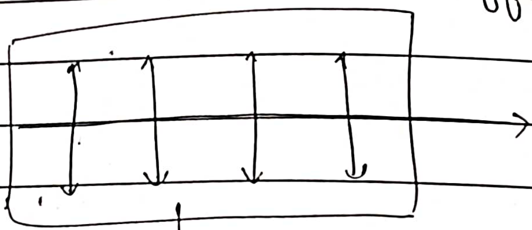
Unit - 02

Polarisation

(commercial camera, sunglasses, sunlight - partially polarised)

Electric and magnetic field lines are ⊥ and rays move in different direction.

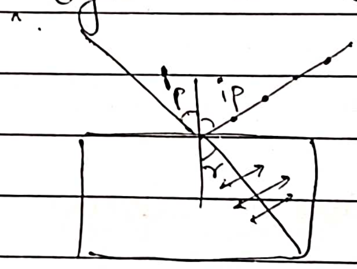


Plane of polarisation

Their are 4 methods of polarising a light.

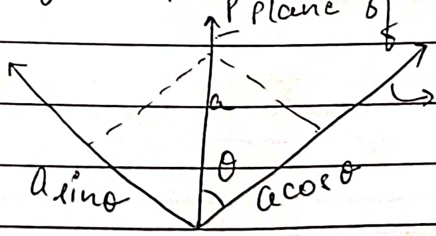
1.) Reflection 2) Double refraction 3) Scattering
4) Selective absorption

* Reflection : Brewster's law
for a particular angle of incidence max. polarised light is reflected.



$\tan i_p = \mu$ (numerical can be asked)

Malus law : (property of polarised light)
valid only for polarised light



$OP = a$

$OA = a\cos\theta$

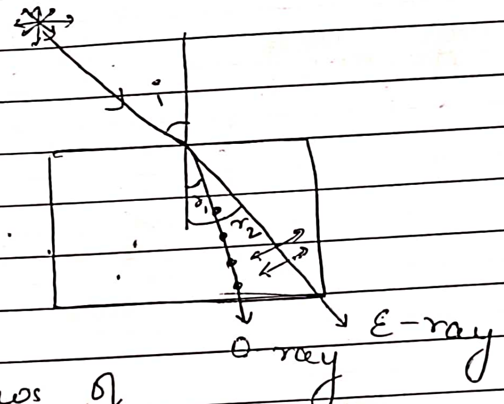
$I = ka^2\cos^2\theta$ - (1)

$\theta = 0°$

$I_0 = ka^2$ - (2)

$I = I_0\cos^2\theta$ - (3)

* Double refraction:
(Birefringes)



O ray follow all the laws of refraction.
E-ray ~~foll~~ don't follow all laws of refraction.

for O-ray
$\mu_0 = \frac{\sin i}{\sin r_1}$

for E-ray
$\mu_0 = \frac{\sin i}{\sin r_2}$

$r_1 < r_2$ $\mu_0 > \mu_E$ $V_0 < V_E$

$r_1 > r_2$ $\mu_0 < \mu_E$ $V_0 > V_E$

optic axis principal section (plane) unioxial biaxial

optic axis :- It is the optic axis of crystal is the direction in which ray of transmitted ~~light~~ it suffere no double refraction (birefringes)

Uniaxial : Calcite, quartz, sodium nitrite, ice ruby etc.

biaxial : borax, mica, topaz etc.
ABO_3, $CaTiO_3$

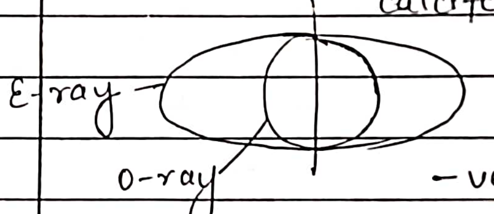
* Huygen's theory of double refraction:
(uniaxial crystal)

1) ~~(a)~~ when any wavefront strike the doubly refracting crystal, every point of crystal becomes a source of two wavefronts

(a) Ordinary wavefront corresponds to the ordinary ray (o-ray) since o-ray have same velocity have all direction the secondary wavefronts is spherical.

(b) Extra-ordinary wavefront corresponding to E-ray since E-ray have diff. velocity in diff. directions the e-ordinary wavefront is ellipsoid of revolution with optics axis as the axis of revolution.

calcite

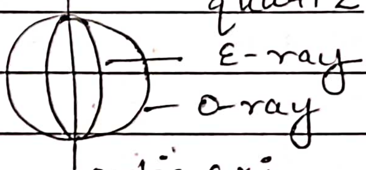


-ve crystal

optic axis

$V_E > V_O$

quartz



optic axis

+ve crystal

$V_O > V_E$

The sphere and ellipsoid touch each other at points which lie on the optic axis of crystal because of V_O ~~&~~ V_E is same at the optic axis.

~~The~~ In some crystal (calcite, turmaline) called -ve crystals because ellipsoid lies outside the sphere and $V_E > V_O$.

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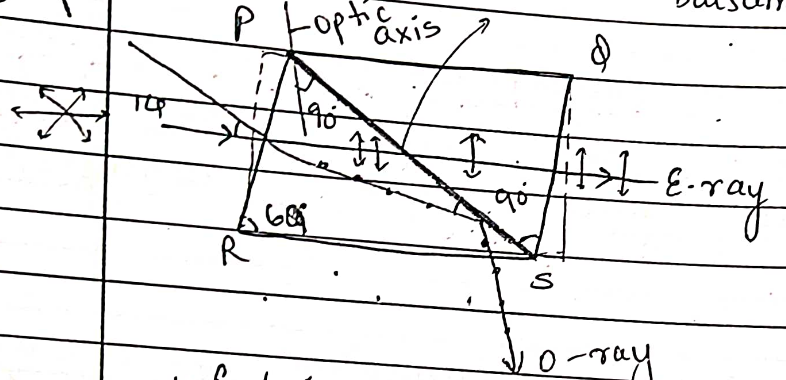
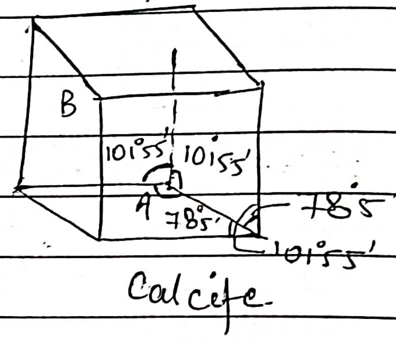
Some crystal (ice, quartz) called +ve crystal have ellipsoid inside sphere and $V_o > V_E$ ∵ at the optic axis.

Nicol Prism : canada balsam
(Imp)



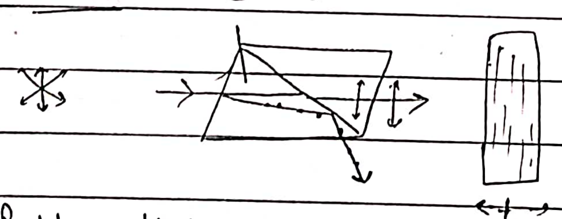


* Calcite crystal
* $l = 3w$
* $71° \to 68°$
  $109° \to 112°$
* $\mu_o = 1.658$
* $\mu_{CB} = 1.55$
  $\mu_E = 1.486$
* $\theta_c = 68°$

There are 3 reasons for changing angles:
- Field of view
- Parallel to RS
- TIR

(full explanation needed)

It can be used as polariser and analyser.

Quarter wave plate	Half wave plate
Calcite $V_E > V_o$	$\mu_o t - \mu_E t = \frac{\lambda}{2}$ – (5)
	$t = \frac{\lambda}{2(\mu_o - \mu_E)}$ – (6)
Path difference $\mu_o t - \mu_E t = \frac{\lambda}{4}$ – (1)	$\mu_o - \mu_E = 0.172$
$t(\mu_o - \mu_E) = \frac{\lambda}{4} \Rightarrow$ ~~$\mu_o t - \mu_E t$~~ $t = \lambda$ – (3)	

Quartz,

$t = \dfrac{\lambda}{4(\mu_E - \mu_0)}$ | $t = \dfrac{\lambda}{2(\mu_E - \mu_0)}$

Optical activity : Laevo rotatory / dextro rotatory (Complete krna hai)

$\theta \propto l$ (length of material / tube)

$\theta \propto c$

$\theta \propto \dfrac{1}{\lambda^2}$

$\theta = \theta_1 + \theta_2 + \theta_3$ (net)

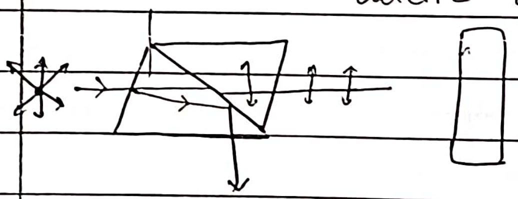
Specific rotation :- $S = \dfrac{\theta}{l \times c}$ l = decimeter, c = gm/cc, θ = degree

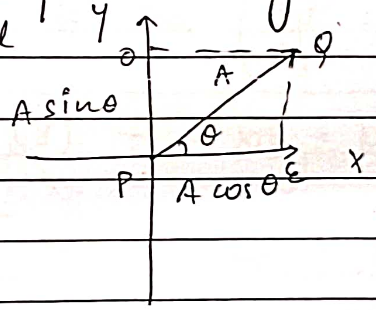
The specific rotation of a substance at a particular temp and for a given wavelength of a light used may be defined as the rotation produced by one decimeter length of its solution when the concentration is 1gm/cc.

(numerical can be asked)

Elliptically and circularly polarised light:

calcite crystal





$PQ = A$

$PO = A\sin\theta$ [E-ray] $\rightarrow x = A\cos\theta(\sin(\omega t + \delta))$ — (1)

$PE = A\cos\theta$ [O-ray] $\rightarrow y = A\sin\theta \cdot \sin(\omega t)$ — (2)

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

$$\frac{x}{a} = \cancel{a} \sin(\omega t + \delta) \qquad -(3)$$

$$\frac{y}{b} = \sin \omega t \qquad -(4)$$

$$\frac{x}{a} = \sin\omega t \cos\delta + \cos\omega t \sin\delta$$

$$= \cancel{\frac{y}{b}} = \frac{y}{b}\cos\delta + \sqrt{1-\frac{y^2}{b^2}} \cdot \sin\delta$$

$$x^2 \left(\frac{x}{a} - \frac{y}{b}\cos\delta\right) = \sqrt{1-\frac{y^2}{b^2}} \cdot \sin\delta$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2}\cos^2\delta - \frac{2xy\cos\delta}{ab} = \left(1-\frac{y^2}{b^2}\right)\sin^2\delta$$

$$= \sin^2\delta - \frac{y^2}{b^2}\sin^2\delta$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = \sin^2\delta + \frac{2xy}{ab}\cos\delta$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cos\delta = \sin^2\delta \qquad -(5)$$

$$\left[\because \cos\omega t = \sqrt{1-\frac{y^2}{b^2}}\right] \quad -(6)$$

I $\delta = 0$, we get,

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab} = 0 \qquad -(7)$$

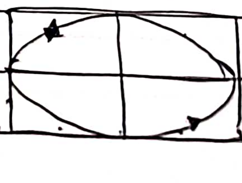
$$\left(\frac{x}{a} - \frac{y}{b}\right)^2 = 0 \Rightarrow \frac{x}{a} = \frac{y}{b}$$

$$y = \frac{bx}{a} \qquad -(8)$$

↳ straight line or plane polarised light

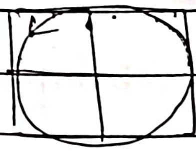
$\delta = \pi/2$, we get, $\dfrac{x^2}{a^2} + \dfrac{y^2}{b^2} = 1 \quad -(9)$

Elliptically



Polarimeter

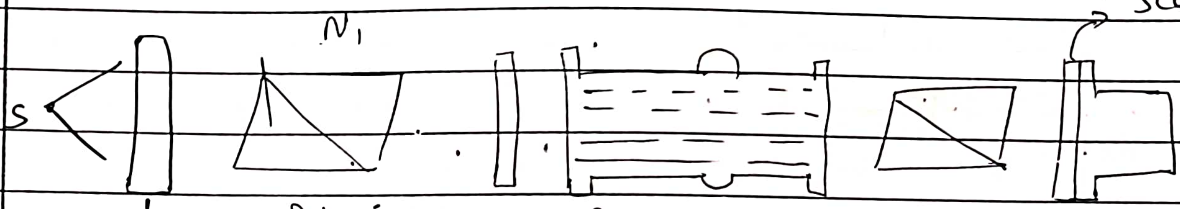
special $a = b$, $x^2 + y^2 = a^2$
circularly Polarised light



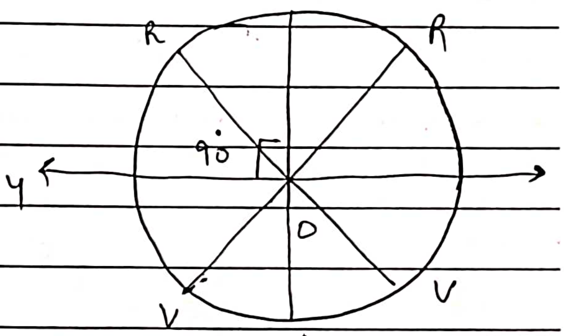
(3) $\delta = \pi$

At diff. value of δ we get different direction of polarised light.

★ Biquartz Polarimeter:



Quartz, cut to a optic waves
$t = 3.55mm$
yellow → $90°$
Phenomenon rotatory dispersion
Sensitive tint / greyish violet tint

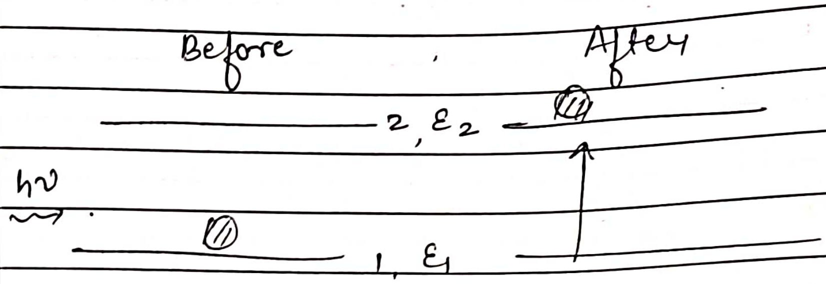


★ LASER: (Definition, property and application)

Light Amplification Stimulated emission Radiation

light source	light power	Power density
Sun	10^{26} w	5×10^2 w/cm²
filament lamp	3 w	10^{-2} w/cm²
surgery - He-Ne	1 mw	4×10^4 w/cm²
cutting tools - CO_2 laser	14 w	10^{14} w/cm²

1.) Absorption:



$\varepsilon_2 - \varepsilon_1 = h\nu$

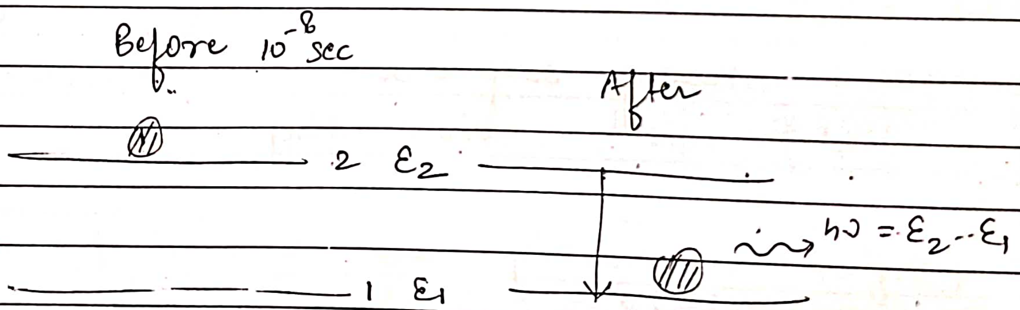
$P_{1\to 2} = P_{12} = u\nu B_{12}$ — (1)

Energy density (power density)

Property of

B_{12} = constant (Einstein coefficient of absorption of radiation)

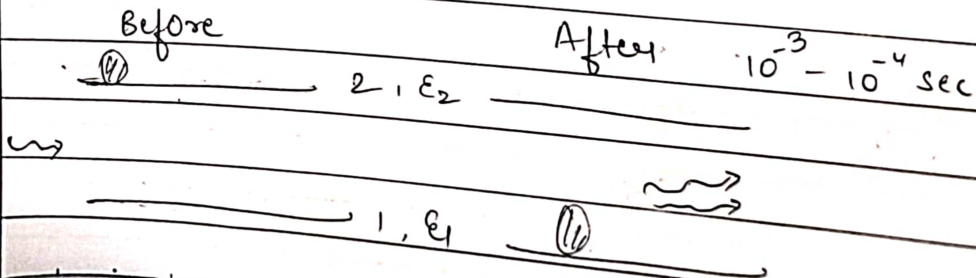
2) Spontaneous emission:



$P_{2\to 1} = P_{21} = A_{21}$ — (2)

A_{21} = einstein coefficient of spontaneous of radiation

3.) Stimulated emission:



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$$P_{21} = u(\nu) B_{21} \quad -(3)$$

B_{21} = Einstein coefficient of stimulated emission of radiation.

$$\boxed{P_{21} = A_{21} + u(\nu) B_{21}} \quad -(4)$$

Relation betn spontaneous and stimulated emission:-

let us consider an assembly of atom in thermal equilibrium at temp t with radiation of freq. ν and energy density $u(\nu)$.

let N_1 = No. of atoms.

the no. of atoms in state '1' that absorb a photon and rise to state '2' per unit time is

$1 \to 2$ $\quad N_1 P_{12} = N_1 B_{12} u(\nu) \quad -(5)$

the no. of atom in state '2' that draw to state '1' either stimulated or spontaneous, emitting a photon /t.

$2 \to 1$ $\quad N_2 P_{21} = N_2 [A_{21} + B_{21} u(\nu)] \quad -(6)$

At thermal equilibrium

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

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

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

Maxwell Boltzman constant:

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

$$E_2 - E_1 = h\nu$$

$$N_1 = N_0 e^{-E_n/KT}$$

$$\mu(\nu) = \frac{A_{21}}{B_{12}(e^{h\nu/KT}-1)} \quad -(10)$$

planck's black body radiation,

$$\mu(\nu) = \frac{8\pi h\nu^3}{c^3} \times \frac{1}{e^{h\nu/KT}} \quad -(11)$$

comparing eqn (10) and (11),

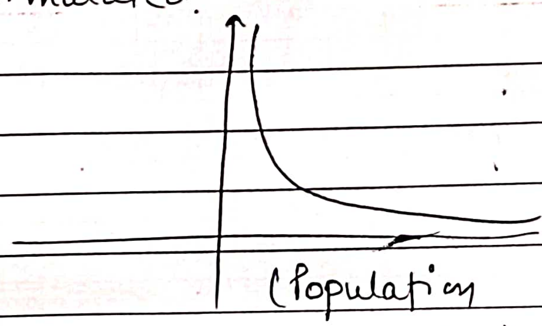
$$\boxed{\frac{A_{21}}{B} = \frac{8\pi h\nu^3}{c^3}} \quad -(12)$$

$$\frac{(P_{2\to1})\,spont}{(P_{21\to1})\,stim.} = \frac{A_{21}}{u(\nu)B_{21}} \quad -(13)$$

$$\frac{(P_{2\to1})\,spon.}{(P_{2\to1})\,sti} = (e^{h\nu/KT}-1) \quad -(14)$$

case (1), $h\nu > KT$ spontaneous

case (2), $h\nu < KT$ - stimulated.



(Population inversion)

$\mu(\nu) = 8\pi h$

Comparing eqn (10) and (11)

$$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}} \quad -(12)$$

$$\frac{(P_{2\to1})_{spont}}{(P_{2\to1})_{stimulated}} = \frac{A_{21}}{4\gamma B_{21}} \quad -(13)$$

$$\frac{(P_{2\to1})_{spont.}}{(P_{2\to1})_{stimu.}} = \left(e^{h\nu/KT} - 1\right)$$

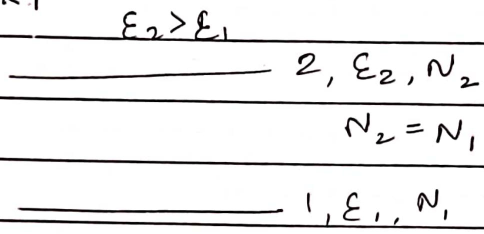
Case 1 : $h\nu > KT$ – spontaneous

Case 2 : $h\nu < KT$ – stimulated

$$\frac{(P_{2\to1})_{spont.}}{(P_{2\to1})_{stim.}} = \frac{h\nu}{KT}$$

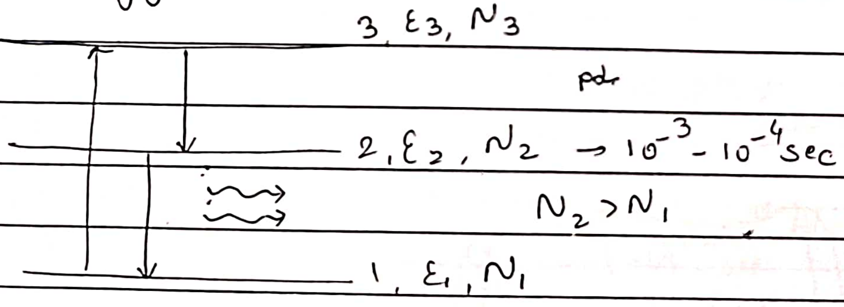
Population inversion : $N_n = N_0 e^{-E_n/KT}$

2 Energy level system

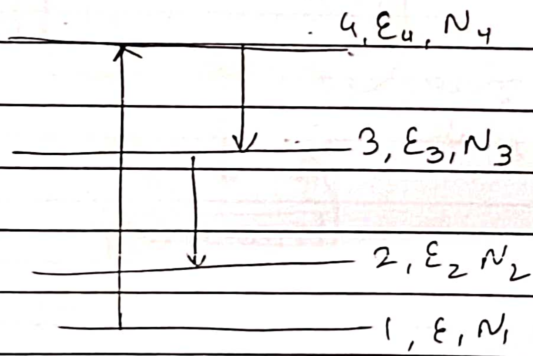


$N_3 < N_2 < N_1$

3 Energy Levels



4 - Energy Levels



(Explanation needs to be done)

Pumping: It is a process to achieve population inversion.

1.) Excitation by photon : (Example : Ruby laser, solid state laser, Dye laser etc.)

2) Excitation by electron : $e_1 + X \rightarrow X^* + e_2$

[e.g. Gas laser etc.]

3.) Excitation by inelastic collision : [eg. He - Ne laser etc.]

$e_1 + X \rightarrow X^* + e_2$

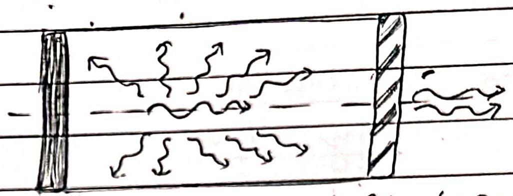
$X^* + Y \rightarrow X + Y^*$

4) Excitation by chemical process : $H + F \rightarrow (HF)^*$

(eg. chemical laser

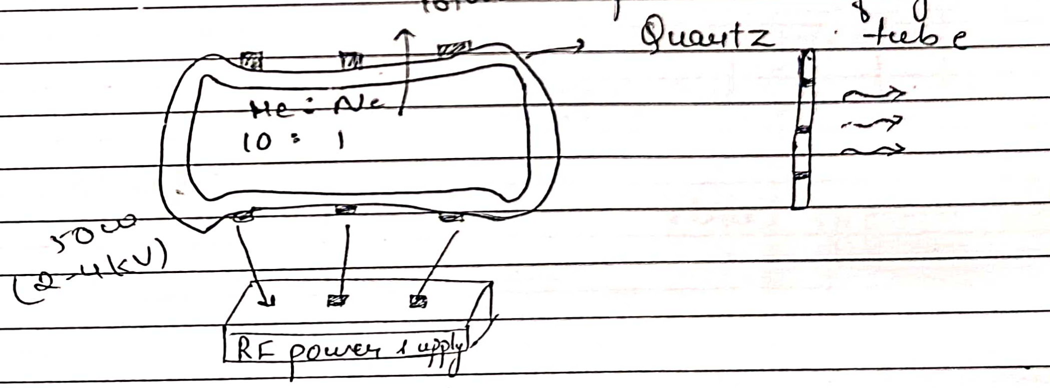
Optical Resonator :

(optical cavity or gain medium)



(Short notes can be asked)

He - Ne laser



1) Active medium : He : Ne = 10 : 1

He ↓ 1 mm Hg (Pressure)

Ne ↳ 0.1 mm Hg

2) Pumping : He will excite electron in Ne

1.) $e_1^0 + He \longrightarrow He^* + e_2$

2.) $He^* + Ne \longrightarrow He + Ne^*$

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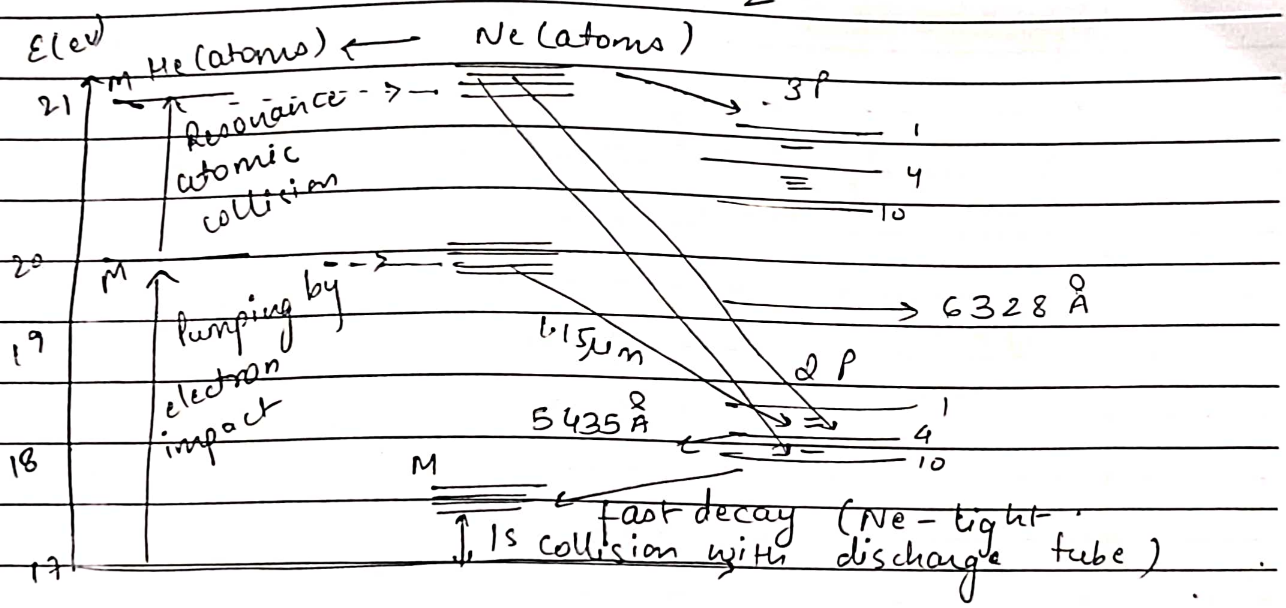
3.) Optical resonator :

Mirror M₁ & M₂



Resonance atomic collision means high energy transformation

Energy level diagram

Energy level of He : Ls coupling

Energy level of Ne : Paschean Notatic

3S → 2p (H) → laser transmission

There are more than 180 transition in He-Ne but only four are responsible for laser transmission which are :

1.) 3S → 3P

2.) 3S → 2P

3.) 2P → 1S

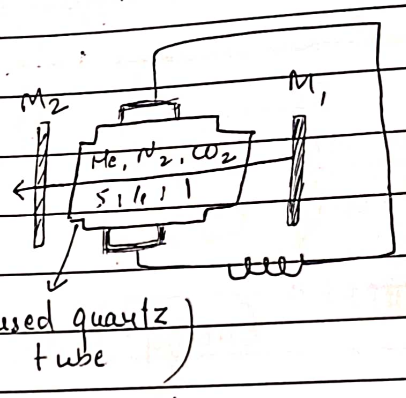
1.) 3.39 μm & 1.15 μm are infrared light thus absorbed by quartz tube.

2.) To depopulate is (metastable state) we t.. diameter very less of 1.5cm. If is not depopulate to transition in 2P not took place 2P will not depopulate and whole process stops.

3.) Intensity of 5435Å is less thus not responsible for laser transmission.

(Semiconductor laser (Diode laser) last me likha h)

Carbon dioxide laser :-
(IR region)



L = 5m , D = 2.5 cm

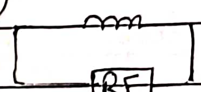
P ∝ L

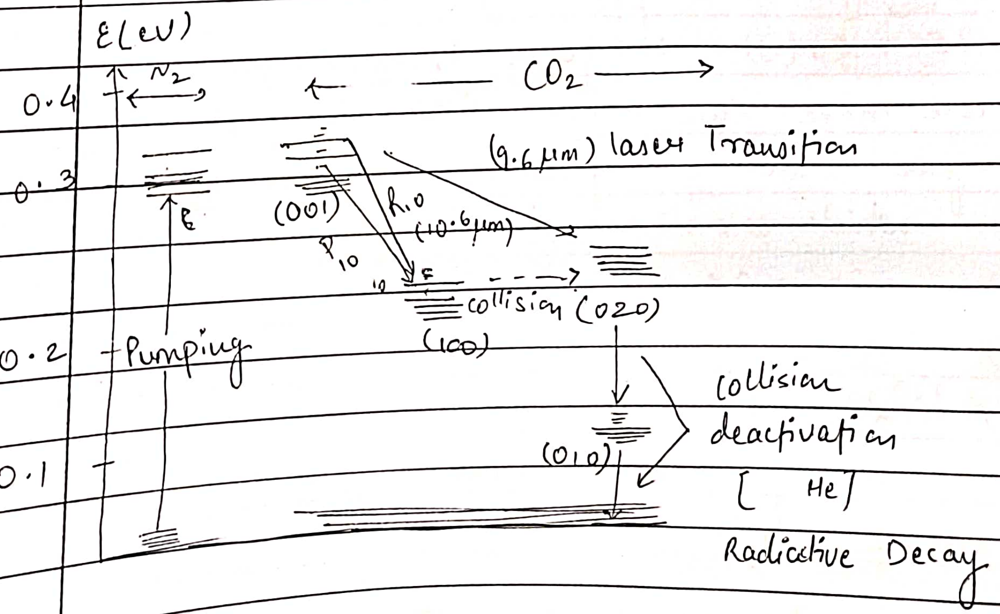
Selection Rule (Rotation energy level)

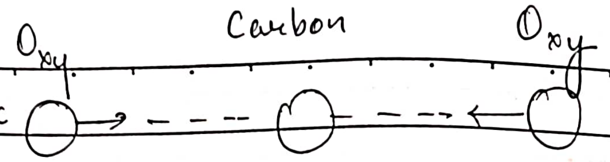
$\Delta J = \pm 1$

P_{10} $\Delta J = +1$

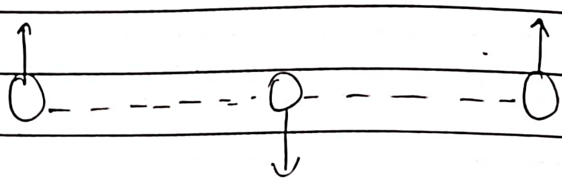
R_{10} $\Delta J = -1$



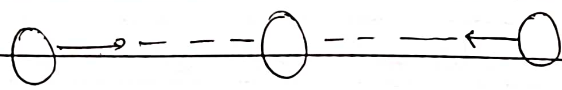




1.) Symmetric mode (ν00)



2.) Bending mode (0ν0)



3.) Assymetric mode (00ν)

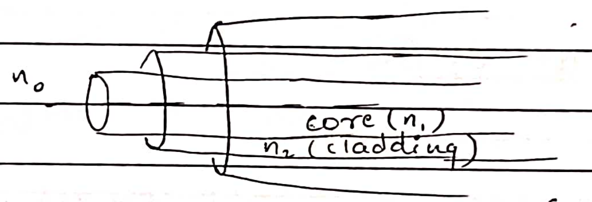
Active medium $He : N_2 : CO_2$: 5 : 4 : 1

Pumping (i.) $e_1 + N_2 \rightarrow N_2^* + e_2$

(ii.) $N_2^* + CO_2 \rightarrow N_2 + CO_2^*$

Optical Resonator

Optical fiber :



$n_1 > n_2$

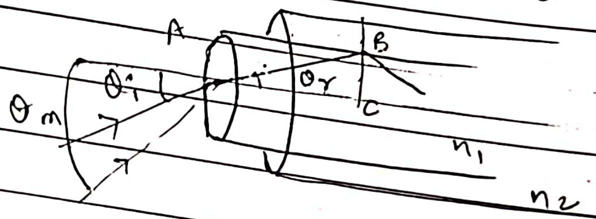
Types

material of core and cladding

	Core	cladding	
1.)	$SiO_2 + P_2O_5 / GeO_2$	SiO_2	(glass)
2.)	SiO_2	$SiO_2 + B_2O_3$ / flourene	
3.)	Glass	Plastic	
	Plastic	Plastic	

Application :-
1.) Optical fibers are used in comm.
2.) used in medicine
3.) military & space application

Light propogation through optical fibre:



Snell's law, $\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_0}$ — (1)

$\sin\theta_i = \frac{n_1}{n_0}\sin[90-\phi] = \frac{n_1}{n_2}\cos\phi$ — (2)

at $\theta_i = \theta_m$, $\phi = \phi_c$

$\sin\phi_m = \frac{n_1}{n_0}\cos\phi_c$ — (3)

$\phi = \phi_c$ $\sin\phi_c = \frac{n_2}{n_1}$ — (4) $\sin\theta_m = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$ — (5)

(medium)

θ_m = acceptance angle

$\sin\theta'_m = \sqrt{n_1^2 - n_2^2}$ — (6)

Numerical can be asked in eq^n (5) & (6)

Acceptance angle: It is the max. angle that a light ray can have relative to the axis of fiber and propogate through fiber.

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acceptance cone = $2\theta_m$

$$\theta_m = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$

• Fractional refractive index change:

$$\Delta = \frac{n_1 - n_2}{n_1} \quad \text{— (7)}$$

It is the ratio of change in refractive index of core and cladding to the refractive index of core.

• Numerical Aperture: (NA)

$$NA = \sqrt{n_1^2 - n_2^2} \quad \text{— (8)}$$

or $NA = \sin\theta_m$ — (9)

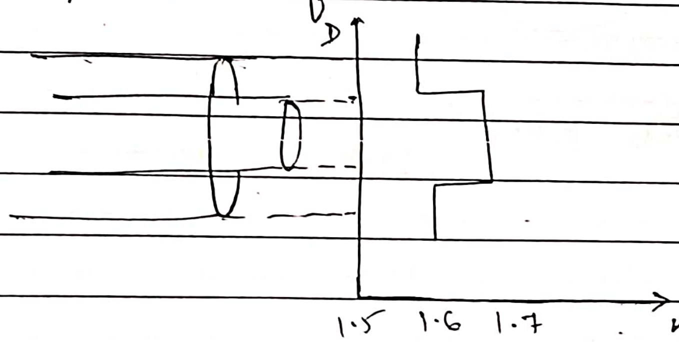
$NA = n_1\sqrt{2\Delta}$ — (10)

$$\sin\theta_m = \sqrt{(n_1 - n_2)(n_1 + n_2)} = \sqrt{\Delta n_1 (n_1 + n_2)}$$

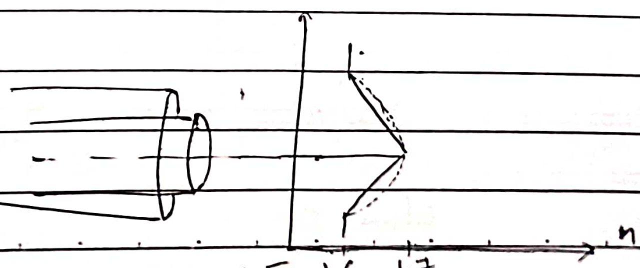
$$= \sqrt{\Delta n_1 (2n_1)} = n_1\sqrt{2\Delta}$$

Refractive index profile of core:

1.) Step index fiber:



2.) Graded Index O.F.



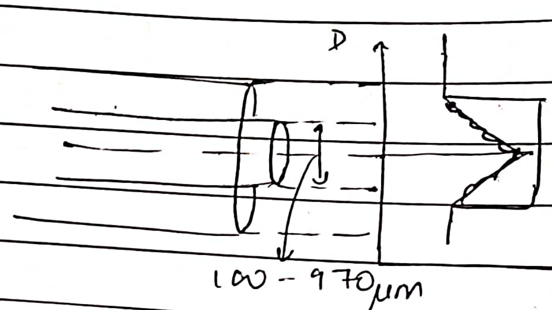
Modal dispersion

3.) Modes :- electromagnetic field distribution

Single mode fiber

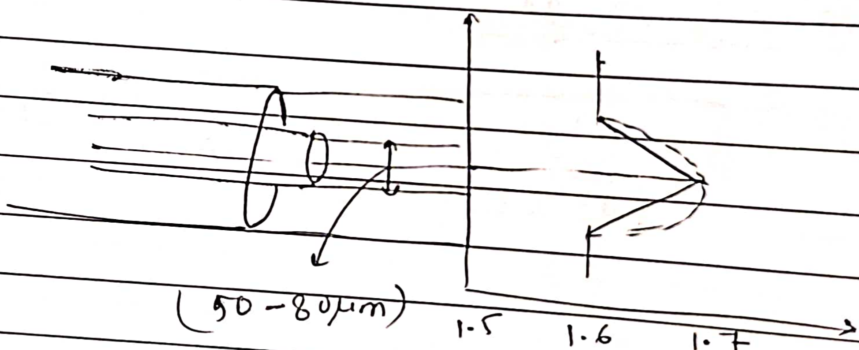
Multi mode fiber

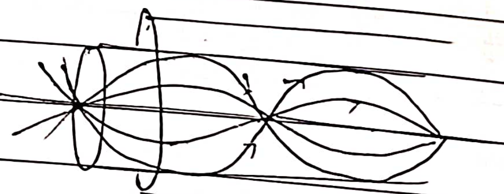
Multimode ~~graded~~ step index fiber :



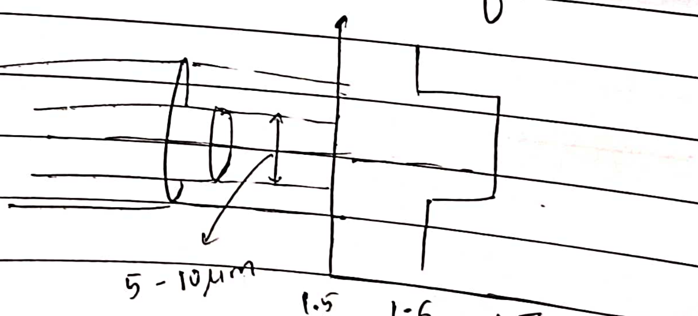
modal dispersion is fast.

Multimode graded index fiber :





single step ~~graded~~ index fiber :



along the axis

long dist. comm.

Diff: betn single mode and multi mode fiber. single mode - laser
multi mode - any light

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V-number

$$V = \frac{2a\pi}{\lambda}\sqrt{n_1^2 - n_2^2} \quad -(1)$$

a = radius of core
2a = diameter of core

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

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

This is called the normalise frequency of optical fiber.

Multimode :-

→ Step index

$$N_{max} \simeq \frac{V^2}{2}$$

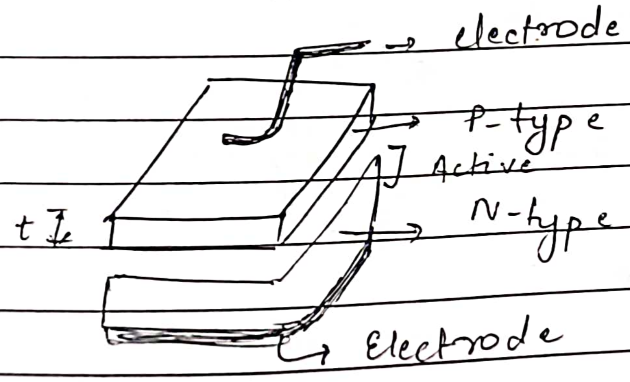
→ Graded index

$$N_{max} \simeq \frac{V^2}{4}$$

Single node :- $V < 2.405$
Multi mode : $V > 2.405$

$V \cong 2.405$ minimum one mode will travel

Semiconductor laser (Diode laser) :



GaAs ≈ 3 (μ)

$t \approx 0.5\,mm$

* GaAs / GaP
  ↳ heavy doping

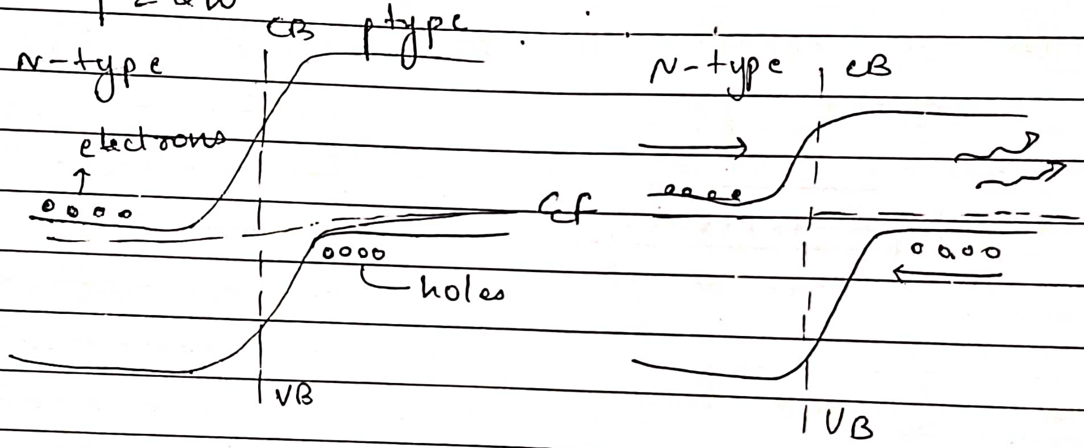
Single crystal

p-type (pentavalent impurity)

* 1) Le (Penetration depth)
  ↳ 2) active region becomes narrow.
  (3) more electrons.
  (process will be controlled by electrons)

* Platelate type structure.

* $\rho = 2W$

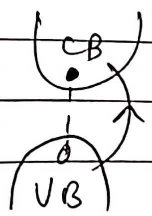


Forward biased

Due to heavy doping VB of p-type come close to CB of N-type.

efficiency = 30% to 40%.
(output) o/p 72mm

GaAs
(Direct band gap)



CB & VB are properly aligned