# LASERS

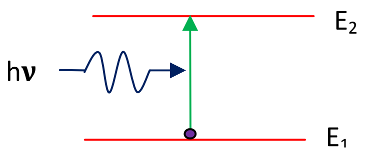
## Spontaneous and Stimulated Emission.

An atom may be excited to a higher energy state when a photon of appropriate energy is incident on the atom. This is called *induced absorption*.

Atom + Photon ⟶ Atom*

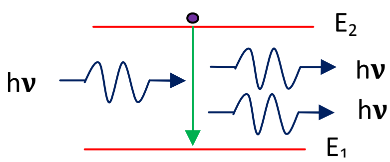
Atom* is an excited atom with a life time of about 10 ns. An atom in the excited state may spontaneously decay into a lower energy level within 10 ns releasing energy in the form of a photon, which is emitted in a random direction. This process is called ***spontaneous emission***.

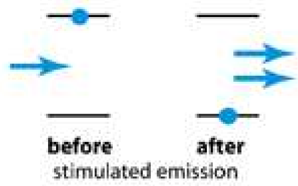
Atom* ⟶ Atom + Photon




An atom in the excited state may be caused to de-excite by an incoming photon of exactly the same energy. This process of causing an excited atom to return to the lower energy state with the help of a photon of exactly the same energy is called ***stimulated emission***. The emission then goes into the same direction as the incoming photon. In effect, the incoming radiation is amplified. This is the physical basis of light amplification in amplifiers and lasers.

Atom + Photon ⟶ Atom + 2 Photons




Stimulated emission can only occur for incoming photons that have a photon energy close to the energy of the laser transition. Therefore, the laser gain occurs only for optical frequencies (or wavelengths) within a limited gain bandwidth. A laser normally operates at the optical wavelength where the gain medium provides the highest gain.

## Population Inversion and Optical Pumping.

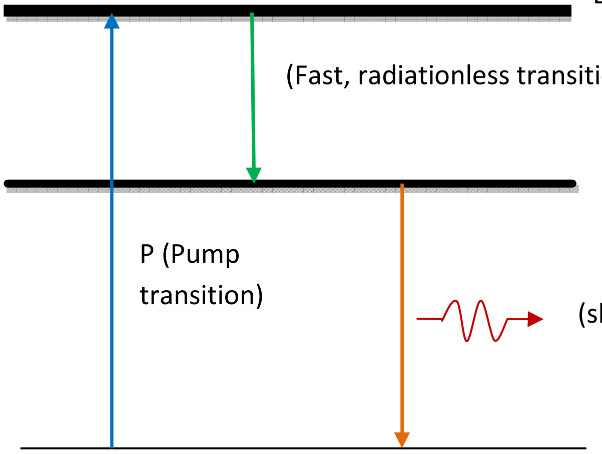
The average life time of an excited atom is about 10 ns. This means that before the excited atom can emit a photon by stimulated emission, a spontaneous emission will occur. The photons emitted by spontaneous emission are not coherent. The ratio of number of excited atoms $N_2$ to that of number of atoms in ground state $N_1$ is given by the Boltzmann equation :

$$\frac{N_2}{N_1} = e^{-\left(\frac{E_2 - E_1}{kT}\right)}$$

Where k = Boltzmann constant, T = absolute temperature.

This equation shows that $N_2 < N_1$ . Thus, the population of higher energy state is very much less than that of the ground state. Hence, there is very little stimulated emission. By some means if the number of atoms in the excited state becomes more than number of atoms in the ground state then more stimulated emissions occur. The process by which this is achieved is called ***Population Inversion***.

When photons of appropriate energy is incident on a mixture of ground state and excited state atoms then the unexcited atoms gets excited and excited atoms undergo stimulated emission. If the population of unexcited atoms is more, induced absorptions will be more than the stimulated emissions. To overcome this difficulty, atoms of three energy levels are considered. The atoms at the ground state are raised to higher energy state by external agency. This state is short lived and hence the atoms decay to an intermediate state called the metastable state by radiationless transition. This process of transferring the atoms from ground state to the metastable state is called ***Optical Pumping***. The life time in the metastable state is about 3 ms. A passing photon incident on these atoms in the metastable state causes stimulated emission producing coherent photons or Laser transitions.

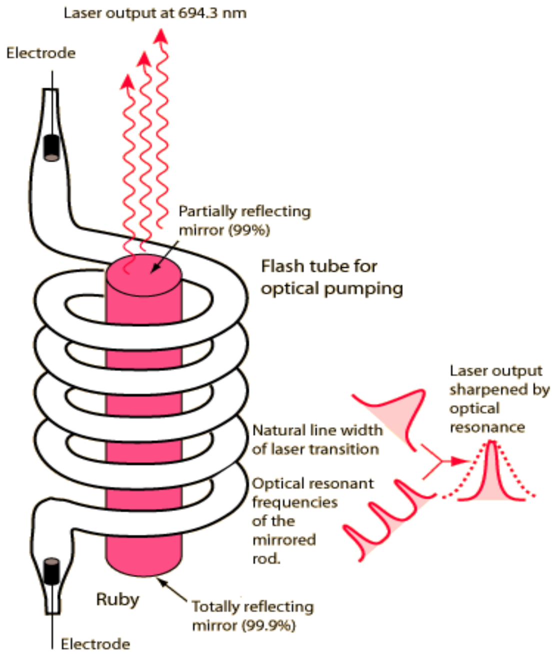


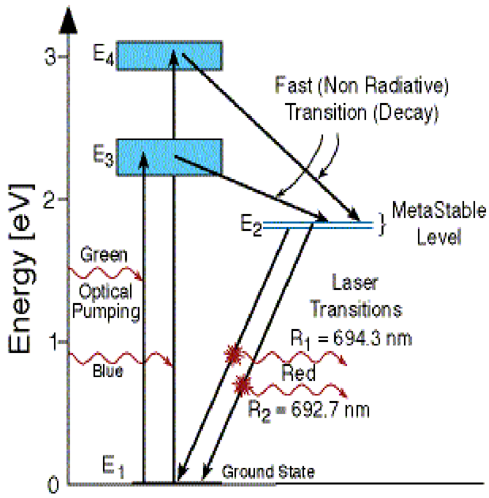

## Properties of Lasers.

1. All photons have same energy and intensity is very high
2. Perfectly parallel beam and hence no collimation as in other visible radiation is possible
3. Perfectly monochromatic source
4. Spatially coherent. Hence, interference between two laser beams from different sources is possible
5. Has a very high directional property and does not diverge over short distances.

## **Ruby Laser.**

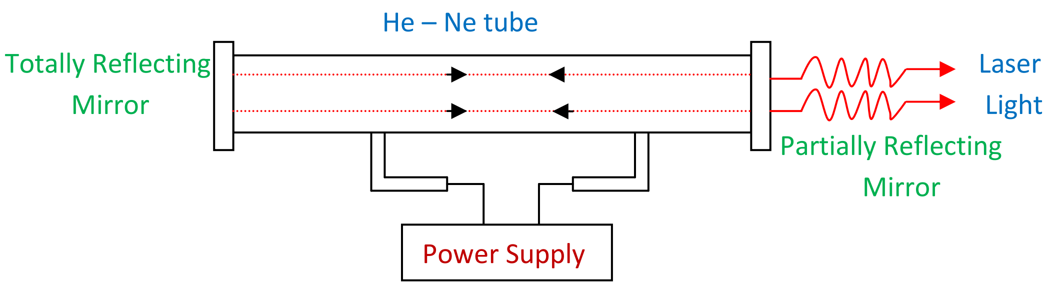
Ruby Laser is a single crystal of Ruby in the shape of a cylindrical rod. It is a crystal of $Al_2O_3$ in which some of the aluminium ions are replaced by Chromium ions. It gives the characteristic red colour. The two plane faces of the rod and are highly polished. One end is totally silvered and the other end is partially silvered. A Xenon flash lamp encloses the ruby crystal in the form a spiral. It emits light of wavelength 550nm which is used to excite the chromium ions to a higher energy level from which it falls to the metastable state. Chromium has a metastable level of life time 3 ms. The energy given out by the chromium ions in falling to the metastable state is absorbed by the other ions in the crystal. The photon released during the stimulated decay of chromium ions are reflected back and forth between the two mirrors. The length of the rod is made exactly equal to an integral multiple of half wavelength of the radiation trapped in the rod in order to get an optical standing wave. The beam of light incident normally on the two end faces increases in intensity and travels parallel to the axis of the ruby cylinder. Out of this, about 1% comes out through the partially silvered surface B as the laser beam. The ruby laser is a pulsed laser usually operated by high power pulses of short duration.

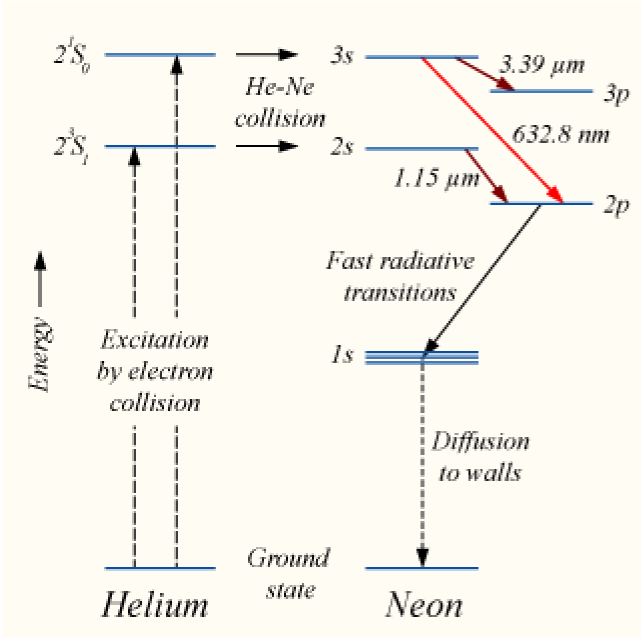



## He-Ne Laser.

A mixture of Helium and Neon at a pressure of 0.001 atmosphere is placed inside a tube with one end perfectly reflecting and the other end partially reflecting. The distance between the two mirrors to be exactly equal to the integral multiple of half wavelength of the lasers. When an electric discharge is produced along the tube, the high energy electrons in the discharge excite the He atoms in inelastic collisions. The energy is transferred quickly to the Ne atoms by collisions. Subsequently, the Ne atoms pass from the 5s to the 3p level emitting light of wavelength 632.8 nm. This induces more transitions of excited Ne atoms from the 5s to the 3p level resulting in coherent amplification of light. Part of this light is transmitted out of the tube as laser beam. The laser beam is continuous.






**Uses**.

1. Interference experiments since it is highly coherent
2. Alignment of objects
3. Drill holes in thin metals, cut metal sheets where metal has high melting point
4. Measure distances very accurately
5. Optic fiber communication
6. Holography
7. Infrared spectroscopy experiments and to get Raman Spectrum