UNIT III - PHOTONICS

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Lecture for Engineering Physics students

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Chapter - III

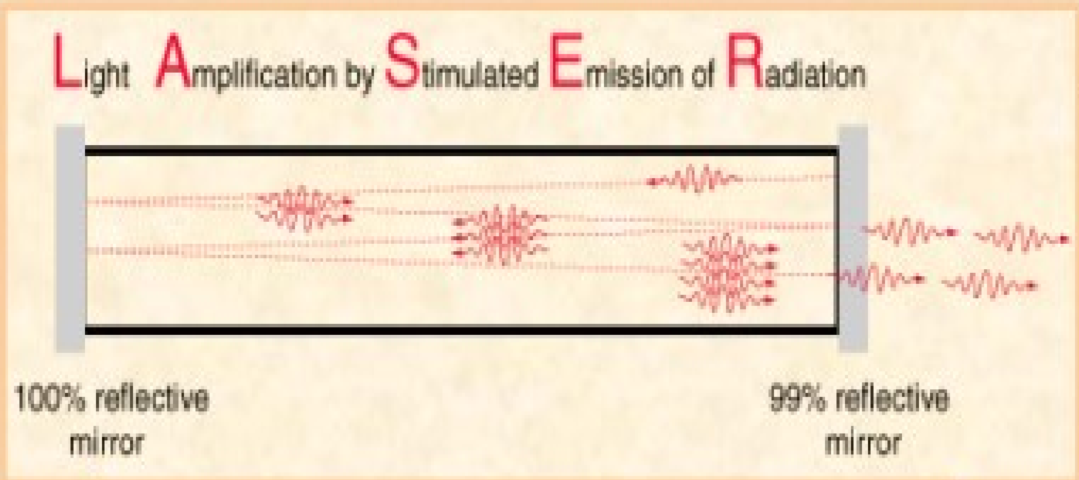
PHOTONICS

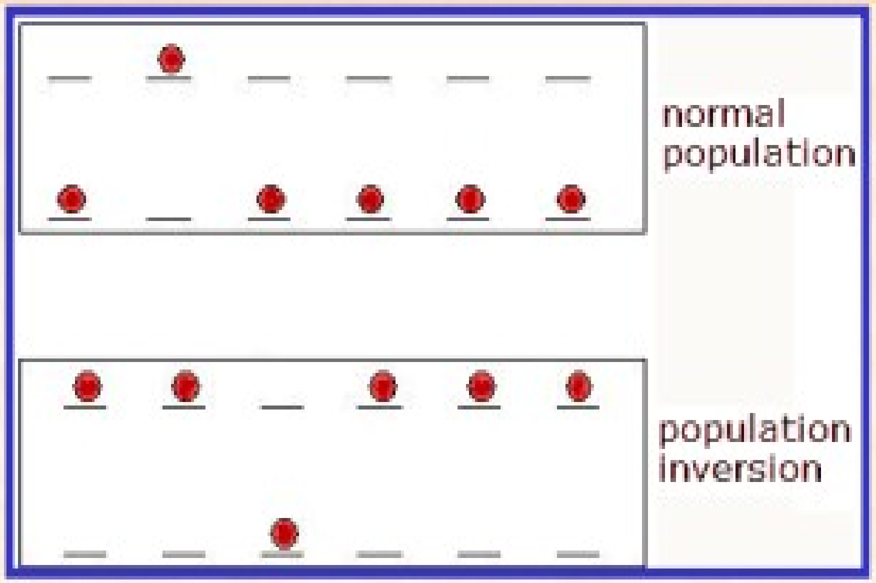
(LASERS AND OPTICAL FIBERS)

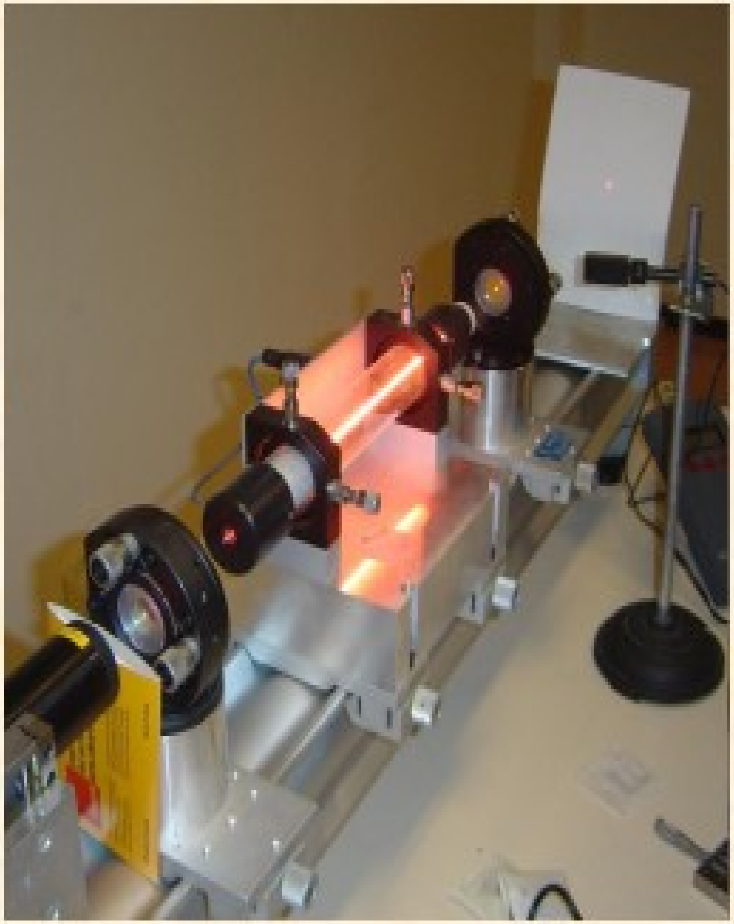
PLAN OF THE PRESENTATION

- Properties of Lasers
- Basics of Lasing principles
- Einstein's Theory
- Different types of Lasers & Applications

Lasing Principles & Conditions







Introduction to Lasers

Introduction

Laser and its characteristics

LASER, the acronym derived from "Light Amplification by Stimulated Emission of Radiation", made an enormous impact on the scientific world.

Working principle of laser

Due to stimulated emission, the photons multiply in each step giving rise to an intense beam of photons that are coherent and moving in the same direction. Hence, the light is amplified by stimulated emission of radiation, termed as LASER.

Introduction

Characteristics of Laser

The most striking features or characteristics of lasers are:

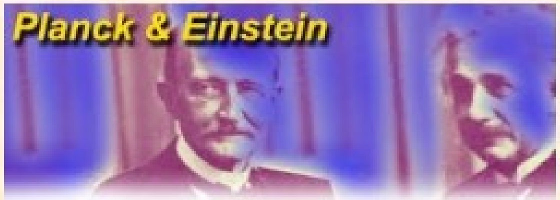
- Directionality
- High intensity
- Extraordinary monochromaticity
- High degree of coherence

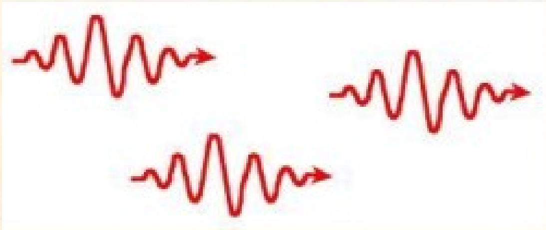
Introduction

Distinguish between ordinary light and laser beam

S.No	Ordinary light	Laser light
1	In ordinary light the angular speed is more	In laser beam the angular speed is less
2	They are not directional	They are highly directional
3	It is less intense	It is highly intense
4	It is not a coherent beam and is not in phase	It is a coherent beam and is in phase
5	Examples : Sunlight, mercury vapour lamp etc.	Examples : He-Ne Laser, CO_2 laser etc.

Quantum Nature of Light





- 1900, Max Planck; light consists of discrete bundles or chunks each of energy
  ⇒ **"Quanta"**
- 1905 , Einstein refined the Quantum hypothesis and gave the name **"photon"** to the quantum of light energy

  - Photon represents minimum energy unit of light. It is localized in small volume of space and remains localized as it moves away from the light source.

    Energy of photon; **$E = h\nu$**

  - Light energy '$\rho(\nu)$' emitted by a source must be integral multiple of photon energy ⇒ **Quantization**

    $\rho(\nu) = n\,h\nu$; $n = 1,2,3,\ldots$

Distribution of Atoms

Energy Levels: Permitted orbits with specific amount of energy;

- **Ground State**
- **Excited States**

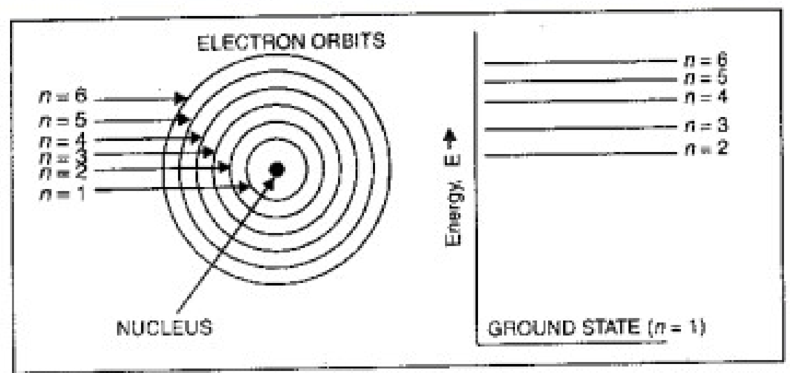


Fig. 1.3. Electron orbits and the corresponding energy levels of the hydrogen atom

- **POPULATION:** Number of atoms per unit volume that occupy a given energy state (N).

Population of an energy state depends on the temperature T, according to Boltzmann's Equation

$$N = e^{-E/KT}$$; where K is the Boltzmann's constant

- **Atoms distributed differently in different energy states;**
  - tends to be at lowest possible energy level.

Thermal Equilibrium

- **At temperature above 0K**,
  - Atoms alway have some thermal energy;
  - Distributed among available energy levels according to their energy.

❖ **At Thermal Equilibrium;**

➢ Population at each energy level decreases with increase of energy level,

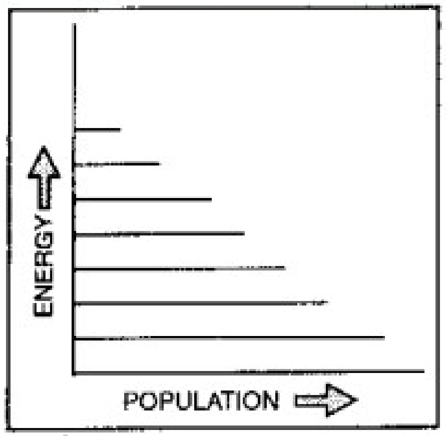


Fig. 1.4. Relative populations of energy levels as a function of energy above the ground state at thermal

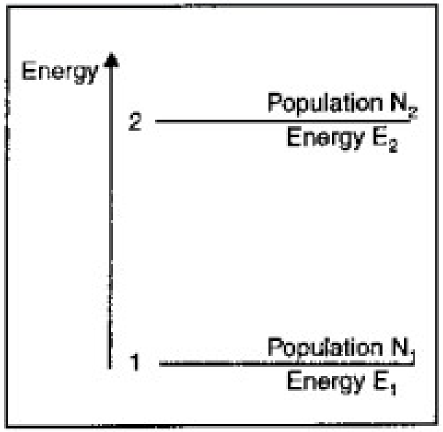


Fig. 1.5. Two energy level system.

For energy levels E_1 and E_2,

- Populations can be computed with Boltzmann's equation

$$N_1 = e^{-E_1/KT} \quad \& \quad N_2 = e^{-E_2/KT}$$

- Ratio of populations, N_2/N_1 is called ***Relative Population.***

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

or $$N_2 = N_1 e^{-\Delta E/KT} \quad ; \quad \Delta E = E_2 - E_1$$

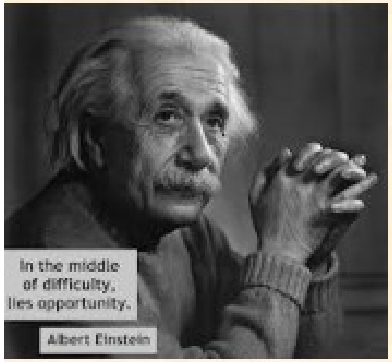
- **Relative Population** (N_2/N_1); dependent on two factors
  - Energy difference (E_2-E_1)
  - Temperature, T

❖ **At Lower Temperature;** All atoms are in the ground states.

❖ **At higher Temperature;** Atoms move to higher states

Einstein's theory of stimulated emission

Einstein's Prediction



- **1917, Einstein predicted that there must be second emission process to establish thermodynamic equilibrium.**
  - Atoms move to excited state under action of incident light
  - Excited atoms tend to return randomly to the lower energy state.
  - It is likely that a stage may be reached when all atoms are excited

➢Violation of thermal equilibrium condition

- **Einstein suggested ⇒ There could be an additional emission mechanism, by which the excited atoms can make downward transitions.**
  - ➢ Predicted that the photons in the light field induce the excited atoms to fall to lower energy state and give up their excess energy in the form of photons.

⟶ **Stimulated Emission**

Einstein's theory of stimulated emission

Let us consider an atomic system under thermal equilibrium condition. In such assembly of atoms, it is also assumed that the atoms are in different energy states.

Let E_1 & E_2 be the energy levels of ground state & excited state. Number of atoms present in the states will be N_1 & N_2 respectively.

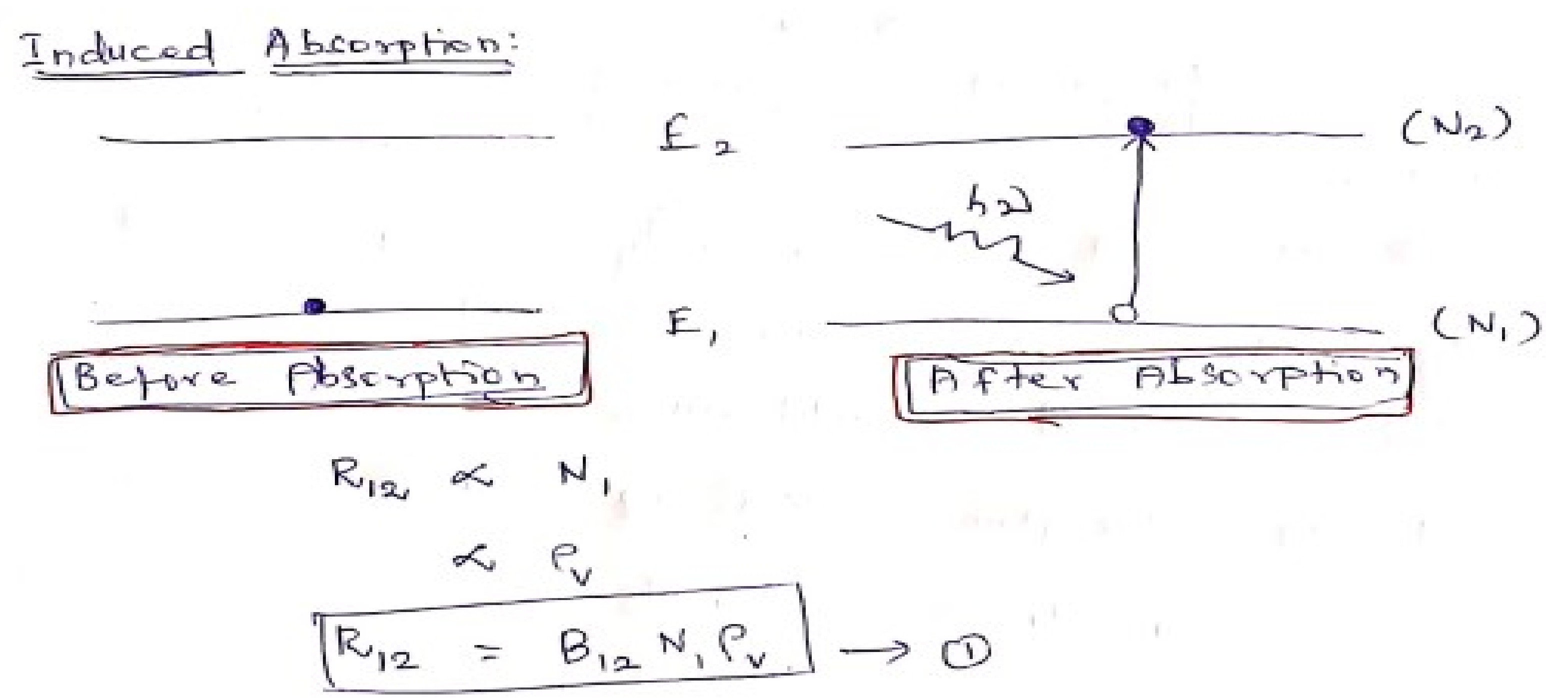
Ground state → E_1, N_1

Excited state → E_2, N_2.

Einstein's theory of stimulated emission

Stimulated or Induced Absorbtion:

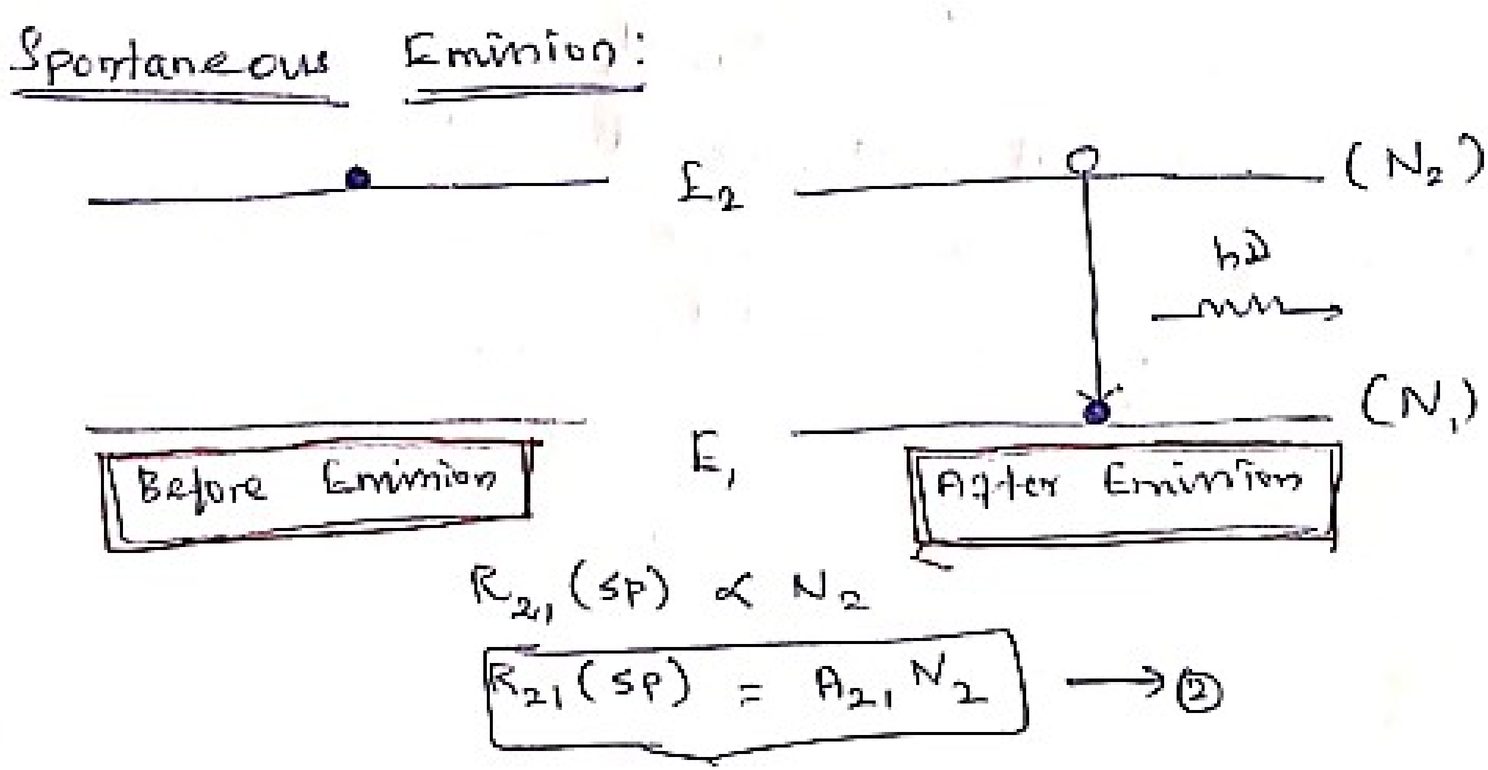
An atom in the lower energy level or ground state energy level E_1 absorbs the incident photon radiation of energy and goes to the higher energy level or excited level E2. This is called stimulated absorption.



Einstein’s theory of stimulated emission

Spontaneous Emission:

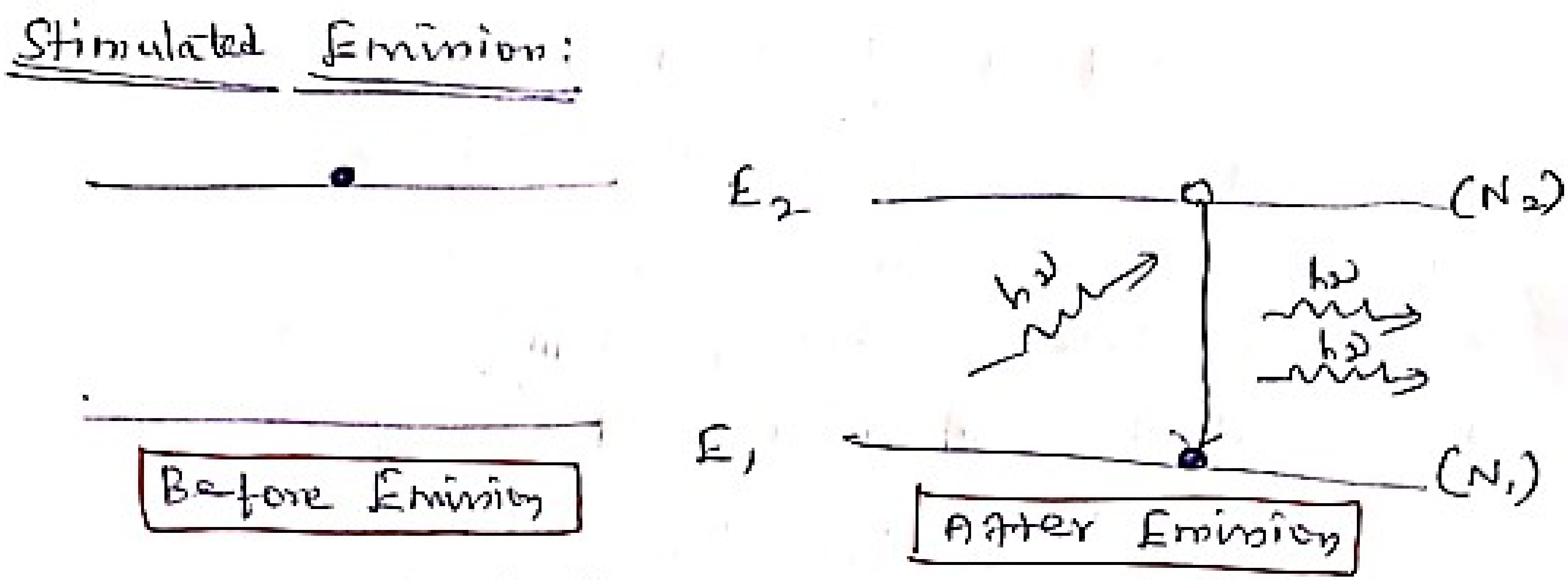
The atom in excited state returns to ground state thereby emitting a photon without any external inducement is called spontaneous emission.



Einstein's theory of stimulated emission

Stimulated Emission:

The process of forced emission of photons caused by the incident photons is called stimulated emission.



$$R_{21}(ST) \propto N_2$$

$$\propto \rho_\nu$$

$$R_{21}(ST) = B_{21}\rho_\nu N_2 \rightarrow (3)$$

Einstein's theory of stimulated emission

Derivation:

Let us first consider only absorption and Spontaneous emission were present.

Under Thermal equilibrium,

Rate of Absorption = Rate of Spontaneous Emission

$$B_{12} N_1 \rho_v = A_{21} N_2$$

$$\rho_v = \frac{A_{21} N_2}{B_{12} N_1} \rightarrow (4)$$

Now, from Maxwell Boltzman distribution law, the population of the states were given as below,

$$N_i = N_0 e^{-E_i/KT} \rightarrow (5)$$

Einstein's theory of stimulated emission

where, i – is the state (energy level).

K – Boltzmann constant and

T – absolute Temperature.

From (5),

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

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

$$\frac{N_1}{N_2} = \frac{N_0 e^{-E_1/KT}}{N_0 e^{-E_2/KT}} = e^{-(E_1-E_2)/KT} \quad [\because E_2 - E_1 = h\nu]$$

$$= e^{(E_2-E_1)/KT}$$

$$\frac{N_1}{N_2} = e^{h\nu/KT} \quad \& \quad \frac{N_2}{N_1} = \frac{1}{e^{h\nu/KT}}$$

→ (6)

Einstein's theory of stimulated emission

Subg (6) in (4),

$$\rho_v = \frac{A_{21}}{B_{12}} \cdot \frac{1}{e^{h\nu/KT}} \rightarrow (7)$$

From Planck's black body radiation, the energy density of external radiation is given by,

$$\rho_v = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{e^{h\nu/KT} - 1} \rightarrow (8)$$

Comparing eqns (7) & (8) we observe that, they do not match exactly with one another. In order to remove this discrepancy, Einstein added stimulated emission into account.

Now, Rate of Absorption = Rate of Spontaneous Emission + Rate of Stimulated Emin

Einstein's theory of stimulated emission

$$B_{12} N_1 \rho_v = A_{21} N_2 + B_{21} N_2 \rho_v$$

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

$$\rho_v = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2} \rightarrow (9)$$

considering $B_{12} = B_{21}$ and dividing the R.H.S. of eqn. (9) by N_2 (Both numerator & denominator),

Eqn. (9) becomes,

$$\rho_v = \frac{A_{21}}{B_{21}\left(\frac{N_1}{N_2}\right) - B_{21}}$$

$$= \frac{A_{21}}{B_{21}} \left(\frac{1}{\frac{N_1}{N_2} - 1} \right)$$

Einstein's theory of stimulated emission

$$\rho_\nu = \frac{A_{21}}{B_{21}} \cdot \frac{1}{e^{h\nu/KT} - 1} \rightarrow (10)$$

Comparing eqns (8) & (10) we found that, they matches exactly with one another. Thus Einstein proved the existance of stimulated emission of radiation. The coefficients B_{12}, B_{21}, A_{21} are known as Einstein's coefficients.

Einstein's theory of stimulated emission

Case (i): Ratio of Absorption to the stimulated Emission

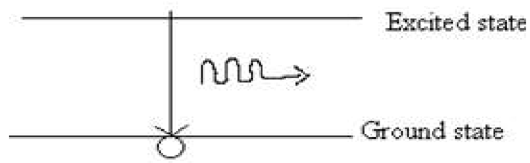
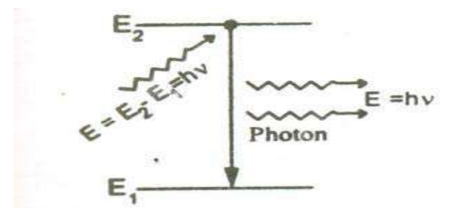
$$\frac{R_{12}}{R_{21}(ST)} = \frac{B_{12} N_1 \rho_\nu}{B_{21} N_2 \rho_\nu} = \frac{B_{12}}{B_{21}} \cdot e^{h\nu/KT} = e^{h\nu/KT}$$

Case (ii): Ratio of Spontaneous Emission to the Stimulated Emission

$$\frac{R_{21}(SP)}{R_{21}(ST)} = \frac{A_{21} N_2}{B_{21} N_2 \rho_\nu} = \frac{A_{21}}{B_{21}} \times \frac{B_{21}}{A_{21}} \cdot e^{h\nu/KT} - 1$$

$$= e^{h\nu/KT} - 1.$$

Distinguish between spontaneous emission and stimulated emission

S.No	Spontaneous emission	Stimulated emission
1.	The atom in excited state returns to ground state thereby emitting a photon without any external inducement is called spontaneous emission 	The process of forced emission of photons caused by the incident photons is called stimulated emission 
2	The emitted photons move in all directions and random	The emitted photons move in the same directions and highly directional.
3	The emitted photons are not monochromatic and not intense	The emitted photons are monochromatic and intense
4.	The photons are not in phase and they are not coherent	The photons are in phase and they are coherent

Population Inversion

- **Laser operation requires obtaining Stimulated emission exclusively.**

  - To achieve a high percentage of stimulated emission, a majority of atoms should be at the higher energy level than at the lower level.

  - *The non-equilibrium state in which the population N_2 of the upper energy level exceeds to a large extent the population N_1 of the lower energy level is known as the* ***state of population inversion.***

- Extending the Boltzmann's distribution, to this non-equilibrium state of P.I.

  $\Rightarrow$ *N_2 can exceed N_1 only if the temperature be negative.*

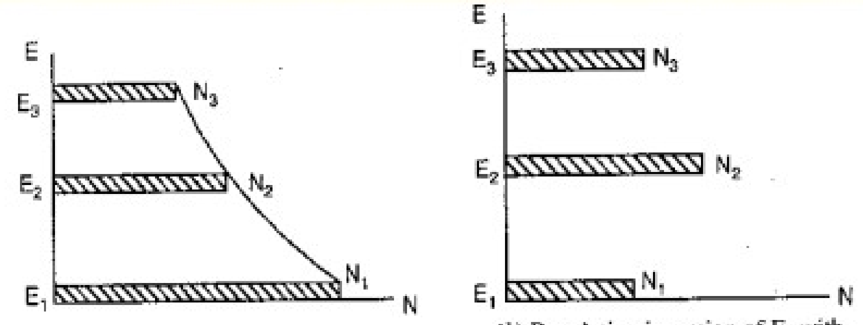
- The state of P.I. is sometimes referred to as a **negative temperature state**.

  - *Does not mean that we can attain temperatures below absolute zero,*

  - *Terminology implies that P.I. is a non-equilibrium state and is attained at normal temperatures.*

- For a system with three energy states E_1, E_2 and E_3 in equilibrium, the uppermost level E_3 is populated least and the lowest level E_1 is populated most
  - *Since the population in the three states is such that $N_3<N_2<N_1$, the system absorbs photons rather than emit photons.*

- If the system is supplied with external energy such that N_2 exceeds N_1 ⇒ **System reached Population Inversion**
- P.I. taken place between the levels E_2 and E_1



(*a*) Population in equilibrium.
(*b*) Population inversion of E_2 with respect to E_1.
Fig. 1.16. Three level system.

- **Under P.I. condition, stimulated emission can produce a cascade of light.**
  - The first few randomly emitted spontaneous photons trigger stimulated emission of more photons and those stimulated photons induce still more stimulated emissions and so on.
  - As long as $N_2 > N_1$, stimulated emissions are more likely than absorption ⇒ **light gets amplified**.

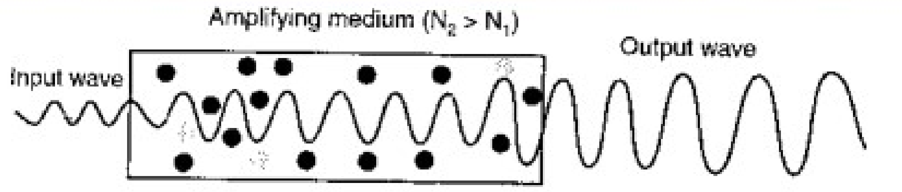


Fig. 1.17. Amplification of a light wave in a medium with population inversion.

- The moment, the population at lower level becomes equal to or larger than at the excited state, ***P.I. ends, stimulated emissions diminish and amplification of light ceases.***

How to achieve P.I. ?

- **Pumping:** *Process by which atoms are raised from the lower level to the upper level.*
- Energy is to be supplied somehow to the laser medium to raise atoms from the lower level to the excited level and for maintaining population at the excited level at a value greater than that of the lower energy.
  - Usual method ⇒ **Heat the material**. Will it do the job ?
  - Heating the material only increases the average energy of atoms but does not make N_2 greater than N_1.
    - **P.I. cannot be achieved by heating the material.**

Pumping Methods

- **To create the state of P.I.** $\Rightarrow$ *selectively excite the atoms in the material to particular energy levels.*
- Most common methods of pumping make use of **Light** and **Electrons.**

Optical Pumping

- Use of photons to excite the atoms
  - A light source used to illuminate the laser medium
  - Photons of appropriate frequency excite the atoms to upper levels.
  - Atoms drop to the metastable level to create the state of P.I.

- ❖ **Optical pump sources** : Flash discharge tubes, Continuously operation lamps, Spark gaps or an auxiliary laser.
- ❖ Optical pumping is suitable for laser medium- transparent to pump light.
- ❖ Mostly used for solid state crystalline and liquid tunable dye lasers.

Electrical Pumping

- Can be used only in case of laser materials that can conduct electricity without destroying lasing activity.

  - **Limited to gases**.

- In case of a gas laser, a high voltage pulse initially ionizes the gas so that it conducts electricity.
- An electric current flowing through the gas excites atoms to the excited level from where they drop to the metastable upper laser level leading to **P.I**.

Direct Conversion

- In semiconductor lasers also electrical pumping is used, but here it is not the atoms that are excited. It is the current carriers; {e- h} pairs which are excited and a population inversion is achieved in the junction region.
- Electrons recombine with holes in the junction regions producing laser light.

  - **A direct conversion of electrical energy into light energy**

Active Centre & Active Medium

- **All types of atoms not suitable for laser operation**.
  - In a medium consisting of different species of atoms, ***only a small fraction of atoms of a particular species are suitable for stimulated emission and laser action.***
  - Those atoms which cause light amplification are called **Active Centers**.
  - Rest of the medium acts as host and supports active centers is called an **Active Medium**.
- ***An active medium is thus a medium which, when excited, reaches the state of population inversion, and eventually causes light amplification.***
- Active medium may be **a solid, a liquid or a gas**.

Metastable States

- An atom can be excited to a higher level by supplying energy to it. Normally, excited states have ***short lifetimes ≈ nanoseconds (10^{-9} s)*** and release their excess energy by spontaneous emission.
- Atoms do not stay at such excited states long enough to be stimulated to emit their energy. Though, the pumping agent continuously raises the atoms to the excited level, many of them rapidly undergo spontaneous transitions to the lower energy level $\Rightarrow$ ***Population inversion cannot be established***.
- For establishing population inversion, the excited atoms are required to **"wait"** at the upper lasing level till a large number of atoms accumulate at that level.

- **What is needed is an excited state with a longer lifetime ?**

  ☞ *Such longer-lived upper levels from where an excited atom does not return to lower level at once, but remains excited for an appreciable time, are known as **Metastable States.***

- Atoms stay in metastable states for about **10^{-6} to 10^{-3}s**. This is **10^3 to 10^6 times longer** than the time of stay at excited levels.
    - Possible for a large number of atoms to accumulate at a metastable level. The metastable state population can exceed the population of a lower level and lead to the state of population inversion.

- **If the metastable states do not exist, there could be no population inversion, no stimulated emission and hence no laser operation.**

❖ **Foundation to the laser operation is the existence of metastable states.**

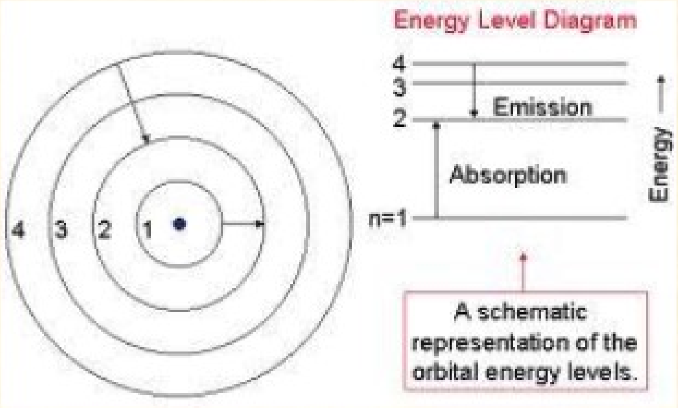
Pumping Schemes

❖ **Atoms characterized by a large number of energy levels.**

➢ Only two, three or four levels are pertinent to the pumping process.

❑ **Classified as**

- Two-level,
- Three-level and
- Four –level schemes.



❖ Two-level scheme will not lead to laser action.

❖ Three-level and four-level schemes are important and are widely employed.

- **Preference to classify the lasers on the basis of material used as Active Medium.**

  - **Broadly divided into four categories;**

    - Solid lasers
    - Gas lasers
    - Liquid lasers
    - Semiconductor lasers

Applications of Lasers

Medicine:

1. Laser is used in the treatment of lever and lungs.
2. It is used to perform microsurgery and bloodless operation.

Industry:

1. Laser is used in cutting, welding, drilling etc

2. It is used to produce small holes in diamond and hard metals.

Scientific and engineering field

1. Using laser we can get three dimensional lensless photography
2. Computer print pits are done with laser printers
3. Laser can be used for forecasting earthquakes.

Nd:YAG laser

- Nd-YAG laser is a Neodymium based doped insulator laser.
- Nd - stands for neodymium (rare earth element) and YAG- stands for Yttrium Aluminum Garnet ($Y_3 Al_5O_{12}$).
- It is a four level solid state LASER.

Principle

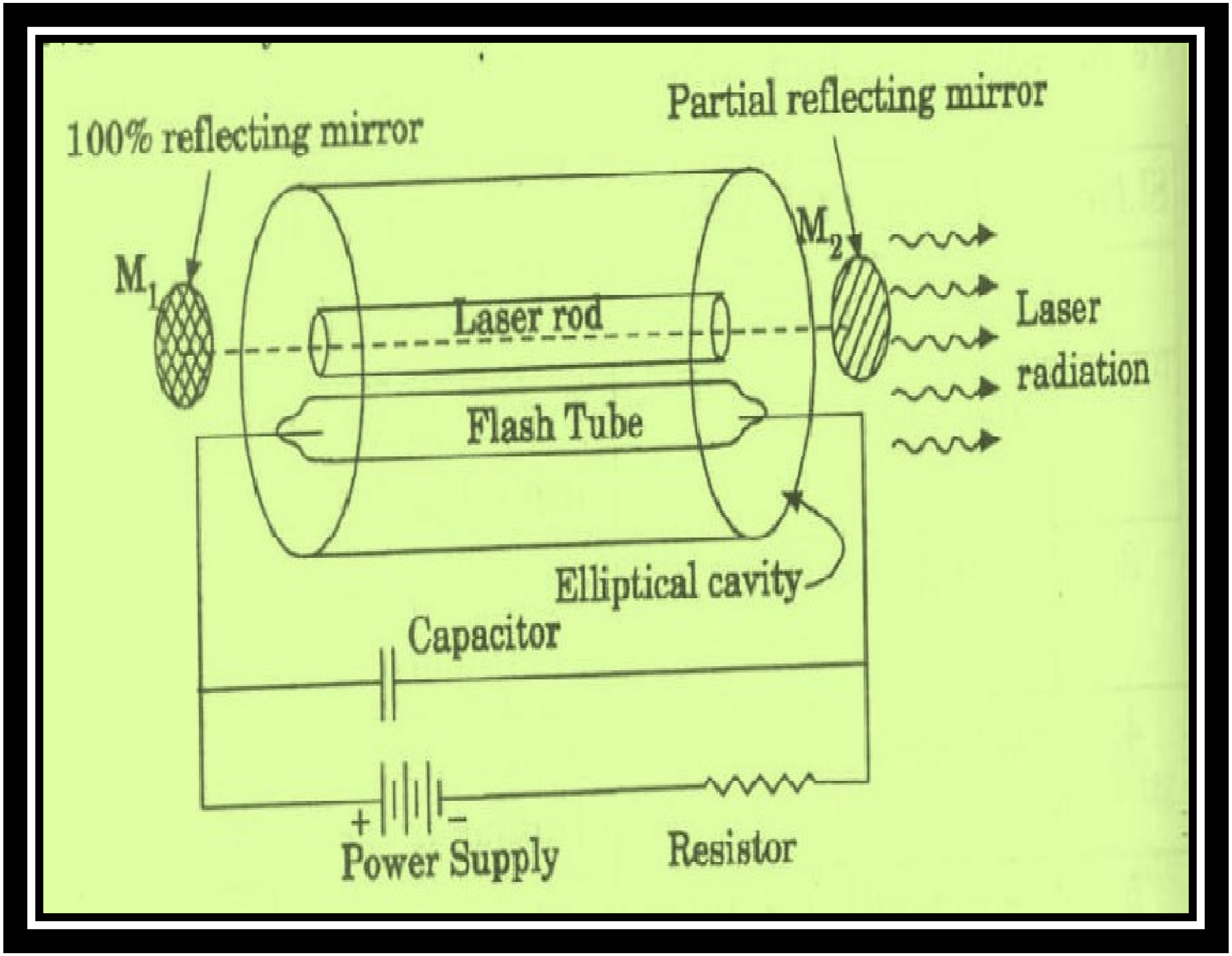
The active medium Nd-YAG rod which is taken in the form a crystal is optically pumped by krypton flash tube. Due to the optical pumping Nd^{3+} ions are raised to the excited levels. During the transition from metastable to ground state, the laser beam of wavelength 1.064μm is emitted.

Nd:YAG laser

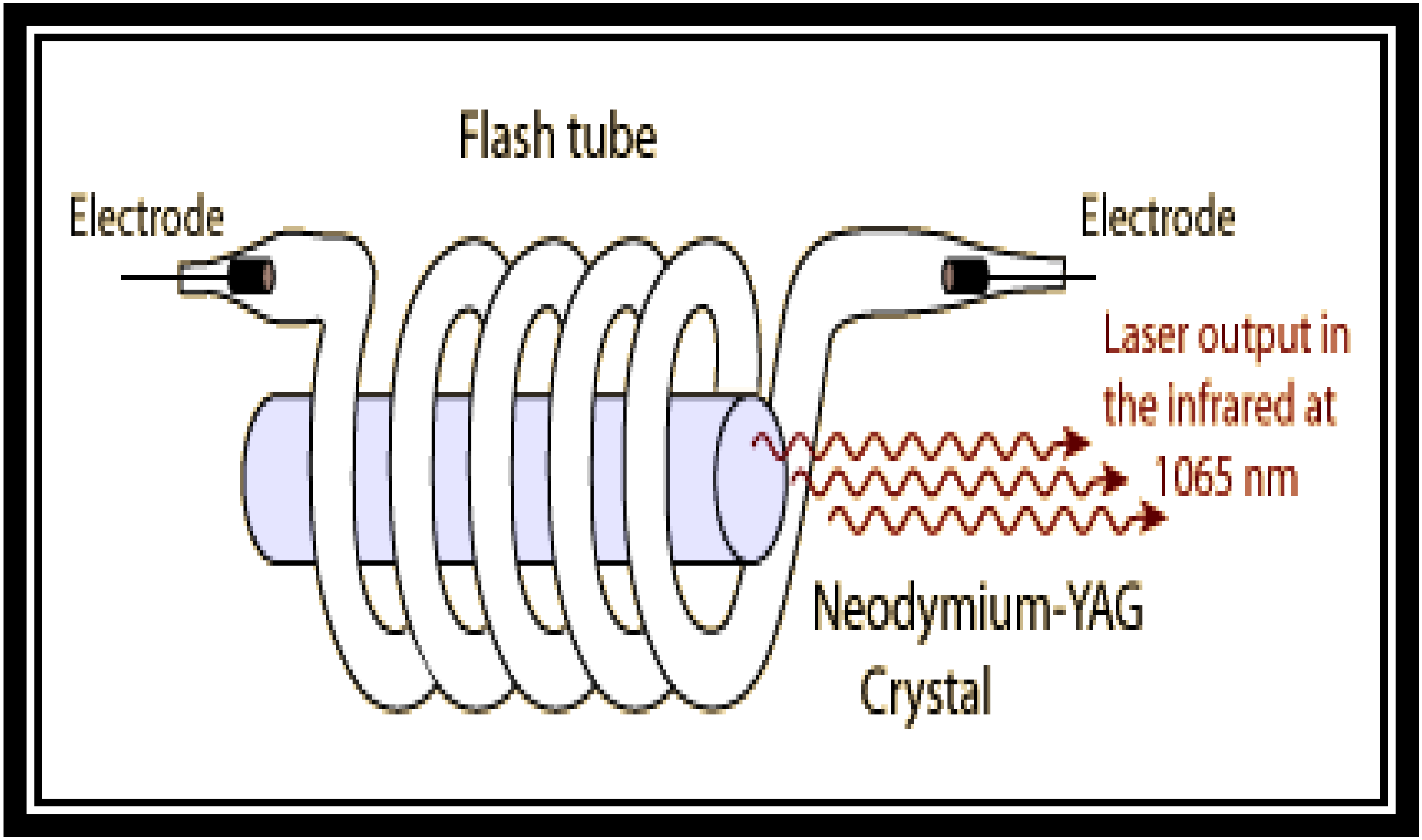
Construction

- The construction of Nd-YAG laser is shown in Fig. A small amount of yttrium ions is replaced by neodymium ions in the active element of Nd-YAG crystal.
- The active element Nd-YAG is cut into a cylindrical rod. The ends of the rod are highly polished and optically flat and parallel. The cylindrical rod (laser rod and a pumping source (Krypton flash tube) are kept inside an elliptical reflector cavity. The optical resonator is formed by using two external reflecting mirrors. One mirror (M_1) is fully reflecting while the other mirror (M_2) is partially reflecting.

Nd:YAG laser


100% reflecting mirror
Partial reflecting mirror
M1
M2
Laser rod
Flash Tube
Laser
radiation
Elliptical cavity
Capacitor
+
–
Power Supply
Resistor

Nd:YAG laser tube



Nd:YAG laser

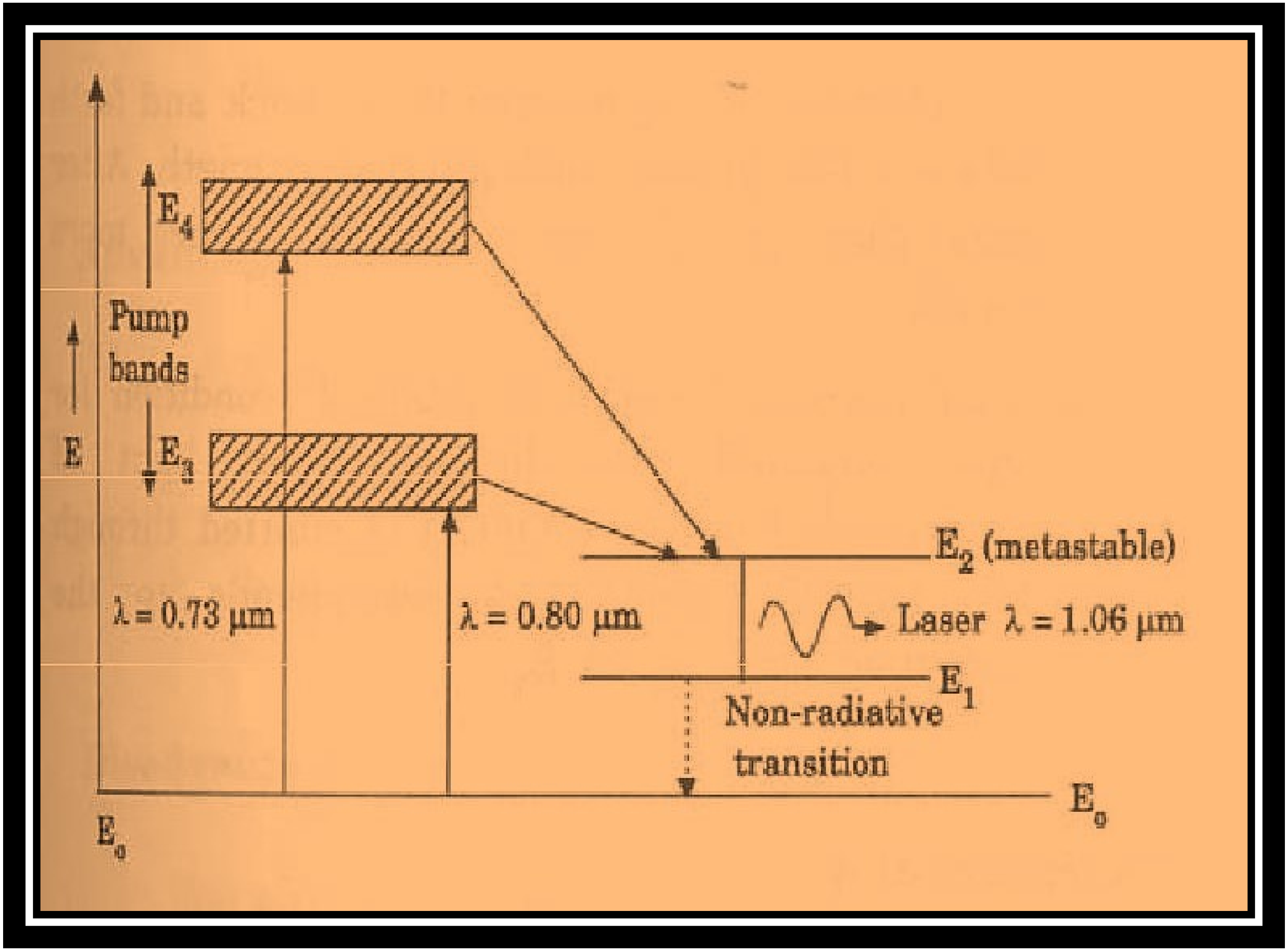
Working

- When the krypton flash lamp is switched on, by the absorption of light radiation of wavelength 0.73μm and 0.8μm, the Neodymium(Nd^{3+}) atoms are raised from ground level E_0 to upper levels E_3 and E_4 (Pump bands).
- The Neodymium ions atoms make a transition from these energy levels E_2 by non-radiative transition. E_2 is a metastable state.
- The Neodymium ions are collected in the level E_2 and the population inversion is achieved between E_2 and E_1.
- An ion makes a spontaneous transition from E_2 to E_1, emitting a photon of energy hγ.

Nd:YAG laser

- This emitted photon will trigger a chain of stimulated photons between E_2 and E_1.
- The photons thus generated travel back and forth between two mirrors and grow in strength. After some time, the photon number multiplies more rapidly.
- After enough strength is attained (condition for laser being satisfied), an intense laser light of wavelength 1.06μm is emitted through the partial reflector. It corresponds to the transition from E_2 to E_1

Energy level Nd3+ ion in Nd-YAG laser



Nd:YAG laser

Characteristics

•**Type:** It is a four level solid state laser.

•**Active medium**: The active medium is Nd: YAG laser.

•**Pumping method**: Optical pumping is employed for pumping action.

•**Pumping source**: Xenon or Krypton flash tube is used as pumping source.

•**Optical resonator**: Two ends of Nd: YAG rod is polished with silver

•(one end is fully silvered and the other is partially silvered) are used as optical resonator.

•**Power output**: The power output is approximately 70 watt.

•**Nature of output**: The nature of output is pulsed or continuous beam of light.

•**Wavelength of the output**: The wavelength of the output beam is 1.06μm (infra-red)

Nd:YAG laser

Advantages:

- It has high energy output.
- It has very high repetition rate operation
- It is much easy to achieve population inversion.

Disadvantages:

- The electron energy level structure of Nd^{3+} in YAG is complicated.

Nd:YAG laser

Applications:

- It finds many applications in range finders and illuminators.
- It is widely used in engineering applications such as resistor, trimming scribing, micro machining operations as well as welding, drilling etc.

CO_2 Laser

Characteristics:

Type: It is a molecular gas laser.

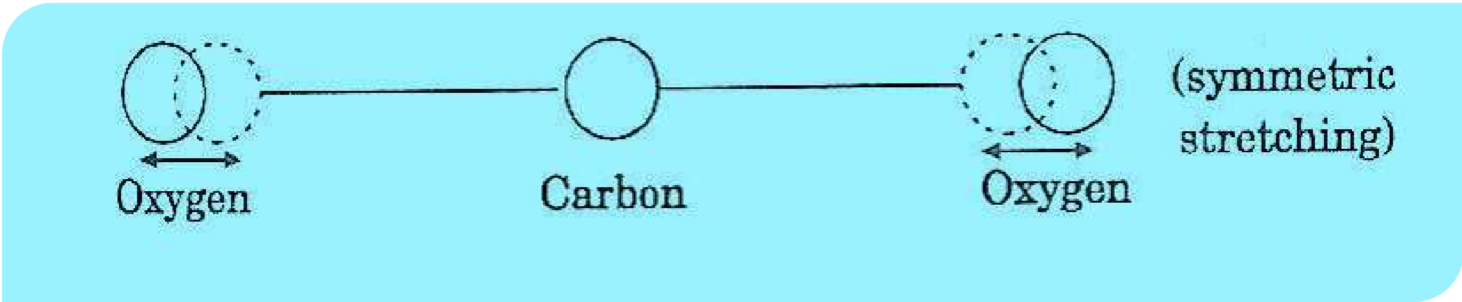
- Active medium: A mixture of CO2 , N2 and helium or water vapour is used as active medium.
- Pumping method: Electrical discharge method is used for Pumping action.
- Optical resonator: Two concave mirrors form a resonant cavity.
- Power output: The power output from this laser is about 10kW.
- Nature of output: The nature of output may be continuous wave or pulsed wave.

Wavelength of output: The wavelength of output is 0.6 μm and 10.6μm.

CO2 Laser

The three vibrational levels of CO_2 molecules:
Symmetric stretching mode:

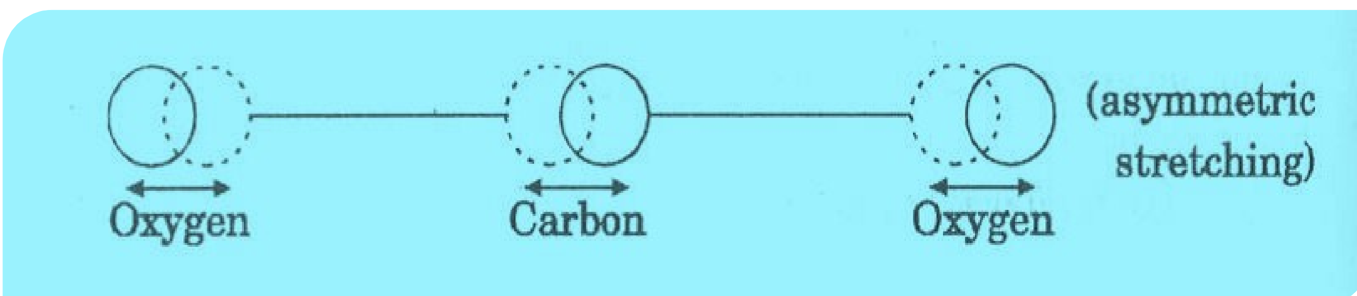
- In this mode of vibration, carbon atoms are at
- Rest and both oxygen atoms vibrate simultaneously along the axis of the Molecule departing or approaching the fixed carbon atoms.



CO_2 Laser

Asymmetric stretching mode:

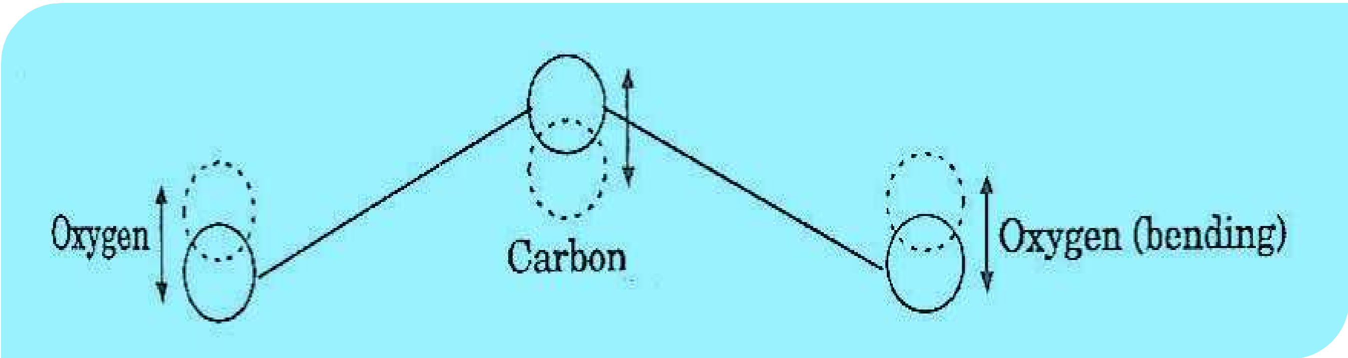
In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.



CO_2 Laser

Bending mode:

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.



CO_2 Laser

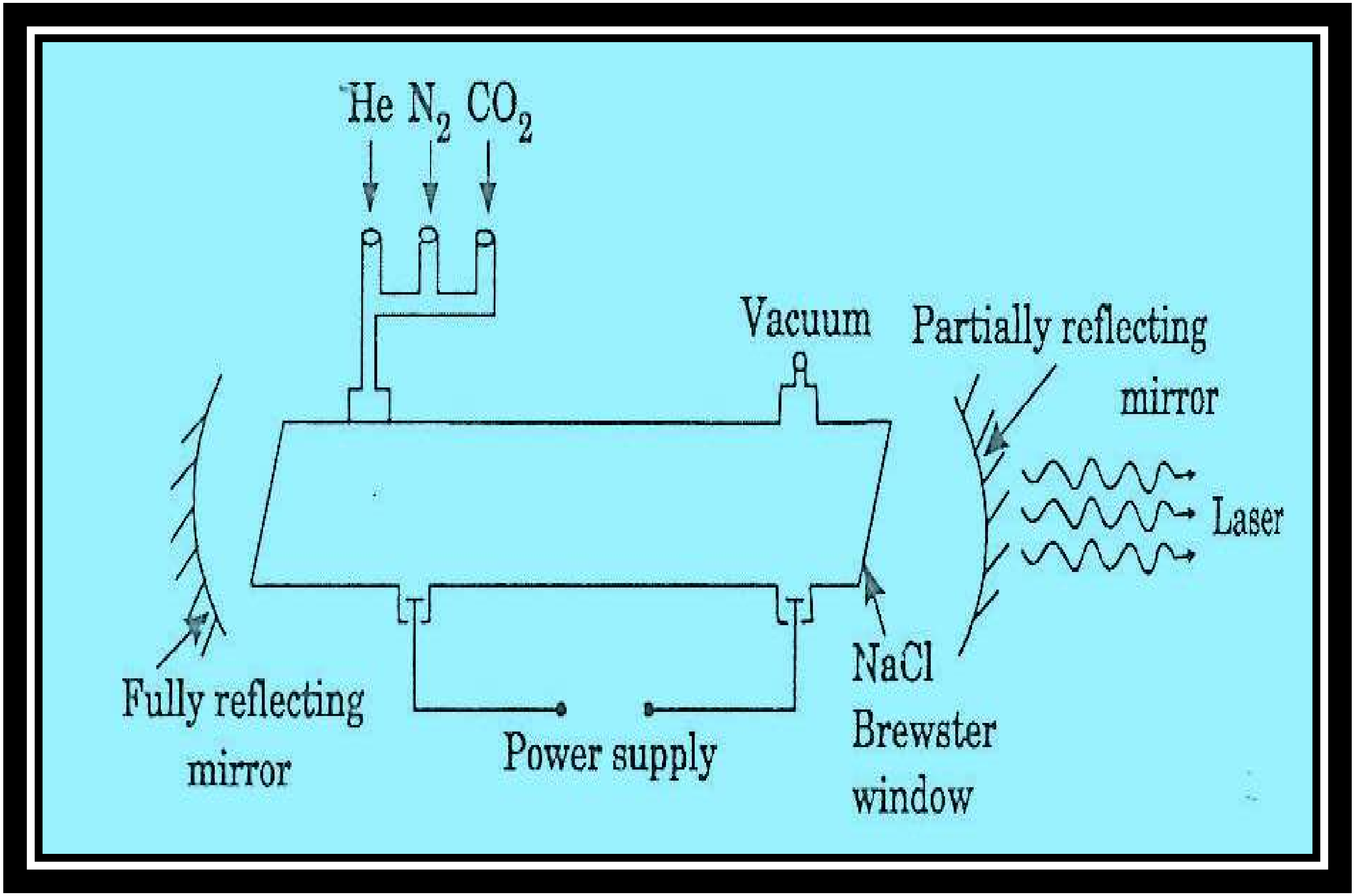
Principle:

The active medium is a gas mixture of CO_2, N_2 and He. The laser transition takes place between the vibrational states of CO_2 molecules

Construction:

It consists of a quartz tube 5m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO_2 (active medium), helium and nitrogen with suitable partial pressures. The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized. Two concave mirrors one fully reflecting and the other partially form an optical resonator.

Construction and working of CO2 laser with energy level diagram



CO2 Laser

Working:

When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

$$N_2 + e^* = N_2^* + e$$

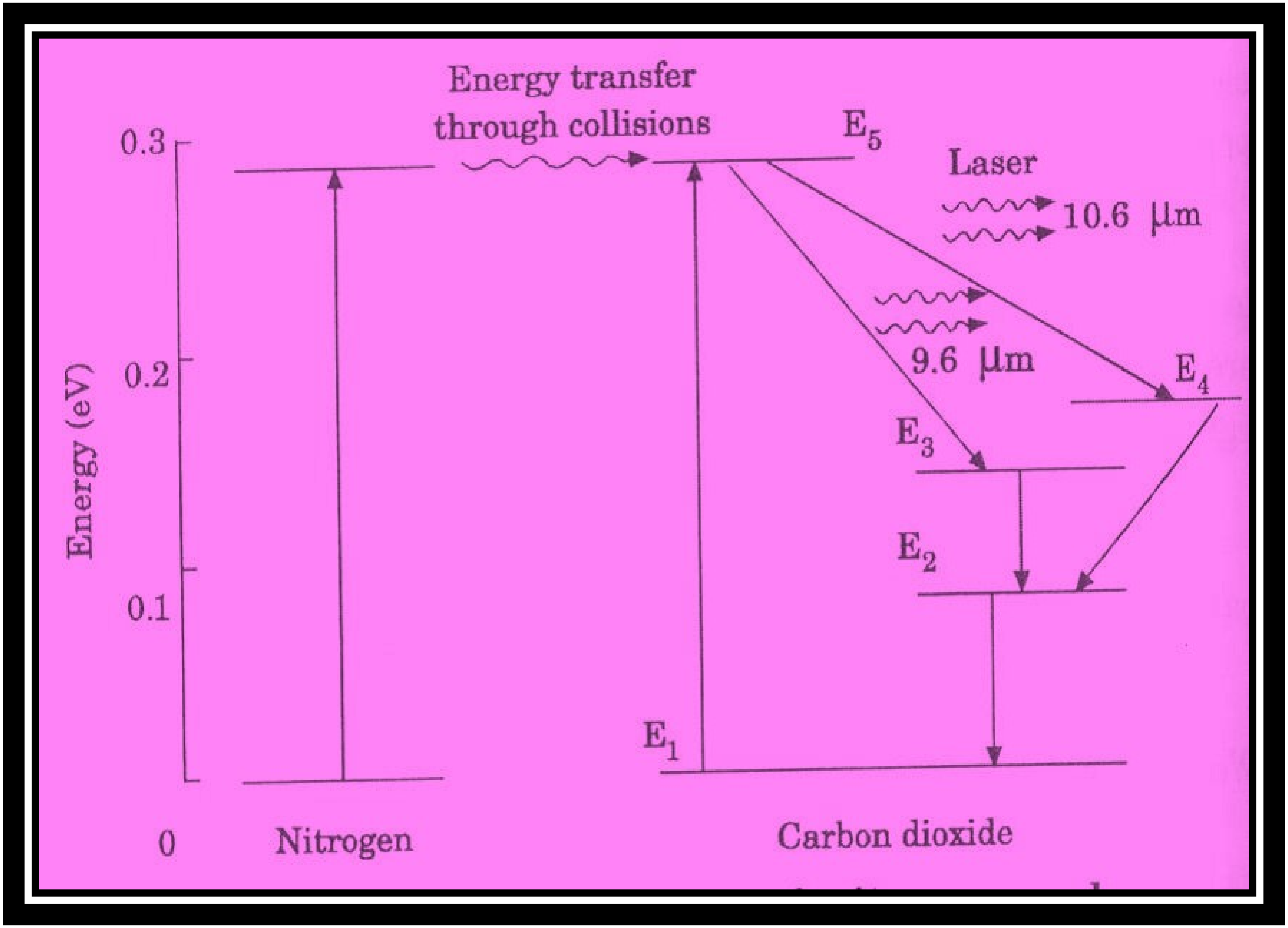
N_2 = Nitrogen molecule in ground state,

e^* = electron with high energy,

N_2^* = nitrogen molecule in excited state,

e= same electron with lesser energy

Energy level diagram of CO2 Laser



CO_2 Laser

Since the excited level of nitrogen is very close to the E_5 level of CO_2 atom, population in E_5 level increases. As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

I. **Transition E_5 to E_4** : This will produce a laser beam of wavelength 10.6µm

II. Transition E_5 to E_3 : This transition will produce a laser beam of wavelength 9.6 µm. Normally 10.6 µm transition is more intense than 9.6 µm transition. The power output from this laser is 10 kW.

CO_2 Laser

Advantages:

- The construction of CO2 laser is simple
- The output of this laser is continuous.
- It has high efficiency
- It has very high output power.
- The output power can be increased by extending the length of the gas tube.

CO_2 Laser

Disadvantages:

- The contamination of oxygen by carbon monoxide will have some effect on laser action
- The operating temperature plays an important role in determining the output power of laser.
- The corrosion may occur at the reflecting plates.
- Accidental exposure may damage our eyes, since it is invisible (infra red region) to our eyes.

CO_2 Laser

Applications:

- High power CO_2 laser finds applications in material processing, welding, drilling, cutting soldering etc.
- The low atmospheric attenuation (10.6μm makes CO_2 laser suitable for open air communication.
- It is used for remote sensing
- It is used for treatment of liver and lung diseases.
- It is mostly used in neuro surgery and general surgery.
- It is used to perform microsurgery and bloodless operations.

Comparison of types of lasers

Laser	Ruby	He-Ne	CO_2	Semiconductor (Ga - As)
Type	Solid state	Gas	Molecular gas	Semiconductor
Active medium	Ruby (Al_2O_3_Cr_2O_3)	He + Ne in ratio 10:1	CO_2 + N_2 + He	P - N junction diode
Active center	Chromium	Neon	CO_2	Recombination of e^{-1} and holes
Pumping method	Optical pumping	Electrical pumping	Electric discharge method	Direct pumping
Optical resonator	Ends of rods polished with silver	Pair of concave mirrors	Mirrors coated with Al	Junction of diodes polished
Power output	10^4 - 10^5 Watts	0.5-50 mW	10KW	1mW
Nature of output	Pulsed	Continuous	Continuous or pulsed	Continuous
Wave length	6943 A°	6943 A°	9.6 & 10.6 µm	8400 A° - 8600 A°

Applications of laser

Medicine:

1. Laser is used in the treatment of lever and lungs.
2. It is used to perform microsurgery and bloodless operation.

Industry:

1. Laser is used in cutting, welding, drilling etc
2. It is used to produce small holes in diamond and hard metals.

Scientific and engineering field

1. Using laser we can get three dimensional lensless photography
2. Computer print pits are done with laser printers
3. Laser can be used for forecasting earthquakes.

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