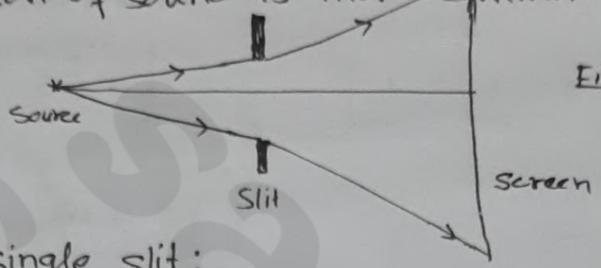
Page 1   Class: XII [Diffraction of light]   Discovered by Grimaldi in (1665 AD)

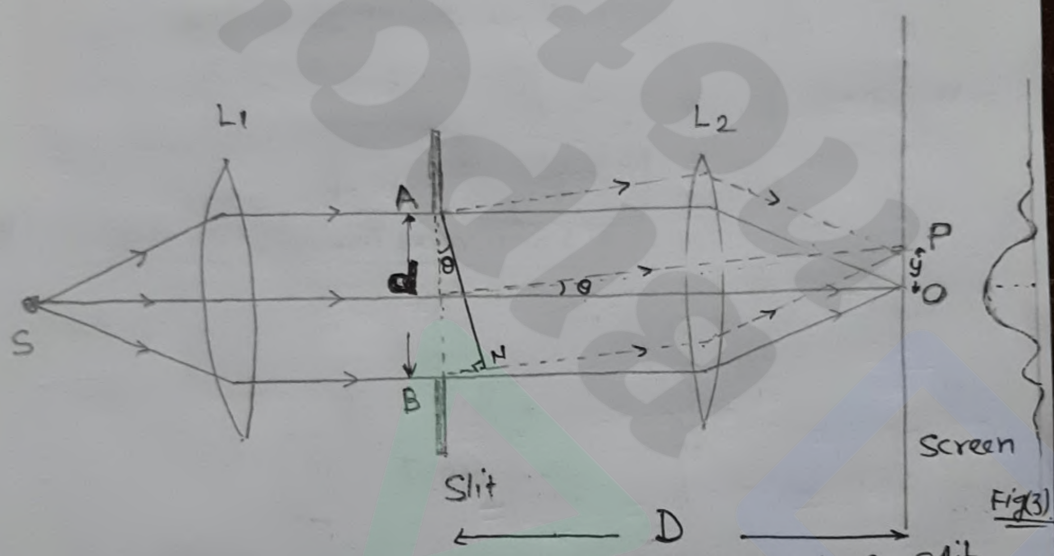
Diffraction is the phenomenon of bending of light around the corners of obstacles (or slit) and spreading into geometrical shadow region.

The necessary condition is that the size of the slit or obstacle must be comparable with the wavelength of the wave. That is why diffraction of sound is more common than that in light.



Fig(1)

Diffraction at a single slit:



Fig(3)

Fig.(2) diffraction of light at a single slit

In Fig.(2) a parallel beam of light is incident normally at slit AB of width d. After diffraction the beam is focussed on screen with lens L_2.

A central maxima followed by minima and maxima of decreasing intensity are observed on screen as shown in fig(3).

At centre 'O' of screen path difference between light coming from A and B is same, hence 'O' corresponds central (or principal) maxima.

Part 2

At point P on screen the path difference between light coming from B and A is

$(BP - AP) = BN = d\sin\theta$

$\therefore d\sin\theta = BN$ --- (1)

(i) For nth secondary minima (ie. dark fringe):

path difference $= n\lambda$; $n = 1, 2, 3, \ldots$

$\therefore d\sin\theta = n\lambda$

$\sin\theta = \frac{n\lambda}{d} \simeq \theta$ [$\because \sin\theta \simeq \theta$ for small angle

Thus for nth minima,

$$\boxed{\theta_n = \frac{n\lambda}{d}} \quad \text{--- (2)}$$

(ii) For nth secondary maxima (ie bright fringe):

path difference $= (2n+1)\frac{\lambda}{2}$; $n = 1, 2, 3, \ldots$

$d\sin\theta = (2n+1)\frac{\lambda}{2} \simeq d\cdot\theta$ [for small θ.

$$\therefore \boxed{\theta_n = \frac{(2n+1)\lambda}{2d}} \quad \text{--- (3)}$$

(iii) Width of central maxima (β_0):

It is defined as the distance between two first minima on either side of central maxima.

Thus

$\beta_0 = 2\beta$

or $\boxed{\beta_0 = \frac{2\lambda D}{d}}$

where β = distance of first minima from centre $= \frac{\lambda D}{d}$ [$\because \theta_1 = \frac{\lambda}{d} = \frac{\beta}{D}$

(iv) Angular width of central maxima

$= \frac{2\left[\frac{\lambda D}{d}\right]}{D}$

$= 2\frac{\lambda}{d}$ radian.

Diffraction grating:

An optical device, used to study the spectra of a source of light and to determine the wavelength of light, is called diffraction grating. There are two types of diffraction grating.

(i) Transmission grating: In transmission gratings, the lines are ruled on glass. The light incident on lines ~~are~~ is scattered and lines behave as opaque obstacle, while the space between two lines transmit light and act as a slit.

(ii) Reflection grating: In reflection grating, lines are ruled on polished metal which scatters light but the unruled parts reflect light regularly.

Theory of diffraction grating:

A diffraction grating consists of a large number of fine, equidistant, closely spaced parallel lines of equal width ruled on glass or polished metal by a diamond point.

If a is the width of each transparency and b is width of each opacity then grating element is given by

$$\text{grating element} = (a+b) = \frac{1}{N} \text{ inch} = \frac{1}{N} \times 2.54\text{cm}$$

where N = number of lines on grating per inch.

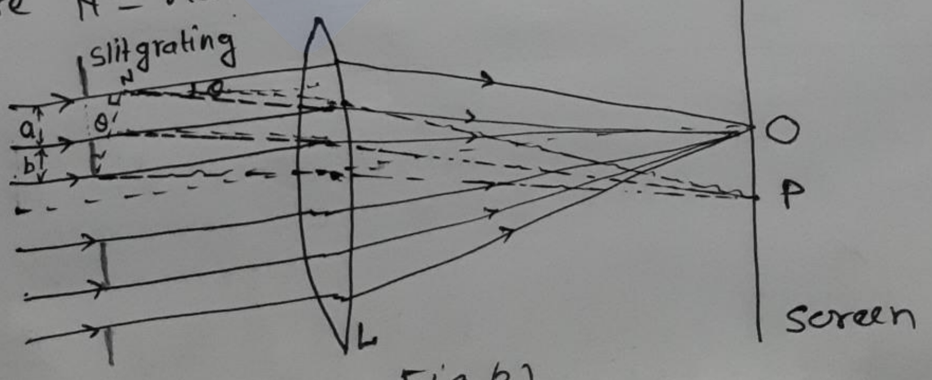


Fig (3)

The diffracted light through N slits is focussed by lens L on screen placed in the focal plane of lens. The pattern obtained on screen is called Fraunhofer diffraction pattern due to N slits which consists of

(i) a central maximum at centre O of the screen. Secondary maxima are formed above and below O.

(ii) A large number of faint subsidiary maxima and minima are formed in between secondary maxima.

For n^{th} order maxima

$$\boxed{(a+b)\sin\theta_n = n\lambda} \quad ; n = 1, 2, 3, \ldots$$

for $n=0$, central maxima is formed.

Resolving power of optical instruments:

For diffraction grating

$$\boxed{\text{resolving power} = \frac{\lambda}{d\lambda} = nN}$$

$$\boxed{\text{Dispersive power} = \frac{\text{Resolving power}}{\cos\theta}}$$

Numericals:

1. How wide is the central diffraction pattern on a screen 3.5 m behind 0.01 mm. slit illuminated by 500nm light.

Soln: Width of central maxima $= \beta_0 = \frac{2\lambda D}{d}$

$$\beta_0 = \frac{2 \times 500 \times 10^{-9} \times 3.5}{0.01 \times 10^{-3}} = 0.35 \text{ meter}$$

(2.) A parallel beam of monochromatic light is allowed to be incident normally on a plane transmission grating having 5000 lines cm^{-1} & second-order spectrum is found to be diffracted through 30°. Calculate the wave-length of light. calculate the wavelength of light.

Soln: Given: For grating,

$$(a+b) = \frac{1}{N} = \frac{1}{5000\ cm^{-1}} = \frac{cm}{5000} = \frac{10^{-2} m}{5000}$$

$$= 0.2 \times 10^{-5} m$$

$\theta_2 = 30°$

$n = 2$ (second order)

$\lambda = ?$

$$(a+b) \cdot \sin\theta_n = n\lambda$$

$$0.2 \times 10^{-5} \times \sin 30° = 2\lambda$$

$$\lambda = \frac{\overset{0.1}{\cancel{0.2}} \times 10^{-5}}{\cancel{2}} \times \frac{1}{2} = 0.5 \times 10^{-6} m = 5 \times 10^{-7} m$$

$$= 5000 \times 10^{-10} m$$

$$= 5000 A°$$

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(3) A plane transmission grating having 500 lines mm^{-1} is illuminated normally by a light of wave-length 600nm. How many diffraction maxima will be observed on screen?

Soln- $(a+b)\sin\theta_n = n\lambda$; here $(a+b) = \frac{1}{500\ mm^{-1}}$

$$= \frac{1mm}{500} = \frac{10^{-3} m}{500}$$

$$= 0.2 \times 10^{-5} m$$

for n_{max}, $\sin\theta_n = 1$

$\therefore (a+b) = n_{max} \cdot \lambda$

$$n_{max} = \frac{a+b}{\lambda} = \frac{0.2 \times 10^{-5}}{600 \times 10^{-9}}$$

$$= 3.33 \simeq 3$$

MCQs (Diffraction)

[1] Diffraction is not seen in the case

(a) when screen is far away
(b) wavelength of light is smaller than slit
(c) wavelength of light is greater than slit
(d) wavelength is very large.

[2] The sky appear blue due to

(a) more scattering of light of larger wavelength
(b) more scattering of lesser wavelength.
(c) the lens of eye is blue.
(d) all of them.

[3] The slit of width 12×10^{-7}m is illuminated with light of wavelength 6000 A°. The angular width of central maxima is

(a) 0° (b) 30° (c) 60° (d) 90°.

[Hint. angular width of central maxima $= \frac{2\lambda}{d}$

$$= \frac{2\times6000\times10^{-10}}{12\times10^{-7}} = 1 \text{ radian}$$

$$= \frac{180^\circ}{\pi} = 57.3^\circ \simeq 60^\circ$$

[4] By which process radiowaves can be detected in a closed room but not light waves?

(a) reflection (b) refraction (c) interference
(d) diffraction.

(5) ~~Find~~ The angle of diffraction for first order secondary minima (if $\lambda = 550$nm) and slit of slit width 0.55mm.

(a) 1 rad (b) 0.1 rad (c) 0.01 rad. (d) 0.001 rad.

Hint: half angular width $= \frac{\lambda}{d} = \frac{550\times10^{-9}}{0.55\times10^{-3}} = 0.001$ rad.

[6] First diffraction minimum due to single slit diffraction is at 30°. If $d = 10^{-6}$ m Then λ is

(a) 4000 A° (b) 5000 A° (c) 6000 A° (d) 7000 A°

<u>Hint:</u> angular at first diffraction minimum = half angular width = $30^\circ = \frac{\pi}{6} = \frac{\lambda}{d}$

$$\therefore \lambda = \frac{\pi d}{6} = \frac{3.14 \times 10^{-6}}{6}$$

$$= 0.52 \times 10^{-6} \simeq 5.2 \times 10^{-7} \text{m}$$

$$\simeq 5000 \text{ A}^\circ$$

[7] In single slit diffraction the intensity is I_0 for principal maxima. The intensity ~~~~ when slit width is doubled will be

(a) I_0 (b) $2I_0$ (c) $4I_0$ (d) $I_0/2$