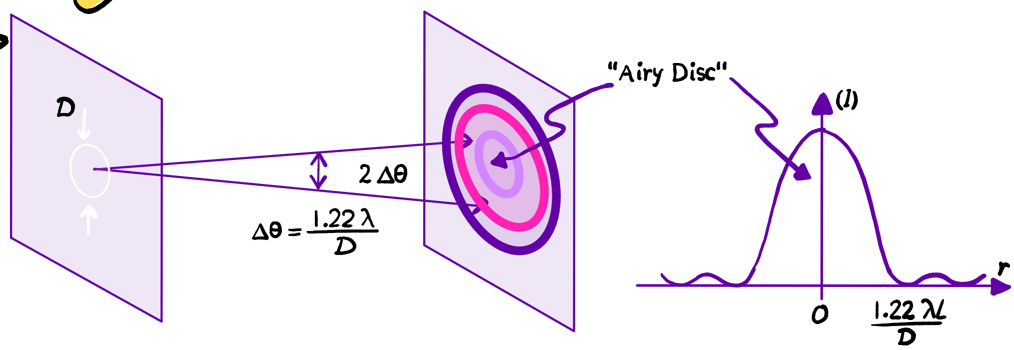
WAVE OPTICS



CLASS 12 New Notes PHYSICS

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Wave Optics: → Wave Optics describes the connection between waves and ray of light.
Acc. to wave theory of light, the light is a form of enegy which travels through a medium in the form of trans-verse wave motion.
- The speed of light in a medium depends upon the nature of medium.

Newton's Corpuscular theory of light

In 1675 AD Newton proposed this theory. Acc to him,

i). light Consist of tiny particles called corpuscles which are emitted by a luminous object.

ii). These corpuscles travels with speed of light in all direction.

iii). The corpuscles carry energy and momentum with them. when they strike retina of the eye, they produce sensation of vision.

iv). The Corpuscles of different Colours are of different sizes. Red coloured corpuscles are larger then blue coloured corpuscles.

v). This theory could explains the reflection, refraction & rectilinear propagation of light.

vi). The Corpuscular theory could not explain interference, diffraction & polarisation of light.

vii). Speed of light in denser medium is more than speed of light in a rarer medium, according to this theory. which is incorrect, therefore the newton's corpuscular theory is wrong.

Huygens' Wave theory of light

In 1678, a Dutch scientist, Christian Huygen's gives wave theory of light. Acc to him,

i). Light travels in the form of waves.

ii). These waves travels in all the direction with the velocity of light.

iii) The waves of light of different Colours have different wavelengths.

iv). Initially, the light waves were assumed to be longitudinal. But later on while explaining the phenomena of polarisation the light waves were considered to be transverse.

v). Huygen's theory could not explain reflection, refraction, Interference, diffraction, polarisation but could not explain photoelectric effect & Compton's effect.

vi). Wave theory introduced the Concept of wavefront.

> Note: The whole universe with all matter and space is filled with a luminiferous medium called ether of low density and very high elasticity.

Wavefront: → A wave front is defined as the continuous locus of all the particles of a medium, which are vibrating in same phase.

Fig Water waves

Types of wavefront

1). Spherical wavefront
2). Cylindrical "
3). Plane wave "

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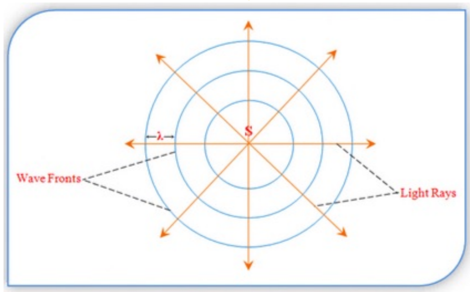
1). Spherical wavefront

When source of light is a point source, the wavefront is spherical.



$$\text{Amplitude } (A) \propto \frac{1}{r}$$

$$\text{Intensity } I \propto A^2$$

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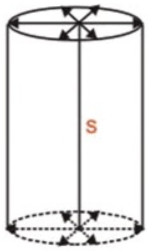
2). Cylindrical wavefront

: when source of light is linear, the wavefront is cylindrical.

$$\text{Amplitude } (A) \propto \frac{1}{\sqrt{r}} \qquad \text{Intensity } I \propto A^2$$



Cylindrical

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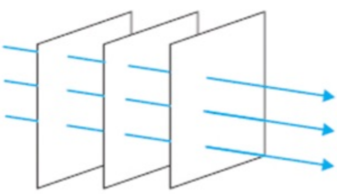
3). Plane wavefront

When source of light is very far off (point or linear), the wavefront is plane.

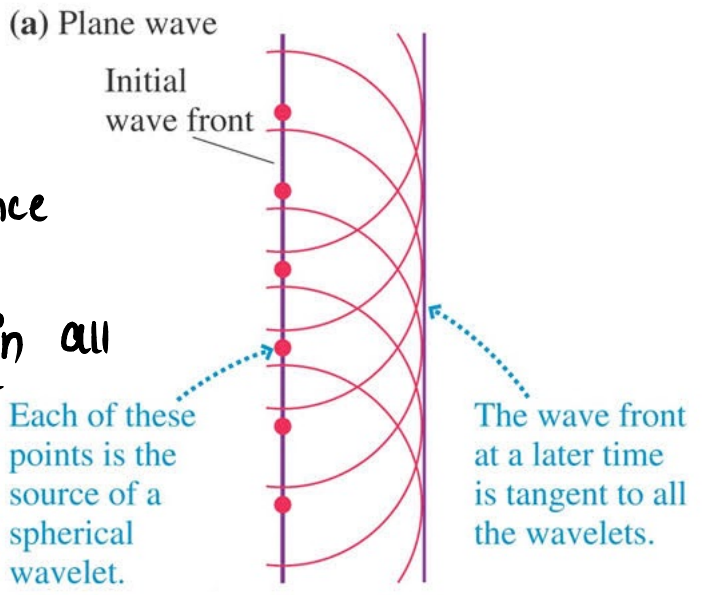
$$\text{Amplitude } (A) \propto r^0$$

$$\text{Intensity } (I) \propto r^0$$



Plane

Huygens' Principle

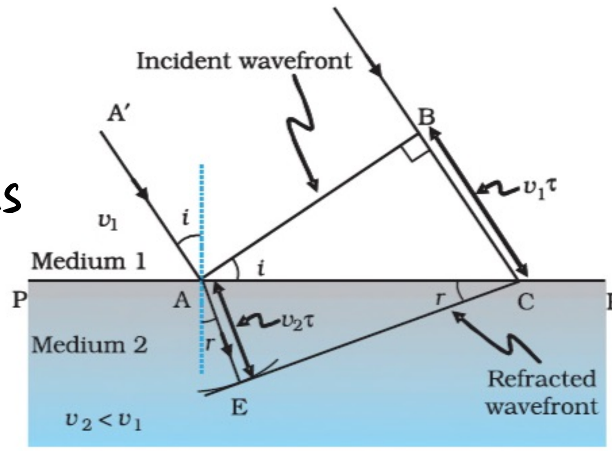


i). Every point on given wavefront (called primary wavefront) acts as a fresh source of new disturbance called secondary wavelets.

ii). The secondary wavelets travels in all direction with the speed of light in the medium.

iii) A surface touching these secondary wavelets tangentially in the forward direction at any instant gives the new (secondary) wave front of that instant.

Refraction of a plane wave front



A plane wave AB is incident at an angle i on the surface PP' separating medium 1 and medium 2. The plane wave undergoes refraction and CE represents the refracted wavefront. The figure corresponds to $v_2 < v_1$ so that the refracted waves bends towards the normal.

Let τ be the time taken by the wave front to travel the distance BC, Thus
$BC = v_1\tau$

To determine the shape of the refracted wavefront we draw a sphere of radius $v_2\tau$ from the point A in the second medium we obtain

$$\sin i = \frac{v_1\tau}{AC} \quad \& \quad \sin r = \frac{v_2\tau}{AC}$$

dividing we get $\boxed{\dfrac{\sin i}{\sin r} = \dfrac{v_1}{v_2}}$

if c represent the speed of light in vacuum then

$$n_1 = \frac{c}{v_1} \quad \& \quad n_2 = \frac{c}{v_2}$$ dividing we get $$\frac{n_2}{n_1} = \frac{c}{v_2} \times \frac{v_1}{c} = \frac{n_2}{n_1} = \frac{v_1}{v_2}$$

i.e $\dfrac{\sin i}{\sin r} = \dfrac{n_2}{n_1}$ or $\boxed{n_{21} = \dfrac{\sin i}{\sin r}}$

• Reflection of a Plane wave by a plane surface.

if v represents the speed of the wave in the medium and if τ represents the time taken by the wavefront in going from point B to C, then distance

$BC = v\tau$

In ΔEAC & BAG.

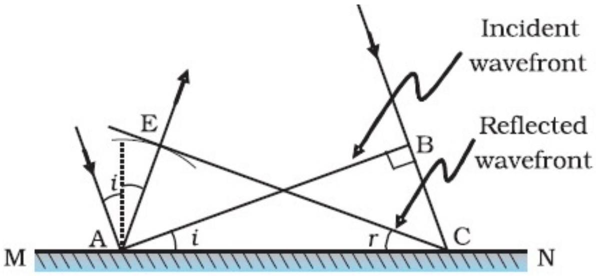
$AC =$ Common

$BC = AC = v\tau$

& $\angle E = \angle B = 90^\circ$

i.e both Triangles are congruent. and therefore angle i & r will be equal

$$\boxed{\angle i = \angle r}$$

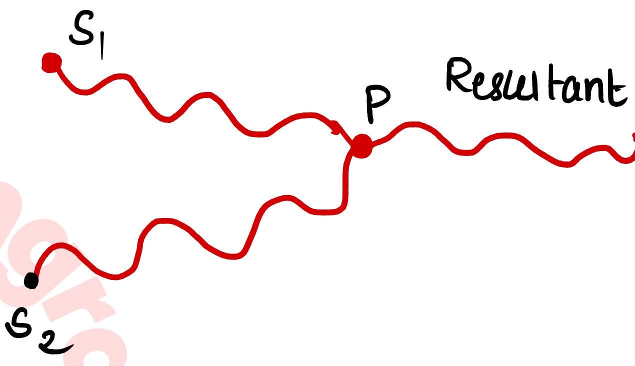


Reflection of a plane wave AB by the reflecting surface MN. AB and CE represent incident and reflected wavefronts.

Principle of Superposition :→

when two waves from S_1 & S_2 meet at some point (say P). Then according to principle of super position net displacement at P (from its mean position at any time is given by

$$\boxed{y = y_1 + y_2}$$

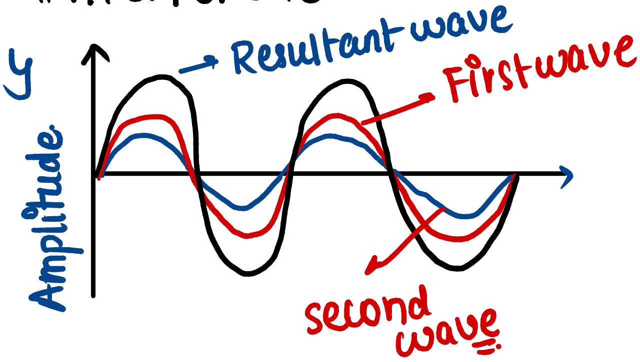


Interference of light wave : when two light waves of similar frequency having a zero or constant phase different propagate in a medium simultaneously in the same direction, then due to their superposition maximum intensity is obtained at few points and minimum intensity at few points. This phenomenomena of redistribution of enegy due to superposition of wave called Interference of light.

Interference

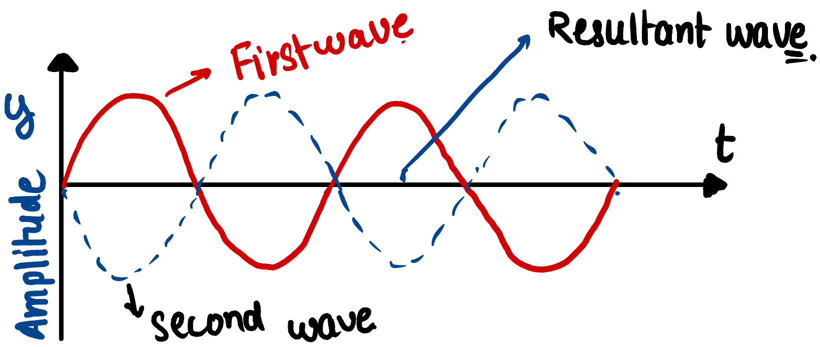
Constructive Interference

when two wave meets in same phase i.e intensity of light is maximum, is called the constructive Interference.

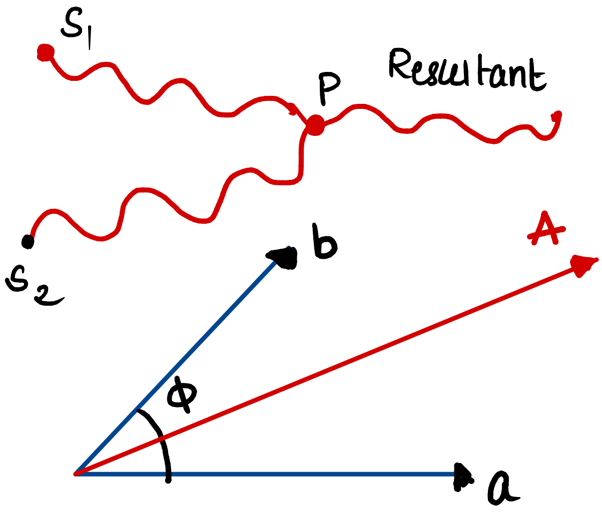


Destructive Interference

when two waves meet in opposite phase i.e Intensity of light is minimum is called the destructive Interference.



Expression for resultant Intensity in Interference of two waves.



$y_1 = a\sin\omega t \qquad y_2 = b\sin(\omega t + \phi)$

a & b are the respective amplitude of the two waves & ϕ is the constant phase difference.

Acc. to superposition principle

$y = y_1 + y_2 \Rightarrow y = a\sin\omega t + b\sin(\omega t + \phi)$

Resultant Amplitude. A

$$A = \sqrt{a^2 + b^2 + 2ab\cos\phi}$$

Direction of Resultant

$$\boxed{\tan\theta = \frac{b\sin\phi}{a + b\cos\phi}}$$

Intensity (I) $\propto$ (Amplitude)^2

So $I_1 = ka^2 \qquad I_2 = kb^2 \qquad I = kA^2$

so $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$ —— ①

if $a = b = A_0$ then $A = 2A_0\cos\frac{\phi}{2}$

$$\boxed{\text{if } I_1 = I_2 = I_0 \text{ then } I = 4I_0\cos^2\frac{\phi}{2}}$$

Condition for Constructive Interference.

I = Maximum so $\cos\phi = +1$

i.e $\phi = 0, 2\pi, 4\pi$ or $\phi = 2n\pi$ where $n = 0, 1, 2, 3 \ldots$

Δx = path difference $\quad \Delta x = \frac{\lambda}{2\pi}\phi \quad$ i.e $\Delta x = n\lambda$

So $I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$

$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$ or $A_{max} = A_1 + A_2$

Condition for destructive Interference

I = minimum so $\cos\phi = -1$

i.e $\phi = \pi, 3\pi, 5\pi$ or $\phi = (2n-1)\pi$ where $n = 1, 2, 3, \ldots$

Path diff. $\Delta x = \left(\frac{\lambda}{2\pi}\right)\phi \Rightarrow \Delta x = (2n-1)\frac{\lambda}{2}$ " " "

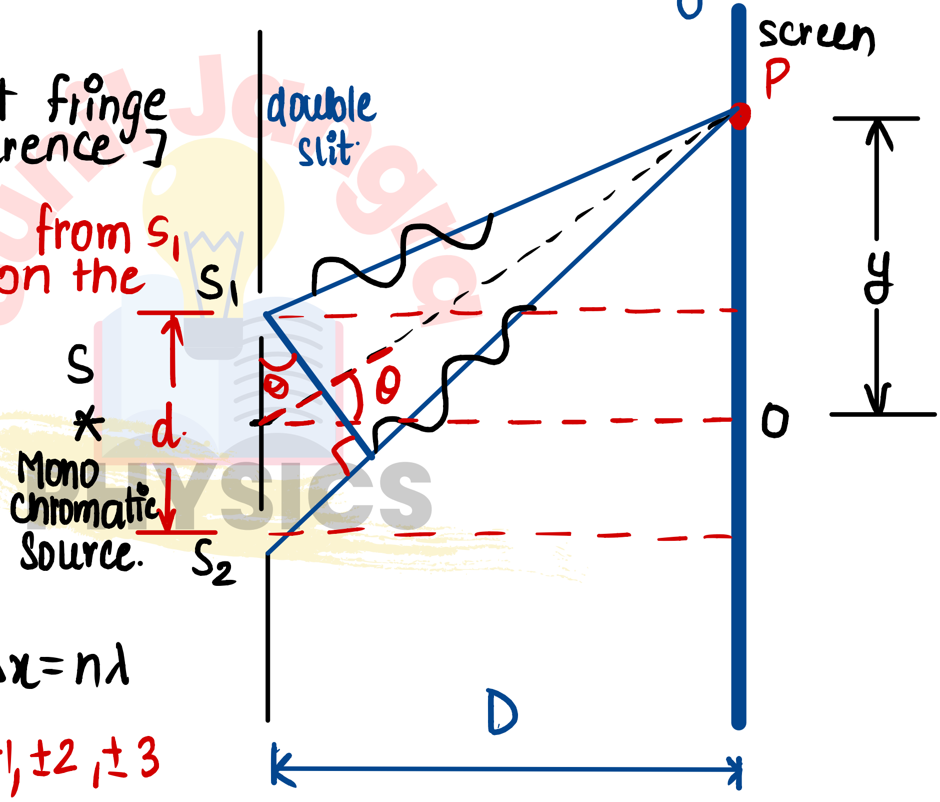
$A_{min} = A_1 - A_2 \qquad I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$

Note $\dfrac{I_{max}}{I_{min}} = \left[\dfrac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right]^2$

- For Interference phenomena to take place, sources must be coherent.
- **Coherent Sources of light.** The sources of light emitting light of same wavelength, same frequency having a zero or constant phase difference are called coherent sources of light.

Young's Double Slit Experiment

One of the first to demonstrate the Interference of light was Thomas Young in 1801.



Let P is the point of bright fringe [constructive Interference]

Fig. shows the light waves from S_1 & S_2 meeting at point P on the screen.

Since $D \gg d$

$$\boxed{\Delta x = S_2P - S_1P}$$

$$\Delta x = d\sin\theta$$

for maximum Intensity $\Delta x = n\lambda$

So $\boxed{d\sin\theta = n\lambda}$ $\quad n = 0, \pm1, \pm2, \pm3$

$n = n^{th}$ order bright fringe.

Here $D \gg d$ so θ is very small

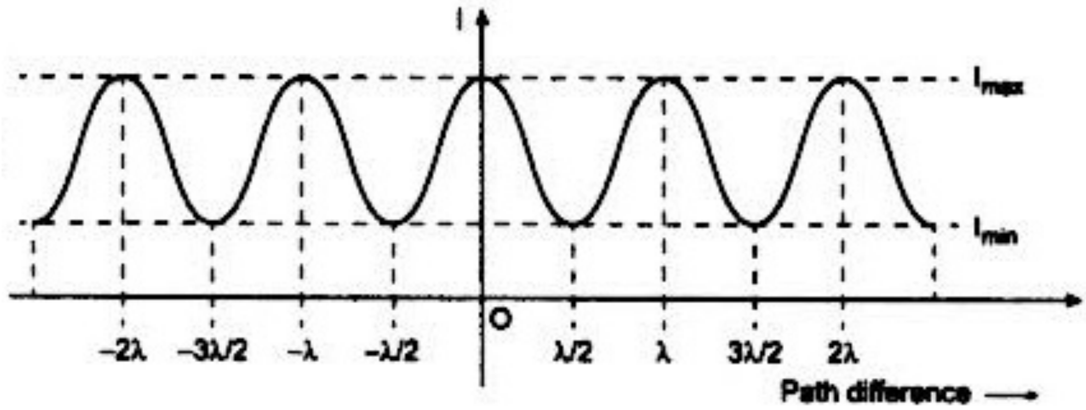
$\sin\theta \simeq \tan\theta = \dfrac{y}{D}$ $\quad$ i.e $\quad d\dfrac{y}{D} = n\lambda \Rightarrow \boxed{y_n = \dfrac{n\lambda D}{d}}$ n^{th} Bright Fringe.

For Dark Fringe

$\Delta x = (2n-1)\dfrac{\lambda}{2} \quad \Rightarrow \quad (2n-1)\dfrac{\lambda}{2} = \dfrac{yd}{D}$

$y_n = (2n-1)\dfrac{\lambda}{2}\dfrac{D}{d}$ $\qquad n = \pm1, \pm2, \ldots$

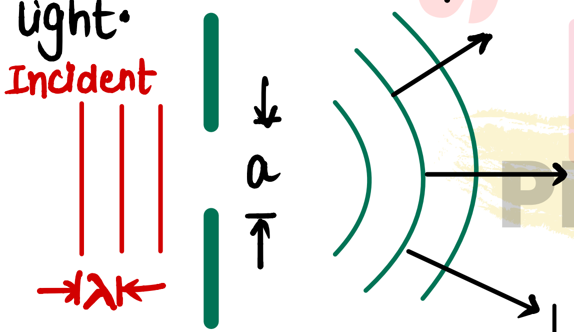
Graph of the intensity distribution in Young's double slit Exp.



Fringe width Distance between two adjacent bright (or dark) fringes is called the fringe width. It is denoted by W.

$$W = \frac{n\lambda D}{d} - \frac{(n-1)\lambda D}{d} \Rightarrow \boxed{\frac{\lambda D}{d} = W}$$

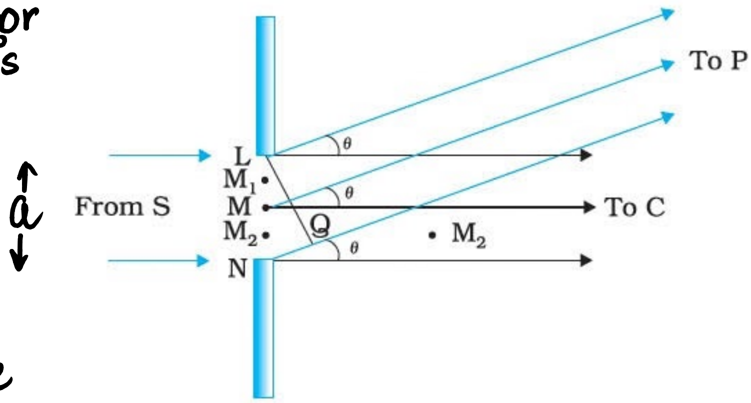
Diffraction The phenomena of bending of light into the region of geometrical shadow of the obstacle is also called diffraction of light.



Fresnel Class	Fraunhofer Class
1). The source is at a finite distance.	1). The source is at infinte distance.
2). No opticals are required	2). Opticals in the form of collimating lens and focusing lens are required.
3). Fringes are not sharp and well defined.	3). Fringes are sharp and well defined.

Path difference = $a\sin\theta$

To established the condition for secondary minima, the slit is divided into 2, 4, 6 equal parts such that correspon-ding wavelets from successive regions interface with path difference of $\lambda/2$ or for n^{th} secondary minima, the slit can be divided into 2n equal parts.



Hence, for n^{th} secondary minima

Path difference $= \frac{a}{2}\sin\theta = \frac{\lambda}{2}$ $\Rightarrow$ $\sin\theta_n = \frac{n\lambda}{a}$ where $n = 1, 2, 3 \ldots$

for secondary maxima, the slit can be divided into $(2n+1)$ equal parts.

Hence, for n^{th} secondary maxima

$$a\sin\theta_n = (2n+1)\frac{\lambda}{2} \quad [n = 1, 2, 3 \ldots]$$

or $$\boxed{\sin\theta_n = (2n+1)\frac{\lambda}{2a}}$$

Width of Central Maxima : It is the distance between first secondary minimum on either side of the central bright fringe C.

width of central maximum $= 2y = \frac{2D\lambda}{a}$

Angular width of central maxima, $2\theta = \frac{2\lambda}{a}$

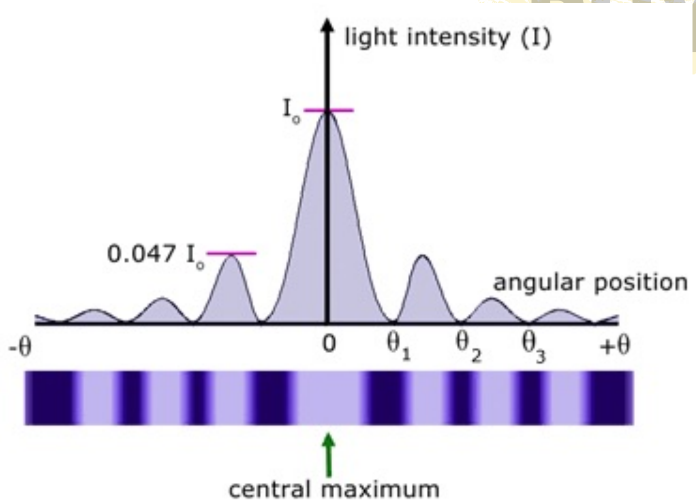


Table 6.5 Difference between interference and diffraction		
S.No.	Interference	Diffraction
1	Superposition of two waves	Bending of waves around edges
2	Superposition of waves from two coherent sources.	Superposition wavefronts emitted from various points of the same wavefront.
3	Equally spaced fringes.	Unequally spaced fringes
4	Intensity of all the bright fringes is almost same	Intensity falls rapidly for higher orders
5	Large number of fringes are obtained	Less number of fringes are obtained