

polarisations and lasers:- The phenomenon of light

1. Reflection

3. Interference

5. Polarization

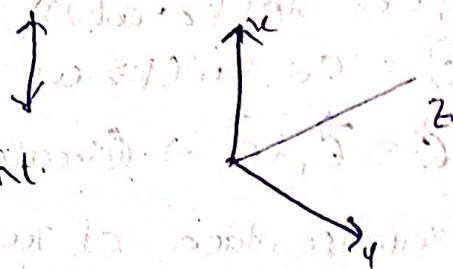
2. Refraction

4. Diffraction

Polarization:- Transverse nature of EM waves is explained by the phenomena of polarization.

* Wave orientation of wave

* It explains the particle nature of light.



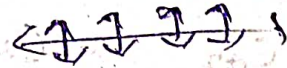
Types of polarization:-

* Linearly polarized light.

* Elliptically polarized light.

* Circularly polarized light.

* Linearly polarized:- The oscillations confined to a particular plane. (plane polarized light)



$$\vec{E} = E_0 \cos(kz - \omega t) \hat{i} \Rightarrow \text{(L.P.L)} \quad (\odot) \quad \vec{E} = E_0 \cos(kz - \omega t) \hat{i}$$

z - spatial coordinate. $\hat{i}$ - polarization direction.

t = time coordinate.

$$\vec{E} = E_0 \cos(kx - \omega t) \hat{z} \text{ - P.D (orientation)}$$

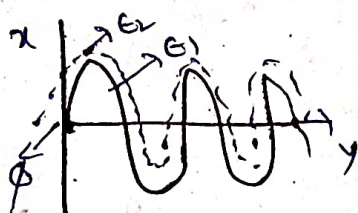
$$\vec{E}_1 = E_0 \sin(kz - \omega t) \hat{i}$$

$$\vec{E}_2 = E_0 \sin(kz - \omega t + \phi) \hat{i}$$

Travelling x

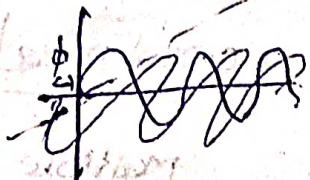
y $\rightarrow$ P.L. ϕ_2

$\phi_2 - \phi_1 = \epsilon \rightarrow$ phase difference b/w E_1 and E_2



$$E_1 = E_0 \sin(kz - \omega t) \hat{i}$$

$$E_2 = E_0 \sin(kz - \omega t + \phi) \hat{i}$$



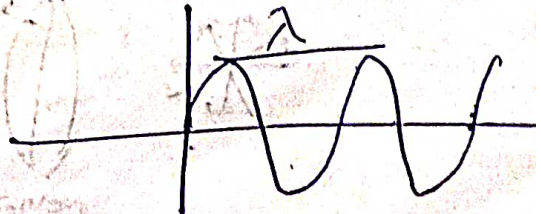
E_2 lags E_1
Phase difference = $\frac{2\pi}{\lambda} \times (\text{path difference})$

if $P.O.D = \lambda \Rightarrow \text{phase diff} = 2\pi$

$2\lambda \quad \Delta\phi = 4\pi$

$\lambda/2 \quad \Delta\phi = \pi$

$\pi/2 \quad \Delta\phi = \pi/2$



$$\frac{\lambda}{2}$$

$$\pi/2$$

$$\lambda/4$$

$$\pi/2$$

Circularly polarized light:

can generate the C.P.L. by adding the two L.P.L of perpendicular different directions. Orientation

$$\vec{E}_1 = E_0 \sin(kz - \omega t) \hat{i}$$

$$\vec{E}_2 = E_0 \sin(kz - \omega t + \pi/2) \hat{j}$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2 \rightarrow \text{Circularly polarized light}$$

* Composition of two L.P.L of two orthogonal direction & maintain $\pi/2$ phase.

(3) Exptial elliptically polarized light:

$$\vec{E}_1 = E_{01} \sin(kx - \omega t) \hat{i}$$

$$\vec{E}_2 = E_{02} \sin(kx - \omega t + \pi/2) \hat{j}$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2$$

$$\frac{E_0}{E_{01}} = \sin(kx - \omega t) \quad \text{--- (1)}$$

$$\frac{E_0}{E_{02}} = \cos(kx - \omega t) \quad \text{--- (2)}$$

* E.P.L is generated by adding two L.P.L with different amplitudes have $\pi/2$ phase difference.

* It traces the elliptical path

$$\left(\frac{E_1}{E_{01}}\right)^2 + \left(\frac{E_2}{E_{02}}\right)^2 = 1 \Rightarrow \text{ellipse equation.}$$

unpolarized light:



multiple orientations.

Generating p.L from u.p.L: which allows the components parallel to path axis.



polarizer

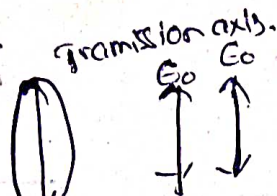


production of p.L by polarizers.

Malus law -

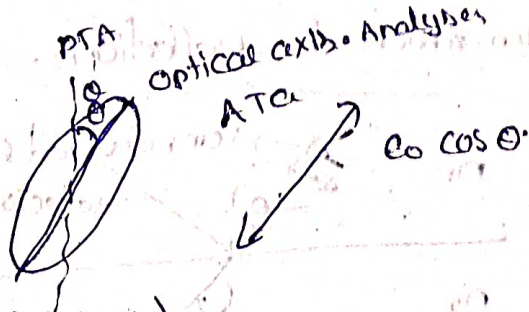


polarizer



(polarizer)

(analyzer)



Intensity of light after the analyzer

$$I \propto (E_0 \cos \theta)^2$$

$$I = \frac{1}{2} (E_0^2 \cos^2 \theta)$$

$$= \frac{1}{2} (E_0^2 \cos^2 \theta) \quad \text{or}$$

$$I \propto E_0^2 \cos^2 \theta$$

$$I = I_0 \cos^2 \theta$$

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

$$I_A = I_0 \cos^2 \theta$$

$$I = \frac{I_0}{3} \Rightarrow \frac{I_0}{3} = I_0 \cos^2 \theta$$

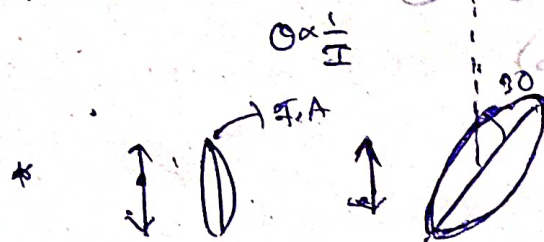
$$\frac{1}{3} = \cos^2 \theta$$

$$\cos \theta = \frac{1}{\sqrt{3}} = \cos^{-1}\left(\frac{1}{\sqrt{3}}\right) = 54.736^\circ$$

$$\textcircled{b} \theta_2 \quad \cos \theta = \frac{1}{\sqrt{5}} = \cos^{-1}\left(\frac{1}{\sqrt{5}}\right) = 63.435^\circ$$

$$\textcircled{c} \theta_3 \quad \theta \propto \frac{1}{I}$$

Note: When Intensity of light when the transmission light of polarizer and analyzer

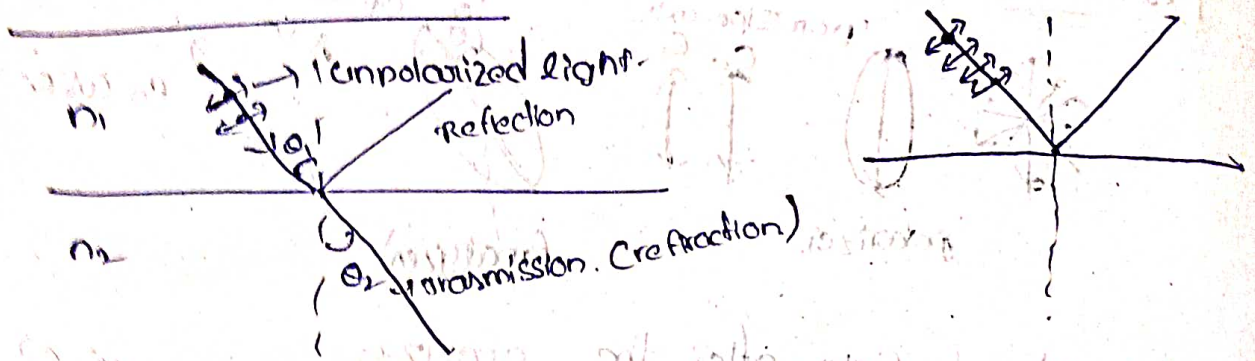


$$I = I_0 \cos^2 \theta$$

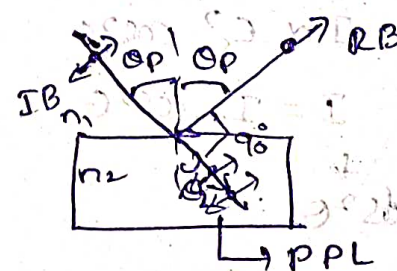
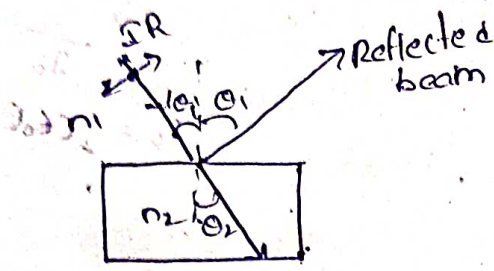
$$I = 10.75 I_0$$

$$\frac{I}{I_0} = \frac{3}{8} = 0.375$$

polarization by Reflection: μ Haeus



$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \text{Snell's law.}$$



Whenever a light is incident at a particular angle the reflected is polarized light and refracted light is partially polarized light. we call that angle is polarizing angle (or) Brewster angle " θ_p "

at $\theta_i = \theta_p$ reflected ray $\perp$ refracted ray.

$$\theta_2 + \theta_p + 90^\circ = 180^\circ$$

$$\boxed{\theta_2 = 90^\circ - \theta_p} \quad \text{--- (1)}$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \text{from (1)}$$

$$n_1 \sin \theta_p = n_2 \sin (90^\circ - \theta_p)$$

$$n_1 \sin \theta_p = n_2 \cos \theta_p$$

$$\frac{\sin \theta_p}{\cos \theta_p} = \frac{n_2}{n_1}$$

$$\tan \theta_p = \frac{n_2}{n_1}$$

$$\theta_p = \tan^{-1} \left(\frac{n_2}{n_1} \right)$$

* $\frac{n_2}{n_1}$ for air-glass interface
water-glass

$$\theta_p = \tan^{-1} \left(\frac{1.5}{1} \right) = 56.31^\circ$$

$$\theta_p = \tan^{-1} \left(\frac{1.33}{1.31} \right) = 48.81^\circ$$

Note: Brewster angle depends on the refractive indices of two medium.

Double refraction:

* Doubly refracting crystal calcite, quartz

* When we pass ray through the crystals. - splits into

(1) Ordinary (o-ray) - $n_o = \frac{c}{v_o}$ } $n_e - n_o = \Delta n$ birefringence.

(2) Extraordinary (e-ray) - $n_e = \frac{c}{v_e}$ } Δn birefringence.

Ex:

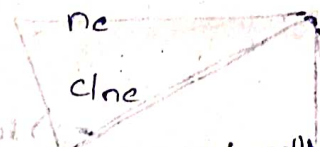
$$c = 3 \times 10^8 \text{ m/s} = 3 \times 10^5 \text{ km/s}$$

Ordinary ray

Extraordinary ray.



o-ray travels with the same velocity in all directions.



E-ray travels with different velocities in different directions.

o-rays form a spherical wavefronts

E-ray forms a ellipsoidal wavefront

Optic axis: both e-ray and o-ray with travel with the same velocity.

$\Delta n = n_e - n_o > 0 \Rightarrow n_e > n_o \rightarrow$ one optic axis } Positive uni-axial crystal

$\Delta n = n_e - n_o < 0 \Rightarrow n_o > n_e \rightarrow$ one optic axis } -ve uni-axial crystal

Ex: calcite (CaCO3)

Quartz (SiO2)

Sodium nitrate (NaNO3)



Negative



Positive

$V_o > V_e$ for quartz (+ve uniaxial crystal)

$V_e > V_o$ for calcite (-ve uniaxial crystal)

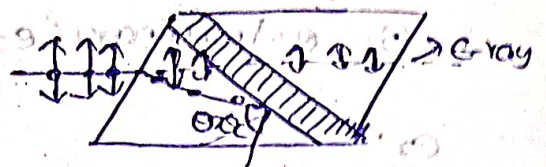
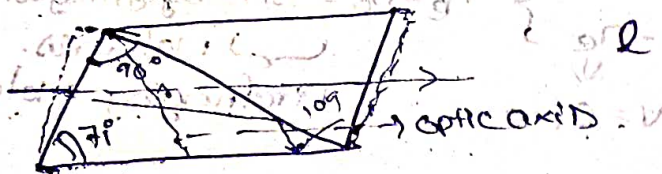
Biaxial crystals :-

Ex: Mika, Sulphur, Topaz, leadoxide

Nicol prism: It can be used as polarizer as well as

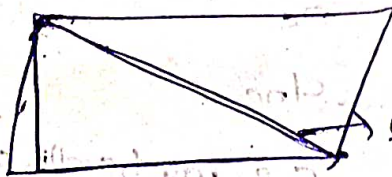
Analyzer. (Analysis)

(polarizer)



* Nicol prism made up of calcite crystal.

* Calcite crystal cut into two pieces



$n_o = 1.68$

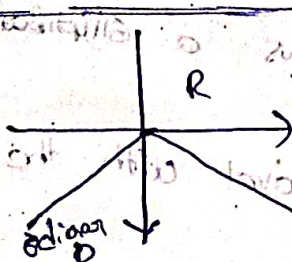
$n_e = 1.49$

larger Canada balsam (1.55)

(4 components, hence total

light reflects

Total Internal Reflection

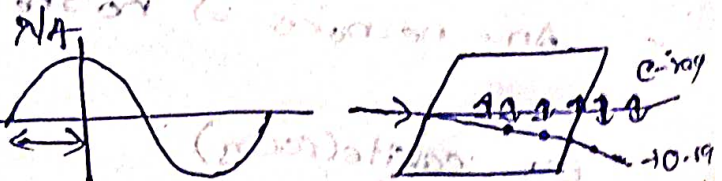


* Because the double reflection phenomenon unpolarized light is converted into polarized light

Retardation plates:

$\frac{\lambda}{4} \Rightarrow$ Quarter wave plate ($\lambda/4$)

$\frac{\lambda}{2} \Rightarrow$ Half wave plate ($\lambda/2$)



$$(n_e - n_o)t = \lambda/4$$

$$t = \frac{\lambda}{4(n_e - n_o)}$$

$$\Delta n = -ve \text{ (calcite)} \quad n_e - n_o = +ve \text{ (quartz)}$$

$$\downarrow$$

$$\lambda/4 \rightarrow \Delta n < 0$$

$$n_o > n_e$$

↓
less velocity

$$(n_o - n_e) \lambda_{\text{exp}} = \lambda/4$$

$$\lambda_{\text{exp}} = \frac{\lambda}{4} \left(\frac{1}{n_o - n_e} \right)$$

$$\lambda_{\text{exp}} = \frac{\lambda}{4} \left(\frac{1}{n_e - n_o} \right)$$

$$\lambda_{\text{exp}} = \lambda \left(\frac{1}{n_e - n_o} \right)$$

$$\text{Ex: } \lambda = 5000 \text{ \AA}$$

$$n_o = 1.583$$

$$n_e = 1.499$$

$$\lambda = \frac{\lambda}{4} \left(\frac{1}{n_o - n_e} \right) \quad \lambda_{\text{exp}}$$

$$= 1250 \text{ \AA} \left(\frac{1}{0.034} \right)$$

$$= 3,676.47 \text{ \AA}$$

$$= 5000 \text{ \AA} \left(\frac{1}{0.034} \right)$$

$$= 14,705.88 \text{ \AA}$$

$$= 14,705.6 \text{ \AA}$$

$$= 36,764.7059 \text{ \AA}$$

$$= 36,760.5 \text{ nm}$$

Optical activity: (Laurent's Half shade polarimeter).

if the solution rotates plane polarization light
Ex: sugar crystals, sugar solution, sodium chlorate etc.,
clinometer

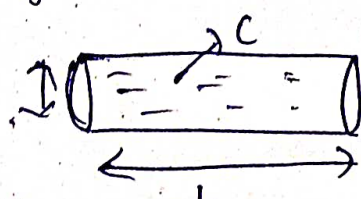
dextrorotary

levorotary

(Right) ↘ ↗

(Left) ↙ ↘

* Let us consider a optical active solution in tube with length 'L' and concentration 'c'



$$\theta \propto c$$

$$\theta \propto L$$

$$\theta \propto L$$

$$\theta = s \cdot L \cdot c$$

$$\left. \begin{array}{l} \theta \propto c \\ \theta \propto L \end{array} \right\} s = \theta / Lc \quad s = \frac{\theta}{Lc}$$

→ specific rotation (constant)

if $s = \theta$ $L = 1$ decimeter length $c = 1$ gr/cc $\text{decimeter} = \frac{1}{10} \text{ cm}$

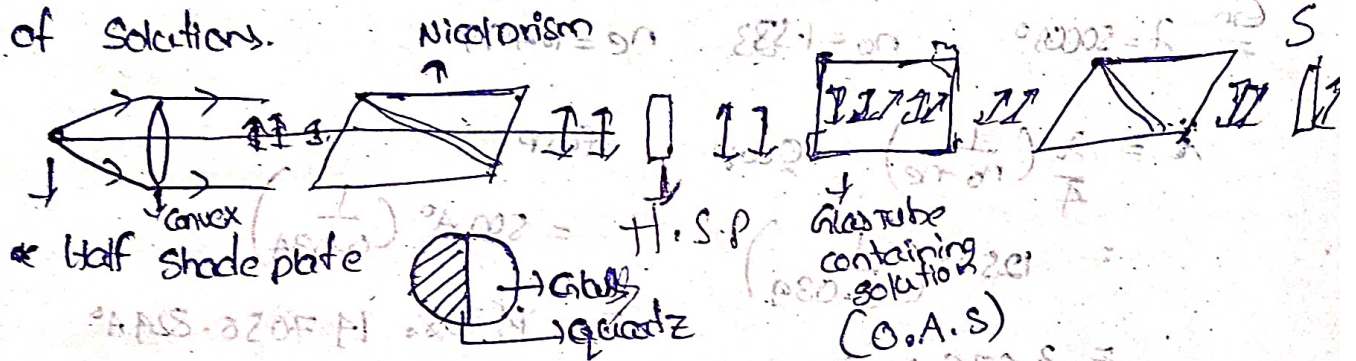
* units $\text{deg}/\text{Dec gr/cc}$ (or) $\frac{\text{deg. cc}}{\text{Dec. gr}}$ (at constant W.L.)

Specific rotation: The amount of rotation done when concentration is 1 gr/cc and length 1 decimeter.

Laurent's Half shade polarimeter:

polarimeter To measure the angle of polarization. (Optical rotation)

* A polarimeter is an instrument used for optical rotation of solutions.



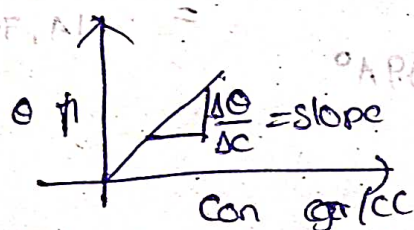
10 gr/cc

45°

15 gr/cc

47°

30°

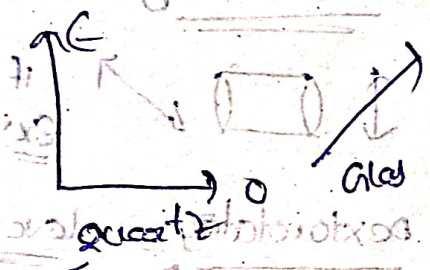
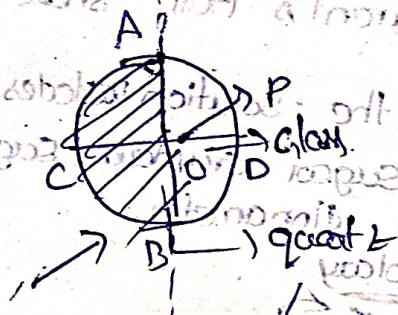


slope $= \frac{45}{10} = 4.5$
 $\text{Slope } S = \frac{\text{Slope}}{L}$

* Half shade plate

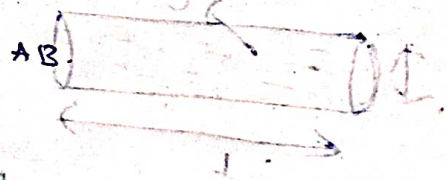
consists of 2
Semi-circle part

* one Semi circle is filled with Glan and another with quartz



* Monochromatic light is used.

* The optic axis is parallel to the



* half-shade polarimeter.

- * glass tube for holding the solution between the nicol prism.
- * Monochromatic light incidents on the polarizer N_1 .
- * light transmitted is plane polarized light.
- * polarized beam passes through the half-shade plate and glass tube G containing the solution.
- * Light emerging from the solution incidents on the analyzer N_2 .
- * Light is observed through the telescope T.
- * Analyzing Nicol N_2 can be rotated about the axis of the tube and the rotation can be measured.

Working.

- * Analyzer is adjusted - field of view is completely dark.
- * Glass tube is filled with solution.
- * field now becomes illuminated.
- * field of view is made dark by rotating the analyzer through a certain angle - (optical rotation of the solution).
- * practically difficulty is to determine the exact position to which complete darkness is achieved. This can be overcome by Laurent's half shade device.

Laser

1. Highly monochromatic (single λ)

2. Less divergence (long distance travel)

3. High power

4. High coherence

LASER (Light Amplification by Stimulated Emission of Radiation)

Einstein

Ch. H. Townes

Maiman

↓ types
solid, gas, liquid, semiconductor, ion laser.

Components of a Laser System:

1. Active medium

2. Pumping mechanism (pumping source)

3. Feedback system

1. Active medium: collection of atoms or molecules, ions or

2. pumping source: - pumping energy to atoms or molecules or ions, to move them from ground state to excited state

3. feedback system: to do amplification

1. stimulated absorption:

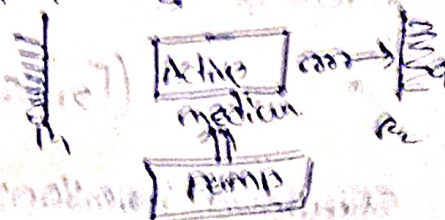
2. spontaneous emission:

3. stimulated emission:

1. stimulated absorption:

$$E_2 - E_1 = h\nu \quad h\nu > E_2 - E_1$$

Excited state is unstable state



R_{12} = rate of stimulated absorption. (number of atoms undergoing the absorption from ground state to excited state per unit time per unit volume).

$R_{12} \propto N_1$ (no. of atoms present in ground state)
 $R_{12} \propto N_1 U(\omega)$ Energy density of incident radiation

$R_{12} = B_{12} N_1 U(\omega)$
 $\rightarrow$ (emission co-efficient of stimulated absorption)

Spontaneous emission:

* All atoms present in g.s. may not go absorption

Normally $N_1 > N_2$
 after stimulation $N_2 > N_1$ (population inversion condition)
 $\rightarrow$ life time is more

after ns short time
 $\downarrow \downarrow$ emits photons (excess energy) $\rightarrow$ random direction.
 The light produced by these photons is known as incoherent light

rate of spontaneous emission (R_{21}) $\propto N_2$

Stimulated inversion:
 $(R_{21})_{st} = A_{21} N_2$ --- (2)
 $\rightarrow$ co-efficient of spontaneous emission
 External radiation $\rightarrow$ Gain photon
 $\downarrow \downarrow$ photon $\rightarrow$ in phase $\rightarrow$ photon

Life time (τ)

$(R_{21})_{st} \propto N_2$ $(R_{21})_{st} = B_{21} N_2 U(\omega)$ --- (3)

$(R_{21})_{st} \propto U(\omega)$

The rate of atoms undergoing the downward transmission is called as rate of stimulated emission

Thermal Equilibrium

* Net Number of upward transmissions is equals to downward transmission

$$(T_{12})_{\text{obs}} = (T_{21})_{\text{spont}} + (T_{21})_{\text{stim}}$$

$$B_{12} N_1 U(\omega) = A_{21} N_2 + B_{21} N_2 U(\omega)$$

$$(B_{12} N_1 - B_{21} N_2) U(\omega) = A_{21} N_2$$

$$B_{12} N_1 U(\omega) = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

$$U(\omega) = \frac{A_{21} N_2}{N_1 \left(\frac{B_{12}}{B_{21}} - 1 \right)}$$

$$U(\omega) = \frac{A_{21}}{\frac{N_1}{N_2} (B_{12} - B_{21})}$$

$$U(\omega) = \frac{A_{21}}{B_{21}}$$

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

Boltzman's relation

$$N = N_0 e^{-E/k_B T}$$

↓ ↓
excited ground
state state

$$N_1 = N_0 e^{-E_1/k_B T}$$

$$N_2 = N_0 e^{-E_2/k_B T}$$

$$\frac{N_1}{N_2} = \frac{e^{-E_2/k_B T}}{e^{-E_1/k_B T}}$$

$$\hookrightarrow \frac{N_1}{N_2} = e^{-\frac{E_1}{k_B T}} e^{E_2/k_B T}$$

$$= e^{\frac{E_2 - E_1}{k_B T}}$$

$$= e^{\frac{h\nu}{k_B T}}$$

$$h = \frac{h}{2\pi} \omega = 2\pi f$$

$$E_2 - E_1 = h\nu = h\omega = hf$$

$$\frac{N_1}{N_2} = e^{\frac{h\nu}{k_B T}} \quad \text{--- (1)}$$

sub (1) in eq (1)

$$v(\omega) = \left(\frac{A_{21}/B_{21}}{\frac{B_{12}}{B_{21}} e^{\frac{h\nu}{k_B T}} - 1} \right) \quad \text{(energy density) --- (3)}$$

$$v(\omega) = \frac{h\omega^3 n_0^3}{\pi^2 c^3} \left(\frac{1}{e^{\frac{h\nu}{k_B T}} - 1} \right) \quad \text{--- (4)}$$

(1) is Planck's formula
is radiation

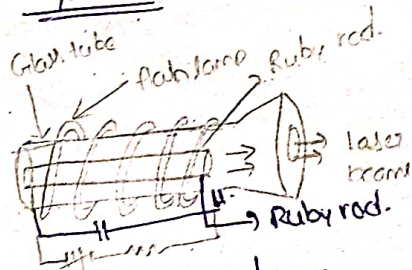
$$\Rightarrow \boxed{A_{21}/B_{21} = \frac{h\omega^3 n_0^3}{\pi^2 c^3}}$$

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

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

$$\boxed{A_{21} = \frac{h\omega^3 n_0^3}{\pi^2 c^3} B_{21}}$$

* ① Ruby laser:-



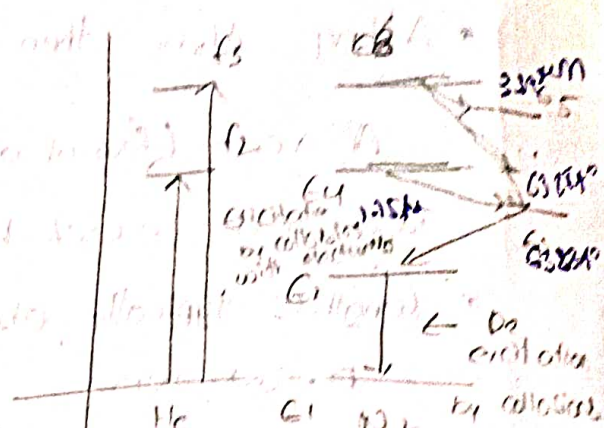
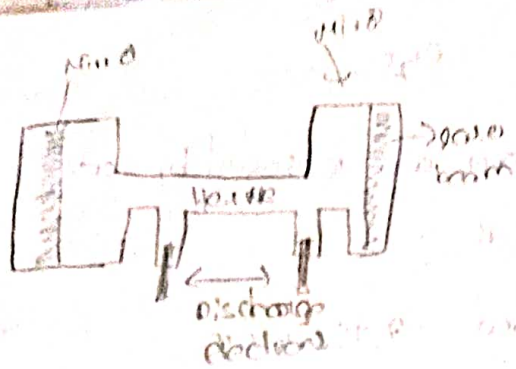
* solid state laser.

* Al_2O_3 (Aluminium Oxide) → Ruby

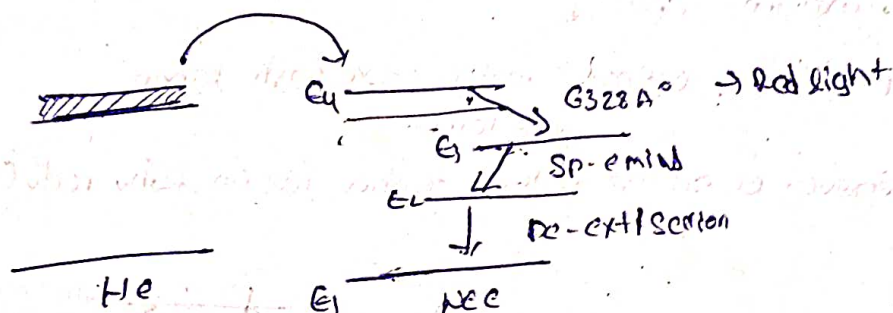
* 3 level laser system

* At the 2 level is impossible to achieve inverse population

* if we can another level it will be easy to have the life time of ground state



* electrons will discharge from electric discharge

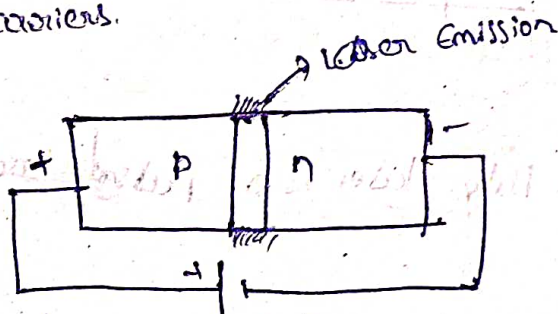


Semi-conductor lasers:-

* Electrons & holes are carriers.

* Semi-conductor laser is nothing p-n junction

* Laser output obtain when only diode is forward (forward bias) bias.



* There are very cheap, compact size and consume low power, compact size.

* There are also known as laser diodes.

* electrical energy is used as pumping source

* p-n junction of semi-conductor diode form the active medium (a) laser medium.

* Optical gain is produced within the semi-conductor material

* Semiconductor laser is made up of active material of gallium arsenide (GaAs) of thickness 0.2 microns. This is sandwiched inbetween ~~p and n-type~~ p-type GaAsAL and n-type GaAsAL. The resonant cavity is provided by polishing opposite faces of the GaAs crystals and the pumping occurs by passing electrical current from external source.

* $7000\text{\AA}$ to $30,000\text{\AA}$ λ can be produced.