Optics

INTERFERENCE OF LIGHT

Interference:

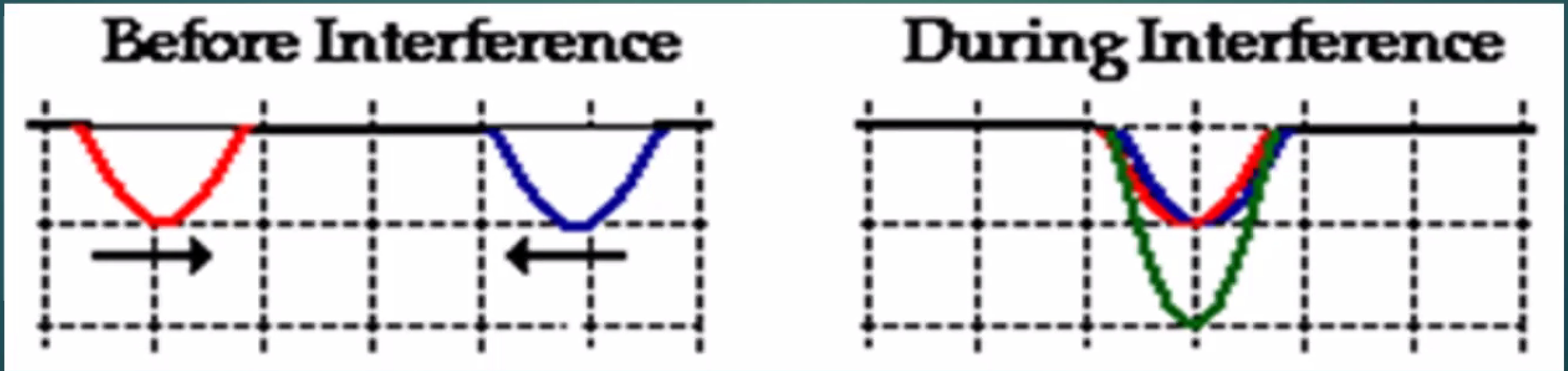
What is Interference and how it occurs……

- **Wave interference** occurs when two waves meet while traveling along the same medium.
- Interference is the phenomenon in which two monochromatic waves superpose to form the resultant wave.
- Its the **redistribution** of energy due to superposition of light from two coherent sources.

- **Constructive Interference:**

occurs at any location along the medium where the two interfering waves have a displacement in the same direction.

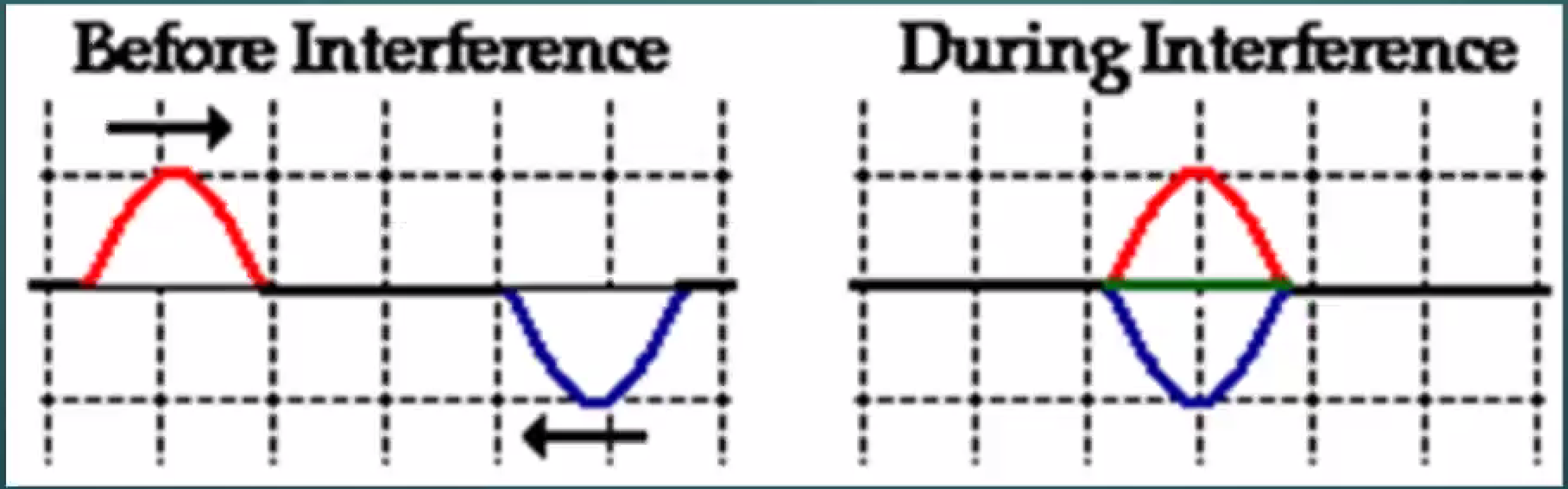
- Suppose if the crest (or trough) of one wave falls on the crest (or trough) of another wave, then the amplitude is maximum(up/down ward).



Destructive interference:

occurs at any location along the medium where the two interfering waves have a displacement in the opposite direction.

- Suppose if the crest of one wave falls on the trough of another wave, then the amplitude here is minimum.
- This is destructive interference. Here the waves do not have displacement in the same direction.



Conditions of Interference

1. The light sources must be **coherent.**
2. The light must be monochromatic. This means that the light consists of just one wavelength.

Coherent source means the plane waves from the sources must maintain constant phase relation . For example, if two waves are completely out of phase with $\varphi = \pi$, this phase difference must not change with time.

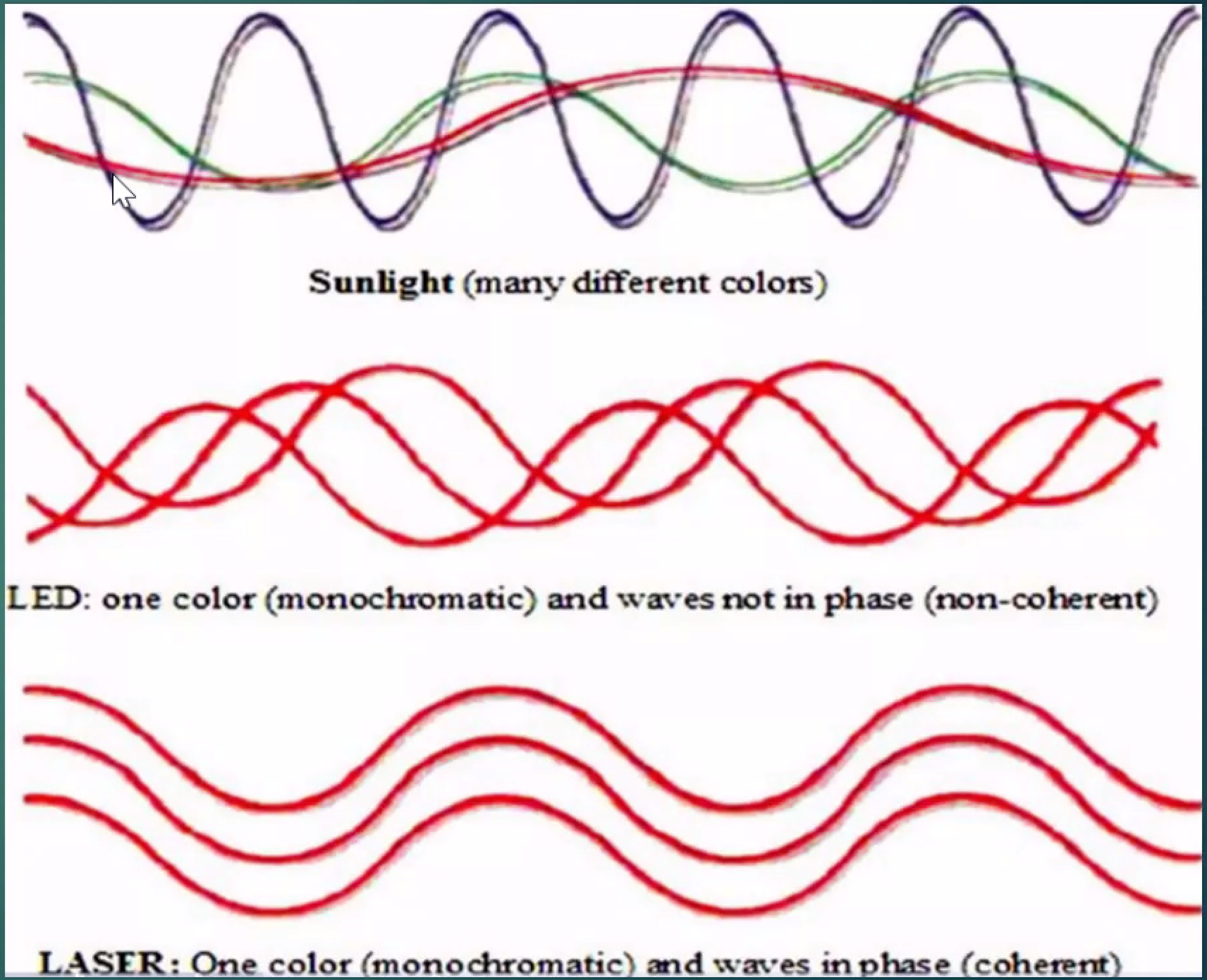
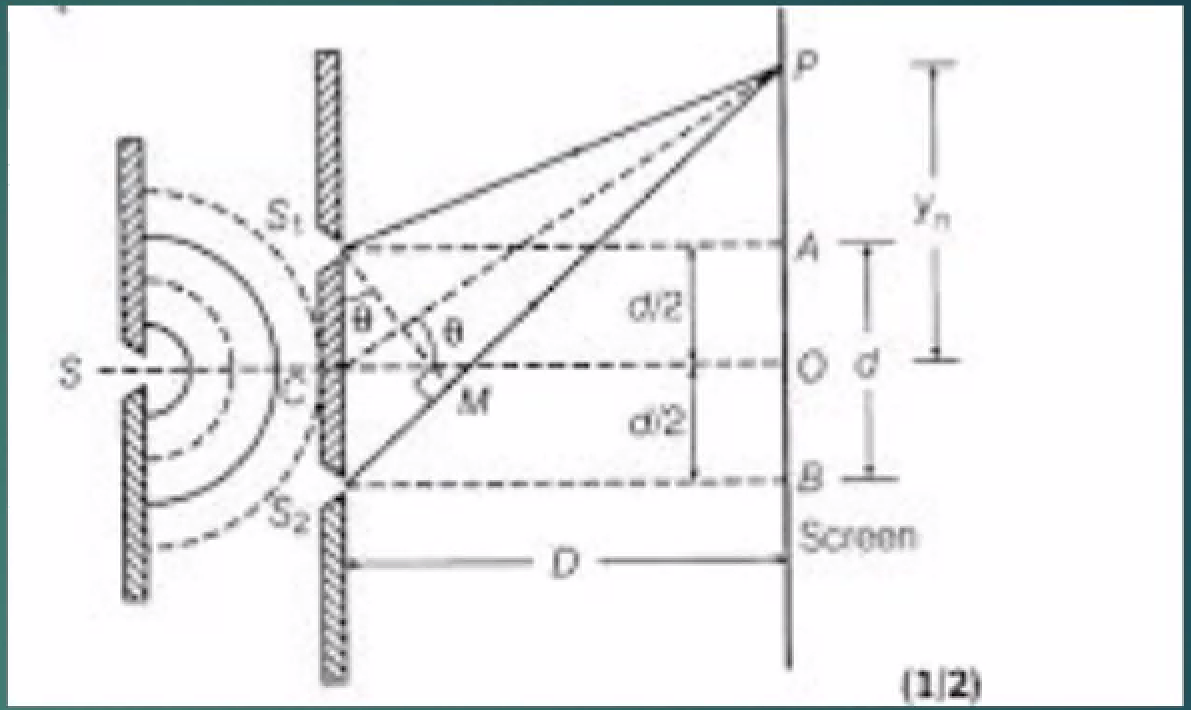


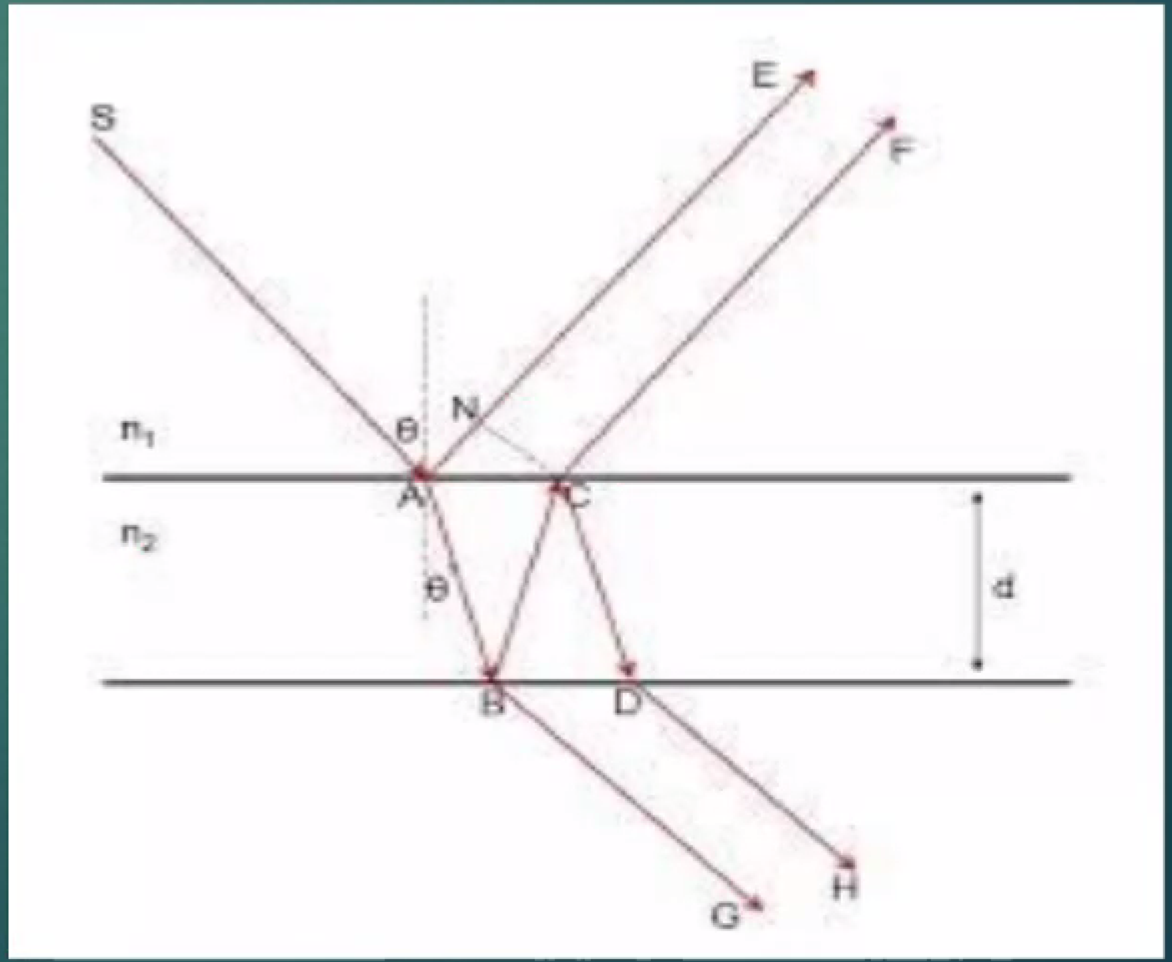
Image Source: https://www.slideshare.net/alexhales123/interference-of-light-53744205

Types of Interference:

1. Division of wave front.
   Ex: Young's double slit experiment.

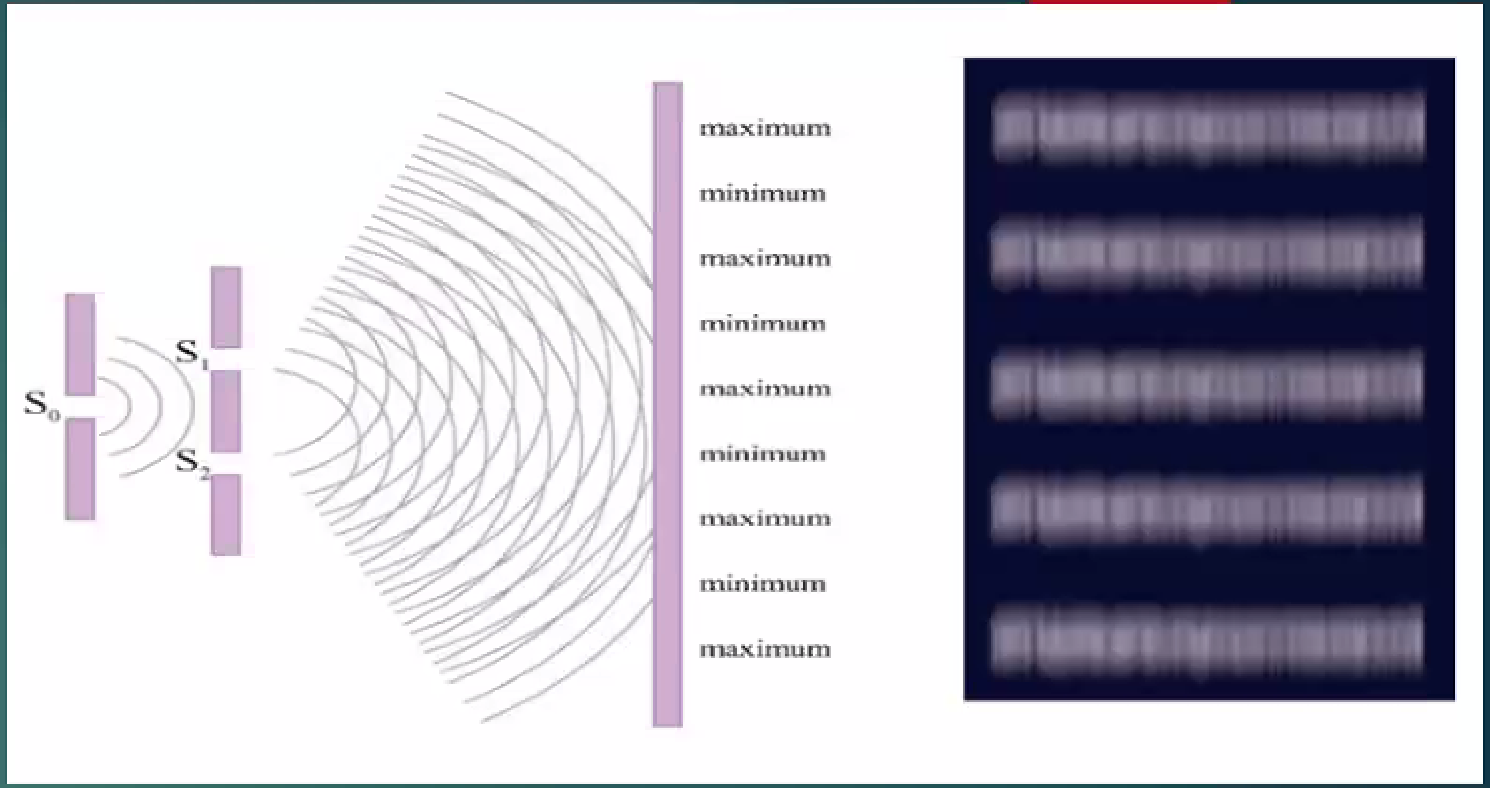


2. Division of amplitude.
   Ex: interference on a thin film, Newton's rings experiment, Michelson interferometer

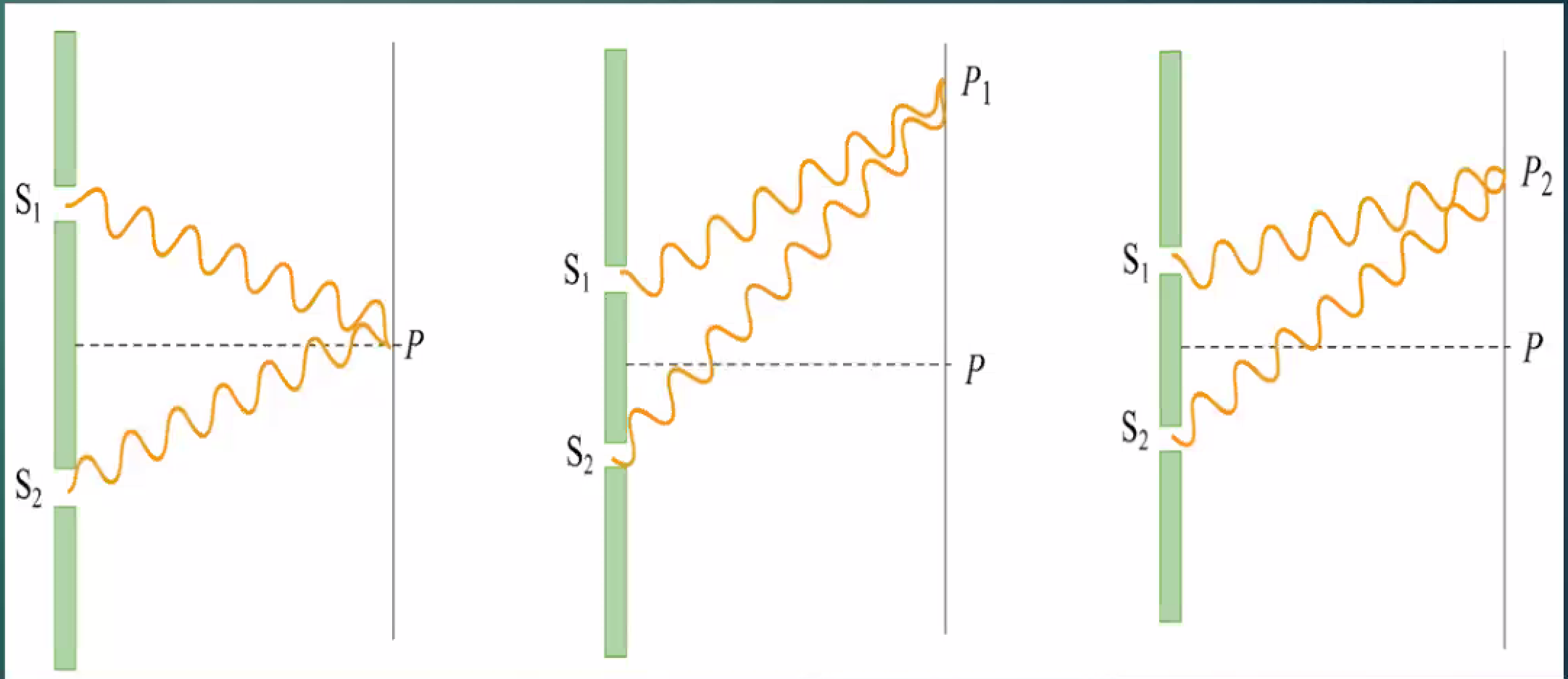


Young's Double-Slit Experiment

- In 1801 Thomas Young carried out an experiment in which the wave nature of light was demonstrated



A monochromatic light source is incident on the first screen which contains a slit S0. The emerging light then arrives at the second screen which has two parallel slits S1 and S2; which serve as the sources of coherent light. The light waves emerging from the two slits then interfere and form an interference pattern on the viewing screen. The bright bands (fringes) correspond to interference maxima, and the dark band interference minima.



Theory of Interference

Let us consider two monochromatic waves coming from two coherent sources incident on a screen with a phase difference $\varnothing$ at a point.

Let y_1 and y_2 are displacement of the two waves respectively such that

$$y_1 = a \sin\omega t \quad \text{.............................(i)}$$

$$y_2 = a \sin(\omega t+\varnothing) \quad \text{.....................(ii)}$$

Then the resultant displacement at that point is

$$y = y_1+y_2$$

$$= a \sin\omega t + a \sin(\omega t+\varnothing)$$

$$= a \sin\omega t + a \sin\omega t \cos\varnothing + a \cos\omega t \sin\varnothing$$

$$= a \sin\omega t\,(1 + \cos\varnothing) + \cos\omega t\,(a \sin\varnothing)$$

Assuming, $a(1 + \cos\varnothing) = R\cos\theta$ ....(iii)

And, $a \sin\varnothing = R \sin\theta$..(iv)

Theory of Interference.....................

Where R and θ are two new constants

$$y = R \sin\omega t \cos\theta + R \cos\omega t \sin\theta$$

$$= R \sin(\omega t + \theta)$$

Now squaring and adding equation (iii) and (iv)we get

$$R^2 = a^2 + a^2 + 2a^2 \cos\varnothing$$

Here R is resultant amplitude of the amplitudes.

We know that intensity of light at point P is proportional to square of the amplitude, so

$$I \propto R^2$$

$$= 2a^2 (1 + \cos\varnothing) \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(v)}$$

Equation(v) shows that Intensity **I** depends on the value of phase difference $\varnothing$ of the two interfering waves .

Theory of Interference.....................

We know that the path difference, $x = (\lambda / 2\pi)\, \varnothing$

i) If we put $\varnothing = 0, 2\pi, 2(2\pi), \ldots\ldots m(2\pi)$ in equation (v) then $x = 0, \lambda, 2\lambda, \ldots\ldots, m\lambda$ and then $\cos\varnothing = 1$ [where m=0,1,2,3…]
and then intensity

$$I = 2a^2\,(1+1) = 4a^2 \text{ which is maximum.}$$

This is the condition of constructive interference or bright fringe.

ii) If $\varnothing = (2m+1)\pi$, and $x = (2m+1)\,\lambda$ [where m=0,1,2,3…]
then $\cos\varnothing = -1$
Then intensity

$$I = 2a^2\,(1-1) \text{ and } I = 0, \text{ which is minimum.}$$

This is the condition of destructive interference or dark fringe.

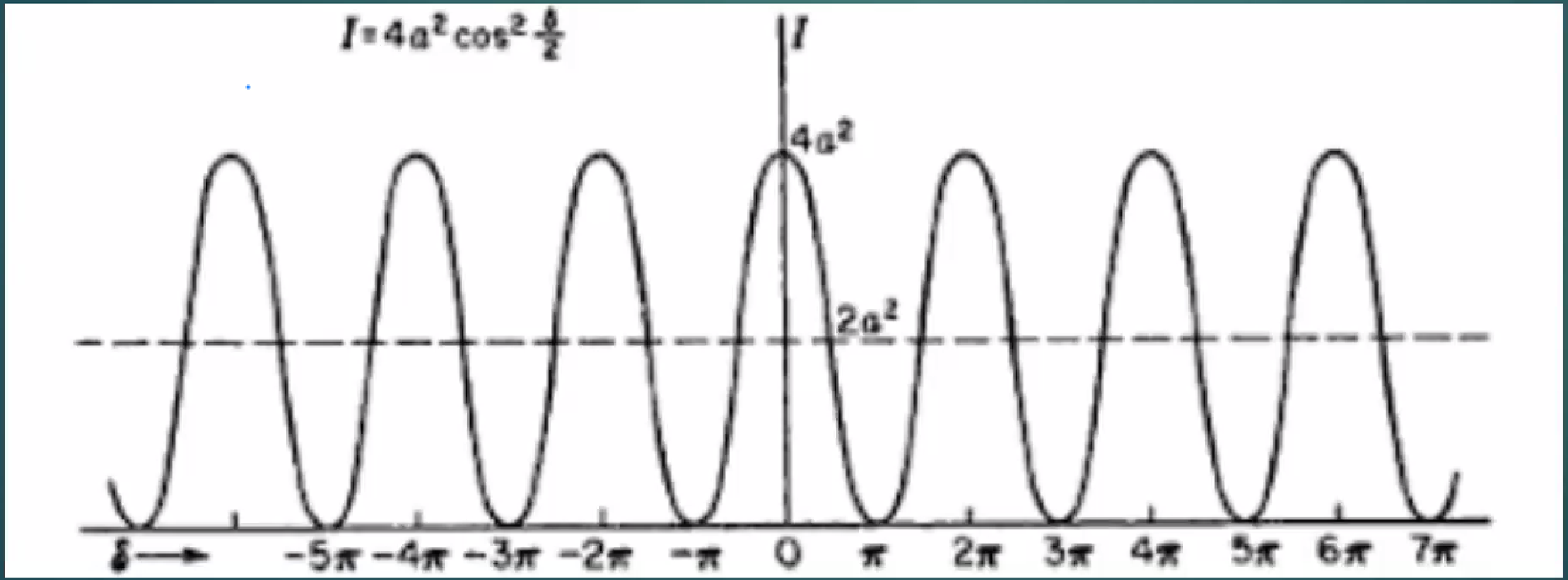
Theory of Interference.....................

Intensity/Energy distribution curve:

Intensity at any point of the screen is expressed as

$I = 2a^2 (1+\cos\varnothing) = 2a^2 .2\cos^2(\varnothing/2) = 4a^2 \cos^2(\varnothing/2)$

And, $I = 4a^2$ for bright fringe and for dark fringe $I=0$.



There is no destruction of light energy but redistribution of energy occurs in this phenomenon. Actually the energy disappeared in the dark fringe appears in the bright fringe. The intensity of bright fringe is $4a^2$ and the dark fringe is 0. However, **the average value of energy over any numbers of fringes is same i.e. $2a^2$.**

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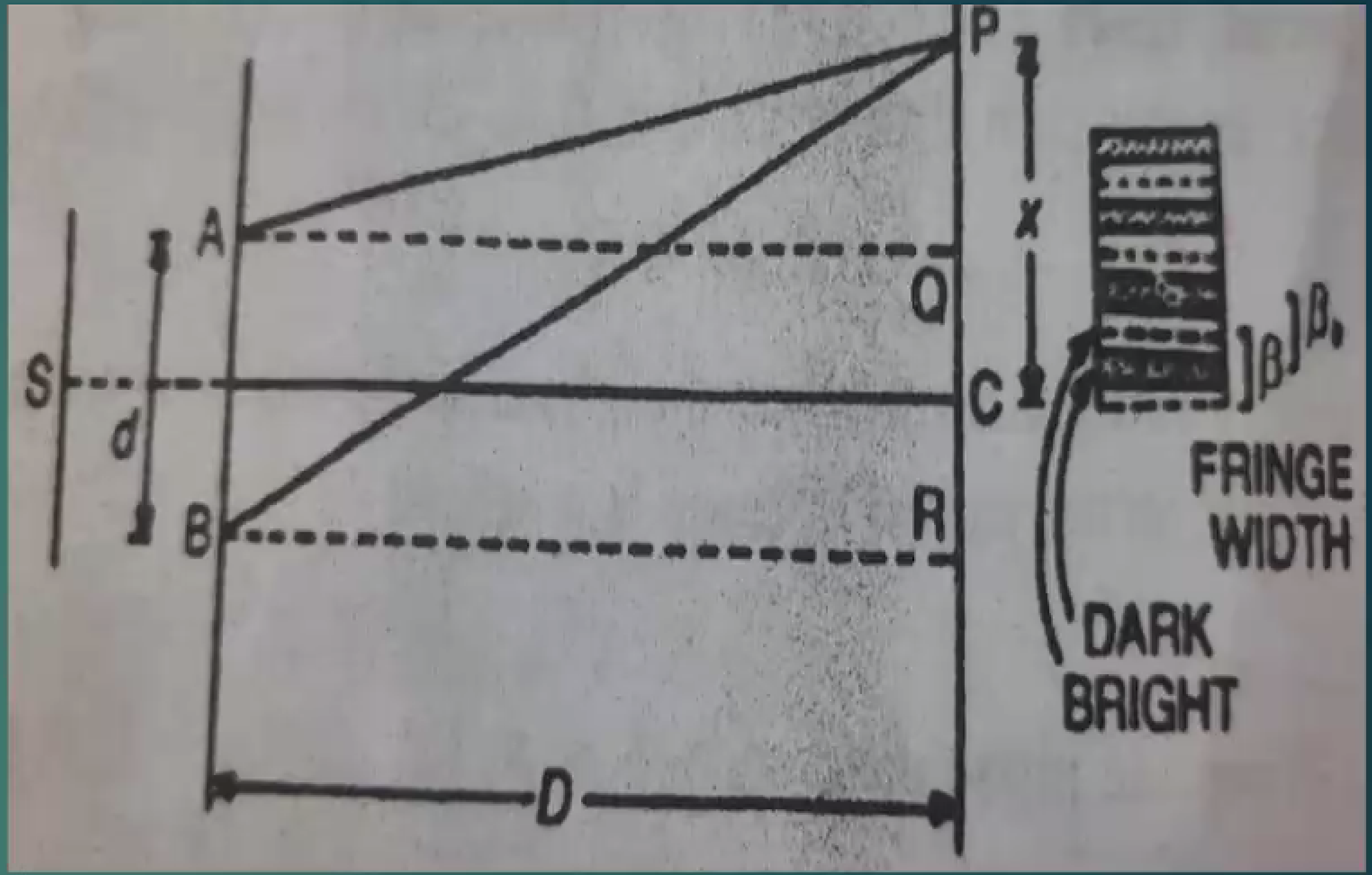
Theory of Interference fringes

- Considering S as narrow monochromatic source
- two pinholes A and B, equidistant from S, acting as two coherent sources
- ***d*** is the distance between A and B.
- A screen at a distance D from the coherent sources.
- Point C on the screen is equidistant from A and B, thus path difference between two waves is zero here, giving C maximum intensity.
- Now considering another point **P** on the screen at a distance **x** from **c**
- The waves reach at point **P from A and B**



Now ,

$$PQ = x - \frac{d}{2} \quad ; \quad PR = x + \frac{d}{2}$$

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

$$= 2xd$$

Theory of Interference fringes.............

- $BP - AP = \frac{2xd}{BP+AP}$

But **BP=AP=D** (Approximately)

So, path difference, $BP - AP = \frac{2xd}{2D} = \frac{xd}{D}$

- For bright fringes: $\frac{xd}{D} = n\lambda; where\ n = 01,2,3 \ldots.$
- or, $x = \frac{n\lambda D}{d}$; $or\ x_n = \frac{n\lambda D}{d}$
- For dark fringes: $\frac{xd}{D} = (2n+1)\frac{\lambda}{2}; where\ n = 01,2,3 \ldots.$
- Or, $x = \frac{(2n+1)\lambda D}{2d}$; $or\ x_n = \frac{(2n+1)\lambda D}{2d}$
- For any two consecutive bright or dark fringes: $x_{n+1} - x_n = \frac{\lambda D}{d}$;

Giving equation of fringe width