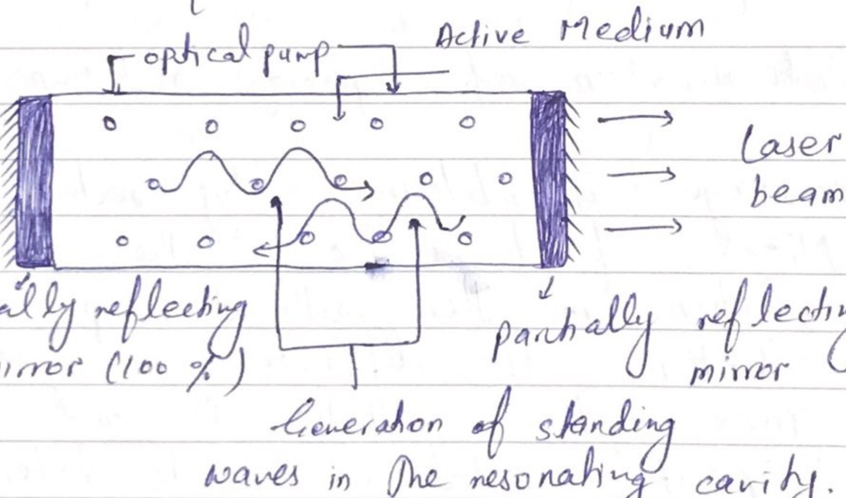
⇒ Lasers:

light travels in a straight line. ~~motion~~ Particles or molecules ~~travels~~ present in ordinary light have random motion, although the exhibition of light is primarily due to an atom being de-excited. To get a focused intense light, the process of de-excitation has to be analyzed and designed as per our needs.

The laser invention happened, because of the order created in the excitation of atoms, thereby intensifying the radiation due to emission.

Major and Basic Components of a Laser:

The basic components of a Laser as shown in below fig.



Active Medium: The term 'active medium' in a Laser device refers to a conglomeration of atoms, molecules, or ions in any state of matter. (solid, liquid, Gas), that creates a situation

* Conglomeratio: A. large group which has gathered together.

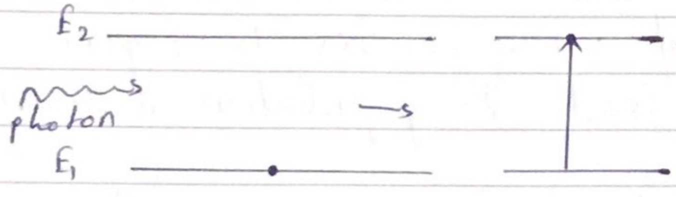
wherein the number of atoms in the higher energy state than that in lower energy state. This happens by the choice of constituents of the active medium.

The active medium is 'photon sensitive'. As an electromagnetic radiation is incident on the active medium, amplification of the incident radiation takes place, contrary to the ordinary medium.

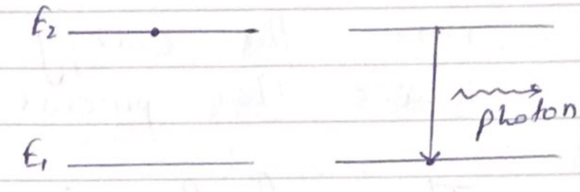
Pumping Source: The pumping mechanism in the laser helps to ~~ac~~ achieve the the state of population inversion. The pumping source keeps a sustained supply of atoms, molecules or ions to the active medium.

Optical Resonator: An optical resonator helps to further intensify and amplify the input as well as the output radiation. For sustained amplified output radiation from the laser, a part of energy is fed-back into the system. This is can be achieved by keeping the active medium in a resonating cavity, which can be as simple as a pair of mirrors. One of them is 100% reflecting where as other one is partially reflecting. Simple parallel planes form a cavity, with the nodes at the ends. If L is the length, then the going and coming of the wave will result in a phase change of '2π' phase.

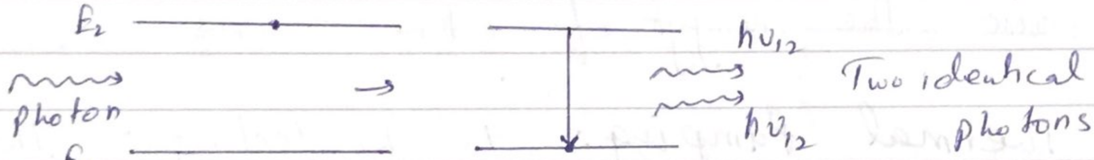
* **Einstein's Coefficient:** Einstein develop the theory of transition among the different energy states, under the influence of electromagnetic radiations. There are three type of radiative transition as shown in fig (a) Absorption (b) Sponteneous emission and (c) Stimulated emission



(a) Absorption



(b) Spponteneous emission



(c) Stimulated emission

According to Boltzmann distribution law, at an absolute temperature T, number of atoms n per unit volume in an energy state E can be written as

$$n = n_0 \exp\left(-\frac{E}{k_B T}\right) \quad — ①$$

k_B = Boltzmann Constan ($k_B = 1.38 \times 10^{-23}$ J/k)

n_0 = no. of atoms in ground state

If there are states of energy E_2 and E_1 for no. of atoms n_2 and n_1, with $E_2 > E_1$

$$\frac{n_2}{n_1} = n_0 \exp\left(-\frac{E_2 - E_1}{k_B T}\right) \qquad n_2 < n_1 \text{ and } E_2 > E_1 \quad — ②$$

where $n_2 = n_0 \exp\left(-\frac{E_2}{k_B T}\right)$ and $n_1 = n_0 \exp\left(-\frac{E_1}{k_B T}\right)$

and $E_2 - E_1 = h\nu$

$$\therefore \frac{n_2}{n_1} = n_0 \exp\left(-\frac{h\nu}{k_B T}\right) \quad \text{——— (3)}$$

The rate equation that governs the spontaneous emission process can represented as follows.

$$R_{sp} = -\left(\frac{dn_2}{dt}\right)_{sp} = A_{21} n_2$$

or $n_{21} = A_{21} n_2$ ——— (4)

energy $E_2 - E_1 = h\nu$ or $\nu = \frac{E_2 - E_1}{h}$

in E_2 energy is higher therefore this is the case of absorption.

$n_{12} = B_{12} n_1 \rho$ —(5) ρ = energy density of electro-magnetic radiation

Transition from higher energy E_2 to lower energy E_1

$n'_{21} = B_{21} n_2 \rho$ —(6)

Coefficients; A_{21}, B_{12} and B_{21} are known as Einstein's coefficients, or Einstein's A and B coefficient.

Now using equation (4), (5) & (6)

$$n_{12} = n_{21} + n'_{21}$$
$$B_{12} n_1 \rho = A_{21} n_2 + B_{21} n_2 \rho$$

$$B_{12} n_1 \rho - B_{21} n_2 \rho = A_{21} n_2$$

$$\rho = \frac{A_{21} n_2}{B_{12} n_1 - B_{21} n_2}$$

$$\rho = \frac{A_{21} n_2}{B_{21} n_2} \left[\frac{1}{\frac{B_{12}}{B_{21}} \cdot \frac{n_1}{n_2} - 1} \right]$$

$$\rho = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} \exp\left(\frac{h\nu}{k_B T}\right) - 1} \right] \quad \text{— (7)}$$

Using Planck's radiation law, we know that

$$\rho = \frac{8\pi h \nu^3}{c^3} \cdot \left[\frac{1}{e^{h\nu/k_B T} - 1} \right] \quad \text{— (8)}$$

Consider $B_{12} = B_{21}$, — (9) then equating equation (7) & (8)

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

$$\left. \begin{aligned} A_{21} &= B_{21} \left[\frac{8\pi h \nu^3}{c^3} \right] \\ \text{or} \quad A_{21} &= B_{12} \left[\frac{8\pi h \nu^3}{c^3} \right] \end{aligned} \right\} \quad \text{— (10)}$$

Equation (9) & (10) are known as Einstein relation.

Equation (7) implies that probability of stimulated emission is same as that of induced absorption.

* using quantum mechanical radiation formula

$$\frac{n_{21}}{n'_{21}} = \frac{A_{21}}{B_{21} \rho} = \exp\left(\frac{h\nu}{k_B T} - 1\right)$$

if $h\nu >> k_BT$ Spontaneous emission is more probable than stimulated emission.

however if $h\nu << k_BT$, Stimulated Emission starts playing an important role.

* Such a condition exist in the microwave region of a spectrum.

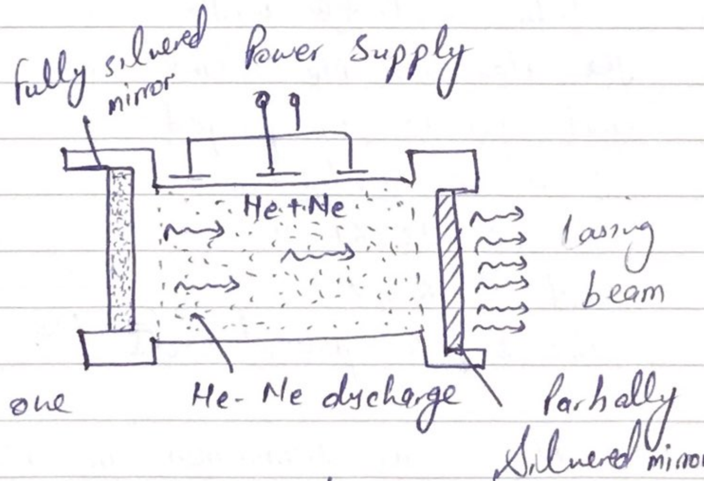
* He- Ne LASER

Type of Laser: Gas Laser (four level pumping)

Active Centres: Ne atoms.

Pumping: Electrical Pumping

Prominent wavelength: 6328 A°, 3.39 μm, 1.15 μm

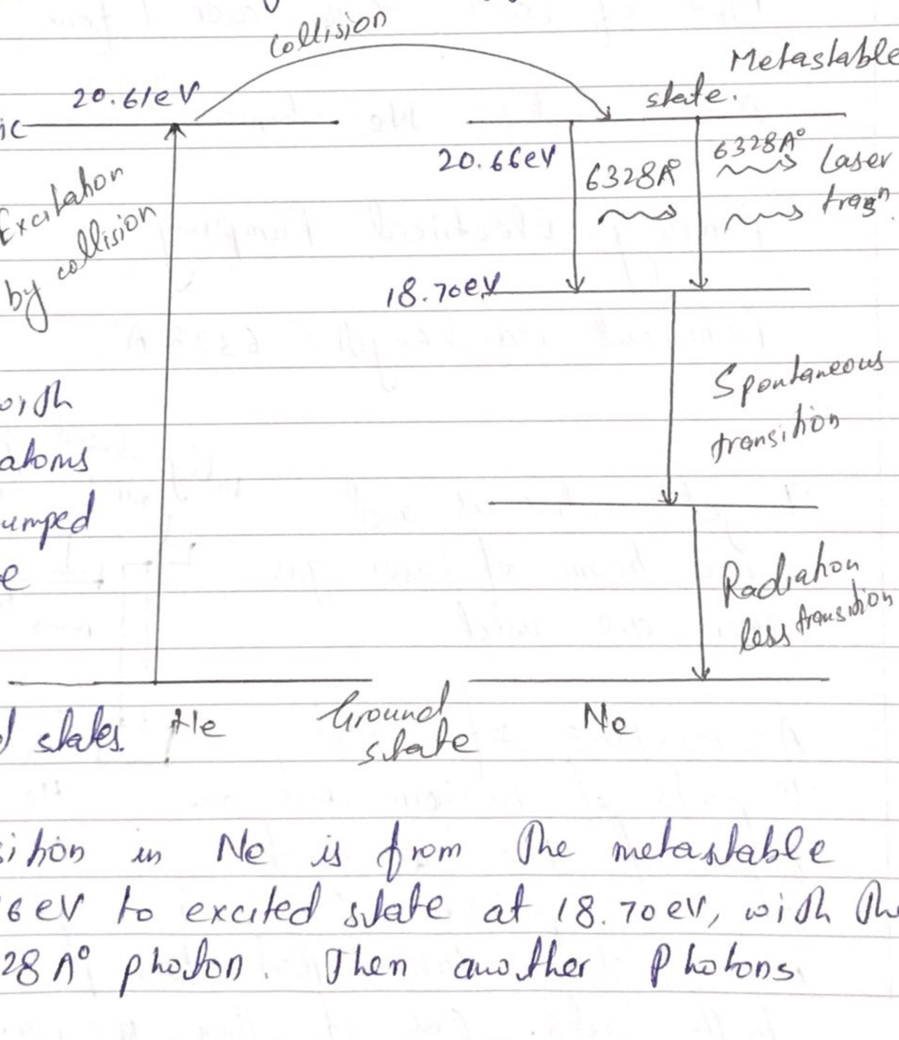


To get continuous and intense beam of laser, gas laser are used.

A mixture of about 10 parts of helium and one parts of Ne ~~is used~~ at low pressure (1 torr) is placed in a glass tube that has parallel mirrors at both ends. One of them is partially silvered and other one is fully silvered. The spacing between the mirror is equal to the an integral number of half wavelengths of the laser light. ~~An electric discharge is produced by means of electrodes outside the tube is connected to a source of high frequency of alternating current~~

A powerful frequency generator is used to produce discharge in the gas so that helium are excited or pumped up to a higher energy level.

When an electric discharge passes through a gas, the electron in the discharge tube collide with the He and Ne atoms and excite or pumped them metastable state 20.61 eV and 20.66 eV above the ground states.



The laser transition in Ne is from the metastable state at 20.66eV to excited state at 18.70eV, with the emission of 6328A° photon. Then another photons is spontaneously emitted in a transition to a lower state; this transition yields only incohrent light. The remaining energy is lost in collision with walls of tube. And the atoms comes to ground state and process is repeated.

* Nd- YAG LASER:

Type of laser: Solid state involving four level pumping

Host: Ytrium Alluminium Garnet ($Y_3 Al_5 O_{12}$)

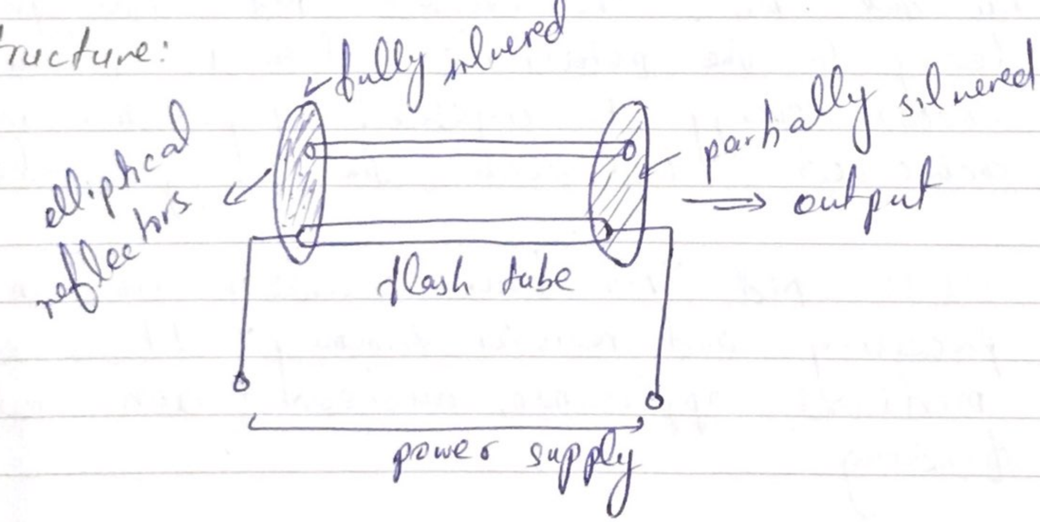
Active Centres: Nd^{3+} ions (Neodynium)

~~Typ~~ Prominent output wavelength: 1.06 μm

Type of pumping: Optical Pumping using Xenon flash lamp

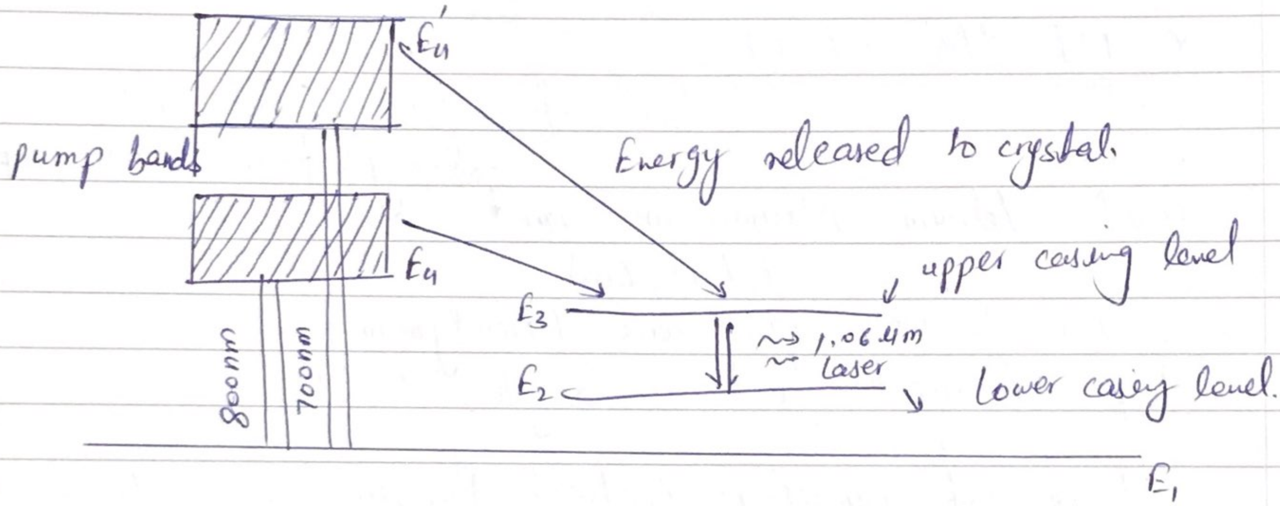
Doping Concentration: 0.725 atomic weight percent or 1.4×10^{26} atoms of Nd per m^3.

Structure:



The laser rods are typically of 10cm in length of diameter of 12 mm. The YAG rod and a flash lamp are housed in reflector cavity of elliptical crossection.

Energy level diagram and Working:



There exist two pump bands E_4 and E_4' in the range of 700nm and 850nm. Pumping is done by Xenon flash lamp. Pumping excites the Nd^{3+} ions from the ground state to the pump bands E_4 and E_4'. The excited Nd^{3+} ions quickly decay to the metastable state E_3, releasing their excess energy to crystal. Population inversion is achieved between the energy levels E_3 and E_2

Uses: Nd-YAG laser is widely used in material processing and resistor trimming. It is used in medical application, nuclear fusion and range finding.