LASER.

→ Light Amplification by Stimulated Emission of radiation.

→ Properties:

- highly coherent
- Perfectly monochromatic
- Perfectly Parallel
- Extremely intense.

Hence, LASER is a device that produce strong, monochromatic, collimated and highly coherent beam of light.

→ Applications:

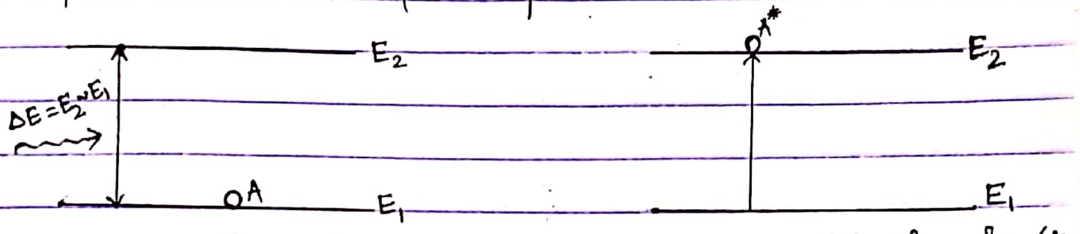
- Technical & Industrial field
  # Cutting, drilling, welding ... etc.
  # Laser beam is used to vaporise unwanted material during manufacture of electric circuits on semiconductor chips.
- Medical applications
  # delicate surgery.
  # Surgical operation is completed in a much shorter time.
  # treatment of kidney stone, cancer, tumer.
  # Cutting & sealing of small blood vessels in brain operation
- Defence applications.
  # to detect and destroy the enemy missiles.
  # to control rockets & satellites.
  # used in laser-rifles, laser pistols .. etc.
- Science & Research.
  # to determine the temperature of plasma and density of electrons.
  # grow thin films of different materials.
  # used in Spectroscopic ~~instru~~ techniques (Raman, IR etc)
  # used in 3-D photography (holography).

and so on......

Absorption :—

A suitable amount of energy is absorbed by the atoms of the ground state to get excited to the higher energy states.

Let the atom(A) residing in lower ground state 'E_1' jumps to the excited state (higher energy state) by "E_2" by absorption of a quantum of radiation (Photon) of energy $\Delta E = E_2 - E_1 = h\nu$. This process of transition is known as induced or stimulated absorption.



(a) Before absorption (b) after absorption

$A \rightarrow$ atom at ground state

$$A + h\nu \longrightarrow A^* \quad \text{—(1)}$$

$A^* \rightarrow$ atom at excited state

If N_1 is the population of atoms in the lower energy state then the rate of absorption is defined as the no. of atoms per unit volume per second which are raised from the lower energy level to the excited energy level.

i.e $$R_{ab} = -\frac{dN_1}{dt} \quad \text{—(2)}$$

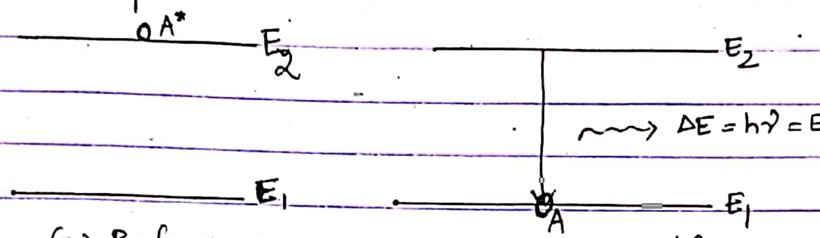
The rate of absorption is proportional to the population of atoms in the lower energy state and the energy density of incidenting light $\rho(\nu)$.

Hence $$R_{ab} = B_{12}\,\rho(\nu)\,N_1 \quad \text{—(3)}$$

where B_{12} is known as Einstein coefficient for induced absorption transition for level $1 \rightarrow 2$.

Spontaneous Emission :-

Suppose an atom is in a higher (excited) state E_2. As $E_2 > E_1$ and the lifetime in this excited state is usually very small ($\sim 10^{-8}$ sec), the atom jumps (decays) to state E_1 (lower ground state) spontaneously (of its own accord), without any external impetus) emitting a photon of frequency ν. This process is called spontaneous emission.



(a) Before (b) After.

$$A^* \longrightarrow A + h\nu \quad —④$$

The rate of spontaneous emission is given as

$$R_{sp} = -\frac{dN_2}{dt} \quad —⑤$$

⇒ ~~Rat~~ No. of photons emitted during the process of spontaneous emission is proportional to the no. of excited atoms only.

$$R_{sp} = A_{21} N_2 \quad —⑥$$

Where

A_{21} is known as Einstein coefficient for spontaneous emission. It gives the probability of spontaneous emission from level $2 \to 1$.

→ Features

i) difficult to control the process of spontaneous emission

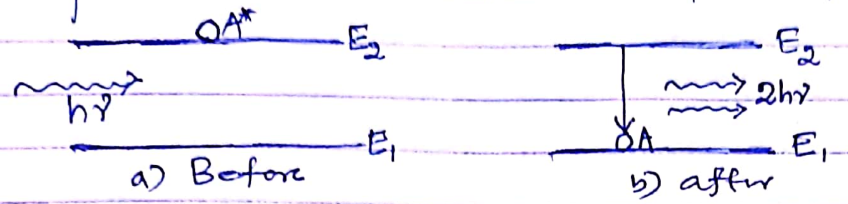
ii) emitted photons during the process have different direction of propagation, initial phase, and plane of polarization.

iii) the emitted light during the process is incoherent.

iv) The intensity of emitted light decreases rapidly.

Stimulated Emission:

The process of emission of radiation from the excited atom under the influence of external impetus is known as stimulated or induced emission.



Suppose an e.m wave (photon) of energy $\Delta E = h\nu = E_2 - E_1$ i.e equal to the energy of spontaneously emitted radiation is made to strike the atom (incident upon the atom); which is residing in the excited state of energy E_2. Under the influence of external impetus, the atom jumps to a lower energy state emitting an additional photon of same energy as of the incident photon.

$$A^* + h\nu \longrightarrow A + 2h\nu \quad \text{--- (7)}$$

The rate of stimulated emission of radiation can be given as

$$R_{st} = B_{21}\, \rho(\nu) N_2 \quad \text{--- (8)}$$

Where B_{21} is known as Einstein Coefficient for stimulated emission.

→ Features

i) The process can be controlled from outside.

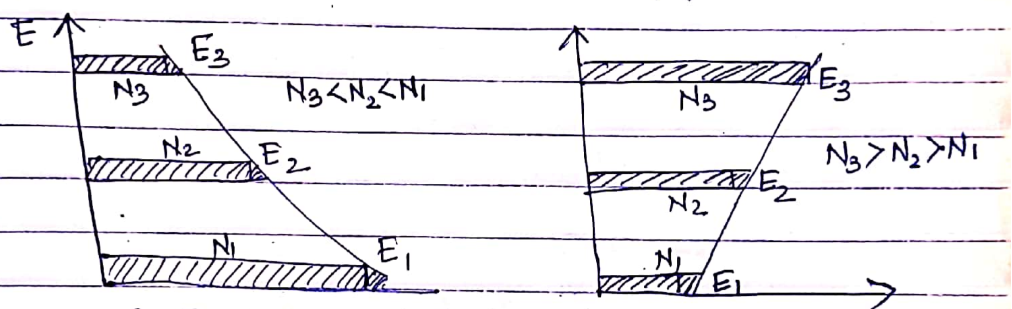
ii) The incident photon and emitted photon have the same direction of propagation, phase, frequency and plane of polarization.

iii) The stimulated radiation is completely coherent. and monochromatic.

Population Inversion:-

Usually, under thermal equilibrium, the no. of atoms (or particles) in the higher excited state (i.e population of E_2) is considerably smaller than the no. of atoms in the lower ground state E_1. But for stimulated emission and for laser action, it is essential that the no. of atoms in the higher state (E_2) must be greater than the no. of atoms in the lower state (E_1).

The situation in which the population of the higher energy state exceeds the population of lower level, is known as population inversion.



(a) Equilibrium state (b) Population inversion

Pumping:-

The Process of achieving population inversion is known as pumping. In other words, the process by which atoms are raised from the lower energy level to the higher energy level is called pumping. There are various pumping processes described below.

(I) Optical pumping: A light source is used to supply luminous energy, that is used widely in solid state lasers (ruby or neodymium).

(II) Electrical pumping: An electric discharge is used in gas or semiconductor lasers.

(III) Thermal pumping:

(IV) Chemical reaction. and so on.

The Ruby laser.

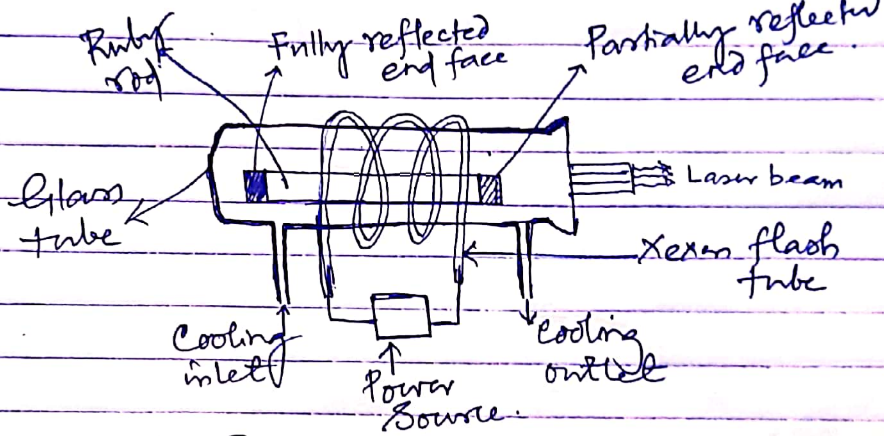
→ 1960, 1st laser.

→ Solid state laser, as it uses a crystalline substance of active material

Principle :

Ruby rod consists of a synthetic ruby crystal (Al_2O_3) doped with chromium ions with concentration of about 0.05% by weight. With this concentration, there are about 1.6×10^{25} Cr^{3+} ions per cubic meter. These ions have a set of three ~~level~~ energy levels suitable for the laser action.

Structure



(I) Active material

→ A cylindrical ruby rod of length 4 cm and width 0.5 cm.

→ The end faces of ruby rod are polished in such way that one face is partially reflecting and the other is fully reflecting.

→ Both faces are perfectly parallel and perpendicular to the axis of the rod.

(II) A resonant cavity.

→ The optically plane and parallel plates (one fully reflecting & other partially reflecting) attached to both ends of the ruby rod is acting as ~~the~~ resonant cavity.

Scanned with CamScanner

(III) Pumping System:
→ A helical xenon flash tube ~~with power~~ supply, which produces white light whenever activated by the power supply.

(IV) Cooling System:
→ An arrangement is made for the circulation of coolant around the ruby rod to control the heat ~~is~~ during the process.

* Working

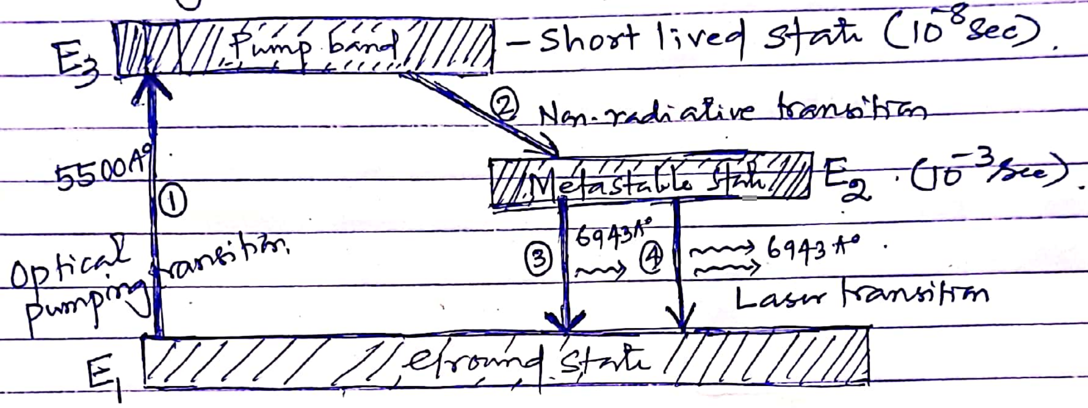


Fig.→ Energy level diagram & transitions in ruby laser.

→ Most of the Cr^{3+} ions are in the ground state E_1. When a flash of light falls upon the ruby rod, the 5500A° radiations photons are absorbed by the Cr^{3+} ions and pumped to excited state E_3. The transition ① is the (optical) pumping transition

→ The excited ions give up part of their energy to the crystal lattice due to collision and decay to the metastable state E_2. The transition ② is thus a radiationless transition.

→ The energy level E_2 (Metastable state) has a longer life-time, the no. of atoms in this state goes on increasing. The population inversion is established between the metastable (excited) state E_2 and the ground state E_1.

→ When an excited atom passes spontaneously from the metastable state to the ground state (transition 3) it emits a photon of wavelength 6943 A°.
This photon travels through the ruby rod parallel to the axis of the crystal is reflected back and forth by silvered ends until it stimulates an excited atom and causes it to emit a fresh photon in phase with the stimulating photon.

→ This stimulated transition (4) is the Laser transition.

→ The photons emitted spontaneously which do not move axially escape through the sides of the crystal.

→ The process is repeated again and again because the photons repeatedly move along the crystal being reflected from its ends.

→ The photons thus multiply. When the photons beam becomes sufficiently intense, part of it emerges through the partially reflected end of the crystal to give the laser light.