module-1

DATE: / /

PAGE NO.:

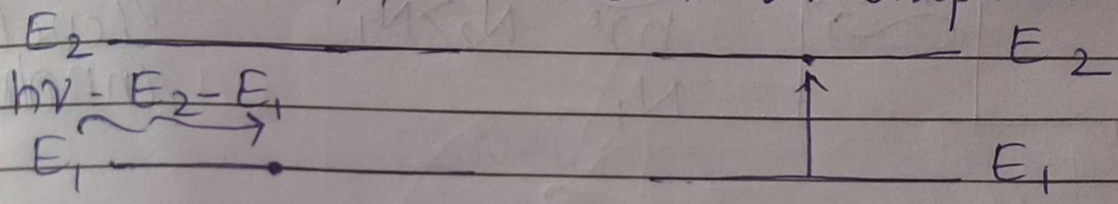
~~Laser~~ Chap 1 : Laser

* Properties of laser

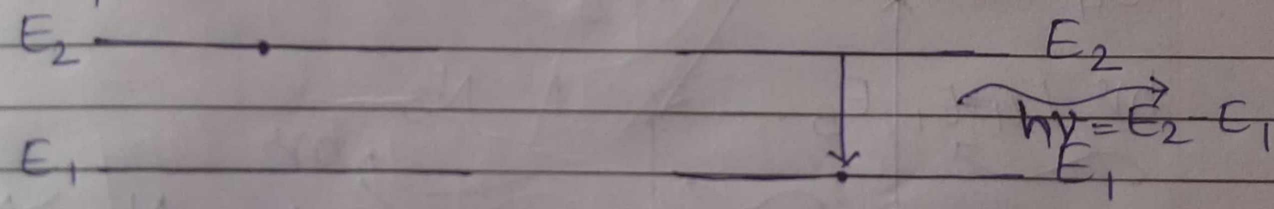
1) Unidirectional
2) Highly Intense
3) Monochromatic
4) coherent

Quantum Transitions

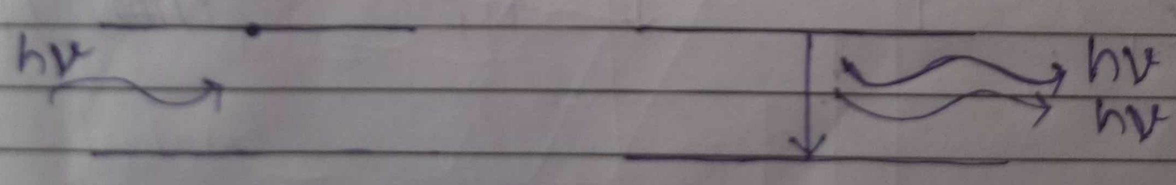
① stimulated / Induced Absorption



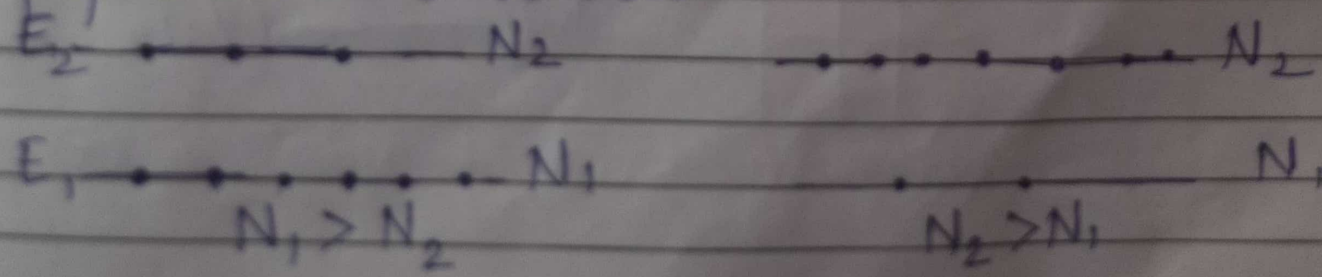
* Spontaneous Emission



* Stimulated Emission

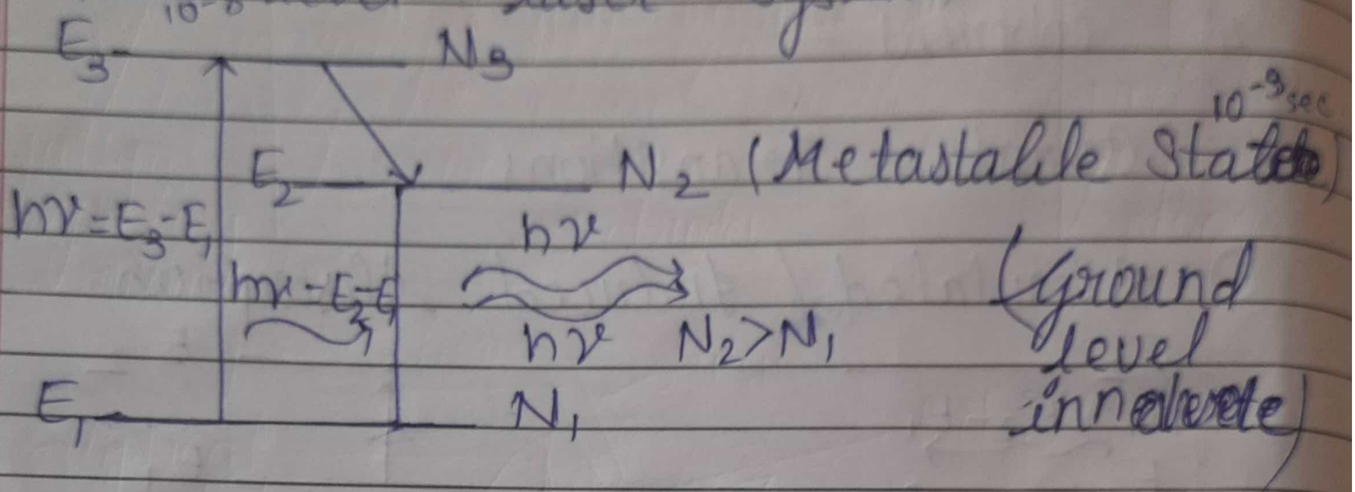


* population Inversion:

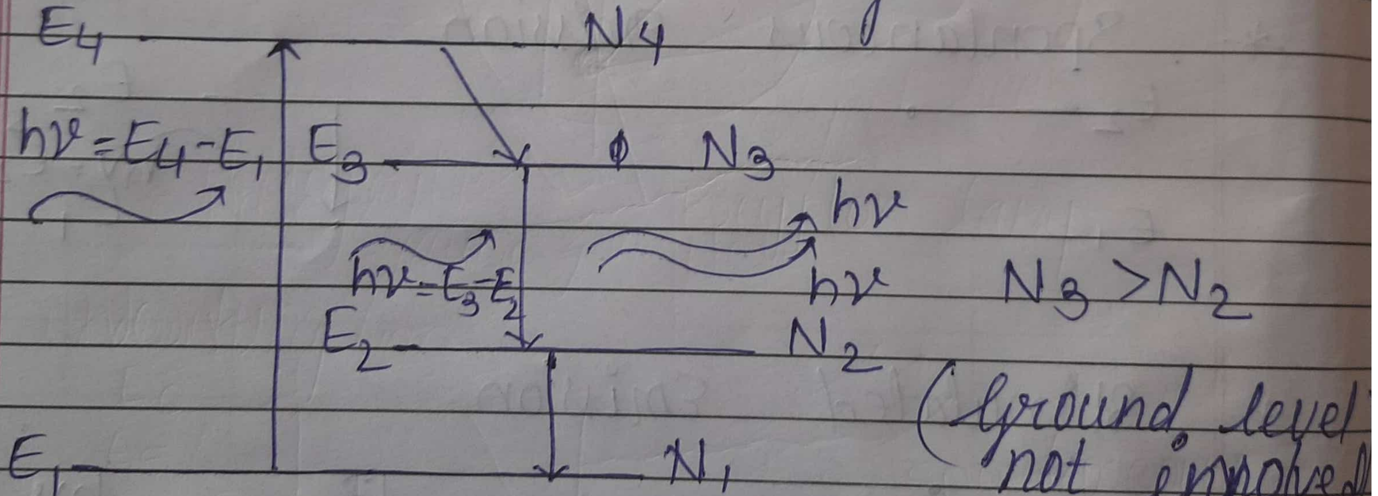


* Pumping → Optical pumping & Electrical pumping

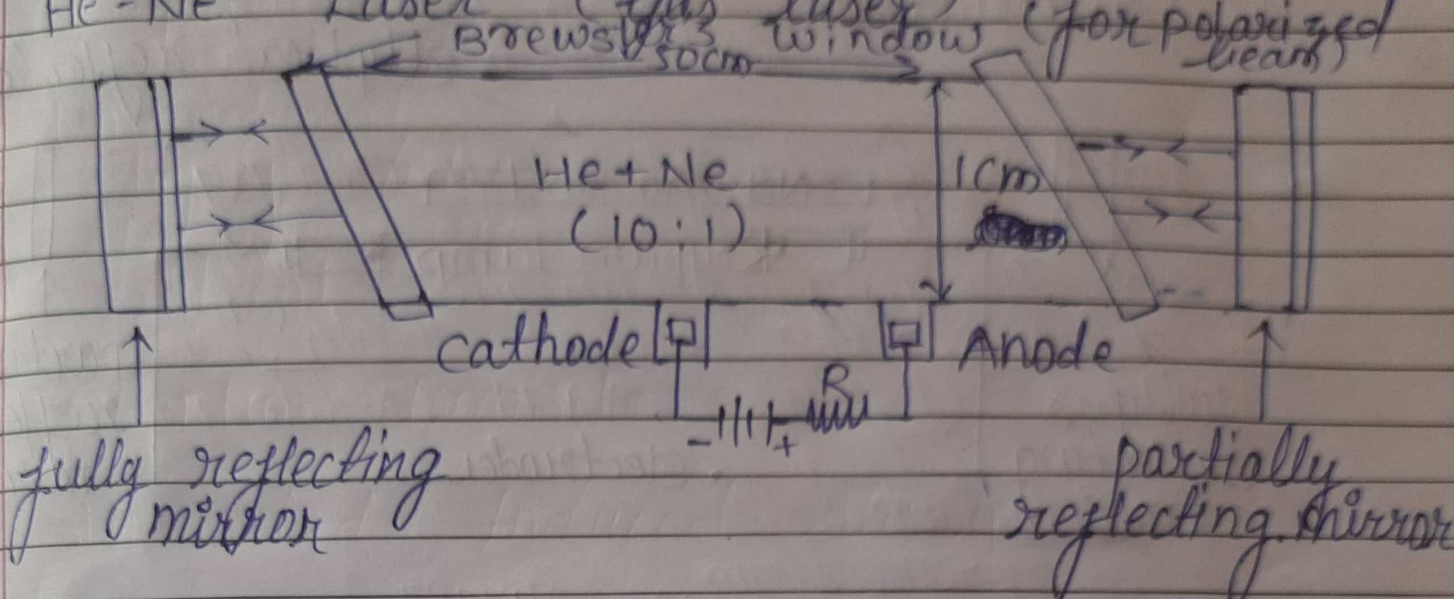
* Three level laser system

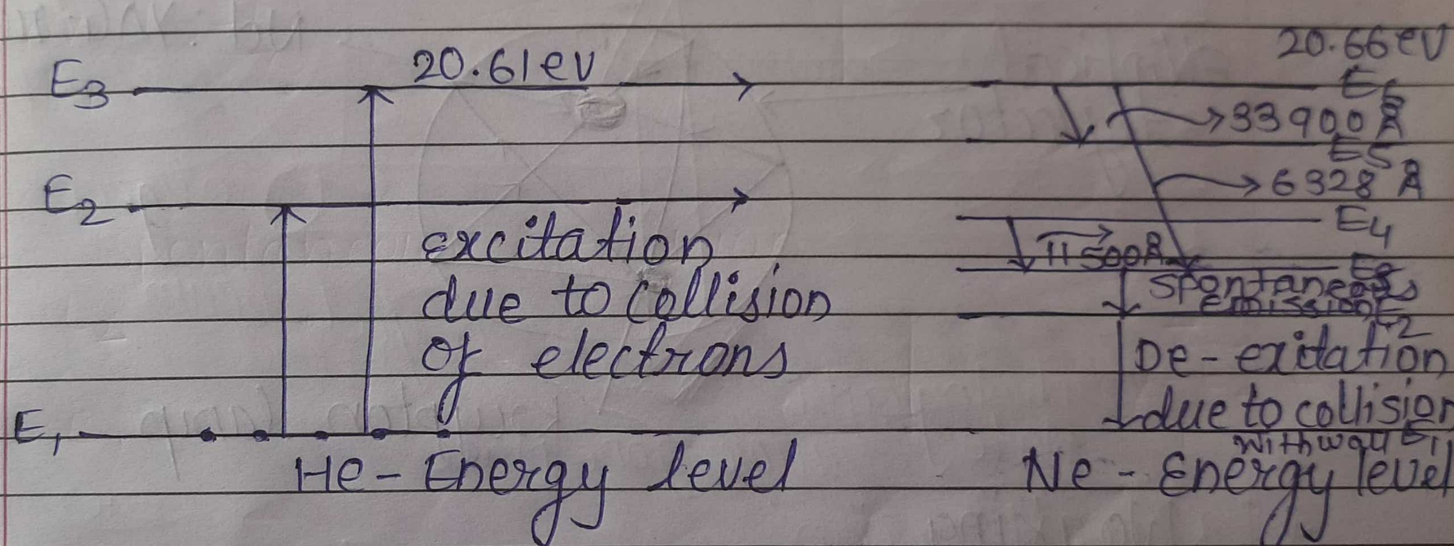


* Four level laser system



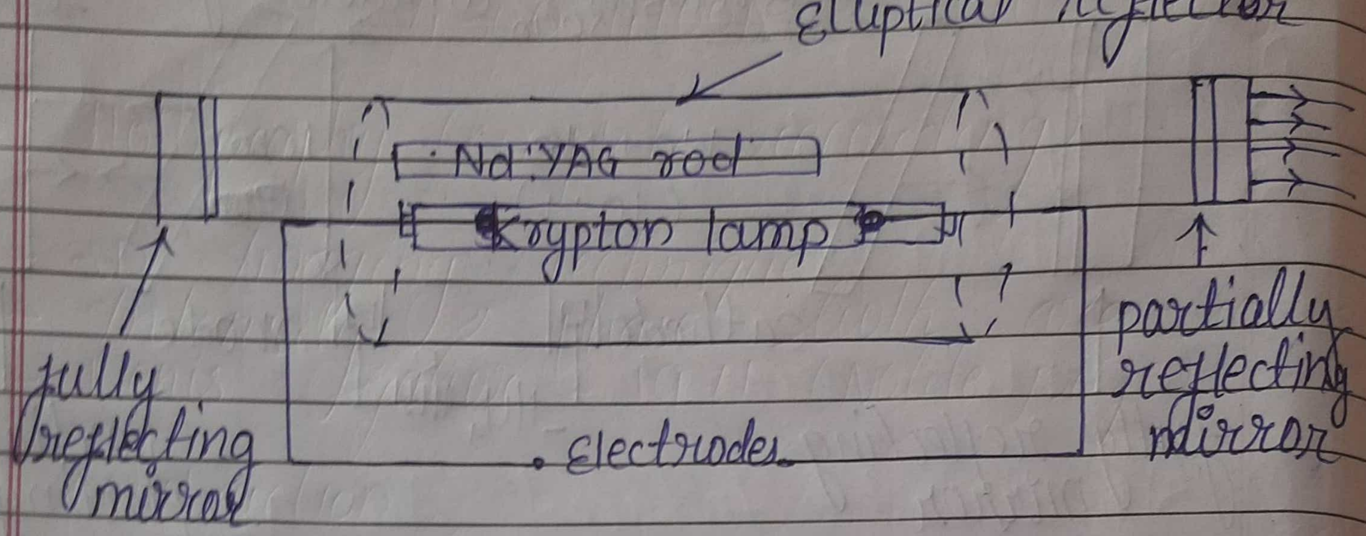
* He-Ne Laser (Gas laser)

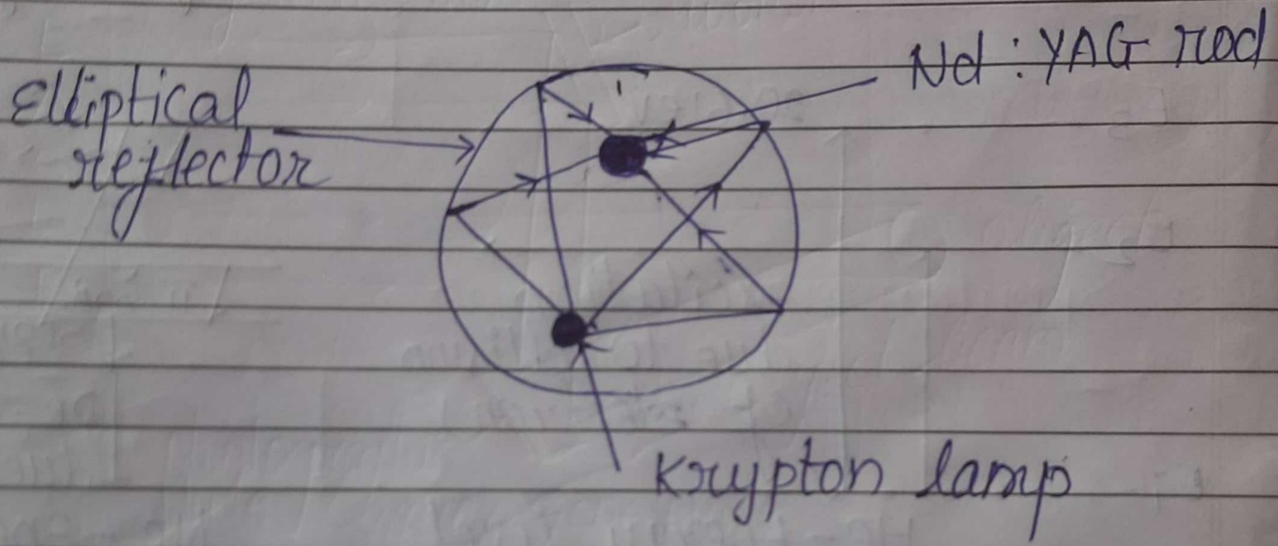




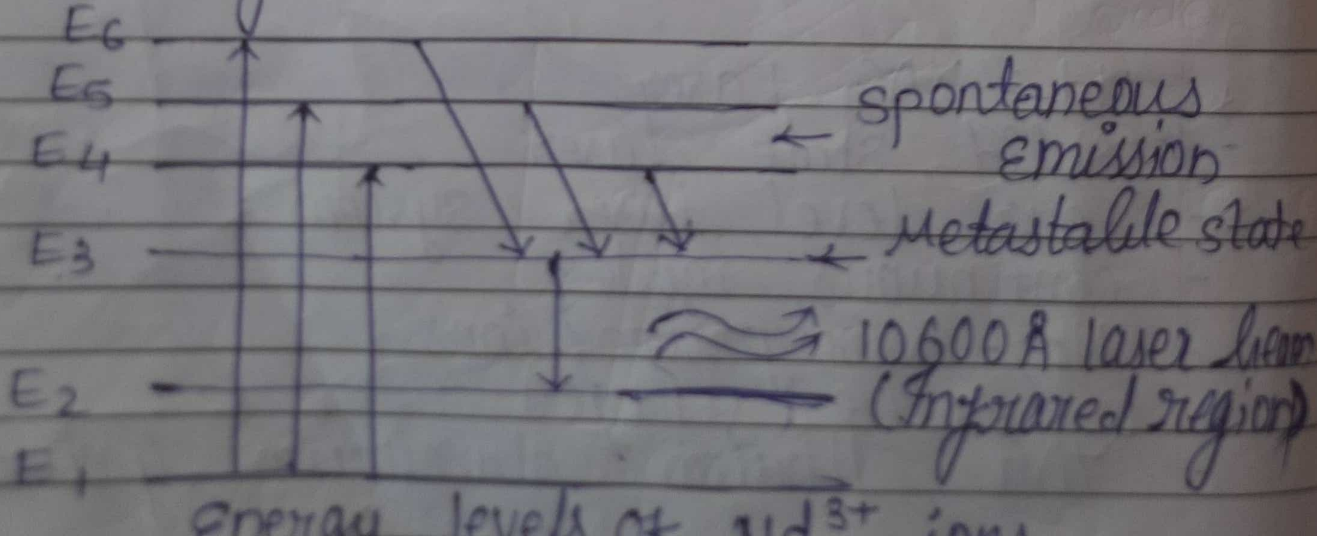
* Nd : YAG Laser
- Solid state laser
- Four level laser system
- continuous mode.
- Nd - Neodymium ions (Active centres)
- YAG - Yttrium Aluminium garnet

* Construction :



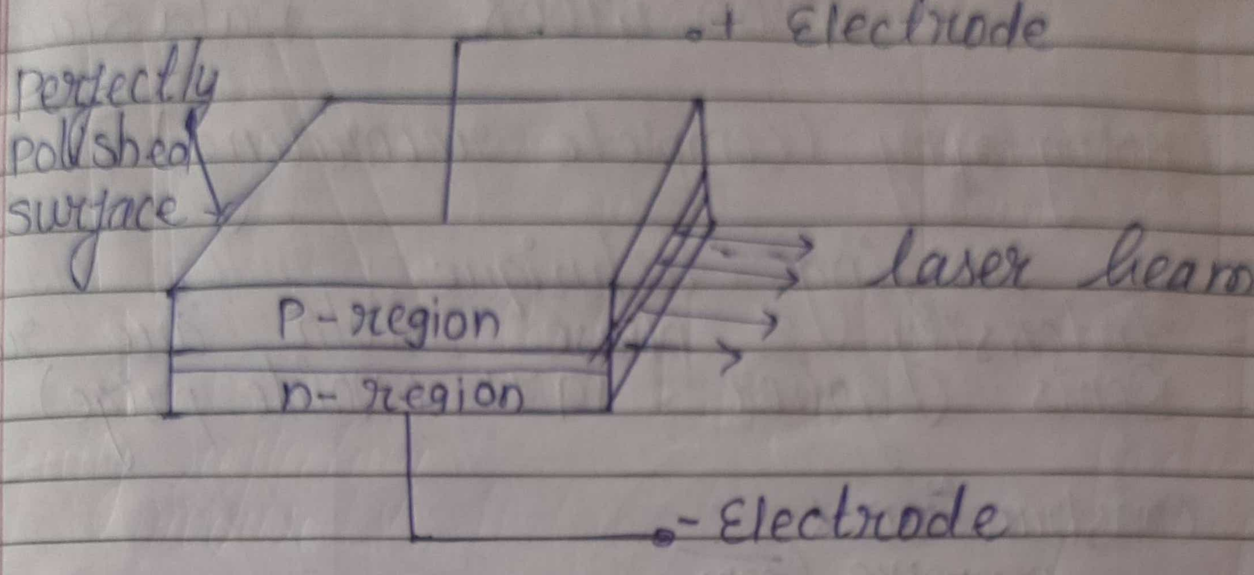


* Working :

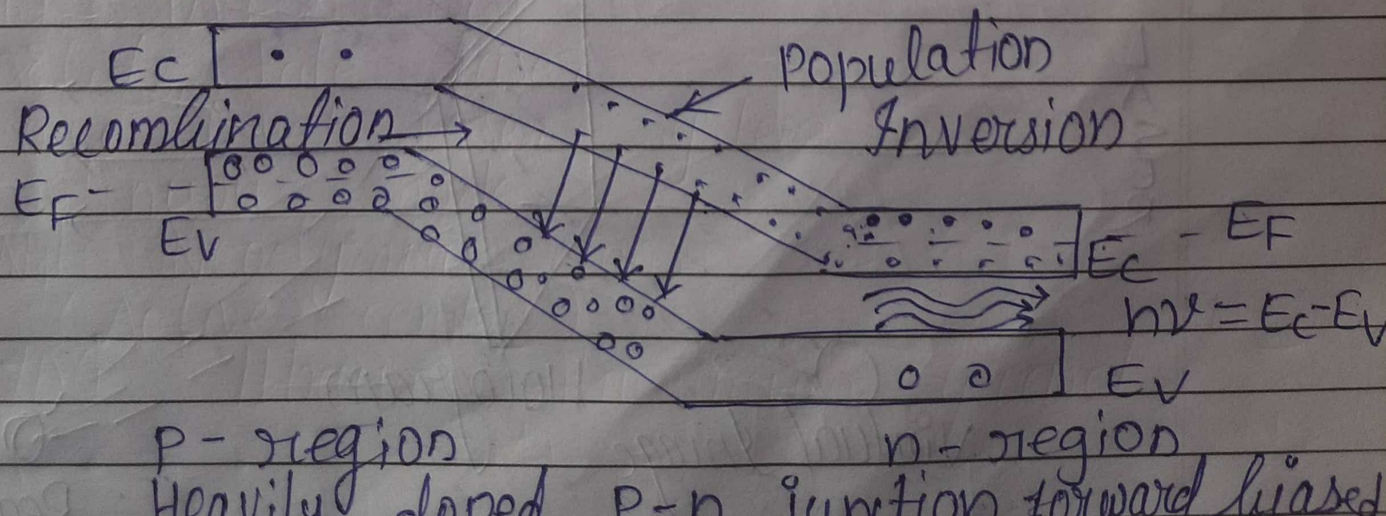


Energy levels of Nd^{3+} ions

* Semiconductor Laser :



* Energy levels of heavily doped P-n junction



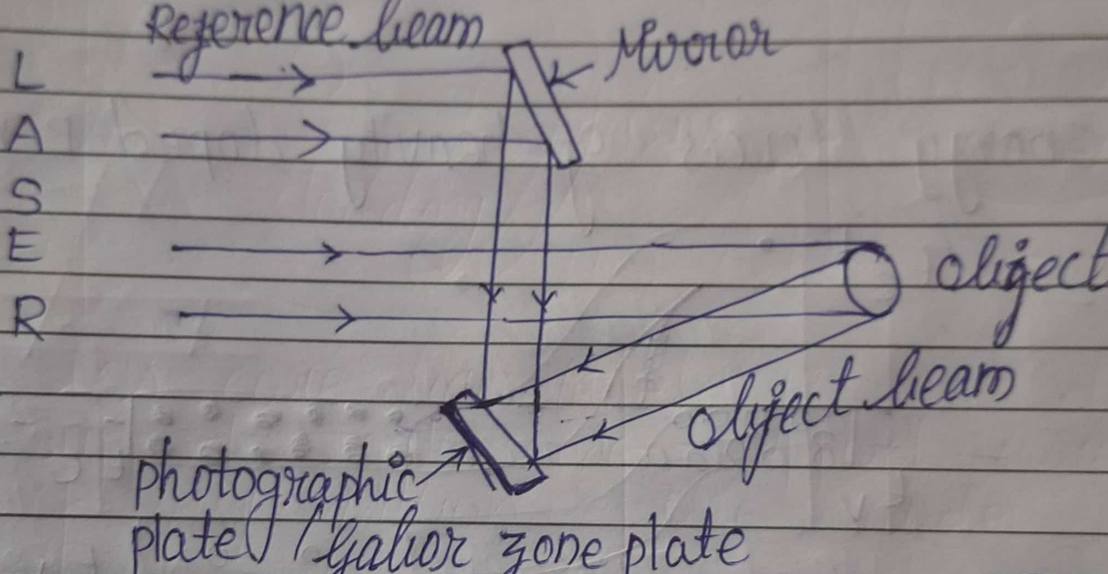
Heavily doped P-n junction forward biased

InGaN	3800, 405Å 4500, 4700Å	Blue /Violet Data storage

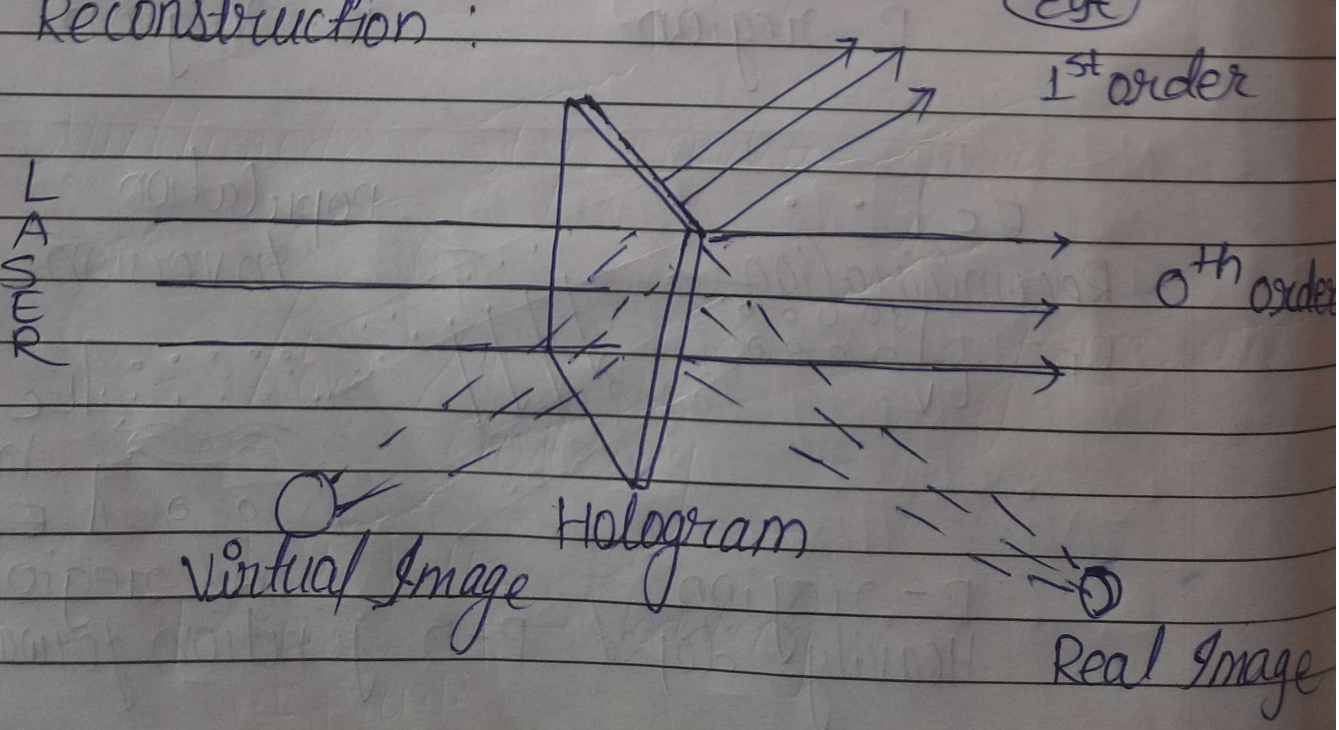
* Holography (complete recording)

- 3D Imaging technique
- Intensity & phase both are recorded
- Denis Gabor - 1971 (Noble prize)

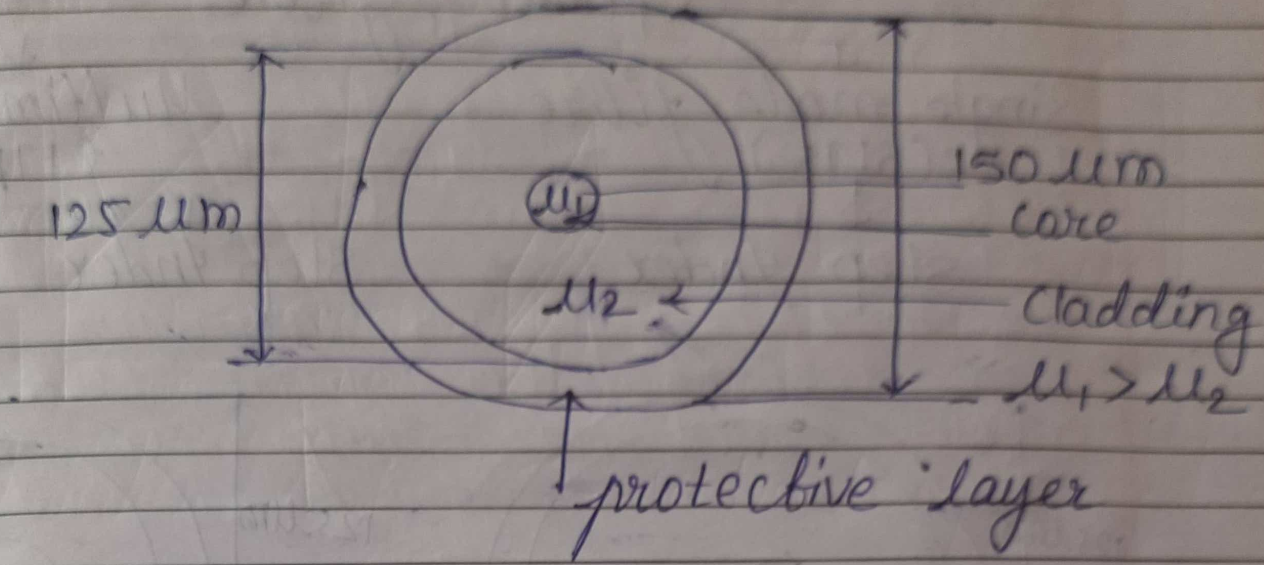
* Construction :



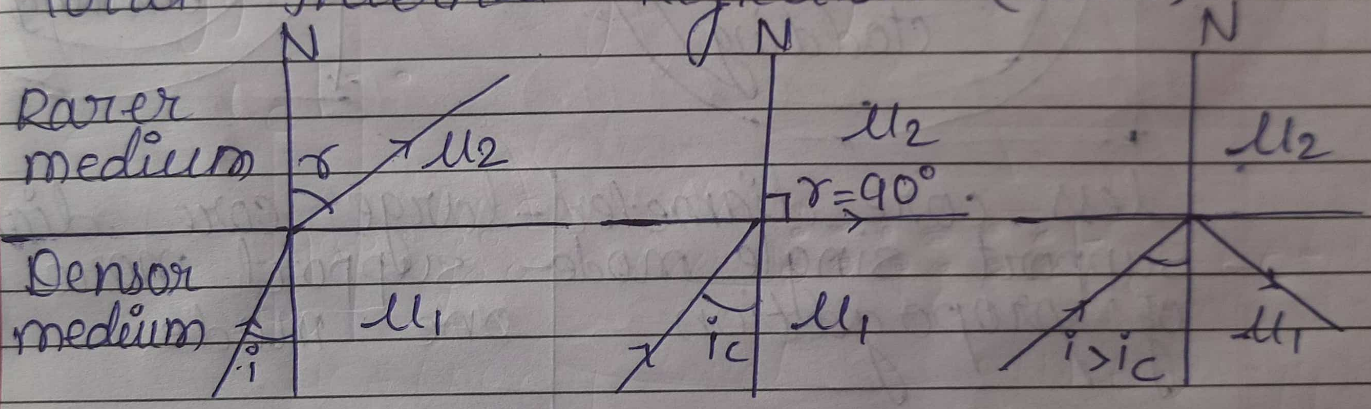
* Reconstruction :



Chap 2. Fibre Optics



* Total Internal Reflection (TIR)



$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

$i = i_c \quad r = 90°$

$$\therefore \sin i_c = \frac{\mu_2}{\mu_1}$$

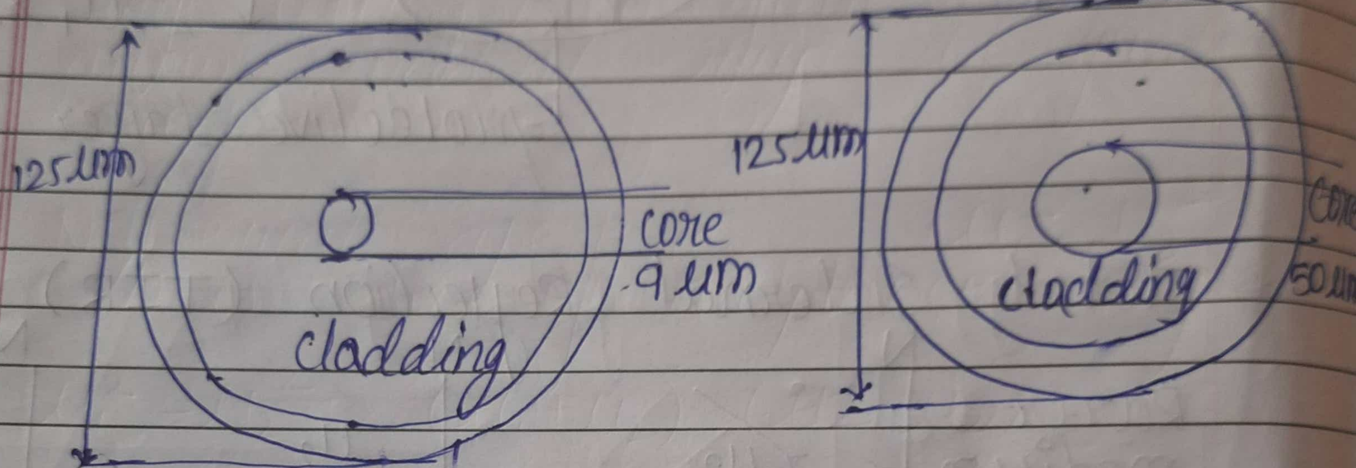
Optical fibre

Single mode fibre (SMF)

step Index

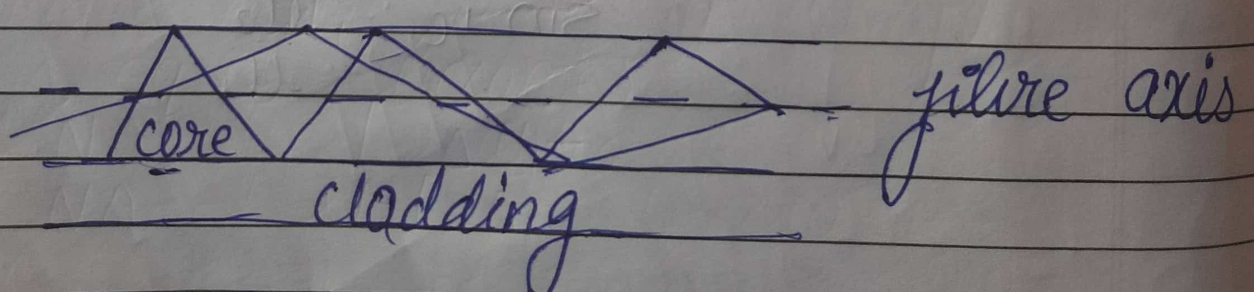
Multimode fibre (MMF)

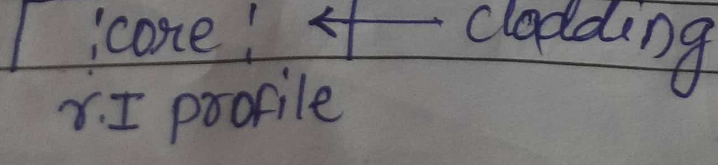
Step Index | Graded Index



Single mode fibre	Multimode fibre
- less core diameter	- large core diameter
- support single mode of propogation	- support more than one mode

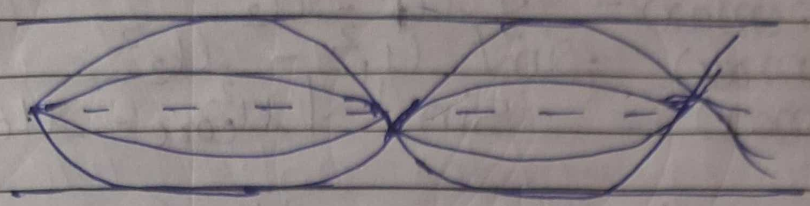
* Multimode step index fibre



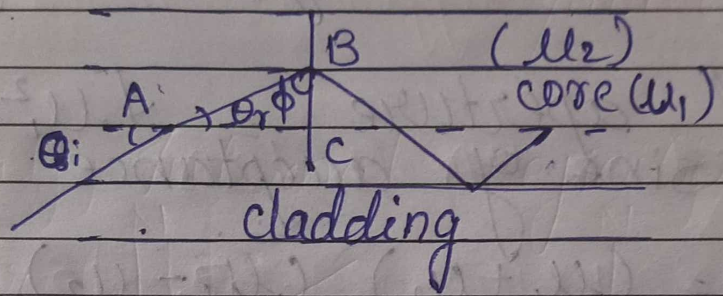


r.I profile

* Multimode graded Index fibre



* Numerical Aperture & Acceptance Angle



$$\frac{\sin \theta_i}{\sin \theta_r} = \mu_1 \quad \text{--- (1)}$$

In ΔABC

$\sin \theta_r = \sin(90 - \phi)$

$\sin \theta_r = \cos \phi$

$\therefore$ equation (1) becomes

$\sin \theta_i = \mu_1 \cos \phi$

When $\theta_i = \theta_{i(max)}$

then $\phi = \phi_c$

$\therefore \sin \theta_{i(max)} = \mu_1 \cos \phi_c$

$\because \cos \phi_c = \sqrt{1 - \sin^2 \phi_c}$

$\therefore \sin \theta_{i(max)} = \mu_1 \sqrt{1 - \sin^2 \phi_c}$

$\because \sin \phi_c = \mu_2 / \mu_1$

$$\sin \theta_{i(max)} = \mu_1 \sqrt{1 - \left(\frac{\mu_2}{\mu_1}\right)^2}$$

DATE / /
PAGE NO.

$$= \mu_1 \sqrt{\frac{\mu_1^2 - \mu_2^2}{\mu_1^2}}$$

$$\sin\theta_i(max) = \sqrt{\mu_1^2 - \mu_2^2}$$

$$\theta_i(max) = \sin^{-1}\sqrt{\mu_1^2 - \mu_2^2}$$

$$\theta_i(max) = \sin^{-1}\sqrt{\mu_{core}^2 - \mu_{clad}^2}$$

↑

Acceptance angle ⇒ Maximum angle of a ray letting the fibre core which allow incident ray be guided by core.

* Numerical aperture $= \sqrt{\mu_1^2 - \mu_2^2}$
  It is sine of acceptance angle

$$\mu_1^2 - \mu_2^2 = (\mu_1 + \mu_2)(\mu_1 - \mu_2)$$

$$= \left(\frac{\mu_1 + \mu_2}{2}\right)\left(\frac{\mu_1 - \mu_2}{\mu_1}\right) \times 2\mu_1$$

$$\because \frac{\mu_1 + \mu_2}{2} \approx \mu_1$$

$$\therefore \mu_1^2 - \mu_2^2 = \left(\frac{\mu_1 - \mu_2}{\mu_1}\right) 2\mu_1^2$$

$$\mu_1^2 - \mu_2^2 = 2\Delta\mu_1^2$$

$$\because \frac{\mu_1 - \mu_2}{\mu_1} = \Delta$$

$\therefore$ eq ② becomes

$$NA = \sqrt{2\Delta\mu_1^2}$$

$$NA = \mu_1\sqrt{2\Delta}$$

DATE: / /
PAGE NO.:

* V-number / Normalized frequency / cut off parameter

$$V = \frac{2\pi a}{\lambda} \sqrt{\mu_1^2 - \mu_2^2}$$

$$V = \frac{2\pi a}{\lambda} \cdot NA$$

$$V = \frac{\pi d}{\lambda} NA$$ d = diameter of core
a = radius of core

for step index of maximum number modes supported

$$N_m \simeq \frac{V^2}{2} \quad \& \quad N_m \simeq \frac{V^2}{4}$$

If $V < 2.405$ – only one mode
$V > 2.405$ – support many mode

1. calculate V-number of an optical fibre having numerical aperture 0.25 and core diameter 20 um. If it is operated at 1.55 um

Ans N.A. = 0.25
Diameter of core = 20 um = 20×10^{-6} m
λ = 1.55 um = 1.55×10^{-6} m
V = ?

formula: $V = \frac{\pi d}{\lambda} NA$

$$= \frac{\pi \times 20 \times 10^{-6}}{1.55 \times 10^{-6}} \times 0.25$$

$$= 10.13$$

DATE / /

PAGE NO.

2. A step Index filre is made with a core of refractive Index 1.52, A diameter of 29 μm and fractional difference Index of 0.0007. It is operated at wavelength of 1.3 μm. find the V-number and Number of modes not filre will support

Ans: $n_1 = 1.52$

$d = 29\ \mu m = 29 \times 10^{-6} m$

$\lambda = 1.3\ \mu m = 1.3 \times 10^{-6} m$

(Δ) fractional difference Index $= 0.0007$

$V = ?$

$N_m = ?$

$$V = \frac{\pi d}{\lambda} \times \cancel{NA}\ n_1 \sqrt{2\Delta}$$

$$= \frac{\pi \times 29 \times 10^{-6}}{1.3 \times 10^{-6}} \times 1.52 \times \sqrt{2 \times 0.0007}$$

$$= 3.98$$

$$N_m = \frac{V^2}{2} = \frac{3.98^2}{2} = 7.94 \simeq 8 \text{ modes}$$

3. The core diameter of a multimode step index filre is 50 μm. The numerical aperture is 0.25 calculate ① Normalized frequency ② Number of guided modes at an operating wavelength of $\lambda = 0.75\ \mu m$

Ans: $d = 50\ \mu m = 50 \times 10^{-6} m$

$\lambda = 0.75\ \mu m = 0.75 \times 10^{-6} m$

$NA = 0.25$

$V = ?$, $N_m =$

$$V = \frac{\pi d}{\lambda} \times NA$$

DATE: / /
PAGE NO.

$$= \frac{\pi \times 50\times10^{-6} \times 0.25}{0.75\times10^{-6}}$$

$$V = 52.35$$

$$NM = \frac{V^2}{2} = \frac{52.35^2}{2} = 1370.26$$

4. What is Numerical aperture and acceptance angle of optical fibre with core refractive index (1.55 and cladding 1.5. Also find fractional Index change.

Ans: $\mu_1 = 1.55$

$\mu_2 = 1.5$

$$NA = \sqrt{\mu_1^2 - \mu_2^2}$$

$$= \sqrt{(1.55)^2 - (1.5)^2}$$

$$= 0.39$$

$$\theta_{i(max)} = \sin^{-1} NA$$

$$= \sin^{-1}(0.39)$$

$$= 22.95$$

$$NA = \mu_1 \sqrt{2\Delta}$$

$$\frac{NA}{\mu_1} = \sqrt{2\Delta}$$

$$\left(\frac{NA}{\mu_1}\right)^2 = 2\Delta$$

$$\Delta = \left(\frac{NA}{\mu_1}\right)^2 / 2$$

$$= \left(\frac{0.39}{1.55}\right)^2 / 2$$

$$= 0.0316$$

DATE / /
PAGE NO.

1. An optical glass fibre of refractive index ~~are~~ 1.5 is to be ~~glo~~ clad with another glass to ensure internal reflection that will contain light travelling within 5° of fibre axis what minimum index of refraction is allowed for cladding?

Ans: $\mu_1 = 1.5$
$\mu_2 = ?$
$\theta = 5^\circ$

$\theta_{i(max)} = \sin^{-1}\sqrt{\mu_1^2 - \mu_2^2}$
$\sin\theta_{i(max)} = \sqrt{\mu_1^2 - \mu_2^2}$
$\sin 5 = \sqrt{(1.5)^2 - \mu_2^2}$
~~sin 5~~
$7.596 \times 10^{-3} = 2.25 - \mu_2^2$
$\mu_2^2 = 2.25 - (7.596 \times 10^{-3})$
$\mu_2^2 = 2.2424$
$\mu_2 = \sqrt{2.2424}$
$\mu_2 = 1.497$

2. Compute the numerical aperature of the optical fibre having a $\mu_1 = 1.5$ critical angle $\mu_2 = 1.45$

Ans: $\mu_1 = 1.5$
$\mu_2 = 1.45$

Numerical Aperature $= \sqrt{\mu_1^2 - \mu_2^2}$
$= \sqrt{(1.5)^2 - (1.45)^2}$
$= \sqrt{0.1475}$

$= 0.3840$

$$i_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$

$$= \sin^{-1}\left(\frac{1.45}{1.5}\right)$$

$$i_c = 75.16^\circ$$

$$\theta_{i(max)} = \sin^{-1}(NA)$$

$$= \sin^{-1}(0.3840)$$

$$= 22.58^\circ$$

3. The glass clad filire is made with core glass of refractive index 1.5 & cladding is doped to give fractional index difference of 0.005 find a) cladding index b) critical internal reflection angle c) The external critical acceptance angle d) Numerical aperture.

Ans: $\mu_1 = 1.5$

$\Delta = 0.005$

a) $$\Delta = \frac{\mu_1 - \mu_2}{\mu_1}$$

$$0.005 = \frac{1.5 - \mu_2}{1.5}$$

$$0.005 \times 1.5 = 1.5 - \mu_2$$

$$7.5 \times 10^{-4} = 1.5 - \mu_2$$

$$\mu_2 = 1.5 - (7.5 \times 10^{-4})$$

$$\mu_2 = 1.49925$$

b) $i_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$

$= \sin^{-1}\left(\frac{1.49925}{1.5}\right)$

$= \cancel{87.907}^{\circ}\ 88.188$

c) $\theta_{i(max)} = \sin^{-1}\sqrt{\mu_1^2 - \mu_2^2}$

$= \sin^{-1}\sqrt{(1.5)^2 - (1.4992)^2}$

$= \cancel{3}.\sin^{-1}\cancel{\sqrt{0.0547}}\ \cancel{0.8664}$

$= \cancel{3.13564}\ \cancel{60.04}$

$= 2.7168$

d) $NA = \sqrt{\mu_1^2 - \mu_2^2}$

$= \sqrt{1.5^2 - 1.49925^2}$

$= \cancel{0.0547}\ \cancel{0.8664}\ 0.0474$

* v - number

$V = \frac{2\pi a}{\lambda}\sqrt{\mu_1^2 - \mu_2^2}$ — a: radius

or

$V = \frac{\pi d}{\lambda} \cdot NA$ — d: diameter

$N_m \simeq \frac{V^2}{2}$ Number of mode

$V < 2.405$ one mode

$V > 2.405$ many mode.

DATE: / /
PAGE NO.:

4. Calculate V- number for an optical fibre having numerical aperture 0.25 & core diameter 20 um if it is operated at 1.55 um

Ans: NA = 0.25

$d = 20\ \mu m = 20 \times 10^{-6} m$

$\lambda = 1.55\ \mu m = 1.55 \times 10^{-6} m$

$$V = \frac{\pi d}{\lambda} NA$$

$$= \frac{\pi \times 20 \times 10^{-6}}{1.55 \times 10^{-6}} \times 0.25$$

$$= 10.13416$$

5. Compute the cutoff parameter and number of modes supported by a fibre $\mu_1 = 1.53$ & $\mu_2 = 1.5$, core radius 50 um & operating wavelength 1 um.

Ans: $\mu_1 = 1.53$

$\mu_2 = 1.5$

$a = 50\ \mu m = 50 \times 10^{-6} m$

$\lambda = 1\ \mu m = 1 \times 10^{-6} m$

$$V = \frac{2\pi a}{\lambda}$$

$$= \frac{2 \times \pi \times 50 \times 10^{-6}}{1 \times 10^{-6}} \cdot \sqrt{(1.53)^2 - (1.5)^2}$$

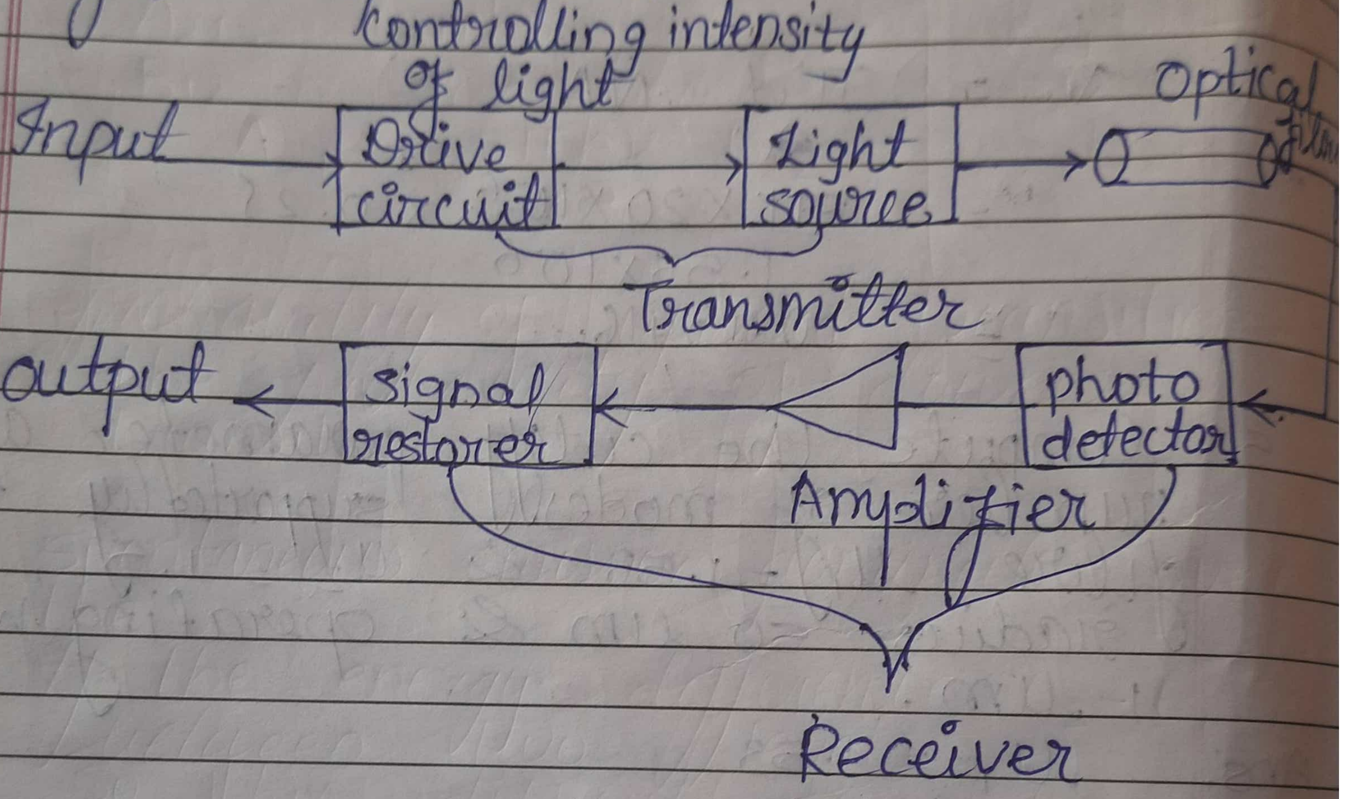
$$= 94.717$$

$$N_m = \frac{V^2}{2}$$

$$= \frac{(94.72)^2}{2}$$

$$= \cancel{47.36}\ 4485.99$$

* fibre optic communication



* Einstein's coefficient

Under thermal equilibrium

No. of atoms absorbing photons per second per unit volume = Number of atoms emitting photons per second per unit volume

DATE: / /
PAGE NO.:

$$B_{12} Q N_1 = A_{21} N_2 + B_{21} Q N_2$$

B_{12}, B_{21} & A_{21} are Einstein's coefficients
Q - Energy density of photon
N_1 & N_2 are no. of atoms in ground state & in excited state

$$B_{12} Q N_1 - B_{21} Q N_2 = A_{21} N_2$$
$$Q \left[B_{12} N_1 - B_{21} N_2 \right] = A_{21} N_2$$

$$Q = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

Dividing numerater & denominater by $B_{12} N_2$

$$Q = \frac{\frac{A_{21}}{B_{12}}}{\frac{N_1}{N_2} - \frac{B_{21}}{B_{12}}} \quad \text{--- (1)}$$

from Boltzman equation $N = e^{-E/KT}$

$$\therefore N_1 = e^{-E_1/KT}, \quad N_2 = e^{-E_2/KT}$$

$$\therefore \frac{N_1}{N_2} = \frac{e^{-E_1/KT}}{e^{-E_2/KT}} = e^{(E_2 - E_1)/KT}$$

$$= e^{h\nu/KT}$$

Substitude above equation in eq (1)

$$Q = \frac{A_{21}}{B_{12}} \left[\frac{1}{e^{h\nu/KT} - \frac{B_{21}}{B_{12}}} \right] \quad \text{--- (2)}$$

Using Planck's energy distribution formula

$$Q = \frac{8\pi h\nu^3}{c^3}\left[\frac{1}{e^{h\nu/kT}-1}\right] \quad — (3)$$

comparing equation (2) & (3) we get

$$\frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3}{c^3}$$

$$\therefore A_{21} = \frac{8\pi h\nu^3}{c^3} B_{12}$$

$$\frac{B_{21}}{B_{12}} = 1$$

$$\therefore B_{21} = B_{12}$$

probability of upward transition = the probability of downward transition

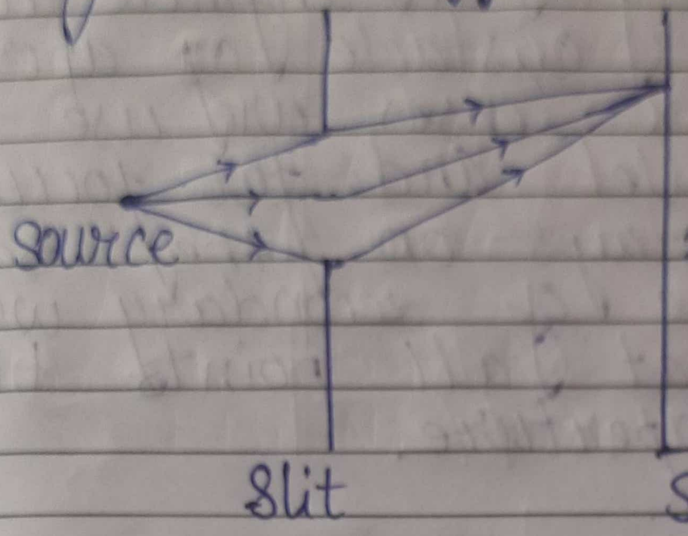
spontaneous emission dominate over the

If the energy difference $E_2 - E_1 = h\nu$ between two levels.

So this difficult to achieve action in higher frequency range and low wavelength.

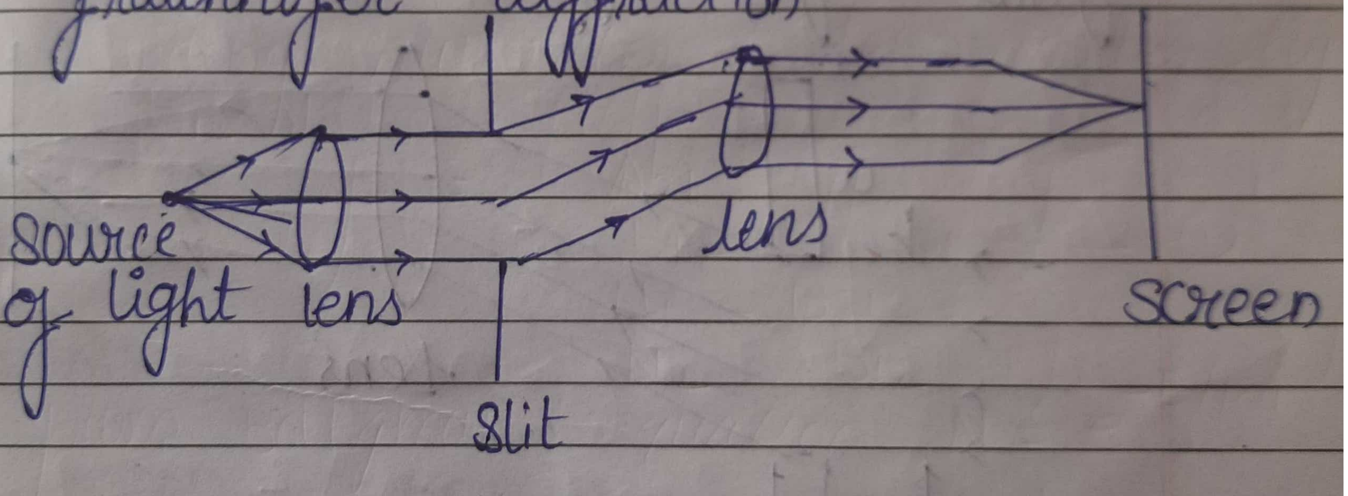
Diffraction

* fresnel diffraction



1. Both source of light are finite distance from the obstacle or aperture
2. lenses are not use to make lights rays parallel or conversion
3. wavefront incident is either spherical or cylindrical

* fraunhofer diffraction

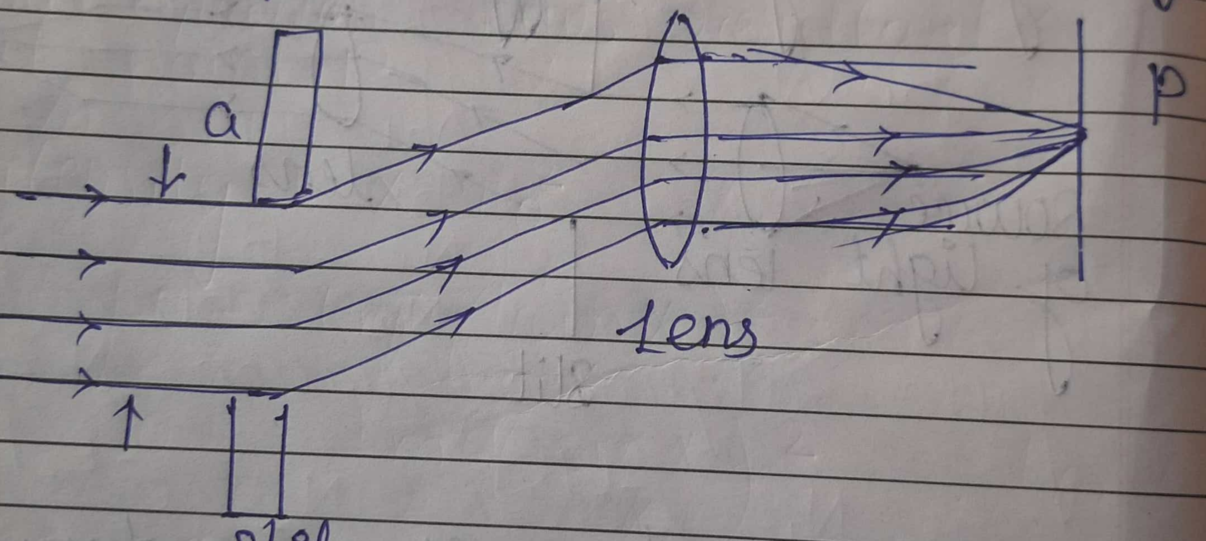


4. The phase of secondary wavelength are not same and all points in the plane of aperture.

* Fraunhofer diffraction

1. Both source of light and screen are effectively at infinite distance from the obstacle or aperture.
2. Two convex lenses are use to make rays parallel and for focusing diffracted rays on the screen.
3. The phase of secondary wavelets is same at all points the phase of the aperture.

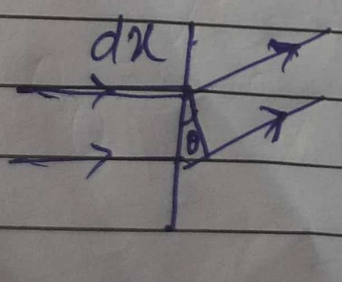
* Fraunhofer diffraction due to single slit



Slit

a = width of slit

$a = dx + dx + dx + \ldots\ldots n$ times

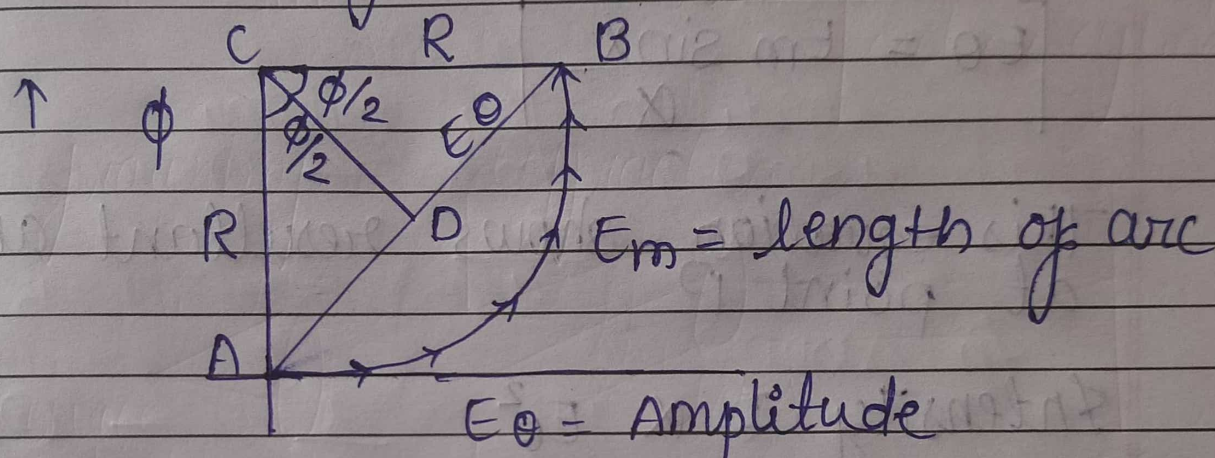


path difference = $dx \sin\theta$
path difference = $a \sin\theta$ — ①

phase difference = $d\phi = \frac{2\pi}{\lambda} . dx \sin\theta$

$\therefore \phi = \frac{2\pi}{\lambda} a \sin\theta$ — ②

phasor diagram



$AD = BD = \frac{E_\theta}{2}$

$\angle ACD = \angle BCD$
$= \frac{\phi}{2} = \frac{\pi}{\cancel{2}} a \sin\theta = \alpha$

In ΔADC

$\sin\frac{\phi}{2} = \frac{AD}{R}$

$AD = R \sin\frac{\phi}{2}$

$AD = \frac{E_\theta}{2} = R \sin\frac{\phi}{2}$

$\therefore \boxed{E_\theta = 2R \sin\frac{\phi}{2}}$ — ③

$\because$ Angle $= \frac{\text{Arc}}{\text{radius}}$

$$\phi = \frac{Em}{R}, \quad R = \frac{Em}{\phi}$$

equation (3) becomes

$$E_\theta = 2\frac{Em}{\phi} \sin\frac{\phi}{2}$$

$$\boxed{E_\theta = Em \frac{\sin \phi/2}{\phi/2}} \quad \text{— (4)}$$

or

$$\boxed{E_\theta = Em \frac{\sin\alpha}{\alpha}}$$

This equation shows resultant amplitude at point P

Intensity $I \propto E_\theta^2$

$$I_\theta = Em^2 \left(\frac{\sin\alpha}{\alpha}\right)^2$$

$$I_\theta = I_m \left(\frac{\sin\alpha}{\alpha}\right)^2 \quad \because I_m \propto Em^2$$

Em = maximum possible value of amplitude

* Condition for central maxima

$$E_\theta = Em$$

$$\alpha = 0, \quad \alpha = \frac{\pi}{\lambda} a \sin\theta = 0$$

$$\sin\theta = 0$$

$$\theta = 0$$

DATE: / /
PAGE NO.:

* condition for central minima

$$E_\theta = E_m \frac{\sin\alpha}{\alpha} = 0$$

$\sin\alpha = 0$ but $\alpha \neq 0$

$\alpha = \pi, 2\pi, 3\pi$

$\alpha = \pm m\pi$

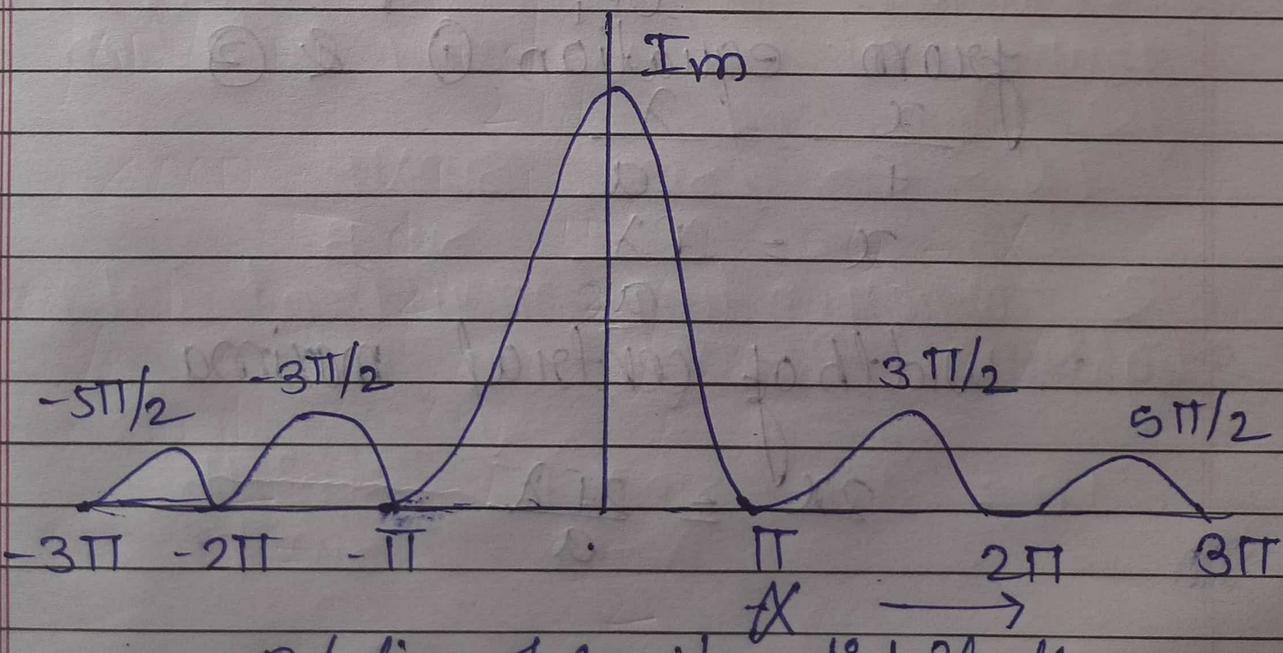
$\frac{\cancel{\pi}}{\lambda} a \sin\theta = \pm m \cancel{\pi}$

$$a \sin\theta = \pm m\lambda$$

$m = 1, 2, 3$

* for secondary maxima

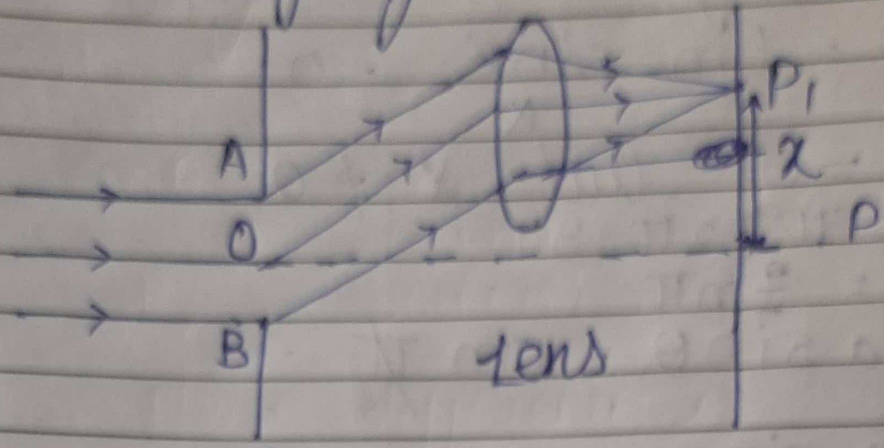
$$\alpha = \pm\left(m + \frac{1}{2}\right)\pi$$



Relative Intensity distribution in single slit diffraction

DATE / /
PAGE NO.

* Position of first minima



condition for minima

$$a\sin\theta = m\lambda \quad — ①$$

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

In ΔOPP_1

$$\sin\theta = \frac{PP_1}{OP_1} = \frac{x}{f} \quad — ②$$

from equation ① & ②

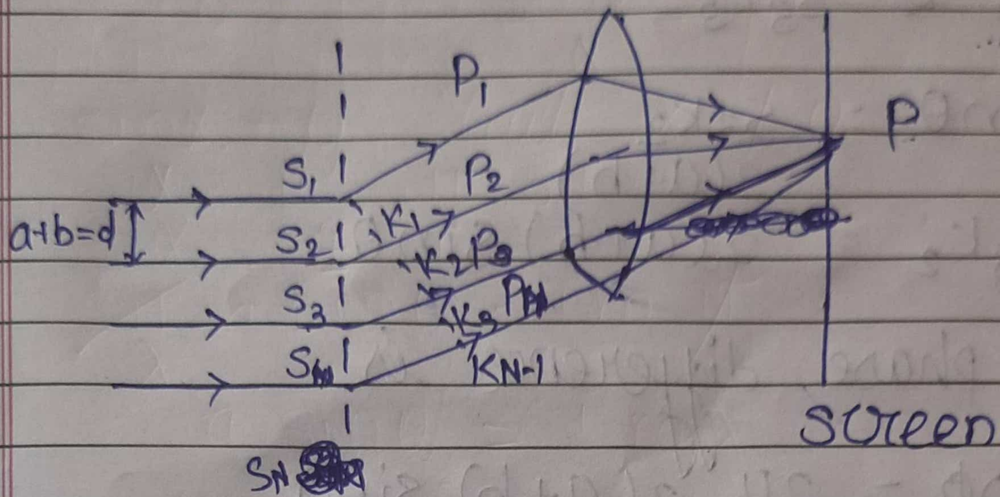
$$\frac{x}{f} = \frac{\lambda}{a}$$

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

∴ Width of central maxima

$$2x = \frac{2f\lambda}{a}$$

* fraunhofer differaction due to N parallel equidistant slits



a = Width of slit, b = opaque space

Resultant amplitude of light due to Single slit

$$E_\theta = E_m \frac{\sin\alpha}{\alpha}$$

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

E_m = maximum amplitude

Path difference between S_1P_1 & S_2P_2

$$\sin\theta = \frac{S_2K_1}{a+b}$$

$$S_2K_1 = (a+b)\sin\theta$$

& phase difference is

$$\Delta\phi = \frac{2\pi}{\lambda}(a+b)\sin\theta$$

DATE / /
PAGE NO.

similarly path difference between S_1P_1 & S_3P_3

$$\sin\theta = \frac{S_3K_2}{2(a+b)}$$

$$S_3K_2 = 2(a+b)\sin\theta$$

$\therefore$ phase difference is

$$2\Delta\phi = \frac{2\pi}{\lambda} \cdot 2(a+b)\sin\theta$$

$\therefore$ phase difference between successive vibration is

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

Resultant amplitude of waves can be found out by vector addition method & given by

$$E_\theta = E_m \frac{\sin\alpha}{\alpha} \frac{\sin N\beta}{\sin\beta}$$

& corresponding resultant intensity of light at P is by

$$I_\theta = I_m \left(\frac{\sin\alpha}{\alpha}\right)^2 \cdot \frac{\sin^2 N\beta}{\sin^2\beta}$$