LASER

Laser is one of the most fascinating development in physics of the recent past. It is an acronym for Light Amplification by Stimulated Emission of Radiation (LASER) and is a device for producing a strong, highly monochromatic, directional and coherent beam of light of high power density. Its working depends on the phenomenon of what is called 'stimulated emission' of radiation, the theory of which was worked out as early as 1917 by Einstein. Laser opened up a completely new and exciting field of development in optics. Although, it differs widely from traditional light sources. It is not used for illumination purposes unlike other usual light sources. Lasers closely resemble radio and microwave transmitters and generate a highly coherent and directional light beam of extreme monochromaticity.

When a light travels through a medium, a gradual reduction in its intensity occurs mainly because of the processes of absorption and scattering of light in the medium. The reduction in intensity with distance in a medium is called attenuation of light. A material medium is composed of identical atoms, which are characterised by a specific system of energy levels. These energy levels are common to all atoms in the medium. We can therefore say that a certain number of atoms occupy a certain energy level. The number of atoms per unit volume that occupy a given energy level is called the population of that energy level. We make a simple assumption here that a particular medium has atoms, which are characterised by only two energy levels. Let E_1 be the ground level and E_2 be the excited level. Atoms are distributed differently in these two energy levels. Let the populati-on at the levels E_1 and E_2 be N_1 and N_2 respectively. At thermal equilibrium, the population at the energy levels can be found with the help of Boltzmann law. The relative population N_2/N_1 is given by —

$$\frac{N_2}{N_1} = e^{-(E_2-E_1)/KT} \longrightarrow (1)$$

Eq. (1) shows that $\frac{N_2}{N_1}$ depends on temperature (T) and energy difference (E_2-E_1). At room temperature, all the atoms are in the ground state. The number of atoms in the lower energy level is always larger than that in the higher energy level. So, under normal conditions higher the energy of the energy level, lesser is its population. As long as a medium is in thermal equilibrium the population of higher energy level cannot exceed

The population of the lower energy level.

Absorption and emission of radiation by matter

Absorption of radiation: An atom has a number of possible quantised energy states charaterised by its principal quantum number n(= 1, 2, 3 ----). It remains in the ground state with minimum energy E_1 in absence of external influences. On being subjected to some action, say irradiation by photons of right frequency ν, it transits to a higher energy state, E_2, absorbing energy $h\nu$ of the radiation. This is called absorption or excitation (Fig. 1.) for which the right frequency ν is given by —

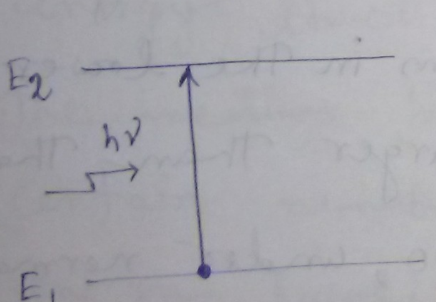

Fig. 1.

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

Absorption is necessarily a stimulated or induced process, the absorbed photon being the stimulating photon.

Spontaneous emission of radiation: Consider now an atom initially in the excited state E_2 (Fig. 2).

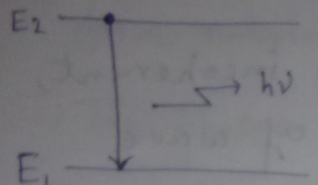

Fig. 2.

An atom stays in the excited state usually for a short period $\sim 10^{-8}$ sec. and returns, of its own, to the initial state E_1, emitting a photon of frequency ν. The process is termed as spontaneous emission or de-excitation and the photon energy is given by $h\nu = E_2 - E_1$.

The salient features of spontaneous emission are-

i) The process of spontaneous emission is essentially probabilistic in nature and cannot be controlled from outside.

ii) The instant of transition, direction of propagation, the initial phase and the plane of polarisation of each photon are all random.

iii) The light resulting through this process is not monochromatic.

iv) As different atoms in medium emit photons in different directions, light spreads in all direction around the medium. The light intensity goes on decreasing rapidly with distance from medium.

v) Light emitted through this process is incoherent, as it results from a superposition of wave trains of random phases.

<u>Stimulated Emission</u>: when a photon of frequency precisely ν or energy $h\nu$ ($= E_2 - E_1$) irradiates an atom, already in the excited state E_2, it cannot exite the atom which is already excited. Instead, it produces the equivalent effect: it de-exites the atom.

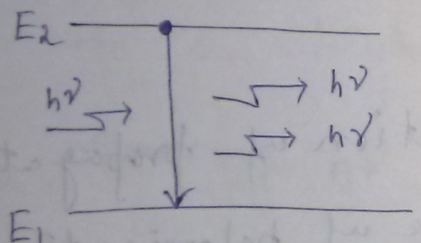

Fig. 3.

So under the influence of the electromagnetic field of a photon of frequency ν incident on it, it makes a transition to the lower energy state E_1, emitting an additional photon of the same frequency ν. (Fig. 3.). So, now there are two photons, one original and the other emitted. This type of transition is called stimulated (or induced) emission of radiation in contrast to spontaneous emission.

Characteristics of stimulated emission

i) The process of stimulated emission is controllable from outside.

ii) The photon induced in this process propagates in the same direction as that of stimulating photon.

iii) The induced photon has features identical to that of the inducing photon. It has the same frequency, phase and plane of polarisation as that of the stimulating photon.

iv) The outstanding feature of this process is the multiplication of photons. For one photon interacting with an excited atom, there are two photons emerging. The two photons travelling in the same direction interact with two more excited atoms and generate two more photons. Therefore, the number of photons builds up in an avalanche like manner.

v) All the light waves generated in the medium are due to one initial wave, and all the waves are in phase. Thus the waves are coherent and interfere constructively.

According to Boltzmann Distribution, under Thermal equilibrium, we can write,

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

Thus, under Thermal equilibrium at room temperature, if a photon of energy $h\nu = E_2 - E_1$ approaches The system it is very likely to be absorbed, rather Than to cause a stimulated emission. For stimulated emission to dominate we must by some means make The population of The upper state greater Than That of The lower state. The system is Then said to possess population inversion. The method by which such a population inversion is achieved is called pumping. To make $N_2 > N_1$, i.e, to get The population inversion The temperature T must be made negative. For This reason a state of population inversion is sometimes misleadingly referred to as a negative temperature. In fact, population inversion can be achieved at ordinary temperature but only under nonequilibrium situation where Boltzmann's law is not applicable.

The situation in which the number of atoms in the higher state exceeds that in lower state is known as population inversion. And the process of achieving population inversion is called pumping.

There are many different methods of pumping. There are four different methods which are usually used.

1. Optical pumping or excitation by photons
2. Excitation with the help of electrons
3. Inelastic collision between atoms
4. Excitation by chemical method

In fact, light (or, more precisely visible radiation) is far more likely to be emitted spontaneously, and so not to have the coherent properties of laser radiation. It was in the microwave region that the first successful amplification by stimulated emission was performed [MASER → Microwave Amplification by Stimulated Emission of Radiation]. For the process to be possible in higher-frequency region, it is necessary to find systems with long-lived excited states (i.e, metastable states) so that stimulated, rather than spontaneous, emission may predominate and this may only be achieved if more than two energy levels are involved.

Two important pumping schemes are widely employed. They are known as Three-level and four-level pumping schemes.

Three-level Pumping Scheme

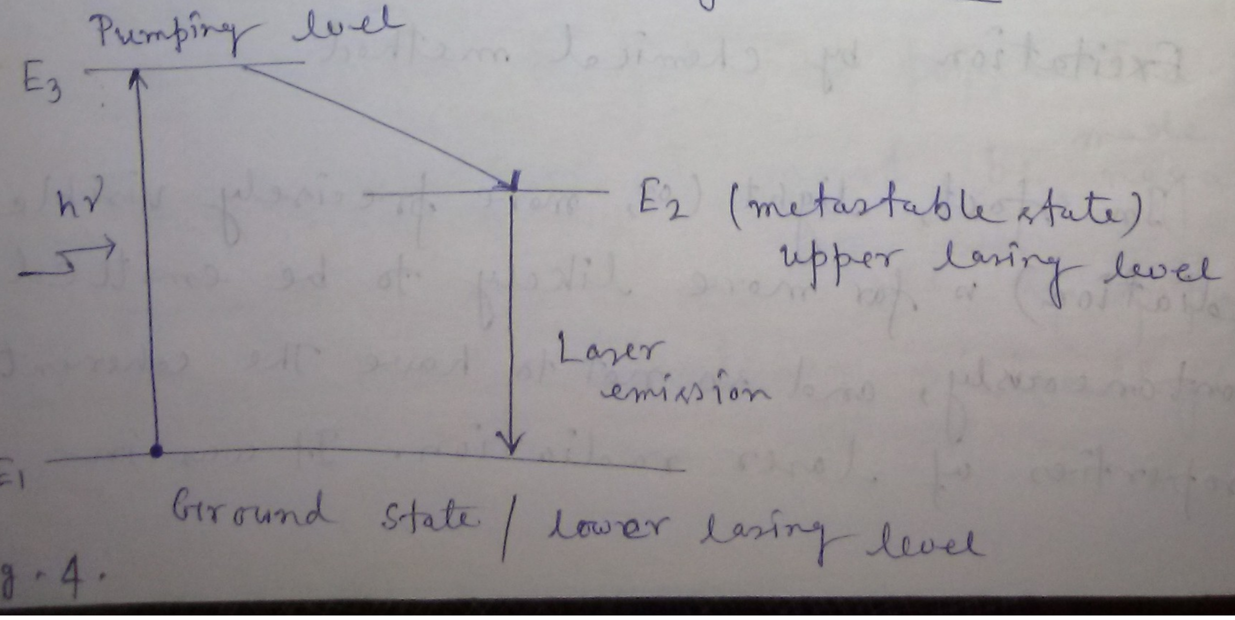

Fig. 4.