Population Inversion:

Under ordinary conditions of thermal equilibrium the number of atoms in higher energy level 2 (N_2) is considerably smaller than the number in lower energy level 1(N_1), so that there is very little stimulated emission compared to absorption. Hence under ordinary condition an incident photon is more likely to be absorbed rather than emission. Hence laser action will not take place. If, however, the large number of atoms are made available in the higher energy level ($N_2 > N_1$) then stimulated emission will take place easily. This process of achieving the large number of atoms in the higher energy level than the lower energy level is known as population inversion.

The term population inversion describes an assembly of atoms in which the majority atoms are in energy levels above the ground state (lower energy level). The process of achieving population inversion is known as “pumping” of atoms. Most commonly used methods are as follows:

1. **Optical pumping** (used in Ruby Laser): In this most suitable pumping technique, the atoms in the ground state are excited to higher energy state by means of optical photons. The energy is supplied continuously in the form of short of flashes of light. The excited atoms from the upper most level (in which the atom can reside only for about 10^{-8} sec) go to the metastable state (a state in which atom can reside for about 10-3 sec, much longer than short lived uppermost level) to create a state of population inversion. In this case the frequency of pumping photons must be higher than emitted photons so that the atoms can be pumped to the higher energy level from the lower energy level. Optical pumping is suitable for those media which are transparent to light. Maiman employed optical pumping method for the production of laser beam in Ruby laser.
2. **Electrical pumping.**
3. **Inelastic atom-atom Collisions:**In this method of pumping, the accelerated electrons produced by electric discharge of the gaseous medium (a mixture of two gases) collide with the atoms of one kind of gas (which are responsible for pumping). The excitation energy of these atoms are readily

transferred to the atoms of other kind of gas (which are responsible for laser transition) in their inelastic collision with them. In this way population inversion is achieved by inelastic atom-atom collisions in He-Ne gas laser. In He-Ne laser, helium is the pumping medium and neon is the leasing medium.

4. **Chemical pumping.**

Metastable States:

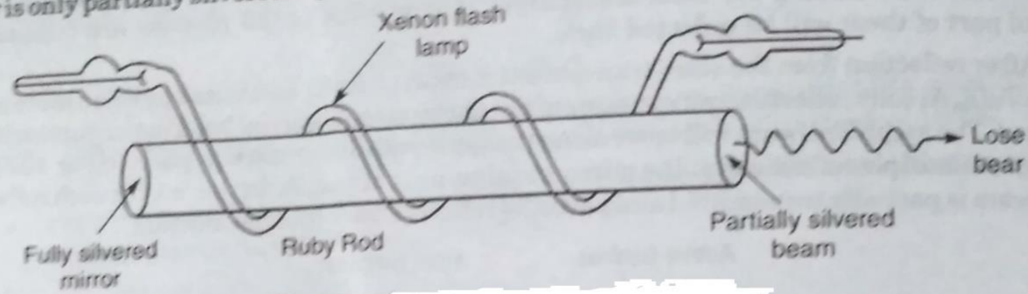
When an atom gets sufficient energy, by any means, its electrons jumps from inner to outer orbits. This state of atom is called excited state. The atom remains in an excited state for a period of 10^{-8} sec. After that short period it comes back to the ground state by releasing excess energy spontaneously. For stimulated emission, the atom should remain for a longer time. As the atoms are continuously going to excited state pumping process they should remain in the higher energy state until the population in the higher state (N_2) becomes greater than that in the lower state (N_1). A long lived energy state (~ 10^{-3} sec) from where the excited atom do not return to the lower level instantaneously is called metastable state. In fact metastable states are those energy levels of the atoms from which the transitions to the ground states are not allowed by selection rules. However, the atom can fall from the metastable state to the ground state either by giving up the appropriate amount of energy to another atom during a collision process or it may absorb radiation and go to a higher energy state which is allowed by selection rule and from there it may return to normal state by emission of radiation. Thus, if certain atoms are excited to the metastable state, the probability of spontaneous emission will be quite nwgligible.

<u>Need of Three Level:</u>

Suppose there are only two energy levels, a metastable state hν above the ground state. The more photons of frequency ν we pump into the assembly of atoms, the more upward transitions there will be from the ground state to the metastable state. However, at the same time the pumping will induce downward transition from the metastable state to the ground state. When half the atoms are in each state, the rate of stimulated emissions will equal the rate of induced absorption, so the assembly cannot even have more than half its atoms in the metastable state. Hence a condition of population inversion will not achieve because (N1 = N2) and therefore in this situation stimulated emission will not take place and laser amplification will not occur.

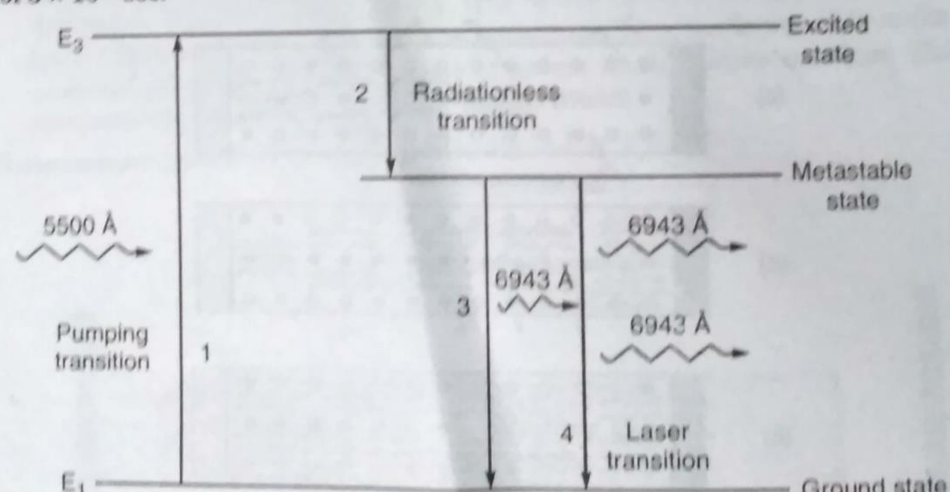
RUBY LASER

Ruby Laser is based on three energy levels and this laser consists of a pink ruby cylindrical rod whose ends are optically flat and parallel as shown in Fig. One end is fully silvered and the other is only partially silvered. Upon the rod is wound a coiled flash lamp filled with xenon gas.



The ruby rod is basically a Al_2O_3 (aluminium oxide) crystal doped with 0.05% (by weight) of chromium oxide (Cr_2O_3). The Al^{3+} ions are replaced by Cr^{3+}. These "impurity" Cr^{3+} ions are responsible for the pink colour (or red colour) of ruby laser.

Working. The energy levels of Cr^{3+} ions on the crystal lattice are shown in Fig. It consists of three-level system. Upper energy level is short-lived state E_3 above the ground-state energy level E_1. There is an intermediate excited state level E_2 which is metastable having a life-time of 3×10^{-3} sec.



Normally, most of the chromium ions (Cr^{3+}) are in the ground state E_1. When a flash of light falls upon the ruby rod, the 5500 Å radiation photons are absorbed by the Cr^{3+} ions which are pumped to the excited state E_3. The transition from E_1 to E_3 is the optical pumping transition. Now the Cr^{3+} ions on the excited ions give a part of their energy to the crystal lattice and decay to the *metastable state* E_2. Hence the transition from E_3 to E_2 is *radiation less transition*. Metastable state E_2 is long-lived state (life time 10^{-3} sec), hence the number of Cr^{3+} ions goes on increasing while, due to pumping, the number in the ground state E_1 goes on decreasing. Thus population inversion is established between the metastable state E_2 and the ground state E_1.

A spontaneous photon emitted by a Cr^{3+} ion at E_2 level initiates the stimulated emission by the other Cr^{3+} ions in the metastable state. The wavelength of the photon (beam) is 6943 Å. This photon travels through the ruby rod and if it is moving along the axial direction and repeatedly reflected. This results in amplified strong laser beam of wavelength 6943 Å. This stimulated transition 4 is the laser transition.

The laser beam is sufficiently intense, part of it emerges through the partially silvered end of the crystal.

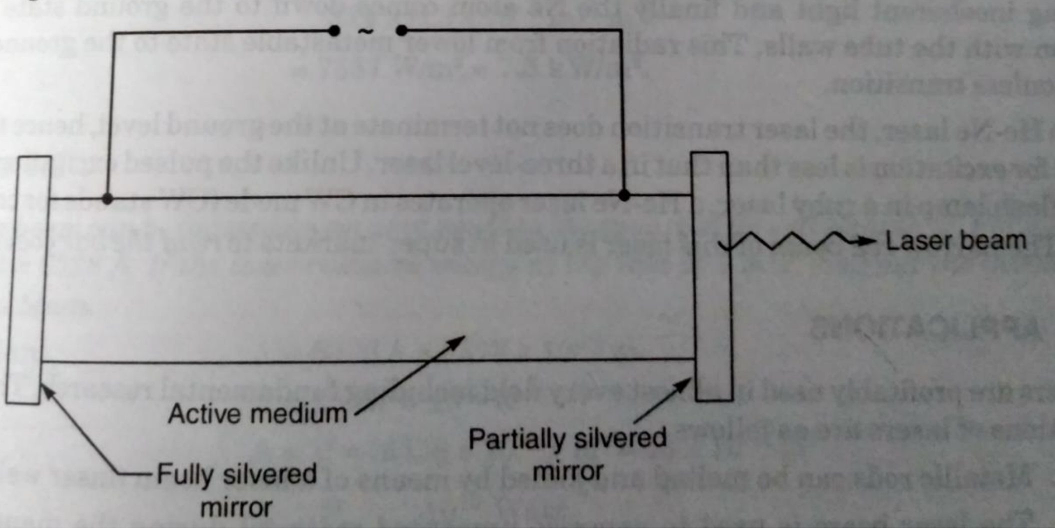
Drawbacks. There are some drawbacks in the three-level ruby laser which are as follows :

1. The laser requires high pumping power because the laser transition terminates at the ground state and more than one-half of ground state atoms must be pumped to the higher state to achieve population inversion.
2. The efficiency of ruby laser is very low because only the green component of the pumping light is utilized while the rest of the components of incident light are left unused.
3. The laser output is not continuous but occurs in the form of pulses of microsecond duration.
4. The defects due to crystalline imperfection are also present in this laser.

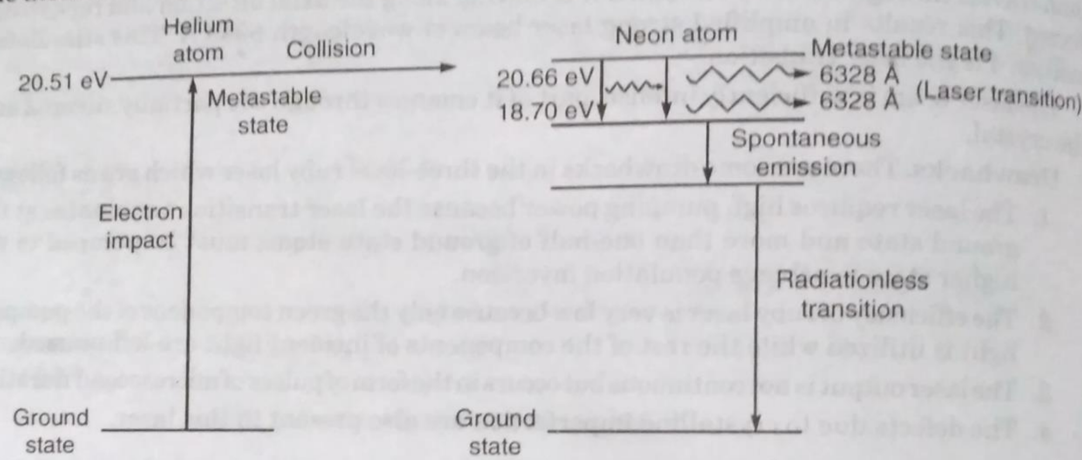
HELIUM NEON LASER

Helium Neon Laser is a four-level laser and was built by Ali Javan, W. Bennett and D. Herriot in 1961.

Construction. The schematic of a typical He-Ne laser is shown in Fig. It consists of a long discharge tube of length about 50 cm and diameter 1 cm. The tube contains a mixture of about 10 parts of helium and 1 part of neon at a low pressure (~ 1 torr). At both ends of the tube are fitted optically plane and parallel mirrors, one of them being only partially silvered. The spacing of the mirrors is equal to an integral number of half-wavelengths of the laser light. In this population inversion is achieved by *electric discharge*. An electric discharge is produced in the gas by means by electrodes outside the tube connected to a source of high-frequency alternating current.



Working. The energy level diagram of He-Ne laser is shown in Fig. ... When the power is switched on, the electrons from the discharge collide with and "pump" the He and Ne atoms to *metastable states* 20.61 eV and 20.66 eV respectively above their ground states. Some of the excited He atoms transfer their energy to ground-state Ne atoms in collisions, with the 0.05 eV of additional energy being provided by the kinetic energy of the atoms. Thus, the purpose of the He atom is to help in achieving a population inversion in the Ne atoms.



When an excited Ne atom passes from the metastable state at 20.66 eV to an excited state of 18.70 eV it emits a photon of wavelength 6328 Å. This photon travels through the gas-mixture and if it is moving parallel to the axis of the tube, is reflected back and forth by the mirror-ends until it stimulates an excited Ne atom and causes it to emit a fresh 6328 Å photon in phase with the stimulating photon. This stimulated transition from 20.66 eV level to 18.70 eV level is the laser transition.

This process is continued and when a beam of coherent radiation becomes sufficiently intense, a portion of it escapes through the partially silvered end.

The Ne atom passes from the 18.70 eV level, spontaneously to a lower metastable state emitting incoherent light and finally the Ne atom comes down to the ground state through collision with the tube walls. This radiation from lower metastable state to the ground state is radiationless transition.

In He-Ne laser, the laser transition does not terminate at the ground level, hence the power needed for excitation is less than that in a three-level laser. Unlike the pulsed excitation from the Xenon flash lamp in a ruby laser, a He-Ne laser operates in CW mode (CW stands for continuous wave). The narrow red beam of this laser is used in super-markets to *read the bar codes*.

APPLICATIONS

The lasers are profitably used in almost every field including fundamental research. The common applications of lasers are as follows :

1. Metallic rods can be melted and joined by means of a laser beam (laser welding).
2. The laser beam is used to vaporise unwanted material during the manufacture of electronic circuits on semiconductor chips.
3. CO_2 gas lasers of about 100 W output are helpful in surgery because they seal small blood vessels while cutting through tissue by vaporising water in the path of their IR beams.
4. Lasers are used to detect and destroy enemy missiles during warfare.
5. Low power semiconductor lasers are used in CD (compact disc) players, laser printers, laser copiers, facsimile machine etc.
6. Semi-conductor lasers are ideal for fiber-optic transmission lines in which the electric signals that would normally be sent along copper wires are first converted into a series of pulses according to a standard code. Lasers then turn the pulses into flashes of *IR* light that travel along thin glass fibers and at the other end are changed back into electric signals.
7. High power lasers are used to bring about thermonuclear reactions which would become the ultimate inexhaustable power source for human civilization.
8. Lasers are also being employed for separating the various isotopes of an element.
9. Lasers are used in the production of three-dimensional images of an object in *holography*.
10. Laser beams have also been used in the "inertial confinement" of plasma.
11. The narrow red laser beam is used in supermarkets to read the bar codes.