Arif CE'17 10/10/13

ffraction :

Diffraction refers to various phenomena which occur when a wave encounters an obstacle. Francesco Maria Grimaldi, an Indi Italian scientist in 1665, observed and first recorded accurately the phenomena diffraction.

This shows the apparant bending of waves around small obstracles and spreading out of waves past small openings. Similar effects occur when light waves travel through a medium with a varying refractive index.

"Bending of light through the sharp edge of an obstacle is called diffraction."

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(Polarisation)

Types of diffraction:

i) Fresnel type of diffraction / near field diffraction

ii) Fraunhofer type of diffraction / far field diffraction

Fresnel diffraction:

In optics, Fresnel diffraction is a process of diffraction that occur when a wave passes through an aperture and diffracts in the near field, causing and diffraction pattern observed in different size and shape depending on the distance bet^n the aperture and the projection.

In this type, the sources of light ~~and the obstacle~~ or the screen, or both are at finite distance from the diffracting apperture. No lens are employed here for rending the light. Then light beam parallel or convergent. In this case, $F \geq 1$

Fraunhofer diffraction:

In optics Fraunhofer diffraction is form of wave diffraction that occurs when plane waves are passed through an apperture causing only the size of an observed apperture. In this type, F<1.

In the Fraunhofer class of diffraction phenomena, the source and the screen on which the pattern is observed are at infinite distances from the apperture or the obstacle causing diffraction.

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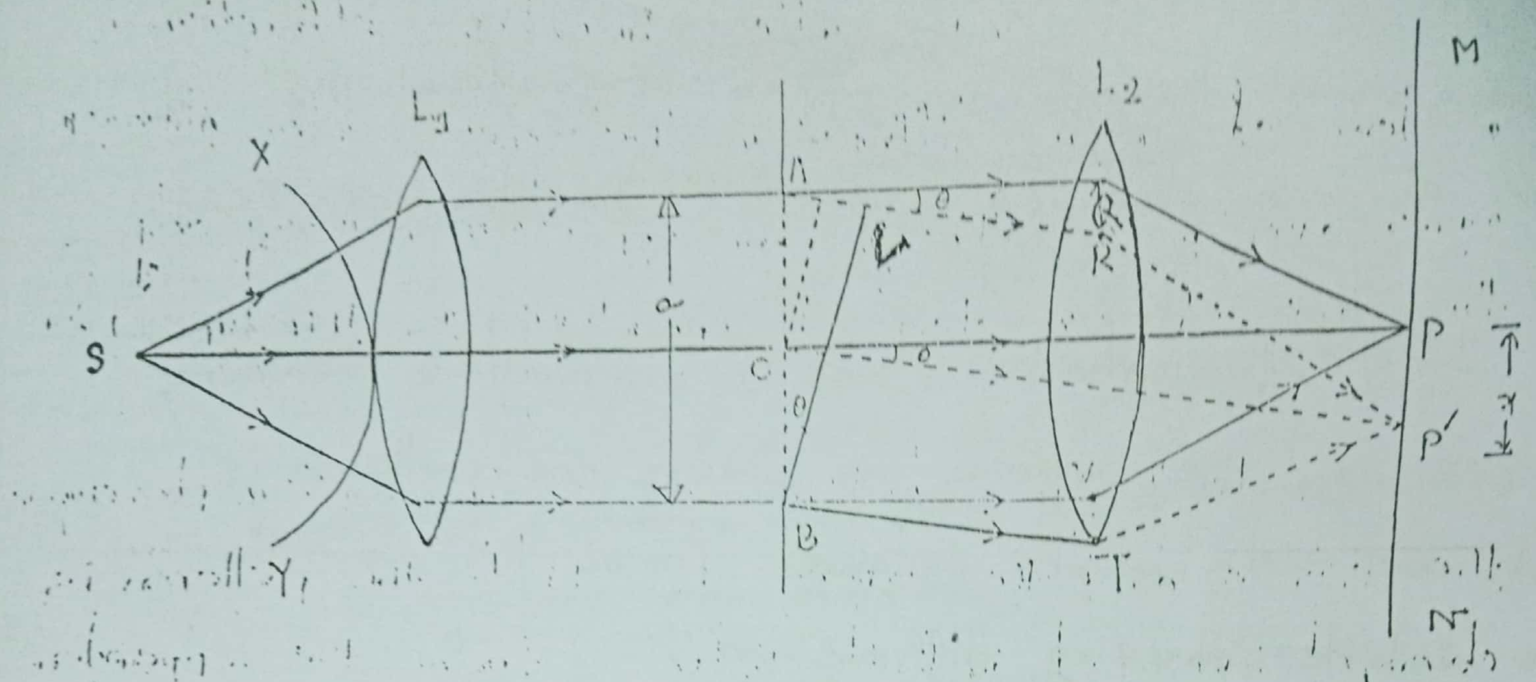
Diffraction at single slit (Fraunhofer diffraction):



The secondary waves travelling in the direction parallel to CP i.e. AQ and BV come to focus at P and a bright image is observed. Since, OA = OB the wave f travel same distance in P and hence the path diffrance is zero and P will be the point of maximum intensity.

Consider the secondary waves is travelling in the direction AR, at an angle θ and reach P'. P' will be maximum and minimum depending on the path diff. In

ΔABL - $\sin\theta = \frac{AL}{AB} \Rightarrow AL = a \cdot \sin\theta$ ... ...(1)

↑ Path diff. betn A and B.

$\Delta L = \lambda$, then P' will be at minimum intensity.

whole wave-front can be considered to be two halves OA and OB. Also when $\Delta L = 2\lambda$, it shows the minimum intensity.

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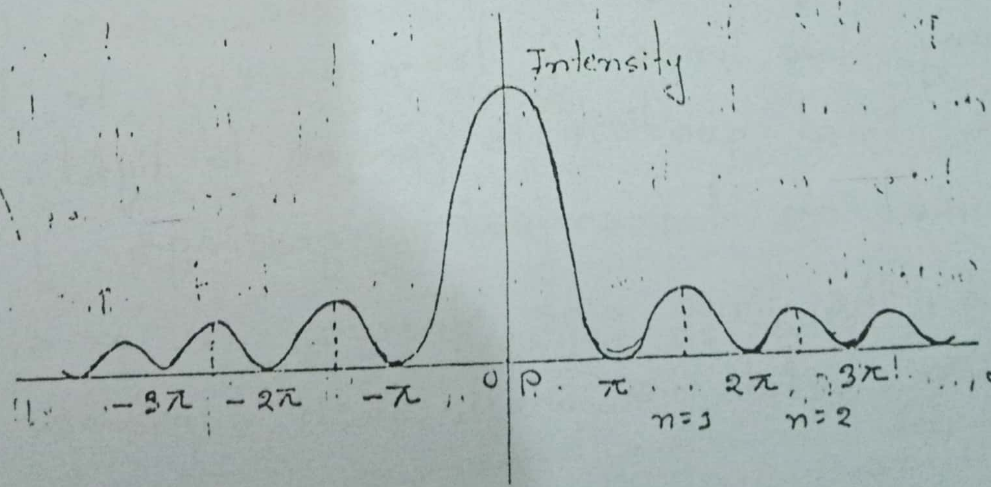
In general, $a \sin\theta = n\lambda$

where, n is an integer.

So, the path different is odd multiple of $\lambda/2$, the maximum intensity i.e -

$$a \sin\theta_n = (2n+1)\lambda/2, \quad n = 1, 2, 3, \ldots$$

Thus the diffraction pattern due to single slit consists of a central maxima at P. Followed by surrounding maxima and minima on both sides.



Plane Diffraction Grating:

A diffraction grating is an exten extremely useful device and in one of its forms it consists of a very large number of narrow slits side by side. The slits are separated by opaque spaces. When a wavefront is incident on a grating surface, light is transmitted through the slits and obstructed by the opaque portions. Such a grating is called a transmission grating.

Joseph Fraunhofen used the first grating, which consisted of a large number of parallel fine wires stretched on a fram. Now, grating are prepared by ruling equidistant parallel lines on a glass surface. The space in betn any two lines is transparent to light and the lined portion is opaque to light. Such surface act as transmission gratings.

If, the lines are drawn on a silvere surface then light is and such surfaces act as reflection grating.

parallel slit sources when light falls upon it.

Grating equation:-

Consider two rays which emerge making an angle, θ with the straight through line.

Constructive (brightness) interference will occur if the difference in their two path lengths is an integer multiples of their wavelength λ, i.e. difference $= n\lambda$, where, n is the order no. 1, 2, 3 ... Now, a triangle in the figure for which

$$n\lambda = (a+b) \sin\theta.$$

This is known as grating equation, where θ is the angle of emerge (called deviation, D for the prism) at which a wavelength will be bright.

$(a+b) = d$, is the distance bet^n the slit.

$d = \frac{1}{N}$, N is the grating constant, is the no. of lines per unit length.

$$n\lambda = \frac{1}{N} \cdot \sin\theta$$

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$$\therefore \sin\theta = nN\lambda$$

[1] Diffraction due to double slit:

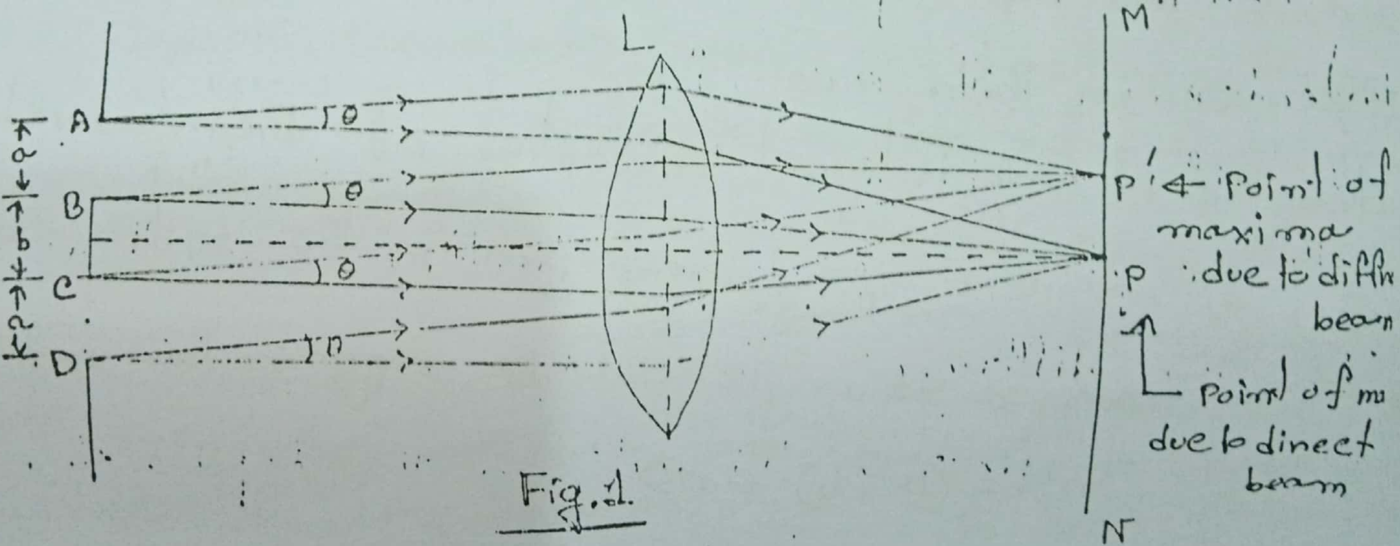

Fig. 1

In fig. 1 AB and CD are two rectangular parallel to one another and perpendicular to the plane of paper. The width of each slit is "a" the width of the opaque portion is "b." "L" is a collecting lens and MN is screen perpendicular to the plane of paper. In this case the diffraction pattern has to be considered in two parts –

i) Interference phenomenon
ii) Diffraction phenomenon

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i) Interference phenomenon:
(maxima & minima)

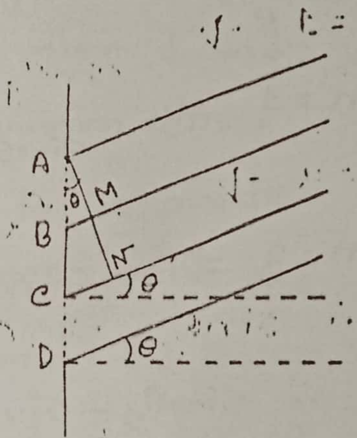

Fig-2

In the ΔACN,

$$\sin\theta = \frac{CN}{AC} = \frac{CN}{a+b}$$

$$\therefore CN = (a+b)\sin\theta.$$

If this path diffrence is equal to odd multipuls of $\lambda/2$, θ if the direction of ~~maxima~~ minima due to interference of the secondary waves of the two slits, –

$$CN = (a+b)\sin\theta_n = (2n+1)\lambda/2.$$

$n = 1, 2, 3, \ldots$

$$\Rightarrow \sin\theta_n = \frac{(2n+1)}{(a+b)} \cdot \lambda/2 \quad \ldots \quad \ldots \quad \ldots (1)$$

If the path diffnence is equal to $n\lambda$ ... θ if the direction of maxima due to interference of secondary waves of the two - slits :-

$$(a+b)\sin\theta_n = n\lambda \quad \text{(1)}$$

$$\therefore \sin\theta_n = \frac{n\lambda}{(a+b)} \quad \text{(2)}$$

$n = 1 \Rightarrow$

$$\sin\theta_1 = \frac{3\lambda}{2} \cdot \frac{1}{(a+b)}$$

$n = 2 \Rightarrow$

$$\sin\theta_2 = \frac{5\lambda}{2} \cdot \frac{1}{(a+b)}$$

From eq^n (1)

$$\therefore \sin\theta_2 - \sin\theta_1 = \frac{\lambda}{a+b}$$

Angular separation bet^n any two consecutive minima (or maxima) is equal to $\frac{\lambda}{a+b}$ - ie, the angular separation is inversely proportional to $(a+b)$.

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Diffraction phenomenon:
(maxima and minima)

Consider the secondary waves travelling in a direction inclined at an angle $\phi$ with the initial direction of the incident light.

If the path difference BM (fig-2) is equal to $\lambda$, the wavelength of light used, then $\phi$ will give the direction of diffraction minimum. Considering the wavefront on AB to be made up of two halves, the path difference bet$^n$ the corresponding points of the upper and the lower halves is equal to $\frac{\lambda}{2}$. The effect at p' due to the wavefront incident on AB is zero. Similarly for the same direction of the secondary waves, the effect at p' due to the wavefront incident on the slit CD is also zero. In general —

$$a \sin \phi_n = n\lambda$$

Putting n = 1, 2, 3.., the values of $\phi_1$, $\phi_2$ etc. corresponding to the directions of diffraction minima can be obtained.
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Dispersive power of a grating:

The diffraction of the n^{th} order principal maxima for wave-length, λ is given by —

$$(a+b)\sin\theta = n\lambda \quad \ldots (1)$$

Differentiating eqn (1) w.r.to θ & λ, we have —

$$(a+b)\cos\theta \cdot d\theta = n\,d\lambda$$

$$\Rightarrow \frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta} = \frac{nN}{\cos\theta} \quad \ldots (2)$$

In equation (2), $\frac{d\theta}{d\lambda}$ is called the dispresive power, θ is the angle of diffraction. The dispersive power of a grating is defined as the ratio of the difference in the angle of diffraction of any two neighbouring spectral lines to the difference in wavelength betn the two spectral lines. from eqn (2) it is clear that the d.p. of grating is directly proportional to the order number and grating constant and inversely proportional to $\cos\theta$.

[Condition of resolution]

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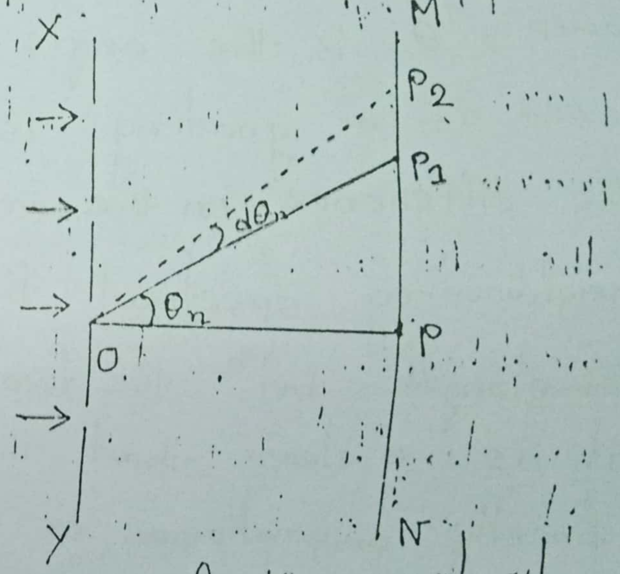
[Q] Resolving power of a grating:

The abilities of an optical instrument, expressed in numerical measure to resolve the images of ~~nearby~~ two nearby points is termed as its resolving power. The resolving power of a grating is defined as the ratio of any spectral line to the difference in wavelength betn this line and a neighbouring line such that the lines appear to the just resolved. Thus the resolving power of a grating $= \frac{\lambda}{d\lambda}$



In fig 1. XY is a grating surface and MN is the field of view of telescope. P in the nth primary maxima of the spectral line of wavelength λ at an angle θ_n. P.

P_1 is the nth primary maxima of the spectral line of wavelength λ at an angle θ_n.

the n^{th} primary maxima of the spectral line of wavelength $(\lambda + d\lambda)$ at an angle of $(\theta_n + d\theta_n)$.

P_1 and P_2 are the spectral lines in the n^{th} order, the direction of n^{th} order maxima is for λ

$$(a+b)\sin\theta = n\lambda \quad \cdots (3)$$

And for $(\lambda+d\lambda)$ in

$$(a+b)\sin(\theta_n + d\theta_n) = n(\lambda+d\lambda) \quad \cdots\cdots\cdots (4)$$

This is possible only when the extra path diffrence is $\frac{\lambda}{N}$.

$$(a+b)\sin(\theta_n + d\theta_n) = n\lambda + \frac{\lambda}{N} \quad \cdots\cdots\cdots (5)$$

Equating the R.H.S of eq^n (4) & (5) ⇒

$$n(\lambda + d\lambda) = n\lambda + \frac{\lambda}{N}$$

$$\Rightarrow n d\lambda = \frac{\lambda}{N}$$

$$\therefore \frac{\lambda}{d\lambda} = nN \quad \cdots\cdots\cdots (6)$$

This quantity $\frac{\lambda}{d\lambda}$ measure the resolving power of a grating - from eq^n (6) it is clear —

$$R.P \propto n$$

$$\propto N.$$

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We can say the D.P. increasing N and R.P also increases with increasing N.

If N is same for two grating, the D.P. will be same but if one larger with produces higher resolution of spectral lines with a grating with large width of grealing surface; the spectra lines are sharp and narrow.

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Distinction betn single slit and double slit diffraction patterns :-

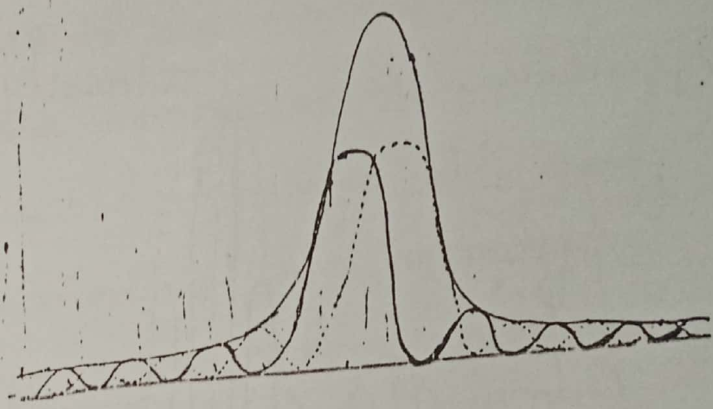
The single slit diff. pattern consists of a central bright maximum with secondary maxima and minima of gradually decreasing intensity.

The double slit diff. pattern consists of equally spaced interference maxima and minima within the central maximum.

The intensity of the central maximum in the diffraction pattern due to double slit is four times that of the central maximum due to diffraction at a single slit.

Resolving Power of !

...solving power: The ability of an optical instrument expressed in numerical measure to resolve the images of two nearby points is termed as its resolving power.



The resolving power of a grating is defined as the ratio of the wave-length of any spectral line to the difference in wavelength betn this line and a neighbouring line such that the two lines appear to be just resolved.

Then the resolving power of a grating = $\frac{\lambda}{d\lambda}$

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* Intensity of double-diffraction:—

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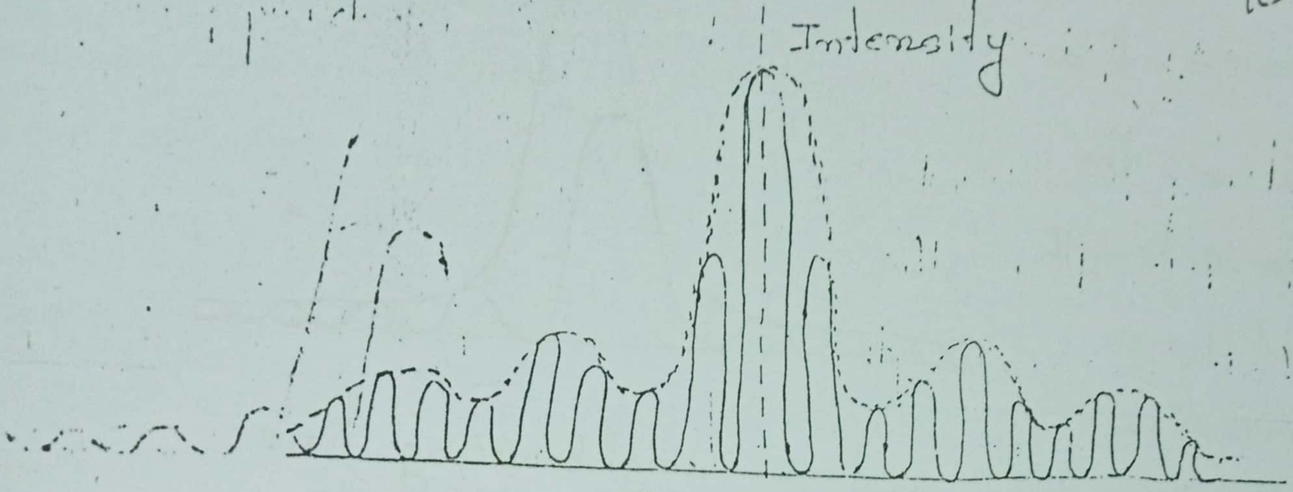

Fig-1

The intensity distribution due to Fraunhofer diffraction at two parallel slits is shown in fig-1. The full line represents equally spaced interference maxima and minima and the dotted curve represents the diffraction maxima and minima.

In the region originally occupied by the central maximum of the single slit diffraction pattern, equally spaced interference maxima and minima are observed. The intensity of the central interference maximum ~~of the single slit~~ is times the intensity of the central maximum the single slit ~~pattern~~ diffraction pattern.

The intensity of the other interference maxima on the two sides of the central maximum gradually decreases. In the region of the secondary maxima due to diffraction at a single slit, equally spaced interference maxima of low intensity are observed.

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