LASERS

LASER stands for light amplification by stimulated emission of radiation. The laser is a device which produces light beam with some extraordinary properties. Lasers are invented and developed between 1959 and 1962. In 1917, Einstein first predicted that the atom can emit radiation by the process of stimulated emission in addition to spontaneous emission and the idea of stimulated emission was used to construct laser by Townes and Schawlov in USA.

COMPARISON OF ORDINARY BEAM OF LIGHT AND LASER BEAM

Sl. No.	Ordinary beam	Laser beam
1	It is not monochromatic	It is monochromatic
2	It is incoherent, i.e. the constituent waves are generally not in the same phase	It is coherent, i.e. the constituent waves are exactly in the same phase
3	It does not travel as a concentrated and parallel beam	It travels as a concentrated parallel beam
4	It is produced by spontaneous emission	It is produced by stimulated beam

INTERACTION OF EXTERNAL ENERGY WITH THE ATOMIC ENERGY STATES

There are three kinds of interactions of the external energy with the atomic energy states. First is known as absorption, in which suitable amount of energy is absorbed by the atoms of the ground state to get excited to the higher energy states. Second is known as spontaneous emission, in which the excited atoms emit photon to come back in the lower energy state without any external impetus. Third is known as stimulated emission, in which atom in the excited state need not wait for the spontaneous emission to occur, but with the influence of suitable energy impetus, excited atom is triggered to the lower energy state, with the release of appropriate energy.

STIMULATED ABSORPTION OR ABSORPTION

In any process of absorption or emission, at least two energy states are involved. In order to describe the process of absorption, let us consider an atomic system with energy states – E_1 (lower) and E_2 (higher). At ordinary temperature most of the atoms will be in the lower energy state. When we allow photons to interact with the system, an atom residing in the lower energy state E_1 may absorb the incident photon and jump to the excited state E_2. This process of transition is known as induced or stimulated absorption or simply absorption. Corresponding to each transition made by an atom one photon disappears from the incident beam. Symbolically absorption is represented as

Photon + Atom $\rightarrow$ Atom*

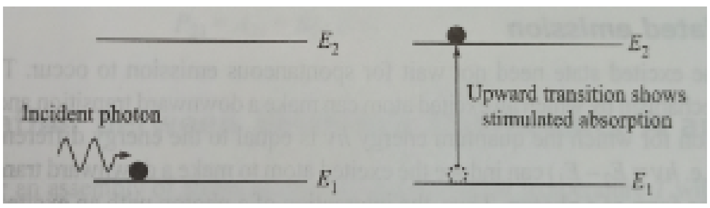


Fig 1: Illustration of absorption process

Usually, the atoms can remain in the excited state for a limited time of the order of known as 10^{-8} sec, which is known as lifetime of excited state.

SPONTANEOUS EMISSION

The excited state of atom with higher energy is highly unstable. When the excited atom in the state E_2 returns to the lower state E_1 after the end of its life time in the excited state without the influence of any external impetus due to the tendency to attain minimum potential energy, the excess energy is released as a photon of energy $h\nu = E_2 - E_1$. This type of process in which photon emission occurs without any interaction with external radiation is called spontaneous emission, which is represented as

Atom* → Atom + Photon

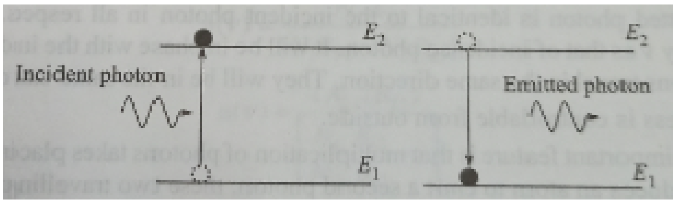


Fig 2: Illustration of spontaneous emission process

Photon emitted spontaneously will not be in phased and hence light from an ordinary light source is incoherent.

STIMULATED EMISSION

An atom in the excited state need not wait for spontaneous emission to occur. There exists an alternative mechanism by which an excited atom can make a downward transition even before the end of its life time in the excited state and emit a photon. If a photon having suitable energy ($h\nu = E_2 - E_1$) is allowed to interact with it then the incident photon can trigger the excited atom to make a downward transition releasing the energy in the form of a photon. This process in which the emission is triggered by the external photon is called stimulated of induced emission and symbolically it is represented as

Photon + Atom* → Atom + 2 Photons

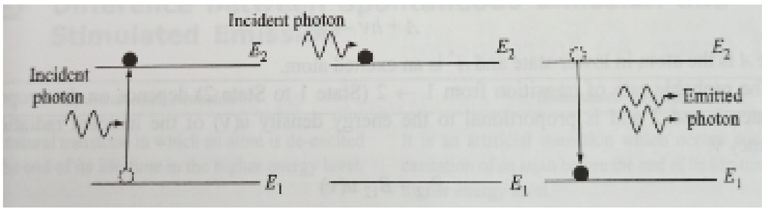


Fig 3: Illustration of stimulated emission process

The two photons will be moving in the same direction having the same frequency and will be in same phase. Hence light output due to stimulated emission will be completely coherent. In other words, stimulated emission process amplifies the intensity of the radiation (as input is 1hv whereas output is 2hv).

DIFFERENCE BETWEEN SPONTANEOUS AND STIMULATED EMISSIONS

SPONTANEOUS EMISSION	STIMULATED EMISSION
It is a natural transition in which an atom is de-excited after the end of its life time in the higher energy state	It is an artificial transition which occurs due to de-excitation of an atom before the end of its life time in the higher energy state
The probability of spontaneous emission depends only on the properties of the two energy states between which the transition occurs	The probability of stimulated emission depends on the properties of the two energy states involved in the transition as well as on the energy density of incident radiation
The emitted radiation is incoherent	The emitted radiation is coherent
The emitted radiation is less intense	The emitted radiation is highly intense
Less directionality, so more angular spread during propagation	High directionality, so less angular spread during propagation
Emitted light is not monochromatic	Emitted light is nearly monochromatic

RADIATIVE AND NON-RADIATIVE TRANSITIONS

Transitions between energy states that occur with the absorption or emission of radiation are called radiative transitions. Transitions that occur without the absorption or emission of radiation are called non-radiative transitions. Non-radiative transitions occur mainly because of exchange of energy between the system and its surroundings. They are very common in laser materials.

METASTABLE SATES

An atom in an excited state remains there for a certain time called the lifetime of that state before making a transition to a lower state. Most of the states have a short lifetime of the order of 10^{-8} s. However, some energy states have very long lifetime, which is of the order of 10^{-6} to 10^{-3} s. Energy states with such long lifetimes are called metastable states and the metastable state allows accumulation of a large number of excited atoms at that level.

The occurrence of metastable state may be explained as follows- In certain cases, regular selection rules do not permit transitions from a particular state to a lower state. In such cases, the system has to remain in that state for longer time until weak perturbations and stimulating radiations induce transitions to lower state. Existences of metastable state are of fundamental importance in lasers.

PRINCIPLE OF LASER

We know that the photon emitted by a stimulated emission process and the photon that triggered the emission will be in the same phase and will travel in the same direction. In a system having a large number of atoms, this process can occur many times, giving rise to a substantial amplification of the incident radiation. Lasers are devices that work on this principle of amplification by stimulated emission. If we have a collection of atoms in the excited state, the build up of an intense beam is illustrated in Fig.4. 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 a total of four photons. These four photons in turn stimulate four excited atoms and generate eight photons, and so on. The number of photons builds up in an avalanche like manner as shown in the figure below.

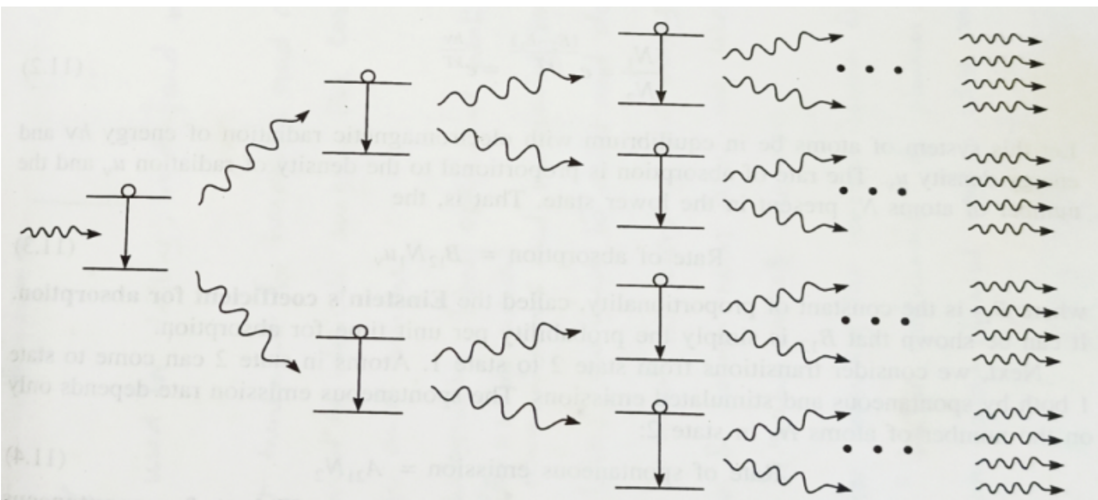
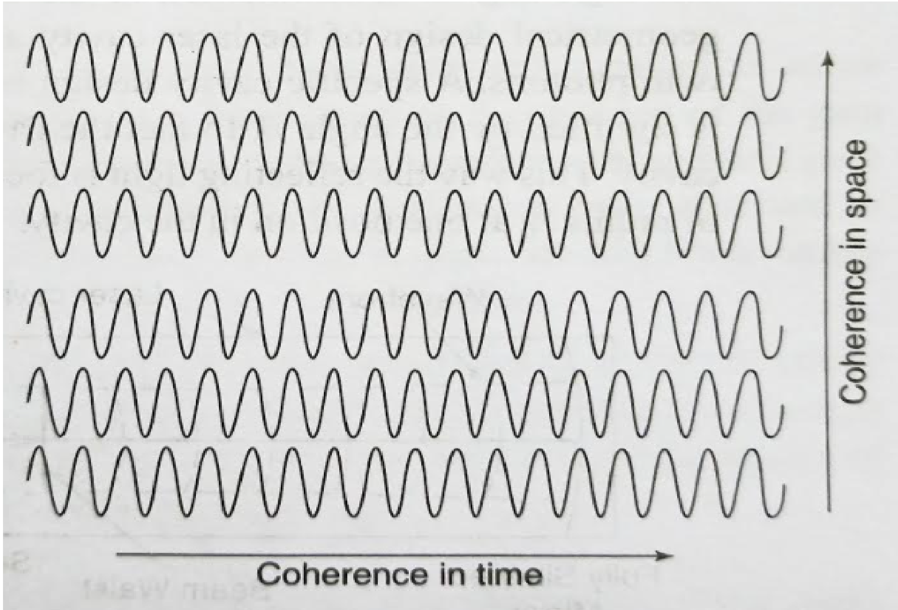


Fig 4: Build up of an intense beam in a laser

CHARACTERISTICS OF LASER LIGHT

- **Coherence:** The most important characteristics which distinguishes the laser from other sources of light is that it is highly coherent. Coherence means that the waves in a radiation field bear the same phase relationship to each other at all times. Coherence is of two types- Temporal coherence and Spatial coherence. Temporal coherence (also called longitudinal coherence) refers to the coherence of two waves at two different locations along the common direction of propagation of the two waves. Spatial coherence (also called transverse coherence) refers to the phase relationship between waves travelling in a plane perpendicular to the direction of propagation, that is, between waves travelling side-by-side.



- **Monochromaticity:** The light from a laser typically comes from one atomic transition with a single precise wavelength. So the laser light has a single spectral colour and is almost the purest monochromatic light available. It means the laser light is not exactly monochromatic, but it has high degree of monochromaticity. The deviation from monochromaticity is due to the Doppler effect of the moving atoms from which the radiation originates. The light from normal monochromatic sources spread a wavelength range of the order of 100A^0 to 1000 A^0. But in case laser light, the spread is of the order of few angstroms (10 A^0) only.
- **Directionality:** The conventional sources emit light in all directions. The light from a typical laser emerges in an extremely thin beam with very little divergence, i.e. the beam is highly collimated. The mirrors or reflecting surfaces used at the ends of the active medium acts as collimating apertures. The laser radiation undergoes multiple reflections within the region between the reflectors. It travels a long distance before coming out of the system, therefore curvature of wavefront is negligible and radiation is a plane wave.
- **Intensity:** The intensity of light from a conventional source decreases rapidly with distance, as it spreads in the form of spherical waves. In contrast, a laser emits light in the form of a narrow beam which propagates in the form of plane waves. As the intensity is concentrated in a very narrow region, its intensity would be very high.