Einstein theory of matter radiation Interaction :-

LASER Light Amplification by stimulated emission of Radiation.

According to einstein Electromagnetic Radiations can interact with matter through following 3 process.

1). Stimulated absorption
2). Spontaneous emission
3). Stimulated emission.

Stimulated absorption let us consider initially an atom is in lower energy state having energy E_1. If a photon of energy $h\nu$ incident on an atom in lower state, the atom absorbs this much amount of energy & Jumps to upper state having energy E_2 such that $h\nu = E_2 - E_1$. Process is known as Induced absorption or Stimulated absorption.

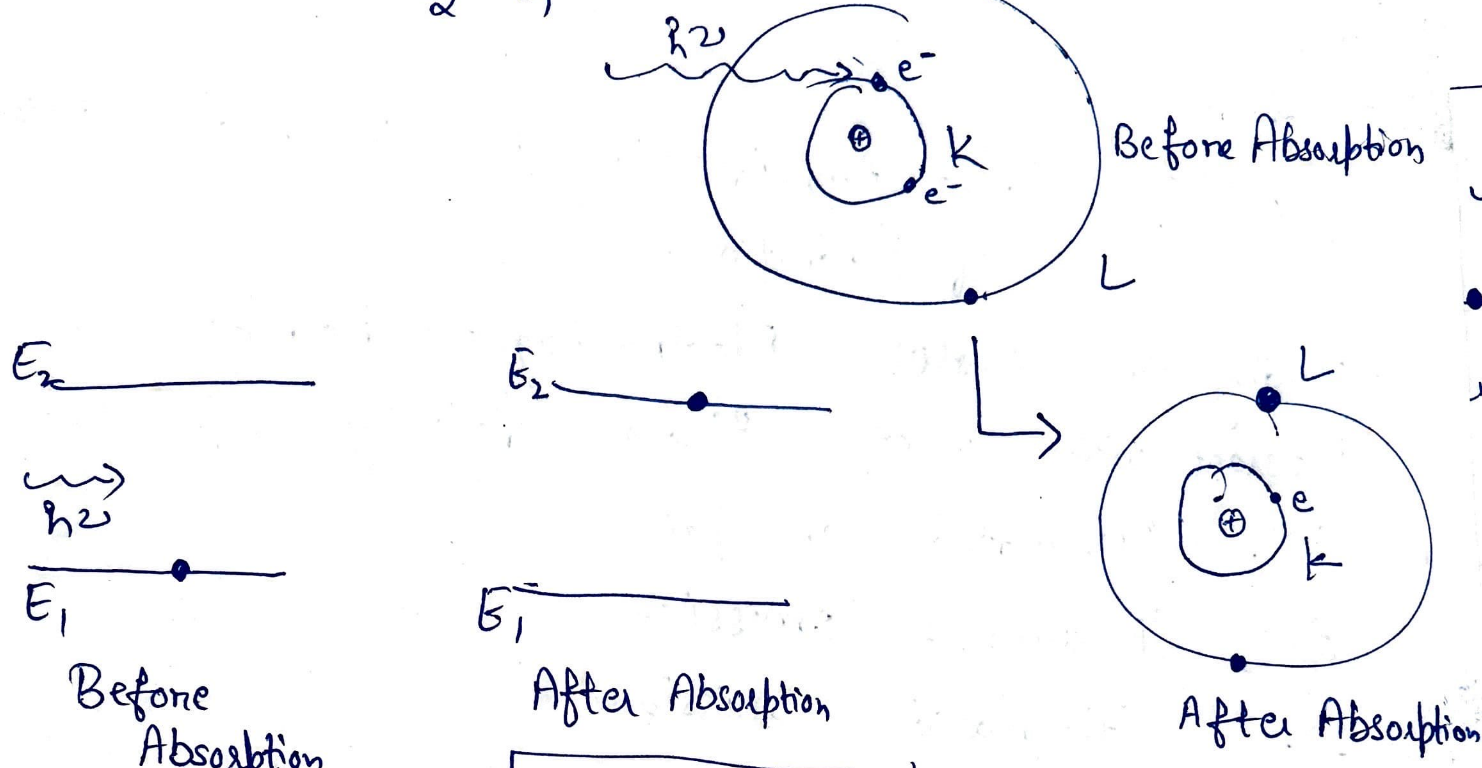
we may express it as

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

$A \rightarrow$ is an atom in Ground state.

$A^* \rightarrow$ atom in excited state.

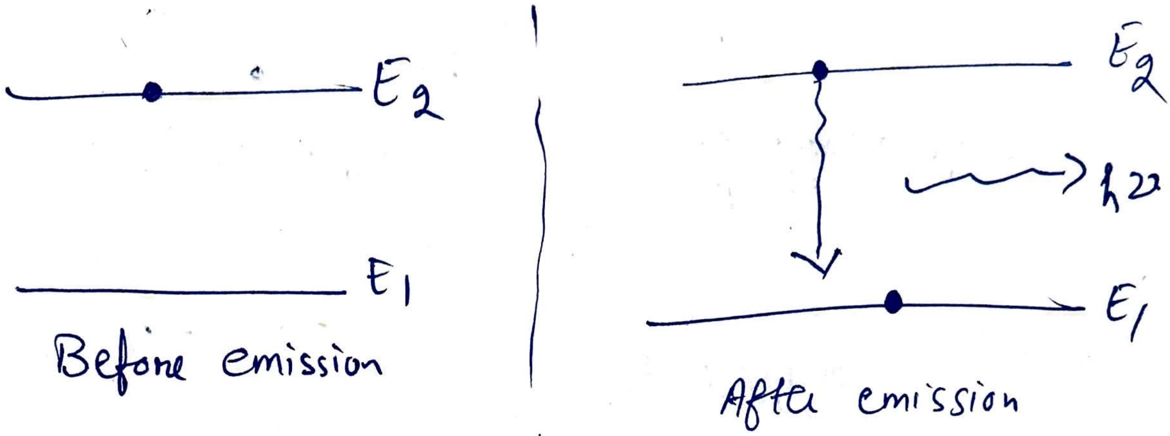
$h\nu = E_2 - E_1$



$$h\nu = E_2 - E_1$$

Spontaneous emission : Consider that initially an atom is in higher energy state E_2. Since normal life time of atom in excited state is 10^{-8} s. So ~~that~~ the atom will make a transition to lower energy state E_1. During this transition atom will release a photon of energy $h\nu$ where $h\nu = E_2 - E_1$. The emission of Photon occurs on its own. This process is known as Spontaneous emission. Thus we can say that process of emission of a photon by an atom without any external agency is Called spontaneous emission.

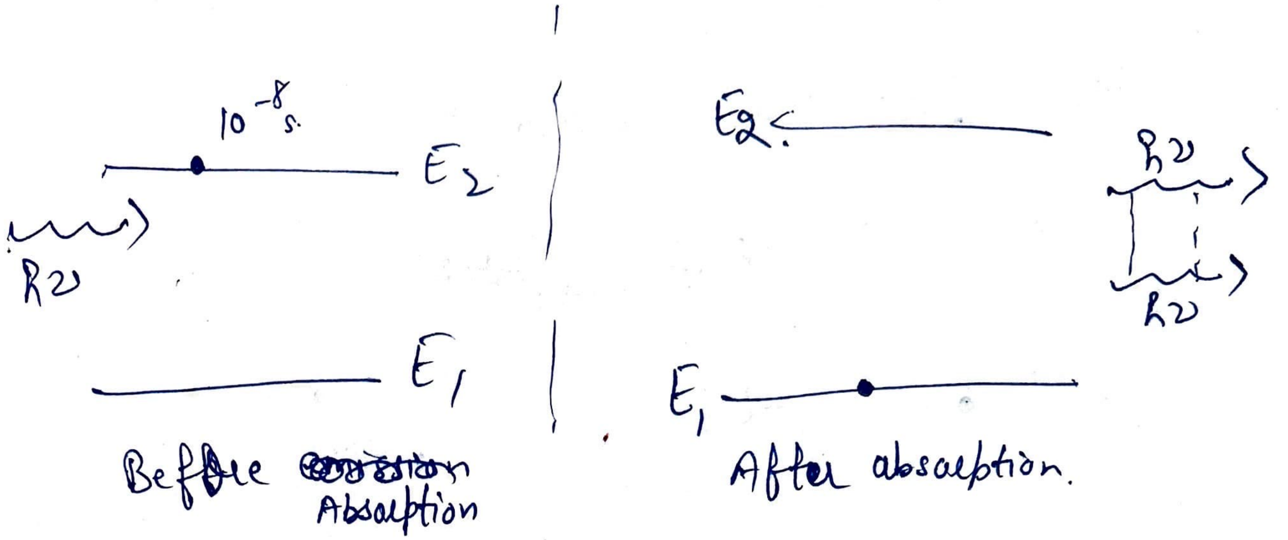
$$A^* \rightarrow A + h\nu$$



$$E_2 - E_1 = h\nu.$$

<u>Stimulated emission</u>:- As suggested by einstein an atom in excited state E_2 Can also make transition to lower energy state E_1 when triggered by photon of energy $h\nu$ during this transition, emission of Second photon take place emitted photon has same frequency, Same direction, Same phase as that of incident photon. The process may be expressed as

$$A^* + h\nu \longrightarrow A + 2h\nu.$$



Einstein's Coefficient

There are 3 einstein's Coefficient

B_{12} → Einstein Coefficient for stimulated absorption

A_{21} → Einstein Coefficient for spontaneous emission

B_{21} → Einstein Coefficient for stimulated emission.

1) Let $E(\nu)$ be energy density of incident radiation

Rate of Stimulated or Induced absorption R_{stA} is directly proportional to

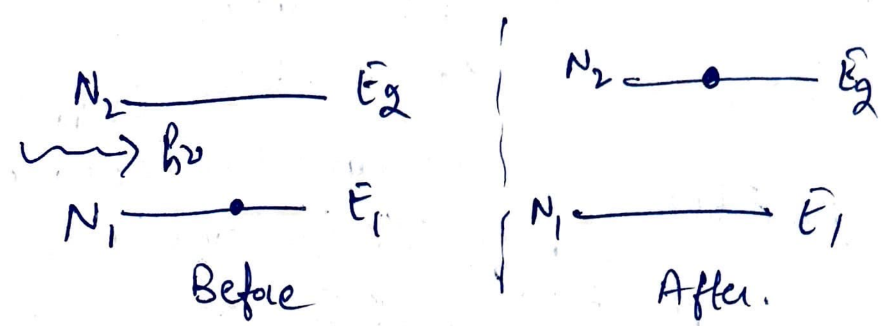
(i) $R_{stA} \propto N_1$

(ii) $R_{stA} \propto E(\nu)$

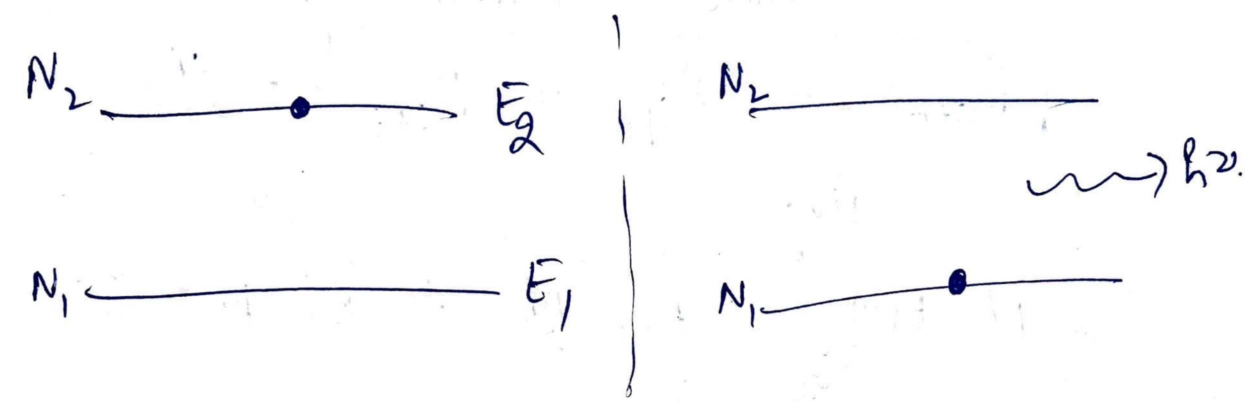
i.e. $R_{stA} \propto N_1 E(\nu)$

$$\boxed{R_{stA} = B_{12} N E(\nu)} \quad —①$$

where B_{12} is Coefficient of proportionality & is called einstein Coefficient for Stimulated absorption. from level 1 to level 2



2). Spontaneous emission



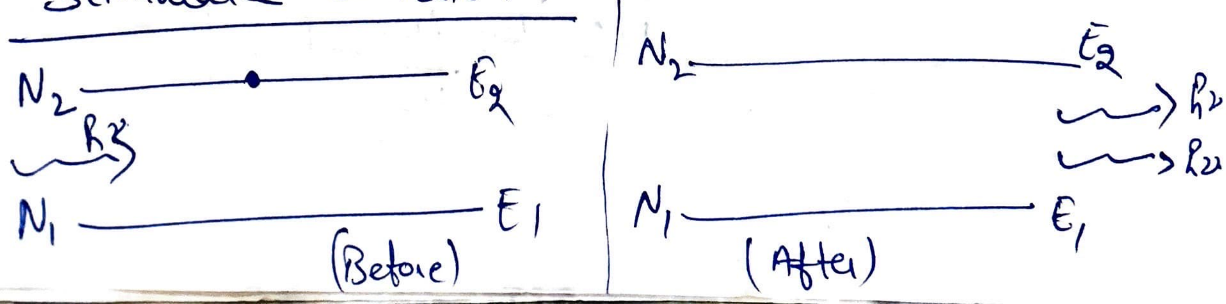
Rate of Spontaneous emission R_{spE} is directly proportional to

$$R_{spE} \propto N_2$$

$$\boxed{R_{spE} = A_{21} N_2} \quad —(2)$$

where A_{21} is Constant of proportionality & is called einstein Coefficient for Spontaneous emission from level 2 to level 1

3). Stimulated emission



Rate of Stimulated emission (R_{StA}) is directly proportional to

$R_{STA} \propto N_2$

$R_{StA} \propto E(\nu)$

i.e. $R_{StA} \propto N_2 \, E(\nu)$

where B_{21} is constant of proportionality & is called einstein coefficient for transition from level 2 to level 1

$$\boxed{R_{StA} = B_{21} \, N_2 \, E(\nu)} \quad \text{--- (3)}$$

In thermo dynamic equillibrium

$$\boxed{R_{StA} = R_{SpE} + R_{StE}} \quad \text{--- (4)}$$

using (1), (2), (3) in (4)

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

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

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

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

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

$$E(\nu) = \frac{A_{21}}{B_{21}\left[\frac{N_1}{N_2}\cdot\frac{B_{12}}{B_{21}} - 1\right]} \quad \text{— (5)}$$

Acc. to Maxwell Boltzmann distribution

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

$$\boxed{\frac{N_1}{N_2} = e^{h\nu/K_B T}} \quad \text{— (6)}$$

using (6) in (5)

$$E(\nu) = \frac{A_{21}}{B_{21}\left[\frac{B_{12}}{B_{21}}\left(e^{h\nu/K_B T} - 1\right)\right]} \quad \text{— (7)}$$

According to planck's Radiation law

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

Comparing equation (7) & (8)

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

$$\boxed{B_{12} = B_{21}}$$

Basics of laser

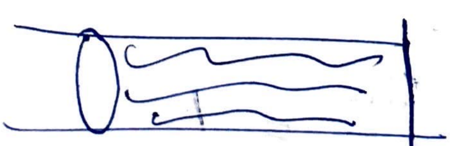
laser is a device that emits a collimated, mono-chromatic, highly intense, unidirectional beam of light. Laser stands for light amplication due to stimulated emission radiations. Laser light is different from ordinary light as it has 4 special features.

1). **Mono Chromaticity** A laser emits light beam of single frequency & single wavelength.

2). **directionality** A laser emits light beam in one particular direction.

3) **Intensity:-** A laser beam can be focused on a very small area. A 1 watt laser is thousand times more intense than 100 W ordinary lamp.

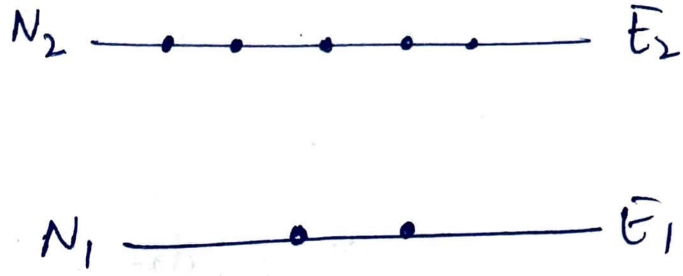
4). **Coherence:-** A laser beam is highly coherent, i.e. there is definite phase correlation b/w photons in a laser beam.



Laser Light

Population Inversion

1). Rate of emission must be greater than rate of absorption. This is the condition for laser action



normally → $N_1 > N_2$

For Laser Action → $N_2 > N_1$

Condition for Laser Action.

This Condition is Called population Inversion

1). $N_2 > N_1$ (• = e^-)

i.e. Probability of Spontaneous emission must be high w.r.t stimulated emission

& coherent beam of light must be sufficiently amplified.

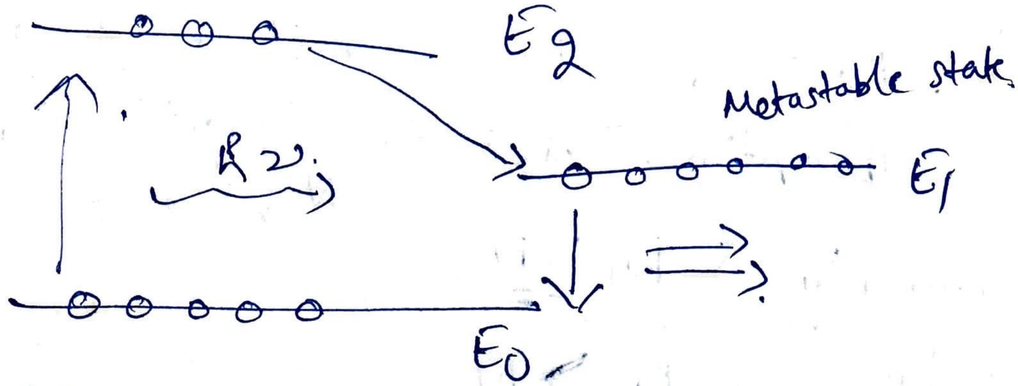
Population Inversion is actually a situation of more atoms in excited state for stimulated emission

Stimulated emission in elevated state is negligible, due to short lifetime & less atoms in excited state (10^{-8} s)

Metastable state required.

* It has longer lifetime 10^{-6} to 10^{-8} s which is required to achieve population inversion
* Mid - level created b/w Ground State & excited State due to which stimulate emission

is increased.



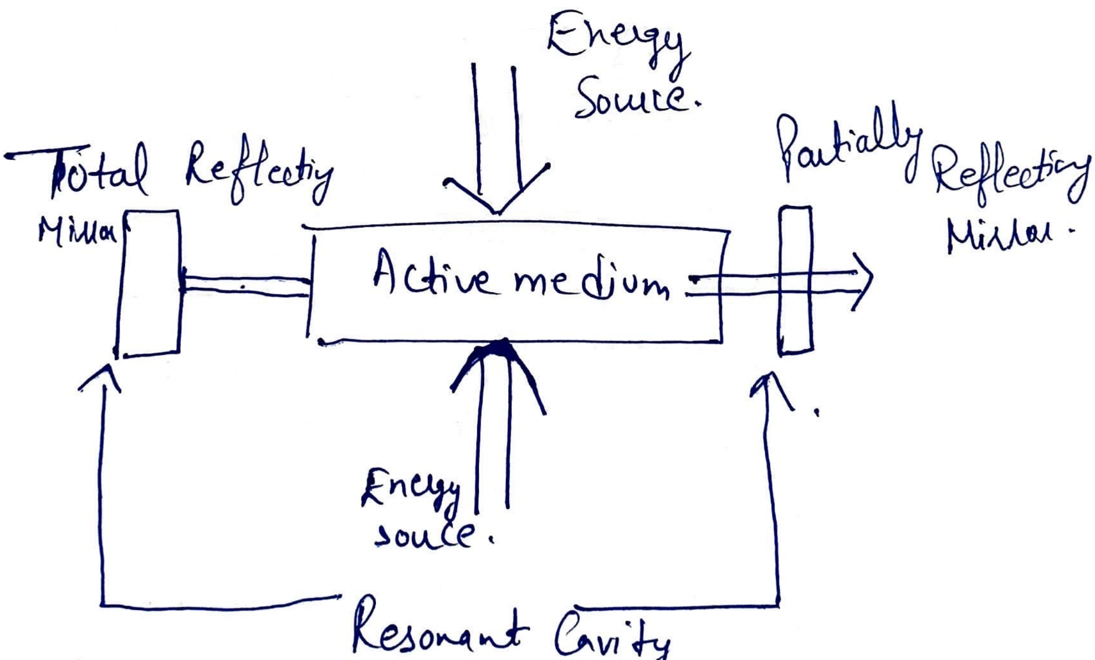
* Population Inversion achieved.

To achieve population inversion various sources for pumping to ~~at~~ start stimulate absorption are used. Various lasers used various kind of pumping source.

Main Components of LASER

There are 3 main Components of LASER
1) Active medium
2) Pumping Source (Energy Source / excitation Mechanism)
3) Resonator Cavity / Optical Resonator.

Active Medium It is the material in which the laser action takes place, The active medium may be a solid such as Ruby rod in Ruby laser, or mixture of gases. such as He-Ne gas in He-Ne laser. Such laser medium are known

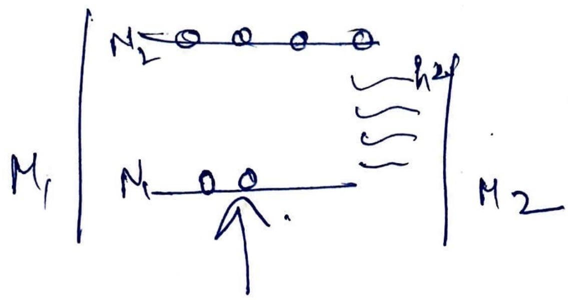


as Active medium or gain medium. Generally in an active medium the no. of e⁻s in Ground State is greater than the excited state.
However, to produce laser action, the no. of e⁻s in excited State should be greater than that in

Ground state i.e. $(N_2 > N_1)$ After Recieving Sufficient energy from souce, the e^-s in G. State are excited to higher energy state. The e^-s in excited state do not stay for longer time as the life time of e^- in excited state is only 10^{-8} sec. Hence after short period of time, e^- in excited state will fall back to G. State by releasing energy in the form of photons. This process is Spontaneous emission. When these emitted photons collide with e^-s in excited state or meta state then photons will force other e^-s to fall back to G. state. As a result, e^-s again release energy in the form of photons. This is called Stimulated emission & this process is continous producing millions of photons, which are having same phase, same frequency, same wavelength. In this way light amplication is achieved in laser medium.

Pumping Souce A process by which population inversion is achieved $(N_2 > N_1)$ in a laser system is called pumping. Type of pumping method used depends on nature of

Active medium used in laser system. For eg:- Solid state Laser. Such as Ruby laser, we use Optical pumping. In gaseous laser such as He-Ne Laser, we use electrical pumping.

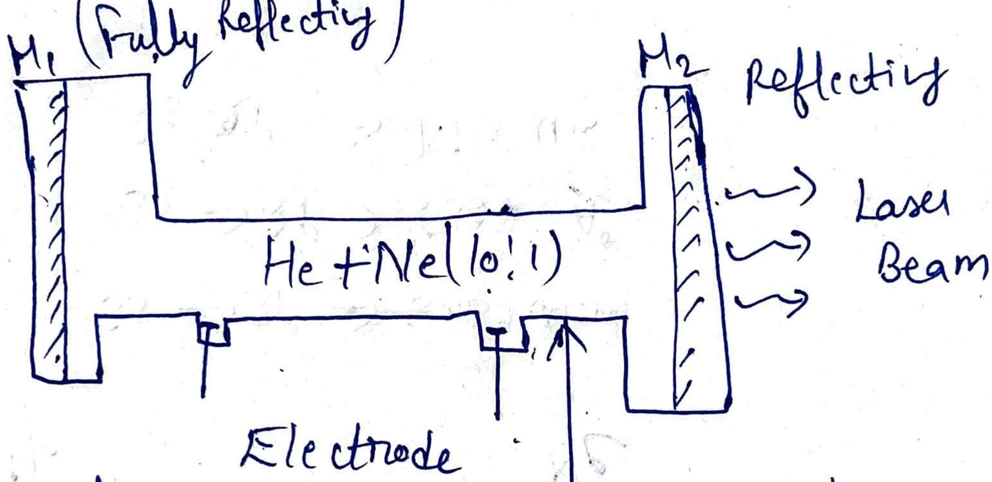


Optical Resonator (Resonator Cavity)

It is a key Component of laser as it guides the process of stimulated emission. It consist of a pair of mirror ~~out of~~ which 1 is 100%. reflecting & other 98% reflecting. The active medium is placed in these two mirrors. Mirror (M_2) is called output Coupler as it allows some of light to leave the Cavity to produce Laser Output beam.

He-Ne Laser

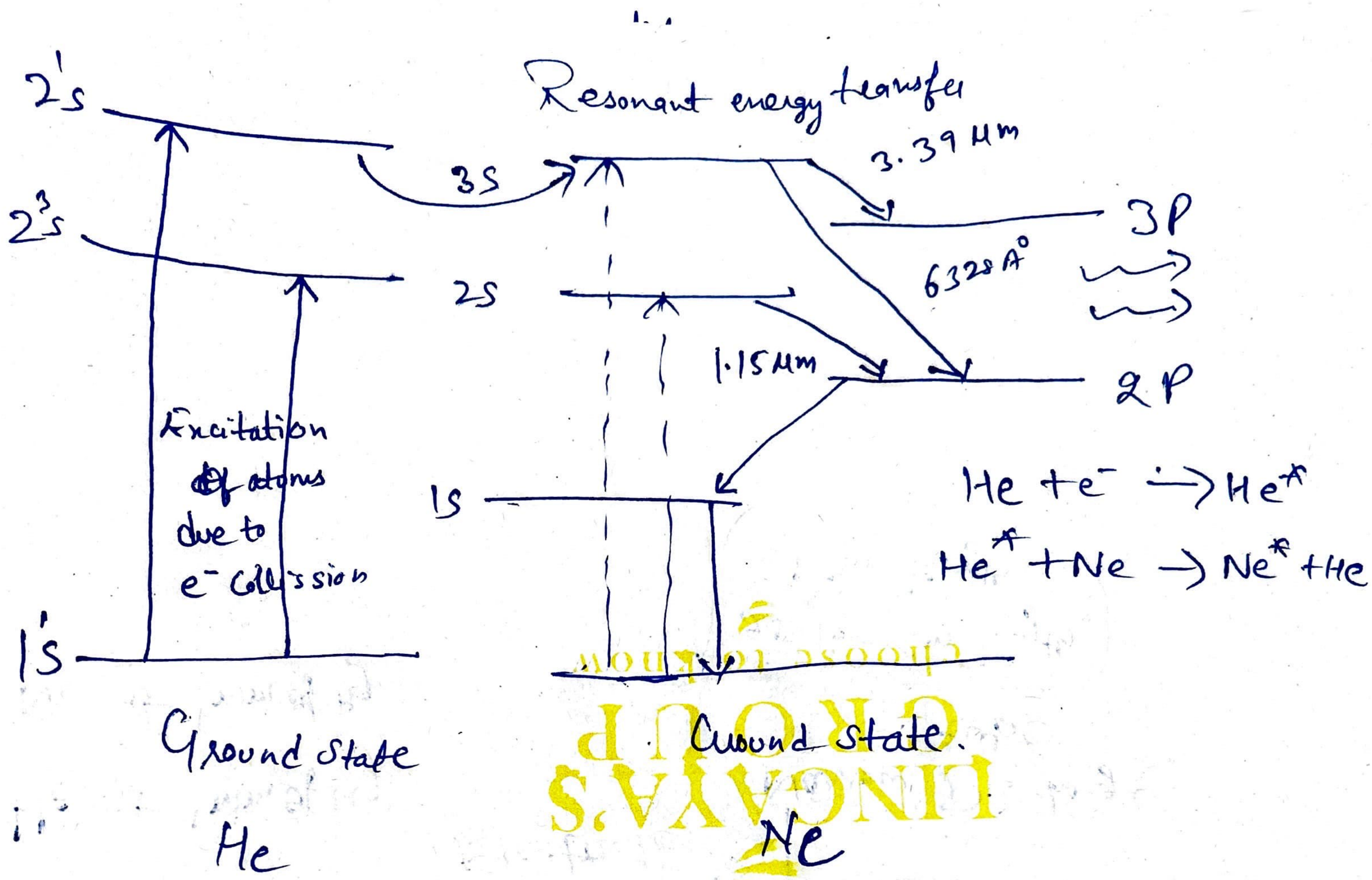
Principle:- He-Ne laser was first gas laser to be operated successfully & was fabricated by



He at 1mm of Hg

Ne at 1mm of Hg

(25-100 cm length
1 cm length)



3S → 3P → 3.39 μm

3S → 2P → 6328 A°

2S → 2P → 1.115 μm

Applications

-> The narrow red beam of He-Ne laser is used in supermarkets to read bar codes.

-> He-Ne laser is used in Holography in producing 3D image of objects

-> He-Ne Laser have many industrial & scientific uses, & are often used in lab demonstration of optics

Characteristics

1) four ~~laser~~ Level laser
2). Easy to Construct & reliable in operations
3) Works in Continuous mode
4). does not require cooling apparatus
5) Light from He-Ne Laser is more
6) directional, more monochromatic, more coherent
7) Employs electrical pumping

CO_2 Laser

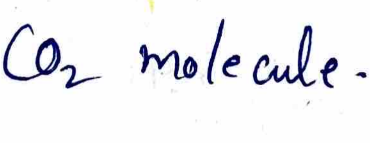
It wa first molecular gas laser. developed in 1964. CO_2 Laser is highest power Continous wave lases that is currently available. Continous wave power output of CO_2 Laser can range from few watt to over 15,000 watts. It produces laser beam of wavelength 1.6 μm & 9.6 μm.

The beam divergence of CO_2 laser ranges from 1 to 10 milli radians.

Principle Active medium is a gas mixture of CO_2, N_2 & He. The laser transistion takes place b/w vibrational states of CO_2 molecu

Vibrational modes of CO_2 molecule.

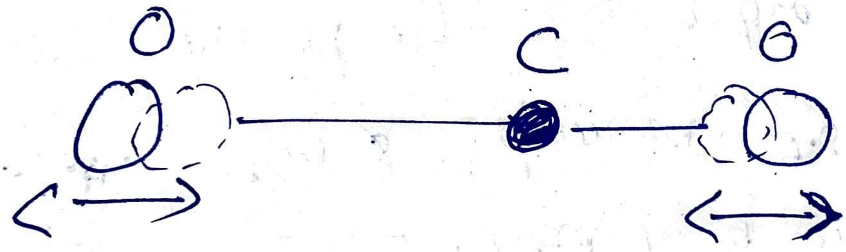
CO_2 molecule has one Carbon atom at the Center with two oxygen atom attached, one at both sides.



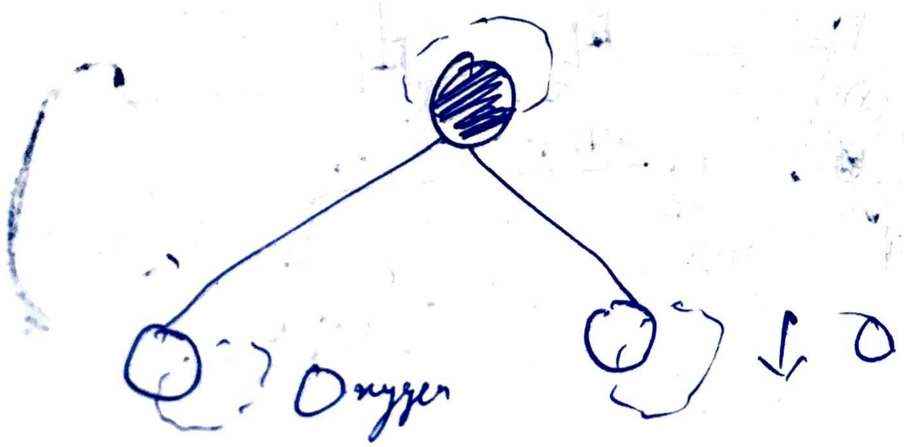
Such a molecule exhibits 3 independent modes of Vibrations which are as follows.

Symmetric Streching mode

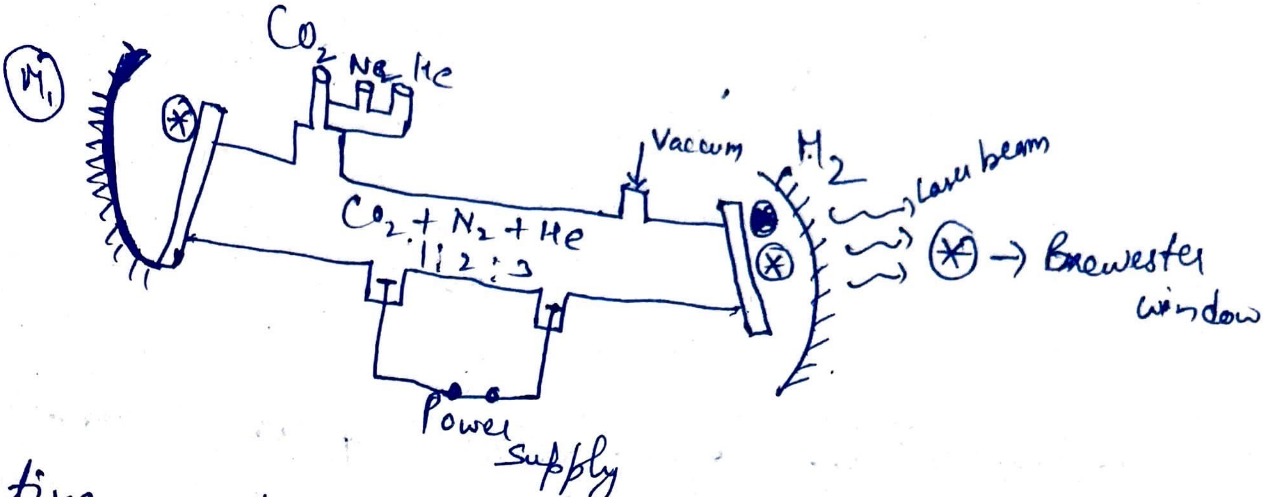
In this mode of vibration, Central Carbon atom is at rest & both Oxygen atoms vibrate Simultaneously along the axis of molecule departing or approaching fixed Carbon atom



Bending mode In this mode of vibration, Oxygen atoms & Carbon atom vibrate perpendicular to molecular axis



Construction



Active medium The active medium in CO_2 laser is a gaseous mixture of $CO_2 + N_2 + He$ in the ratio 1 : 2 : 3. field in a quartz discharge tube of length 5m & diameter 2.5 cm at a pressure of few mm of Hg. The active centers are the CO_2 molecule as lasing action are the CO_2 molecules as lasing action will be achieved due to these molecules. The purpose of N_2 gas molecules is to help in excitation of CO_2 molecule by colliding with CO_2 molecule & transfering the

So, N_2 molecules increases the pumping efficiency

2). Optical resonator Cavity :- The active medium is Inclosed. b/w a set of Concave mirrors which forms an optical resonator Cavity. One mirror M_1 is 100%. reflecting while other mirror m_2 is partially reflecting (90% reflecting + 10% transmitting). Here we use external mirror Cavity configuration gets eroded by discharge & have to be replaced brewster windows are used at each end of discharge tube so that output laser beam is polarised. Instead of using plane mirror, Concave mirrors are used so that diffraction losses are minimised.

3) Pumping Source Electric discharge method is used for achieving population inversion. The two electrodes sealed inside the discharge tube are connected to D.C. power Supply of few kilo volts.

Working

& Energy Level diagram

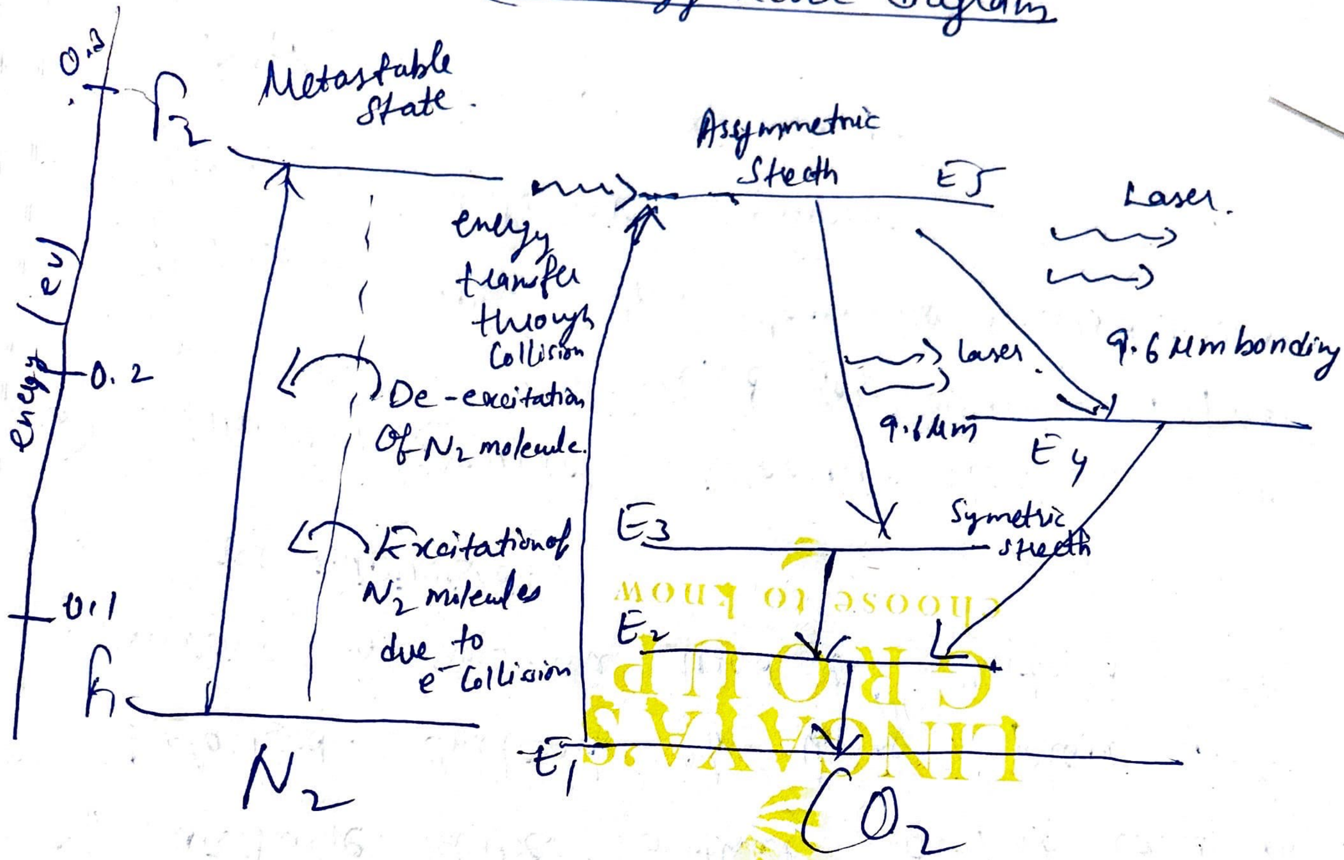


Figure shows the levels of N_2 & CO_2 molecules when electric discharge occurs in the gas the e^-s collide with N_2 molecules & they are raised to excited states. This process is represented by

$$N_2 + e^* \rightarrow N_2^* + e^-$$

Spend sufficient amount of time before getting de-excited. As excited level F_2 of N_2 molecule is very close to the E_5 level of CO_2 molecule. an energy exchange e^- takes place & thus results in excitation of CO_2 molecules to level E_5 & de excitation of N_2 molecules to ground level F_1. Population Inversion is achieved b/w vibrational levels E_5 & E_4 or E_5 & E_3

Thus E_5 is upper laser level. E_4 & E_3 are lower laser levels. E_5 to E_3 with laser wavelength of 10.6 μm. The CO_2 molecules in the levels E_4 & E_3 de-excite to level E_2 through inelastic collisions with unexcited CO_2 molecules in E_2 level. He gas is added in gaseous mixture. CO_2 molecules return to ground state E_1 through inelastic collisions with He molecules. Other function of He is to conduct the heat away from walls of discharge tube as He has high thermal conductivity.

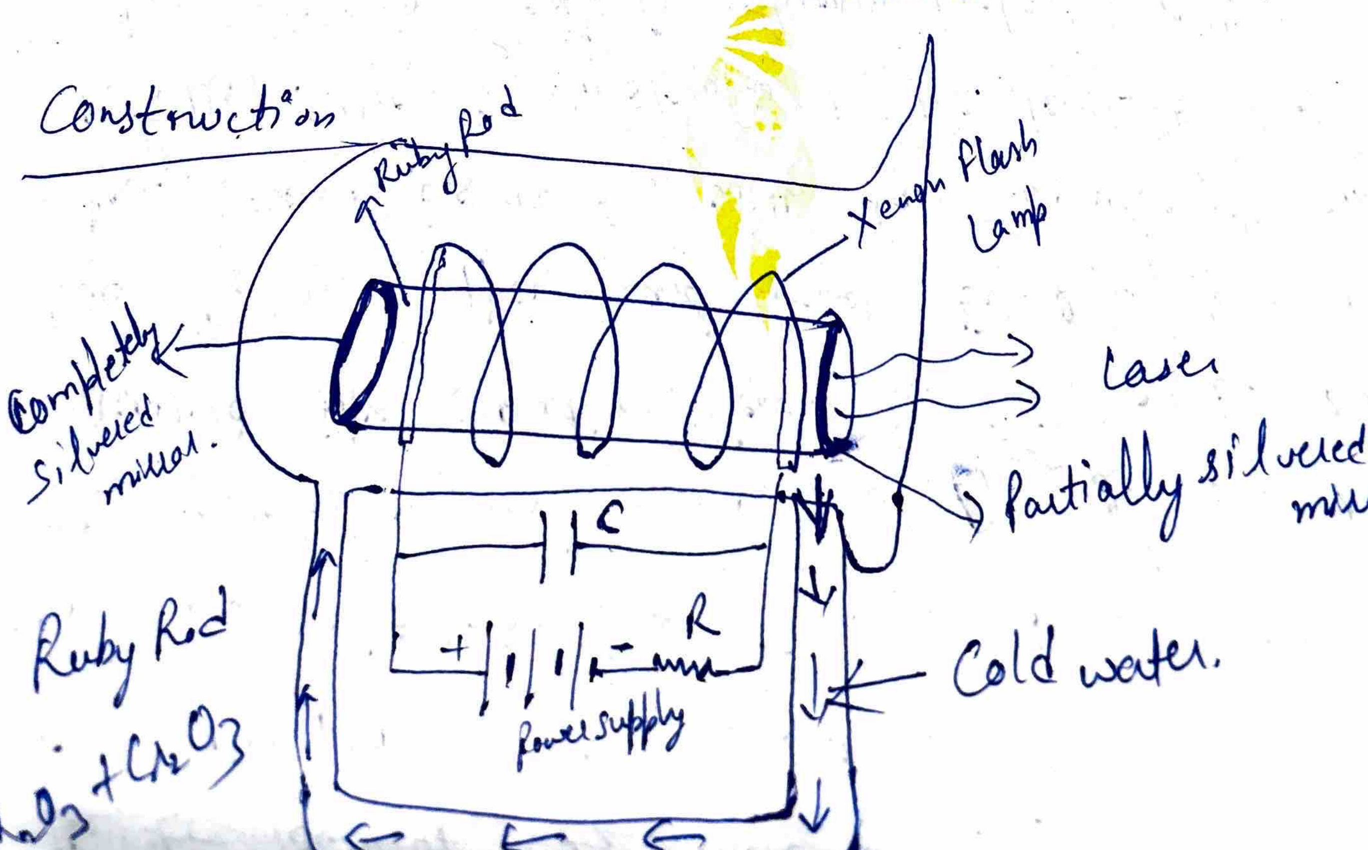
Ruby laser

First laser to be operated successfully as Ruby laser which was fabricated in 1960

The main characteristics of Ruby laser are

1) It is a solid state laser
2) " " " 3- level laser
3) It employs optical pumping
4) It works in pulse mode

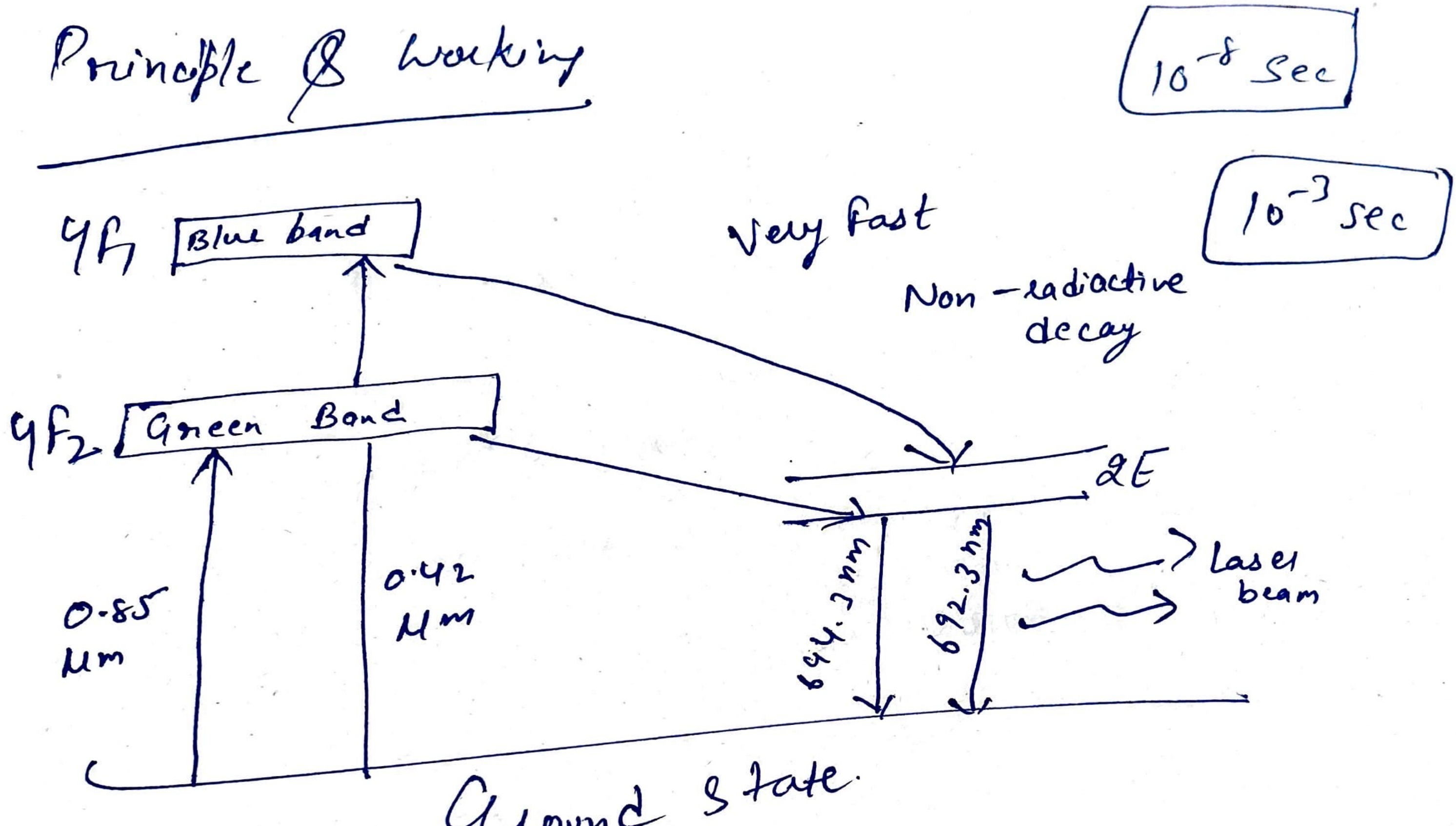
Construction

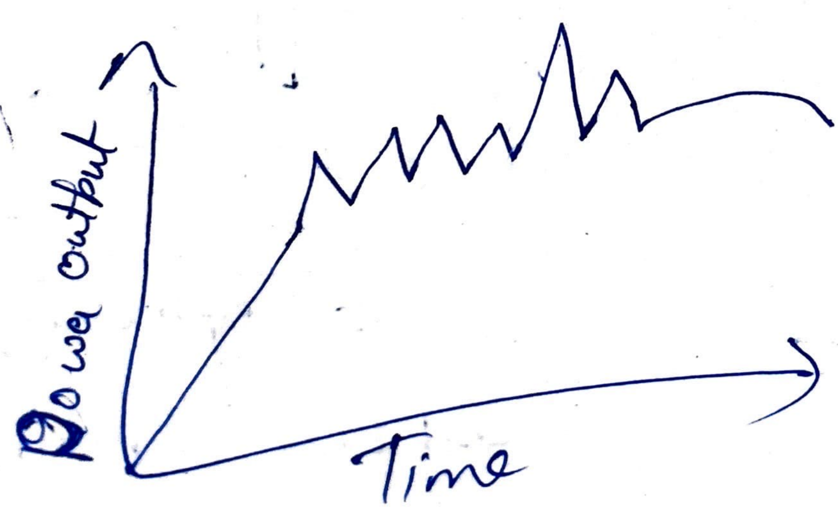


Ruby Rod
$Al_2O_3 + Cr_2O_3$

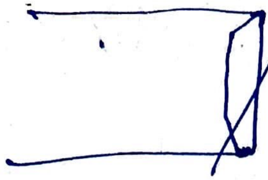
0.05 % Al^{3+} ions are replaced by ...

Principle & working





Construction →



Nd- Yag laser

Full form of Nd- Yag Laser is Neodymium doped yetrium Aluminium garnet Laser. It is a Solid State laser. It is four level laser System which means that four energy levels are involved in laser action. It Operates in both pulse & Continious mode