LASER: Light Amplification by Stimulated Emission of Radiation.

It is a source which emits an intense, almost perfectly monochromatic directional and highly coherent beam of light.

It working depends on the phenomenon of "Stimulated emission".

Stimulated Emission is the one of the ways in which Radiation interact with matter.

Interaction of Radiation with matter

(1) Stimulated Absorption of Radiation

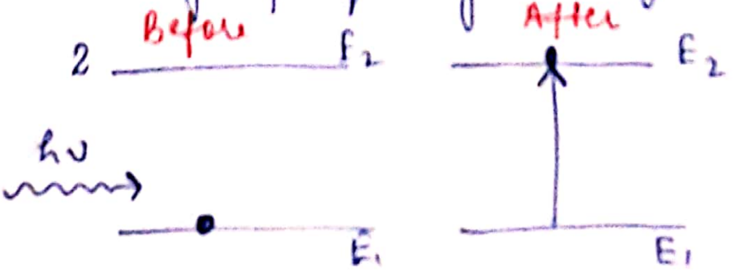
(2) Spontaneous Emission of Radiation

(3) Stimulated emission of Radiation.

1) Stimulated Absorption of Radiation

An atom, initially in a lower state of Energy 1, rise to higher energy state 2, by absorbing a quantum of Radiation (photon) of frequency 'ν' given by

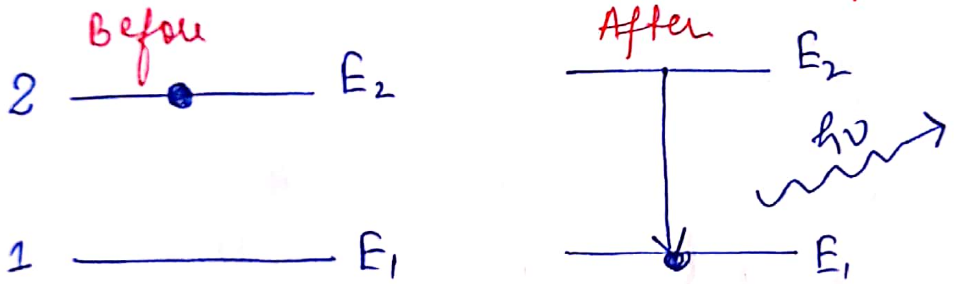
$$\boxed{\nu = \frac{E_2 - E_1}{h}}$$



Stimulated Absorption

where E_1 & E_2 are the energies of the atom in states 1 and 2 respectively. This is stimulated (or induced) absorption of radiation; the absorbed photon being the stimulating photon.

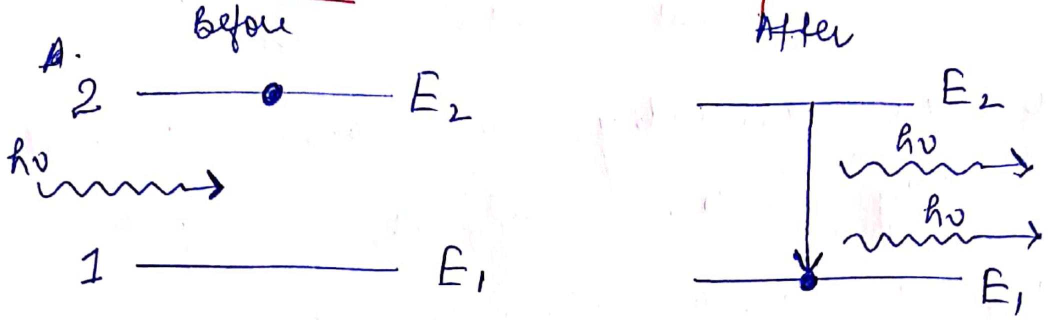
(II) Spontaneous Emission of Radiation



consider an atom initially in the higher [Excited] energy state 2. Since the life-time of atom in excited state E_2 (higher Energy state) is 10^{-8} sec, so, after 10^{-8} sec, the atom will decays to the lower energy state 1, emitting a photon of frequency $\nu = \dfrac{E_2 - E_1}{h}$. This is the spontaneous emission of Radiation.

If there is an assembly of atoms, then on decaying the radiation emitted spontaneously by each atom has a random direction and a random phase, and is incoherent from one atom to another.

III) Stimulated Emission of Radiation –



According to Einstein, an atom in an excited energy state, under the influence of the electromagnetic field of a photon of frequency 'ν' incident upon it, decays to a lower energy state, emitting an additional photon of same frequency ν. Thus, two photons of same frequency, one incident and the other ~~stimulated~~ emitted, move on. This is the stimulated emission of Radiation.

The direction of propagation, energy, phase and state of polarisation of the emitted photon is exactly the same as that of the incident stimulating photon.

∴ The stimulated (emitted) radiation is completely coherent with the stimulating (incident) radiation.

As a result of this process, radiation passing thru an assembly of atoms is amplified.

Population Inversion : A necessary condition for Light Amplification.

Let us consider an assembly of atoms distributed over different energy states. Suppose, a light beam of frequency ν, which coincides with one of the characteristic frequencies of the atoms, is passing through the medium.

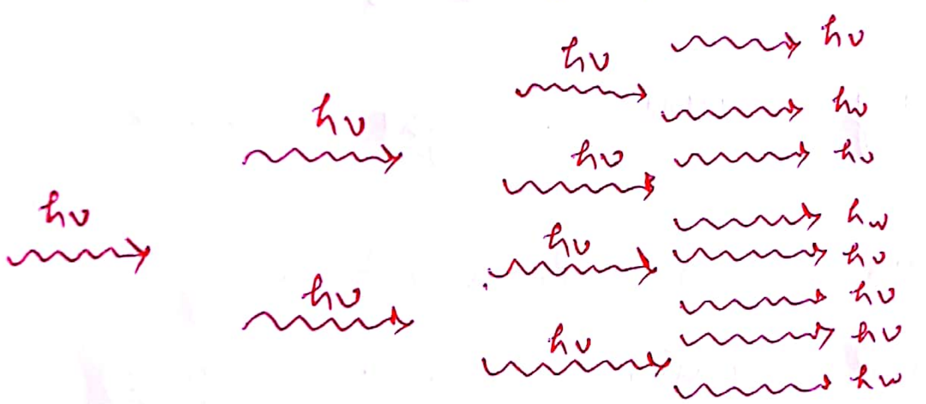
Now, one of the following two processes takes place:-

(i) A light photon (of frequency ν) is absorbed by an atom in an energy state E_1 and the atom is excited to higher energy state E_2. In this case the intensity of the beam passing through the medium generally decreases.

(ii) A light photon (of freq. ν) is incident on an atom in an energy state E_2. This atom decays to a lower energy state E_1, emitting a photon of same frequency ν. This emitted photon is in perfect coherence with the incident photon.
(This is stimulated emission of Radiation).

If there two photons are incident on the two more photons, thus resulting in four coherent photons. This process continues (fig.1) and the intensity of light beam increases exponentially.

This increase in light is called as '<u>Light Amplification</u>'



← fig.1

Necessary condition for the laser action is population inversion. Normally under thermal equilibrium, the number of atom in higher energy state E_2 is smaller than E_1, so there is very little possibility of stimulated emission as compared to absorption. If, however, by some means the number of atoms in the higher energy state be (E_2) made sufficiently larger than E_1, then stimulated emission is promoted. This situation in which the number of atoms in the higher energy state exceeds that in the lower energy state ($N_2 > N_1$) is known as 'POPULATION INVERSION'.

Population Inversion can be achieved by

Pumping:

The process by which atom are raised from a lower to a higher energy state is called as pumping: The pumping action in lasers is done by complex excitation process, such as

(1) Excitation by strong source of light. → Optical pumping

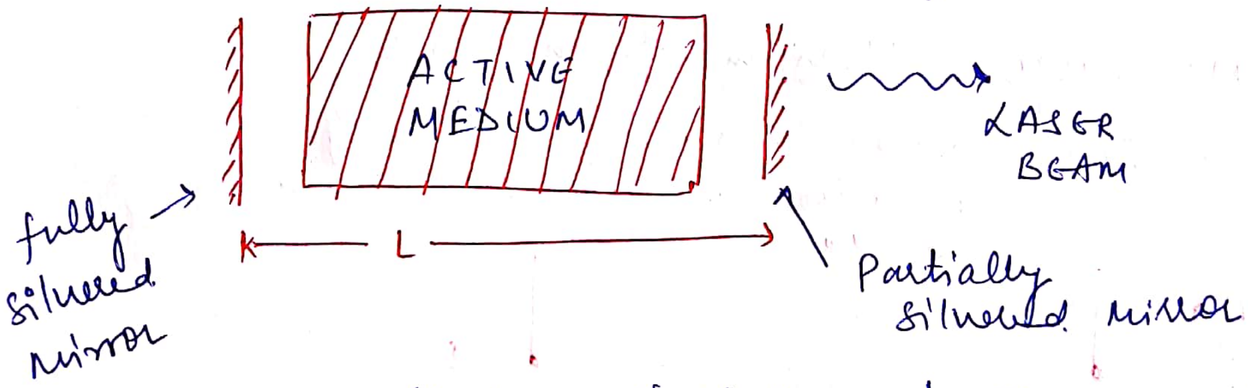
2) excitation by electron impact (electrical pumping)

3) excitation by chemical reaction (chemical pumping)

4) excitation by supersonic gas expansion (gas - dynamic pumping)

Optical Resonator

A medium with population inversion is capable of amplifying a light beam passing through it. However, if the medium is to act as an oscillator which can supply light energy and act as a source of light, a part of the output energy must be fed back into the medium. Such a feedback can be achieved by placed the active medium between 2 mirror facing each other.



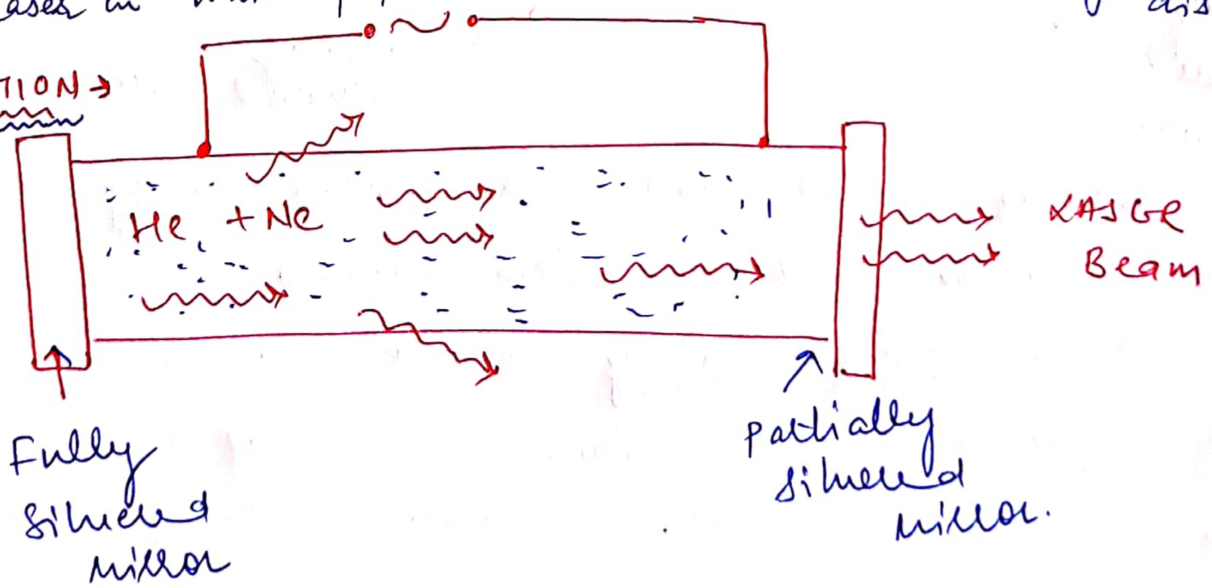
The mirrors reflect most of the output energy back to the medium. Such a system formed by 2 mirrors represents a resonant cavity, is referred to as an Optical Resonator. To obtain an output light beam, one of the mirrors is made partially reflecting.

Let us consider a wave which starts from one of the mirrors & travels towards the other. In passing through the active medium, the wave is amplified. If the second mirror is partially reflecting, the wave is partially transmitted and rest is reflected back towards the first mirror. In travelling to the first mirror, the wave is again amplified and returns to its starting position. Thus, in between the two mirrors, there are waves propagating along both directions. These wave interfere, and for stable standing wave pattern to be formed in the cavity, the total phase change suffered by the wave in one complete round trip must be an integral multiple of 2π.

He- Ne - Laser - Helium - Neon Laser

It was the first Gas Laser operated successfully. It is four level lasers in which population inversion is achieved by electric discharge.

CONSTRUCTION →

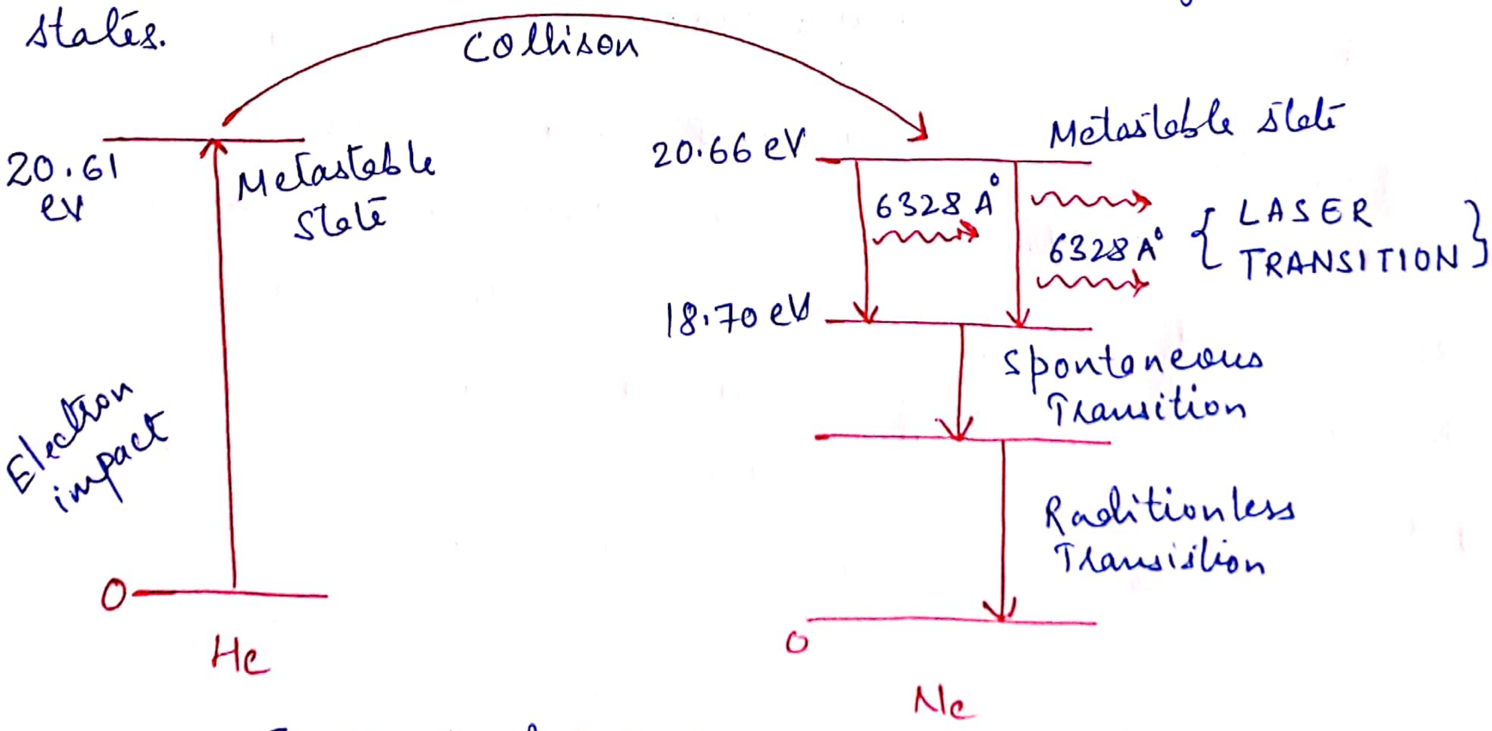


The helium - neon laser consists of long and narrow discharge tube filled with a mixture of He & Ne in the ratio 10:1 at pressure of about 1 mm of mercury.

The gas mixture (He + Ne) forms the lasing medium. It is placed between a pair of optically plane and parallel mirrors which form a resonant cavity. One of the mirrors is fully silvered and the other is partially silvered. The spacing of the mirrors is equal to an integral number of half-wavelength of the laser light. An electric discharge may be produced in the gas mixture by electrodes connected to a high-frequency electric source.

Working → 1) When a discharge is passed through the gas mixture, electron are accelerated down the tube.

2) These accelerated electrons collide with & excite the He and Ne atoms to metastable stable 20.61 eV and 20.66 eV, respectively above their ground states.



Energy level Rep. in He-Ne Laser

3) Some of the excited He atoms transfer their energy to ground-state Ne atoms by collisions, with 0.05 eV of extra energy, He atoms helps in achieving population inversion in Ne atoms.

4) When an excited Ne atom passes spontaneously from the metastable state at 20.66 eV to the state at 18.70 eV, it emits 6328 A° photon.

5) This photon of $\lambda = 6328$ A°, travels through the gas-mixture, and if it is moving parallel to the axis of the tube, is reflected back & forth by mirror ends until it stimulates an excited Ne atom and causes it to emit a fresh 6328 A° photon in phase with the stimulating photon.

6) This stimulated transition from 20.66 eV to 18.70 eV level is the laser transition.

7) This process is continued and a beam of coherent radiation builds up in the tube. When this beam becomes sufficiently intense, a portion of it escapes through the partially-silvered end.

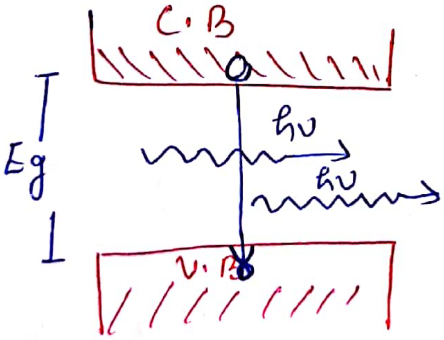
8) From the 18.70 eV level the Ne atom passes down spontaneously to a lower metastable state emitting incoherent light, and finally to the ground state through collision with the tube walls. This final transition is radiationless.

9) Power outputs of He-Ne lasers lie between 1 and 50 mW of continuous wave for inputs of about 5-10 W.

10) He-Ne laser can be tuned (adjusted) to give radiation in any desired wavelength range, by adjusting the end mirrors.

Semiconductor Laser

These lasers are tunable laser, very useful in optical communication and optical-computer design. The first semiconductor laser was made from gallium arsenide, GaAs.



→ fig (1)

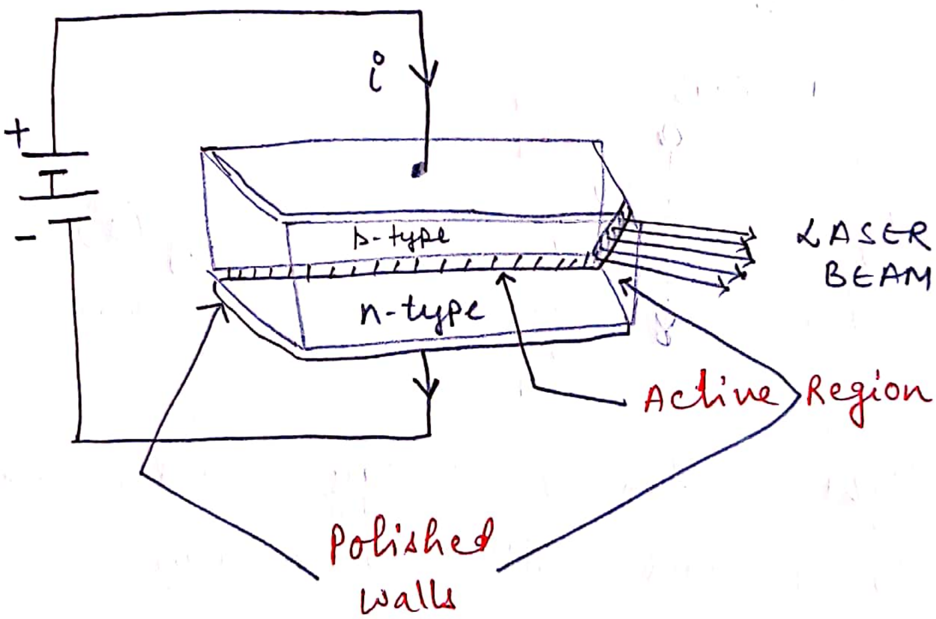
Principal

1) If a light photon of energy greater than Eg happens to interact with the electron in the C.B., than the photon may stimulate an already excited conduction band electron which would drop to the valence band, emitting a fresh photon in coherence with the stimulating photon (fig 1).

2) for this, there should be more no. of electrons in conduction band. This can be achieved by population inversion.

3) Population inversion can be achieved near a p-n junction having high doping densities and forward current. The large number of injected carriers creates a region near the junction where there is a very large number of electrons in the conduction band together with a very large number of holes in the valence band, that is, population inversion.

Construction : The basic structure of gallium arsenide p-n junction, used as an injection laser



(1) The pair of parallel planes perpendicular to the plane of the junction is polished, while the two remaining sides of the diode are roughened.

(2) When a forward bias is applied to the laser diode, a current flows. The injected electron move from the n-side to the p-side and the holes from p-side to the n-side. As the electrons and holes recombine

, photons are emitted. These photons are reabsorbed & radiated away. This is the spontaneous emission which occurs in all direction at low current.

3) As the current is increased, eventually a threshold current ~~in all diode~~ is reached at which the emitted photons stimulate the emission of more photons. These photons are internally reflected several times at the polished walls, stimulating more & more photons, all coherent with them. When the photon beam become sufficiently intense, it emerges out from the junction.

4) The main difficulty with this GaAs laser is the high threshold current density ($\approx 10^5\ A/cm^2$) at room temperature. ∴ This laser can be operated only at low temperatures at which the required current density is lower.