# LASER

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Introduction
Characteristics
Einstein Coefficients
Lasing action — Population Inversion
3-level pumping
4-level "
Ruby laser
He-Ne Laser

LASER → Light Amplication by Stimulated Emission of Radiation

Characteristics of Laser
1) highly monochromatic in nature
2) " coherent " "
3) " polarised " "
4) " intensed or energetic " "
5) " directional
6) " focussed

LQ Atomic Transition (Einstein's Coefficients and their Relation)
Movement of atoms from one energy level to another energy level is known as atomic transition. Let us consider there are two energy levels $E_1$ and $E_2$ in a system where $E_1$ is the ground state and $E_2$ is the excited state.

$$E_2 - E_1 = h\nu$$

$h\nu$ amount of energy is to be supplied to the atoms present in the ground state for the transition from $E_1$ to $E_2$.

In the ground state, energy is minimum whereas life time is more. In the excited state, energy is max whereas life time is less.

During the transition process, $E_1$ to $E_2$ transition takes place by absorption of energy. $E_2$ to $E_1$ transition takes place by emission of energy

$E_1 \rightarrow E_2 \Rightarrow$ Absorption of energy

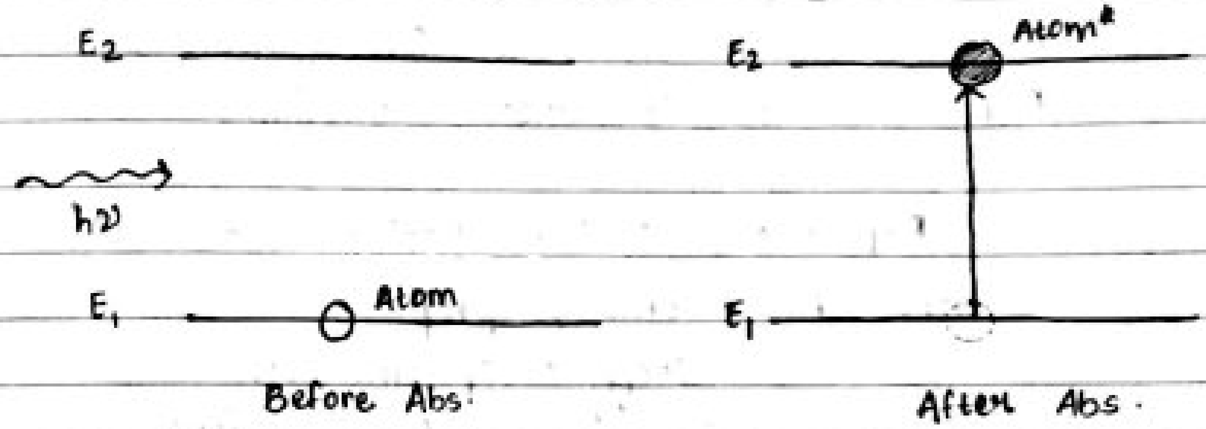
$E_2 \rightarrow E_1 \Rightarrow$ Emission of energy < Spontaneous / Stimulated

Atomic transition is of 3 types:

Stimulated Absorption
Spontaneous Emission
Stimulated "
} Interaction between e-m rad$^n$ with matter.

The coefficients of the above transition processes are called the <u>Einstein's</u> <u>coefficients</u>.

1) Stimulated Absorption Process (Einstein's B-coefficients)




Atom + Photon $\longrightarrow$ Atom*

Let $N_1$ = No. of atoms present at $E_1$

$N_2$ = No. of atoms present at $E_2$

$R_{Ab}$ = Rate of absorption

$U(\nu)$ = Energy density

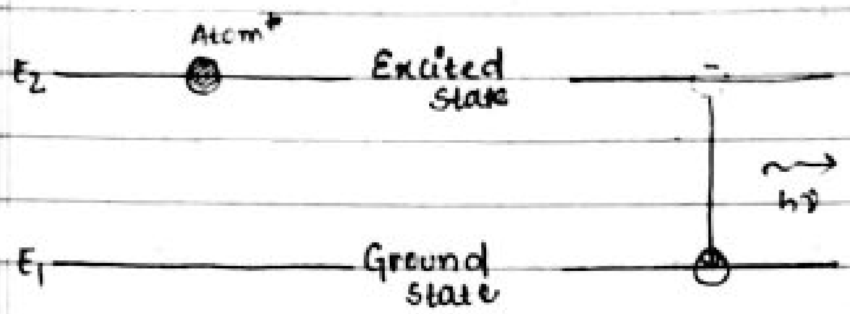
During stimulated absorption

$$\left.\begin{array}{l} R_{Ab} \propto N_1 \\ \quad \propto U(\nu) \end{array}\right\} R_{Ab} = B_{12} N_1 U(\nu) \quad \text{——— (i)}$$

where , $B_{12}$ = Constant of proportionality
= Coefficient of st. Abs.
= Einstein's B coefficient

During the transition from $E_2 \rightarrow E_1 \Rightarrow$ Emission < Normal Excited state ($10^{-8}$ sec) → Spontaneous Emission; Metastable excited state ($10^{-3}$ sec) → stimulated "

2) Spontaneous Emission Process (Einstein's A-coefficient)




During spontaneous emission

$$Atom^* = Atom + h\nu .$$

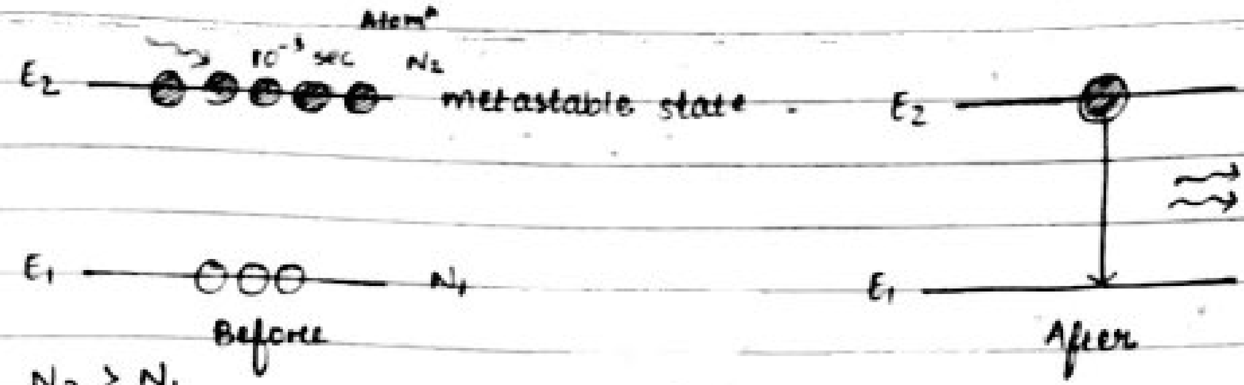
If $A_{21}$ = Einstein's coefficient for spontaneous emission
$R_{sp}$ = Rate of Spontaneous emission

$$R_{sp} \propto N_2 \Rightarrow R_{sp} = A_{21} N_2 \quad \text{——— (ii)}$$

Here $A_{21}$ = Const. of prop.
= Coeff of sp. emission
= Einstein's A - coefficient

3) Stimulated Emission Process (Einstein's **B**- coefficient)

Stimulated emission takes place when there is metastable excited state. In metastable excited state the life time of atoms is very large, i.e. of the order of $10^{-3}$ sec.




$N_2 > N_1$

During stimulated emission process

$$Atom^* + h\nu \longrightarrow Atom + 2h\nu$$

If, $R_{st}$ = Rate of stimulated emission

$$\left.\begin{array}{l} R_{st} \propto N_2 \\ \quad\;\; \propto u(\nu) \end{array}\right\} R_{st} = B_{21} N_2 u(\nu) \quad \text{——— (3)}$$

where, $B_{21}$ = Const. of prop.
= Coefficient of st. emission
= Einstein's B-coeff for st. em.

Relationship between Einstein's A, B coeff.

From the transition process, we obtained the following eq^ns

$$R_{Ab} = B_{12} N_1 u(\nu)$$
$$R_{sp} = A_{21} N_2$$
$$R_{st} = B_{21} N_2 u(\nu)$$

At thermal equilibrium, rate of absorption = rate of emission

i.e., $R_{Ab} = R_{sp} + R_{st}$

or $B_{12} N_1 u(\nu) = A_{21} N_2 + B_{21} N_2 u(\nu)$

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

or $u(\nu) = \dfrac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$

or $u(\nu) = \dfrac{A_{21}}{B_{12}\dfrac{N_1}{N_2} - B_{21}}$

On dividing $B_{12}$ from the numerator and denominator of the above eq^n we find

$$u(\nu) = \frac{(A_{21}/B_{12})}{\left(\frac{N_1}{N_2}\right) - \left(\frac{B_{21}}{B_{12}}\right)} \quad \text{——} (4)$$

From Boltzmann distribution law

$$N_1 = N_0 e^{-E_1/K_B T} \quad \text{——} (5a)$$

$$N_2 = N_0 e^{-E_2/K_B T} \quad \text{——} (5b)$$

where $K_B$ = Boltzmann constant

$T$ = Absolute temperature

$N_0$ = Total no. of atoms present in the system before transition

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

$$= e^{h\nu/K_B T} \quad \text{——} (6)$$

At thermal equilibrium, $B_{12} = B_{21} \Rightarrow \frac{B_{21}}{B_{12}} = 1$ —— (7)

Using eqns (6) and (7) in eqn (4), we get

$$u(\nu) = (A_{21}/B_{12}) \left[\frac{1}{e^{h\nu/K_B T} - 1}\right] \quad \text{——} (8)$$

Further on considering the Planck's hypothesis we can express the energy density as

$$u(\nu) = \frac{8\pi h \nu^3}{c^3} \left[\frac{1}{e^{h\nu/K_B T} - 1}\right] \quad \text{——} (9)$$

Comparing eqns (8) and (9) we find

$$\boxed{\frac{A_{21}}{B_{12}} = \frac{8\pi h \nu^3}{c^3}} \quad \text{——} (10)$$

Eqn (10) represents the relationship between Einstein's A, B coefficients.

# Lasing Action

The mechanism by which laser light is produced is known as lasing action.

1) Metastable state
2) Population Inversion → Pumping Mechanism
3) Stimulated Emission
4) For amplification → Resonator or Resonant cavity

## Population Inversion

Population Inversion is the condition at which more no. of atoms are present in the higher energy state as compared to the lower energy state.

~~During~~ For population inversion, $N_2 > N_1$

Because of population inversion stimulated emission can take place in laser devices.

## Pumping

The mechanism to achieve population inversion.

There are different types of pumping mechanisms:

1) Optical Pumping
2) Thermal "
3) Electric discharge
4) chemical pumping
5) Nuclear "
6) Semiconductor "

15/11/19 **Components of Laser Devices**

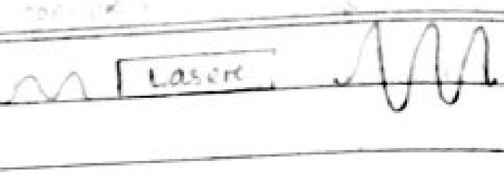
1) Active Medium (Solid / Liquid / Gas) → Active centers + Photons ⇒ Laser

2) Pumping System

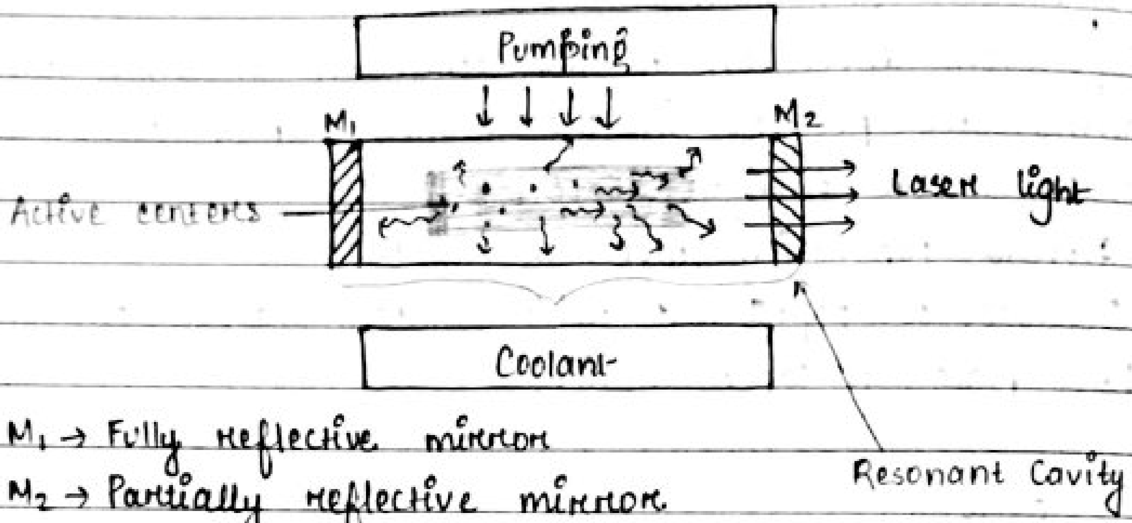
3) Resonant Cavity

4) Coolant arrangement

5) Brewster's Window




Block Diagram of Laser Device




$M_1 \rightarrow$ Fully reflective mirror
$M_2 \rightarrow$ Partially reflective mirror

Based on the type of ~~opt~~ active medium used in a laser device the laser devices are classified as
✓Solid state Laser → Ruby Laser → 3-level Laser
✓Gaseous Laser → He-Ne Laser → 4-level Laser
Liquid state Laser
Semiconductor "

## Ruby Laser

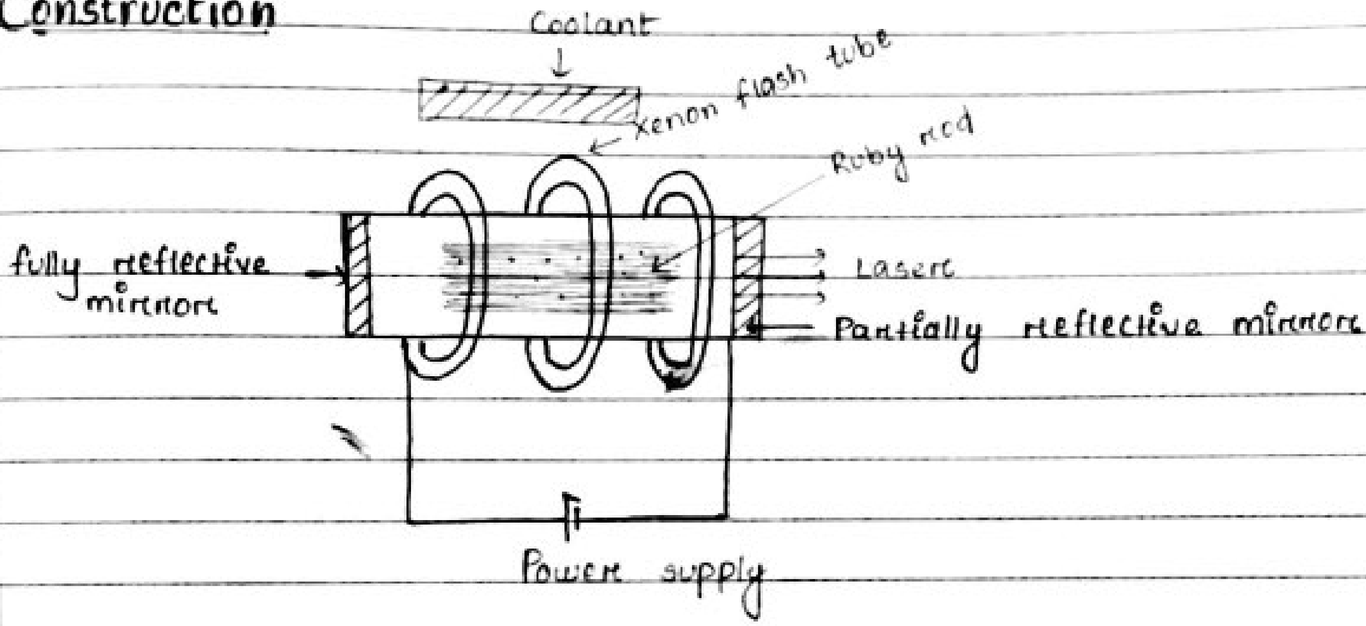
Ruby laser is the first solid state laser invented in 1960.
Ruby belongs to the family of gems.
It is basically $Al_2O_3$ crystal doped with chromium ($Cr^{3+}$) ion which gives it characteristic red colour. The colour of ruby rod depends upon the concentration of chromium ion doped in it.

In ruby laser chromium ions are active centres which are responsible for the lasing behaviour of ruby laser device. The pumping system consist of a xenon flash tube which produces a pulsed laser light of wavelength 6943 Å when the lasing action is completed.

Keypoints.

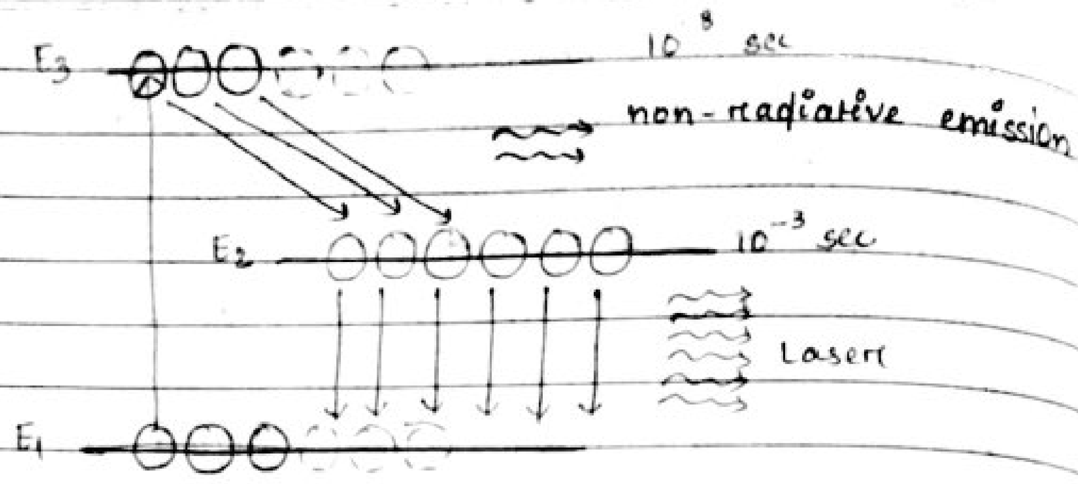
Active medium - Ruby crystal doped with $Cr^{3+}$
Active center - $Cr^{3+}$
Pumping system - Xenon flash tube
3-level Energy system

## Construction




Ruby crystal is taken in the form of a symmetrical rod of about 10 cm in length and about 1 cm in diameter. Its ends are polished in such a way that the end faces are exactly parallel to each other. The ruby crystal is enclosed inside a tube with a coil of xenon flash light. The xenon flash tube produces flashes of light and activates the active centres. The system is cooled with the coolant arrangement.

# Working



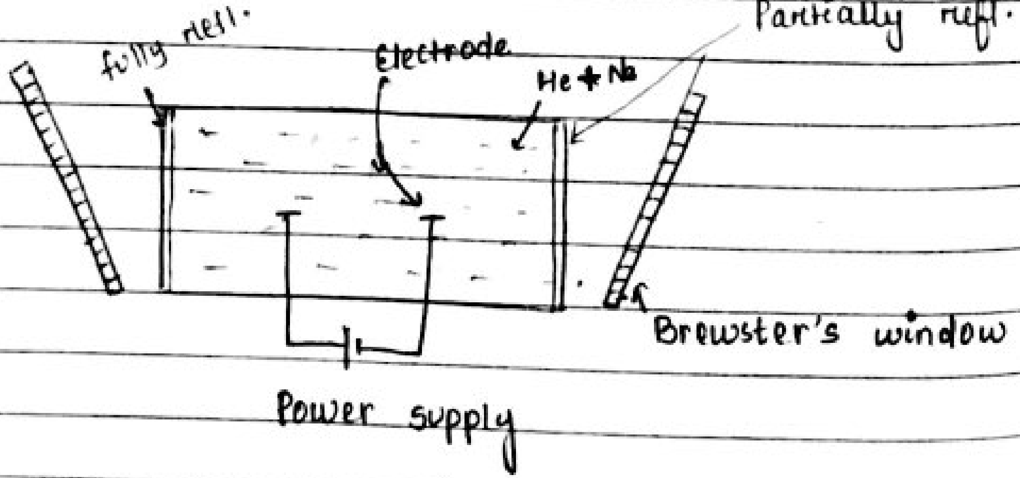

$N_2 > N_1$

## He-Ne Laser

It is one of the types of first gas laser invented in 1961. It consists of a mixture of He & Ne with a suitable proportion. Ne gas will act as an active centre medium with electric discharge as the pumping system. The best known He-Ne laser operates at the wavelength of 6328 Å & produces a continuous laser beam as the output.

Active medium - Mixture of He and Ne gas
Active centre - Ne
Pumping Mech - Electric discharge

### Construction




Resonant cavity

In He-Ne laser system a mixture of He and Ne gas in the ratio of 10:1 is taken inside a quartz tube at low pressure. The pumping source is provided by an electric discharge of very high voltage through the electrodes. The optical cavity consist of a fully reflective mirror at the input end and partially reflective mirror at the output end. An arrangement of Brewster's window is found in He-Ne laser to obtain a highly polarised laser light.

**Working**

The working of He-Ne laser is based on 4-energy level system.