



Engineering PHYSICS

Unit - ①

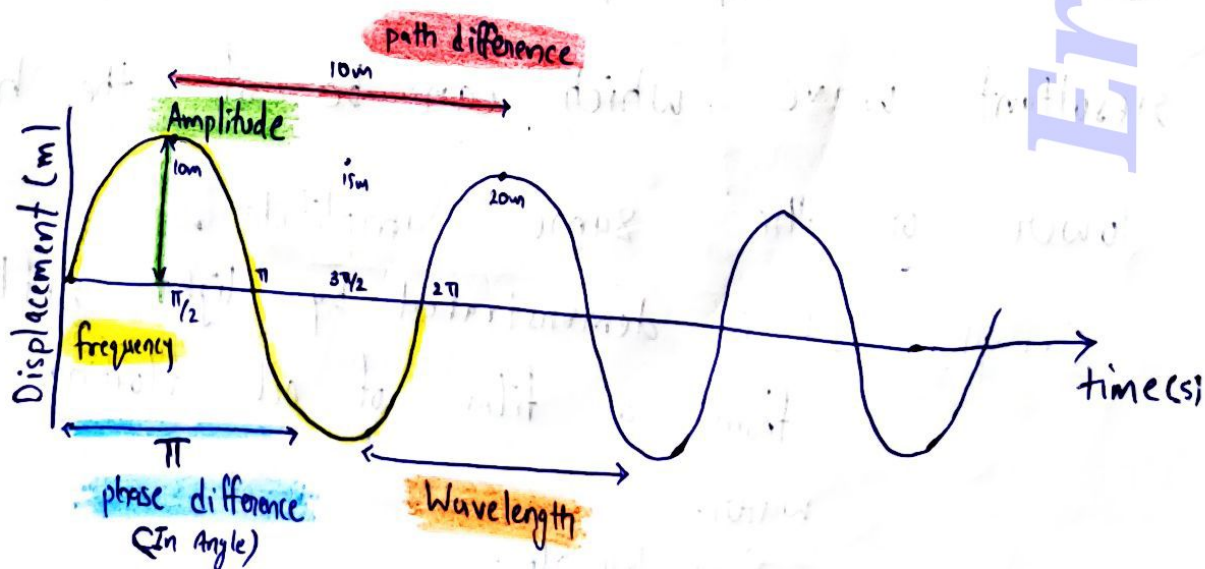
Wave Optics

Optics is a branch of physics which deals with the "Theory of light and its propagation in a given medium".

Optics $\rightarrow$ Ray or Geometrical Optics
 $\rightarrow$ Physical or Wave Optics

Ray optics :- It deals with image formation by optical systems.

Wave optics :- It deals with nature of light. It is the study of how light behaves when it propagates as a wave.



Amplitude :- maximum displacement moved by a point on a vibrating body on wave.

Wavelength :- The distance b/w two successive crests or ~~thru~~ troughs of a wave.

frequency :- No. of waves that pass a fixed point in a given amount of time.

path difference :- The difference in the path traversed by the two waves.

phase difference :- The difference in the phase angle of two waves.

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Interference of Light

Interference is the natural phenomenon in which two waves superimpose of waves to form a resultant wave, which can be of the higher, lower or the same amplitude.

Example - It is demonstrated by light reflected from a film of oil floating on water.

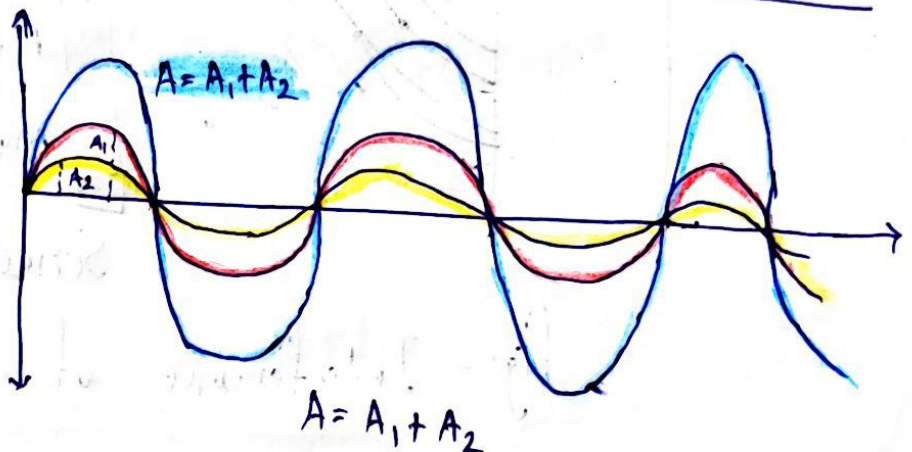
- Soap Bubble.

Types of interference:-

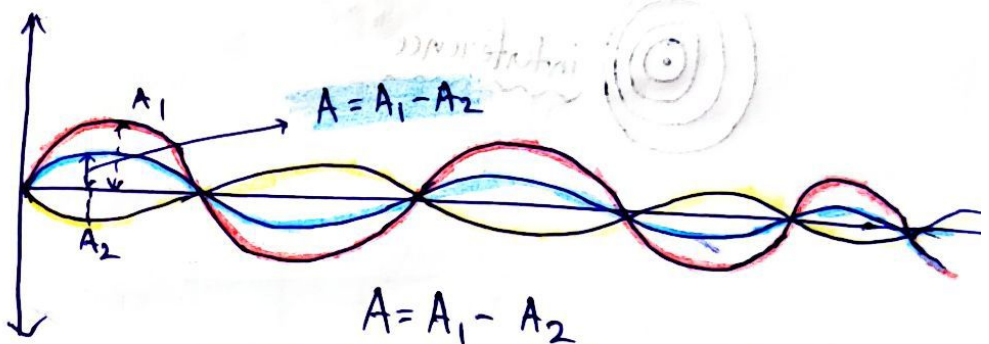
Constructive $\Rightarrow$ where intensity is maximum,
[Bright fringes] interference is called Constructive.

Destructive $\Rightarrow$ where intensity is minimum,
[Dark fringes] interference is called Destructive.

Constructive
Interference $\Rightarrow$
(Bright)



Destructive
Interference $\Rightarrow$
(Dark)



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Condition for sustained Interference:-

- $\rightarrow$ Should have same frequency, wavelength, amplitude, with zero path & phase difference
- $\rightarrow$ Separation b/w 2 slits should be very small
- $\rightarrow$ Separation b/w screen & slits should be large.

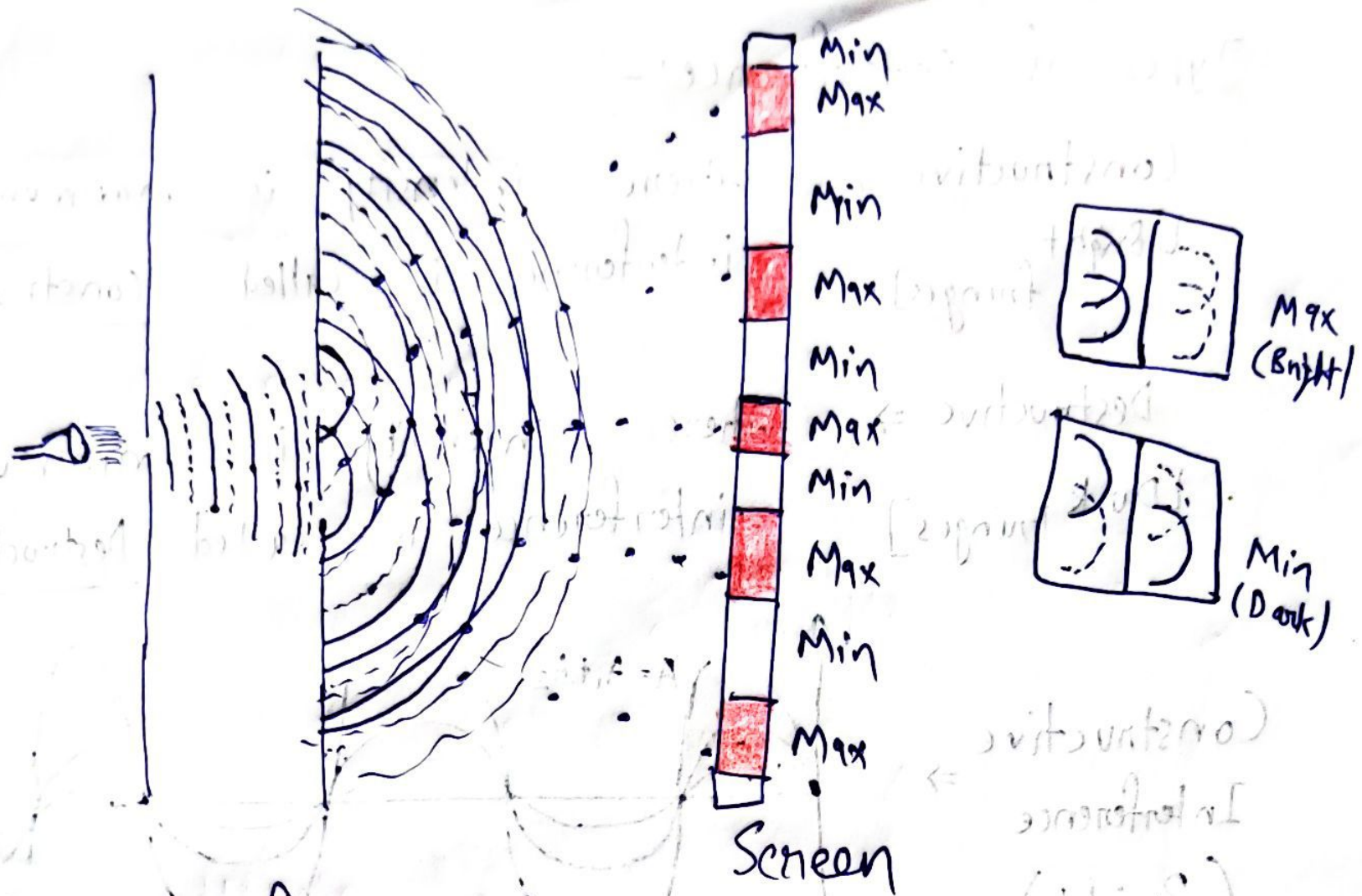


fig - Interference of light

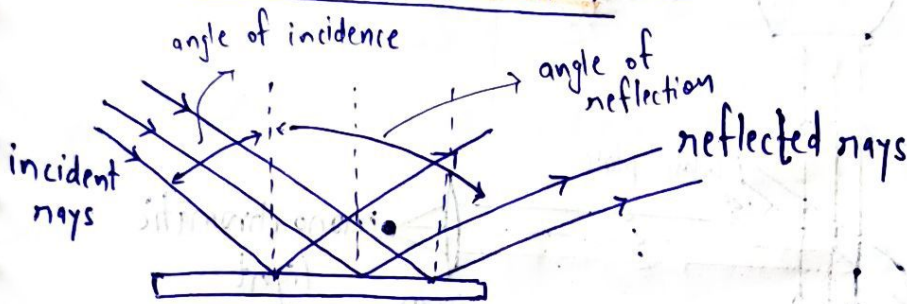


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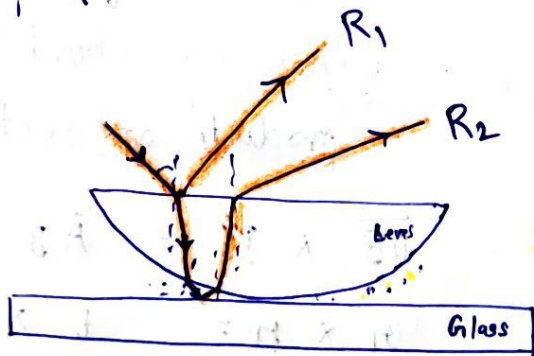
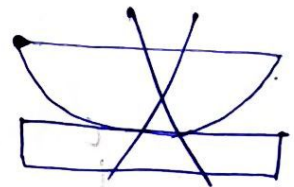
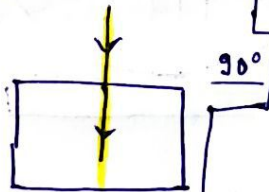
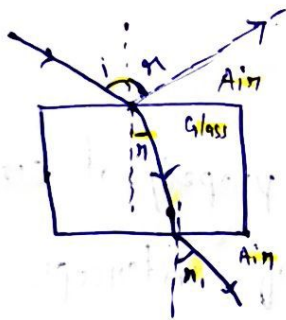
Newton's Rings

Newton's Rings is a phenomenon in which an interference pattern is created by the reflection of light b/w two spherical surfaces and an adjacent touching flat surface.

Law of Reflection :-



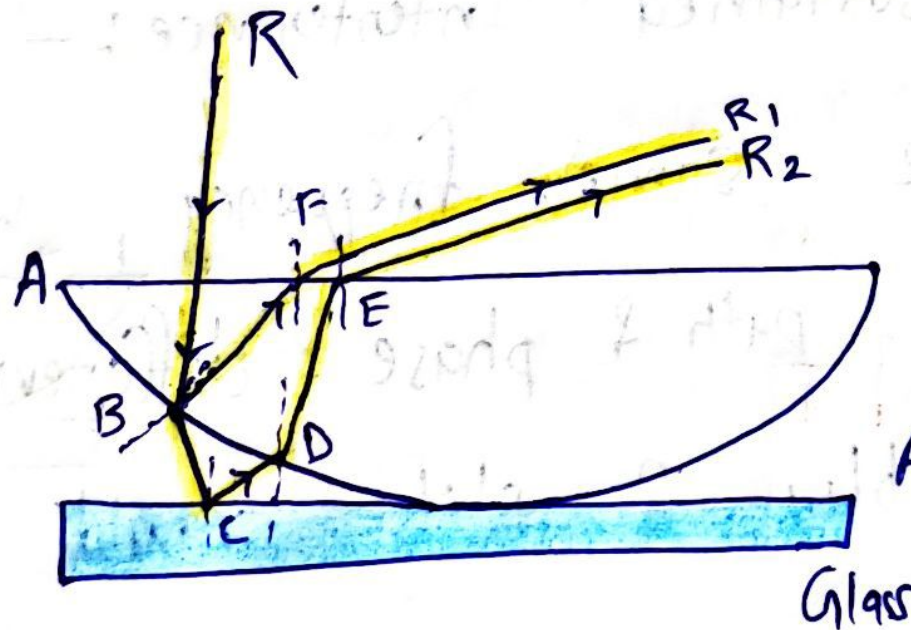
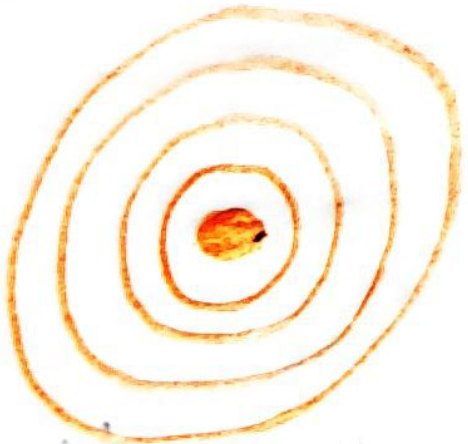
Law of Refraction :-



PLANO CONVEX LENS



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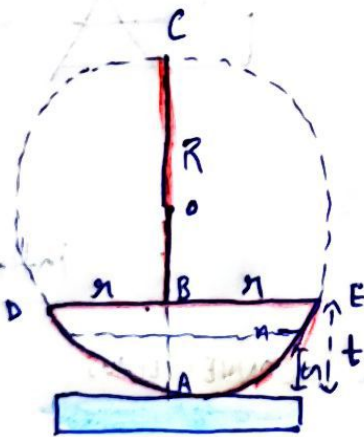
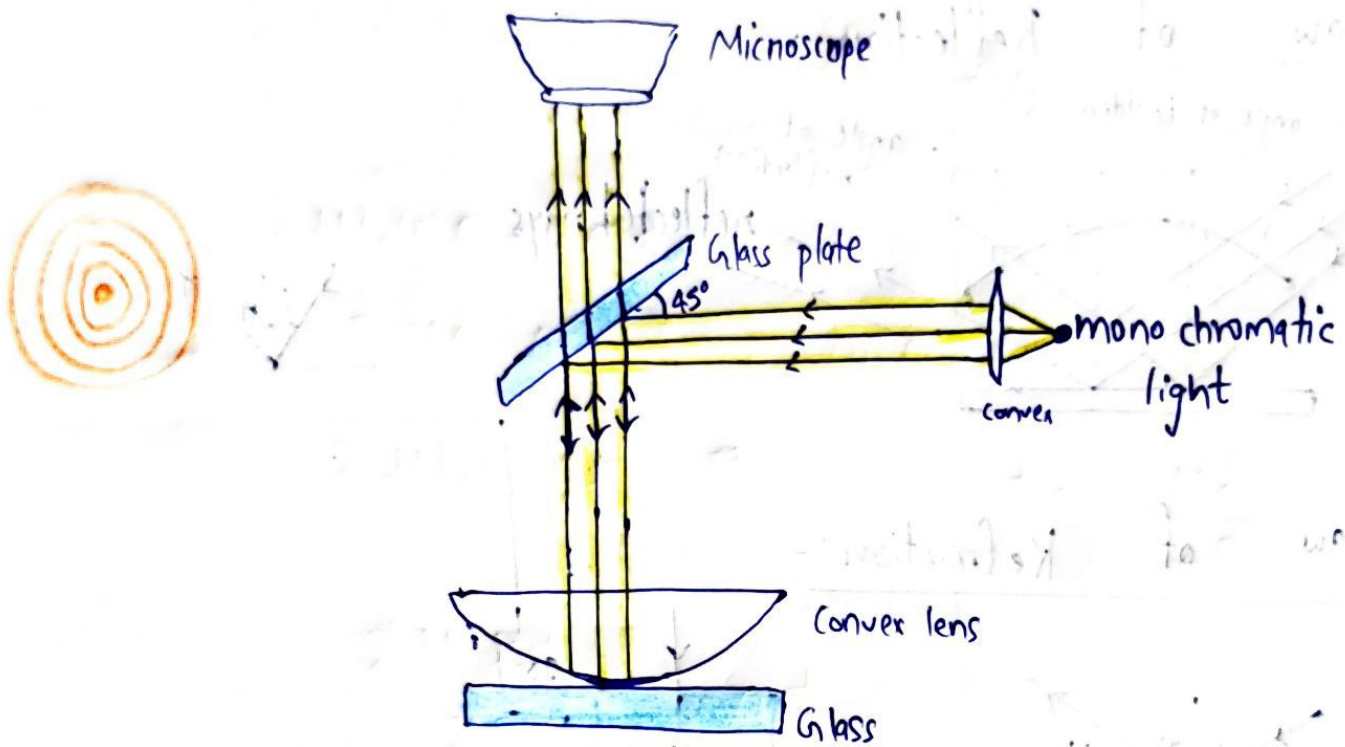
Plano Convex lens

Air film

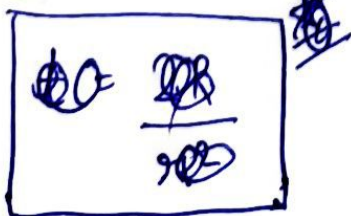
Glass

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Newton's Rings Experiment



Here
t = thickness of film



According to property of circle,
the product of intercepts of
intersecting chord is equal to
product of sections of diameter

$$\overline{DB} \times \overline{BE} = \overline{AB} \times \overline{BC}$$

$$n \times n = t \times (2R - t)$$

$$n^2 = 2Rt - t^2$$

Since $t \ll$

so

$$n^2 = 2Rt \Rightarrow$$

$$t_n = \frac{n^2}{2R}$$

Diameter of Newton's Ring

⇒ For bright ring (constructive interference in thin film)



path difference

(b/w waves reflected by air film)

$$\Delta = 2\mu t \cos \theta + \frac{\lambda}{2}$$

so for n^{th} order of bright fringe

path difference = $n\lambda$ (as bright fringe = $\gggg$)

$$\Rightarrow \frac{\lambda}{2} + 2\mu t_n \cos \theta = n\lambda \quad (n\lambda - \lambda/2 \Rightarrow (2n-1)\lambda/2)$$

$$\Rightarrow 2\mu t_n \cos \theta = (2n-1) \frac{\lambda}{2}$$

since $\theta = 0^\circ$, $\cos \theta = 1$

$$\Rightarrow 2\mu t_n = (2n-1) \lambda/2$$

$$\boxed{t_n = \frac{r_n^2}{2R}}$$

$$\Rightarrow 2\mu \frac{r_n^2}{2R} = (2n-1) \lambda/2$$

$$D = 2R$$

$$r_n = \left[(2n-1) \frac{\lambda R}{2\mu} \right]^{1/2}$$

$$\sqrt{4} = 2 \\ 2^2 = 4$$

$$D_n = 2r_n = 2 \left[(2n-1) \frac{\lambda R}{2\mu} \right]^{1/2}$$

$$\boxed{D_n = \left[4(2n-1) \frac{\lambda R}{2\mu} \right]^{1/2}}$$

For bright ring.

$$\Rightarrow \boxed{D_n = \sqrt{2(2n-1)\lambda R}} \\ \text{if } \mu = 1 \text{ (Airy)}$$

⇒ For Dark Rings

$$\Delta = 2\mu t \cos \theta + \lambda/2$$



Path diff. should be equal to odd multiples of $\lambda/2$

$$\Delta = (2n+1) \lambda/2$$

$$\Rightarrow 2\mu t_n \cos \theta + \lambda/2 = (2n+1) \lambda/2$$

$$\Rightarrow 2\mu t_n \cos \theta = \frac{(2n+1)\lambda}{2} - \lambda/2$$

$$\Rightarrow 2\mu t_n \cos \theta = n\lambda$$

$$\text{Since } \theta = 0^\circ, \cos \theta = 1$$

$$\Rightarrow 2\mu t_n = n\lambda \quad \Rightarrow \quad t_n = \frac{n\lambda}{2\mu}$$

$$\Rightarrow \frac{2\mu r_n^2}{4R} = n\lambda$$

$$\Rightarrow r_n^2 = \frac{n\lambda R}{\mu} \quad \Rightarrow \quad r_n = \sqrt{\frac{n\lambda R}{\mu}}$$

$$D_n = 2r_n = 2 \sqrt{\frac{n\lambda R}{\mu}}$$

$$\boxed{D_n = \sqrt{\frac{4\lambda R n}{\mu}}} \quad \text{for dark Ring}$$

In case of medium is air, $\mu = 1$

$$\boxed{D_n = \sqrt{4\lambda R n}}$$

Wavelength of monochromatic light using N.R exp.



Since we know :

$$\text{Diameter of } n^{\text{th}} \text{ dark ring} = [4\lambda R n]^{1/2} \quad \text{--- (1)}$$
$$D_n^2 = 4n\lambda R$$

for $(n+p)^{\text{th}}$ dark ring = $D_{n+p}^2 = (4(n+p)\lambda R)$ --- (2)

Subtracting eqn (1) from (2)

$$D_{n+p}^2 - D_n^2 = 4(n+p)\lambda R - 4n\lambda R$$

$$D_{n+p}^2 - D_n^2 = 4p\lambda R$$

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} \quad \star$$

Wavelength

Refractive index of Liquid (μ)

air (μ_{air})

$$(D_n^2)_{\text{air}} = 4n\lambda R \quad (\text{In air film}) \quad \text{--- (1)}$$

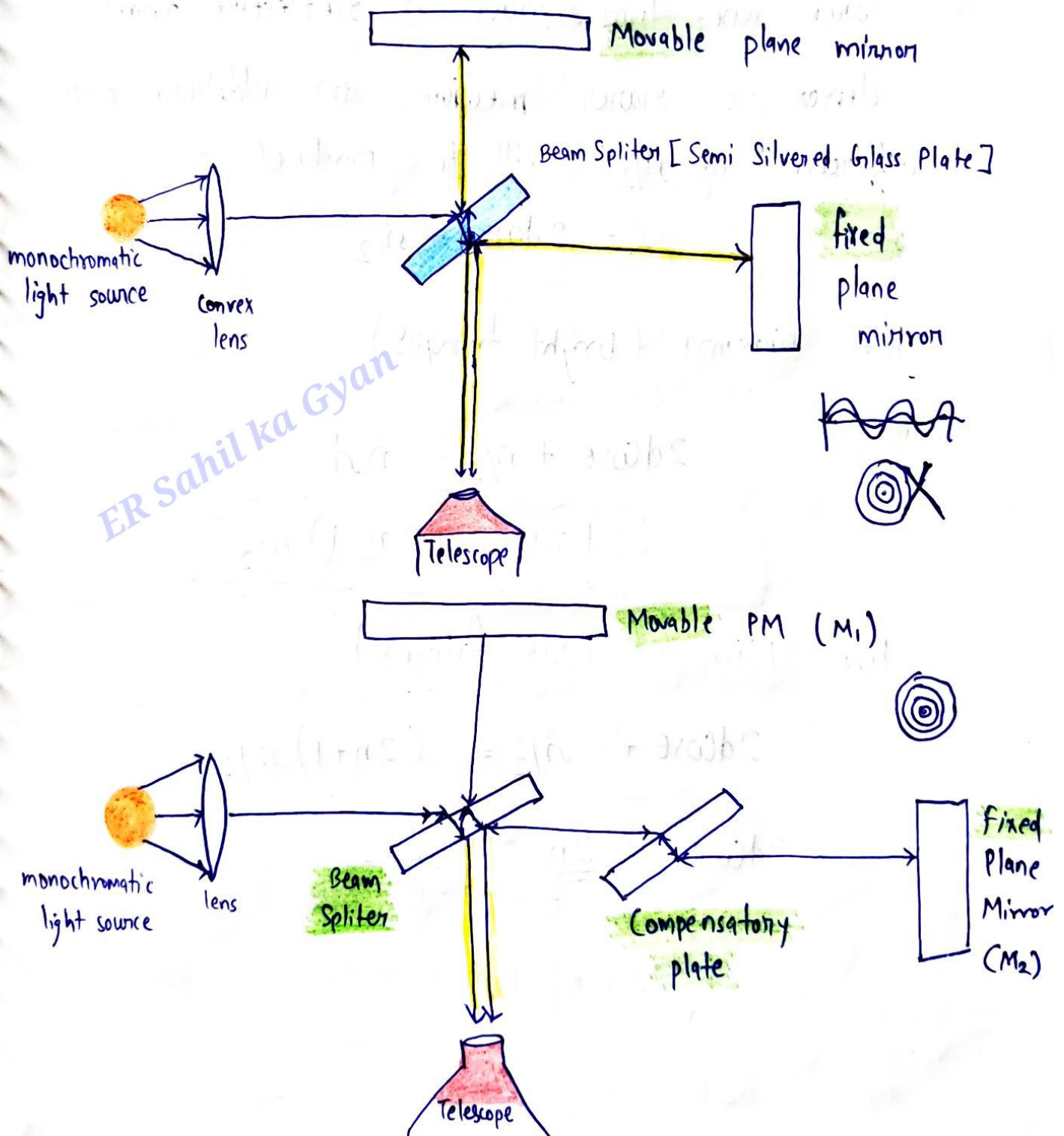
$$(D_n^2)_{\text{liquid}} = \frac{4n\lambda R}{\mu} \quad (\text{In liquid film}) \quad \text{--- (2)}$$

(1) / (2)

$$\frac{(D_n^2)_{\text{air}}}{(D_n^2)_{\text{liquid}}} = \mu \quad \star$$

Michelson Interferometer

The Michelson interferometer produces interference fringes by splitting a beam of light so that one beam strikes a fixed mirror and the other a movable mirror. When the reflected beams are brought back together, an interference pattern results.



The **fringe** formed in this experiment are known as fringes of equal inclination (Haidinger's fringes).

→ When mirror M_1 & M_2 are **perpendicular** to each other then circular fringes are formed.

The path difference b/w light waves

$$\Delta = 2d \cos \theta$$

→ When one light wave is reflected from denser to rarer medium, an additional path difference of $\lambda/2$ will be produced so

$$\Delta = 2d \cos \theta + \lambda/2$$

for **Maxima** (Bright fringes)

$$2d \cos \theta + \lambda/2 = n\lambda$$

$$\boxed{2d \cos \theta = (2n-1) \lambda/2}$$

for **Minima** (Dark fringes)

$$2d \cos \theta + \lambda/2 = (2n+1) \lambda/2$$

$$2d \cos \theta = \frac{2n\lambda}{2} + \lambda/2 - \lambda/2$$

$$\boxed{2d \cos \theta = n\lambda}$$

Determination of Wavelength using M.I.

→ As we know for dark fringes:

$$n\lambda = 2d \cos \theta$$

Since $\theta = 0^\circ$, $\cos \theta = 1$

$$2d = n\lambda \Rightarrow$$

$$\lambda = \frac{2d}{n}$$



Determination of difference in close wavelength of two spectral lines: $[\lambda_1 \text{ \& } \lambda_2]$

→ Suppose wavelength of λ_1 is λ_1 & λ_2 is λ_2

For n^{th} dark fringe of wavelength λ_1

$$2d \cos \theta = n\lambda_1$$

For $(n+1)^{\text{th}}$ dark fringe of wavelength λ_2

$$2d \cos \theta = (n+1)\lambda_2$$



Let n_1 & n_2 be the changes in order at the centre of the field when mirror M_1 is moved through a distance 'd' b/w two successive positions of maximum distinctness of the fringes.

$$\lambda = \frac{2d}{n} \Rightarrow 2d = n\lambda$$

$$2d = n_1 \lambda_1 = n_2 \lambda_2 \quad \text{--- (1)}$$

If λ_1 is greater than λ_2 ($\lambda_1 > \lambda_2$)
therefore so $n_2 = n_1 + 1$

$$2d = n_1 \lambda_1 = (n_1 + 1) \lambda_2 \quad \text{--- (2)}$$

$$n_1 \lambda_1 = (n_1 + 1) \lambda_2$$

$$n_1 (\lambda_1 - \lambda_2) = \lambda_2$$

$$n_1 = \frac{\lambda_2}{\lambda_1 - \lambda_2} \quad \text{--- (3)}$$

putting value of n_1 in eqn - (1), we get

$$2d = \frac{\lambda_1 \lambda_2}{\lambda_1 - \lambda_2}$$

$$\lambda_1 - \lambda_2 = \frac{\lambda_1 \lambda_2}{2d}$$

$$\therefore \lambda_{av}^2 = \lambda_1 \lambda_2$$

$$\lambda_1 - \lambda_2 = \frac{\lambda_{av}^2}{2d}$$

$$\frac{d\lambda}{\lambda_1 \lambda_2} - \frac{d\lambda}{\lambda_1 \lambda_2} = \frac{1}{2d}$$

Taking λ_{av} as mean of λ_1 & λ_2

$$\frac{1}{\lambda_2} - \frac{1}{\lambda_1} = \frac{1}{2d}$$

Hence diff. in wavelength ($\lambda_1 - \lambda_2$) can be
calculated in term of wave no.

Since $v_1 = \frac{1}{\lambda_1}$, $v_2 = \frac{1}{\lambda_2}$

so

$$v_2 - v_1 = \frac{1}{2d}$$

DIFFRACTION OF LIGHT

The bending of light around an obstacle or slit and spreading out in the geometrical shadow is called diffraction.

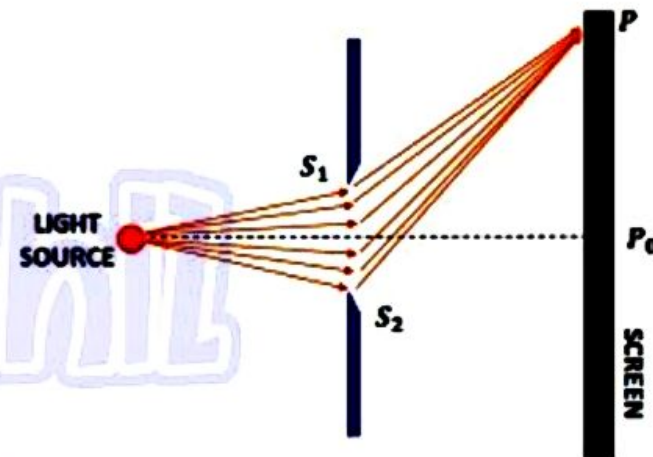
Diffraction of light depends on

- Size of obstacle (a)
- Wavelength of light (λ)

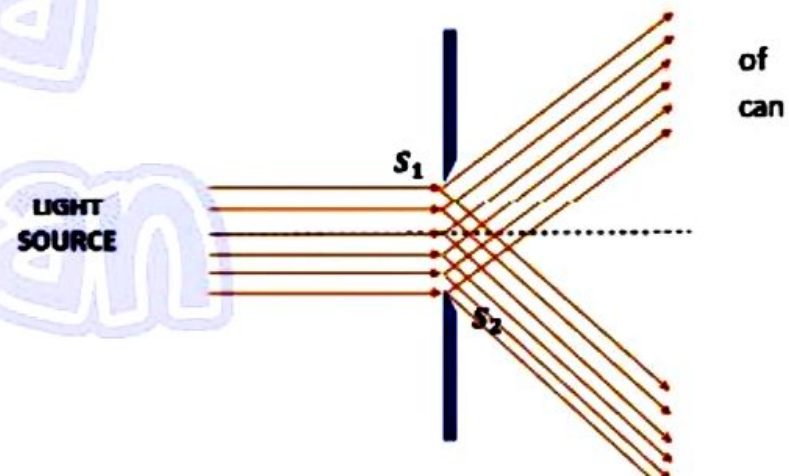
Diffraction is of two types:

1. Fresnel's Diffraction
2. Fraunhofer's Diffraction

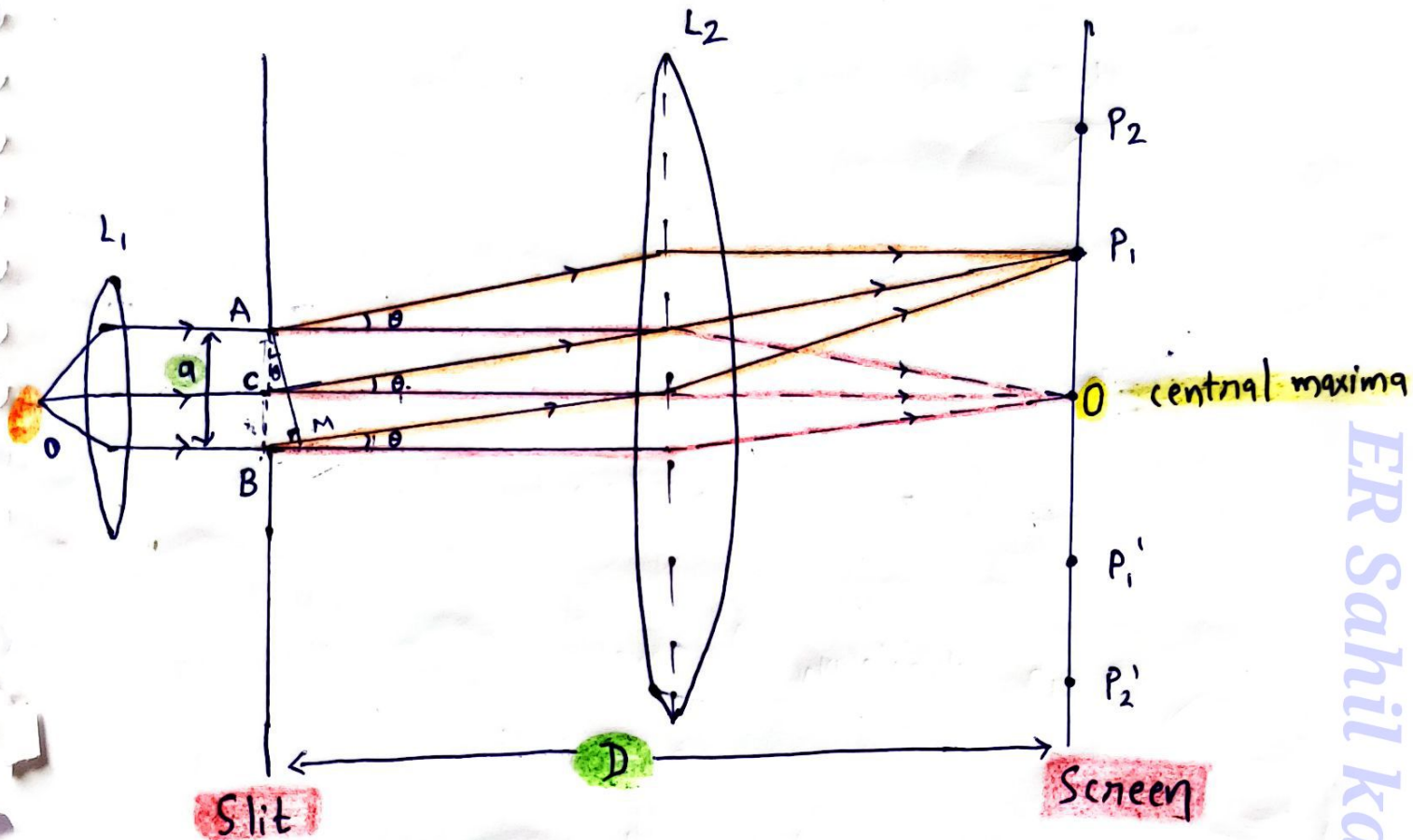
1. FRESNEL'S DIFFRACTION :- In this type of diffraction source and screen are at a finite distance from diffracting element. The incident wave front may be circular or cylindrical but should not be plane. In this theoretical analysis is much complex.



2. FRAUNHOFER'S DIFFRACTION :- In this kind of diffraction source and screen are kept at infinite distance and observed by using lens. The theoretical analysis is simple, the pattern is image of source.



FRAUNHOFER'S Diffraction at a Single Slit



- Intensity & Position of Central maxima
- Position of minima
- Intensity and Position of Secondary maxima
- Width of Principle maxima

So Here AB is wavefront
and BM is path difference of wave
reaching P.

So In $\triangle BMA$, $BM = \text{path difference} = \Delta$

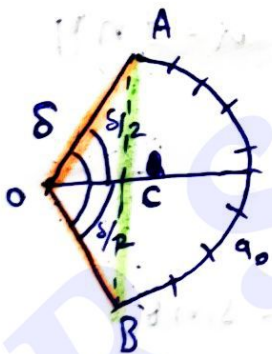
$$\sin \theta_n = \frac{BM}{AB} = \frac{\Delta}{a}$$

$$\boxed{BM = \Delta = a \sin \theta_n}$$

$$\rightarrow \phi = \frac{2\pi}{\lambda} \cdot BM = \frac{2\pi}{\lambda} \cdot a \sin \theta_n$$

$\rightarrow$ Now, Suppose wavefront AB is an area
as shown & is divided into 'p' smaller
part with same width a_0 .

$$\delta = \frac{\phi}{p} = \frac{\frac{2\pi}{\lambda} \cdot a \sin \theta_n}{p} = \frac{2\pi a \sin \theta_n}{p \lambda}$$



$$\delta = \frac{AB}{OB} = \frac{p a_0}{\lambda} \Rightarrow \lambda = \frac{p a_0}{\delta}$$

$$\delta/2 = AOC = BOC$$

$$\sin \delta/2 = \frac{AC}{OA} \quad (\triangle AOC)$$

$$AC = OA \sin \delta/2$$

and $AB = 2AC = 2OA \sin \delta/2 = 2\lambda \sin \delta/2 = \frac{2p a_0}{\delta} \sin \delta/2$

$$I = R^2 \Rightarrow I = \left[p a_0 \left(\frac{\sin \delta/2}{\delta/2} \right) \right]^2$$

resultant
amplitude

$$So \Rightarrow I = I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2$$

Where $I_0 = (pq_0)^2$, $\frac{\delta}{2} = \alpha = \frac{\pi}{\lambda} (a \sin \theta)$

Now intensity & position of central maxima:-

At P_0 , $\theta = 0^\circ$

$$\alpha = \frac{\pi}{\lambda} (a \sin 0^\circ) = 0$$

Then $\lim_{\alpha \rightarrow 0} \frac{\sin \alpha}{\alpha} = 1$

on $I = I_0 \Rightarrow I = (pq_0)^2$

max. intensity

Position of minima:-

Intensity minimum $\Rightarrow \frac{\sin \alpha}{\alpha} = 0 \Rightarrow I = 0$

$\sin \alpha = 0 \therefore \alpha = \pm n\pi$

$$\Rightarrow \delta = 2\alpha = \frac{2\pi}{\lambda} a \sin \theta$$

$$\Rightarrow \alpha = a \frac{\pi}{\lambda} \sin \theta \Rightarrow \pm n\pi = \frac{a\pi}{\lambda} \sin \theta$$

$$\Rightarrow a \sin \theta = \pm n\lambda \Rightarrow \theta = \sin^{-1} \left(\pm \frac{n\lambda}{a} \right)$$

So $\theta_1 = \sin^{-1} \frac{\lambda}{a}$, $\theta_2 = \sin^{-1} \left(\pm \frac{2\lambda}{a} \right)$ -----

Intensity & Position of Secondary Maxima:-

Since $I = I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2$

$$\frac{dI}{d\alpha} = \frac{d}{d\alpha} \left(I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2 \right)$$

$$\frac{dI}{d\alpha} = 2 I_0 \left(\frac{\sin \alpha}{\alpha} \right) \left(\frac{\alpha \cos \alpha - \sin \alpha \cdot 1}{\alpha^2} \right)$$

→ for secondary maxima $\Rightarrow \frac{dI}{d\alpha} = 0$

$$2 I_0 \left(\frac{\sin \alpha}{\alpha} \right) \left(\frac{\alpha \cos \alpha - \sin \alpha}{\alpha^2} \right) = 0$$

$\therefore I_0 \neq 0$ & $\frac{\sin \alpha}{\alpha} \neq 0 \therefore \alpha \neq 0$

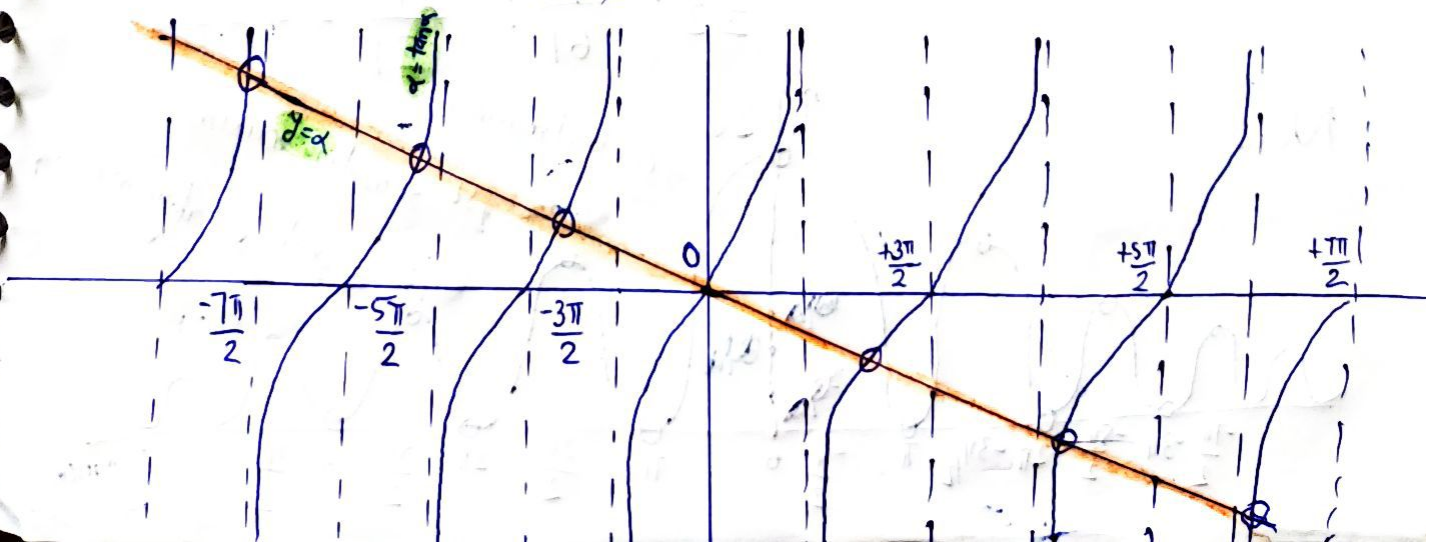
$$\alpha \cos \alpha - \sin \alpha = 0 \Rightarrow \boxed{\alpha = \tan \alpha}$$

so $\boxed{y = x}$

The intersection point of these two curves will be position of secondary maxima.
(odd multiple)

$$\alpha = 0, \pm \frac{3\pi}{2}, \pm \frac{5\pi}{2}, \pm \frac{7\pi}{2}, \dots \pm \frac{(2n+1)\pi}{2}$$

since $I = I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2$



1st secondary maxima

$$I = I_0 \left(\frac{\sin 3\pi/2}{3\pi/2} \right)^2 = I = I_0 \left(\frac{-1}{3\pi/2} \right)^2 = I_0 \frac{4}{9\pi^2}$$

$$I_1 = \frac{I_0}{22} \quad \checkmark$$

2nd secondary maxima

$$I = I_0 \left(\frac{\sin 5\pi/2}{5\pi/2} \right)^2 = \frac{I_0}{61} \quad \checkmark$$

So we can say:—

$$I_0 = \frac{4I_0}{9\pi^2} : \frac{4I_0}{25\pi^2} : \frac{4I_0}{49\pi^2} \dots$$

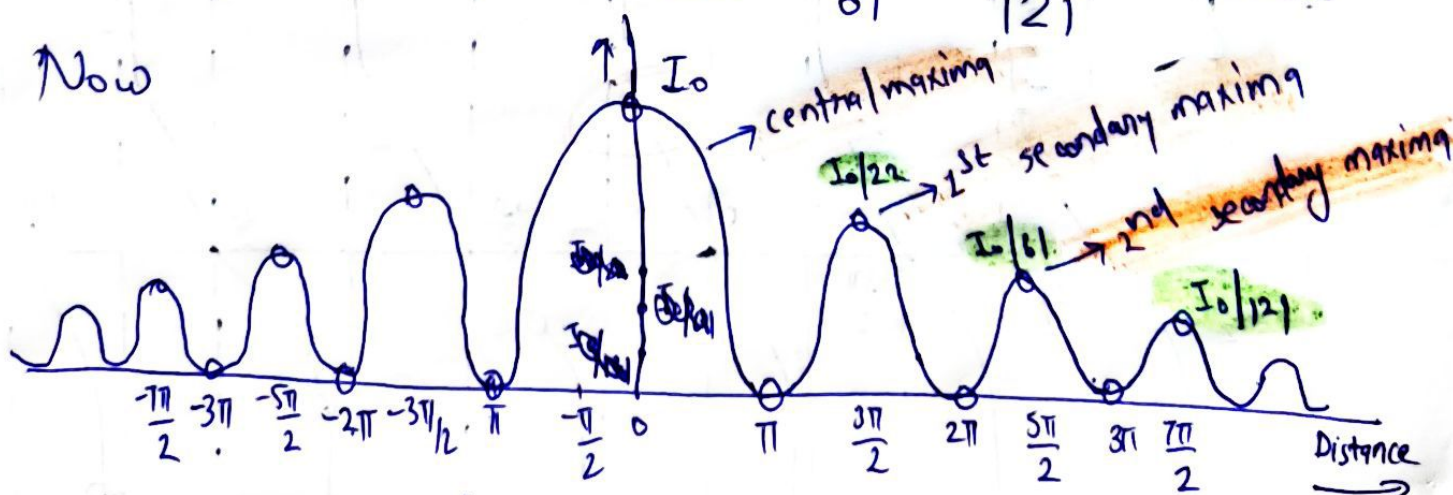
OR

$$1 : \frac{4}{9\pi^2} : \frac{4}{25\pi^2} : \frac{4}{49\pi^2} \dots$$

OR

$$1 : \frac{1}{22} : \frac{1}{61} : \frac{1}{121} \dots$$

Now



Width of principle maxima:-

The distance b/w first ~~two minima~~ is called the width of principle maxima.

If lens L_2 is very near to slit S_1 & S_2 or screen is far away from lens

$$\sin \theta = \frac{\lambda}{f} \quad \text{--- (1)}$$

$$a \sin \theta = n \lambda \quad \checkmark$$

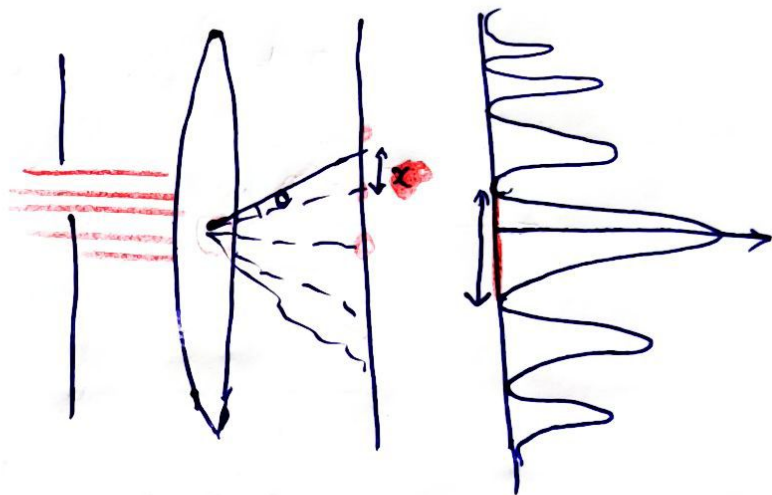
$$\sin \theta = \frac{\lambda}{a} \quad \text{--- (2)}$$

$$\frac{\lambda}{f} = \frac{\lambda}{a}$$

$$\lambda = \frac{\lambda f}{a}$$

$$W = 2\lambda = \frac{2\lambda}{a} \times f$$

$$W = \frac{2\lambda f}{a} \quad \checkmark$$



Single slit

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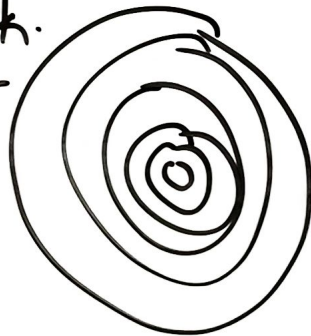
Interference

→ This phenomenon results from superposition of secondary wavelets originating from two coherent sources.

→ Interference fringes are of equal width.

→ All bright fringes are of equal intensity.

→ The intensity of all dark fringes is zero, i.e. all dark fringes are perfectly black.



Diffraction

→ This phenomenon results from superposition of secondary wavelets originating from a single coherent source.

→ Diffraction fringes are never of equal width.

→ The intensity of all bright fringes is not same.

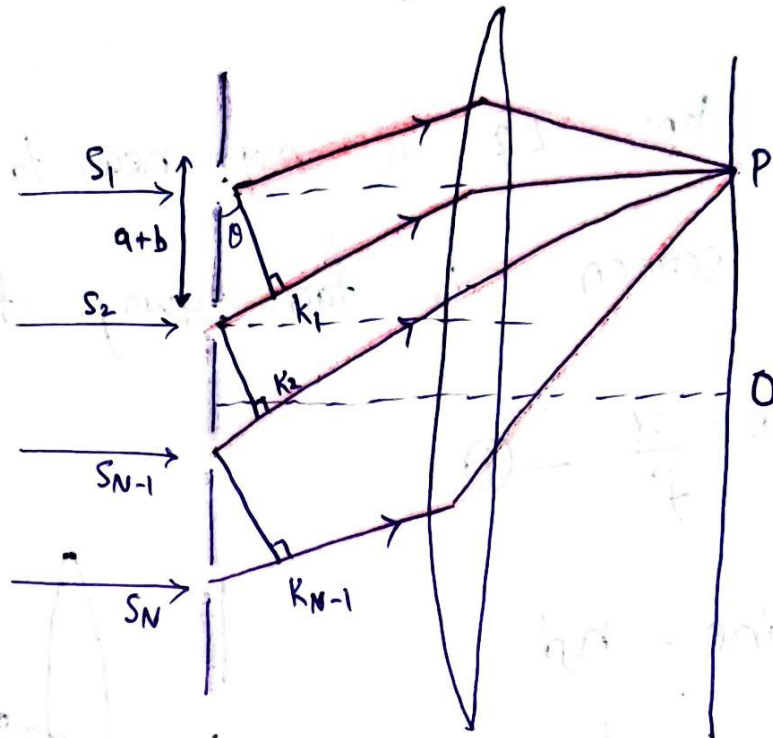
→ The intensity of all dark fringes is not zero, i.e. all dark fringes are not perfectly black.



PLANE Transmission Diffraction Grating

A diffraction grating is a set of multiple identical slits separated by distance comparable to the wavelength of light.

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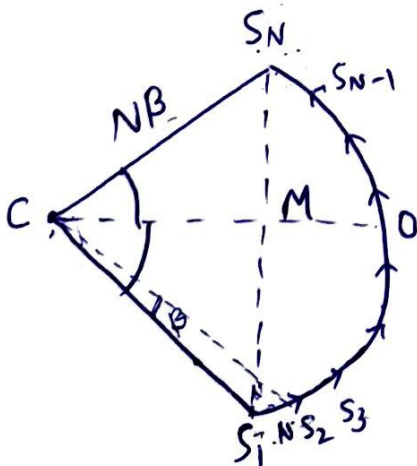
$$\Rightarrow \sin \theta = \frac{S_2 k_1}{S_1 S_2} = \frac{\Delta}{(a+b)} \Rightarrow \Delta = (a+b) \sin \theta$$

$$\alpha = \beta = \frac{\delta}{2}$$

$$\Rightarrow \delta = \frac{2\pi}{\lambda} (a+b) \sin \theta \Rightarrow \beta = \frac{\pi}{\lambda} (a+b) \sin \theta$$

$$\alpha = \frac{\pi}{\lambda} a \sin \theta$$

$$\text{let } \beta = \frac{\pi}{\lambda} (a+b) \sin \theta$$

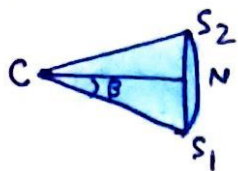


$$S_1 S_N = 2 S_1 M$$

In $\Delta CS_1 M$

$$\sin \theta = \frac{S_1 M}{CS_1}$$

$$S_1 S_N = 2 (CS_1) \sin \theta$$



$$\sin \beta = \frac{S_1 N}{CS_1} \Rightarrow S_1 N = CS_1 \sin \beta$$

$$S_1 S_2 = 2(CS_1) \sin \beta \quad (2)$$

①/②

$$\frac{S_1 S_N}{S_1 S_2} = \frac{2 CS_1 \sin N \beta}{2 CS_1 \sin \beta}$$

$$S_1 S_N = (S_1 S_2) \frac{\sin N \beta}{\sin \beta} \quad , \quad \text{we know } S_1 S_2 = p q_0 \frac{\sin \alpha}{\alpha}$$

$$R_N = S_1 S_N = p q_0 \left(\frac{\sin \alpha}{\alpha} \right) \left(\frac{\sin N \beta}{\sin \beta} \right)$$

$$I = R_N^2$$

$$I = (p q_0)^2 \left(\frac{\sin \alpha}{\alpha} \right)^2 \frac{\sin^2 N \beta}{\sin^2 \beta} \quad (\text{Intensity})$$

where $I_0 = (p q_0)^2$, $\alpha = \frac{\pi}{\lambda} a \sin \theta$, $\beta = \frac{\pi}{\lambda} (a+b) \sin \theta$

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Intensity & Position of Maxima :—

$$I = (p q_0)^2 \left(\frac{\sin \alpha}{\alpha} \right)^2 \frac{\sin^2 N \beta}{\sin^2 \beta} \quad \checkmark$$

intensity will be maximum, $\beta = \pm n \pi \quad \checkmark$

$$\sin N \beta = 0$$

$$\frac{\sin N \beta}{\sin \beta} = \frac{0}{0} \quad (\text{in determinate form}) \quad \oplus$$

$$\lim_{\beta \rightarrow \pm n \pi} \frac{\sin N \beta}{\sin \beta} = \lim_{\beta \rightarrow \pm n \pi} \frac{\frac{d}{d\beta}(\sin N \beta)}{\frac{d}{d\beta}(\sin \beta)} = \lim_{\beta \rightarrow \pm n \pi} \frac{N \cos N \beta}{\cos \beta} = \pm N$$

$$I = I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2 N^2$$

Intensity and Position of Minima:—

$$I = I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2 \left(\frac{\sin N\beta}{\sin \beta} \right)^2$$

minima $I = 0$

$$\sin N\beta = 0$$

$$N\beta = \pm n\pi$$

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

$$(a+b) \sin \theta = \pm \frac{n\lambda}{N}$$

$$\theta = \sin^{-1} \left(\frac{\pm n\lambda}{(a+b)N} \right)$$

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Intensity & Position of Secondary Maxima:—

Since • $I = I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2 \left(\frac{\sin N\beta}{\sin \beta} \right)^2$

$$\frac{dI}{d\beta} = 0$$

$$\frac{d}{d\beta} \left[I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2 \left(\frac{\sin N\beta}{\sin \beta} \right)^2 \right] = 0$$

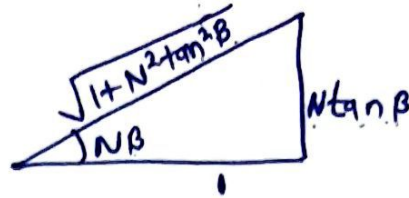
$$I_0 \times \left(\frac{\sin \alpha}{\alpha} \right)^2 \times 2 \left(\frac{\sin N\beta}{\sin \beta} \right) \left(\frac{\sin \beta \cdot \cos N\beta - \sin N\beta \cdot \cos \beta}{\sin^2 \beta} \right) = 0$$

$$I_0 \times \left(\frac{\sin \alpha}{\alpha} \right)^2 \neq 0, \quad 2 \left(\frac{\sin N\beta}{\sin \beta} \right) \neq 0$$

$$\sin \beta \cdot \cos N\beta - \sin N\beta \cdot \cos \beta = 0$$

$$\frac{\sin N\beta}{\cos N\beta} = \frac{\sin \beta}{\cos \beta}$$

$$\tan N\beta = \frac{N \tan \beta}{1}$$



$$\sin N\beta = \frac{N \tan \beta}{\sqrt{1 + N^2 \tan^2 \beta}} \quad \checkmark$$

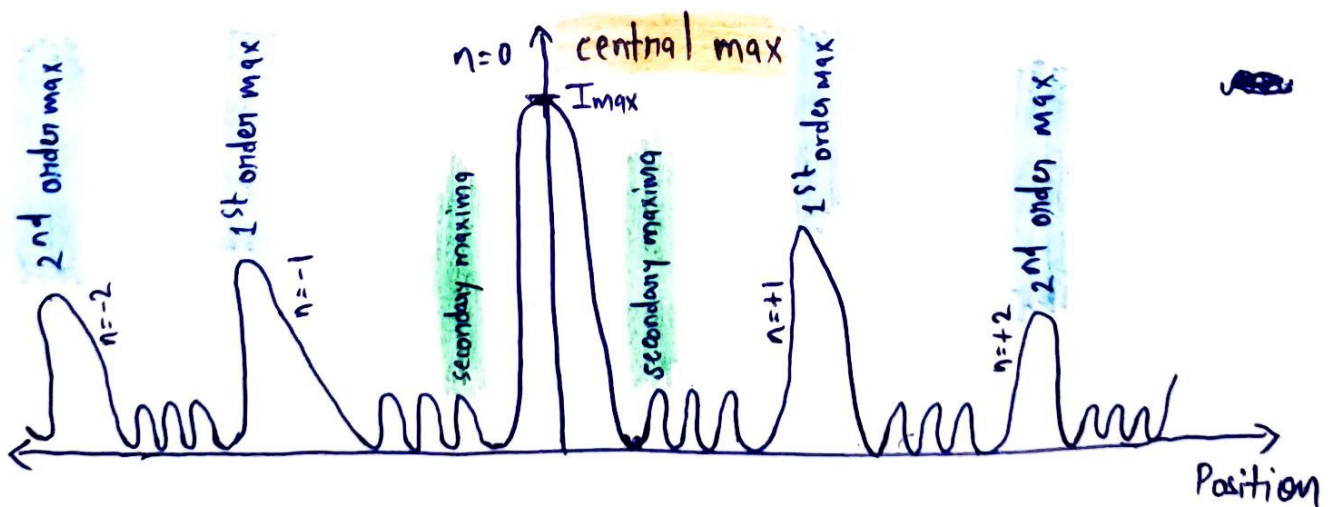
$$\frac{\sin^2 N\beta}{1 + N^2 \tan^2 \beta} = \frac{N^2 \frac{\sin^2 \beta}{\cos^2 \beta}}{1 + N^2 \tan^2 \beta} \Rightarrow \frac{\sin^2 N\beta}{\sin^2 \beta} = \frac{1}{\sin^2 \beta} \left(\frac{N^2 \frac{\sin^2 \beta}{\cos^2 \beta}}{1 + N^2 \tan^2 \beta} \right)$$

$$\Rightarrow \frac{\sin^2 N\beta}{\sin^2 \beta} = \frac{N^2}{\cos^2 \beta \left(1 + N^2 \frac{\sin^2 \beta}{\cos^2 \beta} \right)} = \frac{N^2}{\cos^2 \beta + N^2 \sin^2 \beta}$$

$$\Rightarrow \frac{\sin^2 N\beta}{\sin^2 \beta} = \frac{N^2}{(1 - \sin^2 \beta) + N^2 \sin^2 \beta}$$

$$\Rightarrow \frac{\sin^2 N\beta}{\sin^2 \beta} = \frac{N^2}{1 + (N^2 - 1) \sin^2 \beta}$$

$$I = I_0 \left(\frac{\sin \alpha}{\alpha} \right)^2 \left(\frac{N^2}{1 + (N^2 - 1) \sin^2 \beta} \right)$$



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Determination of wavelength of light using Plane Transmission Grating :-

The wavelengths of spectral lines in the visible spectrum of mercury light can be measured up to 4 digit accuracy using spectrometer and a transmission diffraction grating.


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



Here $(a+b)$ = Grating element which is equal to reciprocal of no. of lines drawn on grating per ~~cm~~ inches.

A grating have 15000 ~~inches~~ lines/inch. so

$$(a+b) = \frac{2.54}{15000} = 1.69 \times 10^{-6} \text{ m}$$

$$\lambda = \frac{(1.69 \times 10^{-6}) \sin \theta_n}{n}$$

where

θ_n = diffraction angle

n = order of spectrum

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Resolving Power :-

When two objects are very near to each other, they may appear as one and it be impossible for the naked eyes to see them separately.

So the resolving power of an optical instruments (telescope, microscope, prism, grating) is the ability of an optical instrument to distinguish (resolve) two closely spaced objects.

$$\text{Resolving Power} = \frac{1}{\text{Resolving limit}}$$

- geometrical resolution (the geometrical positions of two near by point objects is resolved)
- Spectral resolution (we resolve two near by spectral lines which are very close to each other)

Rayleigh Criterion of Resolution :-

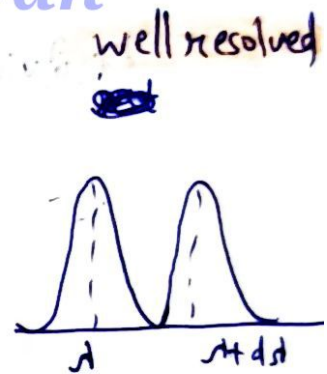
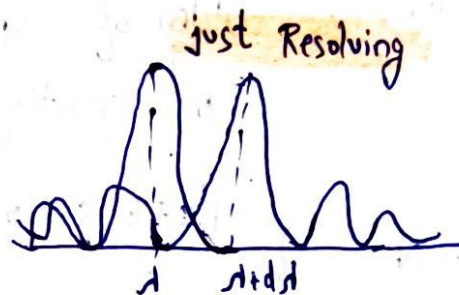
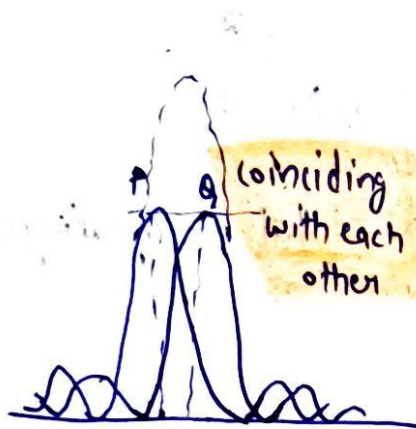
- According to Rayleigh, two near by points source images are said to be just resolved if the position of central maxima of one point source coincides with the minimum of another point source.

It is possible to resolve the two objects as long as the central maxima of two diffraction patterns do not overlap. If the two central maxima overlap the two objects look like one.

→ Resolving power of eyes is about 1° or

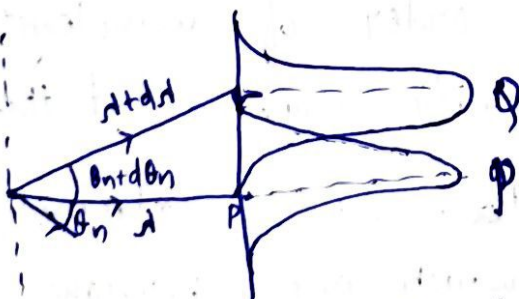
$$\theta = \frac{\lambda}{d} = 2 \times \frac{10^{-3}}{5} = 4 \times 10^{-4} \text{ rad}$$

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Resolving Power of Plane Transmission Grating :-

resolving power of grating = $\frac{\lambda}{\Delta\lambda}$ ✓



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

$$(a+b) \sin (\theta_n + \Delta\theta_n) = n(\lambda + \Delta\lambda) \quad \text{--- (2) ✓}$$

According to Rayleigh, the spectral line of λ & $\lambda + \Delta\lambda$ will resolve if nth maxima is formed & 1st minimum is formed in direction $(\theta_n + \Delta\theta_n)$.

$$N(a+b) \sin(\theta_n + d\theta_n) = n\lambda \quad \text{--- (3)}$$

for minima - $nN \pm 1$

$$N(a+b) \sin(\theta_n + d\theta_n) = (nN + 1)\lambda$$

from eqn (2)

$$nN(\lambda + d\lambda) = (nN + 1)\lambda$$

$$nN\lambda + nNd\lambda = nN\lambda + \lambda$$

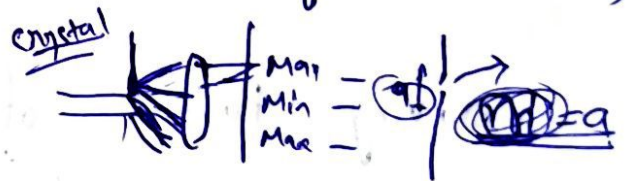
$$\frac{d\lambda}{\lambda} = \frac{1}{nN} \Rightarrow \boxed{\frac{\lambda}{d\lambda} = nN}$$

Resolving power = Order of spectrum $\times$ total no. of rulings on grating.

$$R = nN = \begin{cases} (a+b) \sin\theta = n\lambda \\ n = \frac{(a+b) \sin\theta}{\lambda} \Rightarrow \boxed{\frac{N(a+b) \sin\theta}{\lambda}} \end{cases}$$

$N(a+b) = W$ (Total width of ruled surface)

X-ray Diffraction



Diffraction of light on waves can be observed only when the slit width is order of wavelength. X-rays are also electromagnetic waves but their wavelength is quite smaller. It is extremely difficult to make slits which are narrow enough for study of X-ray Diffraction.

Since interatomic spacing in a crystal is of same order as wavelength of X-rays, a crystal may therefore be used as a three dimensional diffraction grating.

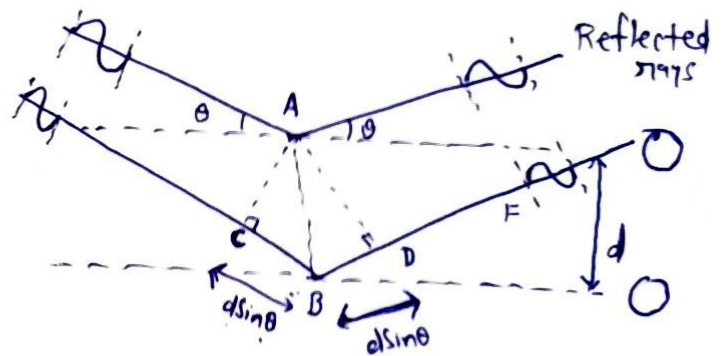
Bragg's Law for X-rays diffraction:-

Let X-rays are incident on crystal having interplaner at spacing angle θ , then path difference b/w reflected rays R_1 & R_2 is

$$\Delta = CB + BD$$

$$\Delta = 2d \sin \theta \quad \text{--- (1)}$$

$$\Delta = n\lambda \quad \text{--- (2)}$$



$$n\lambda = 2d \sin \theta$$

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→ for first order (minimum) spectrum $n=1$

$$2d \sin \theta = \lambda \Rightarrow \sin \theta = \frac{\lambda}{2d} \quad \text{But } \sin \theta \leq 1$$

$$\frac{\lambda}{2d} \leq 1 \Rightarrow \boxed{\lambda \leq 2d}$$

If $\lambda = 1 \text{ \AA}$ then X-ray with wavelength less than $2 \text{ \AA}$ are most useful for study of crystal.

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{1 \times 10^{-10}} = 19.86 \times 10^{-16} \text{ Joule}$$

so X-rays $\Rightarrow$ **12.4 keV** (10-50 keV)