Types of pumping source in lasers:

Depending upon the type of laser, the most commonly used pumping methods are listed below:

a) **Optical pumping:** In this, the population inversion is achieved by means of light energy delivered from appropriate pumping source such as gaseous discharge or flash tubes. For example, in ruby laser, xenon flash tube is used.

b) **Electric discharge pumping:** this type of pumping accomplished by means of intense electrical discharge in the medium and is particularly suited to gas media like He-Ne laser and CO_2 laser. The electric discharge coverts the gas into a plasma where active centers collide in-elastically with free electrons and population inversion is achieved.

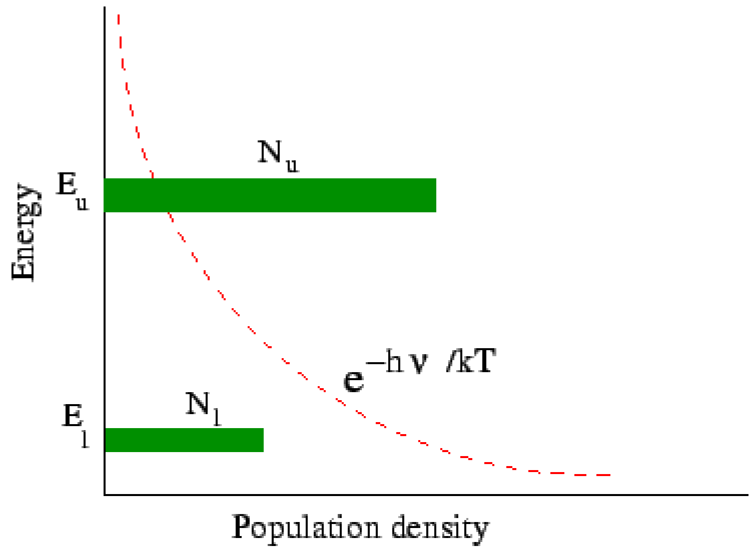
c) **Chemical pumping:** It raises active centers into the higher levels by means of suitable exothermal chemical reactions in the active medium.

d) **Heat pumping:** In this type of pumping, the active material is first brought to a high temperature then rapidly cooled down.

Population Inversion:

When atoms are in equilibrium with the surrounding, the population of atoms in the ground state is more than that in any of the excited states. Population of excited states can be increased by absorption of radiation. However, the life time in the excited states being typically of the order of 10^{-8} seconds, atoms which make transitions to the excited states fall back to the ground state soon thereafter. This is also indicated by the ratios of the Einstein coefficients. It is, therefore, not possible to keep the population in the excited states higher than that in the ground state. The basic principle involved in the operation of laser is **population inversion**, a situation in which the population of the excited state is kept higher than that of the ground state.

When $N_u < N_l$, i.e. the population in the upper level is less than that in the lower level, the number of transitions from the lower to the upper level with absorption of radiation is more than that with emission and hence the radiation is attenuated. On the other hand, if $N_u > N_l$, emissions are more than absorption and the radiation is amplified as it passes through the material.



The figure shows population inversion required for light amplification with the dashed curve being the Boltzmann distribution.
As atoms get de-excited, the laser action would stop unless atoms are continuously pumped into the upper level by some means.

Einstein Relations A and B Coefficients:

The distribution of atoms in the two energy levels will change by absorption or emission of radiation. Einstein introduced three empirical coefficients to quantify the change of population of the two levels.

- **Absorption -** If B_{12} is the probability (per unit time) of absorption of radiation, the population of the upper level increases. The rate is clearly proportional to the population of atoms in the lower level and to the energy density u(v) of radiation in the system. Thus the rate of increase of population of the excited state is given by

$$\frac{\partial N_2}{\partial t} = B_{12} u(v) N_1$$

  Where, B_{12} is a constant of proportionality with dimensions m^3/s^2-J.

- **Spontaneous Emission -** The population of the upper level will decrease due to spontaneous transition to the lower level with emission of radiation. The rate of emission will depend on the population of the upper level. If A_{12} is the probability that an atom in the excited state will spontaneously decay to the ground state,

$$\frac{\partial N_2}{\partial t} = -A_{12} N_2$$

The equation above has the solution

$$N_2(t) = N_2(0) e^{-t/\tau}$$

Where $\tau = 1/A_{12}$ gives the average lifetime of an atom in the excited level before the atom returns to the ground state. Thus the spontaneous emission depends on the life-time of the atom in the excited state. The process is statistical and the emitted quanta bear no phase relationship with one another, i.e. the emission is **incoherent**.

- **Stimulated Emission -** Stimulated or induced emission depends on the number of atoms in the excited level as well as on the energy density of the incident radiation. If B_{12} be the transition be the transition probability per unit time per unit energy density of radiation, the rate of decrease of the population of the excited state is $B_{21}u(v)N_2$.

The rate equation for the population of the upper level is

$$\frac{dN_2}{dt} = B_{12} u(v) N_1 - [A_{21} + B_{21} u(v)] N_2$$

Since N_1+N_2 =constant,

$$\frac{\partial N_2}{\partial t} = -\frac{\partial N_1}{\partial t}$$

The emitted quanta under stimulated emission are coherent with the impressed field. The spontaneous emission, being incoherent, is a source of noise in lasers. When equilibrium is reached, the population of the levels remain constant, so that $dN_2/dt = 0$ and the rate of emission equals rate of absorption, so that

$$B_{12} u(v) N_1 = [A_{21} + B_{21} u(v)] N_2$$

$$N_2/N_1 = (g_2/g_1)\exp(-hv/kT)$$

Using the Boltzmann factor, and simplifying, we get

$$u(v) = \frac{A_{21}.\frac{g_2}{g_1}}{B_{12} e^{hv/kT} - B_{21}\frac{g_2}{g_1}} = \frac{A_{21}/B_{21}}{\frac{g_1}{g_2} e^{hv/kT} \frac{B_{12}}{B_{21}} - 1}$$

If we regard the matter to be a blackbody and compare the above expression for the energy density with the corresponding energy density expression derived for the blackbody radiation, viz.,

$$u(v) = \frac{8\pi h v^3}{c^3}\frac{1}{e^{hv/kT} - 1}$$

we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h v^3}{c^3}$$

And

$$\frac{B_{21}}{B_{12}} = \frac{g_1}{g_2}$$

The last equation shows that in the absence of degeneracy, the probability of stimulated emission is equal to that of absorption. In view of this we replace the two coefficients by a single coefficient B and term them as B- coefficient. The spontaneous emission coefficient will be called the A- coefficient.
The ratio of spontaneous emission probability to the stimulated emission probability is

$$\frac{A}{Bu(v)} = e^{hv/kT} - 1$$

so that for low temperatures, when $hv/kT \gg 1$, spontaneous emission is much more probable than induced emission and the latter may be neglected. For high enough temperatures, stimulated emission probability can be significant though for optical frequencies, this requires very high temperature. For microwave frequencies the stimulated emission processes may be significant even at room temperatures.

Exercise:
Find the ratio of the probability of spontaneous emission to stimulated emission at 300 K for (a) microwave photons ($\nu = 10^{13}$ Hz.) and (b) optical photons ($v = 10^{15}$Hz).
(Ans. (a) 0.17 (b) $\sim 10^7$.)

The role of the Helium gas in He-Ne laser is to increase the efficiency of the lasing process. Two effects make Helium particularly valuable:

1. The direct excitation of Neon gas is inefficient, but the direct excitation of He gas atoms is very efficient.

2. An excited state of the He atom (labeled E5) has an energy level which is very similar to the energy of an excited state of the Neon atom (also labeled E5).

The excitation process of the Neon atoms is a **two stages process:**

- The high voltage causes electrons to accelerate from the cathode toward the anode. These electrons collide with the He atoms and transfer kinetic energy to them.
- The excited Helium atoms collide with the Neon atoms, and transfer to them the energy for excitation.

Helium gas does not participate in the lasing process, but **increases the excitation efficiency**

So that the lasing efficiency with it increase by a factor of about 200.

The main advantage of gas lasers (He-Ne lasers) is that they are less prone to damage by overheating and can be run continuously. At room temperature, a ruby laser (solid laser) will only emit short bursts of laser light, each laser pulse occurring after a flash of the pumping light. It would be better to have a laser that emits light continuously. Such a laser is called a continuous wave (CW) laser.

The helium-neon laser was the first continuous wave (CW) laser ever constructed.

Working and principle:-

In helium-neon lasers, we use high voltage DC as the pump source. A high voltage DC produces energetic electrons that travel through the gas mixture. *The gas mixture in helium-neon laser is mostly comprised of helium atom*s. Therefore, helium atoms observe most of the energy supplied by the high voltage DC. When the power is switched on, a high voltage of **about 10 kV** is applied across the gas mixture. This power is enough to excite the electrons in the gas mixture. The electrons produced in the process of discharge are accelerated between the electrodes through the gas mixture.

In the process of flowing through the gas, the energetic electrons transfer some of their energy to the helium atoms in the gas. Thus, the lower energy state electrons of the helium atoms gain enough energy and jumps into the excited states or metastable states. The **metastable** state electrons of the helium atoms cannot return to ground state by spontaneous emission. However, they can return to ground state by transferring their energy to the lower energy state electrons of the neon atoms.

Now, the energy levels of some of the excited states of the neon atoms are identical to the energy levels of metastable states of the helium atoms. After some period, the metastable states electrons of the neon atoms will spontaneously fall into the next lower energy states by releasing photons or red light. *This is called spontaneous emission*.

The neon excited electrons continue on to the ground state through radiative and non-radiative transitions. It is important for the **continuous wave (CW) operation.** The light or photons emitted from the neon atoms will moves back and forth between two mirrors until it stimulates other excited electrons of the neon atoms and causes them to emit light. Thus, optical gain is achieved. This process of photon emission is called stimulated emission of radiation. The light or photons emitted due to stimulated emission will escape through the partially reflecting mirror or output coupler to produce laser light.

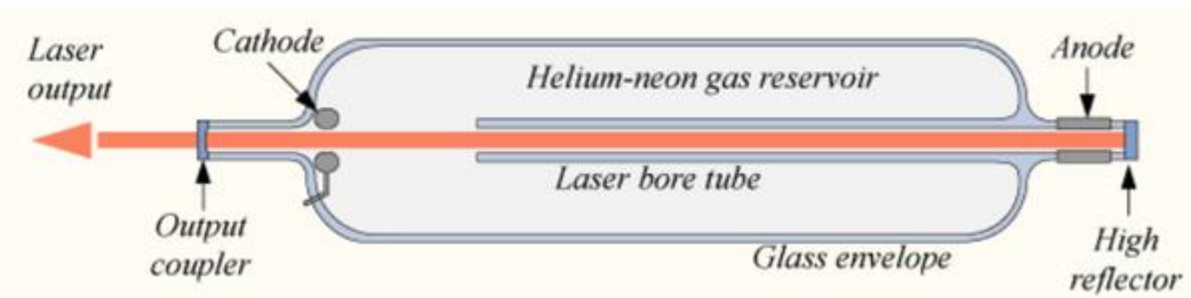
A helium-neon laser, usually called a He-Ne laser, is a type of small gas laser. He-Ne lasers have many industrial and scientific uses, and are often used in laboratory demonstrations of optics. He-Ne laser is a four-level laser. Its usual operation wavelength is 632.8 nm, in the red portion of the visible spectrum.

Construction of Helium Neon Laser

The setup consists of a discharge tube of length 80 cm and bore diameter of 1.5 cm. The gain medium of the laser, as suggested by its name, is a mixture of helium and neon gases, in a 5:1 to 20:1 ratio, contained at low pressure (an average 50 Pa per cm of cavity length) in a glass envelope.

The energy or pump source of the laser is provided by an electrical discharge of around 1000 volts through an anode and cathode at each end of glass tube. A current of 5 to 100 mA is typical for CW operation.

He Ne lasers are normally small, with cavity lengths of around 15 cm up to 0.5cm and optical output powers ranging from 1 mW to 100 mW.



Working

A description of the rather complex He. -Ne excitation process can be given in terms of the following four steps.

(a)When the power is switched on, an energetic electron collisionally excites a He atom to the state labeled 2S.A He atom in this excited state is often written He*(21 S), where the asterisk means that the He atom is in an excited.

(b) The excited He*(21 S) atom collides with an unexcited Ne atom and the atoms exchange internal energy, with an unexcited He atom and excited Ne atom, written Ne*(3s), resulting. This energy exchange process occurs with high probability only because of the accidental near equality of the two excitation energies of the two levels in these atoms. Thus, the purpose of population inversion is fulfilled

Energy level diagram of Helium Neon laser

When the excited Ne atom passes from metastable state (3s) to lower level (2p), it emits photon of wavelength 632 nm.

This photon travels through the gas mixture parallel to the axis of tube, it is reflected back and forth by the mirror ends until it stimulates an excited Ne atom and causes it to emit a photon of 632nm with the stimulating photon.

The stimulated transition from (3s) level to (2p) level is laser transition.

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

The Ne atom passes to lower level 1s emitting spontaneous emission and finally the Ne atom comes to ground state through collision with tube wall and undergoes radiation less transition.

Applications of Helium - Neon Laser:

The Narrow red beam of He-Ne laser is used in supermarkets to read bar codes.

The He- Ne Laser is used in Holography in producing the 3D images of objects.

He-Ne lasers have many industrial and scientific uses, and are often used in laboratory demonstrations of optics.

Why is helium used in higher proportion than neon in He-Ne laser?

He-Ne laser is a 10:1 mixture, at low pressure in a glass tube. The gas mixture is mostly helium, so that helium atoms can be excited and further collide with neon atoms, exciting them so it may radiate 632.8 nm. Without helium, the neon atoms would be excited mostly to lower excited states and radiate non-laser lines. A He-Ne laser that has lost enough helium loses its laser functionality because of low pumping efficiency.

The role of the Helium gas in He-Ne laser is to increase the efficiency of the lasing process. Two effects make Helium particularly valuable:

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Thus

Helium gas does not participate in the lasing process, but **increases the excitation efficiency**

Neon and helium belong to the same group. Helium is an inactive gas at room temperature. If you infer a property of neon, what would be your inference?

Helium and neon are grouped and located on the far right of the periodic table and referred to as "noble" gasses. (The change in designation from "inert" gasses was made in the 1960's) To say that helium is inactive is technically incorrect in that it is in a highly active gaseous state. That being said, I'll assume that the correct term in the question is non-reactive. Since helium and neon are both in group 18, they are atomically similar. Because noble gases' outer shells are full, they are extremely stable, tending not to form chemical bonds and having a small tendency to gain or lose electrons. It can be inferred that since both belong to the same group of the table, under standard conditions they will behave similarly. Therefore, since helium is mono-atomic (un-bonded with other atmospheric gasses) at room temperature, neon is also mono-atomic at room temperature. Other physical/atomic and chemical properties will also be similar.

They both are noble gases. They do not form bonds unless the gases are ionized or under high pressure. In an experiment where these gases are used without making any of these changes to the atoms, both neon and helium will take no part in the reaction. If neon, or any other noble gas was used, to form compounds, atoms from the halogen series will bond the best.

A property of neon, if that's all you want, is that it can be used in neon lights.

In He-Ne laser why it is necessary to use narrow tubes?

The gas inside must reach a critical point of energy where the medium starts to lease. If the tubes are narrow, the energy density increase, and the excited gas will lease easily. The narrower the tube, the higher the gain.

For efficient operation, the population of the final state in the laser transition should be rapidly depleted. This is achieved by increasing the probability of collisions between the Ne atoms and the walls of the discharge tube by reducing the tube diameter.

The gain of the He-Ne laser is inversely proportional to the tube radius; the narrower the discharge tube, the higher the gain. In most He-Ne lasers the tube diameter is not larger than a few millimeters. An additional benefit of the small tube diameter is that the emission is restricted to the TEM_{00} mode; higher order transverse modes cannot oscillate in very narrow tubes.)

Why does neon have higher electron gain enthalpy than helium?

This may be because the valence shell of helium is 1s, having the lowest energy thus easier to put another electron in the next subshell that is ,2s

If we talk about Ne we have to first overcome the 2p energy and should have enough energy to loose when Ne accepts another electron in much higher energy level that is , 3s(to be least stable)

After Ne, the decrease in ∆eg H is gradual, because the next electron is to be added in a subshell of the same quantum level.

And of course as the size of the atom increases effective nuclear charge increases, making it easier to accept an electron, down the group 18

Why is helium more easily excited than neon?

due to small size of helium there is larger repulsion between electrons of 1s and has less nuclear charge

hence easily excited than a 2p electron of neon.

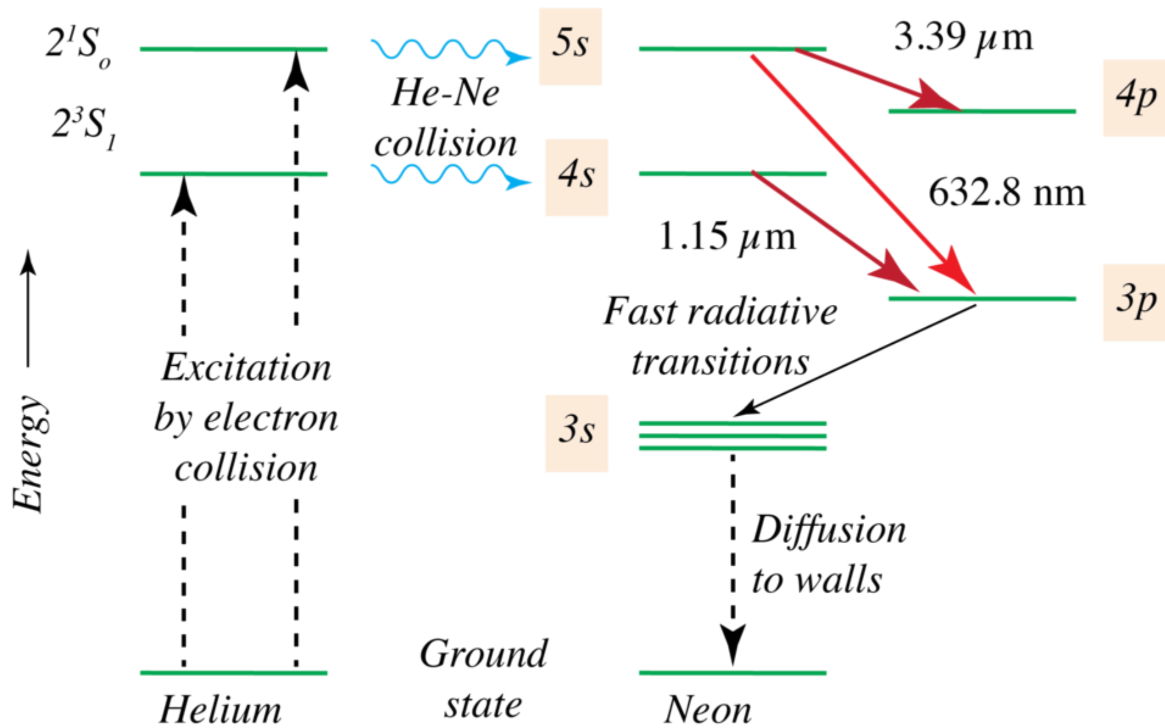
Why is the collision between helium and neon inelastic in the helium-neon laser?

If the internal states of the two atoms allow conservation of momentum and energy during a collision then energy can be transferred from the internal state of one atom into another.

In this case, a helium atom that is in an excited state can transfer some of its excitation energy into a neon atom excited state because the energy levels are very similar. The collision is inelastic because the internal energies of the two atoms changed during the collision.

For any collision to be completely elastic, there must be NO change in total kinetic energy. This implies that there must be no changes in internal energy. The helium and neon atoms DO change their internal energies, therefor the collisions are NOT completely elastic.

Because of energy transfer between the He* and Ne to form the He-Ne* excimer complex.



Ruby Laser:

A ruby laser is a solid-state laser that uses the synthetic ruby crystal as its laser medium. Ruby laser is the first successful laser developed by Maiman in 1960.

Ruby laser is one of the few solid-state lasers that produce visible light. It emits deep pink light of wavelength 6943 Å.

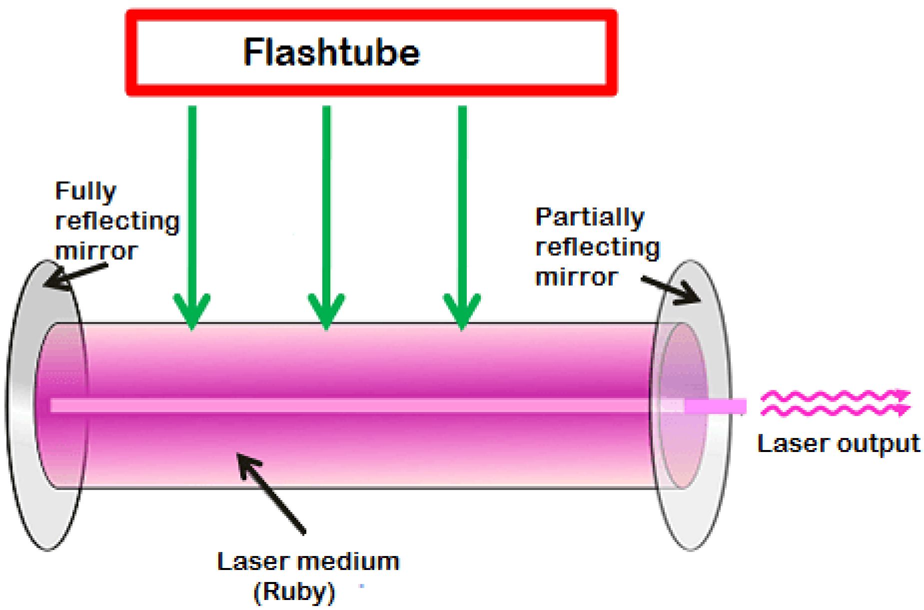
Construction of ruby laser

A ruby laser consists of three important elements: laser medium, the pumping source, and the optical resonator.

Laser medium or gain medium in ruby laser

Ruby laser consist of a synthetic ruby crystal, doped with chromium ions with concentration of about 0.05% by weight. Chromium ions act as active centers in ruby crystal, so it is the chromium ions that produce the laser .With this concentration of doping , there are about $1.6*10^{25}$ chromium ions per cubic meter .These ions have a set of three energy level suitable for the laser action. The ruby has good thermal properties.

Ruby is a crystal of aluminum oxide (Al_2O_3) in which some of the aluminum ions (Al^{3+}) are replaced by chromium ions (Cr^{3+}). This is done by small amounts of chromium oxide (Cr_2O_3) doping in the melt of purified Al_2O_3.The ruby crystal is in the form of cylinder. Length of ruby crystal is usually 2 cm to 30 cm and diameter 0.5 cm to 2 cm.



Pump source or energy source in ruby laser

The pump source is the element of a ruby laser system that provides energy to the laser medium. In a ruby laser, population inversion is required to achieve laser emission. Population inversion is the process of achieving the greater population of higher energy state than the lower energy state. In order to achieve population inversion, we need to supply energy to the laser medium (ruby).

In a ruby laser, we use a helical flash lamp filled with xenon is used as a pumping source. The ruby crystal is placed inside a xenon flash lamp. Thus, optical pumping is used to achieve population inversion. The flashtube supplies energy to the laser medium (ruby). When lower energy state electrons in the laser medium gain sufficient energy from the flashtube, they jump into the higher energy state or excited state.

Optical resonator

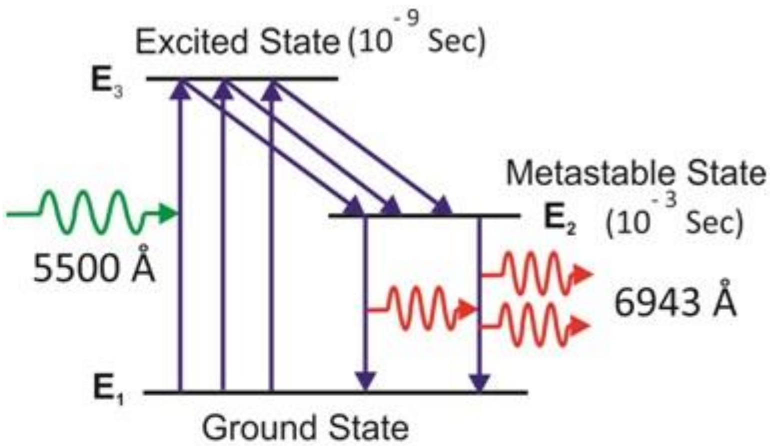
The ends of the cylindrical ruby rod are flat and parallel. The cylindrical ruby rod is placed between two mirrors. The optical coating is applied to both the mirrors. The process of depositing thin layers of metals on glass substrates to make mirror surfaces is called silvering. Each mirror is coated or silvered differently.

At one end of the rod, the mirror is fully silvered whereas, at another end, the mirror is partially silvered.

The fully silvered mirror will completely reflect the light whereas the partially silvered mirror will reflect most part of the light but allows a small portion of light through it to produce output laser light.

Working of Ruby Laser

Ruby is a three energy level laser system. After absorbing light photons of wavelength 5500Å from xenon flash lamp, some of the Cr^{+3} ions at ground energy level E1 get excited to higher energy level E3. At this energy level, they are unstable and by losing a part of their energy to the crystal lattice, they fall to the metastable energy level E2, whose lifetime is much longer (approx10^{-3}sec). therefore, the number of Cr^{+3} ions goes on increasing in E2 state while the number of these ions in the ground state E2 goes on decreasing due to pumping by flash lamp and soon the population inversion is achieved between states E2 and E1.



Energy Level Diagram of Ruby LASER

Now some of the Cr^{+3} ions will decay spontaneously to the ground state E1 by emitting photons of wavelength 6943Å. the photons those are moving parllel to the axis of the rod will reflect back and forth by the silvered ends of the rod and stimulate other excited Cr^{+3} ions to radiate another photon with same phase. Thus, due to successive reflections of these photons at the ends of the rod the number of photons multiplies. After a few microsecond a monochromatic, intense and collimated beam of pink light of wavelength of 6493Å emerges through partially silvered ends of the rod. The ruby laser is a pulsed laser that emits light in the form of very short pulses .