UNIT-5

LASER

Light Amplification by Stimulated Emission of Radiation.

1917 → Albert Einstein
↳ Theoretical.

1954 → C.H Towes & co-workers (Conf. Stimulated Emission)

1960 → Ruby laser — T.H Maiman.

1961 → A. Javan [He-Ne LASER].

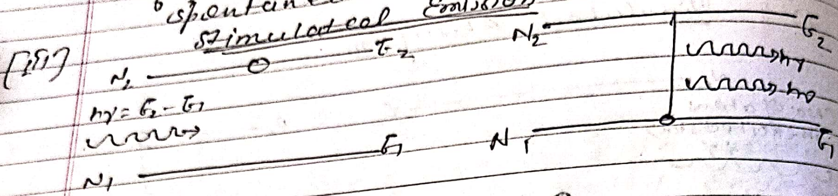
LASER :- It is a device which emits a monochromatic powerful and ~~colligat~~ collimated beam of light.

→ The most important features of lasers are :

i) High degree of coherence.
) High Directionality.
Extraordinary Monochromaticity
High Intensity.

The emission of radiation from higher to lower energy energy state without any external state influence is called as spontaneous emission.

[III] Stimulated Emission



We know that average life time of an atom in the excited state is "10^{-8} sec." During this short interval, let a photon of energy at $h\nu$ is incident on the atom.

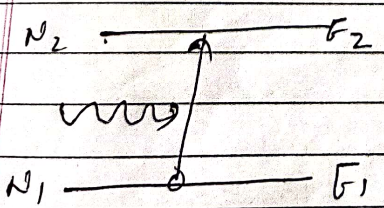
Einstein observed that there is interaction between the atoms in excited state and the incident photon. During interaction the photon induced the excited atom to make transition to ground state. This transition produces a second photon which is identical to inducing photon with respect to frequency, phase and propagation direction. This process is called stimulated or induced emission.

The process of force emission of photon caused by the incident photon is called as stimulated emission.

Difference Between Spontaneous Emission & Stimulated Emission :

Spontaneous Emission	Stimulated emission
i) The emission has a broad spectrum i.e. many wavelengths	i) The emission has a mono chromatic radiation i.e. single wavelength
2) ~~In over~~ Incoherent radiation	2) Coherent radiation
3) Less intense	3) High intense
4) Less Directionality & More angular spread	4) High directionality & less angular spread.

Einstein Coefficient & Relation b/w einstein coeffcn



$P_{1\to2}$ (no. of absorption per unit time per unit volume) $\propto N_1$ (no. of atom in ground state)

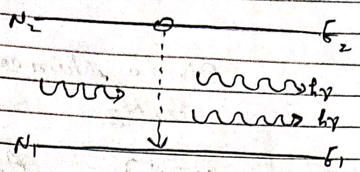
$P_{1\to2} \propto u(\nu)$ (energy density of incident Radiation)

(i) Stimulate absorption

(iii) <u>Stimulated Emission</u>:

$P_{2\to1} \propto N_2$

$P_{2\to1} \propto u(\nu)$

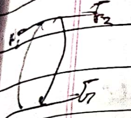


So, $P_{2\to1} \propto N_2 u(\nu)$

$$\boxed{P_{2\to1} = B_{21} N_2 u(\nu)}$$

↳ Prop. constant for stimulated emission.

Acc. to thermal equilibrium condition



Rate of Absorption = Rate of Emission.

$$P_{1\to2} = P_{2\to1}(\text{spontaneous}) + P_{2\to1}(\text{stimulated})$$

Put the values of $P_{1\to2}$; $P_{2\to1}$ (spon.) & $P_{2\to1}$ (stimul.) in this relation.

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

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

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

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

Divide Numerator & Denominator by $B_{21} N_2$

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

Acc. to Boltzman's distribution law.

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

So,

$$u(\nu) = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} e^{h\nu/KT} - 1} \right] \longrightarrow (A)$$

Acc. to Planck's theory of radiation

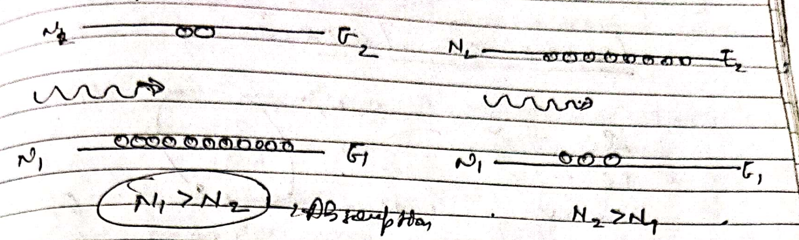
$$u(\nu) = \frac{8\pi h \nu^3}{c^3} \left[\frac{1}{e^{h\nu/KT} - 1} \right] \longleftarrow (B)$$

On comparing eqn (A) & (B), we get.

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

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

Population Inversion :— $N_2 > N_1$



The process by which the population of a particular higher energy state is made more than that of a specified lower energy state is called as population inversion.

A system or medium in which population inversion is achieved is called as active system or active medium.

Pumping

The process by which Population inversion is achieved is known as pumping action.

e.g. (1) Optical Pumping

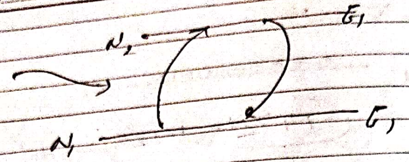
(2) Electrical discharge method.

(3) Inelastic collision between atom

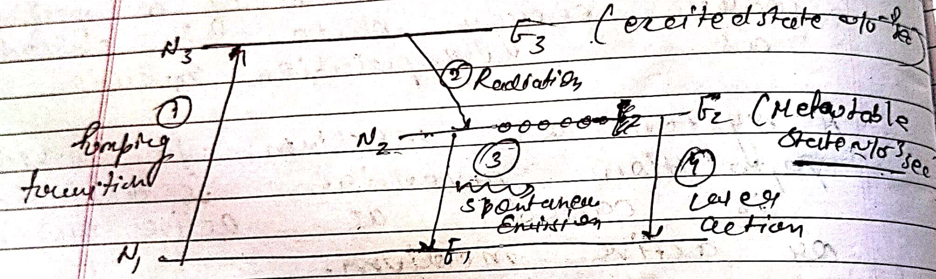
(4) Direct conversion.
(5) Chemical reaction.

Levels of Laser:

2L → ✗
3L → ✓
4L → ✓



2 Level Laser not possible because
Rate of Absorption = Rate of emission.



Metastable State:

We know that normally atom in excited state has very short life time which is of the order of (10^{-8} sec). Therefore even if we supply energy continuously to atoms to transfer them from ground state to (E) (E_1)

excited state (E_2) then they immediately come down to ground state. So in this way population inversion cannot be acheived.

In order to acheive population inversion we must have a energy state which has a long life time. Such energy state is called as metastable state. At these state order of life time is 10^{-3} sec. The metastable state allows accumulation of large number of excited atoms at this level. Hence the population inversion can be achieved.

Note :-

Metastable state can be obtained in a crystal by adding impurity atoms.

Initially the atomic population of ground state E_1 is maximum when the atoms are subjected to intense radiation (pumping) of frequency

$$h\nu = E_3 - E_1 \Rightarrow \nu = \frac{E_3 - E_1}{h}$$

A large number of atoms that are originally in the Ground state E_1 are pumped to upper most energy level E_3.

This transition is known as pumping transition.

The excited state E_3 is short life state. Therefore cannot stay for a longer time.

Some of the pumped atoms may spontaneous transition to the lowest energy level E_1. But most of them decay into metastable state E_2. This transition from E_3 to E_2 is radiation less transitions.

As the energy level E_2 is long ~~li~~ lived state ($\sim 10^{-3}$ sec) So atomic population on E_2 state increasing gradually

When the atomic population of level E_2 becomes more than the atomic population of lower ~~lev~~ energy level E_1.

Now photon of energy $h\nu$ $h\nu = E_2 - E_1$ can initiate stimulated emission of laser transition

4·L

N

1)

2)

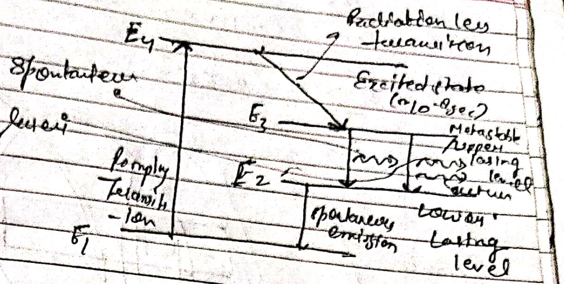
3)

(1)

(2)

(3)

4-L Laser :-



MAIN COMPONENTS OF A LASER :-

1) Active medium. →
2) Pumping Source.
3) Optical Resonator.

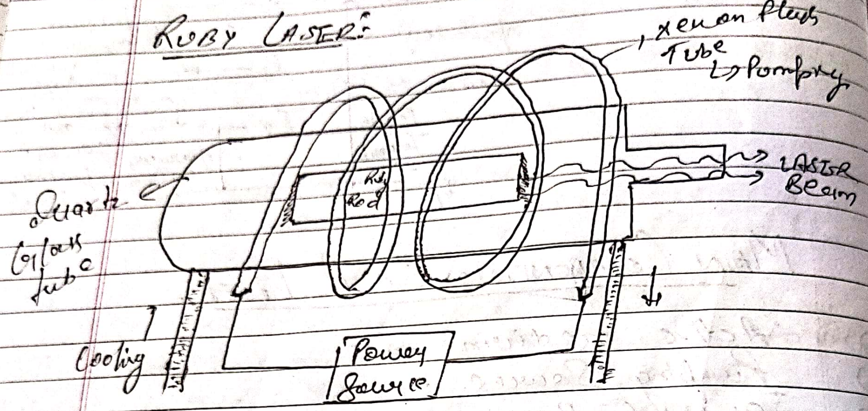
(1) This is basic material in which atomic transition takes place. When the active medium is excited it acheives population inversion. The active medium may be in solid, liquid or gas.

(2) The Energy Source required for acheiving population inversion.

(3) The Optical resonator consist of two reflecting mirrors R_1 & R_2. The mirror R_1 is fully reflecting and the other mirror R_2 is partially reflecting.

The active material is placed in between them.

RUBY LASER:



1960 ; T.H Maiman

Ruby Rod
↓
$Al_2O_3 + Cr_2O_3$
↓
(0.05%)

l = 10cm

Dia = 0.8cm.

CONSTRUCTION OF RUBY LASER :-

~~It~~ It consist of ~~some~~ ~~main~~ four main part

(1) An active working material → Ruby Rod is a active medium.

Ruby is a crystal of aluminium oxide (Al_2O_3) in which some aluminium atoms are replaced by chromium atoms. The active material in the ~~Ruby~~ rod are chromium ions. When Ruby crystal contain about 0.05 % of chromium its colour is pink. This type of Ruby Rod work as active medium.

(2) A Resonant Cavity → The end ~~phase~~ faces of the Rod are made strictly parallel and polished to High degree. The end faces are then silvered in such a way that one end face becomes fully reflecting and the other end partially reflecting. This works as resonant cavity.

(3) Exciting System: The Ruby Rod is surrounded by a helical xenon flash tube which provides the pumping line to raise the chromium ions to upper energy level.

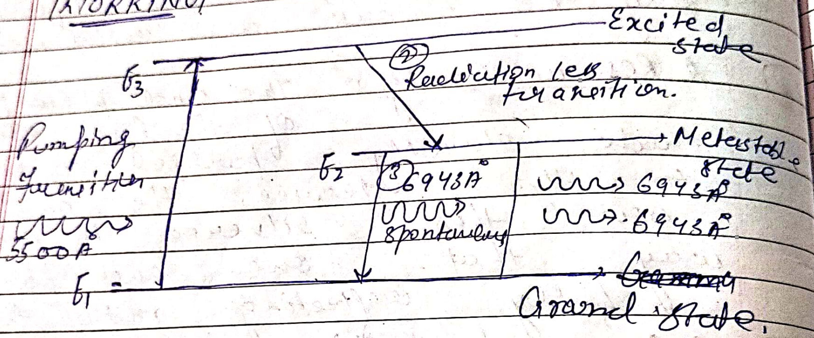
(4) Cooling System :— When flash of xenon tube is on for ~~one~~ millisecond and the tube consumes many thousand joules of energy.

LASER
Beam

Only a part of this energy is used in pumping the Chromium ions while the rest heats up the apparatus.

For this purpose a cooling arrangement is used.

WORKING



(Energy level Diagram of Ruby laser).

CHARACTERISTICS OF RUBY LASER

1) This is a 3 level solid state laser
2) Ruby Rod is used as active medium.
3) Optical Pumping is used for pumping action.
4) The power output is $10^{+4}-10^{6}$ Watt
5) The frequency of output beam is 4.32×10^{14} Hz

1) The wavelength of output beam is 6943 Å.

2) The nature of output pulse beam of light.

APPLICATIONS OF U.V LASER !

1) It is used in laboratory experiments.
2) It is used in soldering & welding.
3) It is used to drilling of brittle materials.
4) It is used in the treatment of opticology (Retina)
5) It is used in "LIDAR."
(light detection and Ranging).

DRAWBACKS:

1) Ruby laser Requires high pumping power.

2) The efficiency of Ruby laser is very small

$$\eta = \frac{P_{out}}{P_{inp}}$$

3) The laser output is not continuous

4) The defects due to 'crystalline imperfection' also present in this laser.

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Q. Calculate the energy and momentum of a photon of a laser beam of wavelength 6328 Å.

Sol.
$E = h\nu$

$E = h\frac{c}{\lambda} = \frac{6.64 \times 10^{-34} \times 3 \times 10^{8}}{6328 \times 10^{-10}}$

$E = 0.003147 \times 10^{-16}$ J

$\lambda = \frac{h}{p} \Rightarrow p = \frac{h}{\lambda}$

Q. Find the intensity of a laser beam of 100 mW power and having a diameter of 1.3 m.

Sol. $P = 100$ mW

$I = \frac{P}{A} = \frac{P}{\pi r^2} = \frac{100 \times 10^{-3}}{3.14 \left(\frac{1.3}{2}\right)^2}$

Q. An atom is stimulated from the state of energy of 1×10^{-34} J to excited level of 7.62×10^{-34} J. What is the frequency of stimulated photons.

Sol. $h\nu = E_2 - E_1$

Q. In a U-V layer total no. of chromium ions is 2.8×10^{19}. If the laser emits radiation of wavelength 7000 Å. Calculate the energy of laser pulse.

$E = h\nu$

$E = nh\nu$

Q. Calculate the Population ratio of two states in He-Ne laser that produces light of wavelength $6000\,\mathring{A}$ at $800\,K$.

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