due to stimulated emission and so are always coherent.

[Radiofrequency region : $3 \times 10^6 - 3 \times 10^{10}$ Hz
Microwave " : $3 \times 10^{10} - 3 \times 10^{12}$ Hz
Infrared " : $3 \times 10^{12} - 3 \times 10^{14}$ Hz
Visible and Ultraviolet region : $3 \times 10^{14} - 3 \times 10^{16}$ Hz
X-ray region : $3 \times 10^{16} - 3 \times 10^{18}$ Hz
γ-ray region : $3 \times 10^{18} - 3 \times 10^{20}$ Hz]

Components of Laser

The essential components of a laser are : (i) an active medium, (ii) a pumping agent and (iii) an optical resonator.

Active medium

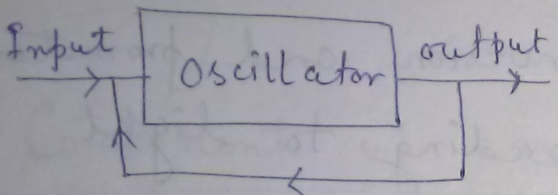
Atoms are in general characterised by a large number of energy levels. However, all types of atoms are not suitable for laser operation. Even in a medium consisting of different species of atoms, only a small fraction of atom of a particular type have energy level system suitable for achieving population inversion. Such atoms can produce more stimulated emission than spontaneous emission and cause amplification of light. Those atoms, which cause laser action, are called active centres. The rest of the medium acts as host and supports active centres. The medium hosting the active centres is called the active medium. It is also called the laser medium. An active medium is a medium which when excited reaches the state of population inversion and promotes stimulated emission leading to light amplification.

Pump

For achieving and maintaining the condition of population inversion, we have to raise continuously the atoms in the lower energy level to the upper energy level. It requires energy to be supplied to the system. Pumping is the process of supplying energy to the laser medium with a view to transfer it into the state of population inversion. Because N_1

is originally very much larger than N_2, a large amount of input energy is required to momentarily increase N_2 to a value comparable to N_1. Pump is the agency which supplies the energy.

Optical Resonant Cavity / Optical resonator



Positive Feedback

Fig. 6.

Laser is a light source and it is analogous to an electronic oscillator. An electronic oscillator [Fig. 6] is essentially an amplifier supplied with a positive feedback. A part of the output of the amplifier is taken and fed back at its input. When the amplifier is switched on, electrical noise signal of appropriate frequency present at the input will be amplified; the output is fed back to the input and amplified again and so on. A stable output is quickly reached when the oscillator acts as a source of a particular frequency.

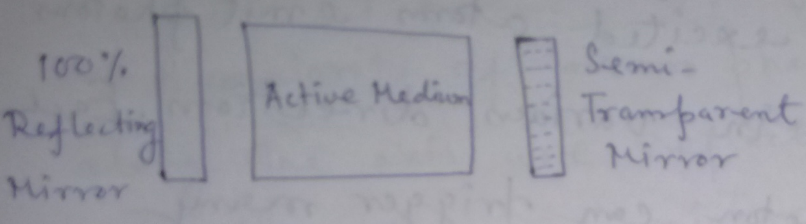


Fig. 7.

In laser the active medium is the amplifying medium. It is converted into an oscillator through the feedback mechanism established by an optical resonator. A pair of optically plane parallel mirrors [Fig. 7.] constitutes an optical resonant cavity. It is known as a Fabry-Perot resonator. One of these mirrors is fully reflecting and reflects all the light that is incident on it. The other mirror is made partially reflecting such that more than 90% of incident light is reflected from it and a small fraction is transmitted through it as the laser beam.

In laser, the role of noise is played by chance photon emitted spontaneously. The active centres in the medium are in the ground state initially. Through suitable pumping mechanism, the medium is taken into the state of population inversion. Some of the excited atom emit photons spontaneously in various direction. Each spontaneous photon can trigger many stimulated transition along the direction of propagation. As the initial spontaneous photon are moving in different direction, the photon stimulated by them also travel in different direction. Many of such photon leave the medium without reinforcing their strength. In the absence of the end mirrors, the net effect would have been the production of incoherent light. Now, because of the end mirrors, a specific direction is imposed on photons. Photon travelling along the axis are amplified through stimulated emission while the photons emitted in any other direction will pass through the sides of the medium and are lost forever. Thus, a specific direction is selected for further amplification of light.

A majority of ~~atoms~~ photons travelling along the axis are reflected back on reaching the end mirror. They travel towards the opposite mirror and on their way stimulate more and more atoms and build up the photon strength. The photons that strike the opposite mirror are reflected once more into the medium. The photons travel once more through the medium generating more photons and more amplification. As the photons are reflected back and forth between the mirrors, stimulated emissions sharply increase and the amplification of light is augmented. The mirrors thus provide positive feedback of light into the medium so that stimulated emission acts are sustained and the medium operates as an oscillator.

At each reflection at the front-end mirror, light is partially transmitted through it. The transmitted component constitutes a loss of energy from the resonator. When the losses at the mirrors and within the medium balance the gain, the laser oscillations build up. A steady and strong laser beam will emerge from the front-end mirror. So, in the absence of resonator cavity, there would be no amplification of light.

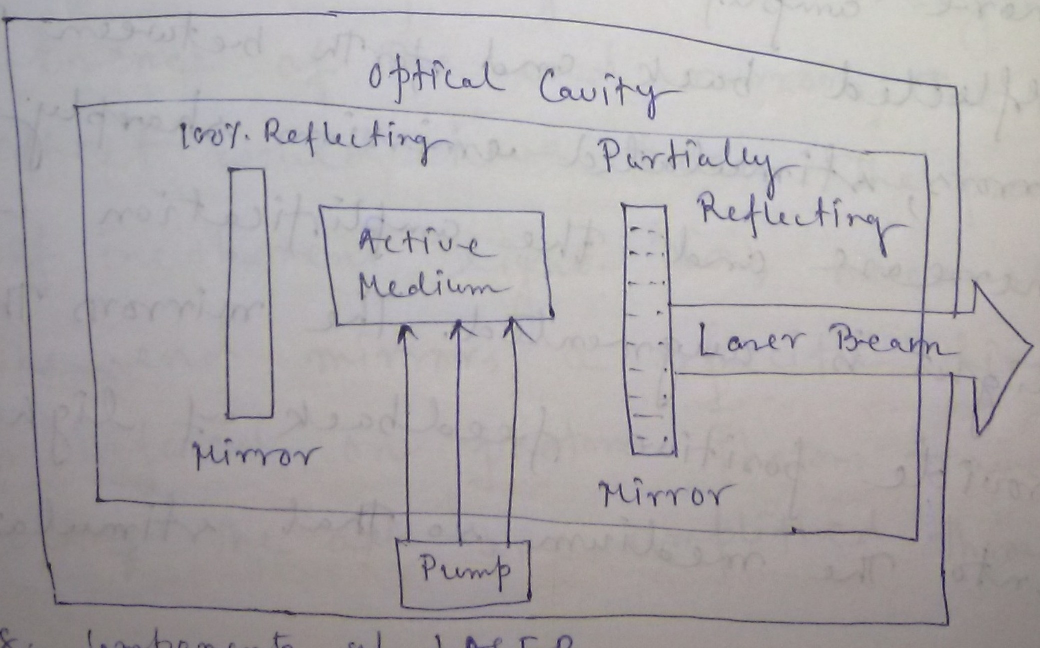
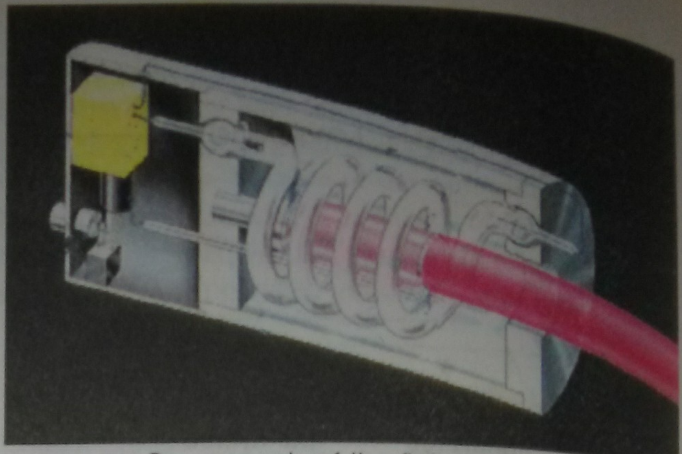


Fig. 8. Components of LASER

22.14.1 RUBY LASER

Ruby laser belongs to the class of solid state lasers. The term solid state has different meanings in the field of electronics and lasers. A solid state laser is one in which the active centers are fixed in a crystal or glassy material. Solid state lasers are electrically non-conducting. They are also called **doped insulator lasers**.



Components of the first ruby laser.

Historically, the ruby laser was the first laser. It was invented in 1960 by Theodore Maiman, U.S.A. The ruby laser rod is in fact a synthetic ruby crystal, Al_2O_3 crystal, doped with chromium ions at a concentration of about 0.05% by weight. Cr^{3+} ions are the actual active centers and have a set of three energy levels suitable for realizing lasing action whereas aluminum and oxygen atoms are inert.

Construction: The schematic of a ruby laser is shown in Fig.22.24. Ruby rod is taken in the form of a cylindrical rod of about 4 cm in length and 0.5 cm in diameter. Its ends are grounded and polished such that the end faces are exactly parallel and are also perpendicular the axis of the rod. One face is silvered to achieve 100% reflection while the other is silvered to give 10% transmission and 90% reflection. The silvered faces constitute the Fabry-Perot resonator. The laser rod is surrounded by a helical photographic flash lamp filled with xenon. Whenever activated by the power supply the lamp produces flashes of white light.

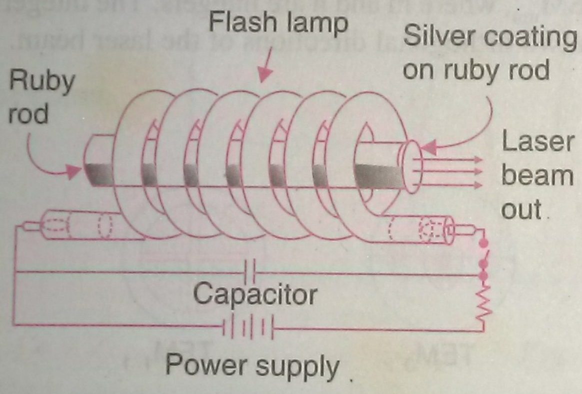


Fig. 22.24

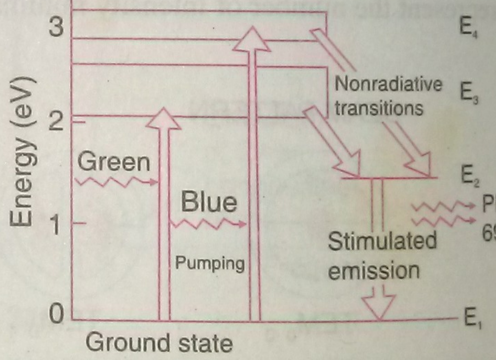


Fig. 22.25

Working: Ruby laser uses a three – level pumping scheme. The energy levels of Cr^{3+} ions in the crystal lattice are shown in Fig. 22.25. There are two wide energy bands E_3 and E_3' and a pair of closely spaced levels at E_2. When the flash lamp is activated, the xenon discharge generates an intense burst of white light lasting for a few milliseconds. The Cr^{3+} ions are excited to the energy bands E_3 and E_3' by the green and blue components of white light. the energy levels in these bands have a very small lifetime ($\approx 10^{-9}$ s). Hence the excited Cr^{3+} ions rapidly lose some of the energy to the crystal lattice and undergo non–radiative transitions. They quickly drop to the levels E_2. The pair of levels at E_2 are metastable states having a lifetime of approximately 1000 times more than the lifetime of E_3 level. Therefore, Cr^{3+} ions accumulate at E_2 level. When more than half of the Cr^{3+} ion population accumulates at E_2 level, the state of population inversion is established between E_2 and E_1 levels. A chance photon emitted spontaneously by a Cr^{3+} ion initiates a chain of stimulated emissions by other Cr^{3+} ions in the metastable state. Red photons of wavelength 6943 Å travelling along the axis of the ruby rod are repeatedly reflected at the end mirrors and light amplification takes place. A strong intense beam of red light emerges out of the front-end mirror.

Note that the green and blue components of light play the role of pumping agents and are responsible for causing population inversion. The spontaneous photons of $\lambda = 6943$ Å, corresponding to red colour, act as the input of the oscillator which actually gets amplified. The xenon flash lasts for a few milliseconds. However, the laser does not operate throughout this period. Its output occurs in the form of irregular pulses of microsecond duration. It is because the stimulated transitions occur faster than the rate at which population inversion is maintained in the crystal. Once stimulated transitions commence, the metastable state E_2 gets depopulated very rapidly and at the end of each small pulse, the population at E_2 has fallen blow the threshold value required for sustained emission of light. As a result the lasing ceases and laser becomes inactive. The next pulse appears after the population inversion is once again restored. The process repeats.

22.14.2 ND: YAG LASER

Nd: YAG laser is one of the most popular types of solid state laser. It is a four-level laser. Yttrium aluminium garnet, $Y_3Al_5O_{12}$, commonly called YAG is an optically isotropic crystal. Some of the Y^{3+} ions in the crystal are replaced by neodymium ions, Nd^{3+}. Doping concentrations are typically of the order of 0.725% by weight. The crystal atoms do not participate in the lasing action but serve as a host lattice in which the active centres, namely Nd^{3+} ions reside.

YAG Laser.

Construction: Fig. 22.26 illustrates a typical design of Nd: YAG laser. The system consists of an elliptically cylindrical reflector housing the laser rod along one of its focus line and a flash lamp along the other focus line. The light leaving one focus of the ellipse will pass through the other focus after reflection from the silvered surface of the reflector. Thus the entire flash lamp radiation gets focused on the laser rod. The YAG crystal rods are typically of 10 cm in

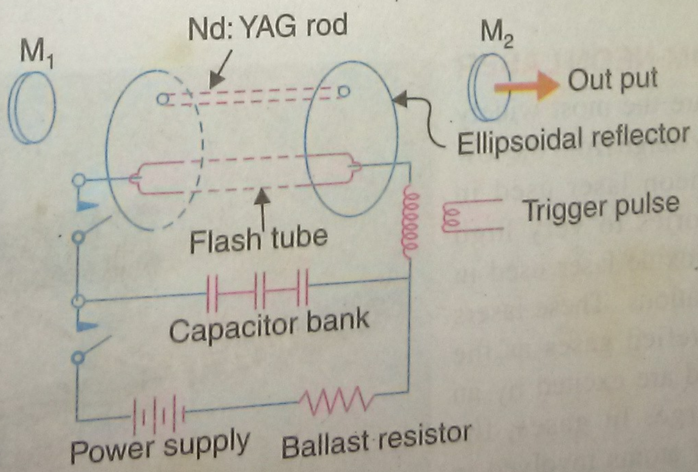
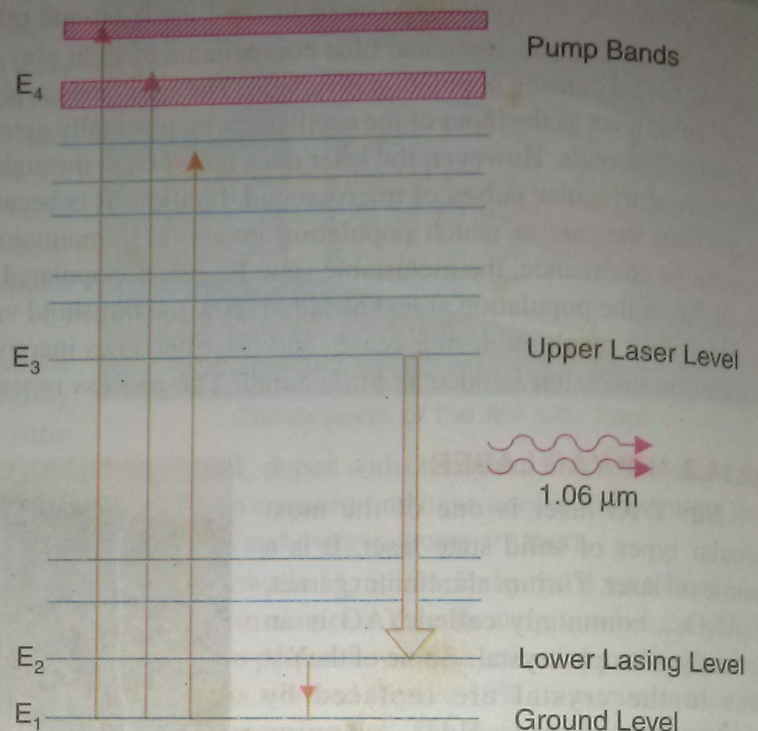


Fig. 22.26

length and 12 mm in diameter. The two ends of the laser rod are polished and silvered and constitute the optical resonator.

Working: A simplified energy level diagram for the neodymium ion in YAG crystal is shown in Fig. 22.27. The energy level structure of the free neodymium atom is preserved to a certain extend because of its relatively low concentration. However, the energy levels are split and the structure is complex. It is essentially a four-level system with the terminal laser level E_2 sufficiently far removed from the ground level. The pumping of the Nd^{3+} ions to upper states is done by a krypton arc lamp. The optical pumping with light of wavelength range to 5000 to 8000Å excites the ground state Nd^{3+} ions to the multiple energy levels at E_4. The metastable level E_3 is the upper laser level, while the E_2 forms the lower laser level. The upper laser level E_3 will be rapidly populated, as the excited Nd^{3+} ions quickly make downward transitions from the upper energy bands. The lower laser level E_2 is far above the ground level and hence it can not be populated by Nd^{3+} ions through thermal transitions from the ground level. Therefore, the population inversion is readily achieved between the E_3 level and E_2 level. The laser emission occurs in infrared (IR) region at a wavelength of about 10,600Å (1.06 μm). As the laser is a four-level laser, the population inversion can be maintained in the face of continuous laser emission. Thus Nd: YAG laser can be operated in CW mode. An efficiency of better than 1% is achieved. Nd: YAG lasers find many industrial applications such as resistor trimming, machining operations like welding, hole drilling etc. They are also used in surgery.

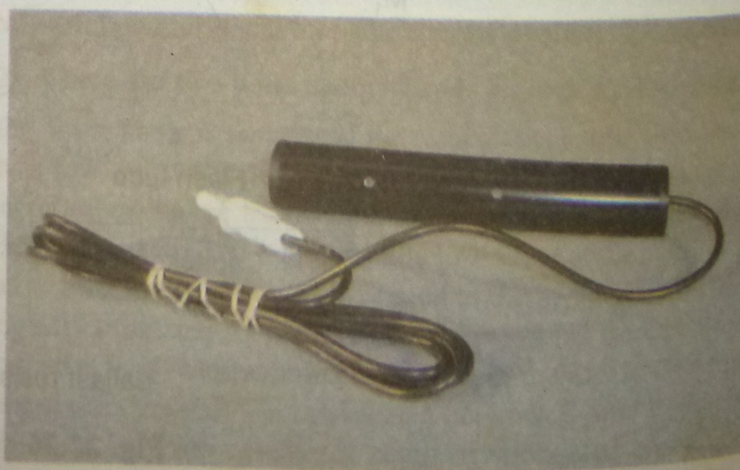


Energy levels and transitions in a Nd : YAG later.

Fig. 22.27

22.14.3 HELIUM-NEON LASER

Gas lasers are the most widely used lasers. They range from the low power helium-neon laser used in college laboratories to very high power carbon dioxide laser used in industrial applications. These lasers operate with rarefied gases as the active media and are excited by an electric discharge. In gases, the energy levels of atoms involved in the lasing process are narrow and as such require sources with sharp



Helium-Neon Laser.

wavelength to excite atoms. Finding an appropriate optical source for pumping poses a problem. Therefore optical pumping is not used in gas lasers. The most common method of exciting gas laser medium is by passing an electric discharge through the gas. Electrons present in the discharge transfer energy to atoms in the laser gas by collisions.

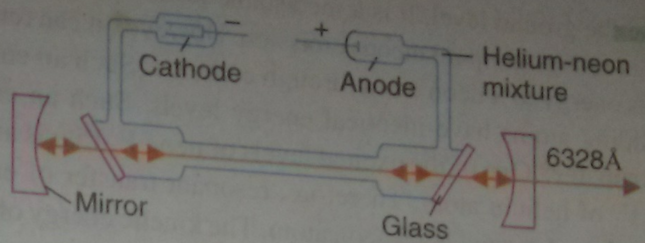
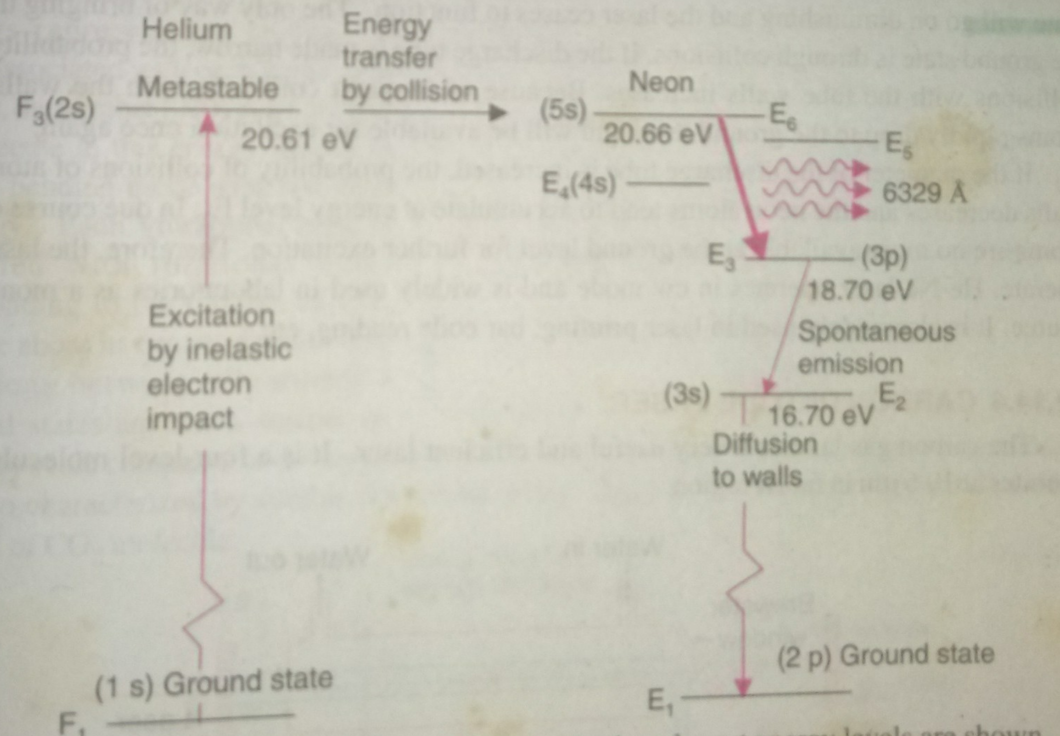


Fig. 22.28.

The first gas laser was He-Ne laser which was invented in 1961 by Ali Javan, William R. Bennett, Jr. and Donald R.Herriott.

Construction: The schematic of a He-Ne laser is shown in Fig.22.28. Helium – Neon laser consists of a long discharge tube filled with a mixture of helium and neon gases in the ratio 10: 1. Neon atoms are the active centers and have energy levels suitable for laser transitions while helium atoms help in exciting neon atoms. Electrodes are provided in the discharge tube to produce discharge in the gas. They are connected to a high voltage power supply. The tube is hermetically sealed by inclined windows arranged at its two ends. On the axis of the tube, two mirrors are arranged externally which form the Fabry-Perot optical resonator. The distance between the mirrors is adjusted to be $m\lambda/2$ such that the resonator supports standing wave pattern.



Energy level diagram for a helium-neon laser. Only the relevant energy levels are shown.

Fig. 22.29

Working: Helium – Neon laser employs a four – level pumping scheme. The energy levels of helium and neon are shown in Fig.22.29. When the power is switched on, a high voltage of about 10 kV is applied across the gas. It is sufficient to ionize the gas. The electrons and ions produced in the process of discharge are accelerated towards the anode and cathode respectively. The energetic electrons excite helium atoms through collisions. One of the excited levels of helium F_3 (2s) is at 20.61

eV above the ground level. It is a metastable level and the excited helium atom cannot return to the ground level through spontaneous emission. However, it can return to the ground level by transferring its excess energy to a neon atom through collision. Such an energy transfer can take place when the two colliding atoms have identical energy levels. Such an energy transfer is known as **resonant energy transfer**. One of the excited levels of neon E_6 (5s) is at 20.66eV, which is nearly at the same level as F_3 of helium atom. Therefore, resonant transfer of energy can occur between the excited helium atom and ground level neon atom. The kinetic energy of helium atoms provides the additional 0.05 eV required for excitation of the neon atoms. Helium atoms drop to the ground state after exciting neon atoms. This is the pumping mechanism in He-Ne laser. The role of helium atoms is to excite neon atoms and to cause population inversion. The probability of energy transfer from helium atoms to neon atoms is more, as there are 10 helium atoms per 1 neon atom in the gas mixture. The probability of reverse transfer of energy from neon to helium atom is negligible.

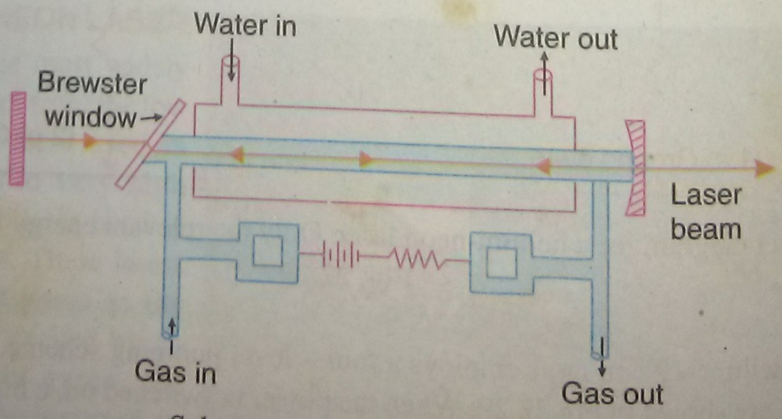
The upper state of neon atom E_6 is a metastable state. Therefore, neon atoms accumulate in this upper state. The E_3 (3p) is sparsely populated at ordinary temperatures, and a state of population inversion is readily established between E_6 and E_3 levels. Random photons emitted spontaneously prompt stimulated emission and lasing occurs. The transition $E_6 \rightarrow E_3$ generates a laser beam of red colour of wavelength 6328 Å. Other possible transitions produce 3.39 μm and 1.15 μm laser beams respectively. These transitions are not shown in Fig. 22.29.

From the level E_3 the neon atoms drop to E_2 (3s) level spontaneously. E_2 level is however a metastable state. Consequently, neon atoms tend to accumulate at E_2 level. It is necessary that these atoms are brought to the ground state E_1(2p) quickly; otherwise the number of atoms at the ground state will go on diminishing and the laser ceases to function. The only way of bringing the atoms to the ground state is through collisions. If the discharge tube is made narrow, the probability of atomic collisions with the tube walls increases. Because of frequent collisions with the walls, the neon atoms rapidly drop to the ground level and will be available for excitation once again.

If the diameter of the discharge tube is increased, the probability of collisions of atoms with the walls decreases and the neon atoms tend to accumulate at energy level E_2. In due course of time, the atoms are no more available at the ground level for further excitation. Therefore, the laser ceases to operate. He-Ne laser operates in cw mode and is widely used in laboratories as a monochromatic source. It is also widely used in laser printing, bar code reading, etc.

22.14.4 CARBON DIOXIDE LASER

The carbon gas laser is a very useful and efficient laser. It is a four-level molecular laser and operates at 10.6 μm in far IR region.



Schematic of a carbon dioxide laser

Fig. 22.30