## INTERFERENCE

## Coherent source:

Two sources of light, which continuously emit light waves of same wavelength or frequency, same amplitude and are always in phase or have constant phase difference are called coherent sources. In actual practice, it is not possible to have two independent sources which are coherent.

### Method of producing coherent source:

- By division of wave front (e.g. Youngs' double slit, Lloyd's mirror, Fresnel's biprism etc.)
- By division of amplitude (e.g. Newton's Rings method)

### Incoherent Source:

Two independent light sources which do not emit light waves of same wave length and same amplitude and also phases are different are called incoherent source of light.

## INTERFERENCE

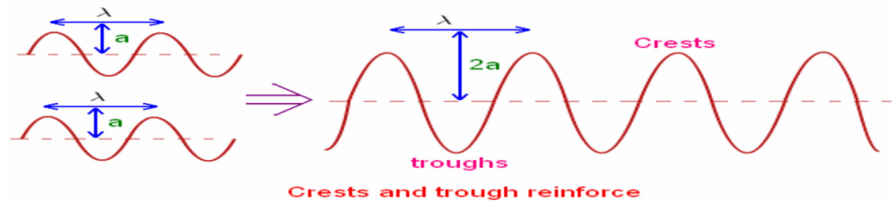
The phenomenon of non-uniform distribution or re-distribution of energy in the medium due to superposition of light waves from two coherent sources traveling along same direction is called interference of light.

- At some points in the medium, the intensity of light is maximum (constructive interference) while at some other points, the intensity is minimum (destructive interference). In case, the two waves are of same amplitude, then at points of destructive interference, the intensity of light is zero i.e complete darkness results.
- Usually, on the interference of two light waves, we obtain alternate bright and dark bands of light called interference fringes.

### Type of interference

### 1. Constructive Interference

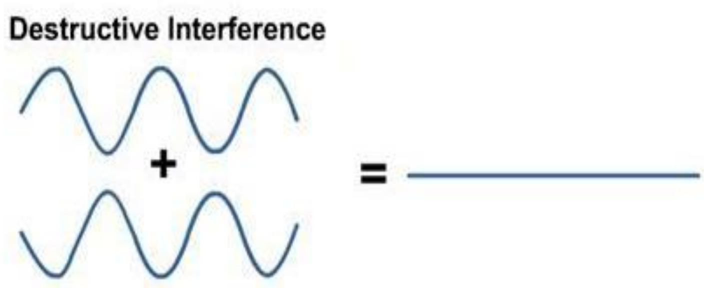
When a crest of one wave meets a crest of other, there will be a stronger crest and when a trough of one wave meets a trough of other, there will be a stronger trough. As amplitude at all such points is maximum, they represent positions of constructive interference.




→ $y = y_1 + y_2$
→ **Amplitude is maximum**
→ **Intensity maximum**
→ **Bright fringe are formed**
→ **Path difference =** $n\lambda$ **Where, n is integer**

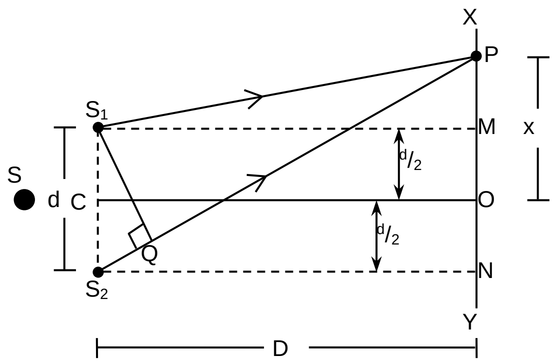
**2. Destructive interference**:

When a crest of one wave meets a trough of other or vice-versa, the effects will cancel out. So the amplitude is minimum (or zero), they represent positions of destructive interference.




- $y = y_1 + (-y_2) = 0$
- **resultant amplitude is minimum**
- **Intensity minimum**
- **Dark fringes are formed**
- Path difference = $(2n + 1)\ \lambda/2$ where n=0,1,2,3………..

## Young's Double slit experiment




*Fig*

Let us consider S be the monochromatic source of light. Let $S_1 and\ S_2$ be the two coherent sources separated by a small distance 'd' which are kept at a distance 'D' from the screen XY. Point 'C' lies midway between $S_1 and\ S_2$ and CO is the normal from C into the screen. The point 'O' is at equidistant from $S_1 and\ S_2$. Since the wave from $S_1 and\ S_2$ arrives at O in the same phase and path difference between two waves is zero, the point 'O' will be the center of a bright fringe. Let P be any point at distance $x_n$ from 'O' on the screen can be calculated by finding path difference.

The Path difference between $S_1 and\ S_2$ at P is given by, Path difference= $S_2P - S_1P$

In $\Delta S_1MP$

$(S_1P)^2= (S_1M)^2+ (PM)^2$

$(S_1P)^2 =D^2+ (x_n- \frac{d}{2})^2$ ………..(i)

Similarly, In $\Delta S_2NP$

$(S_2P)^2= (S_2N)^2+ (PN)^2$

$(S_2P)^2 =D^2+ (x_n+ \frac{d}{2})^2$………..(ii)

Subtracting equation (i) from (ii) we get

$(S_2P)^2 -(S_1P)^2 = D^2+ (x_n+ \frac{d}{2})^2 - D^2- (x_n- \frac{d}{2})^2$

$(S_2P)^2 -(S_1P)^2 = 2x_nd$……………..(iii)

$S_2P)^2-(S_1P)^2= 2xd$

$(S_2P - S_1P)(S_2P + S_1P) = 2xd$

Since the point P lies very closes to point O

Then, $S_2P \approx S_1P \approx D$ So,

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

Path difference= $\frac{x_n d}{D}$……………….(iv)

**<u>for bright fringe (constructive interference)</u>**

Path difference = $n\lambda$ ……….. Where n = 0,1,2,3

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

or $\mathbf{x_n = \frac{n\lambda D}{d}}$**……………(V)**

Here, For n = 0, $x_0 = 0$; central bright fringe

For n = 1, $x_1 = \frac{\lambda D}{d}$; 1st bright fringe

For n = 2, $x_2 = \frac{2\lambda D}{d}$ ;2nd bright fringe

For n = 3, $x_3 = \frac{3\lambda D}{d}$; 3rd bright fringe

<u>Fringe width($\beta$)</u>

The distance between two successive bright fringes called fringe width.

i.e. fringe width ($\beta$) = $x_1 - x_0 = x_2 - x_1 = \ldots = x_{n+1} - x_n$

$\therefore \boldsymbol{\beta} = \frac{\lambda D}{d} - 0 = \frac{\lambda D}{d}$ ………(v)

**<u>For dark fringe (Destructive interference)</u>**

Path difference = $(2n+1)\frac{\lambda}{2}$ where n = 1,2,3,4…..

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

or $x_n = \frac{(2n+1)\lambda D}{2d}$ … … … … … (vi)

For, = 1; $x_1 = \frac{3\lambda D}{2d}$ …………….. $1^{st}$ dark fringe

For, $n = 2$; $x_2 = \frac{5\lambda D}{2d}$…………….. $2^{nd}$ dark fringe And so on

<u>Fringe width($\beta$)</u>

The distance between two successive dark fringes called fringe width.

i.e. fringe width ($\beta$) = $x_2 - x_1 = \ldots.. = x_{n+1} - x_n$

$$\therefore \boldsymbol{\beta} = \frac{5\lambda D}{2d} - \frac{3\lambda D}{2d} = \frac{\boldsymbol{\lambda D}}{\mathbf{d}} \quad \ldots\ldots\ldots(vii)$$

**From equation (v) and (vii), it is shows that bright and dark fringes are equally spaced.**

**<u>Conditions for sustained Interference of light:</u>**

Some important conditions for obtaining sustained interference.

(I) Two sources of light must be coherent, amplitude should be equal, monochromatic, sources very close to each other.

(II) Two sources should be point sources or very narrow sources.

(III) Same phase or maintain constant phase difference with time.

(IV) The interference beams should be of same wave length and frequency.

**Optical path**

The optical path of a medium is defined as the distance which the light travels in vacuum during the same time for which it travels in the medium.
Let 'v' and 'd' be the speed and distance travelled by light in an optically denser medium at any time 't'.

We know that, $t = \frac{d}{v}$

Let light travels distance 'L' with velocity 'c' in vacuum for the same time 't' then

$$t = \frac{L}{c}$$

From these two equations, we get

$$\frac{L}{c} = \frac{d}{v} \quad \Rightarrow \quad \text{or,} \quad L = \left(\frac{c}{v}\right) d$$

Since, $\mu = \left(\frac{c}{v}\right)$ is the absolute refractive index of the medium

$\therefore$ Optical Path(L) = $\mu$ d

Hence optical path of a medium is also defined as the product of refractive index of the medium ($\mu$) & geometrical distance (d).

## SHORT QUESTIONS

1. Can two independent sources of light produce interference?
2. Why have the two sources of light to be close to each other for the production of good interference pattern?
3. Distinguish between interference and diffraction.
4. What do you understand by coherent sources?
5. In young's double slit experiment, how is the fringe width altered if the separation between the slits is doubled and the distance between the slits and the screen is halved?
6. What are the conditions for sustained interference of light?
7. What are the conditions for constructive and destructive interference of light waves?
8. Does the interference of light waves obey the law of conservation of energy? Explain.
9. A two-slit interference experiment is setup and the fringes are displayed on a screen. Then the whole apparatus is immersed in a water. How does the fringe pattern change?
10. Two waves are represented in usual notation as $y_1 = a_1$ sin wt and $y_2 = a_2$ con wt. Their intensities are $I_1$ and $I_2$. What would be the ratio of their amplitudes when $I_1 = 2I_2$?
11. What are coherent sources of light? Can two different bulbs, similar in all respects, act as coherent sources?

## *NUMERICAL PROBLEMS*

1. Two slits are 0.3 mm apart and placed 50 cm from a screen. What is the distance between the second and third dark lines of the interference pattern when the slits are illuminated with a light of 600 mm wavelengths? Ans: $10^{-3}$ m
2. In an experiment using Young's slits the distance between the centre of the interference pattern and the tenth bright fringe on either side is 3.44 cm. Distance between the slits and the screen is 2.0 m. If the wavelength of the light used is $5.89 \times 10^{-7}$ m, determine the slit separation and the angle made by the central bright fringe at the slit.
**Ans: $3.42 \times 10^{-4}$ m, $1.72 \times 10^{-3}$ radian**
3. In a Young's double slit experiment, the separation between the first and fifth bright fringes is 2.5 mm when the wavelength of light used is $6.2 \cdot 10^{-4}$ mm. The distance from the slits to the screen is 80 cm. Calculate the separation of the two slits. Ans: $8 \times 10^{-4}$ m
4. In a two-slit interference experiment, the slits are 0.200 mm apart, and the screen is at a distance of 1.00 m. The third bright fringe is found at 9.49 mm from the central fringe. Find wavelength of the light used. Ans: $6.33\times10^{-7}$m
5. Two slits spaced 0.45 mm apart are placed 75 cm from a screen. What is the distance between the second and third dark lines of the interference pattern on the screen when the slits are illuminated with monochromatic light of wavelength 500 nm?
**Ans: 0.833mm**
6. In a Young's slits experiment, the separation of four bright fringes is 2.5 mm when the wavelength used is $6.2\times10^{-7}$m. The distance from the slits to the screen is 0.80m. Calculate the separation of the two slits. . 0.794mm
7. In young's double slit experiment, the slits are 0.03cm apart and the screen is placed 1.5m away. The distance between the central bright fringe and fourth bright fringe is 1cm. Calculate the wave length of light used Ans: $5\times10^{-7}$m
8. Two coherent sources A and B of radio waves are 5m apart. Each source emits waves with wavelength 6m. Consider points along the line between two sources, at what distances, if any, from A is the interference constructive. Ans: 2.5 m
9. The separation between the consecutive dark fringes in a Young's double slit experiment is 1 mm. The screen is placed at a distance of 2 m from the slits of 1.0 mm separation. What is the wavelength of light used in the experiment? Ans: $5\times10^{-7}$ m