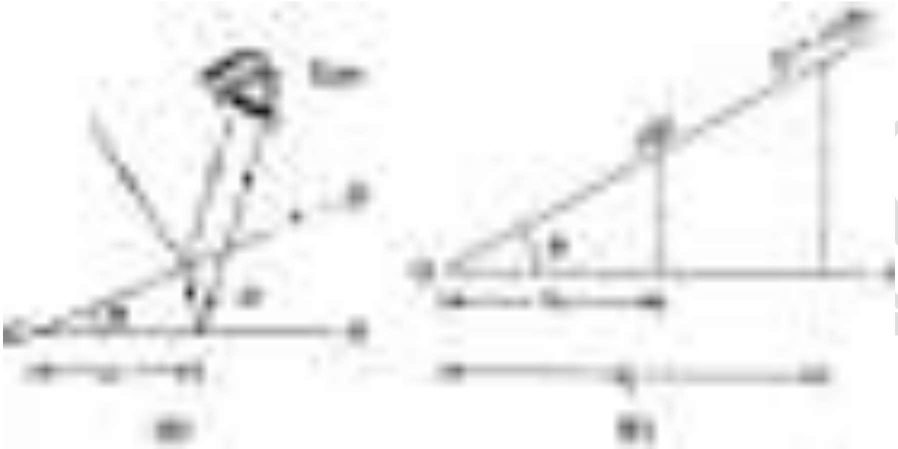

Fig. 9. Interference in wedge-shaped film

The film appears bright when 't' the thickness of film satisfies

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

For $n = 0$: $\quad t = \dfrac{\lambda}{4\mu\cos r}$

For $n = 1$: $\quad t = \dfrac{3\lambda}{4\mu\cos r}$

For $n = 2$: $\quad t = \dfrac{5\lambda}{4\mu\cos r}$ $\quad$,………., etc.

The film will appear dark if 't' satisfies the condition

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

For $n = 0$: $\quad t = 0$

For $n = 1$: $\quad t = \dfrac{\lambda}{2\mu\cos r}$

For $n = 2$: $\quad t = \dfrac{2\lambda}{2\mu\cos r}$ $\quad$,………, etc.

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It is observed that in the direction of increasing thickness of the film there will alternate bright and dark fringes parallel to the edge of the film.

Further, for small angle of incidence, $\cos r = 1$ because angle r will also be small. For small angle θ, the thickness $t = x\theta$, thus the condition for darkness reduces to

$$2\mu\, x\, \theta = n\lambda$$

If x_1 is the distance of the nth dark band from the edge of the wedge and x_2 that of the $(n+m)$th dark band [Fig. 8(b)] then

$$x_1 = \frac{n\lambda}{2\mu\theta} \text{ and } \quad x_2 = \frac{(n\,+\,m)\lambda}{2\mu\theta}$$

Therefore,
$$x_2 - x_1 = \frac{(n\,+\,m)\lambda}{2\mu\theta} - \frac{n\lambda}{2\mu\theta}$$

$$\Rightarrow \quad \boxed{x_2 - x_1 = \frac{m\lambda}{2\mu\theta}}$$

From this result one can find (i) λ if μ and θ are known (ii) μ when θ and λ are given and (iii) θ when μ and λ are given. Here $(x_2 - x_1)$ is the distance corresponding to m fringes. The fringe width

$$\boxed{\beta = \frac{x_2 - x_1}{m} = \frac{\lambda}{2\mu\theta}}$$

If white light is used to illuminate the film, each wavelength of the different colours of white light produces its own system of interference fringes. The fringe width of violet will be minimum and that of red be maximum. At the edge of the film, $t = 0$ hence the path difference will be $\lambda/2$ and each constituent wavelength of white light gives minimum intensity at the edge and the edge of film will appear dark. In the direction of increasing thickness, few coloured fringes of mixed colour are obtained. At large thickness of the film there is overlapping of the fringes which produces uniform illumination.

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FRINGES OF EQUAL THICKNESS (FIZEAU FRINGES)

In thin film of thickness of the order of a few λ, the rays from various parts of the film have almost the same inclination and hence the path difference between the overlapping waves changes mainly due to the changes of thickness. The fringes produced in such cases are mainly due to the variation in thickness of the film. Each fringe will be the locus of points of the same thickness. Such fringes are called **fringes of equal thickness.** The fringes of equal thickness are also known as **Fizeau fringes**.

Newton's rings are formed as result of interference between light waves reflected from the top and bottom surfaces of a thin air film enclosed between a plano-convex lens and a plane glass plate. The occurrence of alternate bright and dark rings depends on the optical path difference arising between the reflected rays. If the light falls normally on the air film the optical path difference between the waves reflected from the two surfaces of the film is

$$\Delta = 2t - \lambda/2$$

It is seen that the path difference between the reflected rays arises due to the variation in the thickness t of the air film. Reflected light will be of minimum intensity for those thickness or which the path difference is $m\lambda$ and maximum intensity for those thickness for which the path difference is $(2m + 1)\lambda/2$. Thus, each maxima and minima is a locus of constant film thickness. Therefore, the fringes are known as fringes of equal thickness.

FRINGES OF EQUAL INCLINATION (HAIDINGER FRINGES)

In thin films interference fringes are produced due to the path difference $2\mu t \cos r$ between the overlapping rays. For a given film the path difference may arise due to (i) the angle of refraction r inside the film or (ii) the change in thickness.

We can express the change in path difference by differentiating the expression $2\mu t \cos r$.

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Change in path difference, $\delta(\Delta) = 2\mu t\, \delta(\cos r) + 2\mu t \cos r\, \delta(t)$

When the film is of uniform (constant) thickness, the change is path difference is only due to the change in r. If the thickness of the film is large, the path difference will change appreciably even when r changes in a small way. Fringes are produced in this case due to the superposition of rays, which are equally inclined to the normal. These fringes are called **fringes of equal inclination**. The fringes of equal inclination are also known as **Haidinger fringes**.

In this case all the pairs of interfering rays of equal inclination pass through the plate as a parallel beam and hence meet at infinity. The other pairs of different inclination meet at different points at infinity. Therefore, they can be located with a telescope focussed to infinity. The fringes are therefore said to be localized at infinity. To produce Haidinger fringes, the source must be an extended source, the film thickness must be appreciably large and the observing instrument is to be focussed for parallel source.

NEWTON'S RINGS

It is the case of interference in a wedge-shaped thin film of variable thickness, the film of air or particular liquid is enclosed between a glass plate and convex lens. The thickness of the film at the point of contact is very small and gradually increases from the centre outwards, but the thickness of the film has only one value along a particular circle. The thickness of the film along different circles is different and increases with radii.

When the air film is illuminated normally by monochromatic light circular interference fringes are observed. The fringes are concentric circles, uniform in thickness and with point of contact as the centre. With monochromatic light, bright and dark circular fringes are produced in air film. The rings gradually become narrower as their radii increase. When viewed with white light the fringes are coloured. The interference rings so formed were first investigated by

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Newton and were called Newtons's rings. These rings are used to measure the wavelength of monochromatic light and refractive index of rare liquids.

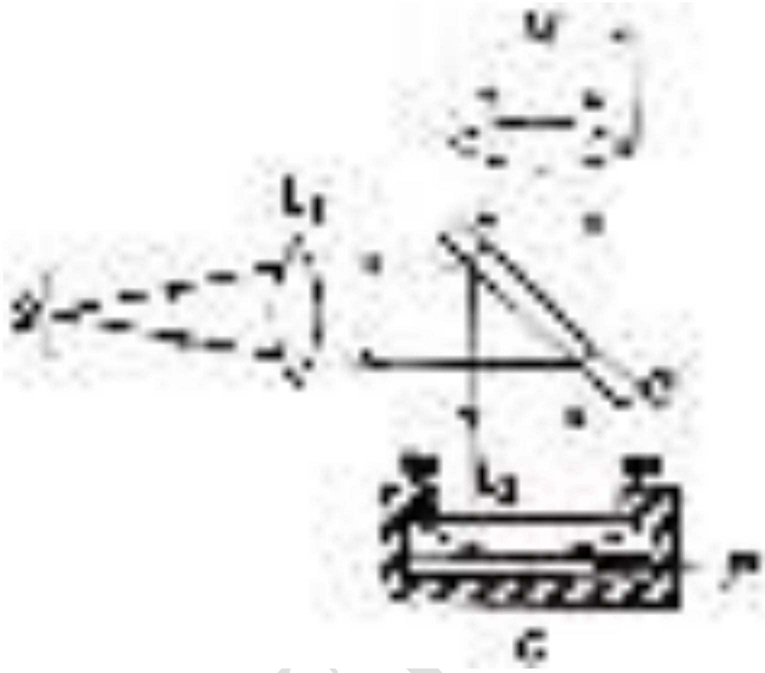

Fig. 10. Experimental arrangement for Newton's rings

Experimental Arrangement: An experimental setup to form Newton's rings is shown in the Figure. L_2 is a plano-convex lens of large radius of curvature, it is placed on an optically plane glass plate P. The convex surface of lens makes contact with the plate at point C and encloses a thin film of air or a rare transparent liquid forming a thin wedge-shaped film. The light from a monochromatic extended source is held parallel by convex lens L_1 and is incident on the glass plate G reflects the light vertically downward. Part of the light is reflected from the curves surface of the lens L_2 and the transmitted part is reflected from the surface of the glass plate P. This reflected part suffers a phase change of π because the air film is backed by the glass plate. These two reflected rays interfere and give rise to an interference pattern in the form of circular rings. These rings are localized in the air film. If a travelling microscope M is focused at the point of contact of the lens and plate, concentric rings alternatively dark and bright are seen. The central ring is dark.

NEWTON'S RING BY REFLECTED LIGHT

The mechanism of interference by reflected beams of light is shown below. An incident wave along AB is divided into two at B. The first reflected part is BD. It is reflected by the curved surface of the lens. The second reflected part is $B'D'$. These interfere to give the pattern in reflected beam. The transmitted pattern can also be seen along TT'. In order to remove the transmitted part and reflection from the lower surface of the plate, the lower surface of the plate is blackened.

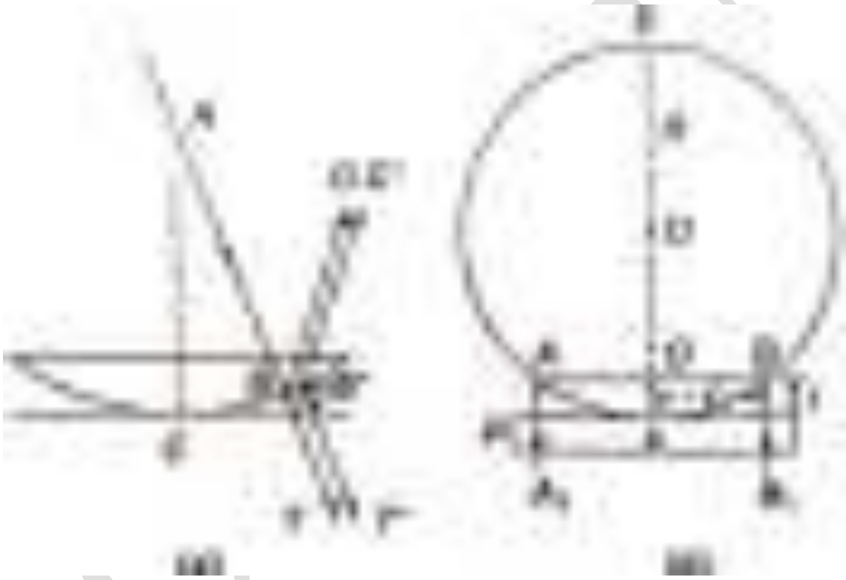

Fig. 11. Newton's rings by reflected light

Theory: Suppose R is the radius of curvature of the convex surface of the lens and C the point of contact of the lens with the plane surface such that the points A and B are equidistant from C. Completing the circle $ACBE$ as shown below, draw AA_1 and BB_1 perpendiculars to the plane A_1B_1. Let $AA_1 = BB_1 = t$ be the thickness of the air film at a distance r $(= CA_1 = CB_1)$ from the point of contact C of the lens with the plate.

From the geometry of the circle, we have

$$ED \times DC = AD \times DB$$

$$\Rightarrow \qquad (CE - CD) \times DC = AD \times DB$$

$$\Rightarrow \qquad (2R - t) \times t = t \times t$$

where r is the radius of the ring.

As R the radius of curvature of the lens is very large as compared to thickness t of the film, so that t^2 can be neglected as compared to $2Rt$.

$$\therefore 2Rt = r^2 = \left(\frac{AB}{2}\right)^2 = \left(\frac{d}{2}\right)^2 = \frac{d^2}{4}$$

$$\Rightarrow \qquad \frac{d^2}{4R} = 2t \qquad \ldots(1)$$

where d is the diameter of the ring.

The path difference between the two rays, one reflected from A and other from $A_1 = 2\mu t \cos r$.

Since one of the rays is reflected from the denser medium (at A_1 or B_1), a further path difference of $\lambda/2$ is introduced because of reflection under different conditions. Thus, the points A and B will lie on a bright ring of diameter AB if the total path difference is

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

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

Here r is angle of reflection. Since the rays are incident practically normal, so that angle r is nearly zero i.e. $\cos r \approx 1$.

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

$$\Rightarrow \qquad 2t = \frac{(2n - 1)\ \lambda/2}{\mu} \qquad \ldots(2)$$

Putting the value of $2t$ from equation …., we get the condition for nth bright ring

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$$\frac{d_n^2}{4R} = \frac{(2n-1)\ \lambda/2}{\mu}$$

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

$$\Rightarrow \qquad d_n = \sqrt{\frac{(2n-1)\ 2R\lambda}{\mu}}$$

Since, R, λ and μ are constants, therefore $d_n \propto \sqrt{(2n-1)}$ …(3)

Thus, the dimeters of the bright rings are proportional to the square root of odd natural numbers. Similarly, the points A and B will lie on the dark ring when path difference

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

$$\Rightarrow \qquad 2\mu t \cos r = n\lambda$$

For small r, $\cos r \approx 1$, $2\mu t = n\lambda$

$$\Rightarrow \qquad 2t = \frac{n\lambda}{\mu}$$ where $n = 0, 1, 2, \ldots\ldots$, etc.

Putting the value of $2t$ from equation …., we get the condition for nth dark ring

$$\frac{d_n^2}{4R} = \frac{n\lambda}{\mu}$$

$$\Rightarrow \qquad d_n^2 = \frac{4Rn\lambda}{\mu}$$

$$\Rightarrow \qquad d_n = \sqrt{\frac{4Rn\lambda}{\mu}}$$

Since, R, λ and μ are constants, therefore $d_n \propto \sqrt{n}$ …(4)

Thus, the diameters of the dark rings are proportional to the square roots of the natural numbers.

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Fig. 12. Newton's rings in reflected system

When $n = 0$, the diameter of the dark ring is zero and the diameter of the bright ring is $\sqrt{\frac{4R\lambda}{\mu}}$.

Therefore, the central ring is dark. Alternatively, dark and bright rings are produced as shown below. While counting the order of the dark rings 1, 2, 3, ….., etc. the central ring is not counted.

Therefore, the first dark ring, $n = 1$ $\quad d_1 = 2\sqrt{\lambda R/\mu}$

For second dark ring, $n = 2$ $\quad d_2 = 2\sqrt{2\lambda R/\mu}$

Similarly, $\quad d_3 = 2\sqrt{3\lambda R/\mu}$

and $\quad d_4 = 2\sqrt{4\lambda R/\mu}$ and so on.

The difference in the diameters of two nearest dark rings is given by

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$$d_2 - d_1 = 2\sqrt{\frac{2\lambda R}{\mu}} - 2\sqrt{\frac{\lambda R}{\mu}} = 2\sqrt{\frac{\lambda R}{\mu}}\left(\sqrt{2} - 1\right) = 0.414 \times 2\sqrt{\frac{\lambda R}{\mu}}$$

$$d_3 - d_2 = 2\sqrt{\frac{3\lambda R}{\mu}} - 2\sqrt{\frac{2\lambda R}{\mu}} = 2\sqrt{\frac{\lambda R}{\mu}}\left(\sqrt{3} - \sqrt{2}\right) = 0.318 \times 2\sqrt{\frac{\lambda R}{\mu}}$$

$$d_4 - d_3 = 2\sqrt{\frac{4\lambda R}{\mu}} - 2\sqrt{\frac{3\lambda R}{\mu}} = 2\sqrt{\frac{\lambda R}{\mu}}\left(\sqrt{4} - \sqrt{3}\right) = 0.268 \times 2\sqrt{\frac{\lambda R}{\mu}}$$

Hence, the dark rings gradually become narrower as their radii increase. Similarly, it can be shown that bright rings also gradually narrower as their radii increase.

NEWTON'S RING BY TRANSMITTED LIGHT

Newton's rings can also be obtained from the transmitted light. The interference fringes in the transmitted system are produced by the interference of the two transmitted waves BC and B_1C_1. The wave BC originates from AB by single reflection at B while the wave B_1C_1 also originates from AB by two reflections, one at B and the other at A_1 and then a reflection at B_1. At each reflection a phase change of π is introduced so that a total phase change of $\pi + \pi = 2\pi$ is introduced in B_1C_1, which physically means no phase change. Thus the only phase difference between the two waves BC and B_1C_1 is due to the difference in their optical paths travelled $i.e.$ $2\mu t\cos r$, where t is the thickness of the wedge shaped film, μ the refractive index of liquid or any other material, r is the angle of refraction. If the light is incident normally then $r = 0$, thus $2\mu t\cos r = 2\mu t$ as $\cos 0 = 1$.

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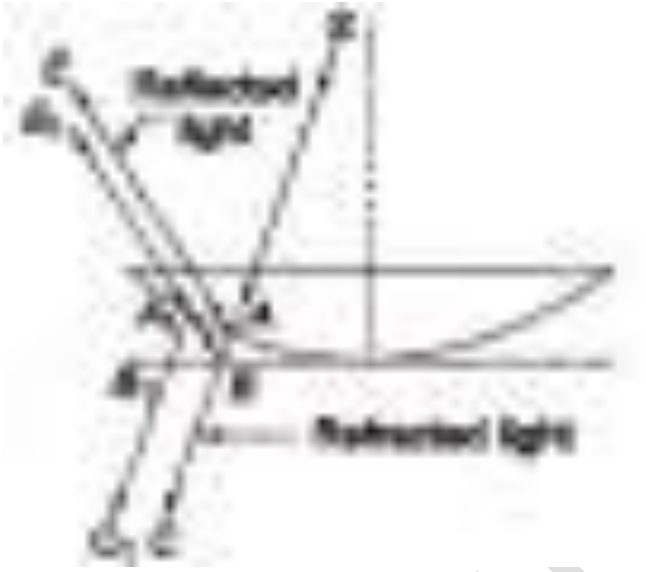

Fig. 13. Newton's rings formation by transmitted light

For bright rings $$2\mu t = n\lambda \qquad \ldots(5)$$

and for dark rings $$2\mu t = (2n-1)\frac{\lambda}{2} \qquad \ldots(6)$$

Taking the value of $2t = \frac{d^2}{4R}$ from equation (1), where the symbols have their usual meaning, the diameter for the bright and dark rings can be calculated. For nth bright ring

$$\frac{d_n^2}{4R} = \frac{n\lambda}{\mu}$$

$$\Rightarrow \qquad d_n^2 = \frac{4n\lambda R}{\mu} \qquad \text{where } n = 0, 1, 2, \ldots, \text{etc} \qquad \ldots(7)$$

and for nth dark ring $$\frac{d_n^2}{4R} = \frac{(2n-1)}{\mu}\frac{\lambda}{2}$$

$$\Rightarrow \qquad d_n^2 = \frac{2(2n-1)\lambda R}{\mu} \qquad \ldots(8)$$

where $n = 1, 2, 3, \ldots\ldots$, etc.

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Fig. 14. Newton's rings formation by transmitted light

When $n = 0$, for bright rings, the diameter is zero *i.e.*, in case of Newton's rings due to transmitted light the central ring is bright. On comparing equations (7) and (8) with equation (3) and (4), it is evident that a dark ring in the reflected system becomes a bright ring in the transmitted system and vice-versa. The central spot which is dark in the reflected system is bright in the transmitted system. **Thus, the two systems are complementary to each other.**

MEASUREMENT OF WAVELENGTH

To determine the wavelength λ of light, the source S is replaced by a given source of monochromatic light. Focus the travelling microscope on the Newton's rings formed. Measure the diameter d_n and d_{n+m} of the nth and $(n + m)$th dark rings with its help. Find the radius of curvature R of the lower surface of the lens with the help of a spherometer. Taking $\mu = 1$ for air, the wavelength λ of light can be calculated as follows:

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As d_n is the diameter of the nth dark ring: $$\frac{d_n^2}{4R} = \frac{n\lambda}{\mu} \quad \ldots(1)$$

and d_{n+m} is the diameter of the nth dark ring: $$\frac{d_{n+m}^2}{4R} = \frac{(n+m)\lambda}{\mu} \quad \ldots(2)$$

Subtracting, we get $$\frac{d_{n+m}^2 - d_n^2}{4R} = \frac{m\lambda}{\mu}$$

$$\Rightarrow \quad \lambda = \frac{\mu\left(d_{n+m}^2 - d_n^2\right)}{4Rm} \quad \ldots(3)$$

If $\mu = 1$ (air) then $$\boxed{\lambda = \frac{d_{n+m}^2 - d_n^2}{4Rm}} \quad \ldots(4)$$

Thus, the wavelength of the given source can be calculated.

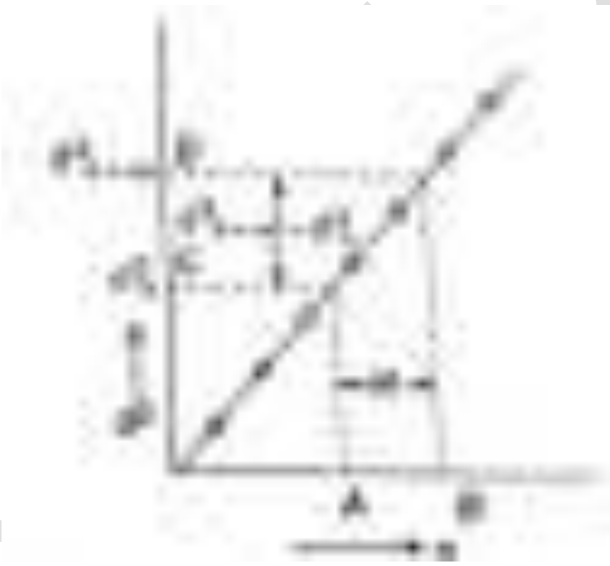

Fig. 15. Plot of the number of rings versus square of diameter

A graph is plotted between a number of rings 'n' and square of diameter of corresponding ring. From the graph:

$$\boxed{\frac{d_{n+m}^2 - d_n^2}{m} = \frac{CD}{AB}} \quad \ldots(5)$$

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DETERMINATION OF REFRACTIVE INDEX OF LIQUID

The transparent liquid whose refractive index is to be measured is introduced between the lens and the glass plate. The diameters of the nth and $(n+m)$th dark rings are measured with the help of a travelling microscope. Measuring the radius of curvature R of the lower surface of the lens with a spherometer and knowing the wavelength of light employed, value μ for given liquid is calculated as under:

As d_n is the diameter of the nth dark ring: $$\frac{d_n^2}{4R} = \frac{n\lambda}{\mu} \quad \ldots(1)$$

and d_{n+m} is the diameter of the nth dark ring $$\frac{d_{n+m}^2}{4R} = \frac{(n+m)\lambda}{\mu} \quad \ldots(2)$$

Subtracting, we get $$\frac{d_{n+m}^2 - d_n^2}{4R} = \frac{m\lambda}{\mu}$$

$$\Rightarrow \quad \boxed{\mu = \frac{4m\lambda R}{(d_{n+m}^2 - d_n^2)}} \quad \ldots(3)$$

Taking the diameter of the bright ring instead of the dark ring, similar relation can be deduced as below:

For nth bright ring: $$\frac{d_n^2}{4R} = \frac{(2n-1)}{\mu}\frac{\lambda}{2} \quad \ldots(4)$$

For $(n+m)$th bright ring: $$\frac{d_{n+m}^2}{4R} = \frac{(2n+2m-1)}{\mu}\frac{\lambda}{2} \quad \ldots(5)$$

Subtracting $$\frac{d_{n+m}^2 - d_n^2}{4R} = \frac{m\lambda}{\mu}$$

$$\Rightarrow \quad \boxed{\mu = \frac{4m\lambda R}{(d_{n+m}^2 - d_n^2)}} \quad \ldots(6)$$

which is the same as equation (3).

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When the wavelength of light used is not known, then we measure the diameter of a particular dark ring (say nth) with air and then with the liquid introduced in between the lens and the glass plate. Suppose d_{air} and d_{liq} are the diameters of the nth dark rings in the two cases, then

$$d_{air}^2 = \frac{4nR\lambda}{1}$$

and

$$d_{liq}^2 = \frac{4nR\lambda}{\mu}$$

Dividing we get

$$\boxed{\mu = \left(\frac{d_{air}^2}{d_{liq}^2}\right)} \qquad \ldots(7)$$

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PROBLEM SET – INTERFERENCE OF LIGHT

MULTIPLE CHOICE QUESTIONS

1. Two coherent sources of light produce constructive interference when the phase difference between them is

   (a) π (b) 2π (c) $3\pi/2$ (d) $\pi/2$

2. Two coherent sources of light produce destructive interference when the phase difference between them is

   (a) π (b) 2π (c) $3\pi/2$ (d) $\pi/2$

3. A phase difference of π between the two waves reaching a point is equal to the path difference of

   (a) $\lambda/2$ (b) λ (c) 2λ (d) $\lambda/4$

4. A phase difference of 2π between the two waves reaching a point is equal to the path difference of

   (a) $\frac{\lambda}{2}$ (b) λ (c) 2λ (d) $\frac{\lambda}{4}$

5. In Newton's rings the diameter of the rings is proportional to

   (a) λ (b) λ^2 (c) $\sqrt{\lambda}$ (d) $1/\sqrt{\lambda}$

6. The brilliant colours in thin films of soap are due to

   (a) dispersion (b) diffraction (c) scattering (d) interference

7. Interference and diffraction of light supports in

   (a) Wave nature (b) quantum nature (c) transverse nature

   (d) electromagnetic nature

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8. Two coherent monochromatic light beams of intensities I and $4I$ are superposed. The maximum and minimum possible intensities in the resulting beam are

   (a) $5I$ and I (b) $5I$ and $3I$ (c) $9I$ and I (d) $9I$ and $3I$

9. Two beams of light having intensities I and $4I$ interfere to produce a fringe pattern on a screen. The phase difference between the beams is $\pi/2$ at a point A and π at point B. Then the difference between resultant intensities at A and B is

   (a) $2I$ (b) $4I$ (c) $5I$ (d) $7I$

10. If the monochromatic source of light in Young's double slit experiment is replaced by a white-light source, then

    (a) No fringes will be formed.

    (b) there will be white fringes only.

    (c) There will be a coloured central fringe only.

    (d) There will be a central white fringe flanked on either side by a few coloured fringes.

SHORT QUESTIONS

1. What do you understand by phase difference and path difference?
2. Explain the phenomenon of interference of light.
3. What is a coherent source?
4. What are the conditions for interference of light?
5. State the conditions of maxima and minima in interference pattern.
6. What is fringe width?
7. Distinguish between division of wavefront and division of amplitude.
8. What do you understand about Newton's rings?

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9. The central spot in the Newton's rings is dark in reflected system and bright in transmitted system. Explain.
10. Why Newton's rings are circular?
11. Write short notes on colour of thin film.
12. Write down the conditions for sustained interference pattern.
13. Write short note on Young's double slit experiment.

LONG QUESTIONS

1. Explain the terms phase difference, wave front, coherent sources and incoherent sources. List some of the methods to obtain coherent sources.
2. Explain the phenomenon of interference of light. What are the conditions for interference of light? Explain constructive and destructive interference.
3. Discuss the theory of interference due to two slits and find the expression for fringe width.
4. Show that in Young's double slit experiment, the fringe width is directly proportional to the wavelength of light.
5. Explain with mathematical treatment, the formation of Newtons's rings.
6. What are Newton's rings? Explain how can these be used to find the wavelength of light.
7. Give necessary theory of Newton's rings method for determining the refractive index of liquid and derive the expression used.
8. With the help of a neat diagram, show an experimental arrangement to produce Newton's rings by reflected sodium light. Prove that in reflected light the diameter of dark rings are proportional to the square root of the natural number.

9. Explain the interference exhibited by thin wedge-shaped film and find the expression for fringe width.
10. What do you understand by division of wave front and division of amplitude? In what context these phenomena are used? Give examples.
11. Discuss the formation of Newton's rings by (i) reflected light (ii) transmitted light. Derive an expression for diameter of nth dark ring in reflected light.

NUMERICAL QUESTIONS

1. Two coherent sources whose intensity ratio is 9: 4 produce interference fringes. Deduce the ratio of maximum to minimum intensity of the fringes system.
2. Two waves of amplitude 4 and 2 units are superposed with their vibrations parallel. Deduce the ratio of the maximum to minimum intensity as phase relation varies.
3. Two coherent beams of intensities 1.6 and 0.4 unit produce a resultant intensity of 0.6 unit at a certain point. Calculate the minimum phase difference with which the beams reach the point.
4. Two narrow parallel slits $0.5 \times 10^{-3}\ m$ apart are illuminated by a monochromatic light of wavelength 5890 Å. Calculate the width of the fringes which are obtained on a screen distant $0.5\ m$ from the slit.
5. Green light of wavelength 5100 Å from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen $2\ m$ away is $0.02\ m$. Find the double slit separation.
6. In Young's double slit experiment, the separation of the slit is $1.9 \times 10^{-3}\ m$ and the fringes spacing is $0.31 \times 10^{-3}\ m$ at a distance of $1\ m$ from the slits. Calculate the wavelength of light.

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7. Sodium light of wavelength 5890 Å falls on a double slit of separation $2.0\ mm$. The distance between the slits and screen is $0.04\ m$. Locate the position of tenth bright fringe.
8. In a Newtons's ring experiment the diameter of the 5^{th} and 25^{th} rings are $0.3\ cm$ and $0.8\ cm$ respectively. Find the wavelength of light. [Given: $R = 100\ cm$]
9. If the diameter of nth dark ring in an arrangement giving Newton's ring changes from $0.03\ cm$ to $0.25\ cm$ as liquid is introduced between the lens and the plate, calculate the value of refractive index.
10. When space between the flat disc and convex surface in a Newton's rings set up is filled with a liquid, the radius of the fringes is reduced to 80 % of the original value. Calculate the refractive index of the liquid.

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