study time
Subject ____
Date.: __/__/__
MON TUE WED THR FRI SAT SUN

LASER

Word 'LASER' is acroynm of light amplification by stimulated emission of radiation.

Interaction of radiation with matter

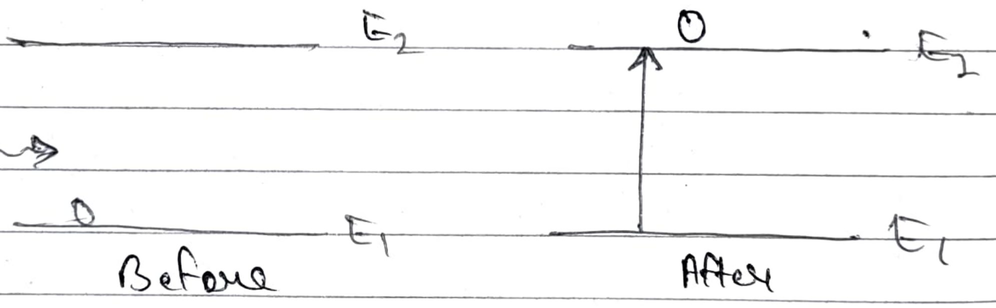
A radiation interacts with matter when the energy of photon ($h\nu$) is equal to the difference of two energy levels ($E_2 - E_1$); i.e. $h\nu = E_2 - E_1$.

A radiation interacts with matter by three process:

(1) Absorbtion

The process in which an atom residing in it's lower energy state E_1 is raised to upper state E_2 by absorbing a photon of energy $h\nu$ ($= E_2 - E_1$) is known as absorbtion.

Process can be shown as below:



The Process can be written as:

$A + h\nu \rightarrow A^*$, where A^* is excited state of A.

The no. of atoms absorbing ~~Be~~ photon ~~Be~~ is given by:

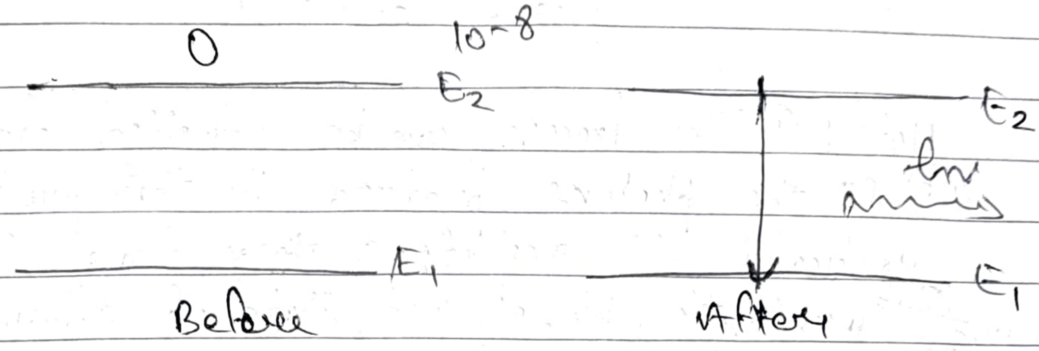
$N_{ab} = B_{12} N_1 \rho(\nu) \Delta t$

where, B_{12} = proportionality const.
N_1 = No. of atoms in ground state (E_1)
$\rho(\nu)$ = photon density
Δt = time-interval

study time
Subject ______
Date: __/__/____
MON TUE WED THR FRI SAT SUN

② Spontaneous Emission

The process in which an atom in an excited state emits photon naturally is termed as spontaneous emission.



generally, an atom stays in an excited state for 10^{-8} sec. This time is termed as Normal life-time of an atom.

The process can mathematically be represented by:

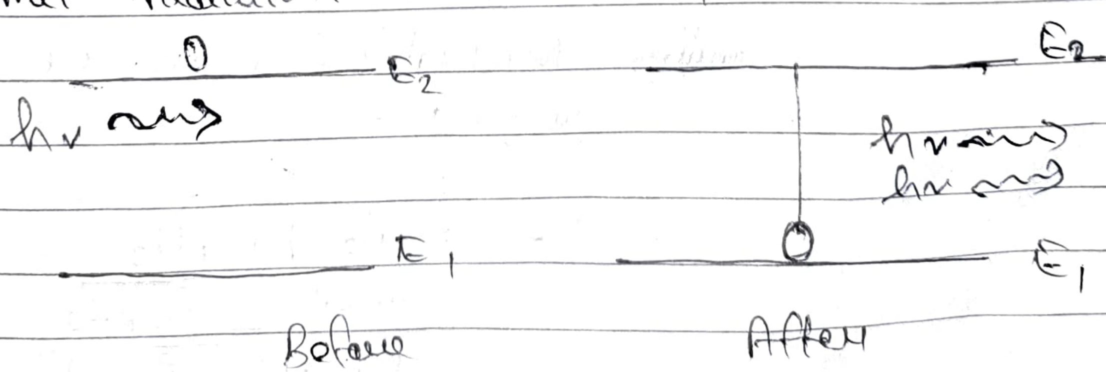
$$A^* \longrightarrow A + h\nu$$

No of atoms emitting photon spontaneously is given by $N_{sp} = A_{21} N_2 \Delta t$,

where A_{21} = proportionality const.
N_2 = No. of atoms in excited state
Δt = time-interval

③ Stimulated Emission

The process in which an incident photon of proper frequency triggers an atom in excited state to emit radiation is known as stimulated emission.



study time

Subject

Date.: __/__/__

MON TUE WED THR FRI SAT SUN

It can be represented by

$$A^* + h\nu \rightleftharpoons A + 2h\nu$$

No. of atoms emitting photon by stimulation is given by

$$N_{st} = B_{21}\, \rho(\nu)\, \Delta t$$

Note: ① The Process can be controlled from outside.

② All the photons produced in this process are identical in all respect; i.e. they have same frequency, energy, wavelength, phase and state of polarization.

③ Multiplication of photon takes place in this process.

④ Stimulated emission is the key Mechanism in laser action.

Einstein's coefficients

Einstein was first to predict the process of stimulated emission in 1917. Under thermal equilibrium, no. of upward transition should be equal to no. of downward transition, for per unit time per unit volume, i.e.

$$N_{ab} = N_{sp} + N_{st}$$

Thus, $B_{12} N_1 \rho(\nu) = A_{21} N_2 + B_{21} \rho(\nu)$ $\quad [\Delta t = 1]$

dividing Numerator & denominator by $B_{21} N_2$, we get

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

study time

Subject ________ Date.: __/__/____

MON TUE WED THR FRI SAT SUN

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

According to Boltzmann's law, the no. of atoms in a energy state is given by;

$$N_1 = N_0 e^{-\frac{E_1}{KT}}$$

Similarly, $N_2 = N_0 e^{-\frac{E_2}{KT}}$

where N_0 is no. of atoms in ground state.

K is boltzmann const., T = Temperature.

N_1 and N_2 are the no. of atoms in energy state E_1 & E_2. Thus, $\frac{N_1}{N_2} = e^{\frac{E_2 - E_1}{KT}}$

or $\frac{N_1}{N_2} = e^{\frac{h\nu}{KT}}$ —(2)

Putting this value of $\frac{N_1}{N_2}$ in eq (1), we get

$$f(\nu) = \frac{A_{21}}{B_{21}} \times \frac{1}{\left[\frac{B_{12}}{B_{21}} e^{\frac{h\nu}{KT}} - 1\right]} \quad \text{—(3)}$$

To maintain thermal equilibrium, System must release energy in form of electromagnetic waves. It is required that the radiation be identical with a black-body radiation and be consistent with a Planck's radiation law, for any value of T.

Acc. to Planck's law, the photon density is given by $f(\nu) = \frac{8\pi h\nu^3}{c^3} \times \frac{1}{e^{\frac{h\nu}{KT}} - 1}$ —(4)

study time
Subject ______
Date: __/__/__
MON TUE WED THR FRI SAT SUN

equation (3) & (4) are same, therefore on comparison, we get

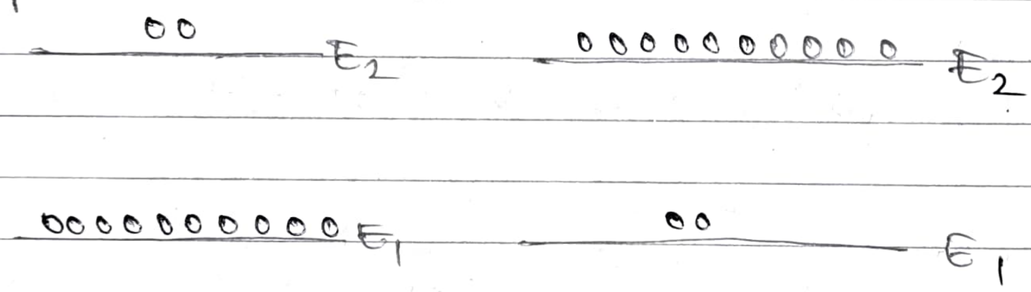
$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \quad \text{--- (5)}$$

$$\frac{B_{12}}{B_{21}} = 1 \quad \text{--- (6)}$$

Here, the constants B_{12}, A_{21} and B_{21} are known as Einsteins coefficient and eq (5) and (6) shows a relation between them.

Population Inversion

The condition in which no. of atoms in upper state are more than lower state is termed as population inversion. ($N_2 > N_1$)



Normal State — Population inversion

~~The condition~~ Population inversion is essential for laser action.

Pumping

The process by which atoms are excited from lower state to upper state is termed as pumping. In other words, pumping is a process of supplying energy. It is of following types:

1. optical pumping (excitation by strong source of light)
2. electrical pumping (excitation by electron impact)

(3) Chemical Pumping (excitation of atoms by energy released during a chemical rxn)
(4) Inelastic atom-atom collision pumping
(5) Direct Conversion (electrical energy is directly converted into light)

Main Component of a Laser System

A Laser System Consist of a large no. of Component, which are broadly classified into three:

1. Active Medium
2. Pumping Source
3. Optical Cavity

Active Medium

The Medium which when excited achieves the Condition of population inversion is termed as Active medium.
Active medium is basically a collection of atoms & Molecules.

Pumping Source

The Sources which are used for the excitation of atoms are known as Pumping Sources.

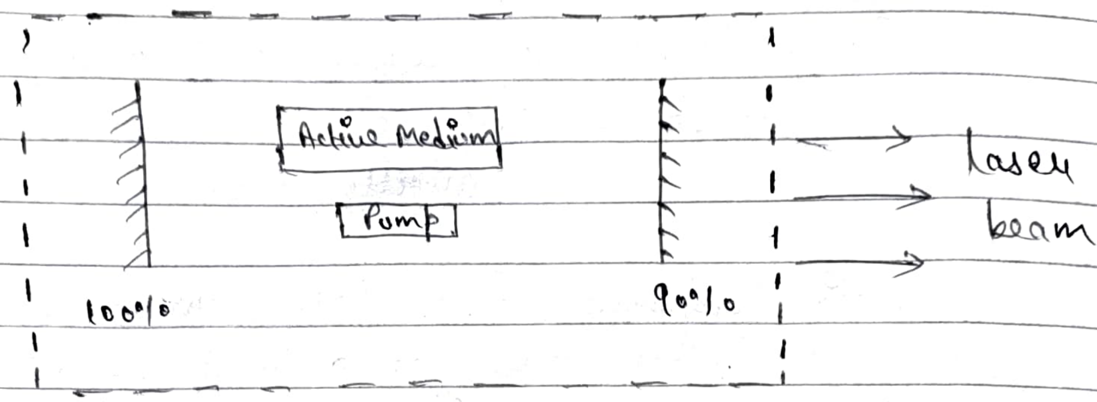
Optical Cavity

It Consists of two mirrors either plane or Curved facing to each other. The reflectivity of one of the mirror is 100% and other is 90%. The amplification of light in a laser system takes place because of optical Cavity.

study time

Subject ____________ Date.: __/__/__

MON TUE WED THR FRI SAT SUN



Types of laser

Lasers are of following types :

1. Solid-State laser (Ruby, Nd : YAG,)
2. Gaseous laser (He-Ne, CO_2, Ar^+, Kr^+ ...)
3. Dye laser
4. Semi-Conductor laser
5. Chemical laser
6. Gas-dynamic laser
7. Free-electron laser (requires no active medium)
8. X-Ray laser
9. other

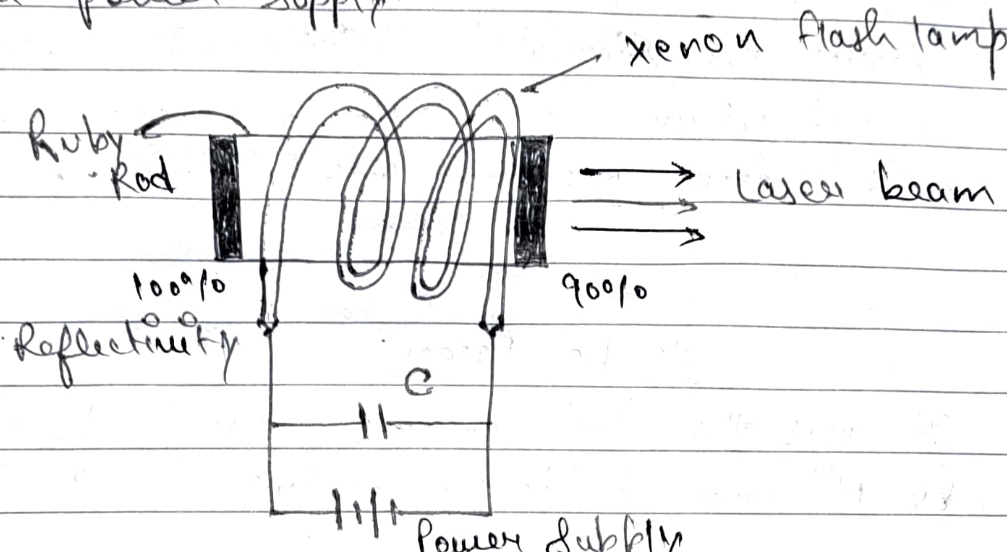
Ruby Laser

It was the first laser of world invented by T.H. Maiman in 1960. (USA) Ruby is basically a crystal of Al_2O_3 (Aluminium oxide) doped with Cr_2O_3 (chromium oxide) (0.05% by weight).

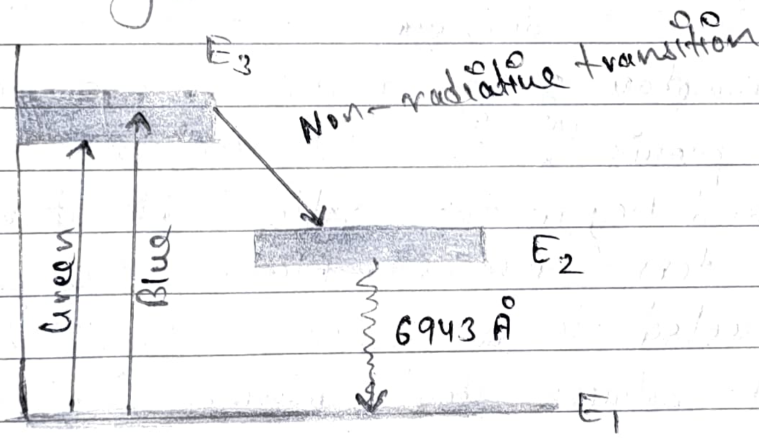
Construction

Ruby rod is taken in form of a cylindrical rod of length 4 cm and diameter 0.5 cm. The end faces of the rod are cut parallel to each other and perpendicular to the axis of rod. The end faces are silvered to achieve 100% and

90 % reflectivity respectively. The rod is surrounded by helical xenon flash lamp; which is connected with a power supply.



Working



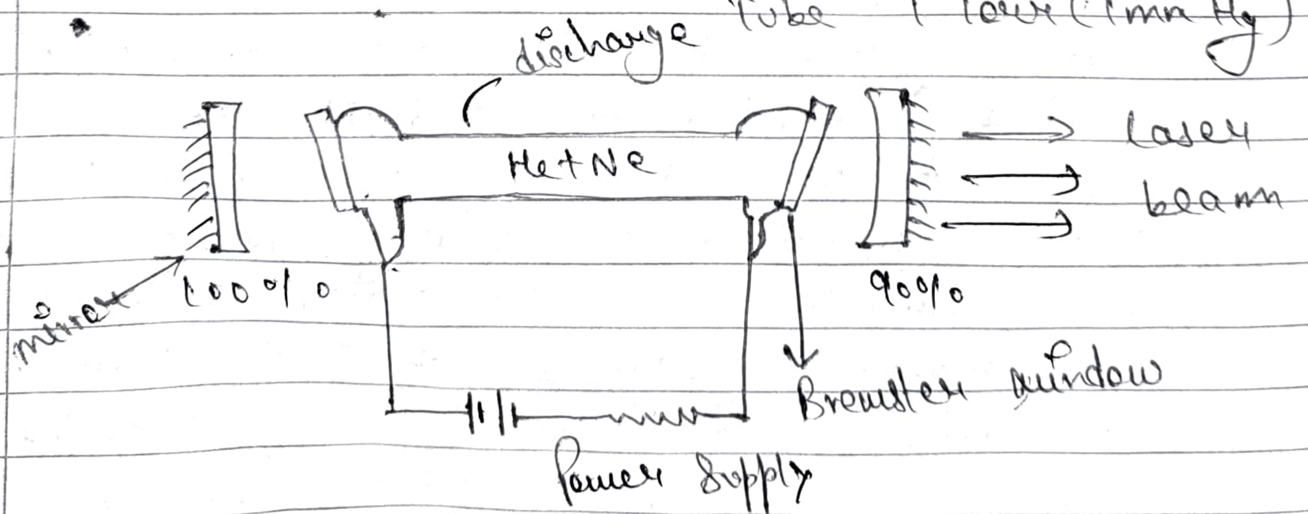
As the power is switched on, xenon flash lamp produces flash of white light on Ruby Rod. chromium ion (Cr^{3+}) absorbing green and blue component from white light are excited to the energy band E_3 from E_1. The energy-band E_3 have a very short life-time as a result of which the excited Cr^{3+} ions lose their energy in collisions with crystal lattice. By non-radiative transition Cr^{3+} ions Jump to the ~~...~~ energy-band E_2 as shown in figure. The energy E_2 is a meta-stable state (a state having 1000 times longer life-time). ~~At~~ Therefore, Cr^{3+} ions starts to accumulate at E_2. After some time, the condition of population inversion is established between E_2 and E_1. A chance photon emitted spontaneously starts the stimulated emission. As a result of this a red colour laser beam of wavelength 6943 Å is emitted from one end (90% Reflectivity).

He-Ne Laser

It was the first gaseous laser of the world invented by Ali Javan & his co-workers in 1961 (USA).

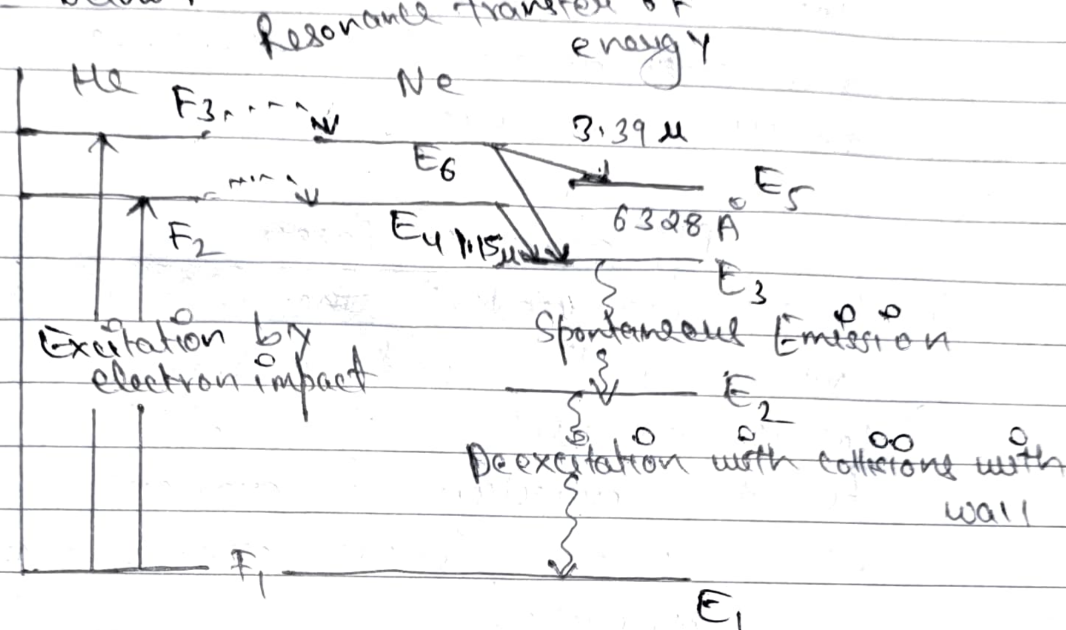
Construction

~~It is~~ It's discharge tube of length 50 cm diameter 1 cm is taken. Brewster windows are provided at ends. The tube contains a mixture of He and Ne; in the ratio 10:1 at a pressure of one torr (1 mm Hg). Electrodes are provided and connected to a power supply (10 kV). The tube is kept between two mirrors having reflectivity 100% and 90%.



Working

The energy-level diagram of He and Ne are as shown below:



As the power is switched on, electrons and ions are produced in the discharge tube and are accelerated. The accelerated electrons collide with He atom and excite each to the level F_2 and F_3. The level F_2 and F_3 of He are meta-stable state and the energy of these two levels is nearly same as E_4 and E_6 level of Ne. Therefore, by resonance transfer of energy excited He atoms collides with Ne atom in ground state and excited them to the level E_4 and E_6. The level E_4 and E_6 of Ne are also meta-stable state. Therefore, the condition of population inversion is established. Chance photons emitted spontaneously starts the laser action and three laser transitions 3.39 µ ($E_6 \to E_5$), 6328 Å ($E_6 \to E_3$) and 1.15 µ ($E_4 \to E_3$) are produced. By changing the dielectric material of mirror, the two infra-red photons (3.39 µ and 1.15 µ) are diminished; and the visible photon 6328 Å is boost up. Thus, Red colour light of wavelength 6328 Å is emitted as a laser beam from this (He-Ne) laser.

By spontaneous emission, the atoms at E_3 are deexcited to the level E_2. The atoms at E_2 losing their energy in collisions with wall of tube and are de-excited to the level E_1 and the process is continue.

Application of laser

① Lasers are used in the field of engineering for cutting, welding and drilling.

② Lasers are used in the field of medical Science for the correction of eye-lens curvature; removal of stones from internal organs, Angio-plasty and in Cosmetics.

③ Lasers are used in Fibre-optic Communication, holography, in the detection of atmospheric pollution, war, etc.