Chapter 1

Interference

1.1 INTRODUCTION

Light is a form of energy which itself is not visible directly but can be experienced indirectly and makes other bodies visible. According to Einstein, "Light is the fastest messenger of nature". Optics is the branch of Physics which deals with nature and properties of light. Optics is divided into two branches: Geometrical Optics and Physical Optics. Geometrical Optics deals with propagation of light like reflection, refraction, rectilinear propagation, etc. whereas Physical Optics deals with explanation of optical phenomenon using different theories proposed from time to time about the nature and mode of propagation of light. The phenomenons of interference, diffraction and polarization which cannot be analyzed using geometrical optics, are well explained using physical optics principle.

1.2 INTERFERENCE OF LIGHT

With a single source of light, the distribution of light energy in the surrounding space is uniform but when there are two sources, under certain conditions, the distribution is no longer uniform. There are certain regions where on account of superposition of waves enhanced light intensity is observed while at certain other places, the two sets of waves destroy each other so darkness is produced.

When two light waves of the same frequency travel in the same direction and have a phase difference that remains constant with time, there is redistribution of energy in space; this phenomenon of redistribution of energy due to the superposition of two light waves is called **Interference**. The points where the intensity is maximum, interference at these points is called *Constructive Interference* and at some other points where intensity is minimum, the interference at these points is called *Destructive Interference*. Usually when two light waves are made to interfere, we get alternate dark and bright bands of a regular shape, called *interference fringes*.

1.2.1 Principle of Superposition

Let us consider the superposition of two waves of same frequency having constant phase difference.

Let a_1 and a_2 are the amplitude of these waves. The displacement due to one wave at any instant t is given by,

$$y_1 = a_1 \sin(\omega t) \quad \text{... (1)}$$

and the displacement due to other wave at the same instant is given by,

$$y_2 = a_2 \sin(\omega t + \delta) \quad \text{... (2)}$$

where δ is the phase difference between two waves at an instant t.

By the principle of superposition, when two or more waves reach at a point simultaneously, the resultant displacement is equal to the sum of the displacements of all the waves. Hence, the resultant displacement is

$$= a_1 \sin \omega t + a_2 \sin(\omega t + \delta)$$

$$= a_1 \sin \omega t + a_2 \sin \omega t \cos \delta + a_2 \cos \omega t \sin \delta$$

$$= \sin \omega t (a_1 + a_2 \cos \delta) + \cos \omega t (a_2 \sin \delta)$$

Let $a_1 + a_2 \cos \delta = A \cos \phi$ ... (3)

and $a_2 \sin \delta = A \sin \phi$ ... (4)

where A and φ are new constants. This gives

$$Y = A \cos \phi \sin \omega t + A \sin \phi \cos \omega t$$

$$Y = A \sin(\omega t + \phi) \quad \text{... (5)}$$

Obviously, the resultant disturbance has amplitude A and phase difference φ.

Squaring eqn. (3) and eqn. (4) and adding we get,

$$\left(a_1 + a_2 \cos(\delta)\right)^2 + \left(a_2 \sin(\delta)\right)^2 = A^2$$

or $A^2 = a_1^2 + a_2^2 \cos^2 \delta + 2a_1 a_2 \cos \delta + a_2^2 \sin^2 \delta$

or $A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos \delta$ ... (6)

On dividing equation (4) by (3), we get

$$\tan \phi = \frac{a_2 \sin \delta}{a_1 + a_2 \cos \delta} \quad \text{... (7)}$$

The intensity at any point is proportional to the square of the amplitude i.e.

$$I \propto A^2$$

In arbitrary units $I = A^2$

$$I = a_1^2 + a_2^2 + 2a_1a_2 \cos\delta \quad \text{... (8)}$$

Special Cases

Case I: Condition for Constructive Interference

The Intensity (I) will be maximum at points where the value of cos δ = 1, i.e. phase difference $\delta = 2n\pi$ where $n = 0, 1, 2, 3, ...$

$$I_{max} = a_1^2 + a_2^2 + 2a_1a_2$$

or, $$I_{max} = (a_1 + a_2)^2 \quad \text{... (9)}$$

In other words, the intensity will be maximum when the phase difference is an integral multiple of 2π.

In this case,

$$I_{max} > a_1^2 + a_2^2$$

Thus, the resultant intensity will be greater than the sum of the individual intensities of the wave.

If $a_1 = a_2 = a$

$$I_{max} = (a + a)^2 = 4a^2 \quad \text{... (10)}$$

Case II: Condition for Destructive Interference

The intensity (I) will be minimum at points where $\cos\delta = -1$ i.e. phase difference $\delta = (2n + 1)\pi$,

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

$$I_{min} = a_1^2 + a_2^2 - 2a_1a_2$$

or, $$I_{min} = (a_1 - a_2)^2 \quad \text{... (11)}$$

In destructive interference, the intensity will be minimum when the phase (δ) is odd multiple of π.

In this case,

$$I_{min} < (a_1^2 + a_2^2) \quad \text{... (12)}$$

Thus, the resultant intensity will be less than the sum of the individual intensities of the waves.

If $a_1 = a_2 = a$

$$I_{min} = (a - a)^2 = 0$$

Conservation of Energy in Interference

The resultant intensity of superposition of two waves is given as:

$$I = a_1^2 + a_2^2 + 2a_1a_2 \cos\delta \quad \text{... (13)}$$

$$I_{max} = a_1^2 + a_2^2 + 2a_1 a_2$$

$$= (a_1 + a_2)$$

and $$I_{min} = a_1^2 + a_2^2 - 2a_1a_2$$

$$= (a_1 - a_2)^2$$

If $a_1 = a_2 = a$ then

$$I_{max} = 4a^2 \text{ and } I_{min} = 0$$

Therefore, average intensity (I_{av}) will be given as

$$I_{av} = 2a^2 \quad \text{... (14)}$$

Thus, in interference only some part of energy is transferred from the position of minima to the position of maxima. This shows that the phenomenon of interference is in accordance with the law of conservation of energy.

1.2.2 Conditions for Sustained Interference

To obtain a well-defined observable interference pattern, following conditions must be satisfied:

1. The two interfering source should be coherent i.e. the phase difference between them must remain constant with time.
2. The two waves should have the same frequency.
3. If the interfering waves are polarized, they must be in the same state of polarization.
4. The separation between the light sources ($2d$) should be as small as possible to get large fringe width.
5. The distance (D) of the screen from the two sources should be quite large to obtain widely spaced fringes.
6. The amplitudes of the interfering waves should be equal or at least very nearly equal for good contrast.
7. The two sources must be narrow, because broad sources contain many narrow sources and consequently the resultant interference pattern will be the combined effect of such coherent sources. The interference pattern due to individual source will therefore overlap and will give a uniform illumination on the screen.
8. The screen should be dark. If the screen is not dark, the minimum intensity will not appear to be zero, resulting into a poor contrast between maxima and minima.

1.2.3 Young's Double Slit Experiment

Historically, the phenomenon of Interference of Light was first discovered by Thomas Young in 1801. His experimental setup was capable of exhibiting an interference pattern due to the superposition of two beams of light. Young allowed the sunlight to pass through a pinhole S and then at some distance through two sufficiently close pin holes S_1 and S_2 in an opaque screen. Finally, the light was received on a screen on which he observed an uneven distribution of light intensity. Young found that the illumination on the screen consisted of many alternate bright and dark spots. In accordance with the modern laboratory technique, narrow parallel slits replace pin holes and the slits are illuminated with monochromatic light. Light is received on a screen placed at a certain distance to the right and parallel to the plane containing the slits S_1 and S_2.

According to Huygens principle, cylindrical wavelets spread out from slit S and as path $SS_1 = SS_2$, the wavelets reach slits S_1 and S_2 at the same instant. A train of Huygens wavelets, therefore, diverges to the right from both of these slits, which have precisely equal phases at the start. Furthermore, their amplitude wavelength and velocity are also equal. Suppose in two-dimensional (Figure 1.1), continuous circular arcs represent the wave crests while dotted circular arcs represent the wave troughs in each wave. At points marked by P's, a crest of one wave is superimposed on a crest of the other or a trough of one superposes on a trough of the other. In other words, at these points the two waves meet in the same phase. Therefore, according to the principle of superposition, at these points the resultant amplitude is twice that of each component wave. On the other hand, at points marked by D's, crest of one wave is superimposed on the trough of the other and vice versa i.e. the waves meet in opposite phase. Hence, according to the principle of superposition, at these points they neutralize each other and the resultant intensity is zero. Thus, on the screen a number of alternate bright and dark regions of equal width, called interference fringes are observed parallel to the slits.

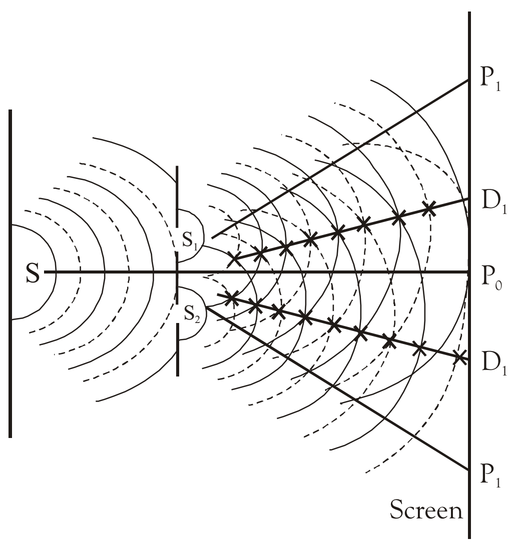


Figure 1.1: Young's experiment

1.2.4 Coherence

When two sources produce waves having sharply defined phase difference and that remains constant with time, they are said to be "coherent". The waves produce a stable, well-defined fringe pattern on a screen placed in their path. When the phase difference between two light waves arriving at a point vary with time in a random way, the wave sources are said to be incoherent. In this case, at a certain instant conditions, they may be right for maximum intensity and a short time later (nearly 10^{-8} sec) they may be right for minimum intensity and this is true for all points. This results in uniform illumination.

Thus, coherence refers to degree of correlation between the phases at different parts in a beam of light. There are two independent concepts of coherence.

(a) Temporal Coherence

(b) Spatial Coherence

Temporal Coherence

A beam is said to possess Temporal Coherence if the phase difference of the two waves crossing two points lying along the direction of propagation of the beam is time independent. It is also called longitudinal coherence. Temporal coherence comes about because two waves in a laser beam remain coherent for a long time as they move past a given point. That is they stay in the same phase with each other for many wavelengths. The more monochromatic a source, the greater the temporal coherence.

In optics, temporal coherence is measured in an interferometer such as the Michelson interferometer, in which a wave is combined with a copy of itself that is delayed by time τ. A detector measures the time-averaged intensity of the light exiting the interferometer. The resulting interference visibility gives the temporal coherence at delay τ. If visibility = 1 then the two waves are coherent else the property is lost by the delay time. The Michelson experiment measures the *temporal coherence* of a light wave: the ability of a light wave to interfere with a time-delayed version of itself. Some typical values of coherence length:

- Well-stabilized laser: coherence time, τ_c is 10^{-4} seconds, coherence length l_c is 30 *Km*
- Filtered thermal light: coherence time, τ_c is 10^{-8} seconds, coherence length l_c is 3 *m*

Spatial Coherence

Spatial Coherence or transverse coherence is the cross-correlation between two points in a wave for all time. Roughly, it can be understood that if light at the top of the beam is coherent with light at the bottom of the beam then beam will have spatial coherence. This is the relevant type of coherence for the Young's double-slit interferometer. Spatial coherence is also termed as transverse coherence because the phase difference of two waves crossing the two points lying on a plane perpendicular to the direction of propagation of the beam is time independent. It is also used in optical imaging systems and particularly in various types of astronomy telescopes. Consider a tungsten light-bulb filament. Different points in the filament emit light independently and have no fixed phase-relationship. If we consider the profile of the emitted light in detail, at any point in time it will be distorted. Since for a white-light source such as a light-bulb τ_c is small, the filament is considered a spatially incoherent source. In contrast, a radio antenna array, has large spatial coherence because antennas at opposite ends of the array emit with a fixed phase-relationship. Light waves produced by a laser often have high temporal and spatial coherence (though the degree of coherence depends strongly on the exact properties of the laser). Spatial coherence of laser beams also manifests itself as speckle patterns and diffraction fringes seen at the edges of a shadow.

Methods of Producing Coherent Sources

There are two general methods of producing coherent sources.

1. ***Division of Wave Front:*** In this method, the wave front is divided into two or more parts by the use of mirrors, lenses and prisms. The well-known methods are Young's double slit experiment, Fresnel's biprism and Lloyd's single mirror etc.
2. ***Division of Amplitude:*** In this method, the amplitude of the incoming beam is divided into two or more parts by partial reflection or refraction. These divided parts travel different paths and finally brought together to produce interference. This class of interference requires broad source of light. The common examples of such interference of light are the brilliant colours seen when a thin film of transparent material like soap bubble or thin film of oil spread on the surface of water is exposed to extended source of light. These are two types of such interference.
   (i) Interference of waves reflected from front and back surfaces of the film.
   (ii) Interference of transmitted waves.

No Interference by Independent Sources

Two independent light sources such as two bulbs cannot produce interference fringes. This is because there is no steady phase difference between the light waves emitted from them. The reason is as follows:

Every source of light is made up of innumerable atoms, which are the ultimate sources of light. Each atom consists of a central positively charged nucleus, around which electrons move in some definite orbits. When an atom gets energy by some external cause, one (or more) of its electron are excited to some higher orbits. This state of the atom, called the excited state, lasts only for about 10^{-8} sec after which the electron jumps back to the lower orbit. During this jump, the atom radiates light. That is, the atom does not emit a continuous infinites train of light waves but at short intervals. These short intervals are different for different atoms. Thus, the innumerable atoms in the source emit light so that the phase of the light wave from a source varies with time in a random way. Therefore, the phases of the waves from two independent sources will be changing independent of each other. Hence, there is no possibility of steady interference fringes.

1.3 THEORY OF INTERFERENCE

Let S_1 and S_2 be the two virtual sources produced by the biprism, and XY be the screen on which the fringes are obtained. The point O on the screen is equidistant from S_1 and S_2. Therefore, the waves from S_1 and S_2 reach O in the same phase and reinforce each other. Hence, the point O is the centre of a bright fringe.

The illumination of any other point P can be obtained by calculating the path difference $S_2P - S_1P$. Let us join S_2P and S_1P and draw perpendiculars S_1M_1 and S_2M_2 on the screen. Let $S_1S_2 = 2d$, $S_1M_1 = S_2M_2 = D$ and $OP = x$

$$(S_2P)^2 = (S_2M_2)^2 + (PM_2)^2 = D^2 + (x+d)^2$$

$$= D^2\left[1+\frac{(x+d)^2}{D^2}\right]$$

or $$S_2P = D\left[1+\frac{(x+d)^2}{D^2}\right]^{1/2}$$

$$= D\left[1+\frac{1}{2}\frac{(x+d)^2}{D^2}\right] \quad as\ (x+d) << D$$

or $$S_2P = D + \frac{1}{2}\frac{(x+d)^2}{D}$$

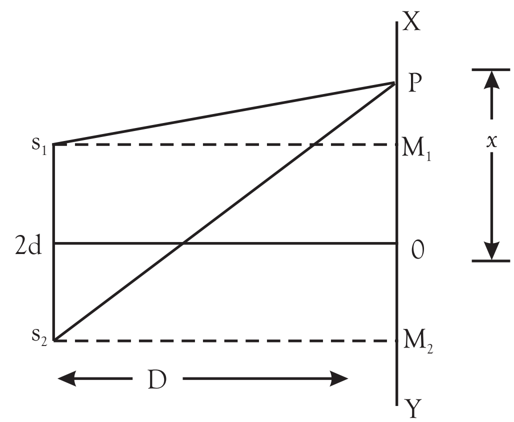


Figure 1.2 : Theory of interference

Similarly,

$$S_1P = D + \frac{1}{2}\frac{(x-d)^2}{D}$$

Thus, path difference,

$$\Delta = S_2P - S_1P = \frac{1}{2}\frac{(x+d)^2}{D} - \frac{1}{2}\frac{(x-d)^2}{D} = \frac{2xd}{D} \quad \text{... (15)}$$

The resultant intensity at a point is maximum or minimum accordingly as the path difference between the waves is an integral multiple of wavelength or an odd multiple of half wavelength. Thus, for P to be the centre of a bright fringe, we must have

$$S_2P - S_1P = \frac{2xd}{D} = n\lambda$$

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

or, $$x = \frac{n\lambda D}{2d}$$

For P to be centre of a dark fringe, we must have

$$S_2P - S_1P = \frac{2xd}{D} = (2n+1)\frac{\lambda}{2}$$

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

$$x = \frac{D}{2d}(2n+1)\frac{\lambda}{2} \quad \text{... (16)}$$

Let x_n and x_{n+1} denote the distances of the n^{th} and $(n+1)^{th}$ bright fringes. Then the distance between $(n + 1)$th and n^{th} bright fringes is given by

$$x_{n+1} - x_n = \frac{D}{2d}(n+1)\lambda - \frac{D}{2d}(n\lambda) = \frac{\lambda D}{2d} \quad \text{... (17)}$$

This is independent of n, so that the distance between any two consecutive bright fringes is the same, $\frac{\lambda D}{2d}$. The same result holds for dark fringes. The distance $\frac{\lambda D}{2d}$ called the fringe width denoted by ω.

Thus, fringe width may be written as

$$\boxed{\omega = \frac{\lambda D}{2d}} \quad \text{... (18)}$$

1.4 FRESNEL'S BIPRISM

Fresnel's biprism is used to obtain coherent sources. The biprism produces two virtual images of the slit by refraction. A biprism consists of two identical prisms of very small vertex angle (nearly 1/2°) with their bases cemented together. In practice biprism is made from a single piece of glass by suitably grinding and polishing it. The two sections of biprism make an obtuse angle of 179°.

A narrow slit S is illuminated by monochromatic light. The biprism is placed in front of the slit with refracting edge parallel to the slit. Light from S passes through two halves of the biprism and the wave-fronts are refracted symmetrically and separately. The refracted rays appear to come from the two virtual images S_1 and S_2 of the slit S. As they are derived from the same original source, they act as coherent sources and they are formed in the plane of the slit. The interference pattern is obtained on the screen. It is observed in the shaded portion where the two beams overlap. It is observed through an eyepiece as shown in figure 1.3. The eyepiece is provided with micrometer to measure the fringe width and separation between the virtual sources.

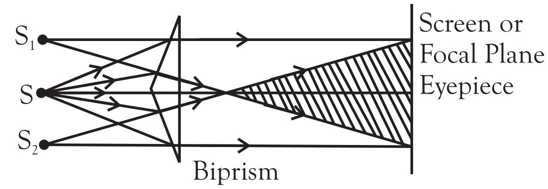


Figure 1.3 : Fresnel's biprism

1.4.1 Determination of the Wavelength of Light

In order to determine the wavelength of monochromatic light with the help of biprism fringes, we use the formula $\omega = \frac{\lambda D}{2d}$

or $$\lambda = \frac{\omega 2d}{D} \quad \text{... (19)}$$

The value of fringe width ω, the distance $2d$ between the virtual coherent sources S_1 and S_2 and the normal distance D of the plane of observation of the fringes from the slit should be measured after making a few adjustments in the apparatus. The experiment is performed on a heavy metallic optical bench, about 2 meter in length and supported on four leveling screws at the base. The bench is provided with a scale on one side. The bench carries four upright stands for the adjustable slit, the biprism high power micrometer, Ramsdon's eyepiece and a convergent lens. These upright are capable of movement along and perpendicular to the length of the bench and may be adjusted to any desired height.

Adjustments

For obtaining sharp fringes, the following adjustments are made in the given order.

1. The optical bench is levelled in the horizontal plane.
2. The eyepiece is focused on the cross wire. One of the cross wire is set vertical by means of plumb line.
3. The slit, the biprism and the eyepiece are adjusted to the same height.
4. The slit is made vertical by rotating it in its own plane.
5. The biprism is moved at right angles to the optical bench until two equally bright virtual slit images S_1 and S_2 are observed on looking through the biprism along the axis of the bench. The biprism is now rotated in its own plane until, on moving the eye across the bench of the images crosses the edge of the biprism as a whole. This makes the edge of the biprism approximately parallel to the slit.
6. The eyepiece is moved at right angles to the length of the bench until the overlapping region comes in the field of view.

7. The slit is now made narrow. The fringes at once appear.
8. The biprism is slowly rotated in its own plane until the fringes are perfectly distinct. The edge of the biprism is now accurately parallel to the slit.
9. Finally, the line joining the slit and edge of the biprism is made parallel to the optical bench by removing the lateral shift. For this the cross wire is set on a fringe in the centre and the eyepiece is moved along the bench away from the biprism. If the line joining the slit to the edge is not parallel to the bench, the fringe system shifts laterally. The biprism is moved laterally until the cross wire is again set on the same fringe. Now the eyepiece is moved towards the biprism when the fringe system again shifts but in the opposite direction. Now the eyepiece is moved laterally until the cross wire is again set on the same fringe. The process is repeated until the lateral shift completely disappears.

The following measurements are made:

(a) Measurement of Fringe Width (ω): After obtaining the fringe, the vertical cross wire of the eyepiece is set on a bright fringe on one side of the interference pattern. The reading of the micrometer screw is taken. Then the eyepiece is moved laterally so that the vertical cross wires coincide with successive bright fringes and the corresponding readings are noted. From these readings, the fringe width(ω) is founded using formula

$$\omega = \frac{\text{Distance moved}}{\text{Number of fringes crossed}}$$

(b) Measurement of D: The reading of the stands of the slit and eyepiece on the scale of the optical bench are taken. The difference of the two readings gives D, which is corrected for the bench error.

(c) Measurement of 2d: To measure the distance $2d$ between S_1 and S_2, a convex lens of short focal length is mounted between the biprism and the eyepiece. By moving the lens along the length of the bench, two positions L_1 and L_2 are obtained such that the real images of S_1 and S_2 are obtained in the eyepiece.

Let d_1 and d_2 respectively be the separations between the real images in the positions L_1 and L_2 respectively. If u and v respectively be the distances of the slits and the eyepiece from the lens in the positions L_1 and L_2 then from the magnification formula we have

$$\frac{d_1}{2d} = \frac{v}{u} \qquad \text{... (20)}$$

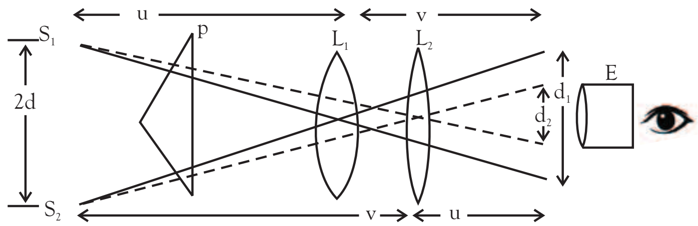


Figure 1.4 : Arrangement for determination of distance between the virtual images

As the two positions of the lens are conjugate, we have for the second positions L_2

$$\frac{d_2}{2d} = \frac{v}{u}$$

Multiplying above equations, we get,

$$\frac{d_1 d_2}{4d} = 1 \text{ or } 2d = \sqrt{d_1 d_2} \qquad \text{... (21)}$$

Several sets of the readings of d_1 and d_2 are taken by moving the eyepiece with different positions and mean value of $2d$ is found. Finally, the wavelength is determined by the formula $\lambda = \frac{\omega 2d}{D}$.

Alternate Method for Measurement of 2d:

The distance between the two virtual sources in biprism experiment can be found by using the fact that for a prism of very small refracting angle, the deviation δ produced in a ray is given by

$$\delta = (\mu - 1)\alpha \qquad \text{... (22)}$$

where μ is the refractive index of the material of the prism and α is the refracting angle.

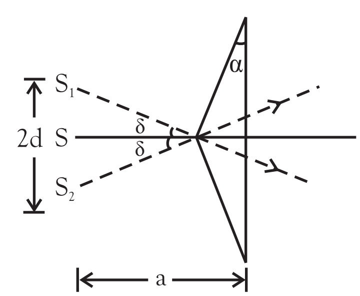


Figure 1.5 : Angle of deviation from biprism

From figure (1.5)

$$\delta = \frac{d}{a} \qquad \text{... (23)}$$

From equations (22) and (23), we have

$$\boxed{2d = 2a(\mu - 1)\alpha} \qquad \text{... (24)}$$

Where, α is in radians

1.4.2 Interference with White Light

When the slit in the biprism experiment is illuminated with white light, the interference pattern consists of a central white (a chromatic) fringe having on both sides a few colored fringes and then a general illumination. A pair of white light coherent sources is equivalent to a number of pairs of monochromatic sources, each producing its system of fringes with a different fringe width *(ω)* which depends on *(λ)*

$$\omega = \frac{\lambda D}{2d}$$

At the centre of the pattern, the path difference and hence the phase difference between the interfering waves is zero for all wavelengths. Therefore, all different colored interfering waves produced bright fringe at the centre. The superposition of different colors make the central fringe white; this is the "zero order fringe".

As we move on either side of the centre, the path difference gradually increases from zero. At a certain point, it becomes equal to half the wavelength of the component having the small wavelength i.e., violet. This is the position of the first dark fringe of violet. Beyond this we obtain the first minimum of blue, green, yellow and of red in the last. The inner edge of the first dark fringe, which is the first minimum for violet, receives sufficient intensity due to red, hence it is reddish. The outer edge of the first dark fringe, which is minimum of red, receives sufficient intensity due to violet and is therefore violet. The same applies to every other dark fringe. Hence, we obtain a few colored fringes on both sides of the central fringe.

As we move further away from the centre, the path difference becomes quite large. Then, from the range 4000-7800Å, a large number of wavelength (colors) will produce maximum intensity at the point, and an equally large number will produce minimum intensity at the point. Hence, uniform white illumination will result at each point.

1.4.3 Displacement of the Fringes by the Introduction of a Thin Lamina

When a thin transparent plate, say of glass or mica, is introduced in the path of one of the two interfering beams, the entire fringe pattern is displaced to a point towards the beam in the path of which the plate is introduced. If the displacement be measured, the thickness of the plate can be obtained provided the refractive index of the plate and the wavelength of light be known.

Let S_1 and S_2 be the two coherent monochromatic sources having light of wavelength λ. Let a thin plate of thickness t be introduced in the path of light from S_1. Let μ be the refractive index of the plate for the monochromtic light employed.

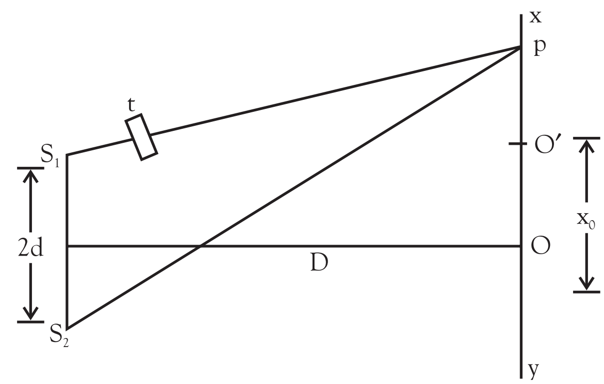


Figure 1.6 : Displacement of fringes

Now light from S_1 travel partly in air and partly in the plate. For the light path from S_1 to P, the distance traveled in air is $(S_1P - t)$ and that in the plate is t. If c and v be the velocities of light in the air and in the plate respectively, then the time taken for the journey from S_1 to P.

$$= \frac{S_1P - t}{c} + \frac{t}{v} \qquad \left[\because \mu = \frac{c}{v} \text{ or } \frac{1}{v} = \frac{\mu}{c}\right]$$

$$= \frac{S_1P - t}{c} + \frac{\mu t}{c}$$

$$= \frac{S_1P + (\mu - 1)t}{c}$$

It follows from this relation that the effective path in air from S_1 to P is $[S_1P + (\mu-1)t]$, that is, the air path S_1P is increased by an amount $(\mu - 1)t$ as a result of the introduction of the plate. Let O be the position of the central bright fringe in the absence of the plate, the optical path S_1O and S_2O being equal. On introducing the plate, the two optical paths become unequal. Therefore, the central fringe is shifted to $\boldsymbol{O'}$, such that at $\boldsymbol{O'}$ the two optical paths become equal. A similar argument applies for all the fringes. Now, at any point P, the effective path difference

$$= S_2P - [S_1P + (\mu - 1)t]$$
$$= S_2P - S_1P - (\mu - 1)t$$

Let $S_1S_2 = 2d$ and distance of screen from $S_1S_2 = D$ and $OP = x_n$ so that

$$= S_2P - S_1P = \frac{2d}{D}x_n$$

Thus, effective path difference at P

$$\frac{2d}{D}x_n - (\mu - 1)t$$

If the point P is to be the centre of the n^{th} bright fringe, the effective path difference should be equal to n λ. That is

$$\frac{2d}{D}x_n - (\mu - 1)t = n\lambda$$

or, $x_n = \frac{D}{2d}[n\lambda + (\mu - 1)t]$

In the absence of the plate (t = 0) the distance of the n^{th} maximum from 0 is $\frac{n\lambda D}{2d}$. Therefore, the displacement of the n^{th} bright fringe is given by

$$x_0 = \frac{D}{2d}[n\lambda + (\mu - 1)t] - \frac{Dn\lambda}{2d}$$

$$\boxed{x_0 = \frac{D}{2d}(\mu - 1)t} \quad \text{... (25)}$$

This expression is independent of n so that the displacement is the same for all the bright fringes.

1.4.4 Determination of Thickness of a Mica Sheet

The equation (25) shows that the introduction of the given mica plate in one of the interfering beams produces a shift x_0, i.e

$$x_0 = \frac{D}{2d}(\mu - 1)t$$

Thus, $$t = \frac{x_0(2d)}{D(\mu - 1)} \quad \text{... (26)}$$

Experiment

First of all the necessary adjustments of the biprism are made using sodium light. The sodium light is then replaced by an incandescent filament lamp (white light), which gives a few colored fringes with central white fringe. The crosswire is set on the white fringe and the reading of micrometer screw is taken. Now the mica plate is introduced in the path of one of the interfering beams. The whole pattern is shifted. The crosswire is again set on the white fringe and reading is taken. The difference between the two readings gives the displacement (x_0) of the pattern due to the introduction of the mica plate. The quantities $2d$ and D are measured in the usual way. Taking the value of μ for mica, t is calculated by the above formula.

1.5 SHAPE OF INTERFERENCE FRINGES

We can now very easily form an idea regarding the shape of the interference fringes by deriving the equation of the locus of points having a given path difference from two slits S_1 and S_2. Let O the middle point of S_1S_2 be chosen as the origin of the coordinates. Let P be any point outer screen, we easily get

The path difference between S_1P and S_2P is given by

$$\Delta = S_2P - S_1P = \left[D^2 + (x+d)^2\right]^{\frac{1}{2}} - \left[D^2 + (x-d)^2\right]^{\frac{1}{2}}$$

On rearranging the terms

$$\Delta + \left[D^2 + (x-d)^2\right]^{\frac{1}{2}} = \left[D^2 + (x+d)^2\right]^{\frac{1}{2}}$$

Squaring on both sides and expanding the LHS of the equation, we get

$$\Delta^2 + \left[D^2 + (x-d)^2\right] + 2\Delta\left[D^2 + (x-d)^2\right]^{\frac{1}{2}} = \left[D^2 + (x+d)^2\right]$$

$$2\Delta\left[D^2 + (x-d)^2\right]^{\frac{1}{2}} = 4xd - \Delta^2$$

On squaring both sides, the above equation may be reduced to

$$4\Delta^2 D^2 + 4\Delta^2 x^2 + 4\Delta^2 d^2 - 8\Delta^2 xd = 16x^2 d^2 + \Delta^4 - 8\Delta^2 xd$$

$$4\Delta^2 D^2 + 4\Delta^2 x^2 + 4\Delta^2 d^2 = 16x^2 d^2 + \Delta^4$$

Dividing this equation by $4\Delta^2$ and rearranging, we get

$$\frac{x^2}{\frac{\Delta^2}{4}} - \frac{D^2}{\frac{(4d^2 - \Delta^2)}{4}} = 1$$

This is the equation of hyperbola in a standard form with the foci S_1 and S_2 on the z-axis. The loci of points of constant path difference are thus hyperbola. Furthermore, if instead of slits we have two coherent point sources S_1 and S_2, then the loci of points of constant path difference (hence fringes) are concentric circles.

The eccentricities of the hyperbola are given by

$$e = \left[\frac{\Delta^2}{4} + \frac{4d^2 - \Delta^2}{4}\right]^{1/2} \div \frac{\Delta}{2} = \frac{2d}{\Delta} \quad \text{... (27)}$$

In an optical experiment, the path difference Δ, corresponding to the condition of constructive or destructive interference, is of the order of 10^{-8}cm and 2d of the order of 10^{-2}cm. The eccentricity is, therefore, very large. As a consequence, hyperbolic are practically straight line.

1.6 INTERFERENCE IN THIN FILMS

When a film of oil spread over the surface of water is illuminated by white light, beautiful colors are seen. This is due to interference between the light waves reflected from the film, and between the light waves transmitted through the film.

A thin film may be a thin sheet of transparent material such as glass, mica, an air film enclosed between two transparent sheets or a soap bubble. When light is incident on such film, it is partially reflected from the upper surface and a major portion is transmitted into the film. Again, a small part of transmitted component is reflected back into the film by lower surface and the rest of it is transmitted out of the film. A small portion of light thus gets partially reflected in succession several times within the film as shown in figure 1.7. Therefore, interference in thin films is due to division of amplitude. Newton and Hook first observed the thin film interference. However, Thomas Young gave the correct explanation of the phenomenon.

Brilliant colours are often exhibited when a beam of white light from an extended source is reflected from the skin of soap bubble or from a thin layer of bubble floating on water or from a thin wedge shaped air film between two glass plates. The explanation of the origin of this colour phenomenon was given by Dr Young in 1802 in terms of the interference of light waves reflected from the upper and the lower surfaces of the thin film.

A ray of monochromatic light SA be incident at an angle i on a parallel sided transparent thin film of thickness t and refractive index ($\mu > 1$).

At A it is partly reflected along AR_1 and partly refracted along AB at angle r. At B it is again partly reflected along BC and partly refracted along BT_1. Similar reflections and refractions occur at C, D, ... etc. as shown in figure 1.7. Thus, we get a set of parallel reflected rays AR_1, CR_2, ………….. etc. and a set of transmitted rays BT_1, DT_2, ……………. etc. Let us first consider the reflected rays only.

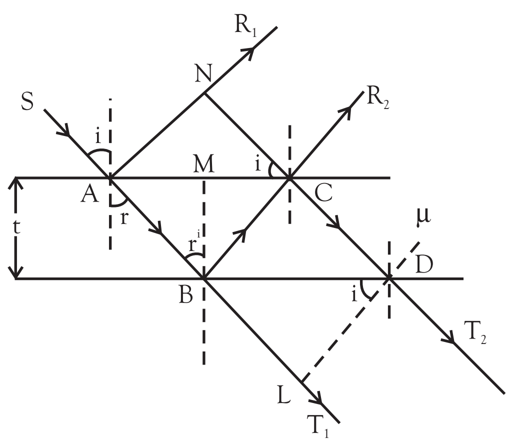


Figure 1.7 : Interference in thin films

At each of the points A, B, C, D, ……. only a small part of light is reflected and the rest is refracted. Therefore, the rays AR_1 and CR_2 each having undergone one reflection, have almost equal intensities. The rest have rapidly decreasing intensities and can be ignored. The rays AR_1 and CR_2 being derived from the same incident ray, are coherent and in a position to interfere. Let us first calculate the path difference between them.

Let CN and BM be perpendicular to AR_1 and AC. As the path of the rays AR_1 and CR_2 beyond CN are equal, the path difference between them is

$$\Delta = \text{path } ABC \text{ in film} - \text{Path } AN \text{ in air}$$

$$= \mu(AB + BC) - AN \qquad \text{... (28)}$$

From figure

$$AB = BC = \frac{BM}{\cos r} = \frac{t}{\cos r}$$

$$\begin{aligned} AN &= AC \sin i \\ &= (AM + MC)\ \sin i \\ &= (BM\ \tan r + BM\ \tan r)\sin i \\ &= 2t\ \tan r\ \sin i \\ &= 2t\frac{\sin r}{\cos r}\sin i \\ &= 2t\frac{\sin r}{\cos r}(\mu \sin r) \end{aligned}$$

$$AN = 2\mu t\frac{\sin^2 r}{\cos r}$$

Substituting the values of AB, BC and AN in equation 28, we get

$$\Delta = \mu\left[\frac{t}{\cos r} + \frac{t}{\cos r}\right] - 2\mu t\frac{\sin^2 r}{\cos r}$$

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

The ray AR_1 having suffered a reflection at the surface of a denser medium undergoes a phase change of π which is equivalent to a path difference of λ. Hence, the effective path difference between AR_1 and CR_2 is $2\mu t \cos r - \dfrac{\lambda}{2}$

1.6.1 Conditions of Maxima and Minima in Reflected Light

The two rays will reinforce each other if the path difference between them is an integral multiple of λ i.e., for maxima

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

or $$2\mu t \cos r = (2n+1)\frac{\lambda}{2} \qquad \text{... (29)}$$

Again the two rays will destroy each other if the path difference between them is an odd multiple of $\dfrac{\lambda}{2}$. i.e. for minima

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

$$2\mu t \cos r = n\lambda \qquad \text{... (30)}$$

1.6.2 Conditions of Maxima and Minima in Transmitted Light

Similarly the path difference between the transmitted rays BT_1 and DT_2 is given by

$$\Delta = \mu\ (BC + CD) - BL = 2\mu t \cos r$$

In this case, there is no phase change due to reflection B or C because in either case the light is traveling from denser to rarer medium. Hence, the effective path difference between BT_1 and DT_2 is also $2\mu t \cos r$.

Conditions for Maxima and Minima in Transmitted Light

The two rays BT_1 and DT_2 will reinforce each other if

$$2\mu t \cos r = n\lambda \text{ (condition of maxima)} \quad \text{... (31)}$$

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

Again the two rays will destroy each other if

$$2\mu t \cos r = (2n + 1)\frac{\lambda}{2} \text{ (condition of minima)} \quad \text{... (32)}$$

where $n = 0, 1, 2$

A comparison of equations (29), (30), (31) and (32), shows that the conditions for maxima and minima in the reflected light are just the reverse of those in the transmitted light. Hence, the film, which appears bright in reflected light, will appear dark in transmitted light and vice versa. In other words, the appearances in two cases are complementary to each other.

1.6.3 Production of Colours in Thin Film

When a thin film of oil on water or a soap bubble, exposed to an extended source of white light is observed under reflected light, brilliant colors are seen in the film or the bubble. These colors arise due to the interference of the light reflected from the top and bottom surfaces of the film. The eyes looking the film receive rays of light reflected from both the surfaces of the film. The path difference between these interfering rays depends upon t (thickness of film) and upon r and hence upon inclination of the incident rays (the inclination is determined by the position of the eye relative to the region of the film which is being looked. Now white light consists of a continuous range of wavelengths (colors). At a particular point of the film and for a particular position of the eye (i.e., for a particular t and a particular r) the rays of only certain wavelengths will have a path difference satisfying the condition of maxima.

Hence, only those wavelengths (colors) will be present with maximum intensity and other neighboring wavelengths will be present with less intensity. While some others which satisfy the condition of minima will be missing. Hence, the point of the film will appear colored. The colour will clearly vary with the thickness of the film as well as with the position of the eye with respect to the point of the film (i.e., with the inclination of the rays). Therefore, if the same point of the film is observed with eye in different position or different points of the film are observed with eye in the same position, a different set of colors will be observed. If the film is of uniform thickness every where and the incident light is parallel the path difference at each point of the film will be the same and the entire film will have uniform colour.

Colours in Reflected and Transmitted Light

The colors observed in this film in reflected light will be complementary to those observed in transmitted light. This is because the conditions for maxima and minima in the reflected light is just the reverse of those in the transmitted light.

Blackness of an Excessively Thin Film in Reflected Light

In extremely thin film when seen in the white light, appears to be completely dark in the reflected light. The reason is that if the film is extremely thin $t \to 0$ the effective path difference in the reflected part is

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

and thus, condition of minima is satisfied for each wavelength of white light, thus, the film appears dark in the reflected light.

1.6.4 Interference in Film of Varying Thickness (Wedge Film)

Consider a thin film in the shape of a wedge whose sides form a small angle θ and illuminated with plane monochromatic light waves. The directly reflected wave BR and the internally reflected wave B_1R_1 originate from the same incident wave propagating along AB and they are capable of producing several interference effects. The two interfering waves do not reach the eye along parallel paths but as shown in figure and they appear to diverge from a point O in the rear of the film. Destructive or constructive interference, therefore, occurs at the point O, which is however, virtual. If the two interfering waves BR and B_1R_1 fall on lens, they will cross each other at a real point O. Consequently, real reinforcement or destructive interference would occur at O.

The optical path difference, between the waves BR and B_1R_1 is expressed by

$$\Delta = \mu(BC + CB_1) - BD$$

$$= (BE + EC + CB_1) - BD$$

From figure 1.8

$$BD = \mu\ BE$$

Thus,

$$\Delta = EC + CB_1 \quad \text{... (33)}$$

In figure, BN and CN are respective normal to the upper and lower surfaces of the film hence, we get $\angle BNC = \theta$ and $\angle PCB = \theta + r = \angle CBN + \angle CNB$ and $\angle PCB = \theta + r$

Also $\angle CB_1O = \angle PCB_1 = (\theta + r) = \angle B_1OC$. Thus, B_1OC is an isosceles triangle, with $CB_1 = CO$

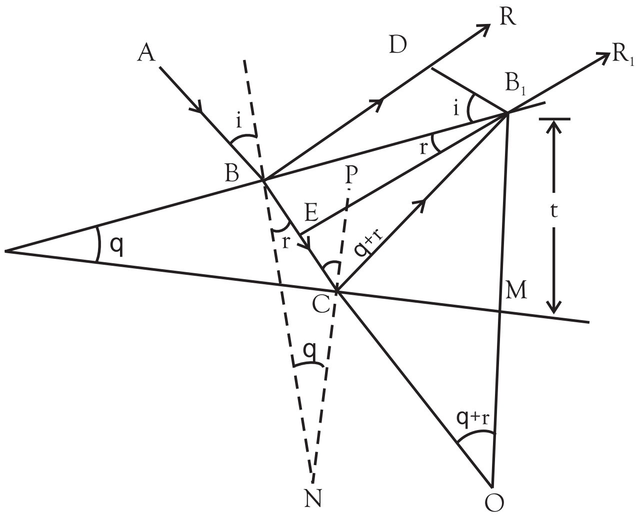


Figure 1.8 : Interference in wedged shaped film

The path difference Δ reduces to

$$\Delta = \mu(EC + CO) = \mu EO$$
$$= B_1 O \cos(\theta + r)$$
$$\Delta = 2\mu t \cos(\theta + r) \quad \text{... (34)}$$

Where t stands for the thickness of the film at the point B_1. The path difference Δ thus varies because of both changing thickness as well as changing angle of incidence provided the broad light source be at finite distance from the film. Now taking into account the change of phase of the wave due to reflection at B, the wave BR and B_1R_1 will interfere constructively when

$$2\mu t \cos(\theta + r) = (2n+1)\frac{\lambda}{2} \quad \text{... (35)}$$

Where n = 1, 2, 3 ....

and they will interfere destructively when

$$2\mu t \cos(\theta + r) = 2n\frac{\lambda}{2} \quad \text{... (36)}$$

As we proceed along the film in the direction in which its thickness increases, alternate dark and bright bands parallel to the edge of the film is observed. Since each band is the locus of constant thickness of the film, these fringes are called fringes of constant thickness.

Expression for Fringe Width

The distance between the two successive bright fringes or dark fringes or fringe width may be obtained as follows:

For n^{th} dark fringe, we have

$$2\mu t \cos(\theta + r) = 2n\frac{\lambda}{2} \quad \text{... (37)}$$

Let x_n be the distance of n^{th} dark fringe from the edge of the film, then from figure 1.9 we have

$$\tan\theta = \frac{t}{x_n} \text{ or } t = x_n \tan\theta$$

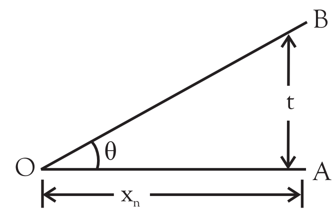


Figure 1.9 : Position of n^{th} minima

Putting this value of t in equation (37) we get,

$$2\mu x_n \tan\theta \cos(\theta + r) = (n)\lambda \quad \text{... (38)}$$

Similarly if x_{n+1} be the distance of $(n+1)^{th}$ dark fringe then

$$2\mu x_{n+1} \tan\theta \cos(\theta + r) = (n+1)\lambda \quad \text{... (39)}$$

Subtracting equation 38 from equation 39, we have

$$\omega = x_{n+1} - x_n = \frac{\lambda}{2\mu \tan\theta \cos(\theta + r)} \quad \text{... (40)}$$

For normal incidence $i = r = 0$, and cos $(\theta + r)$ =

$$\Rightarrow \quad \omega = \frac{\lambda}{2\mu \tan\theta \cos\theta} = \frac{\lambda}{2\mu \sin\theta}$$

For very small value of

$$\sin\theta = \theta$$

$$\omega = \frac{\lambda}{2\theta}$$

For refractive index of unity

$$\omega = \frac{\lambda}{2\theta} \quad \text{... (41)}$$

Wedge Angle

The wedge angle may be determined experimentally. The position of two dark fringes located at distance x_1 and x_2 from the apex are noted. Let t_1 and t_2 be the thickness of the wedge at x_1 and x_2.

The condition of dark fringe at t_1 and t_2 may be given as

$$2\mu t_1 = m\lambda$$

But $\quad t_1 = x_1 \tan\theta = x_1\theta$

$$\Rightarrow \quad 2\mu x_1\theta = m\lambda \quad \text{...(a)}$$

Similarly $\quad 2\mu x_2\theta = (m+N)\lambda \quad \text{...(b)}$

Where N is the number of dark fringes between at x_1 and x_2.

Subtracting eq. (a) and (b)

$$2\mu(x_2 - x_1)\theta = (N)\lambda$$

$$\theta = \frac{(N)\lambda}{\mu(x_2 - x_1)}$$

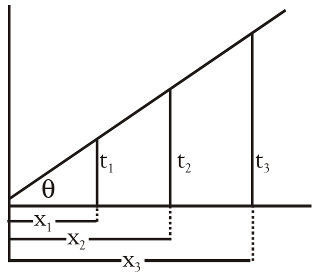


Figure 1.10 : Determination of wedge angle and thickness of thin object

Spacer Thickness

The spacer thickness t_3 may be determined experimentally.

$$t_3 = x_3 \tan\theta = x_3\theta$$

$$\Rightarrow \quad t_3 = \frac{x_3 N\lambda}{2(x_2 - x_1)}$$

1.7 NEWTON'S RING

Newton's ring is a very good example of interference from a wedge shape film. A thin air film of increasing thickness in all directions from one point can be very easily formed by placing a glass plate on a plane convex lens of a large radius of curvature so that its convex surface faces the plate. The air film thus possesses a radial symmetry about the point of contact. When it is illuminated normally preferably with monochromatic light, we observe interference fringes, which are the locus of points of equal thickness, and circular rings concentric with point of contact. The rings gradually becomes narrower as their radii increases. These rings are called Newton's ring.

1.7.1 Experimental Arrangement for Obtaining Newton's Ring

The experimental arrangement is shown in figure 1.11.

A plano convex lens of large radius of curvature is placed on a plane glass plate P such that the curved surface of the lens touches the glass plate. Light from a monochromatic source (sodium lamp) is allowed to fall on a glass plate *G* which is held inclined at an angle of 45° with the vertical. The light reflected from *G* falls normally on the air film which is enclosed between lens and glass plate P.

Interference occurs between the rays reflected from the upper and lower surfaces of the air film. A low power microscope *M* focused on the air film where the rings are formed sees the interference rings.

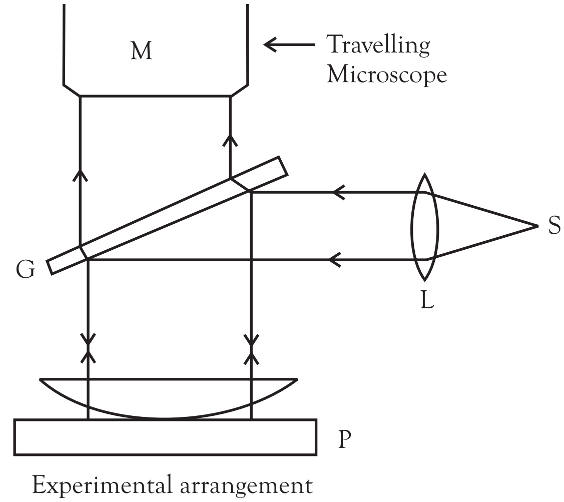


Figure 1.11 : Newton's ring setup

Theory

The effective path difference between the interfering rays is

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

For air film $\mu = 1$ and $r = 0$ (for normal incidence) and $\theta < 45°$

$$\Delta = 2t + \frac{\lambda}{2}$$

At the point of contact of the lens and plate $t = 0$, hence $\Delta = \frac{\lambda}{2}$, condition for minimum intensity, Hence, the central spot is dark.

Condition for Maximum Intensity (Bright Fringe)

$$\Delta = n\lambda$$

or, $$2t + \frac{\lambda}{2} = n\lambda$$

or $$2t = (2n-1)\frac{\lambda}{2}$$

Condition for Minimum Intensity

$$\Delta = (2n+1)\frac{\lambda}{2}$$

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

or $$2t = n\lambda$$

It is clear that bright or dark fringe of any particular order n will occur for a constant value of t. Since in the air film t remains constant along a circle with its centre at the point of contact, the fringe are in the form of concentric circles since each fringe is a locus of constant film thickness. These are known as the fringes of constant thickness.

Diameter of Rings

Let us consider that the thickness of air film at point Q, is t and r_n is the radius of the ring at that point.

In figure

$$OC = CQ = R$$

$$HC = R - t,\ HQ = r_n$$

In right angle triangle CHQ,

$$CQ^2 = CH^2 + HQ^2$$

$$R^2 = (R \quad t)^2 + r_n^2 = R^2 + t^2 \quad 2Rt + r_n^2$$

$$r_n^2 = 2Rt \quad t^2$$

In actual practice, R is quite large and t is very small. Therefore, t^2 may be neglected in comparison with 2 Rt

$$r_n^2 = 2Rt$$

or
$$r_n^2 = R \times 2t \qquad \text{... (42)}$$

For Bright Rings

$$2\mu t \cos(\theta \pm r) = (2n-1)\lambda/2$$

or
$$2t = (2n-1)\lambda/2$$

By putting the value of $2t$ in eqn. (42) we get,

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

$$\left(\frac{D_n}{2}\right)^2 = R \times (2n-1)\frac{\lambda}{2}$$

$$D_n^2 = 2\lambda R\,(2n-1) \qquad \text{... (43)}$$

The equation (43) denotes the diameter of n^{th} bright ring.

$$D_n = \sqrt{2\lambda R\,(2n-1)}$$

$$D_n \propto \sqrt{(2n-1)} \qquad \text{... (44)}$$

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

For Dark Rings

$$2\ \mu t \cos(\theta + r) = n\lambda$$

or
$$2t = n\lambda$$

Putting the value of $2t$ in equ. (40) we get

$$r_n^2 = R \times n\lambda = n\lambda R$$

$$\left(\frac{D_n}{2}\right)^2 = n\lambda R$$

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

$$D_n \propto \sqrt{n} \qquad \text{... (45)}$$

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

In terms of refractive index (μ), the expressions for diameters of bright and dark rings will be as follows:

For bright rings $$D_n = \frac{\sqrt{2(2n-1)\lambda R}}{\mu}$$

For dark rings $$D_n = \frac{\sqrt{4n\lambda R}}{\mu} \qquad \text{... (46)}$$

Determination of the Wavelength of Sodium Light using Newton's Rings

Experimental arrangement is shown in figure 1.10. Light from a monochromatic source is reflected by the glass plate inclined at 45° to the horizontal. L is a Plano convex lens of large focal length. The traveling microscope focused on the air film views Newton's rings. Concentric circular bright and dark rings are seen, with the centre dark. With the help of a traveling microscope, we measure the diameter of the n^{th} dark ring.

Diameter of n^{th} order dark ring is

$$D_n^2 = 4n\lambda R \qquad \text{... (47)}$$

Similarly, diameter of $(n + p)^{th}$ order dark ring

$$D_{n+p}^2 = 4(n+p)\lambda R \qquad \text{... (48)}$$

Subtracting equation (47) from eqn. (48) we have,

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

or
$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}$$

The radius of curvature of lower surface of the lens is determined with the help of a spherometer but more accurately it is determined by Boy's method. Hence, the wavelength of a given monochromatic source of light can be determined.

Determination of Refractive Index of Liquid by Newton's Ring Method

The experiment is performed in two steps:

(i) When there is an air film between glass plate and plano convex lens, and

(ii) When there is liquid film, instead of air film, between glass plate and plano convex lens.

In both the cases diameter of n^{th} and $(n + p)^{th}$ rings are determined. If the diameters of n^{th} and $(n + p)^{th}$ rings are D_n and D_{n+P} when medium is air and when medium is liquid then:

For air medium,

$$D_n^2 = 4n\lambda R \text{ and } D_{n+p}^2 = 4(n+p)\lambda R$$

$$D_{n+p}^2 - D_n^2 = 4p\lambda R \qquad \text{... (49)}$$

For liquid medium of refractive index μ is then

$$\left(D_n^1\right)^2 = \frac{4n\lambda R}{\mu} \quad \text{and} \quad \left(D_{n+p}^1\right)^2 = \frac{4(n+p)\lambda R}{\mu}$$

$$\Rightarrow \left(D_{n+p}^1\right)^2 - \left(D_n^1\right)^2 = \frac{4p\lambda R}{\mu} \qquad \text{... (50)}$$

Using equation (49) and (50), we get

$$\mu = \frac{D_{n+p}^2 - D_n^2}{\left(D_{n+p}^1\right)^2 - \left(D_n^1\right)^2} \qquad \text{... (51)}$$

The equation (51) can be used to determine the refractive index of liquid.

1.7.2 Newton's Rings with both Surface Curved

In Newton's Ring experiment, if the plane glass plate is replaced by a curved surface, the rings are formed by reflection from the upper and lower surfaces of the air film. The following arrangements are made:

Case 1:

When the lower surface is convex.

The total thickness of the air film at an point is

$$t = t_1 + t_2 \qquad \text{... (52)}$$

If R_1 and R_2 be the radii of curvatures of the upper and lower curved surfaces respectively, then,

$$t = \frac{r_n^2}{2R_1} + \frac{r_n^2}{2R_2}$$

or

$$2t = \frac{r_n^2}{R_1} + \frac{r_n^2}{R_2} \qquad \text{... (53)}$$

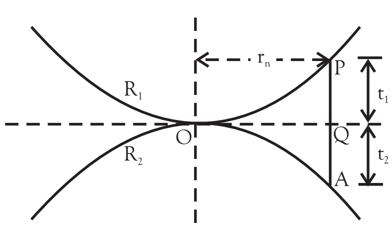


Figure 1.13 : Newton's ring due to lower convex surface

Where r_n is radius of ring corresponding to thickness t.

The condition for dark rings for air film at normal incidence.

$$2t = n\lambda \qquad \text{... (54)}$$

Using equations (53) and (54) we get,

$$r_n^2\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = n\lambda \qquad \text{... (55)}$$

If D_n is the diameter of n^{th} dark ring, then

$$r_n = \frac{D_n}{2} \qquad \text{... (56)}$$

Thus, $$\frac{D_n^2}{4}\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = n\lambda$$

or, $$D_n^2 = \frac{4n\lambda}{\left[\frac{1}{R_1} + \frac{1}{R_2}\right]} \qquad \text{... (57)}$$

Case 2:

When the lower surface is concave, the thickness of the film

$$= t_1 - t_2 \qquad \text{... (58)}$$

Substituting $t_1 = \frac{r_n^2}{2R_1}$ and $t_2 = \frac{r_n^2}{2R_2}$ in above equation, we have

$$t = \frac{r_n^2}{2R_1} - \frac{r_n^2}{2R_2} \quad \text{or} \quad 2t = r_n^2\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \qquad \text{... (59)}$$

Substituting the value of $2t$ in equation (53), we have

$$r_n^2\left[\frac{1}{R_1} - \frac{1}{R_2}\right] = n\lambda$$

$$\frac{D_n^2}{4}\left[\frac{1}{R_1} - \frac{1}{R_2}\right] = n\lambda$$

$$D_n^2 = \frac{4n\lambda}{\left[\frac{1}{R_1} - \frac{1}{R_2}\right]} \qquad \text{... (60)}$$

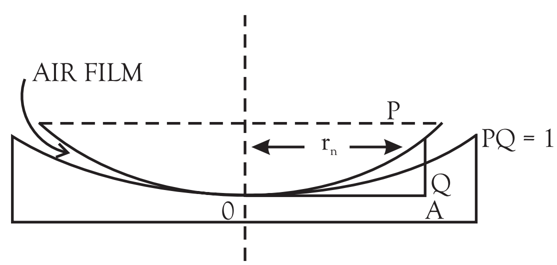


Figure 1.14 : Newton's ring due to lower concave surface

Combining equation (57) and equation (60), for general equation as

$$D_n^2 = \frac{4n\lambda}{\left[\frac{1}{R_1} \pm \frac{1}{R_2}\right]}$$

Example 1: Two straight and narrow parallel slits 3 *mm* apart are illuminated by monochromatic light of wavelength 5900Å. Fringes are obtained on a 0.60 *m* distant screen from the slits. Calculate the value of the fringe-width.

Solution: The separation between two slits is the separation between two coherent sources. It is given that $2d = 3 \times 10^{-3}$ *mm*.

Distance between the source and screen, $D = 0.60$m.

Wavelength of light = 5900Å = 5.9×10^{-7} *m*.

⇒ The fringe-width is given by,

$$\omega = \frac{D\lambda}{2d} = \frac{0.60 \times 5.9 \times 10^{-7}}{3 \times 10^{-3}}$$

$\omega = 1.18 \times 10^{-4}$ *m*.

Example 2: In a biprism experiment, the eyepiece was placed at a distance of 120 *cm* from the source. The distance between the two virtual sources was found to be 0.75 *cm*. Calculate the wavelength of the light used if the eyepiece is required to move through in a distance of 1.8888 cm for 20 fringes.

Solution: Given: $\omega = \frac{1.888}{20} = 0.944 cm = 0.000944 m$

D =120 *cm* = 1.20 *m* and $2d$ = 0.075 *cm* = 0.00075 *cm*

From the relation,

$$\omega = \frac{D\lambda}{2d}$$

the wavelength

$$\lambda = \frac{\omega \cdot 2d}{D}$$

$$= \frac{0.000944 \times 0.00075}{1.20} = 5900 \times 10^{-10} m$$

Example 3: Biprism is kept 5 *cm* away from a slit illuminated by monochromatic light (λ = 5890Å). The width of the fringes obtained on a screen placed at a distance of 75 *cm* from the biprism is 9.424×10^{-2}*cm*. What is the distance between the two coherent sources?

Solution: Given: $\lambda = 5890 \times 10^{-2}$ *m*, $\omega = 9.424 \times 10^{-4}$ *m*,

$D = 5 + 75 = 80$ *cm* = 0.80 *m*

From the expression,

$$\omega = \frac{D\lambda}{2d}$$

The separation between the two coherent sources is given by,

$$2d = \frac{D\lambda}{\omega}$$

$$= \frac{0.80 \times 5890 \times 10^{-10}}{9.424 \times 10^{-4}} = 0.0005\ m.$$

Example 4: In two slit experiment, the distance of screen from the two slits is 1.0 *m*. When length of wavelength 6000Å is made incident, fringes of width 2.0 *mm* are obtained on the screen. Compute: (a) the distance between the slits (b) The fringe-width if the wavelength of incident light is 4800Å.

Solution: (a) Given: $D = 1.0$ *m*, λ = 6000Å = 6×10^{-7}*m*,

$\omega = 2.00$ *mm* = 2×10^{-3} *m*

$$\omega = \frac{D\lambda}{2d}$$

$$2d = \frac{D\lambda}{\omega} = \frac{1.0 \times (6 \times 10^{-7})}{2 \times 10^{-3}}$$

or $2d = 3 \times 10^{-4}$ *m* = 0.3 *mm*

i.e., distance between the two slits = 0.3 *mm*.

(b) Given: ω_1 = 2.0 *mm* = 2×10^{-3} *m*, λ_1 = 6000Å = 6×10^{-7} *m*.

λ_2 = 4800Å = 4.8×10^{-7}m, ω_2 = ?

We know that,

$\omega \propto \lambda$,

$$\frac{\omega_1}{\omega_2} = \frac{\lambda_1}{\lambda_2} \text{ or } \omega_2 = \omega_1 \frac{\lambda_2}{\lambda_1}$$

$$\omega_2 = (2 \times 10^{-3}) \times \frac{4.8 \times 10^{-7}}{6.0 \times 10^{-7}}$$

$= 1.6 \times 10^{-3}$ *m*.

Example 5: Two coherent sources of monochromatic light of wavelength 6000Å produce and interference pattern on a screen kept at a distance of 1 meter from them. The distance between two consecutive bright fringes on the screen is 0.5 *mm*. Find the distance between the two consecutive bright fringes on the screen 0.5 *mm*. Find the distance between the two coherent sources.

Solution: Given: λ = 6000Å = 6000×10^{-10} *m*, D = 1, w = 0.5 *mm* = 5×1^{-4} *m*

$$\omega = \frac{D\lambda}{2d} \text{ or } 2\text{d} = \frac{\text{D}\lambda}{\omega}$$

$$\Rightarrow \quad 2d = \frac{1 \times 6000 \times 10^{-10} m}{5 \times 10^{4}} = 1.2 \times 10^{-3} m$$

or $2d = 1.2$ *mm*

Example 6: In a two slit interference pattern at a point, we observe 10^{th} order maximum for λ = 7000Å. What order will be visible here, if the source of light is replaced by the light of wavelength 5000Å?

Solution: For maximum intensity or maxima at point on the screen in two slit interference pattern, the path difference between two coherent sources must be an even multiple of half wavelength of light used, i.e.,

Path difference, $\Delta = 2n\ (\lambda/2) = n\lambda$,

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

Suppose at a point n_1th order maximum for wavelength λ_1 and n_2^{th} order maximum for wavelength λ_2 will be visible, then

$$\Delta = n_1\lambda_1 = n_2\lambda_2$$

Here, λ_1 = 7000Å, n_1 = 10, λ_2 = 5000Å, n_2 = ?

$$\Rightarrow \quad n_2 = \frac{n_1\lambda}{\lambda_2} = \frac{10\times 7000}{5000} = 14$$

That is, 14^{th} order maximum will be visible.

Example 7: The inclined faces of a glass prism (μ = 1.5) make an angle of 1° with the base of the prism. The slit is 10 *cm* from the biprism and is illuminated by light λ = 5900Å. Calculate the fringe-width observed at a distance of 1 *m* from the biprism.

Solution: $\omega = \dfrac{D\lambda}{2d}$

$$2d = 2a\ (\mu - 1)$$

Here, $\mu = 1.5$; $\alpha = 1° = \dfrac{\pi}{180}$ radian; $a = 10$ *cm*; $b = 100$ *cm*;

$D = a + b = 10 + 100 = 110$ *cm* $= 1.1$ *m*; $\lambda = 5900 \times 10^{-10}$ *m* ; ω = ?

$$\Rightarrow \quad \omega = \frac{5900\times 10^{-10}\times 1.1\times 180\times 7}{2(1.5-1)\times 22\times 0.1} = 0.037\ cm.$$

Example 8: The distance between the slit and the biprism and between the biprism and the screen are 50.0 *cm* each. The obtuse angle of biprism is 179° and its refractive index 1.5. If the width of the fringes is 0.0135 *cm*, calculate the wavelength of light.

Solution: Given: ω = 0.0135 *cm*, a = 50 *cm*, D = 50 + 50 = 100 *cm*.

$$\mu = 1.5, \quad \alpha = \frac{180-179}{2} = \left(\frac{1}{2}\right)^{o} = \left(\frac{\pi}{360}\right)^{rad}$$

$$\omega = \frac{D\lambda}{2d} \quad \text{and } 2d = 2a(\mu-1)\alpha$$

$$\lambda = \left(\frac{2d}{D}\right)\omega = \frac{2a(\mu-1)\alpha}{\text{D}}\cdot\omega$$

$$= \frac{2\times 50(1.5-1)(\pi/360)}{100}\times 0.0135\ cm$$

$$= 5893 \times 10^{-8}\ cm$$

$$\lambda = 5893\ \text{Å}$$

Example 9: In Fresnel's biprism, the fringes of 0.185 *mm* width are formed on a screen placed at 1 meter distance from slit. A convex lens placed at 30 *cm* from slit forms the two images of two coherent sources. The separation between the image was found to be 0.70 *cm*. Calculate the wavelength of the light used.

Solution: Fringes width ω = 0.185 *mm* = 0.0185 *cm*

Distance of screen from slit D = 1 meter = 100 *cm* (object)

Distance of lens from slit, u = 30 *cm*,

Distance of lens from screen image n = 70 *cm*

Now, Lens magnification, $\dfrac{d_1}{2d} = \dfrac{\nu}{u}$

So, $\dfrac{0.70}{2d} = \dfrac{70}{30}$ *or* $2\text{d} = \dfrac{30}{70}\times 0.70$

using $\omega = \dfrac{\lambda D}{2d}$

or $\lambda = \dfrac{\omega\cdot 2d}{D}$

or $$\lambda = \frac{0.0185\times\frac{30}{70}\times 0.70}{100} = \frac{0.0185\times 0.3}{100}$$

$$= 5550 \times 10^{-8}\ cm.$$

Example 10: In Fresnel's biprism experiment with a source of light of wavelength 5890Å, a thin mica sheet of refractive index 1.6 is placed normally in the path of one of the interfering beams and the central bright fringe is shifted to a position of third bright fringe from the centre. Calculate the thickness of mica sheet.

Solution: Given: λ = 5890 Å = 5890×10^{-8} *cm*, μ = 1.6, fringes sift = 3ω

Fringe shift $= \dfrac{D(\mu-1)t}{2d} = \dfrac{\omega}{\lambda}(\mu-1)t, \qquad \left[\omega = \dfrac{D\lambda}{2d}\right]$

$$\Rightarrow \quad \frac{\omega}{\lambda}(\mu-1)t = 3\omega$$

or $$t = \frac{3\lambda}{\mu-1} = \frac{3\times 5890\times 10^{-8}\ cm}{1.6-1} = 2.94\times 10^{-4}\text{cm}.$$

Example 11: A parallel beam of light ($\lambda = 5890 \times 10^{-8}\ cm$) is incident on a thin glass plate ($\mu = 1.5$) such that the angle of refraction into the plate is 60°. Compute the smallest thickness of the glass plate which will appear dark by reflection.

Solution: $2\mu t \cos r = n\lambda$

Here, $\mu = 1.5$, $r = 60°$, $\cos 60° = 0.5$, $n = 1$, $\lambda = 5890 \times 10^{-8} cm$

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

$$t = \frac{1 \times 5890 \times 10^{-8}\, cm}{2 \times 1.5 \times 0.5}$$

$$= 3.926 \times 10^{\ 5}\ cm.$$

Example 12: Light of wavelength 5890Å falls on the thin glass plate ($\mu = 1.5$) such that the angle of refraction in plate is 60°. Calculate the minimum thickness of the plate so that the plate appears dark in the reflected light.

Solution: Given: $\mu = 1.5$, $\lambda = 5890Å = 5.89 \times 10^{-7} m$, $r = 60$.

The condition for the destructive interference in the reflected light is,

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

For the minimum thickness $n = 1$

$\Rightarrow \quad 2\mu t \cos r = \lambda$

$$\text{or} \quad t = \frac{n\lambda}{2\mu \cos r}$$

$$t = \frac{5.89 \times 10^{-7}\, cm}{2 \times 1.5 \times \cos 60} = \frac{5.89 \times 10^{-7}}{2 \times 1.5 \times (1/2)}$$

$$= 3.927 \times 10^{-7}\ cm$$

Example 13: Light of wavelength 5893Å is reflected at normal incidence from a soap film of refractive index 1.42. What is the least thickness of the film that will appear (a) bright and (b) dark?

Solution: Given: $\lambda = 5893Å = 5893 \times 10^{-10} m$, $r = 0°$, $\mu = 1.42$

(a) The condition for thin film to appear bright in reflected light is given by,

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

$$\text{or} \quad 2 \times 1.42 \times t \times 1 = \frac{(2-1) \times 5893 \times 10^{-10}}{2}$$

$$\text{or} \quad t = \frac{5893 \times 10^{-10}}{2 \times 2 \times 1.42} = 1037.5 \times 10^{-10}\, m$$

(b) The condition for thin film to appear dark in reflected light is given by,

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

Hence, $2 \times 1.42 \times t \times 1 = 1 \times 5893 \times 10^{-10}$

[$\cos r = 1$]

$$\text{or} \quad t = \frac{5893 \times 10^{-10}}{2 \times 1.42}$$

$$= 2075 \times 10^{-10} = 2.075 \times 10^{-7}\, m.$$

Example 14: A soap film ($\mu = 1.33$) is illuminated with light of different wavelength at an angle of 45°. There is complete destructive interference for $\lambda = 5890Å$. Calculate the thickness of the soap film,

Sol. Given: $\mu = 1.33$, $i = 45°$

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

$$\Rightarrow \quad \sin r = \frac{\sin 45}{1.33} = \frac{1}{\sqrt{2} \times 1.33} = 0.5317$$

$$\cos r = \sqrt{1 - \sin^2 r}$$

$$\Rightarrow \quad = \sqrt{1 - (0.5317)^2} = 0.8469$$

for destructive interference

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

or $2 \times 1.33 \times 0.8469 = 1 \times 5890 \times 10^{-10}$

$$\Rightarrow \quad t = \frac{5893 \times 10^{-10}}{2 \times 1.33 \times 0.8469}$$

$$= 2.614\ \times 10^{-7}\, m = 2.614 \times 10^{-4}\, mm$$

Example 15: A soap film of refractive index 1.43 is illuminated by white light incident at an angle of 30°. The refracted light is examined by a spectroscope in which dark band corresponding to the wavelength 6×10^{-7} is observed. Calculate the thickness of the film.

Solution: The condition for dark bank in reflected light is given as

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

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

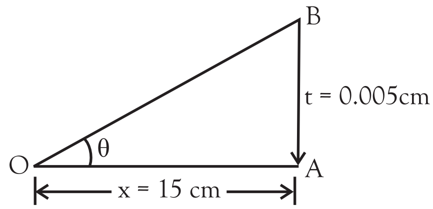
$$\Rightarrow \quad \cos r = \sqrt{1 - \sin^2 r} = \sqrt{1 - (0.35)^2} = 0.94$$

$$\text{For } n = 1 \quad t = \frac{\lambda}{2\mu \cos r} = \frac{6 \times 10^{-7}\, m}{2 \times 1.43 \times 0.94}$$

or $t = 2.23 \times 10^{-7}\ m$

Example 16: Two glass plates enclose a wedge shape air film, toughing at one edge and are separated by a wire of 0.05 *mm* diameter at a distance of 15 *cm* from the edge. Determine the fringe width. Monochromatic light of λ = 6000Å from a source falls normally on the film.

Solution: Given: x = 15 *cm*, λ = 6000Å = 6000 × 10^{-8} *cm* , AB = 0.005 *cm*



Fringe width $\omega = \lambda/2\theta$

$$\theta = \frac{AB}{OA} = \frac{0.005}{15}$$

$$\omega = \frac{\lambda}{2\theta} = \frac{6000\times10^{-8}\times15}{2\times0.005} = 0.09\ cm$$

Example 17: Light of wavelength 6000 Å falls normally on a thin wedge shaped film of refractive index 1.4 forming fringes that are 2 *mm* apart. Calculate the angle of the wedge.

Solution: λ = 6000 × 10^{-10} *m*; μ = 1.4, ω = 2.0 *mm* = 2.0 × 10^{-3} *m*

The fringe-width in the case of wedge shaped film for normal incidence is given by,

$$\omega = \frac{\lambda}{2\mu\theta}$$

or Angle of wedge $\theta = \dfrac{\lambda}{2\mu\omega}$

$$= \frac{6000\times10^{-10}}{2\times1.4\times2\times10^{-3}} = 1.07\times10^{-4}\text{ radians.}$$

Example 18: In Newton's rings experiment, the diameter of the 15th ring was formed to be 0.590 *cm* and that of the 5th ring was 0.336 *cm*. If the radium of the plano convex lens is 100 *cm*, compute the wavelength of the light used.

Solution: Given: D_{15}= 0.590 *cm* = 0.590 × 10^{-2} *m*

D_5= 0.336 *cm* = 0.336 × 10^{-2} *m*

p = (15–5) = 10; R = 100 *cm* = 1.0 *m*.

The wavelength of the monochromatic light is given by,

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}$$

or
$$\lambda = \frac{(0.590\times10^{-2})^2 - (0.336\times10^{-2})^2}{4\times10\times1}$$

$$= 5880\times10^{-10}\,m.$$

Example 19: Newton's rings are observed in reflected light using light of wavelength 5890Å. The radius of the convex surface of the lens is 100 *cm*. A liquid is put between curved surface of lens and plate. The diameter of 10th ring is 4.2 *mm*. Calculate the refractive index of liquid when (a) ring is dark, and (b) ring is bright.

Solution: (a) When ring is dark, $\dfrac{\mu D_n^2}{4R} = n\lambda$ or $\mu = \dfrac{4Rn\lambda}{D_n^2}$

Here λ = 5890 Å,= 5890 × 10^{-8} *cm*; R = 100 *c*, D_{10}= 4.2 *cm*, n = 10.

so $\mu = \dfrac{4\times100\times10\times5890\times10^{-8}}{0.42\times0.42} = 1.335$

(b) Whenring is bright,

$$\frac{\mu D_n^2}{4R} = (2n-1)\frac{\lambda}{2} \quad \text{or} \quad \mu = \frac{4R(2n-1)\lambda}{2D_n^2}$$

or $\mu = \dfrac{4\times100\times(2\times10-1)\times5890\times10^{-8}}{0.42\times0.42\times2} = 1.268$

Example 20: Newton's rings are observed in reflected light of wavelength 6000Å. The diameter of the 10th dark ring is 0.5 *cm*. Find the radius of curvature of the lens and the thickness of the corresponding air film.

Solution: Here λ = 6000Å, $D_{10(\text{dark})}$ = 0.5 *cm*, R = ? t = ?

For dark rings,

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

$$t = \frac{D_n^2}{8R} \qquad \left[t = \frac{r_n^2}{2R}, D_n = \frac{r_n}{2}\right]$$

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

$$= \frac{(0.5)^2}{4\times10\times6\times10^{-5}} = \frac{25\times10^2}{4\times10\times6\times10^5}\ cm$$

$$= \frac{25\times100}{4\times6} = 104.16\ cm$$

Since $t = D_n^2/8R$

$$\Rightarrow \quad t = \frac{(0.5)^2}{8\times104.16} = \frac{25\times10^2}{8\times104.16} = 3\times10^{-4}\ cm$$

MULTIPLE CHOICE QUESTIONS

1. Which one of the following does not support the wave nature of light?

(*a*) Interference (*b*) Diffraction

(*c*) Polarization (*d*) Photoelectric effect

2. Two sources of light are said to be coherent if they have,

(*a*) Nearly the same frequency

(*b*) The same frequency

(*c*) Different wavelength

(*d*) The same frequency and having a constant phase of difference

3. The light wave from two coherent sources of intensity I, in interference at the minima, intensity of light is zero. The intensity of light at the maxima is

(*a*) 2 I (*b*) 4 I

(*c*) 6 I (*d*) I

4. In Interference pattern, the fringe width varies

(*a*) Inversely as wavelength

(*b*) Directly as wavelength

(*c*) Directly as the separation between slits

(*d*) Inversely as the distance between the slits and screen

5. In Young's double slit experiment, the separation between the slits is halved and distance between the slits and screen is doubled. The fringe width is:

(*a*) Unchanged (*b*) Halved

(*c*) Doubled (*d*) Quadrupled

6. In a Fresnel's biprism experiment, the central fringe is

(*a*) Bright

(*b*) Dark

(*c*) First bright and the dark

(*d*) First dark and then bright

7. Narrow source is required in

(*a*) Biprism experiment

(*b*) Newton's rings experiment

(*c*) In both above

(*d*) None of the above

8. In Interference of light waves, the following conserved

(*a*) Intensity (*b*) Energy

(*c*) Amplitude (*d*) Momentum

9. Interference occurs in

(*a*) Longitudinal wave only

(*b*) Transverse wave only

(*c*) Electromagnetic wave only

(*d*) All of the above waves

10. Thin films of oil on water surface shows brilliant colours due to

(*a*) Dispersion (*b*) Interference

(*c*) Diffraction (*d*) Polarization

11. Newton's rings are

(*a*) Loci of points of equal thickness

(*b*) Loci of points of equal inclination

(*c*) Loci of points of equal thickness and equal inclination

(*d*) None of the above

12. In Newton's rings arrangement, the diameter of rings formed is proportion to

(*a*) λ (*b*) $\lambda/2$

(*c*) $\sqrt{\lambda}$ (*d*) $\frac{1}{\sqrt{\lambda}}$

13. In which of the following, the interference is produced by the division of wave front?

(*a*) Fabry Perot interferometer

(*b*) Michelson Interferometer

(*c*) Newton's rings

(*d*) Fresnel's biprism

14. When light wave suffers reflection at the interface between glass and air, the change of phase of the reflected wave is equal to

(*a*) $\pi/2$ (*b*) π

(*c*) zero (*d*) 2π

15. In Newton's experiment, if the distance between the lens and the plate is increased, the order of ring at a given point

(*a*) Increases (*b*) Unchanged

(*c*) Decreases (*d*) None of the above

16. To demonstrate the phenomenon of interference, we require two sources, which emit radiations:

(*a*) of nearly same frequency

(*b*) of the same frequency

(*c*) of different wavelength

(*d*) of the same frequency and having a definite phase relationship.

[**Hint:** To demonstrate, interference, we need two coherent sources, which should emit light of the same frequency and having a definite phase relationship.]

17. Two beams of light having intensities I and 41 interfere to produce a fringe pattern on a reason. The phase-difference between the beams is π/2, at a point A and π at a point B. Then the difference between the resultant intensities at A and B is:

(*a*) 2I (*b*) 4I

(*c*) 5I (*d*) 7I

[Hint: As $I = I_1 + I_2 + 2\sqrt{I_1 \cdot I_2}\cos\phi$

$\Rightarrow I_A = I + 4I + 2\sqrt{I \cdot 4I} \times \cos\pi/2 = 5I$

$I_B = I + 4I + 2\sqrt{I \cdot 4I} \times \cos\pi/2$

$= 5I + 2.2I(-1)$

$= 5I - 4I = I$

$\Rightarrow I_A - I_B = 5I - I = 4I$].

18. The velocity of light in glass, whose refractive index (μ_g) = 1. 5 is 2×10^8 ms^{-1}. In certain liquid, the velocity of light is found to be 2.6 × 10 ms. The refractive index (μ_w) of that liquid is:–

(*a*) 1.5 (*b*) 1.2

(*c*) 1 (*d*) 2.1

[**Hint:** $c = \mu v = 1.5 \times 2 \times 10^8 = 3 \times 10^8$ms^{-1}

$\mu = \frac{c}{v} = \frac{3\times10^8}{2.6\times10^8} = 1.2$].

19. Two waves have intensity ratio 25 : 4. What is the ratio of maximum to minimum intensity ?

(*a*) $\frac{16}{25}$ (*b*) $\frac{25}{4}$

(*c*) $\frac{9}{49}$ (*d*) $\frac{49}{9}$

[Hint: $\frac{I_1}{I_2} = \frac{a^2}{b^2} = \frac{25}{4}, \frac{a}{b} = \frac{5}{2}$

$\frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2} = \frac{(5+2)^2}{(5-2)^2} = \frac{49}{9}$]

20. Two waves having intensity of the ratio 25 : 4 produce interference. The ratio of maximum to minimum intensity is:–

(*a*) 5 : 2 (*b*) 7 : 3

(*c*) 49 : 9 (*d*) 9 : 49

[Hint: $\frac{I_1}{I_2} = \frac{a^2}{b^2} = \frac{25}{4} \Rightarrow \frac{a}{b} = \frac{5}{2}$

$$\frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2} = \frac{(5+2)^2}{(5-2)^2} = \frac{49}{9}.$$

21. Two light waves having their intensities in the ration 16:9, interfere to produce interference pattern. What is the ratio of maximum intensity to minimum intensity in this pattern ?

(*a*) 4 : 3 (*b*) 25 : 7

(*c*) 625 : 49 (*d*) 49 : 1

[Hint: Since, $\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right)^2$

Given, $\frac{I_1}{I_2} = \frac{16}{9} \therefore \frac{I_{max}}{I_{max}} = \left(\frac{7}{1}\right)^2 = \frac{49}{1}$]

22. If a shift of 100 circular fringes is observed when the movable mirror of Michelson's interferometer is shifted by 0.03 mm, then the wavelength of light used is:

(*a*) 150 nm (*b*) 300 nm

(*c*) 600 nm (*d*) 1200 nm

[**Hint:** Given, n = 100 and d = 0.03 mm

$\Rightarrow \lambda = \frac{2d}{n} = \frac{2\times0.03\times10^{-3}}{100}$

$= 0.06 \times 10^{-5}$

$= 600 \times 10^{-9}$ m = 600 nm.

23. The correct statement of Fermat's principle is:

(*a*) the ray of light corresponds to the path for which the time taken is minimum.

(*b*) the ray of light corresponds to the path for which the time taken is extremum.

(*c*) the ray of light corresponds to the path for which the time taken is maximum.

(*d*) none of the above

24. System-matrix for a thick lens is:

(*a*) $\begin{bmatrix} 1-P_2\left(\frac{T}{\mu}\right) & -P_1-P_2\left(1-P\times\frac{l}{\mu}\right) \\ \frac{l}{\mu} & -P_1\left(\frac{l}{\mu}\right)+1 \end{bmatrix}$

(*b*) $\begin{bmatrix} \frac{1}{\mu} & 1-P_2\left(\frac{l}{\mu}\right) \\ -P_1-P_2\left(1-P_1\frac{l}{\mu}\right) & 1-P_2\left(\frac{1}{\mu}\right) \end{bmatrix}$

(*c*) $\begin{bmatrix} 1 & 0 \\ D/\mu_2 & 1 \end{bmatrix}$

(*d*) None of these

25. Fermat's Principle is applicable to:

(*a*) homogeneous media only.
(*b*) inhomogeneous media only
(*c*) both homogeneous and inhomogeneous media
(*d*) nothing can be said definitely

26. The lateral chromatic aberration can be reduced by :

(*a*) By using plane - convex lens
(*b*) By combining a converging and diverging lens
(*c*) Increasing dispersive power of the lens
(*d*) None of the above

27. The magnification produced by combination of thin lenses is equal to:

(*a*) The sum of magnifications produced by each lens individually.
(*b*) The ratio of magnifications produced by each lens individually.
(*c*) The product of individual magnifications produced by each lens separately.
(*d*) None of these

28. Which determines the longitudinal chromatic aberration of a lens?

(*a*) Dispersive power only
(*b*) Focal length only
(*c*) Both (*a*) and (*b*)
(*d*) None of the above

29. The intensity of light emerging from one slit in a Young's double-slit interference set up is four times that of the other. The ratio of maximum intensity to minimum intensity in the fringe pattern is:

(*a*) 4 : 1 (*b*) 2 : 1
(*c*) 9 : 1 (*d*) 3 : 1

[**Hint:** Since $I \Rightarrow a^2$

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

$$\Rightarrow \frac{I_{\max}}{I_{\min}} = \frac{(2+1)^2}{(2-1)^2} = \left(\frac{3}{1}\right)^2 = \frac{9}{1}]$$

30. If r is the core radius, n_i and n_2 are the refractive index of medium 1 and 2 respectively and λ is the wavelength of light, men the condition for single-made or mono-made operation is:

(*a*) $2r = \dfrac{2.405\lambda}{\pi(\mu_1^2 - \mu_2^2)^{1/2}}$ (*b*) $2r > \dfrac{2.405\lambda}{\pi(\mu_1^2 - \mu_2^2)^{1/2}}$

(*c*) $2r < \dfrac{2.405\lambda}{\mu(\mu_1^2 - \mu_2^2)^{1/2}}$ (*d*) $r < \dfrac{2.405\lambda(\mu_1 + \mu_2)^2}{\pi(\mu_1^2 - \mu_2^2)^{1/2}}$

31. When the phase difference between two points of electromagnetic wave at time $t > 0$ is zero, then the wave has:

(*a*) Spatial coherence
(*b*) Temporal coherence
(*c*) Perfect spatial coherence
(*d*) Coherence

32. Two lenses of powers –1.75 diopter and +2.25 diopters are placed in contact. Calculate the focal length of the Jens.

(*a*) 12 m (*b*) 5 diopter
(*c*) 2 m (*d*) 20 m

[**Hint:** Given, $P_1 = -1.75$ diopter
$P_2 = +2.25$ diopter ⇒ focal length, $f_m = 1/P$

$$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} = \frac{1}{-1.75} + \frac{1}{2.25} = 2 \text{ metres}]$$

33. The light waves from two coherent sources of intensity V, interfere. At the minimum, the intensity of light is zero. What is the intensity of light at the maximum ?

(*a*) $4I$ (*b*) I^2
(*c*) 47^2 (*d*) 7

[**Hint:** $I_1 = I_2 = I$

As $I_{\min} = (a - b)^2 = 0 \Rightarrow a = b$

$I_{\max} = (a + b)^2 = (a + a)^2 = 4a^2 = 4I$]

34. Two light sources when placed at a distance 'd' apart gave an interference pattern having fringe width 'w'. When the distance between the sources is reduced to dl 2 the fringe width will:

(*a*) become $\dfrac{\omega}{2}$ (*b*) become $\dfrac{3\omega}{2}$
(*c*) become 2ω (*d*) not change

[**Hint:** $\omega = \dfrac{D\lambda}{d}$ or $\omega \Rightarrow \dfrac{1}{d}$

when $d \to d/2$, $\omega \to d \to d/2$, $\omega \to 2\omega$]

35. A biprism consists of :

(*a*) two parallel glass plates
(*b*) two acute angled prism
(*c*) two obtuse angled prism
(*d*) none of these

[**Hint:** Refer to construction of Biprism (A biprism consist of two acute angled prism placed base to base. The acute angle is of the order of 30′ or *i*°)]

36. Interference of light is evidence that:
(a) the speed of light is very large
(b) light is a transverse wave
(c) light is electromagnetic in character
(d) light is a wave phenomenon

37. In a Young's double-slit experiment the center of a bright fringe occurs wherever waves from the slits differ in the distance they travel by a multiple of:
(a) a fourth of a wavelength
(b) a half a wavelength
(c) a wavelength
(d) three-fourths of a wavelength

38. For destructive interference, path difference is
(a) odd number of half wavelengths
(b) even number of half wavelengths
(c) whole number of wavelengths
(d) even whole number of wavelengths

39. Constructive interference happens when two waves are
(a) out of phase (b) zero amplitude
(c) in phase (d) in front

40. Two waves with phase difference 180° have resultant of amplitude
(a) one (b) zero
(c) same as single wave (d) doubles single wave

41. If two waves are in phase and have same amplitude then resultant wave has
(a) half of amplitude of single wave
(b) same amplitude as single wave
(c) twice of amplitude of single wave
(d) thrice of amplitude of single wave

42. Extra distance travelled by one of waves compared with other is called
(a) path (b) displacement
(c) phase difference (d) path difference

43. Which of the following can be used as monochromator in addition to the prism?
(a) thin film (b) thin glass plate
(c) diffraction grating (d) none of them

44. The diffraction phenomenon is
(a) Bending of light around an obstacle
(b) Rectilinear propagation of light
(c) Oscillation of wave in one direction
(d) None of them

45. Diffraction effect is predominant when
(a) Size of the obstacle is less than the wavelength of light
(b) Size of the obstacle is nearly equal to the wavelength of light
(c) Size of the obstacle is greater than the wavelength of light
(d) None of these

46. The condition for constructive interference is path difference should be equal to
(a) odd integral multiple of wavelength
(b) Integral multiple of wavelength
(c) odd integral multiple of half wavelength
(d) Integral multiple of half wavelength

47. The condition for destructive interference is path difference should be equal to
(a) odd integral multiple of wavelength
(b) Integral multiple of wavelength
(c) odd integral multiple of half wavelength
(d) Integral multiple of half wavelength

48. The ratio of intensities of two waves that produce interference pattern is 16:1 then the ratio of maximum and minimum intensities in the pattern is
(a) 25:9 (b) 9:25
(c) 1: 4 (d) 4:1

49. Correlation between the field at a point and the field at the same point at later time is known as
(a) Temporal coherence (b) Spatial coherence
(c) coherence (d) None of them

50. Superposition of crest and trough results in __________
(a) Destructive interference
(b) Constructive interference
(c) Diffraction (d) Polarization

51. The fringe width (β) of the interference pattern in the Young's double slit experiment increases ________
(a) with increase in wavelength
(b) With decrease in wavelength
(c) independent of wavelength
(d) none of these

52. The fringe width (β) of the interference pattern in the Young's double slit experiment increases ________ distance between the slits and the screen.
(a) with increase in (b) With decrease in
(c) independent of (d) None of these

53. If the thickness of the parallel film increases, the path difference
(a) Increases (b) Decreases
(c) Remains same (d) None of these

54. In case of the thin film, the condition for constructive interference is that the apparent path difference should be equal to
(a) odd integral multiple of wavelength
(b) Integral multiple of wavelength
(c) odd integral multiple of half wavelength
(d) Integral multiple of half wavelength

55. In case of the thin film, the condition for destructive interference is that the apparent path difference should be equal to
(a) odd integral multiple of wavelength
(b) Integral multiple of wavelength
(c) odd integral multiple of half wavelength
(d) Integral multiple of half wavelength

56. In Newton's rings experiment, the diameter of bright rings is proportional to
(a) Odd natural numbers
(b) Natural numbers
(c) Even natural numbers
(d) Square root of odd natural numbers

57. In Newton' rings experiment, the diameter of dark rings is proportional to
(a) Odd natural numbers
(b) Natural numbers
(c) Even natural numbers
(d) Square root of natural numbers

58. What principle is responsible for alternating light and dark bands when light passes through two or more narrow slits?
(a) refraction (b) polarization
(c) diffraction (d) interference

59. Two beams of coherent light travel different paths arriving at point P. If the maximum constructive interference is to occur at point P, the two beams must
(a) arrive 180ø out of phase
(b) arrive 90ø out of phase
(c) travel paths that differ by a whole number of wavelengths
(d) travel paths that differ by an odd number of half-wavelengths

60. On a clear day, the sky appears to be more blue toward the zenith (overhead) than it does toward the horizon. This occurs because
(a) the atmosphere is denser higher up than it is at the earth's surface.
(b) the temperature of the upper atmosphere is higher than it is at the earth's surface.
(c) the sunlight travels over a longer path at the horizon, resulting in more absorption.
(d) none of the above is true.

ANSWERS

1. (c)	**2.** (a)	**3.** (c)	**4.** (d)	**5.** (b)	**6.** (c)	**7.** (c)	**8.** (b)	**9.** (d)	**10.** (c)
11. (d)	**12.** (b)	**13.** (b)	**14.** (c)	**15.** (a)	**16.** (*d*)	**17.** (*b*)	**18.** (*b*)	**19.** (*d*)	**20.** (*c*)
21. (*d*)	**22.** (*c*)	**23.** (*b*)	**24.** (*a*)	**25.** (*c*)	**26.** (*d*)	**27.** (*c*)	**28.** (*c*)	**29.** (*c*)	**30.** (*c*)
31. (*c*)	**32.** (*c*)	**33.** (*a*)	**34.** (*c*)	**35.** (*b*)	**36.** (*d*)	**37.** (*c*)	**38.** (*a*)	**39.** (*c*)	**40.** (*b*)
41. (*c*)	**42.** (*d*)	**43.** (*c*)	**44.** (*a*)	**45.** (*b*)	**46.** (*b*)	**47.** (*c*)	**48.** (*a*)	**49.** (*a*)	**50.** (*a*)
51. (*a*)	**52.** (*a*)	**53.** (*a*)	**54.** (*c*)	**55.** (*b*)	**56.** (*d*)	**57.** (*d*)	**58.** (*d*)	**59.** (*c*)	**60.** (*c*)