Study Material – Sem. 2 – C 4 T

– Interference (Fresnel's Biprism & Lloyd's Mirror) – Dr. T. Kar

Conditions for observable interference pattern

In order to have well defined observable interference pattern the following conditions must be satisfied.

(i) The two beams of light which interfere must be coherent.

Two sources are said to be coherent if the phase difference ϕ between the sources remain constant in time. If the sources are incoherent ϕ changes continually and we get uniform general illumination.

(ii) The interfering waves must have the same frequency. Also their amplitudes must be equal or very nearly equal.

If the amplitudes a and b differ widely, then the intensity $(a+b)^2$ in the bright region and that $(a\sim b)^2$ in the dark region will not differ significantly and hence intensity variation cannot be recognized.

(iii) The original source must be monochromatic or very nearly monochromatic. If the light source is heterogeneous, the optical path difference between the interfering beams must be kept very small.

The spacing $\frac{\lambda D}{d}$ between consecutive bright or dark fringes is a function of λ. So the fringes of different colours will be in step only at the central fringe and soon get out of step on either side of central fringe. If the path difference is large, then dark fringes of some wavelengths may be masked by the bright fringes of some other wavelengths.

(iv) The two interfering beams must propagate along the same direction or must intersect at a very small angle.

If the angle between two interfering wavefronts is large or the distance between two coherent sources is large, the spacing between the interference fringes becomes small and may become indistinguishable even under high magnification.

(v) For interference with polarized light, the waves must be in the same state of polarisation.

Two classes of interference

Optical devices producing interference fringes may be classified into the following two classes. The basis of classification depends on how we produce coherent sources.

(a) Division of wavefront

Optical devices which divide the incident wavefront into two parts by reflection, refraction or diffraction and thereby give rise to two coherent interfering beams come under the division of wavefront class. In order to maintain spatial coherence it is essential to use narrow sources in these cases. The formation of fringes by Biprism, Lloyd's single mirror, Billet's divided lens etc. belong to this category. Since limited portion of the wavefront are used in these devices, diffraction effects are also present along with the interference effects.

(b) Division of amplitude

Optical devices which divide the amplitude of incident light wave into two or more parts by partial reflection and refraction and thereby give rise to two or more coherent interfering beams of light come under the division of amplitude class. Here we require to use broad source of light. As the interference effect corresponding to different points of the source are superposed here we get brighter bands. Since a large section of the wavefront is used, diffraction effects are minimised. The formation of fringes by thin films, Newton's ring, Michelson's interferometer, Febry-Perot interferometer etc. belong to this category.

Young's Experiment

The phenomenon of interference was first demonstrated by Thomas Young in 1801 with a simple experiment. He allowed sunlight to fall on a pinhole S and then at some distance away on two pinholes S_1 and S_2 as shown in fig. 5. Finally, the light was received on an opaque screen. He observed that the illumination on the screen consisted of many alternate bright and dark spots.

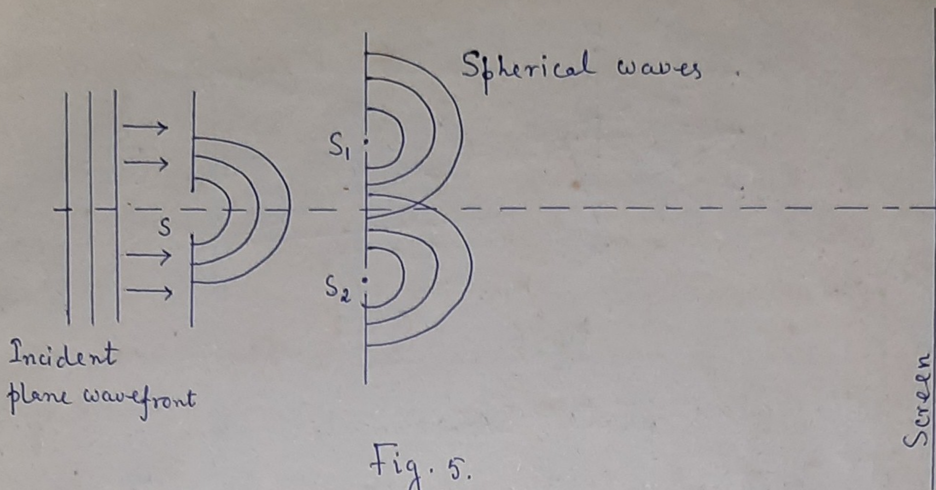

Fig. 5.

According to Huygens' principle spherical wavelets spread out from the pinhole S. Since $SS_1 = SS_2$, these wavelets reach S_1 and S_2 at the same instant of time. Hence the new spherical wavelets diverging from S_1 and S_2 to the right will have equal phase at the start. Thus they act as two coherent sources. The two sets of spherical waves emerging from S_1 and S_2 interfere with each other and form a symmetrical pattern of bright and dark regions on the screen. At the points where the waves meet in same phase maximum brightness is produced. On the other hand, minimum brightness is produced at points where waves meet in opposite phase.

In modern version of the experiment the pinholes are replaced by narrow parallel slit.

Fresnel's Biprism

Fresnel used a biprism to demonstrate the interference phenomenon. A biprism is essentially two prisms each of very small refracting angle (~30′) placed base to base. In practice it is constructed from

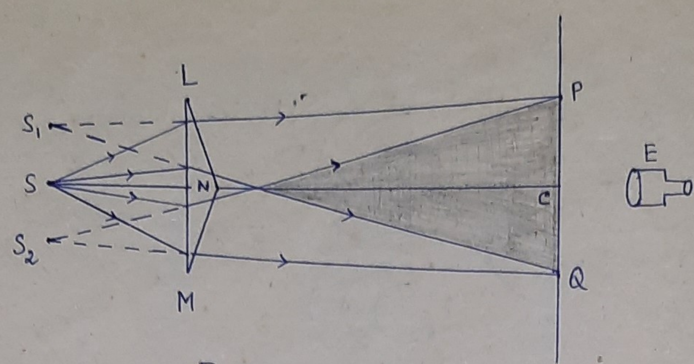

Fig. 6.

a single glass plate. Experimental arrangement using Fresnel's biprism is shown schematically in fig. 6. Light from a narrow slit S illuminated by monochromatic light is incident symmetrically on the biprism LMN. It is desirable to place the plane surface of the biprism towards the source, for in that case deviation of the ray produced by the two surfaces of the prism will be nearly equal and hence the width of the virtual sources S_1 and S_2 would be small which will make the fringes distinct. The incident wavefront is divided into two parts and suffer separate refractions through the two halves of the biprism. The two refracted wavefronts appear to diverge from two virtual sources S_1 and S_2. Hence S_1 and S_2 can be considered as two coherent sources. The emergent wavefronts meet at small angles and produce interference pattern on the screen in the overlapping region PQ. The brightness or darkness at a point on the screen will be dependent only on the path difference of the point from S_1 and S_2. These fringes can be seen by an eye-piece E having a cross-wire. Typical fringe pattern is shown in fig. 7.

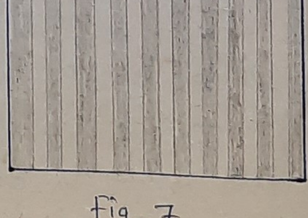

Fig. 7.

Necessity of narrow source

A broad source of light is equivalent to a large number of narrow sources placed side by side. Now if the slit is broad the two virtual coherent sources will also be broad. Now each pair of conjugate points on the virtual sources will give rise to an interference pattern. These interference patterns are slightly displaced from one another. An overlapping of such patterns results in general illumination.

Fresnel's biprism can be used for various optical measurements as discussed below:

(a) Determination of unknown wavelength

Fresnel's biprism can be used to determine the wavelength of monochromatic light.

Theory: [Calculations related to fig. 2. (fringe width determination)]
Fringe width β is given by

$$\beta = \frac{D}{d}\lambda$$

where, $D \rightarrow$ distance between the slit and the screen

$d \rightarrow$ distance between the two virtual coherent sources S_1 and S_2.

Therefore, the unknown wavelength

$\lambda = d\beta/D$.

Thus measuring d, β and D, one can determine λ.

Experiment:

The experiment can be conducted by using a suitable form of optical bench along the bed of which can slide a number of uprights carrying the linear slit S, the biprism LMN and Ramsden's eye-piece E fitted with a micrometer screw.

The slit is illuminated by the monochromatic light and adjustments are made to make the slit S, the edge N of the biprism and one of the cross-wires of the eyepiece perfectly vertical and all in the same vertical plane and at the same height from the bench. At this time the fringes will be very distinct. The biprism and eye-piece stands are given proper lateral movement so that fringes do not suffer lateral shift relative to the cross-wire as the eye-piece is moved.

The fringe width β is now measured by setting the cross-wire at successive fringes with the help of micrometer screw fitted with the eye-piece. Distance D can be measured directly from the bench scale as the distance between the slit and the eyepiece.

To measure d, a convex lens of suitable focal length is placed on another upright inserted between the biprism and the eye-piece. The focal length of the convex lens is such that the distance between the slit and the eye-piece is greater than four times the focal length of the lens. Under this condition, there are two conjugate positions of the convex lens for which real images S_1 and S_2, will be seen by the eyepiece kept at the same place. The distances d_1 and d_2 between the real images of S_1 and S_2, for the first and second positions of the convex lens respectively, are measured by moving the eye-piece perpendicular to the bench and d is given by $\sqrt{d_1 d_2}$.

There may be index error between slit stand and eyepiece stand. It can be corrected for or avoided by measuring fringe widths β_1 and β_2 at two different distances D_1 and D_2 respectively. Then λ is given by

$$\lambda = d\,\frac{\beta_2 - \beta_1}{D_2 - D_1}$$

As all the quantities on the R.H.S are known, λ can be easily determined.

(b) Measurement of the acute angle of biprism

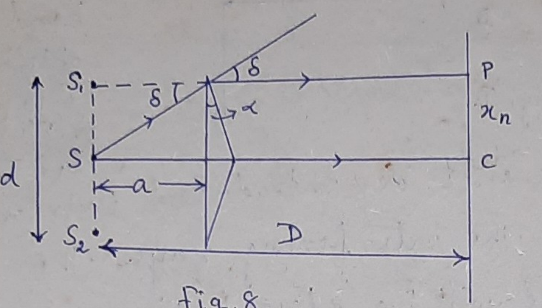

Fig. 8.

Let 'a' be the separation between the source and the biprism. The n th order bright fringe be produced at P, at a distance x_n from the central bright fringe. Now, deviation produced by a thin prism is given by —

$\delta = (\mu - 1)\alpha$, $\alpha \rightarrow$ the acute angle of the biprism. $\mu \rightarrow$ refractive index of the material of biprism for the monochromatic light employed.

Also, from fig. 8, $\delta = \tan\delta = \frac{d}{2a}$

Therefore, $\frac{d}{2a} = (\mu - 1)\alpha$ or, $\alpha = \frac{d}{2a(\mu - 1)} = \frac{D\lambda}{2\beta a(\mu - 1)}$ $\left[\because \beta = \frac{D\lambda}{d}\right]$

Measuring d and a and knowing μ, we can find α. The distance 'a' between the slit and biprism can be obtained directly from the bench scale. The distance 'd' between the virtual sources can be measured with the help of a convex lens. The base angle α of the biprism is kept small. If it is made large then the distance 'd' between the virtual sources becomes large and fringe width β becomes small. For large α, fringe width may become so small that it cannot be distinguished even under high magnification.

(c) Measurement of the thickness of a thin film

Fresnel's biprism can be used to measure the thickness of a thin sheet of transparent material.

Let S_1 and S_2 be the two virtual coherent sources

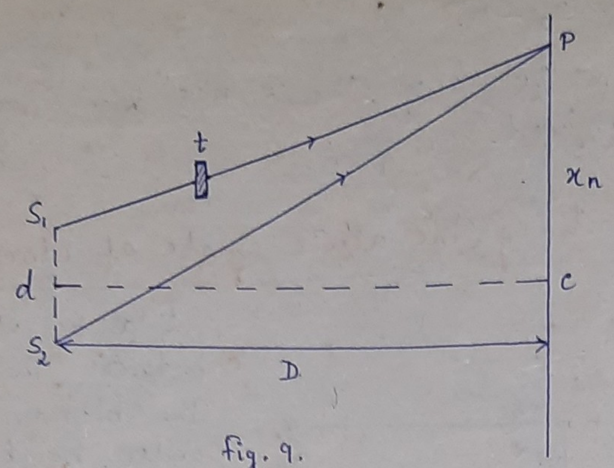

fig. 9.

which are producing interfe-rence fringes on the screen so that C is the position of the central bright band of zero optical path difference, i.e., $S_1C = S_2C$. If a thin film of thickness t be introduced into one of the paths (say, S_1P) of the interfering rays, then the position of the central fringe will be shifted from C to P (say), so that optical path S_1P is again equal to the optical path S_2P. The time taken by light in going from S_1 to P and from S_2 to P will be equal. Thus,

$$\frac{S_2P}{c} = \frac{S_1P - t}{c} + \frac{t}{v}$$

$$\text{or, } \frac{S_2P - S_1P}{c} = \frac{t}{v} - \frac{t}{c} \quad \text{or, } S_2P - S_1P = \left(\frac{c}{v} - 1\right)t = (\mu - 1)t \rightarrow (1)$$

where, $c \rightarrow$ velocity of light in air

$v \rightarrow$ velocity of light in the film

$\mu \rightarrow \frac{c}{v} \rightarrow$ refractive index of the material of the film.

If P is the position originally occupied by the n th order fringe, then, $S_2P - S_1P = n\lambda \rightarrow (2)$

Therefore, from eq. (1) & (2), we get,

$$(\mu - 1)t = n\lambda \rightarrow (3)$$

The lateral shift of the central fringe of zero optical path difference is given by –

$$x_n = CP = \left(\frac{D}{d}\right) n\lambda = n\beta \rightarrow (4)$$

where $\beta = \frac{D\lambda}{d}$ is the fringe width.

From eq. (3) & (4), we get,

$$(\mu-1)t = \frac{x_n}{\beta}\lambda \quad \text{or,} \quad t = \frac{x_n \lambda}{\beta(\mu-1)} \rightarrow (5)$$

Finding x_n, displacement of the central fringe due to introduction of the thin film and β, the distance between two consecutive bright bands, we can find t, the thickness of the film by eq. (5), when the wavelength λ of light and the refractive index μ of the film are known.

Eq. (5) can also be written as —

$$t = \frac{x_n}{\mu-1}\left(\frac{d}{D}\right) \longrightarrow (6)$$

This eq. can also be used to find t.

With a monochromatic source fringes appear to be similar and it is difficult to locate the position where the central fringe is shifted. For this purpose, a white light source is used. With a white source, the central fringe is white and all other higher order fringes are coloured.

Velocity test

Eq. (6) may be written as

$$x_n = \frac{D}{d}\left(\frac{c}{v} - 1\right)t \rightarrow (7)$$

If the light travels with smaller velocity in the denser medium (film) then $\frac{c}{v} > 1$ and x_n is +ve. Hence, the central fringe will be shifted towards the side of the film. Experimental result agrees with this inference arrived at. Hence the conclusion is that light travels with smaller velocity in denser medium.

Lloyd's Single Mirror

In Lloyd's single mirror arrangement [fig. 10] light from a narrow slit S_1 illuminated with a monochromatic light is partly incident at a grazing angle on a metallic mirror M_1M_2 while the rest reaches the screen AB directly. The reflected light appears to diverge from a virtual source S_2. Hence S_1 and S_2 act as coherent sources and interference are formed in region of overlapping EF.

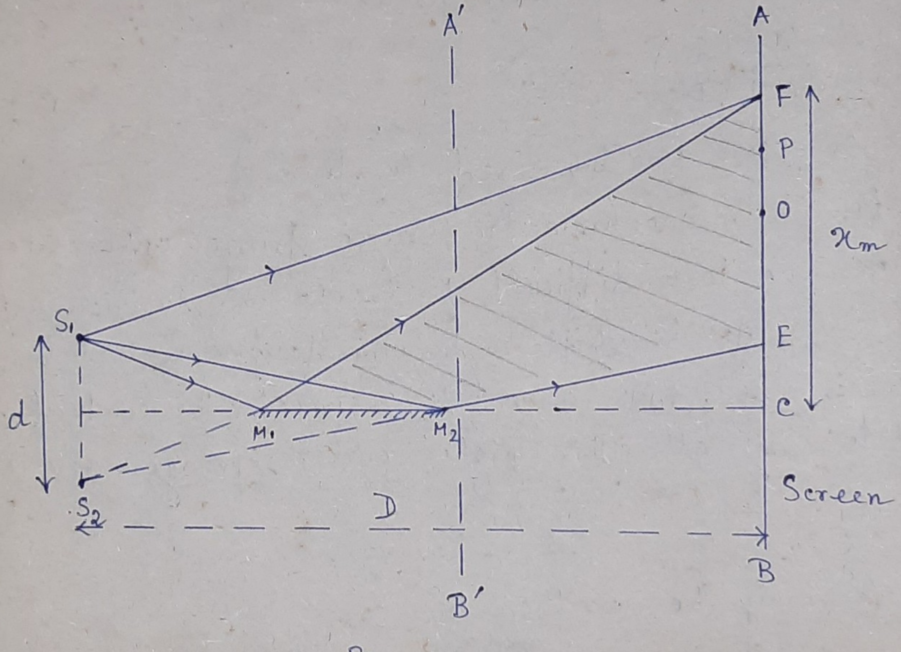

fig. 10.

The central point C on the screen for which $CS_1 = CS_2$ receives only the direct light and for this the central fringe of zero path difference is not visible here. However, if the screen is displaced to the position A'B' the central fringe can be brought into view. The central fringe can also be brought into view by introducing a thin film of mica or glass in the path of direct light.

In This case, The fringe system shifts in direction in which The film is introduced. If t is The thickness of The film and μ is The refractive of The film, The central fringe will be formed at a point such as O for which the condition $S_2O = S_1O + (\mu - 1)t$ is satisfied. The central fringe is found to be dark. This indicates That light reflected from The mirror suffers a sudden phase change of π.