LASER

* The word LASER is acronym of light amplification by Stimulated Emission of radiation.

* The most Common uses of lasers are.

1) Laser printer
2) Compact DISCs (CD) player.
3) Communications
4) Cutting Drilling welding

How is laser different from regular Flash light

* Absorption and Emission

According to Bohr's postulate If an electron in an atom transition from higher exited state (E_2) to a lower exited state (E_1) it emits a radiation of energy $h\nu = E_2 - E_1$

* Similarly when an atom transition from E_2 level to E_1 energy level in an active material it emitts a radiation of energy $h\nu$

The frequency of the emitted radiation

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

h is plank's Constant 6.626×10^{-34} Js.

Quantum Process:

1) Absorption:

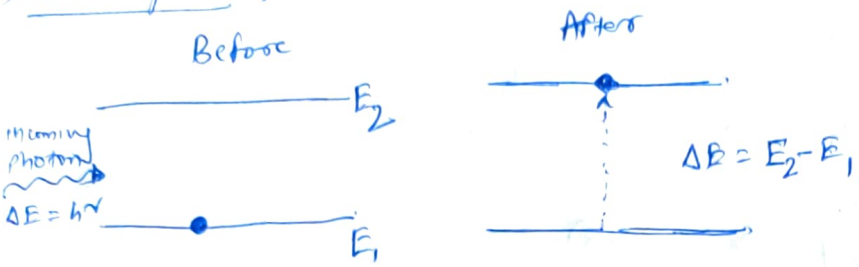
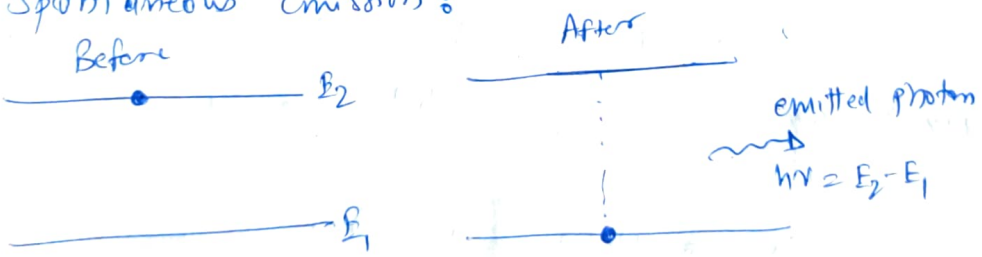


Fig. shows an atom in a ground state E_1 initially. The atom can absorb an amount of energy $h\nu$ and move to the higher excited state E_2.

The energy $h\nu$ is provided by the incident photon and is absorbed. (photon is lost)

2) Spontaneous Emission:



The process in which an excited atom return to ground state by spontaneously emitting an electromagnetic radiation.

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

c: 3×10^8 m/s

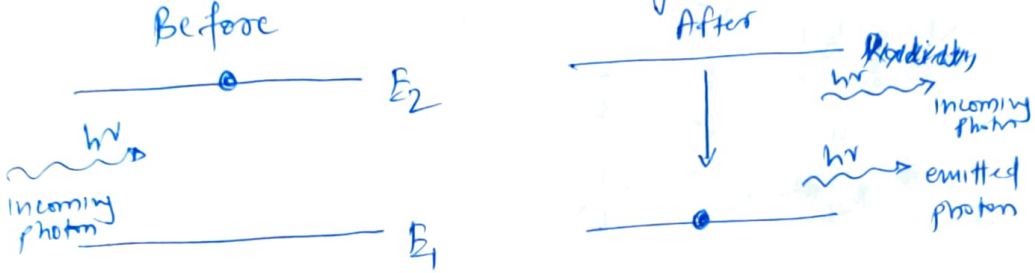
λ: wavelength of emitted radiation

$$\boxed{\Delta E \uparrow \Rightarrow \lambda \downarrow}$$

The Probability of Spontaneous emission increases rapidly with energy difference between two states.

(3) Stimulated Emission

The process in which an external triggering radiation of the same frequency $\nu = \frac{\Delta E}{h} = \frac{E_2 - E_1}{h}$ is used to make the transition of the atom from higher excited state to lower (ground) state.



Thus along with incident photon, one more photon is also produced.

If this two photons are further used to trigger more and more excited state atoms, one can have identical multiple photons. 2, 4, 8. - - - etc.

The incident photon gets coherently amplified in this process and it is called amplification of light by stimulated emission of radiation.

Factors: 1) intensity of trigger photon ($I = \frac{1}{n} h\nu$)
2) The number of atoms in excited state.

(4) Meta Stable State:

A metastable state is a temprory excited state where atoms remain longer than in ordinary excited states

(5) Population Inversion:

The making of more number of atoms in higher state than in lower state is called population inversion

$(N_2 > N_1)$

N_2, E_2

N_1, E_1

According to Boltzmann distribution law

$$N = N_0 e^{-E/KT}$$

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

k : Boltzmann Constant

$= 1.38 \times 10^{-23}$ J/K

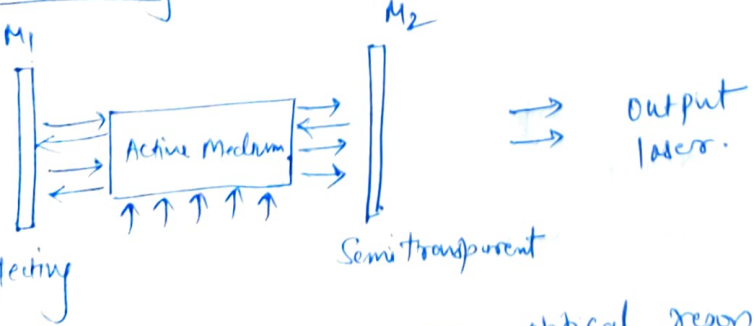
(6) Pumping

The process of raising atoms from lower energy state to the higher state by an external source is called pumping

ex: optical pumping, electrical pumping.

Chemical pumping

(7) Resonant Cavity.



Active medium in stable optical resonator

Resonator Cont'd:

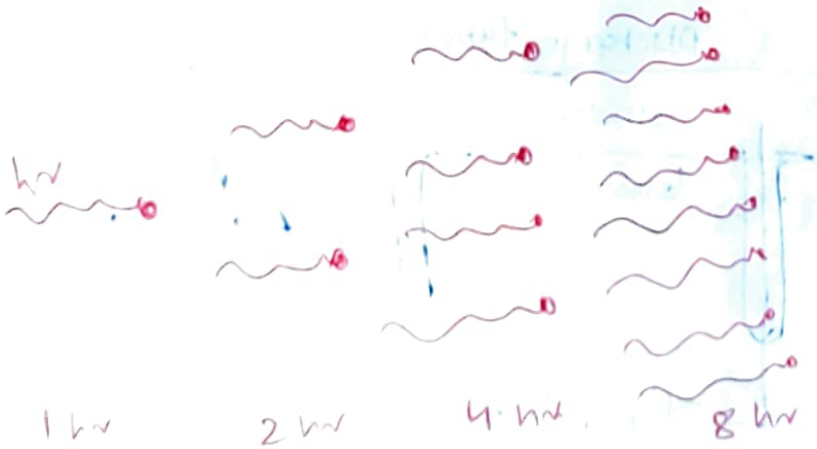
1) The spontaneous emission from atom is purely random and occurs in all possible directions.

2) The emission along directions which are not parallel to the resonator escapes from it.

3) Those which are parallel to the axis of resonator will move to and fro between the mirrors because of multiple reflections.

4) As the photons repeatedly pass through the medium some of them collide with the active centres of the medium. This process leads to the amplification

5) Finally at some point a monochromatic powerful highly collimated laser beam comes out from a partially silvered mirror M_2 as shown in figure.



Coherent amplification of Laser Oscillation

8. Coherence length:

The distance over which the laser light remains Coherent. (i.e. the light waves stay in phase).

→ ex: used in Holography, interferometry

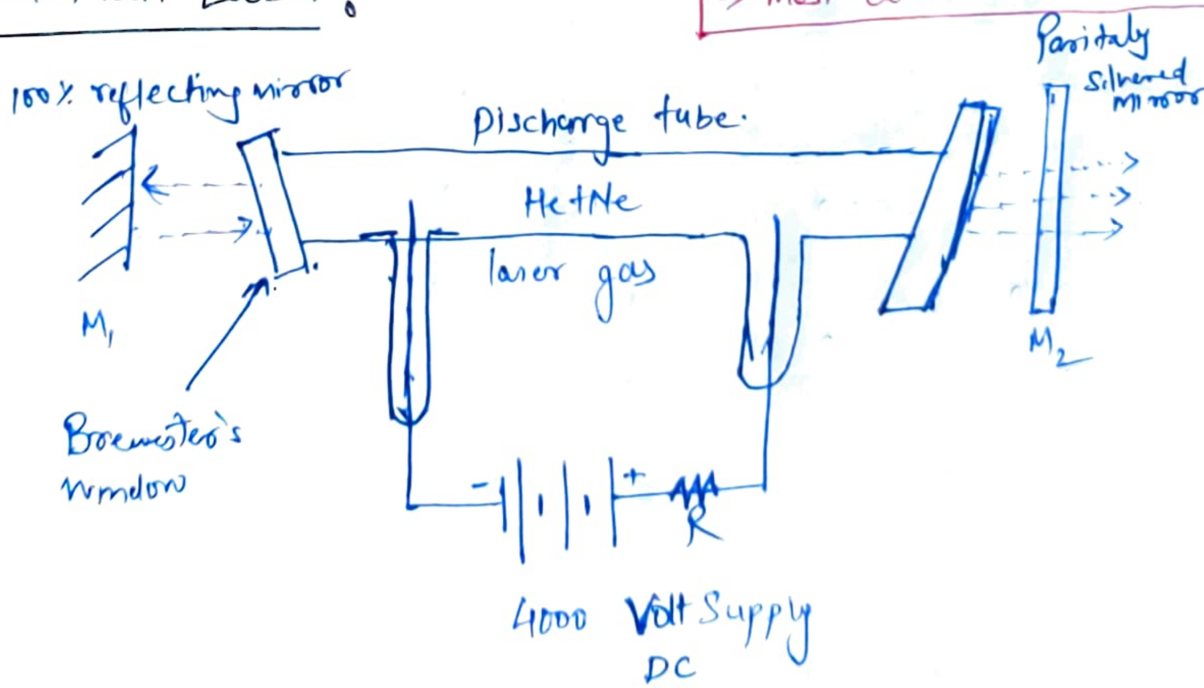
9. Coherence Time:

The time over which the phase of the laser light waves remains Constant.

The coherence length & time measures the laser's phase stability and beam quality.

> Why we are studying HeNe
> → MOST Common Gas laser

10. Helium-Neon Laser:



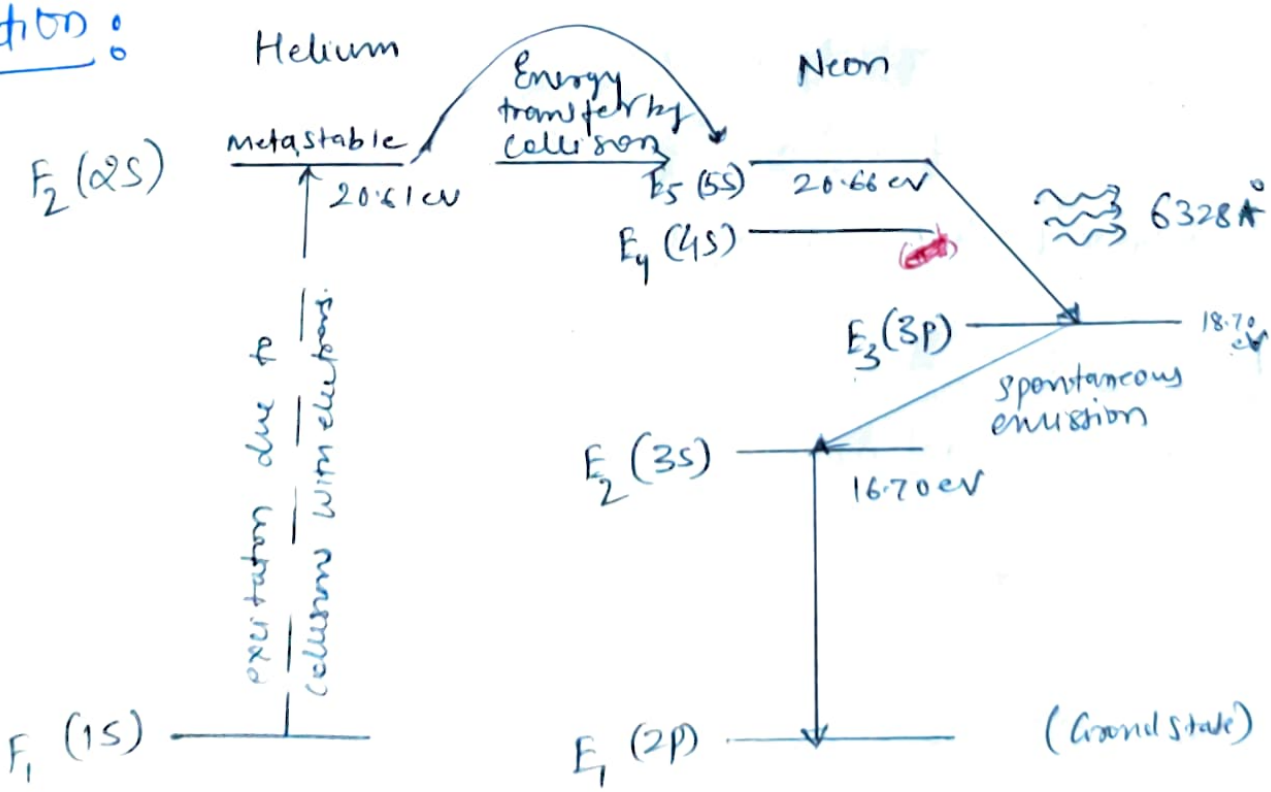
First He-Ne laser was invented by Ali Javan, William Bennet and Donald Herriott.

Plane Polarized

Construction

1) The He-Ne consist of a long narrow quartz tube of Length = 8cm and diameter = 1.5 cm filled with He & Ne gas in the ratio 10:1 at Pressure of 1 torr.
2) It has two electrodes in the discharge tube connected to a high voltage supply of 4000 V D.C.
3) The active medium inside the tube is excited externally by means of high frequency generator with a frequency of tens of Megahertz and input of about 50 watt.
4) One end of the tube is perfectly reflecting mirror (M_1) and on the other end the mirror is partially reflecting (M_2) forming a resonator.

Operation:



Pumping Mechanism:

1) When power is switched on, the high voltage ionizes the Gas mixture and produces electron-ion pairs, colliding with He- and Ne atoms on the way.

2) The excited level F_2 at 20.61 eV from Grond state is a meta stable state and the excited He cannot return to grond state by spontaneous emission.

3) However, the excited He atom can return to grond state level by transferring its excess energy to neon atom through collision. [Resonant energy transfer $F_2 \rightarrow E_5$]
Also, the K.E. of He atoms provides the additional 0.05eV required for excitation of the neon atoms.

Population Inversion:

1) The upper state E_5 is a metastable state and E_3 is sparsely populated at ordinary temperatures. The population in $E_5 > E_3$ a Population inversion is achieved between E_3 and E_5 levels.

LASING:

1) Random photons of red colour wavelength 6328 Å are emitted spontaneously by a few atoms at E_3 energy levels.

2) The Spontaneously emitted photon travels through the gas mixture and triggers stimulated emission of photons of same wavelength.

3) The strength of the stimulated emission increases as the photon bounce back and forth between the mirrors M_1 & M_2

Thus, the transition $E_5 \rightarrow E_3$ of Ne atoms generates a laser beam of wavelength 6328 A°.

3) The Ne atom from E_3 drops to E_2 by spontaneous emission and returns to ground state E_1 via frequent collisions with the walls of the glass tube holding the He-Ne gas mixture.

6) The cycle completes and the Ne atoms are once again available for exitation to higher states due to collisions and participate in lasing action.

Remark:
The role of He atoms in a laser is to excite Ne atoms and cause population inversion.

* Applications of Laser:

1) Industrial application: Cutting, welding and focused drilling

* Laser welding: CO_2 and Nd:YAG

Nd: Neodymium, YAG: yttrium aluminium garnet crystal

2) Lasers in Medicine:

1) He-Ne laser: Ulcer treatment
2) CO_2 laser: Brain and Spinal Surgery
3) Argon laser: Brain, Angioplasty and eye surgery
4) Nitrogen laser: DNA analysis & genetic Engineering

3) Three dimensional Imaging by Holography (H.W.).

Active medium and Active Centres

A medium in which light gets amplified is called an active medium.

Solid: Ruby laser, Nd-YAG laser.

Liquid: Dye laser.

Gas: He-Ne, CO_2 laser.

The centres are typically atoms, ions or molecules or their collection.

* Meta stable state:

If an atom is in excited state and stays there for a short interval of time not exceeding 10^{-8} sec and then it returns to lower energy state.