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PHYSICS

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CLASS 11&12th

CLASS 12th

Wave Optics

01. Principle of Superposition

When two or more waves simultaneously pass through a point, the disturbance of the point is given by the sum of the disturbances each would produce in absence of the other wave (s). I In case of wave or string disturbance means displacement, in cases of sound wave it menas pressure change, in case of Electromagnetic Waves, it is electric field or magnetic field . Superposition of two light travelling in almost same direction results in modification in the distribution of intensity of light in the region of superposition. This phenomenon is called *interference.*

(i) Superposition of two sinusoidal waves

Consider superposition of two sinusoidal waves (having same frequency), at a particular point.

Let, $x_1(t) = a_1 \sin \omega t$

and, $x_2(t) = a_2 \sin (\omega t+\phi)$

represent the displacement produced by each of the disturbances. Here we are assuming the displacement to be in the same direction. Now according to superposition principle, the resultant displacement will be given by,

$$x(t) = x_1(t) + x_2(t)$$
$$= a_1 \sin \omega t + a_2 \sin (\omega t+\phi)$$
$$= A \sin (\omega t+\phi_0)$$

Where $A^2 = a_1^2 + a_2^2 + 2a_1.a_2 \cos\phi$ ....(i)

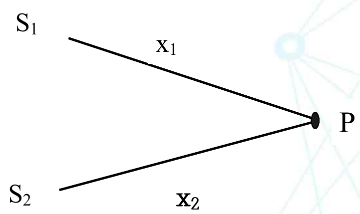
and $\tan \phi_0 = \dfrac{a_2 \sin\phi}{a_1 + a_2 \cos\phi}$ ....(ii)

(ii) Superposition of Progressive Waves: Path Difference

Let S_1 and S_2 be two sources producing progressive waves (disturbance travelling in space given by y_1 and y_2)

At point P,

$$y_1 = a_1 \sin (\omega t - kx_1 + \theta_1)$$
$$y_2 = a_2 \sin (\omega t - kx_2 + \theta_2)$$
$$y = y_1 + y_2 = A \sin (\omega t + \Delta\phi)$$



Here , the phase difference,

$$\Delta\phi = (\omega t - kx_1 + \theta_1) - (\omega t - kx_2 + \theta_2)$$
$$= k(x_2 - x_1) + (\theta_1 - \theta_2) = k\Delta p - \Delta\theta \quad \text{where } \Delta\theta = \theta_2 - \theta_1$$

Here $\Delta p = \Delta x$ is the path difference

Clearly, phase difference due to path difference = k (path difference)

where $k = \dfrac{2\pi}{\lambda}$

$$\Rightarrow \Delta\phi = k\Delta p = \frac{2\pi}{\lambda}\Delta x \quad ....(i)$$

(a) **For Constructive Interference**

$\Delta\phi = 2n\pi, \quad n = 0,1,2.....\quad$ or, $\Delta x = n\lambda$

$A_{max} = A_1 + A_2$

intensity, $\sqrt{I_{max}} = \sqrt{I_1} + \sqrt{I_2} \Rightarrow I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$ ...(ii)

(b) **For Destructive Interference**

$\Delta\phi = (2n+1)\pi, \quad n = 0,1,2....$

or, $\Delta x = (2n+1)\lambda/2$

$A_{min} = |A_1 - A_2|$

intensity, $\sqrt{I_{min}} = \sqrt{I_1} - \sqrt{I_2} \quad I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$ ...(iii)

02. Wavefronts

Consider a wave spreading out on the surface of water after a stone is thrown in. Every point on the surface oscillates. At any time, a photograph of the surface would show circular ring on which the disturbance is maximum. Cleary, all point on such a circle are oscillating in phase because they are at the same distance form the source. Such a locus of point which oscillated in phase is an example of wavefront.

A wavefront is defined as a surface of constant phase. The speed with which the wavefront moves outward form the source is called the phase speed. The energy of the wave travels in direction perpendicular to the wavefront. Figure (a) shows light waves form a point source forming a spherical wavefront in three dimensional space . The energy travels outwards along straight lines emerging form the source i.e. radii of the spherical wavefront. These lines are the rays. Notice that when we measure the spacing between a pair of wavefronts along any ray , the result is a constant. This example illustrates two important general principles which we will use later:

(i) Rays are perpendicular to wavefronts.

(ii) The time taken by light to travel from one wavefront to another is the same along any ray.

If we look at a small portion of spherical wave, far away from the source, then the wavefronts are like parallel planes. The rays are parallel lines perpendicular to the wavefronts. The is called a plane wave and is also sketched in Figure (b)

A linear source such as a slit illuminated by another source behind it will give rise to cylindrical wavefronts. Again, at larger distance form the source, these wavefronts may be regarded as planar.

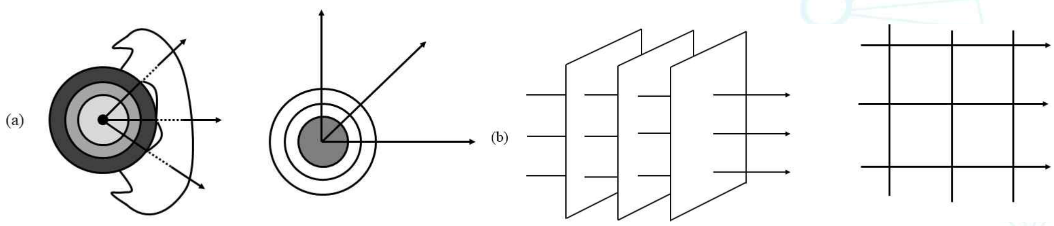


Figure (a) and (b): Wavefronts and the corresponding rays in two cases: (a) diverging spherical wave. (b) plane wave. The figure on the left shows a wave (e.g.. light) in three dimensions. The figure on the right shows a wave in two dimensions (a water surface.)

03. Coherence

Two sources which vibrate with a fixed phase difference between them are said to be coherent. The phase differences between light coming form such sources does not depend on time.

In a conventional light source, however, light comes form a large number of individual atoms, each atom emitting a pulse lasting for about 1ns. Even if atoms were emitting under similar conditions, waves form different atoms would differ in their initial phases. Consequently light coming form two such sources have a fixed phase relationship for about 1ns, hence interference pattern will keep changing every billionth of a second. The eye can notice intensity changes which last at least one tenth of a second. Hence we will observe uniform intensity on the screen which is the sum of the two individual intensities. Such sources are said to be incoherent. Light beam coming from two such independent sources do not have any fixed phase relationship and they do not produce any stationary interference pattern. For such sources, resultant intensity at any point is given by

$$I = I_1 + I_2 \qquad ...(i)$$

04. Young's Double Slit Experiment (Y.D.S.E.)

This was based upon division of a single wavefront into two; these two wavefronts acted as if they emanated form two sources having fixed phase relationship. Hence when they were allowed to interfere, stationary interference pattern was observed.

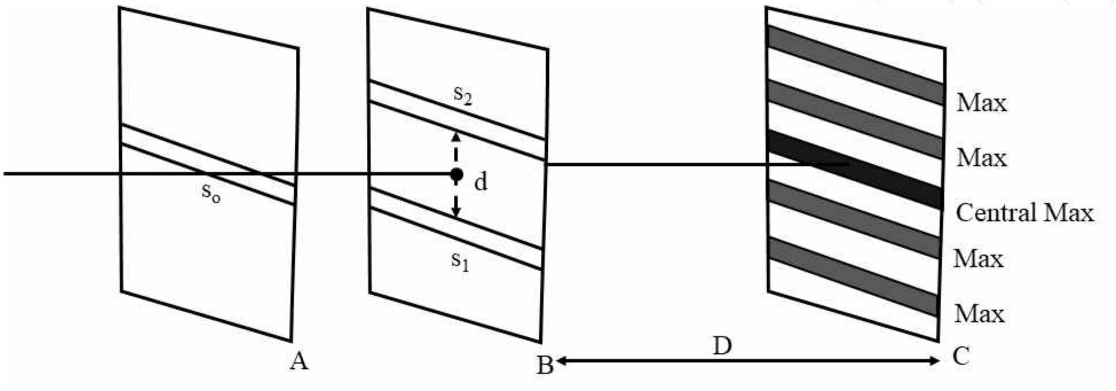


Figure (a): Young's Arrangement to produce stationary interference pattern by division of wave front S_0 into S_1 and S_2