Unit - 3 LASER

Full form - Light Amplification by Stimulated Emission of Radiation.

★ **Definition :-** LASER is a process by which one can get a strong intense, Monochromatic & Unidirectional and highly coherent beam of light.

★ **Application of LASER.**

(i) In medical field.

(ii) LASER printer, LASER mouse, LASER Light.

(iii) ★ In Aircraft (Radar System Based)

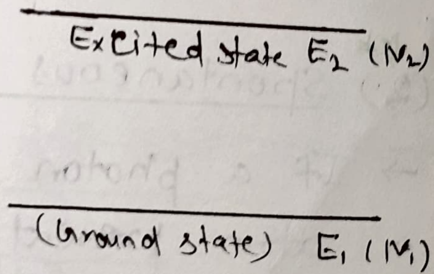
(iv) In material science [LASER Beam machine].

• **Interaction of Light with matter :-**

Every matter consists of small atoms and atoms consists a central tiny partical (Nucleus) and e^- revolved around the nucleus in varios energy Levels (Orbitals).

→ Here we consider two energy level system for LASER E_1 = energy level one also called ground state.

and E_2 = energy level two also called excited state.



N_1 & N_2 = Population density per unit volume (No of atoms)

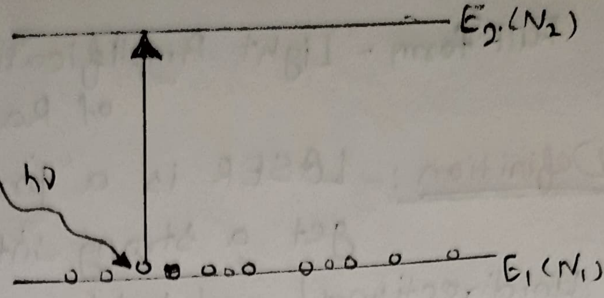
• **There are three basic Process**

(i) Absorption or Stimulated absorption

(ii) Spantaneous emission

(iii) Stimulated emission / Induced emission lifetime = 10^{-8} sec

(1.) Absorption / Stimulated Absorption :- ($N_2 >> N_1$)



Let us consider two energy levels of ground and excited state for an atom. → Suppose if a photon of ($h\nu$) energy interact with an atom present in the ground state. Than the atom gets Exicitation from ground to excited state. This process is called Absorption.

$$E_1 - E_2 = h\nu$$

Let,

$R_{12(abs)}$ = Rate of absorption from Level-1 to Level-2

$R_{12(abs)} \propto N_1$ — (i)

$R_{12(abs)} \propto U[\nu]$ — (ii)

by combining both

$R_{12(abs)} \propto N_1 U[\nu]$

$$\boxed{R_{12(abs)} = B_{12} N_1 U[\nu]} \quad \text{— (iii)}$$

$U[\nu]$ = Incident energy density (Density of photons)

B_{12} = Cofficient of Einstien's for absorption.

(2.) Spontaneous Emission :-

→ If a photon of energy ($h\nu$) interact with an atom present in the ground state, the atom gets excitation from ground state to excited state. The excited atom does not stay for a long time in excited state due to limited lifetime (10^{-8} sec) and get de-exeited and this process is called Spontaneous emission.

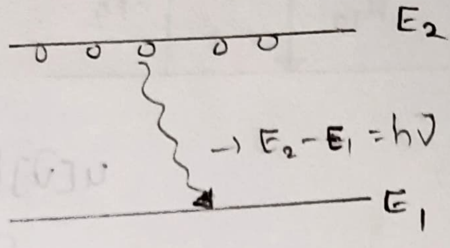
Let

$R_{21E} \rightarrow$ Rate of spontaneous emission from level 2 to level-1.

$R_{21}(spo) \propto N_2$

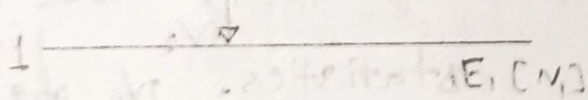
$$\boxed{R_{21(spo)} = A_{21} N_2} \quad \text{---(iv)}$$

A_{21} = Einstien's coff. of spontaneous emission.



(3.) Stimulated emission:-

Consider a Photon of proper energy incident on two energy level system then it may be possible that it interect with an atom lies in excited state and force into jump into lower state and emit a photon energy. So finally two photons are emited (Both in same phase and same direction) Such type of emission is called stimulated or Induced emission.



let

R_{21} (stimulated emission) $\propto N_2$ ---(i)

$R_{21} \propto u[\nu]$ ---(ii)

$$\boxed{h\nu = E_2 - E_1}$$

$R_{21}(sti) \propto N_2\, u[\nu]$

$R_{21}(sti) = B_{21} N_2\, u[\nu]$

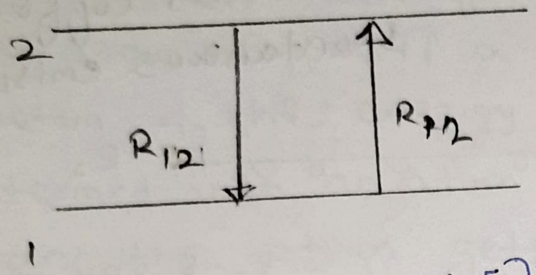
Here

B_{21} = Cofficient of Einstien's for stimulated emission.

★ Relation Between Einstien's cofficient :-

→ In thermal equilibrium Rate of Absorption is equal to Rate of emission.

$$R_{12} \text{ (Rate of absorption)} = R_{21} \text{ (Rate of emission)}$$



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

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

$$\boxed{u[\nu] = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}}$$

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

$$\boxed{u[\nu] = \frac{A_{21} / B_{21}}{\left[\frac{B_{12}}{B_{21}}\left(\frac{N_1}{N_2}\right) - 1\right]}} \quad \text{— (i)}$$

→ To find N_1/N_2 we use maxwell Boltzmaan statistics. No. of atoms in a given energy of state of energy E and at tempr T is given by

$$\boxed{N = N_0 e^{-E/KT}}$$

So

$$N_1 = N_0 e^{-E_1/KT}$$

$$N_2 = N_0 e^{-E_2/KT}$$

So $\frac{N_1}{N_2} = e^{-\frac{1}{KT}[E_1 - E_2]}$

$\frac{N_1}{N_2} = e^{+\frac{1}{KT}[E_2 - E_1]}$

$\because h\nu = E_2 - E_1$

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

So by eq (i)

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

Note Energy Density u[ν] is given by Max Plank in black body radiation

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

by comparing eq (ii) & (iii)

$A_{21}/B_{21} = 8\pi h \nu^3 / c^3$ & $\frac{B_{12}}{B_{21}} = 1$

$\Rightarrow \boxed{\frac{A_{21}}{B_{21}} \propto \nu^3}$ $\boxed{B_{12} = B_{21}}$

At high frequency (in visible region) the probability of spontanous emission is much greater then stimulated emission.

& the probability of absorbtion and stimulated emission is always equal.

Thershold Condition for LASER Operation :-

Rate of Absorption => $R_{12}(abs) = B_{12} N_1 u[\nu]$

Rate of spontaneous emission => R_{12} (Spo. emission) $= A_{21} N_2$

Rate of stimulated emission => R_{21} (Sti. emission) $= B_{21} N_2 u[\nu]$

for LASER action => Rate of emission is much more greater than rate of absorption (Non-equilibrium process)

$$\frac{R_{21}(\text{emission})}{R_{12}(\text{Absorption})} >> 1 \Rightarrow \frac{B_{21} N_2 u[\nu] + A_{21} N_2}{B_{12} N_1 u[\nu]} >> 1$$

$$\frac{\cancel{B_{21}} N_2}{\cancel{B_{12}} N_1} + \frac{A_{21} N_2}{B_{12} N_1 u[\nu]} >> 1$$

As we know that $B_{12} = B_{21}$

$$\frac{N_2}{N_1}\left[1 + \frac{A_{21}}{u[\nu] B_{12}}\right] >> 1$$

from this eq.

$$\frac{N_2}{N_1} >> 1$$

$$\boxed{N_2 >> N_1}$$

this condition is also known population inversion.

Q Calculate the ratio of Population of two energy source of LASER, the transition between which is responsible for emission of Photons of wave length 6928 Å. Assume the transition temp^r to be 18° C

Soln Given $\lambda = 6928 Å$ $\qquad N_2/N_1 = ?$

$T = 18 + 273 = 291 K$

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

$E_2 - E_1 = h\nu = \frac{hc}{\lambda}$

$E_2 - E_1 = \frac{6.62 \times 10^{-34} \cdot 3 \times 10^{+8}}{6928 \times 10^{-10}}$

$E_2 - E_1 = 28 \times 10^{-20}$

$$\frac{N_2}{N_1} = e^{\frac{28 \times 10^{-20}}{1.38 \times 10^{-23} \times 291}}$$

$$\frac{N_2}{N_1} = e^{0.069 \times 10^{3}}$$

$$\frac{N_2}{N_1} = e^{69} = 9.25 \times 10^{+32} \text{ Ans}$$

• Components of a LASER System :-

(1) LASER active medium or Active material.

(2) Optical Resonator

(3) Pumping Source (Energy Source)

(4) Cooling system [He-Ne Sem]

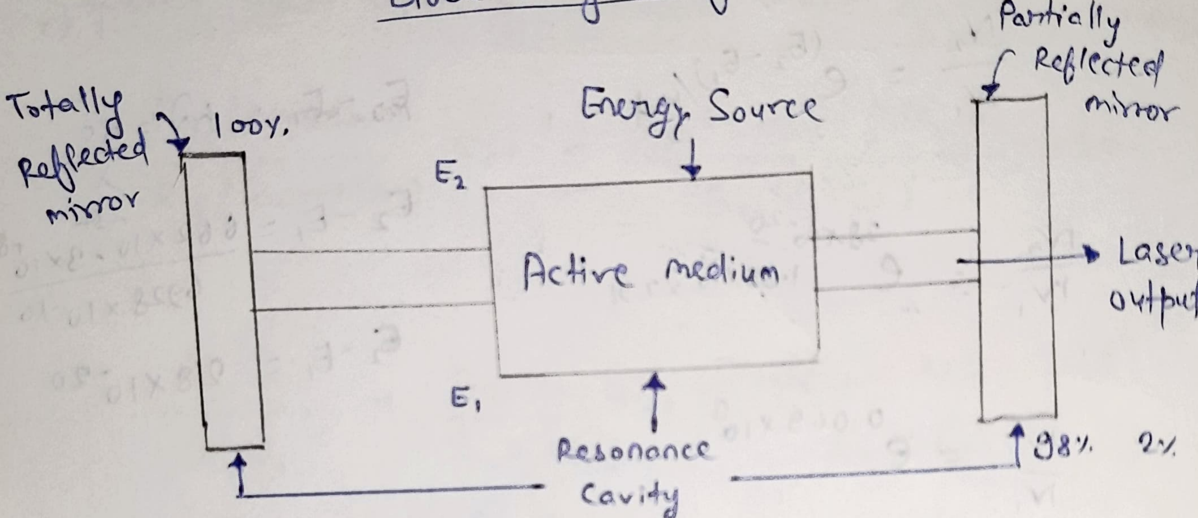
(1) LASER active medium Active material-

- Active medium in a LASER is a collection of atoms or molecules that generates ~~LASE~~ LASER light.
- LASER medium is also known as active medium or gain medium.

- The active medium is pumped into an excited state which is a higher energy state this is done by ~~Supp~~ Supplying energy through an electric current

- The active medium can be in a solid, liquid and gaseous or plasma state. The method used to introduce energy into the active medium depends on its state.

Block diagram of a laser



(2) Pumping Source (Energy Source)

The process by which population inversion ($N_2 >> N_1$) is a achieved in a LASER system is called pumping Source

The type of pumping method used depends on nature of Active medium used in LASER System
→ for ex- In Solid state LASER such as ruby LASER, we use optical pumping. In Gaseous state, such as He-Ne LASER we use electrical pumping,
→ Pumping Source is an energy source used to create population inversion ($N_2 >> N_1$)

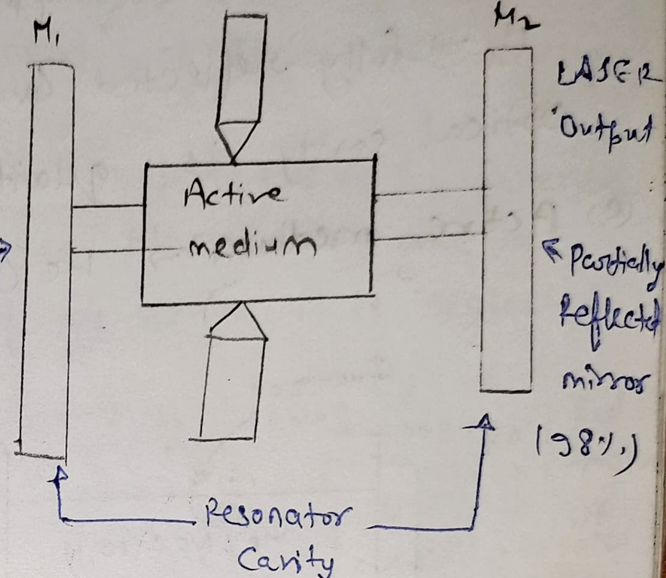
• Methods of Pumping

(a) Optical Pumping
(b) Electrical Pumping
(c) Chemical Pumping
(d) Electron impact

(3) Optical Resonators :-
(Resonators Cavity)

→ It is an arrangement of two plane mirrors, One mirror is 100%. reflected and other (100%) is partially reflected.

Totally reflected mirror



→ LASER active medium is placed between optical resonators and mirror m_2 is also called **output couplet.**

* He - Ne LASER

(i) Characteristics of He-Ne LASER

(a) It is a gas LASER
(b) 4 Level LASER

E_1
E_2 energy levels
E_3
E_4

(c) active medium He with Ne (10:1) ratio
(d) High efficiency comparatively ruby LASER
(e) Continuous output LASER (6328 Å)
(f) Electrical pumping is required
(g) No External Cooling is required.

(ii) Construction of He-Ne LASER

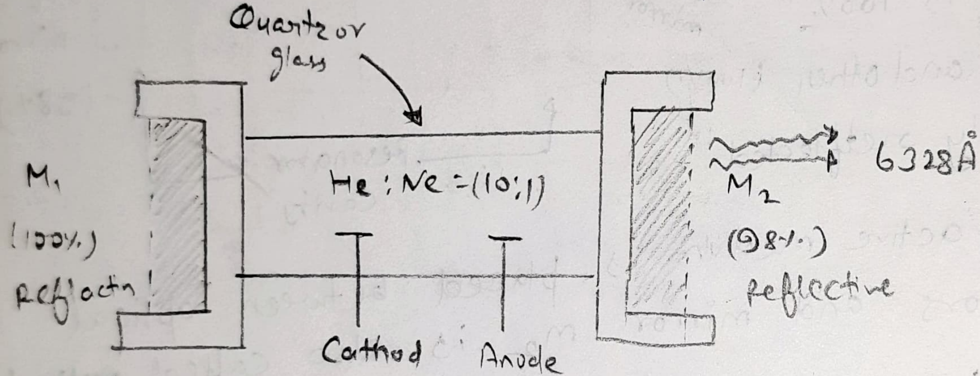
(a) General Parameter → Tube length upto 80cm and diameter 1.5 cm

(b) Optical Cavity/Resonator → It has to mirrors (Plane or spherical)

M_1 → fully reflected & M_2 → Partially reflected.

Optical cavity is quartz or glass cavity.

(c) Active medium → He & Ne gas in the ratio of 10:1



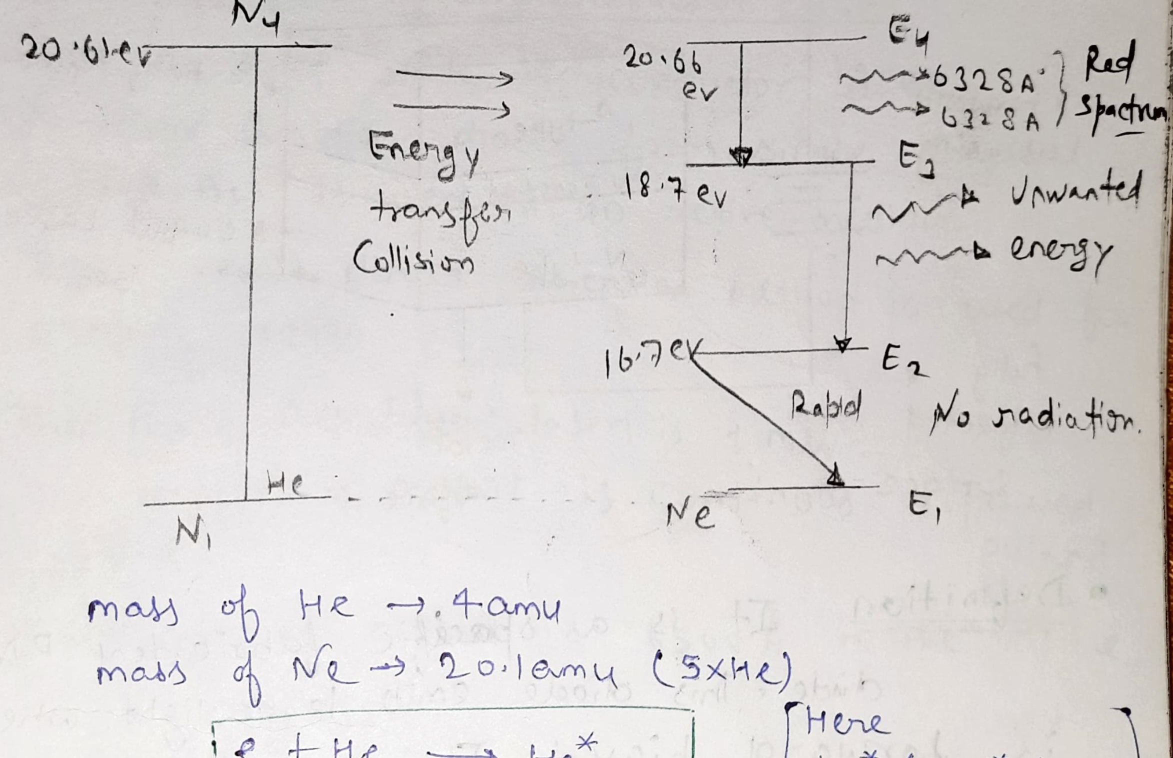
(d) Breusters window → It is a substrate act as a polariser used to eliminate unwanted ~~energy~~ wavelengths.

(e) Energy pumping Source → Electrical pumping is used as cathod & anode terminals are in gas discharged tube.

(iii) Working Principle:- 4 Level LASER Process.

→ The electrical discharged accelerators the e⁻s. These electrons collide with He atoms and these are raised to N_1 to N_4. these excited He atoms can not deexcited spontaneously rather they collide with Ne atoms and transfer their excited energies through the process of resonance energy transfer.

→ Ne atoms are excited to level E_4 to E_3 Reverse energy transfer also takes place, but due to small concentratia of Ne atom, it is neglected.



mass of He → 4 amu
mass of Ne → 20.1 amu (5×He)

$$e + He \rightarrow He^*$$
$$He^* + Ne \rightarrow Ne^*$$

[Here He^* & Ne^* is excited state]

★ Semiconductor LASER (diode)

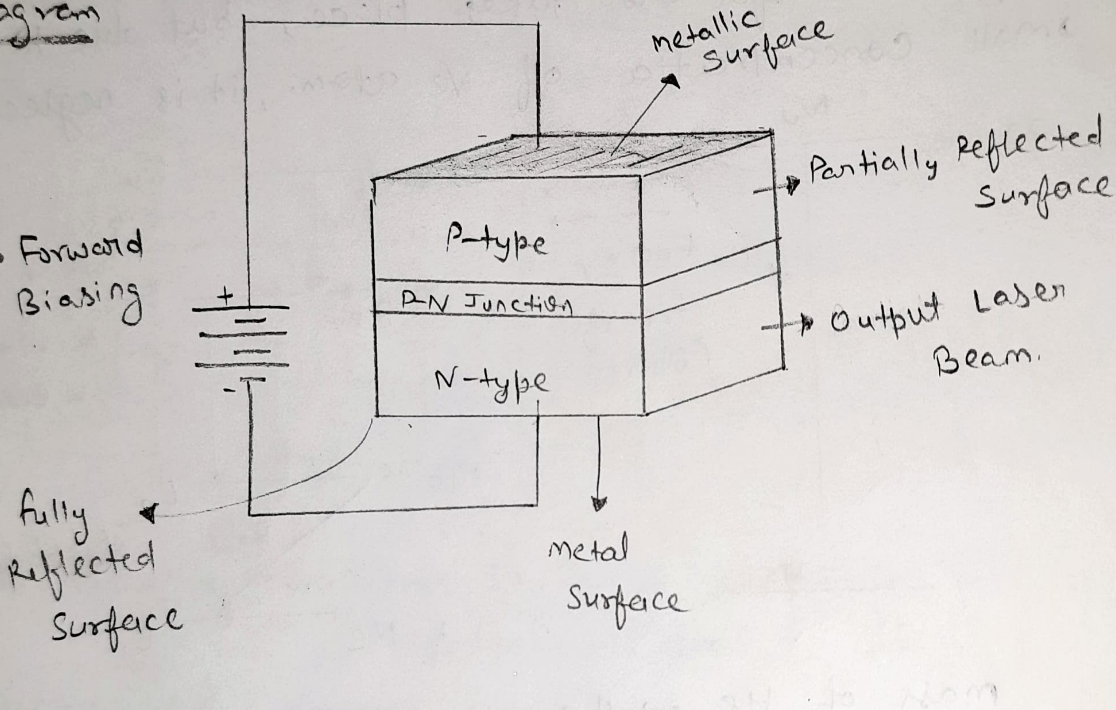
• Components

(i) Active medium :- Deplition Region between P-N Junction
(Tickness - 0.1 μm)

(ii) Pumping Source :- Biasing, External Battery.

(iii) Resonant Cavity :- P-N Junction acts as a Resonant cavity.

Diagram



• Definition It is a specific fabricated P-N Junction diode. This diode emits laser light when it is forward biased. It is made from Ga-As (galium - Arsenic)

Advantage of Semiconductor LASER

1. It has high efficiency (70 to 80%).
2. The small dimensions of semiconductor LASER make it possible to construct quantum amplifire with extremely high sensitive.
3. From cost point of view this laser is economical.
4. Low Power Consumption.
5. Construction of this type laser is very simple.

Characteristics of Semiconducter LASER

1. It is a solid state semiconductor LASER.
2. A P-N Junction made from single Crystal of (Ga-As) is used as an active medium.
3. The ~~react~~ direct conversion method is used for pumping action.
4. The Power Output from this laser is 1 mW.
5. The Nature of output is continous or ~~paused~~ pulsed output.
6. Wavelength of output is 6500 Å in the visible Red region.