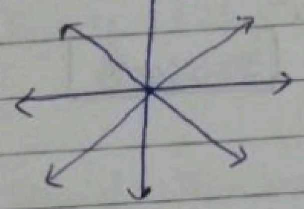
Unit - II

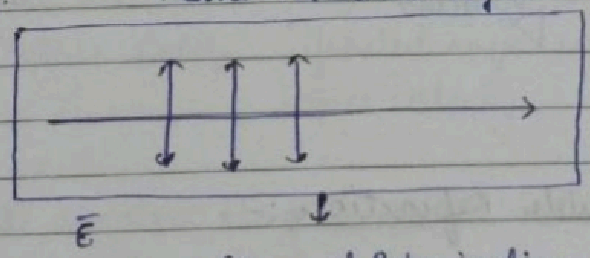
POLARIZATION

* We talk about vibrations of electric and magnetic fields of electromagnetic radiations.



Unpolarised light

Plane Polarized light



Plane of Polarisation

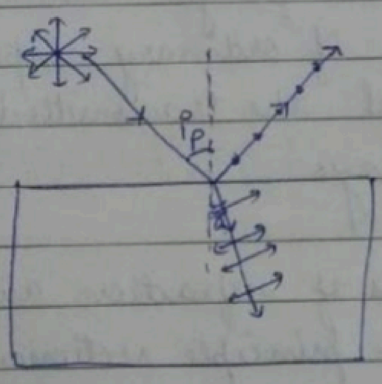
Methods to produce Polarized light -

1) Reflection
2) Refraction (Double Refraction)
3) Selective Absorption]
4) Scattering

(Prepare Short Notes)

Polarization through Reflection:-

Brewster's Law:-



Maximum Polarisation

$\tan i_p = \mu$

$\sin i_p = \mu \sin r$

$i_p + r + 90^\circ = 180^\circ$

$\sin i_p = \tan i_p . \sin r$

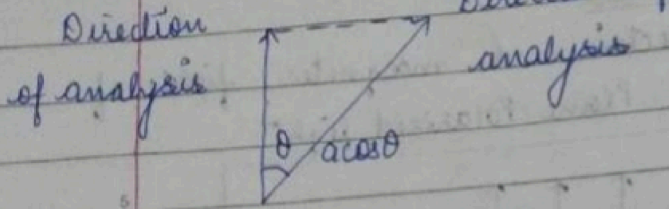
$\cos i_p = \sin r$

$\sin(90 - i_p) = \sin r$

$90 - i_p = r$

$\boxed{r + i_p = 90^\circ}$

Malus Law:-



$I \propto (a\cos\theta)^2$

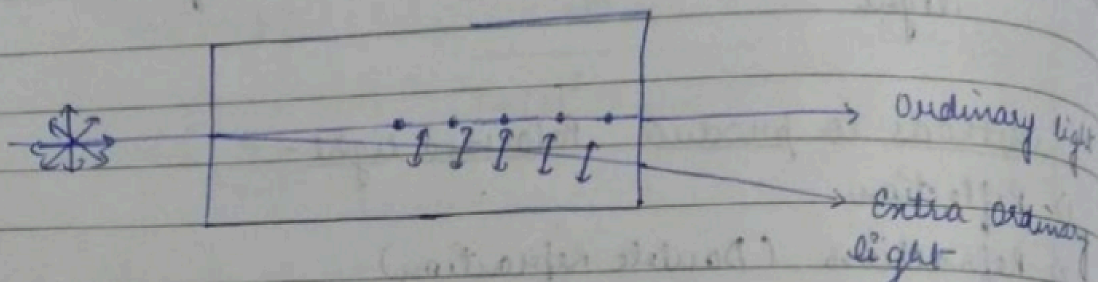
$I = ka^2\cos^2\theta$

At $\theta = 0$

$I_0 = ka^2$

$\cancel{I_0 = I}$ $\boxed{I = I_0\cos^2\theta}$

Double Refraction:-



O-Ray follows laws of refraction.

E-Ray follows few laws of refraction.

The optical axis of a crystal is the direction in which ray of transmitted light ~~travels and~~ suffers no ~~bire fringes~~ birefringence (Double Refraction)

When a beam of ordinary unpolarised light is passed through calcite crystal the transmitted reflected light splits into two refracted rays.

1) Which obey ordinary laws of refraction and having vibration perpendicular to principle section.

2) The other in general doesn't obey the law of refraction and having vibration in principle section (contains optical axis).

Both the rays are plane polarised and this phenomenon is called double refraction.

There are two types of doubly refracting crystals:-

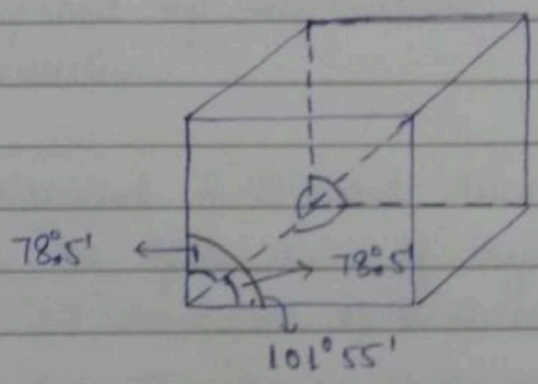
<u>Uniaxial</u>:- There is only one dir^n (optic axis) along which the two refracted rays travel with the same velocity

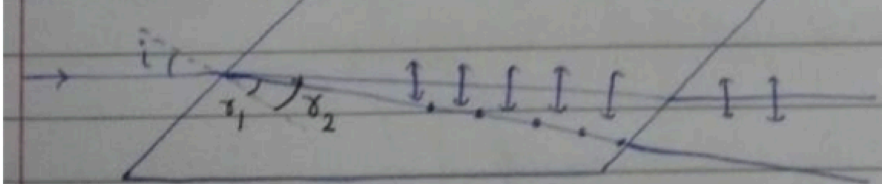
Quartz, Ruby (Al_2O_3), $NaNO_3$, Calcite $CaCO_3$

<u>Biaxial</u>:- There are two such directions along which the velocities are same

Borax, Mica, Topaz, $CaTiO_3$ (Perovskite)

<u>Calcite</u> (<u>Rhombohedral</u>):-





$$\mu_o = \frac{\sin i}{\sin r_1}$$

$$\mu_E = \frac{\sin i}{\sin r_2}$$

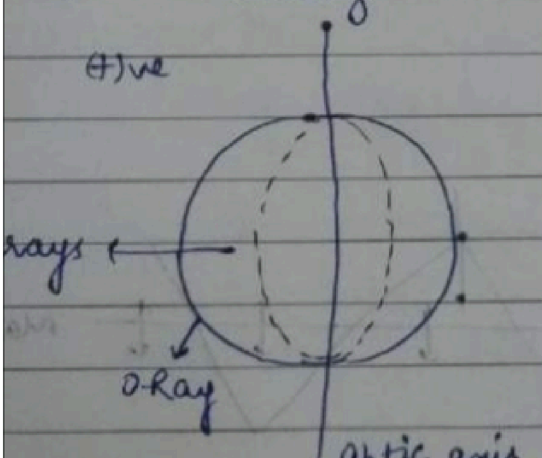
$$r_1 < r_2 \rightarrow \mu_E < \mu_o$$
$$\rightarrow v_E > v_o$$

Huygen's Theory of Double Refraction:-

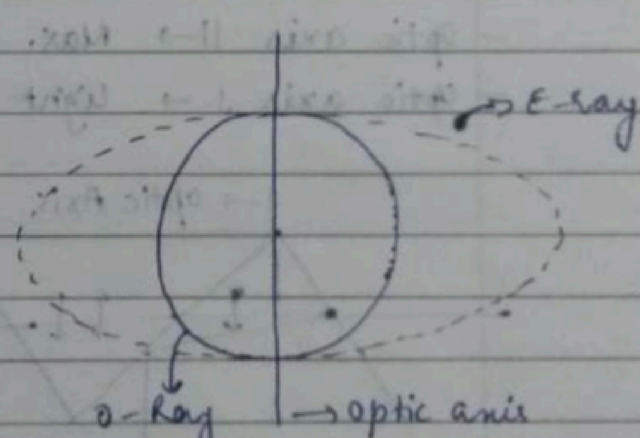
To explain the phenomena of double refraction in uniaxial system, Huygens extended his theory of secondary wavelets. Acc. to this theory -
When any WF strikes a double refracting crystal every point of crystal becomes a source of 2 wavelets.
Ordinary WF corresponding to ordinary ray. Since O-Ray have same velocity along all directions, the secondary WF is spherical.
Every E-ray WF corresponding to E-ray since, E-rays have different velocities in diff. dir^n, the extraordinary WF is ellipsoid of revolution with optic axis as a axis of revolution.

The spherical & ellipsoid touch each other at points which lies on the optic axis of crystal because velocity of E & O rays is same at optic axis.

Quartz



Calcite

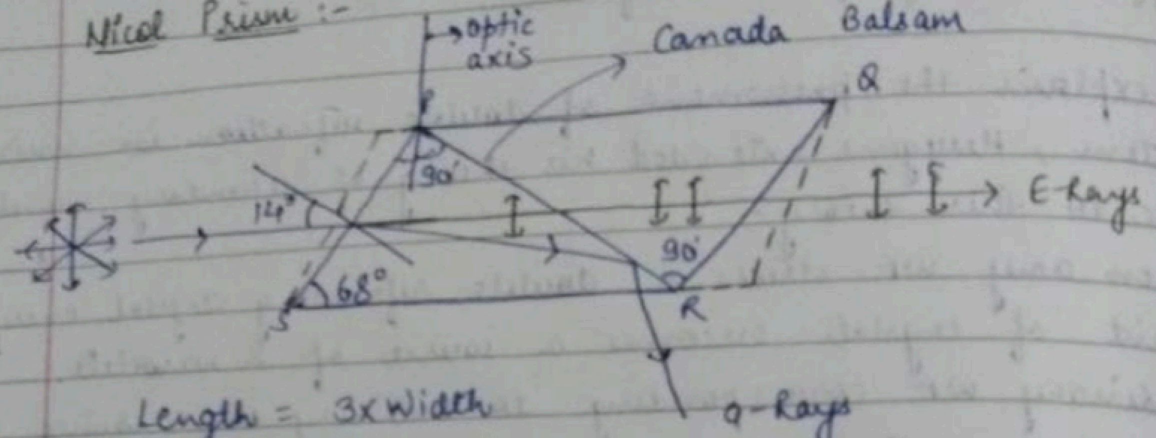


(+)ve crystal, $V_0 > V_E$
$\therefore$ sphere is outside the ellipsoid

(−)ve crystal, $V_0 < V_E$
$\therefore$ Ellipsoid is outside the spherical

Two types of crystal → (+)ve & (−)ve

Nicol Prism :-



Length = 3x Width

Calcite crystal

$71° \rightarrow 68°$
$109° \rightarrow 112°$ → This is done to increase field of

Changed the angle by grinding, smoothing, finishing

$\mu_O = 1.658$

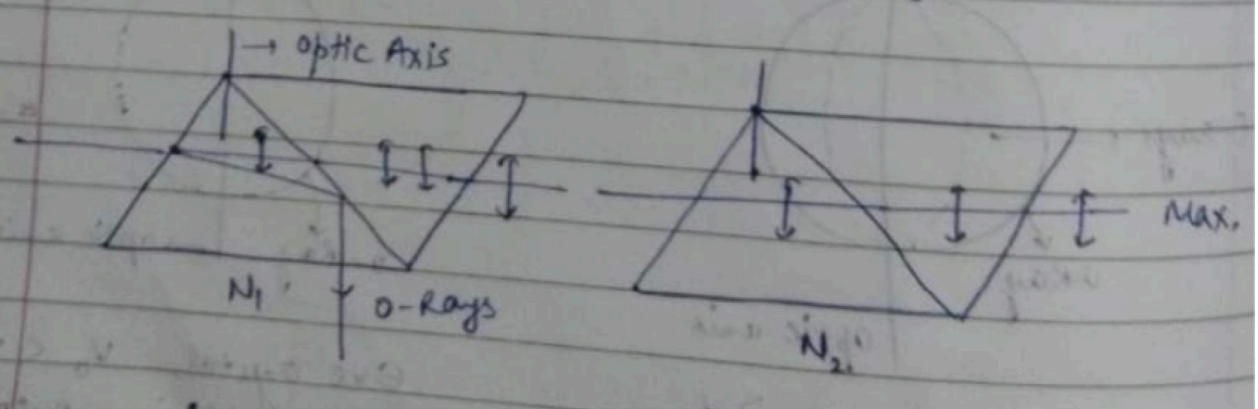
$\mu_{CB} = 1.55$

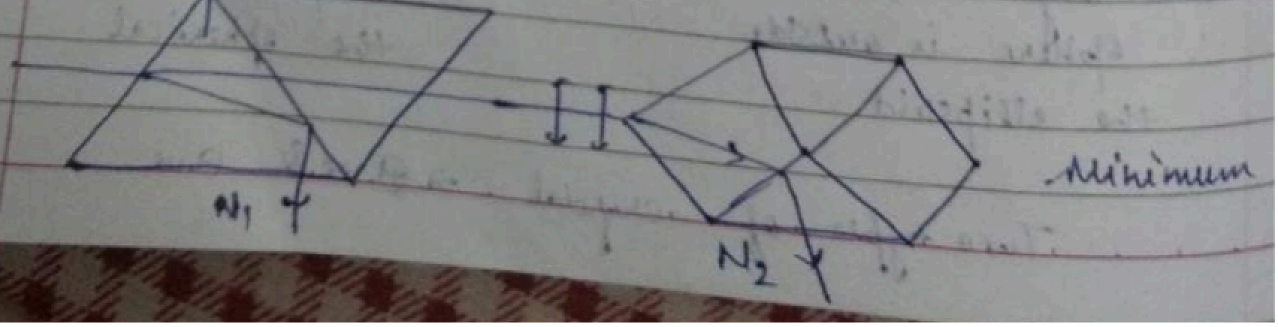
$\mu_E = 1.486$

$\theta_c = 69°$

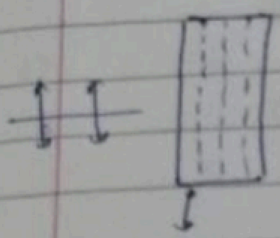
'μ' of Canada Balsam lies in b/w O & E rays which behaves as rarer for one & denser for other ray

- Optic axis ∥ → Max. Intensity
- Optic axis ⊥ → Light Block





Quarter Wave Plate



$$\mu_o t - \mu_e t = \frac{\lambda}{4}$$

$$t = \frac{\lambda}{4(\mu_o - \mu_e)}$$

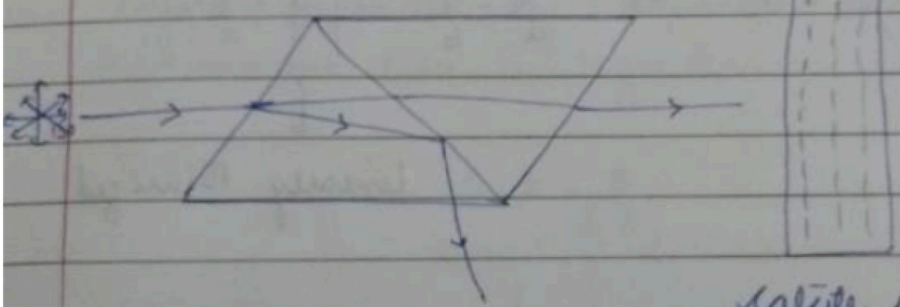
optic axis
Calcite

Half Wave Plate

$$\mu_o t - \mu_e t = \frac{\lambda}{2}$$

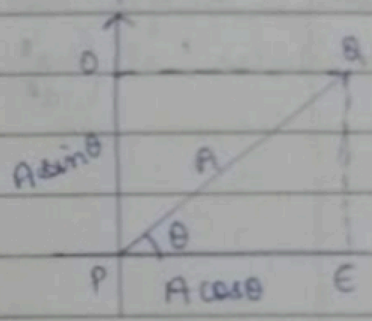
$$t = \frac{\lambda}{2(\mu_o - \mu_e)}$$

Elliptically and Circularly Polarised Light :-



Calcite crystal
$(V_e > V_o)$

Quarter wave Plate



$PQ = A$

$OP = A\sin\theta$ [O-Ray]

$EP = A\cos\theta$ [E-Ray]

δ = Phase difference

$$x = A\cos\theta \sin(\omega t + \delta) \quad \text{—— (1)}$$

$$y = A\sin\theta \sin(\omega t \cancel{+\delta}) \quad \text{—— (2)}$$

$A\cos\theta = a$, $A\sin\theta = b$

$$x = a\sin(\omega t + \delta) \quad \text{—— (3)}$$

$$y = b\sin\omega t \quad \text{—— (4)}$$

$$\frac{y}{b} = \sin\omega t \quad \text{—— (5)}$$

$$\cos\omega t = \sqrt{1 - \frac{y^2}{b^2}} \quad \text{—— (6)}$$

$$\frac{x}{a} = \sin(\omega t + \delta) \quad \text{——} (7)$$

$$\frac{x}{a} = \sin\omega t \cos\delta + \cos\omega t \sin\delta \quad \text{——} (8)$$

$$\frac{x}{a} - \frac{y}{b}\cos\delta = \sqrt{1 - \frac{y^2}{b^2}} \cdot \sin\delta \quad \text{——} (9)$$

$(eq)^n \ (9)^2$

$$\boxed{\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cos\delta = \sin^2\delta} \quad \text{——} (10)$$

(i) $\delta = 0$

$$\left(\frac{x}{a} - \frac{y}{b}\right)^2 = 0 \Rightarrow \frac{x}{a} = \frac{y}{b} \Rightarrow \boxed{y = \frac{b}{a}x}$$

$\downarrow$

Linearly Polarized

(ii) $\delta = 90^\circ$

$$\underbrace{\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1}_{\downarrow}$$

$\delta = (2n+1)\frac{\pi}{2}$

$n = 0, 1, 2, 3, ----$

Ellipse / Elliptically Polarized

Special Case :- $a = b$

$x^2 + y^2 = a^2 \rightarrow$ circle

(iii) $\delta = \pi$

Optical Activity :-

Some substances like Quartz, sugar crystals etc. rotate the plane of vibration of plane polarised light passing through. This phenomena is called optical activity.

1> Clockwise → Dextrorotatory
Anti-clockwise → Laevorotatory

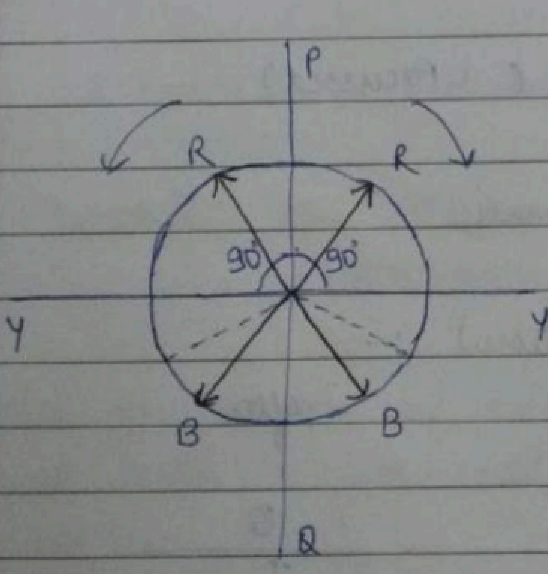
2> $\theta \propto$ Length of material (l) | θ = Angle of Rotation
$\theta \propto$ Concentration (c)
$\theta \propto \frac{1}{\lambda^2}$

$$\theta = \theta_1 + \theta_2 + \theta_3 + \cdots$$

Specific Rotation :-
Specific Rotation of a substance at a particular temp. & for a given wavelength of a light used may be defined as the rotation produced by 1 decimeter length of its solution when the concentration is 1 gm/cc.

$$S = \frac{\theta}{l.c}$$

Polarimeter :-
(Biquartz Polarimeter)



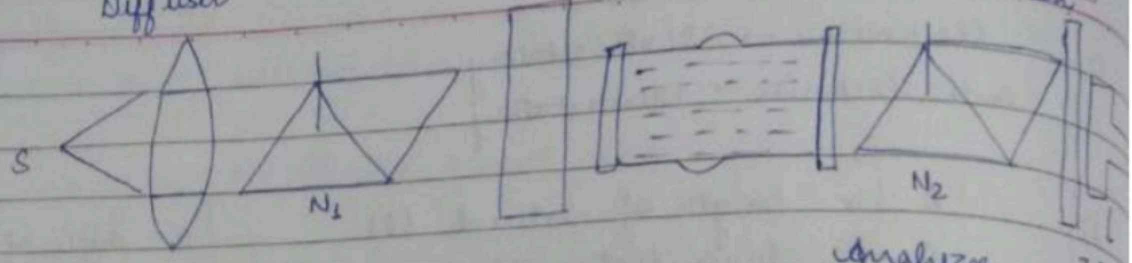
① $t \sim 3.75$ mm
② Cut $\perp_r$ to optic axis
③ $y \to 90°$
④ Rotatory dispersion
⑤ PQ → Greyish violet tint

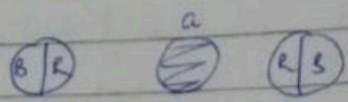
Study Applications LASER

Biquartz

Diffuser

Scale Screen





$a = b$

$a + 180° \approx c$

c & d

$c \approx d$

Distilled:	a	b	c	d
	θ_1	θ_2	θ_3	θ_4
Glucose solⁿ:	a'	b'	c'	d'

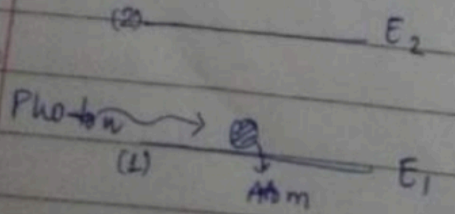
__LASER__ (Light Amplification by ~~Stimulating~~ Stimulated Emission of Radiation)

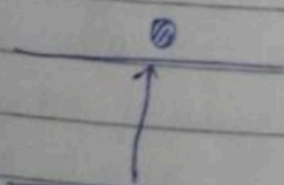
- Laser light → Intense
- $L_c \uparrow$ (coherence length)
- Directional / Highly confined ℓ (Focussed)
- Applications in Medicine
- Laser light is Monochromatic

__Absorption__ (Stimulated Absorption) :-

Before

After





$E_2 > E_1$, $E_2 - E_1 \approx h\nu$

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The no. of atoms in state 1 that absorb a photon & rise to state 2 per unit time $= N_1 P_{12} = N_1 B_{12}\, u(\nu)$

No. of atoms going to state 1 from state 2 either spontaneously or by stimulated emission per unit time $= N_2 P_{21} = N_2 [A_{21} + B_{21}\, u(\nu)]$ — (2)

$$N_1 P_{12} = N_2 P_{21} \quad — (3)$$

$$N_1 B_{12}(u\nu) = N_2 [A_{21} + B_{21}\, u(\nu)]$$

$$u(\nu)\,[N_1 B_{12} - N_2 B_{21}] = N_2 A_{21}$$

$$u(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}} \quad — (4)$$

$$u(\nu) = \frac{N_2 A_{21}}{N_2 B_{21}\left[\frac{N_1}{N_2}\cdot\frac{B_{12}}{B_{21}}\right] - 1}$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \cdot \frac{1}{\left(\frac{N_1}{N_2}\cdot\frac{B_{12}}{B_{21}}\right) - 1} \quad — (5)$$

$$B_{21} = B_{12}$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \cdot \frac{N_2}{N_1 - N_2}$$

$$= \frac{A_{21}}{B_{21}} \times \frac{\cancel{N_0} e^{-E_2/KT}}{\cancel{N_0} e^{-E_1/KT} - N_0 e^{-E_2/KT}}$$

$$N_n = N_0 e^{-E_n/KT}$$

Maxwell's Equation

KT = Thermal Energy

$$= \frac{A_{21}}{B_{21}} \times e$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \times \left[\frac{1}{e^{h\nu/KT} - 1}\right] \quad — (6)$$

$$\frac{N_1}{N_2} = e^{\frac{E_2 - E_1}{KT}} = e^{h\nu/KT}$$

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Planck's Relation: $u(\nu) = \frac{8\pi h\nu^3}{c^3}\left[\frac{1}{e^{h\nu/KT} - 1}\right]$ — ⑦

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

$$\frac{(P_{2\to1})\text{ spontaneous}}{(P_{2\to1})\text{ stimulated}} = \left[e^{h\nu/KT} - 1\right]$$ — ⑨

Cases -

(I) $h\nu > KT$ $\longrightarrow$ spontaneous emission

(II) $h\nu < KT$

$$\frac{(P_{2\to1})\text{ spontaneous}}{(P_{2\to1})\text{ stimulated}} \approx \frac{h\nu}{KT}$$

→ Stimulated emission dominates but spontaneous emission always exist in system.

Pumping:- The process of achieving population inversion.

Exp.

1) Excitation by photon - Ruby laser, Solid state laser & Dye L. etc.
optical Pumping

2) Excitation by electron - Gas laser

$$e + X \longrightarrow X^* + e$$

Electric pumping

3) Excitation by inelastic atomic collision - He-Ne laser

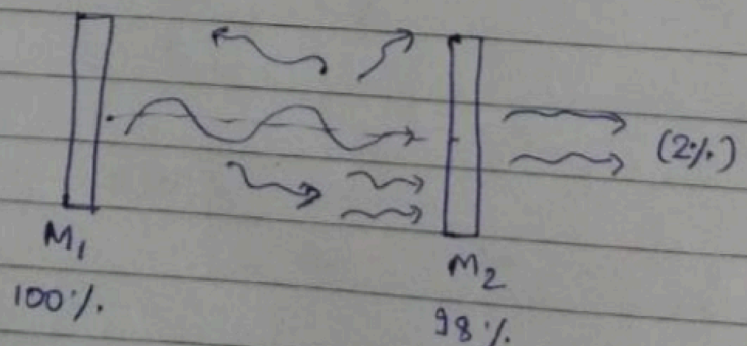
(i) $e + X \longrightarrow X^* + e$

(ii) $X^* + Y \longrightarrow X + Y^*$

4) Chemical Excitation -

$$H + F \longrightarrow (HF)^*$$

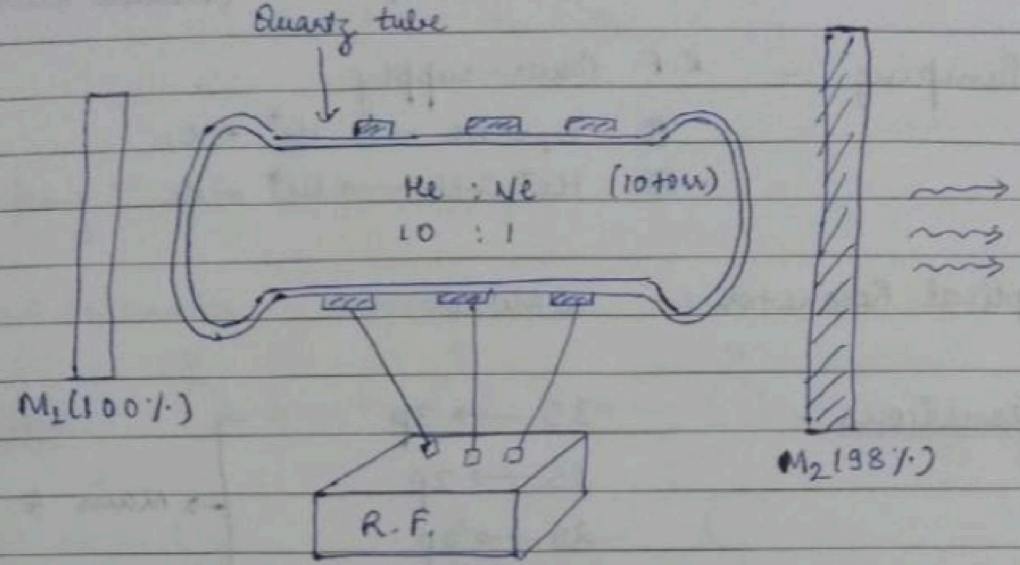
Optical Resonator:-
(or Optical Cavity, Gain Medium)



Only those photons which are parallel to the axis will produce LASER.

Oscillatory Motion
(To & fro)

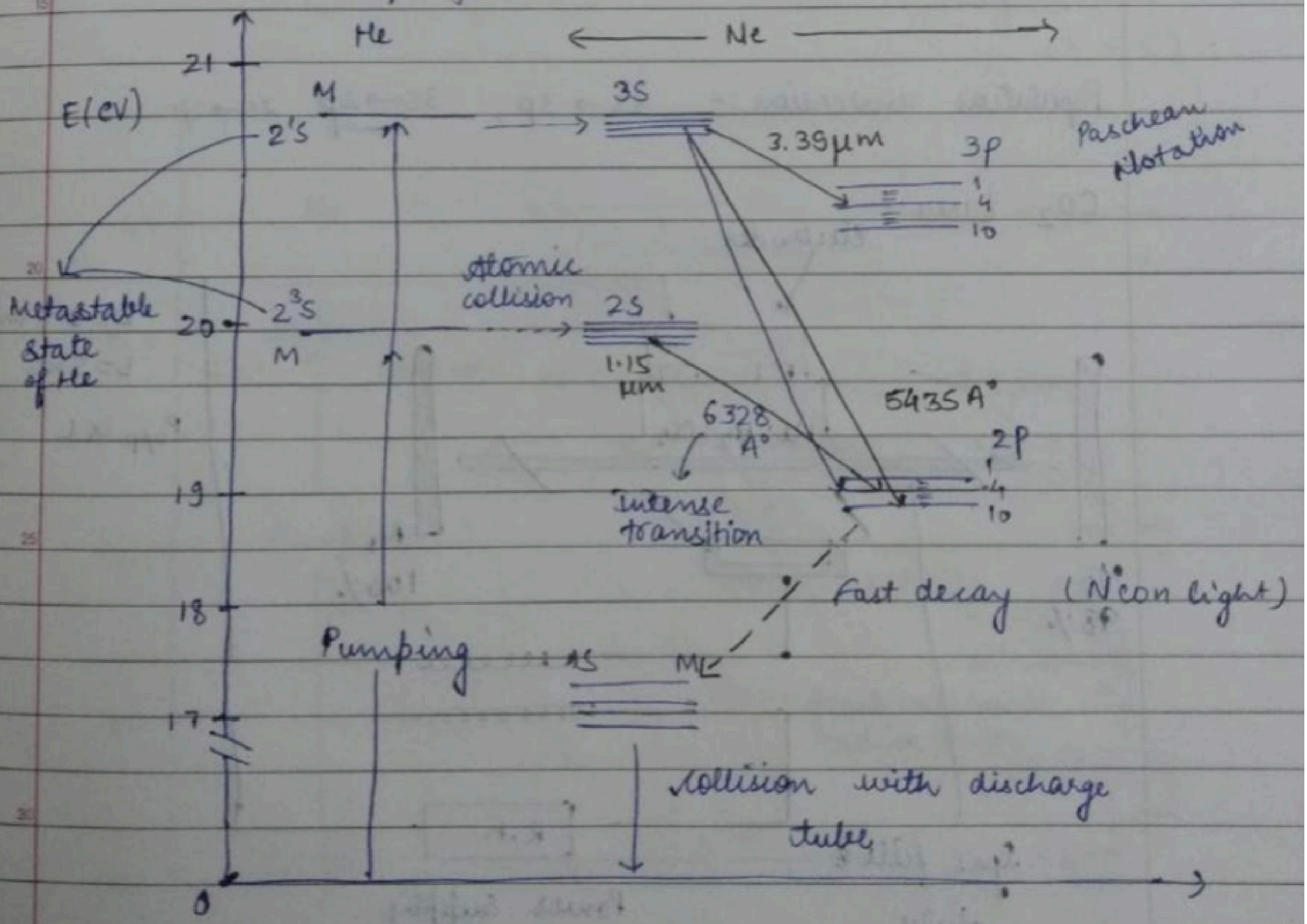
He-Ne Laser :-



$L = 80\,cm$. Power supply

$D = 1.5\,cm$. 10 MHz, 50 W (2-4 kV)

L-S coupling



1) Active medium :- He - Ne gases (Pressure Ratio)
10 : 1

2) Pumping :- R.F. Power supply
(I) $e_1 + He \rightarrow He^* + e_2$
(II) $He^* + Ne \rightarrow Ne^* + He$

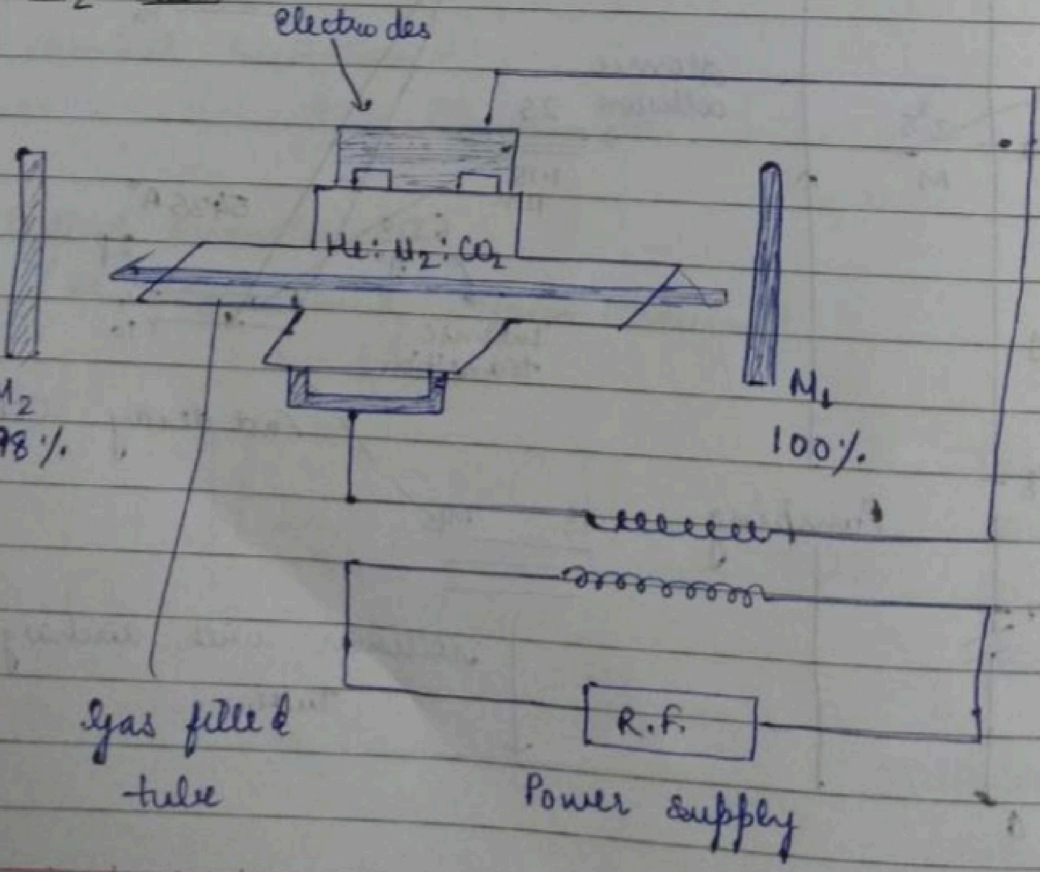
3) optical Resonator :- 2 Mirror

__Transitions__ :-
3S → 3p
3S → 2p
2S → 2p
2p → 1S
→ Main 4 transitions

Approximately 150 transitions take place.

Population inversion :- 3S → 3p, 3S → 2p, 2S → 2p

__CO_2 Laser__ :-



D = 2.5 cm
L = 5 m.
$P_{o/p} \propto L$

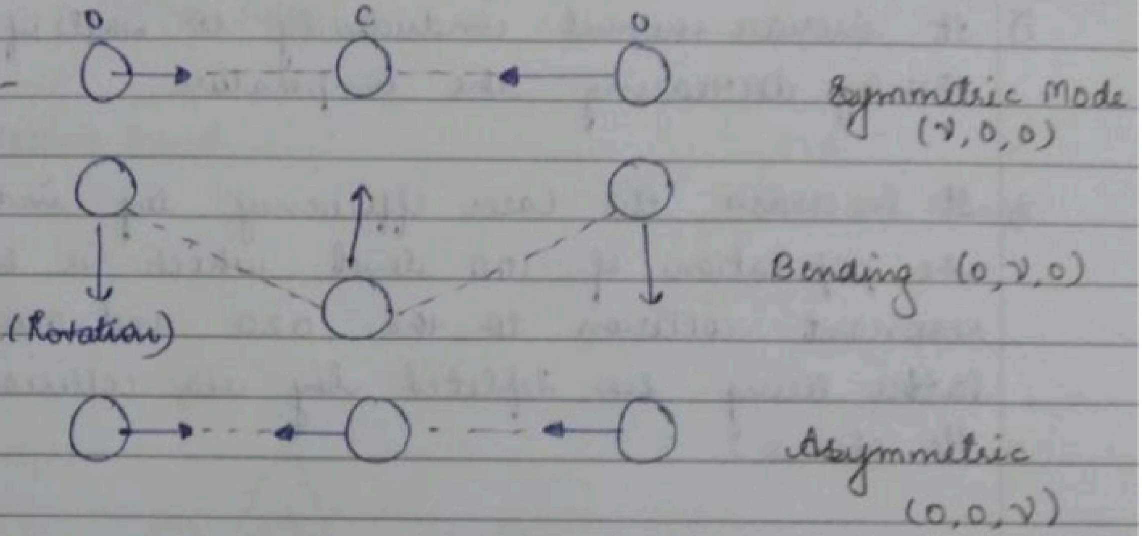
1> Active Medium:

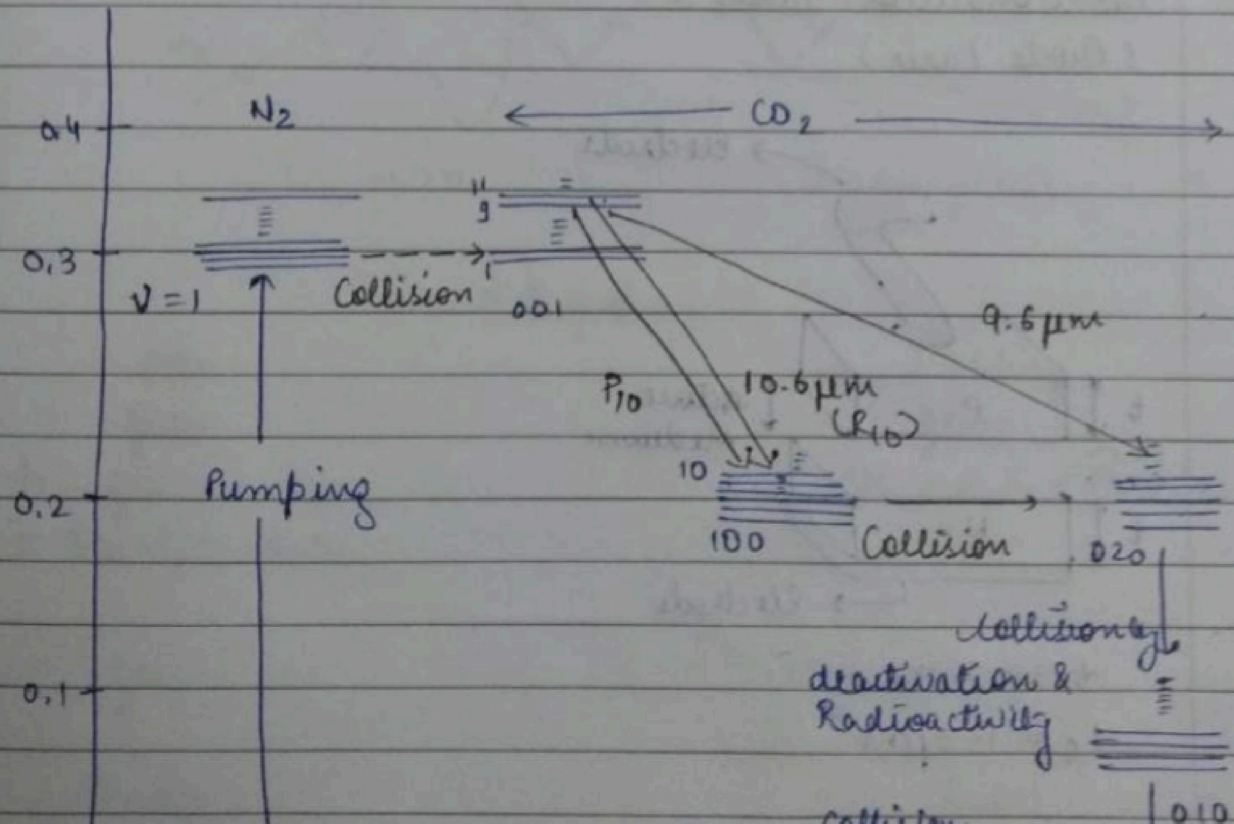
$He : N_2 : CO_2$
5 : 4 : 1

2> Pumping :- RF Power Supply

3> Optical Resonator - Mirror

Vibrations :-





CO_2 Laser - cutting & welding tools | 10 kW = 10m.

Selection Rule - $\Delta \tau = \pm 1$
(Rotation levels)

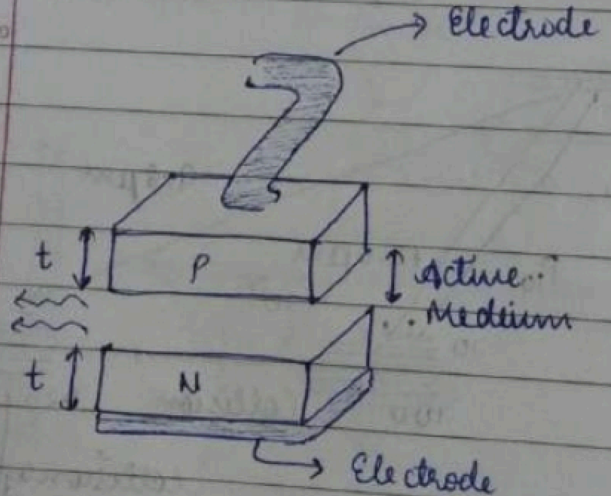
$R_{10} \Rightarrow \Delta \tau = -1$, $P_{10} \Rightarrow \Delta \tau = +1$

Helium has dual role -

i) It increase thermal conductivity to walls of the tube thereby decreasing the temperature.

ii) It increases the laser efficiency by indirectly depleting the population of 100 level which is linked by resonant collision to the 020 and 010 levels, the latter being ~~so~~ depleted ~~by~~ via collision with the He atoms.

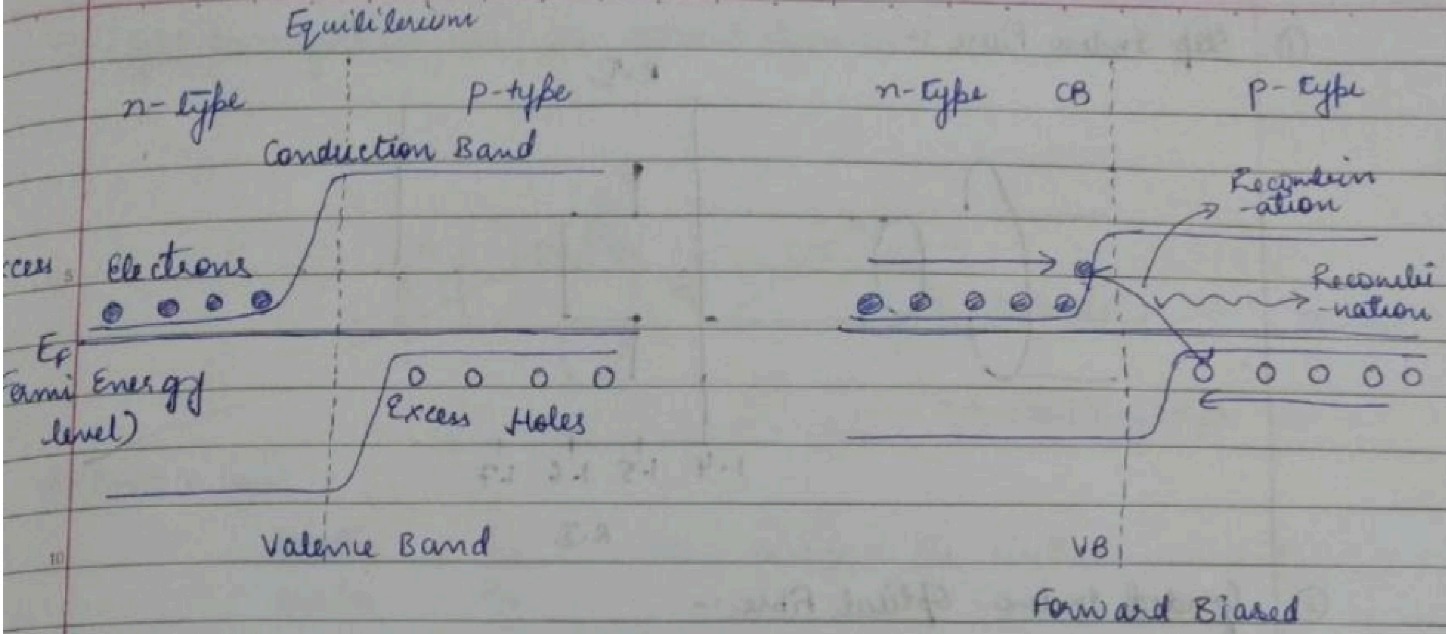
Semiconductor laser :-
(Diode Laser)



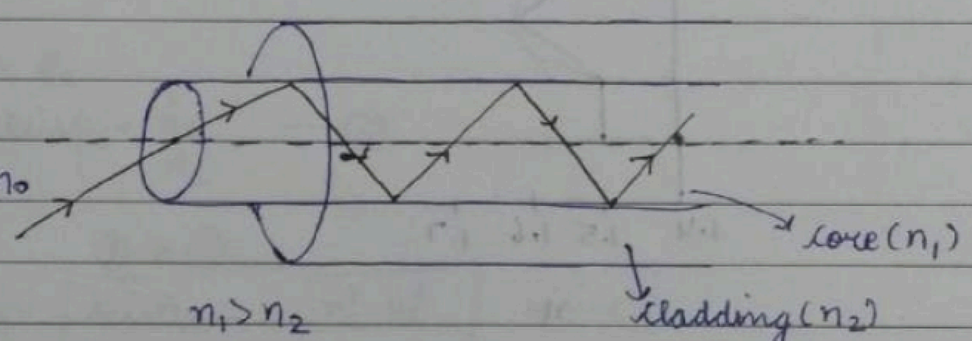
$t \approx 0.5 mm$

$L_c \approx 1\text{-}3 \mu m$

$P_{o/p} \approx 2W$



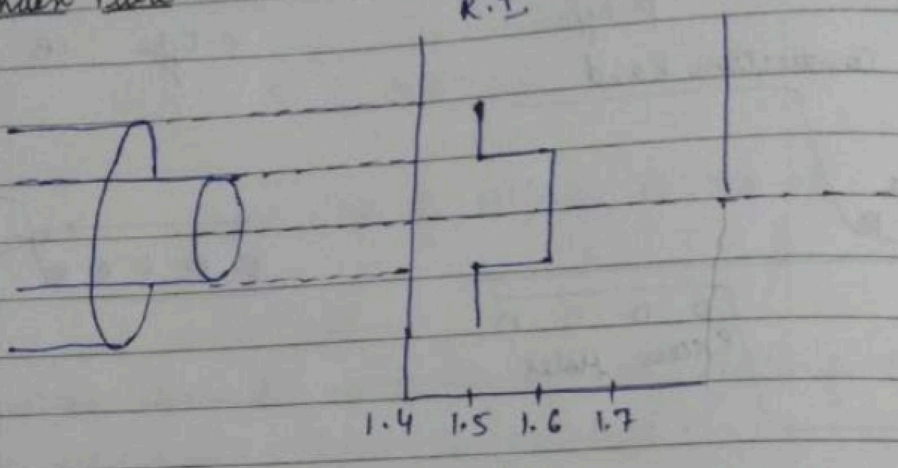
Optical Fibre :-



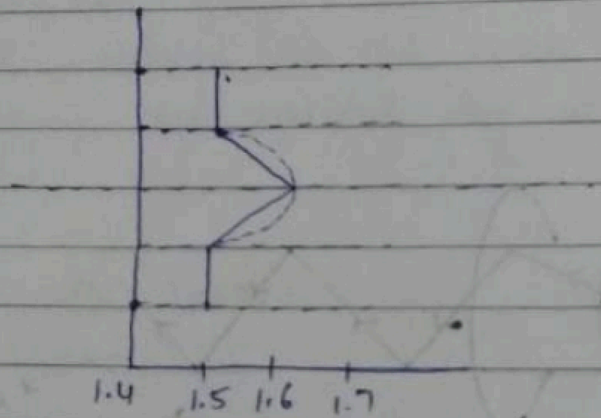
Material

	Core	Cladding
(I)	Glass	Glass
(i)	Glass	$SiO_2 + B_2O_5$ / Fluorine
(ii)	$SiO_2 + P_2O_5 / GeO_2$	SiO_2
(II)	Glass	Plastic
(III)	Plastic	Plastic

① Step Index Fibre :-



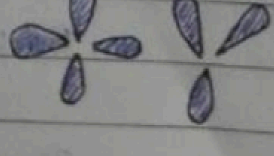
② Graded Index Optical Fibre :-



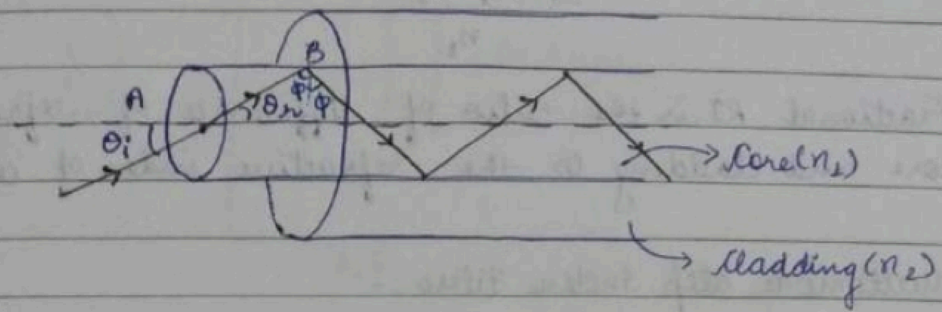
Mode

(1) Single Mode

② Multimode Fibre



Light propagation through Optical Fibre:-



$n_1 > n_2$

(A) Snell's Law

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_0} \Rightarrow \sin\theta_i = \frac{n_1}{n_0} \cdot \sin\theta_r$$

At $\phi = \phi_c \rightarrow$ ~~$\phi_i = \phi_m$~~ $\theta_i = \theta_m$ | $\theta_r = 90 - \phi$

$$\Rightarrow \sin\theta_m = \frac{n_1}{n_0} \cos\phi_c \quad \text{—(1)}$$

(B) At $\phi = \phi_c$

$$\sin\phi_c = \frac{n_2}{n_1} \quad \text{—(2)}$$

(1) & (2)

$$\boxed{\sin\theta_m = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}} \quad \text{—(3)}$$

θ_m is the acceptance angle (max.) & after ...

$n_0 = 1$

$$\boxed{\sin\theta_m = \sqrt{n_1^2 - n_2^2}} \quad \text{—(4)}$$

Numerical Aperture (N.A.) -

$$NA = \sqrt{n_1^2 - n_2^2}$$

or $NA = \sin\theta_m$

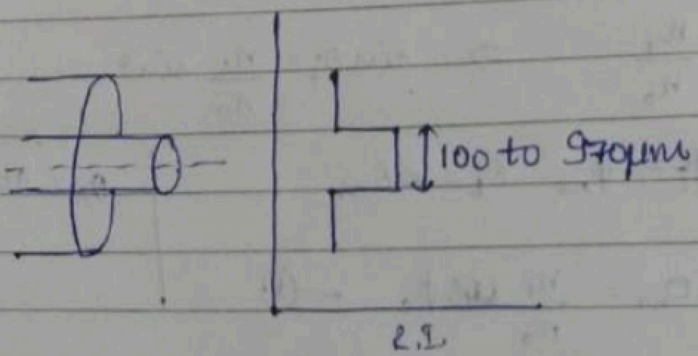
or $NA = n_1\sqrt{2\Delta}$

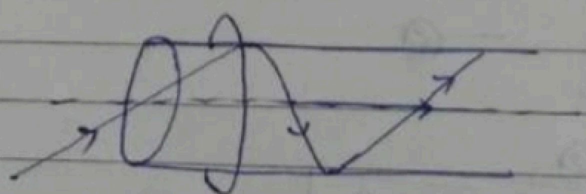
Fractional Refractive Index Change :-

$$\Delta = \frac{n_1 - n_2}{n_1}$$

Fractional RI is the ratio of difference of refractive index of core and cladding to the refractive index of core.

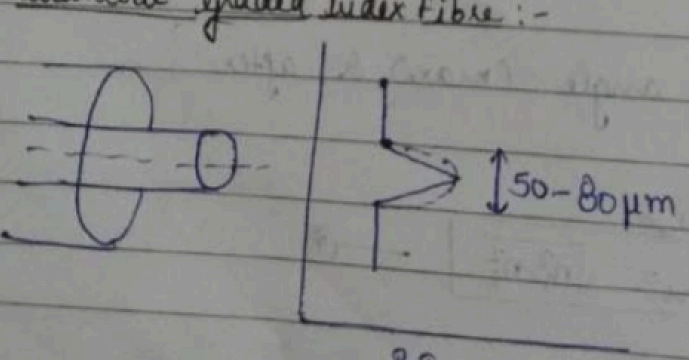
1) Multimode Step Index Fibre :-

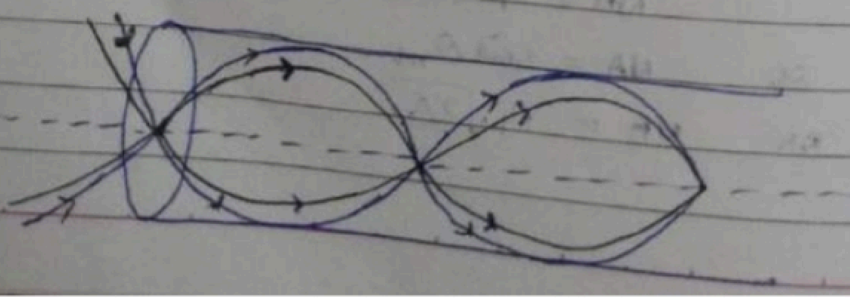




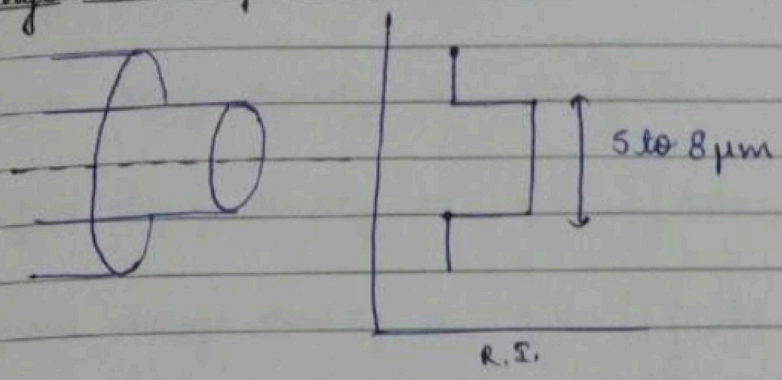
Model dispersion

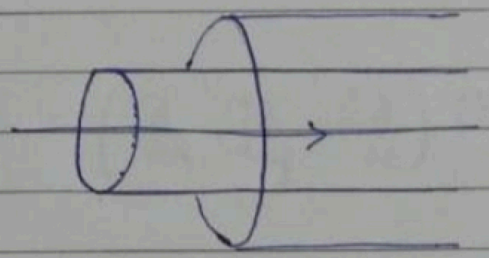
2) Multimode Graded Index Fibre :-





3) Single Mode Step Index Fibre :-





V – Parameter :

An optical fibre is characterised by one more imp. parameter known as V-parameter or normalized frequency.

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

a : Radius of Core

or $$V = \frac{2\pi a}{\lambda}(NA)$$

or $$V = \frac{2\pi a}{\lambda} \cdot n_1\sqrt{2\Delta}$$

Step-I	Graded Index
$N_{max.} \approx \frac{V^2}{2}$	$N_{max.} \approx \frac{V^2}{4}$

Single Mode $V < 2.405$

Multi Mode $V > 2.405$

$V = 2.405 \longrightarrow \lambda = \lambda_c$