LASER:-

LASER:- Light Amplification by Stimulated Emission of Radiations.

LASER action takes place with the interaction of photons with material which results in Stimulated Absorption, Spontaneous Emission & stimulated Emission Process.

Characteristics of LASER beams:-

I) Directionality II) High Intensity

III) High degree of coherence IV) Monochromaticity

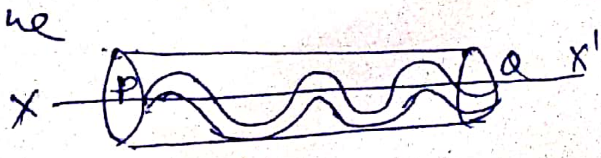
Coherence:- Two light rays which has constant phase with respect to time, are said to be coherence

Coherence are of two types-

1) Temporal coherence:- Temporal coherence is the phase relationship between Radiation fields at different times.

Temporal coherence measure the duration over which this phase relationship is maintained.

- Monochromatic Property of laser is due to temporal coherence.
- Consider a light beam travelling along axis XX'. P & Q are two points lying on this line



Two beams are coherent if path difference between P & Q is constant.

Average length of wave train is called coherent length.

If the velocity of light is c then coherent length L_c is given by.

$$L_c = c\,\Delta t$$

$$L_c = \frac{c}{\Delta \nu}$$

$$\Delta \nu = \frac{c}{L_c} \quad -(1)$$

Also we have $\quad \nu = \frac{c}{\lambda} = c\lambda^{-1}$

on Differentiating wrt λ $\quad \frac{\Delta \nu}{\Delta \lambda} = -\frac{c}{\lambda^2}$

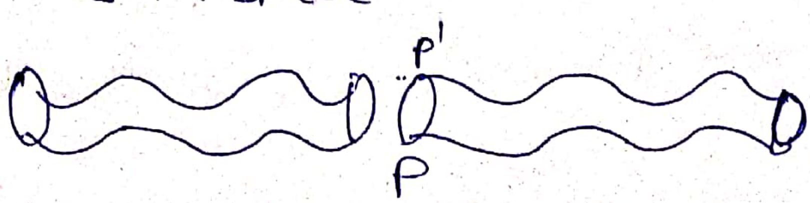
$$\Delta \nu = -\frac{c}{\lambda^2}\Delta \lambda$$

using (1) $\quad \frac{\cancel{c}}{L_c} = -\frac{\cancel{c}}{\lambda^2}\Delta\lambda$

$$\Rightarrow \boxed{\Delta \lambda = \frac{-\lambda^2}{L_c}} \quad \text{or} \quad |\Delta\lambda| = \left|\frac{-\lambda^2}{L_c}\right| = \lambda^2/L_c$$

Hence temporal coherence depend on the value of coherent length and coherent time.

Spatial coherence:- Spatial coherence is the phase relationship between the Radiation field at different points in space.

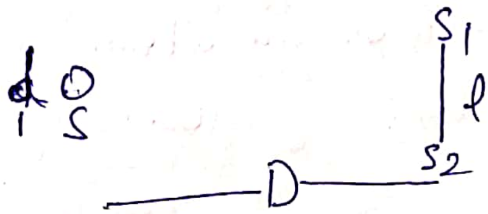


Two beams are said to posses spatial coherence if the Phase difference of the wave crossing P & P' at any instant is constant

Concept of spatial coherence can be Understood by double Slit Experiment as shown in figure.

S1, S2 are two pinhole with Sepration l, the source S is at a distance D from S1 & S2

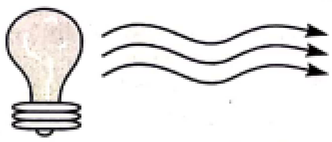
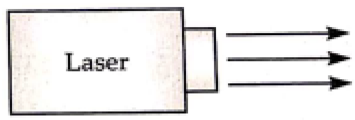
Then the condition for Coherence of S1, S2 is.



$$\frac{\lambda}{a} > \frac{l}{D}$$

or $\boxed{l < \frac{D\lambda}{a}}$

Difference between ordinary light & LASER light.

S.No.	Ordinary Light	Laser Light
		
1.	It has many wavelengths or it is not monochromatic.	It is monochromatic.
2.	It is multidirectional.	It is directional.
3.	It is incoherent *i.e.*, the constituent waves are generally not in the same phase.	It is coherent *i.e.*, the constituent waves are exactly in the same phase.
6.	It does not travel as a concentrated and parallel beam.	It travels as a concentrated and parallel beam.
5.	Ordinary light is produced by spontaneous emission.	Laser beam is produced by stimulated emission.

Principle of LASER and operation of LASER.

To Explain the principle of LASER we used to understand energy transition phenomenon in an atom.

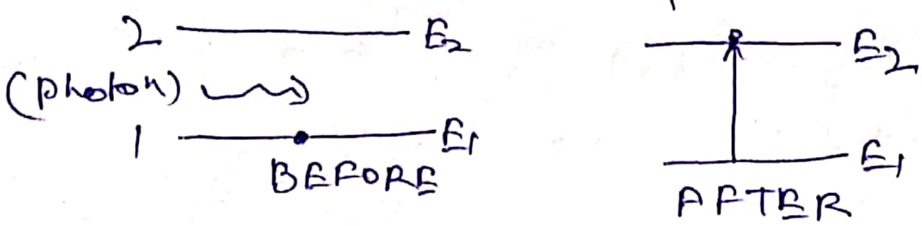
They includes.

1) <u>Stimulated Absorption of Radiations</u>:-

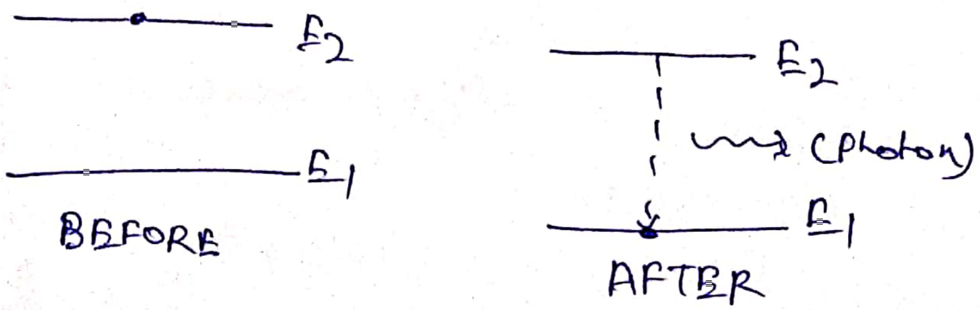
In Stimulated or Induced absorption an atom in a lower level absorb a photon of frequency ν and Moves to a upper level.

Consider an atom in a lower state 1 raise to higher state 2 by absorbing photon of frequency ν given by

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



2) <u>Spontaneous Emission</u>:- In this process an electron in the higher energy level decay to lower level and emit a photon of frequency ν.

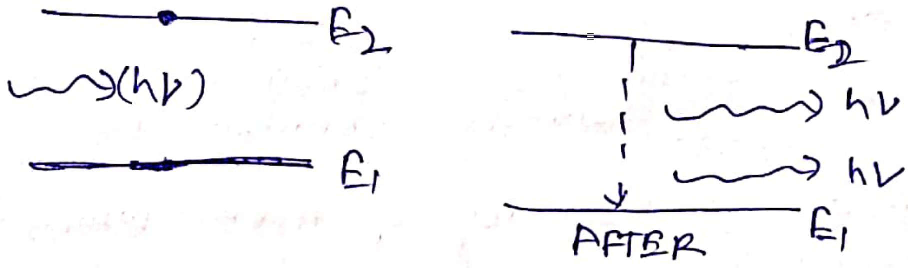


$$h\nu = E_2 - E_1$$

$$\boxed{\nu = \frac{E_2 - E_1}{h}}$$

Stimulated Emission

The Process by which an incoming Photon of Specific frequency interact with an excited electron causing it to drop to lower Energy level.



OR

When a photon of frequency equal to $\nu = (E_2 - E_1)/h$ incident on an atom on the Excited State E_2, then it Stimulate the atom to move to ground State E_1 by emitting a photon of Same frequency ν.

Conditions for LASER action!-

1) Population Inversion!-

The establishment of situation in which number of atoms in a higher Energy State is greater than the lower energy State is Called Population Inversion.

If N_1 is the Number of Atom (Population) in the Energy State E_1 and N_2 is the population in the Energy State E_2. then by using Maxwell Boltzman statistics we have

$$N_1 = N_0 e^{-E_1/KT} \qquad N_2 = N_0 e^{-E_2/KT}$$

Then $\frac{N_2}{N_1} = e^{-(E_2-E_1)/KT} \Rightarrow N_2 = N_1 e^{-(E_2-E_1)/KT}$

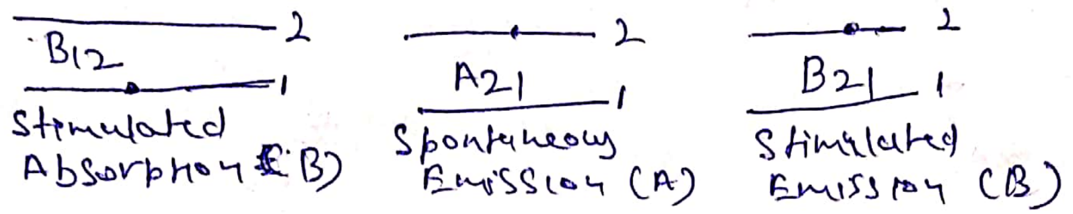
As $E_2 > E_1$, $N_2 < N_1$ (at thermal Equilibrium)

When stimulated absorption starts population decrease with the increase of Energy states $N_2 > N_1$.

Scanned with CamScanner

Einstein A & B Coefficients:-

The Probability rate of transition (Absorption, Spontaneous Emission, Stimulated emission) are Expressed in terms of three constants B_{12}, A_{21}, B_{21} known as Einstein Coefficients



Let us consider an assembly of Atom which is in thermal Equilibrium with Electromagnetic radiation of Frequency (ν) and Energy density $u(\nu)$ at temperature T.

Note:- Einstein A coefficient is Related to Spontaneous Emission of light.

Einstein B coefficient are related to Absorption & Stimulated Emission of light.

Then

1) Number of Absorption transitions Per Unit Volume

$$= N_1 B_{12} u(\nu)$$

(where $u(\nu)$ – Energy Density).

11) Number of Spontaneous transitions Per Unit time Per Unit Volume will be.

$$= N_2 A_{21}$$

111) Number of Stimulated Emission Per Unit time Per Unit Volume will be.

$$= N_2 B_{21} u(\nu)$$

Now at thermal Equilibrium the number of Absorption transition and emission transition should be equal.

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

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

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

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

Dividing by $N_2 B_{21}$

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

According to Boltzman law, Number of Atoms N_1 & N_2 in the Energy States E_1 & E_2 at temperature T are given by -

$$N_2 = N_0 e^{-E_2/KT}$$

$$N_1 = N_0 e^{-E_1/KT}$$

$$\frac{N_2}{N_1} = \frac{e^{-E_2/KT}}{e^{-E_1/KT}} = e^{-\frac{(E_2-E_1)}{KT}} = e^{\frac{-h\nu}{KT}}$$

$$\Rightarrow \frac{N_1}{N_2} = e^{h\nu/KT} \quad \text{—(2)}$$

Substituting (2) in (1)

$$\Rightarrow u(\nu) = \frac{A_{21}/B_{21}}{\left(\frac{B_{12}}{B_{21}}\right) e^{h\nu/KT} - 1} \quad \text{—(3)}$$

According to Plancks Radiation Equn we have -

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{h\nu/kT}-1} \quad -(4)$$

Comparing (3) & (4) we get -

$$\Rightarrow \cancel{\frac{A_{21}}{B_{21}}}$$

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

& $\boxed{B_{12} = B_{21}}$ -(6)

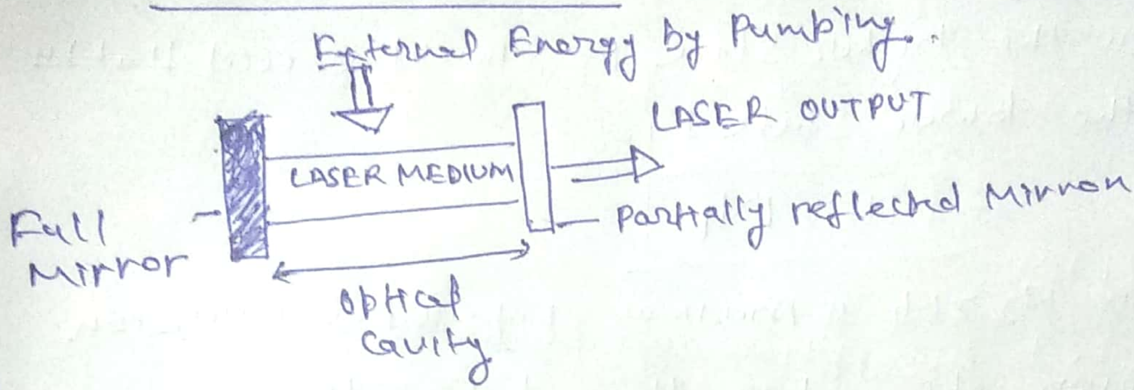
Hence from (6) the Probablity of Stimulated Emission is Equal to Probablity of Stimulated Absorption

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

$$\Rightarrow \frac{A_{21}}{B_{21}} \propto \nu^3 \qquad (E_2 - E_1 = h\nu)$$

It means the Probablity of Spontaneous Emission Increase Rapidly when the Energy difference between two State is large.

Components of laser



1) LASER MEDIUM:- It is the Material in which laser action takes place. The active Medium may be Solid Crystal such as Ruby or gases like CO_2 or Helium or Semiconductor such as GaAs.

This Medium decide the wavelength of Laser Radiation. Laser Medium Contains atoms which can produce more Stimulated emission and cause Amplification. or they are called Active centers.

II) Energy Source (Pumping)

Energy Source Pump the active centres from ground State to excited State to achieve Population inversion. pumping by Energy Source Can be optical Electrical or chemical depending on laser medium which we are using.

III) Resonance Cavity! Resonance Cavity Consist of laser Medium (or Active medium) enclosed between two Mirror one is full Mirror and other is Partially Reflecting Mirror.

How to Achieve Population inversion the number of Atom in the higher state E_2 should exceed ~~that~~ than the lower State E_1.

$$\boxed{N_2 > N_1}$$

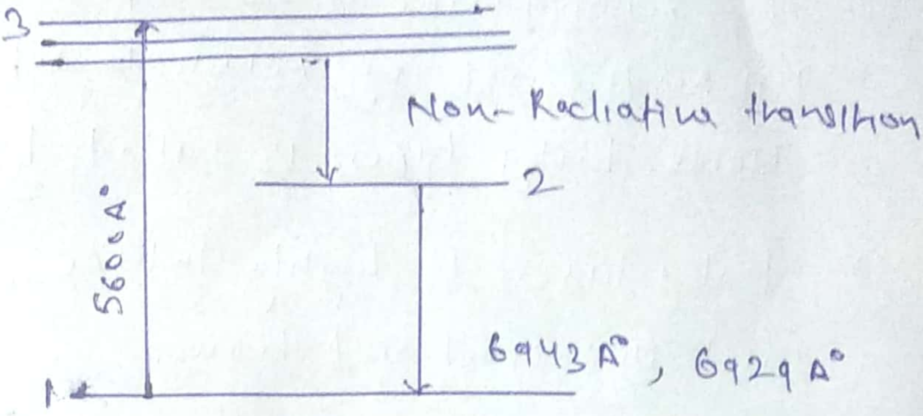
Condition $N_2 > N_1$ is known as population inversion.

* It is never observed in thermal Equilibrium.
* It helps in achieving stimulated Emission.

Pumping process:- The Process by which population inversion is achieved is known as Pumping process.

1) optical Pumping
   (Excitation by a strong source of light eg flash lamp, or lamp).
2) Electrical Pumping.
   (Pumping is usually provided in the form of light or Electric current).

Ruby laser



* Lines 1, 2, 3 shows Energy level of Chromium
* Ruby is a crystal of Aluminum (Al_2O_3) doped with Chromium oxide (Cr_2O_3)
* Aluminum atoms in the crystal are replaced by Cr^{+++} ions, it gives pink color to ruby and give rise to laser action.
* Chromium atom absorb wavelength $\lambda = 5600$ A° and get excited from energy level 1 to energy level 3.
* From this level 3 some excited atom returns to ground state, but some other moves to level 2 which is metastable state.
* Lifetime of atom in the excited state 3 is very less ie 10^{-8} sec.
* Metastable state has very long lifetime (3×10^{-3} sec) as compare to energy level 3 (10^{-8} sec).
* The number of Atom in energy level 2 keeps on increasing and ultimately become more populated than 1. Hence population inversion is established between level 2 & level 1.

* A Stage is reached where population inversion caused by xenon tube is used up and laser beam closes till next flash of xenon. to repeat the process.
Hence Ruby laser is called Pulsed laser.

* Ruby laser is highly intense, coherent, Monochromatic and Unidirectional beam.

Uses:-

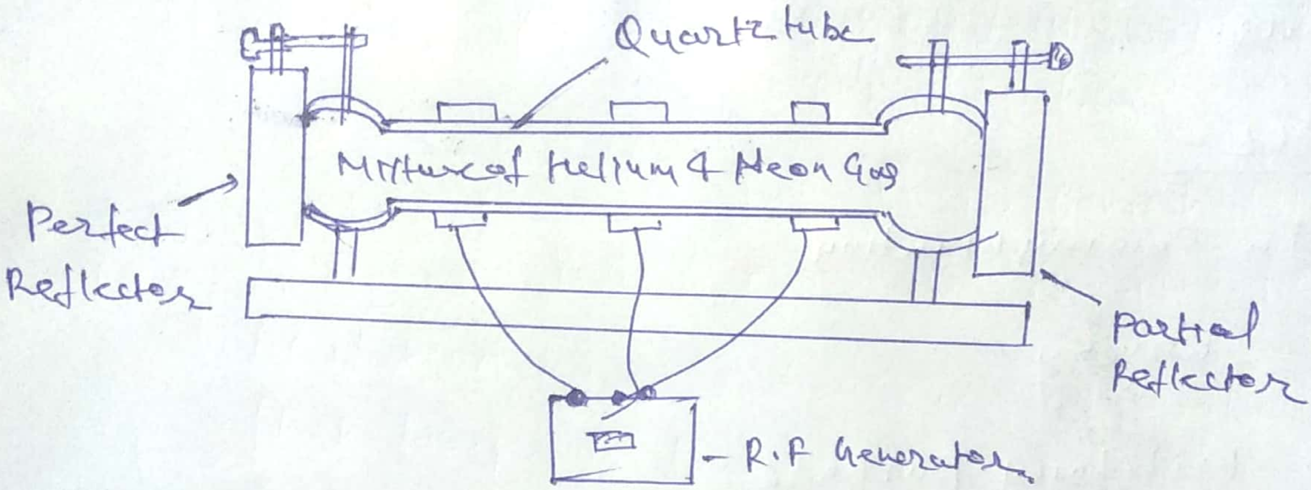
I) Precision welding & drilling in metals
II) Drilling of Industrial diamonds.
III) Holography & Photography of moving objects.

Scanned with CamScanner

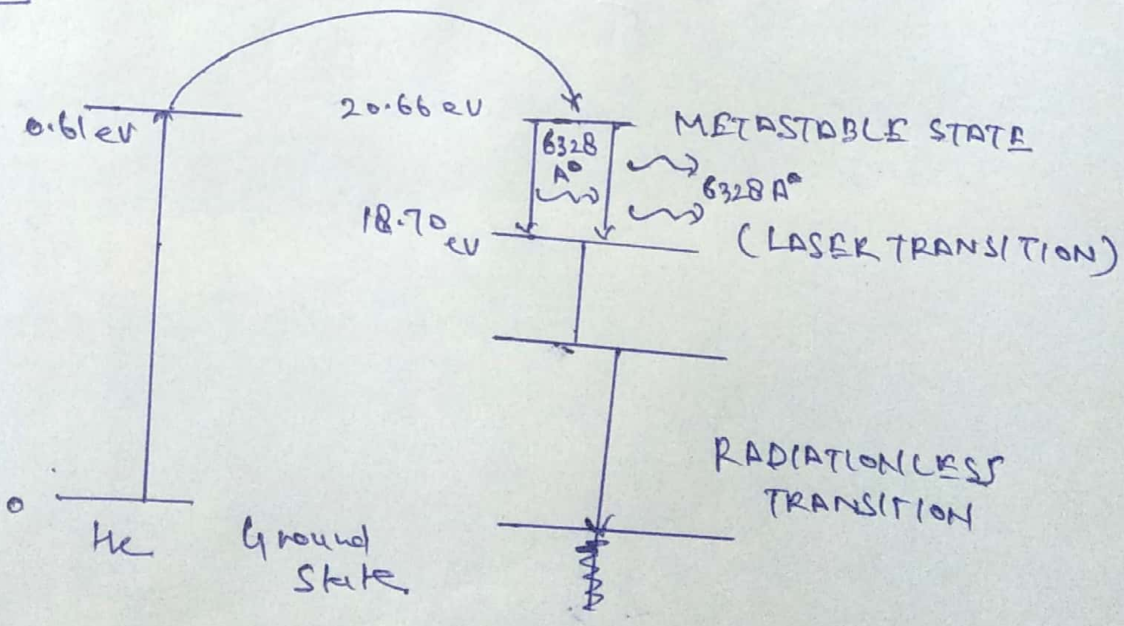
He-Ne Laser

Construction:

* The Active Medium is a Mixture of Helium & Neon. in the ratio 9:1 at pressure about 1 mm of hg.
* One of the mirror is fully silvered & other is partially silvered



Working



* When a discharge is passed through the gas mixture electron are accelerated down to the tube.
* These accelerated electron collide with He & Ne atom to Metastable State 20.61 eV and 20.66 eV.

* When an excited Ne atom pass from the Meta Stable State at 20.66eV to 18.70eV it emits a 6328Å photon.
* This photon travel to gas mixture, reflected back and forth by mirror until it stimulate an excited Ne atom and cause it to emit fresh 6328Å photon. Process is continued & laser transition takes place.

Uses –

i) In communication

ii) Surgery

iii) Military purpose

iv) Holography