23.12 PHASE CHANGE ON REFLECTION

When a ray of light is reflected at the surface of a medium, which is optically denser than the medium through which the ray is travelling, a change of phase equal to π or a path-difference $\lambda/2$ is introduced.

When reflection takes place at the surface of a rarer medium, no change in phase or path-difference takes place.

Let PQ be the surface separating the denser medium below it from the rarer medium above it, as shown in Fig 23.12. A ray of light AB of amplitude a incident on this surface is partly reflected along BC and partly refracted into the denser medium along BD. If r is the co-efficient of reflection at the surface of a denser-medium, *i.e.*, the fraction of the incident light which is reflected, then

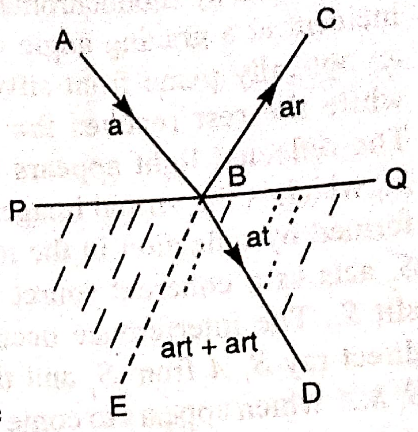

Fig. 23.12

Amplitude of the reflected ray $BC = ar$.

If t is the co-efficient of transmission from the rarer into the denser medium, i.e. the fraction of the incident light transmitted, then

Amplitude of the refracted ray $BD = at$.

If there is no absorption of light, then $r + t = 1$

If the reflected and the refracted rays are reversed, the resultant should have the same amplitude a as that of the incident ray.

When CB is reversed it is partly reflected along BA with amplitude ar^2 and partly refracted along BE.

The amplitude of the refracted ray along $BE = art$.

Similarly when the ray DB is reversed it is partly refracted along BA and partly reflected along BE.

If r' is the co-efficient of reflection at the surface of a rarer medium, then

Amplitude of the reflected ray along $BE = atr'$

If t' is the co-efficient of transmission from the denser into the rater medium, then

Amplitude of the reversed refracted ray along $BA = att'$

The two amplitudes along BA will combine together to produce the original amplitude, *only* if the total amplitude along BE is zero.

$$art + ar't = 0 \quad \text{... (i)}$$

In such a case $$ar^2 + att' = a \quad \text{... (ii)}$$

Equation's (*i*) and (*ii*) are known as *Stokes relations*

From relation (*i*) we have

$$art = -ar't$$

or $$r = -r'$$

The negative sign shows that when one ray has a positive displacement, the other has a negative displacement. Hence the two rays, one reflected in reaching a denser medium and the other reflected on reaching a rarer medium, differ in phase by π from each other.

This explains the presence of a central dark spot in Newton's rings and is also responsible for the reversal of the conditions of darkness and brightness produced in the reflected and transmitted systems in colours of thin films and in the fringes produced by Lloyd's single mirror.

23.13 LIOYD'S SINGLE MIRROR

It is a simple arrangement of producing interference fringes, in which one part of the incident wave-front reaches the screen directly, while the other reaches the screen after suffering reflection from an optically plane front silvered mirror MN. The arrangement of apparatus is shown in

Fig. 23.13. Light from a narrow slit S_1, illuminated by monochromatic light is partly incident at a grazing angle on the surface of an optically plane front silvered mirror MN, while the rest reaches the screen directly. The reflected light appears to diverge from S_2, which is the virtual image of the source S_1 formed by reflection in the mirror MN. Thus S_2 acts as a coherent source with respect to slit S_1. The interference occurs between the direct ray S_1A from S_1 and the reflected ray S_1MA which appears to come from the virtual source S_2.

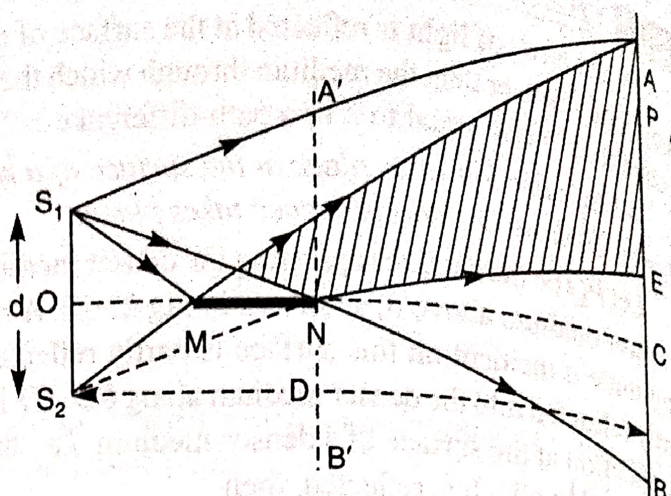

Fig. 23.13.

The light reflected from the extremities of MN lies in the region AE, thus interference between direct and reflected rays occurs only in this region. The point C lying on the right bisector of S_1 S_2 gives the positions of the central fringe of zero path-difference. It is not visible, as no reflected light reaches C. Not only this, even less than half the interference pattern is visible with the arrangement shown. However, this can be brought into view by displacing the screen to the position $A'NB'$, so that it just touches the end N which is equidistant from S_1 and S_2 and passes through the centre of the fringe of zero geometrical path-difference.

The central fringe can also be brought into view by introducing a thin mica plate in the path of the direct ray, which causes, the central fringe to move in the upward direction towards A.

Why central fringe is black. It is found that the central fringe is black, because a phase change of π takes place in the ray S_1MA or S_1NE on reflection at the surface of a denser medium at M or N. We can conclude from this that the light from coherent sources S_1 and S_2 differ in phase by π at all times, instead of being in equal phase, as in double slit Fresnel's biprism and double mirror experiments.

Fringe-width. If P is a point on the screen, then

Path-difference $= S_2P = S_1P$

If d is the distance between the sources S_1 and S_2 and D the distance between the centre of the screen and the centre of the line joining S_1 and S_2, then as proved in Young's double slit experiment (article 23.8)

$$S_2P - S_1P = x\frac{d}{D}$$

The point P will have **minimum intensity,** if

$$\frac{xd}{D} = n\lambda \quad \text{for } n = 0, 1, 2, 3$$

or

$$x = \frac{D}{d}n\lambda \qquad \text{...}(i)$$

The point P will have **maximum intensity,** if

$$\frac{xd}{D} = (2n+1)\frac{\lambda}{2} \quad \text{for } n = 0,1,2,3....$$

or

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

Fringe-width $\qquad \beta = x_n - x_{n-1}$

For minimum intensity $\qquad \beta = \frac{D}{d}\lambda(n-n+1) = \frac{D}{d}\lambda \qquad \text{...(23.18)}$