① **Laser:-** Laser is a device by which we can produced wave or light with following propaties.

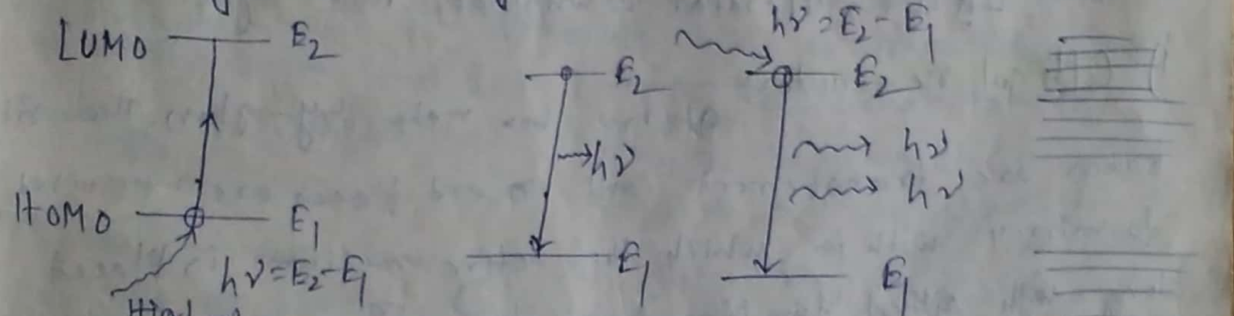
(i) All the wave coming form laser are coherent

(ii) Wave is mono chormatic

(iii) laser beam is ~~unidi~~ unidirectional

LASER - Light Amplification by stimulated emission of radiation

Metastable state:- If the life time of an excited states of atom is very large nearly $\approx 10^{-3}$ sec is called Metastable state.



Highest occupied Molecular orbital (HOMO) →
lowest unoccupied Molecular orbital (LUMO) →

Absorption:- If the atom is initially in the lowest state E_1 it can be raised to E_2 by absorption of a Photon of energy $h\nu$ $h\nu = E_2 - E_1$ this is called absorption.

Spontaneous emission:- If the atom initialy in the upper state E_2, it can drop to lowest state E_1 by emitting of a Photon of energy $h\nu$. This Process is called spontaneous emission.

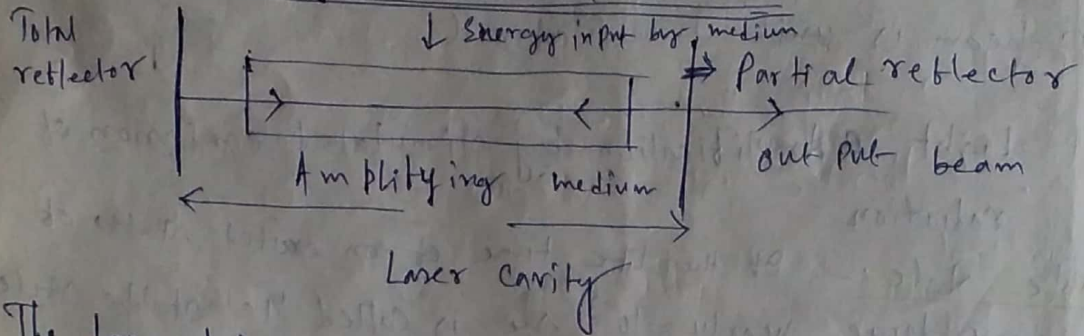
Exited system:- When the electron is in upper level the system is called Excited system.

Population inversion:- When in an electronic system the lower leval are empty or less propolated, then the upper leval, the system is called population inversion system.

Stimulated emission:- If the atom initially in the upper leval E_2, again excited by another Photon of energy $h\nu = E_2 - E_1$ then, two will be emitted

This process is called stimulated emission. out of two photon one is due to spontanous emission and another is from excitation to excited electron.

Schematic diagram of LASER apparatus:—



The LASER apperatar consist of following component

i) **Optical resonator:—**
It is a box made by glass. The side faces are transferent and end faces are murcurised to mirror with in which the active medium is placed along with optical pumping facility. There is a whole in one end face of resonator, through which the LASER light comes out.

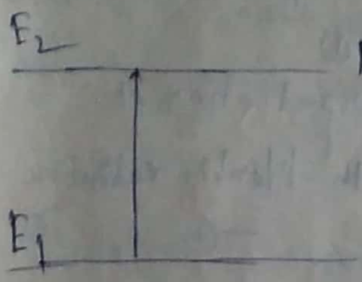
ii) **Active medium:—**
The active medium is mostly gas in LASER some time it is liquid, solid or some other medium, with in the active medium mean LASER action will held.

iii) **Optical pumping:—**
The process in which the atom or molecule of active mideum are excited. Generally it is electric spark, thermal or chemical reaction.

(iv) **Mirror:—**
The end facem of resonator are mirror or refractory it make the LASER light unidirection.

(3)

Einstein's A, B coefficient :-



N_2 We consider two energy leval lower one having energy E_1 and uper having energy E_2, N_1, no. of atom per unit vol^n in lower leval and N_2 N_1 no. of atom/unit vol^n in uper leval at one instant. Let the system is in thermal equiliberium at temp^n T and energy of frequency ν having energy density u_ν.

i) **Absorption :**— The Probable rate of trainsition by absorption form leval 1 to 2 is propotional to u_ν

1. $P_{12} = B_{12} u_\nu$ [B_{12} = Einstein's co-efficient of absorbtion of radiation)

The no. of atom in state one that absorb a photon and rise to state to per unit time is given by $N_1 P_{12} = N_1 B_{12} u_\nu$

(ii) **Spontanious ~~contaner~~ emission :**— No. of atom in state to that drop to state one by spontanious per unit time is $N_2 A_{21}$. [A_{21} = Einstein's const. for spontanious emission

(iii) **Stimulated emission :**— ~~No. of atom in state to~~

The Probality of stimulated emission from state 2 to state 1 is propotional to energy density u_ν.

∴ No. of atom under going stimulated emission from level 2 to leval 1 per unit time is $N_2 B_{21} u_\nu$.

in equiliberium the absorption and emission per unit time is equal. $N_1 B_{12} u_\nu = N_2 A_{21} + N_2 B_{21} u_\nu$

$$N_2 A_{21} = N_2 B_{21} u_\nu - N_1 B_{12} u_\nu$$

$$= u_\nu (N_2 B_{21} - N_1 B_{12})$$

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

$$= \frac{A_{21}}{B_{21}} \cdot \frac{1}{(B_{12}/B_{21})\, e^{h\nu/kT} - 1} \quad \left[\because N_1/N_2 = e^{h\nu/kT}\right] \quad \text{— (1)}$$

This relation for the energy density of radiation of frequency ν must be in accord with Plank's radiation formula, (iv)

$$U_\nu = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{e^{h\nu/kT} - 1} \quad \text{— (2)}$$

Comparing (1) & (2) we get

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

∴ (i) $B_{12} = B_{21}$ ∴ probablity of absorption and stimulating emmision are equal.

(ii) $A_{21}/B_{21} = 8\pi h\nu^3/c^3$ probablity of spontanous emmision increas very rapidly with energy (ν^3)

(A) **Threshold condition for LASER action:-**

The radiation within the active medium of optical resonator suffers multiples reflection from the reflectors placed at the two end of resonator.

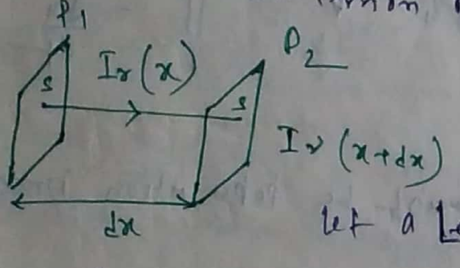
The radiation of active medium suffers losses due to absorption, transmision, scattering of active medium and diffraction by reflacetor.

For sustained Leser action the losses are compensated by induced transitions in the active medium. To sustain the Laser action a minimum population inversion density is required, this is called threshold population inversion.

If t_p is the life of a photon in active medium then $\frac{1}{t_p}$ is the rate of loss of energy.

Let with-in the active medium there is assembly of atoms with N_1 atom per unit vol^n in stat E_1 and N_2 no of atom per unit vol^n in stat E_2.

The transition probability for absorption is $B_{12} u_\nu N_1$, spontaneous emission $N_2 A_{21}$ and for stimulated emission $B_{21} u_\nu N_2$



Let a Leaser beam of energy density u_ν propagate through a active medium along x- direction and consider a thickness dx and cross eational area S.

Energy loss/sec due to absorption in volum $S\,dx$

$$= B_{12} u_\nu N_1 (S\,dx)\, h\cdot\nu$$

Energy gain per sec due to stimulated emission in vol^n $S\,dx$ $= B_{21} u_\nu N_2 (S\,dx)\, h\nu$

$\therefore$ Rate of increase of energy in vol^n $S\,dx$

$$= B_{21} u_\nu N_2 (S\,dx)\, h\nu - B_{12} u_\nu N_1 (S\,dx)\, h\nu$$

$$= (N_2 - N_1)\, B\, u_\nu h\nu\, (S\,dx)$$

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

Net energy leaving the volume $S\,dx$ per sec

$$= \left[I_\nu(x+dx) - I_\nu(x)\right] S$$

$$= (dI_\nu)\, S = \frac{dI_\nu}{dx}\, dx\, S$$

$\therefore$ For sustained Leaser action

$$\Rightarrow (N_2 - N_1)\, B\, u_\nu h\nu\, (S\,dx) = \frac{dI_\nu}{dx}\, dx\, S$$

$$\Rightarrow \frac{dI_\nu}{dx} = (N_2 - N_1)\, B\, u_\nu\, h\nu$$

∴ The rate of increse of intensity is

$$\left(\frac{dI_\nu}{dt}\right)_{gain} = \frac{dI_\nu}{dx} \cdot \frac{dx}{dt}$$

$$= \frac{dI_\nu}{dx} \cdot v$$

$$= (N_2 - N_1)\, B u_\nu\, h\nu \cdot v$$

| v = velocity of light in the medium $= \frac{dx}{dt}$

∴ For $\left(\frac{dI_\nu}{dt}\right)_{gain} > 0$ when $N_2 > N_1$

∴ For Leaser action there must be population inversion

The rate of loss of Intensity is

$$\left(\frac{dI_\nu}{dt}\right)_{Loss} = \frac{I_\nu}{t_p}$$

∴ It the condition sustained leaser action is —

$$\left(\frac{dI_\nu}{dt}\right)_{gain} \geq \left(\frac{dI_\nu}{dt}\right)_{loss}$$

$$\Rightarrow (N_2 - N_1)\, B u_\nu\, h\nu\, v \geq \frac{I_\nu}{t_p}$$

Now $A/B = \frac{8\pi h \nu^3}{c^3}$,

$\frac{1}{A_{21}} = t_{s,p}$ = spontanious life of upper state.

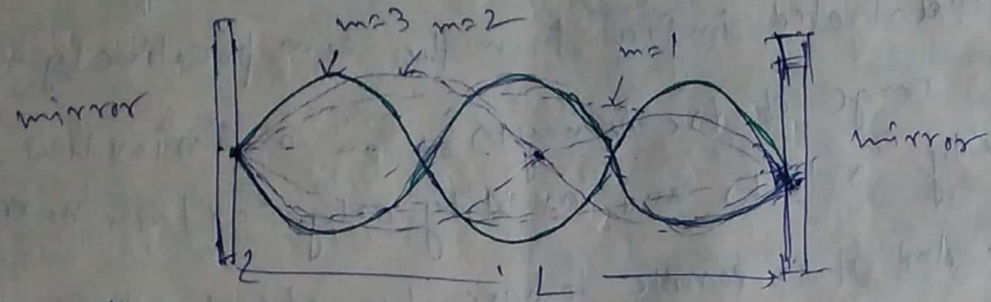
| $A = A_{21}$ is spontaneous emission transition probility.

$I_\nu = u_\nu$

$$\therefore (N_2 - N_1) \geq \frac{8\pi^2 t_{s,p}\, \nu^2}{c^3 t_p}$$

Standing Waves:–

The reflection feild inside the resonator gives rise to a stationary wave pattern with a node at each mirror



When the cavity resonets, the distance L betⁿ the mirror has clearly an integral multipul of half wave lengths.

$\therefore L = \frac{m\lambda}{2}$, $m = 1, 2, 3 ----$

Where m correspond to exiel mode number

Expressed in terms of frequency

$$\nu_m = \frac{(c/n)}{\lambda} = \frac{mc}{2Ln}$$

Where c is the speed of light in vaccum and n the index of the active medium

So, an infinite number of longitudinal cavity modes are possible, each with a distinct frequency ν_m

The frequency separation $\Delta\nu$ betⁿ two consecutive modes is given by –

$$\Delta\nu = \nu_{m+1} - \nu_m$$

$$= \frac{c}{2Ln}[(m+1) - m]$$

$$\Delta\nu = \frac{c}{2Ln}$$

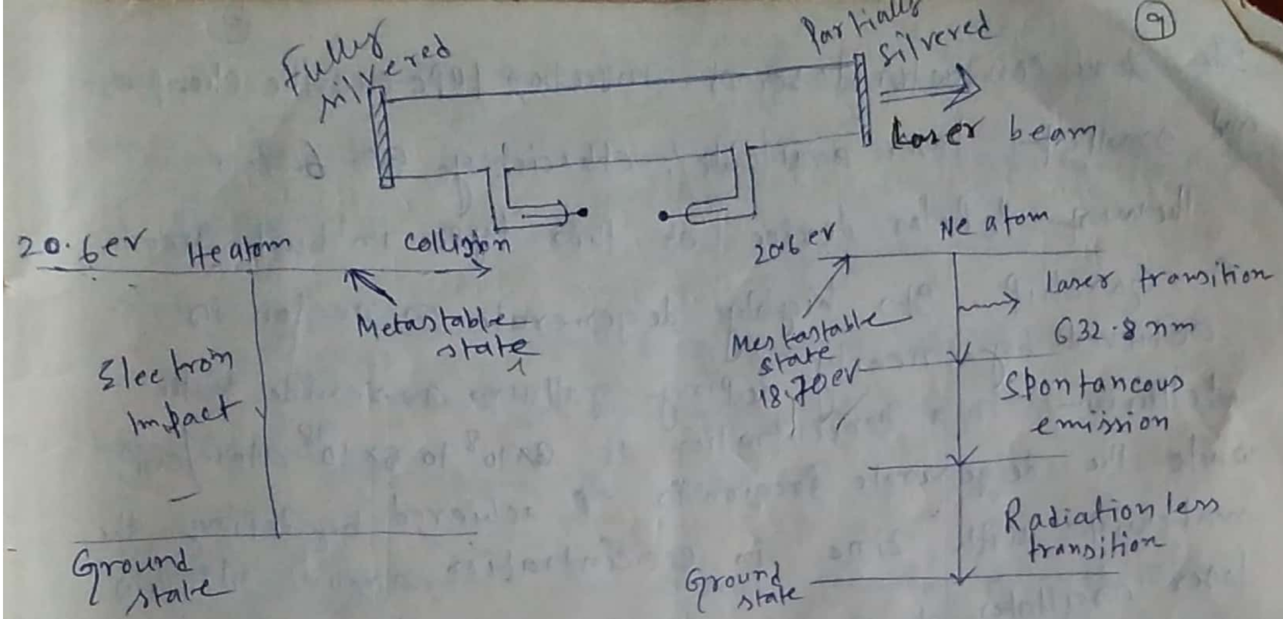
The important point to be noded is that the resonant modes of the cavity are narrower in frequency

than the width of a single spontaneous emission line
that may engulf several resonant cavity modes.
The broad emission line and the narrow cavity modes
are illustrated in fig from the comparatively
broad range of frequencies of an emission line,
the cavity selects and amplify only certain narrow
bands. And it is possible to have, by adjustment of
separation of cavity modes, only one mode in the
band width of an emission line, This explains
the extreme monochromaticity of laser radiation.

(5)

* Helium - Neon Laser (four level laser system)

The helium - neon gas laser
achives a population inversion in a different way. Mixture
of about 7 parts of helium and 1 part of neon at a low
pressure (~1mm mercury) is placed in a glass tube that
has ||el mirrors. One of them partly transparent at both
ends. The spacing of the mirrors is equal to an integral
number of half-wave-length of the leaser light. An electric
discharged is ~~production~~ produced in the gas by means of
electrodes out side the tube connected to a source of high
frequency alternating current and collisions with electrones
from the discharged excited He and Ne atoms to metastable state
20.61 and 20.66 ev respectively above there ground state. Some
of the excited. He atoms transfer their energy to ground state
Ne atoms in collision with the oser of additional energy being
provided by the kinetic energy of the atoms. The purpose
of the He atoms is thus to help achieve a population
inversion in the Ne atoms.

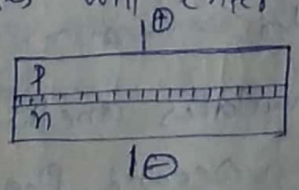


The leaser transition in Ne is from the metasta-ble state at 20.66 ev to an exciated state at 18.70ev with the emission of 632.8 n.m Photon. Then another photon is spontaneously emitted in a transition to a lower metastable state, this transition yields only incoherent light. The re-maining excitation energy is lost in collision with the tube walls.

Because the electron impacts that excite the He and Ne atoms occur all the time, unlike the pulsed excita-tion from the xenon flash lamp in a ruby laser, a He-Ne leaser operates continuously.

Semi Conductor laser:-

The most common way to the papulation inversion in semi conductor mate-rials is by ~~joing~~ joining a p type and an n type materials to gather. A dc voltage is applied to p-n junction as shown. In forward biasing of the electric field, conduction electrons ~~with~~ will be injected from the n side into the junction area, while holes will enter the junction from p side.



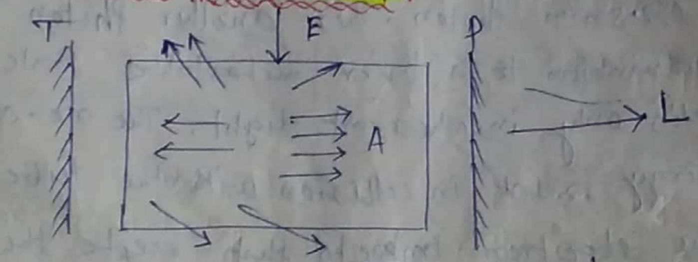
p-n junction

The p-n junction will experience transition of electron from the conduction band into the valence band, that is, they are recombine emitting the surplus energy as radiation. After that placing the system with in optical resonator laser action will take place.

The semi conductor laser of injection type are the cheapest and smallest laser available, efficiency 50-60%.

The most popular device of this type in built around a GaAs chip. Its highly degenerate n region is achieved by nearly doping gallium arsenide with tellurium in a concentration of 3×10^{8} to 5×10^{18} atom/cm^3 while the degenerate p region is achieved by doping the material with zinc in concentration around 10^{19}. This laser oscillates at wave lengths from .82 to 0.9 µm in the infrared.

⊛ An optical resonator :-



To sustain laser oscillation, a part of the output must be fed back into the system. Such a positive feed back is brought about by placing the active medium between a pair of plane parallel mirrors facing each other, one at each end of the medium, one of them is a total reflector T and the other a partial one P that allows a part of the generated laser beam L to pass out. The arrangement is known as an optical resonator.

Action :- To cause population inversion, the medium A is fed with pump energy E which is then released from excited atoms by stimulated emission. A photon released by one excited atom stimulates another it encounters in its path to release a second photon, the two co-harent photons add completely to a beam of twice the intensity. As the beam courses through the medium, its amplitude rapidly increases. The reflector reverses the beam allowing it another passage in fact, multi-ple reversions may occure) through the excited medium for further amplification, on reaching P, a part 2 of the beam escapes as a laser beam.

stimulated Photons emitted inclined to the axis are lost through the side of the system so that the final emergent beam is always along the axis.