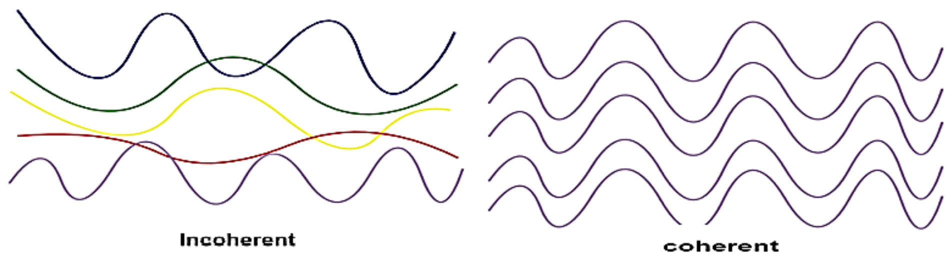
Chapter-4
Laser System and Applications

Introduction: Laser is an acronym for "Light Amplification by Stimulated Emission of Radiation" In 1960 laser was introduced as an appealing method for the production of highly directional, coherent, monochromatic and polarized light beam. The principle of laser is based on the phenomenon of Stimulated Emission of Radiation by Einstein in 1917.

1. **Coherence:**

It is an important characteristic of laser beam. In lasers the wave trains of same frequency are in phase, the radiation given out is in mutual agreement not only in phase but also in the direction of emission and polarization. Thus it is a coherent beam. Due to high coherence it results in an extremely high power.

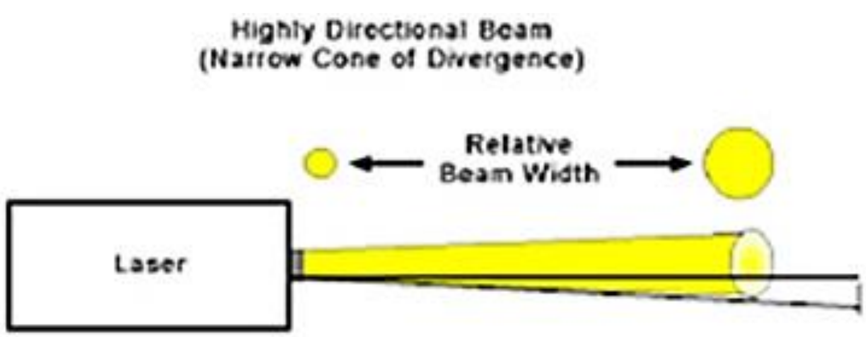


2. **Monochromatic:**

Monochromaticity refers to a pure spectral color of a single wavelength. A beam is more and more monochromatic if the line spread in frequency is narrow or small. This line width is an outcome of the homogeneous broadening factors and inhomogeneous broadening factors. Despite these broadening mechanisms the line width in a laser is generally very small as compared to the normal lights.

3. **Directionality**

Ordinary light spreads in all directions and its angular spread is 1m/m. But it is found that laser is highly directional and is angular spread is 1mm/m. For example, the laser beam can be focused to very long distance with a few divergence or angular spread.



Divergence or angular spread is given by

$$\phi = \frac{r_2 - r_1}{d_2 - d_1}$$

Where d_1, d_2 are any two distances for the laser source emitted and r_1, r_2 are the radii of the beam spots at a distance d_1, and d_2 respectively as shown

4. High Intensity:

Since an ordinary light spreads in all directions, the intensity reaching the target is very less. But in the case of laser, due to high directionality, the intensity of laser beam reaching the target is of high intense beam. For example, 1 mill watt power of He-Ne laser appears to be brighter than the sunlight.

Principle of Spontaneous and Stimulated emission – Einstein's Quantum theory of radiation (Quantum Process):

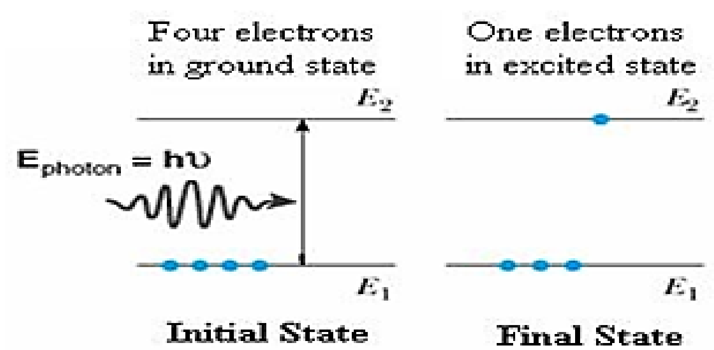
We know that, when light is absorbed by the atoms or molecules, then it goes from the lower energy level (E_1) to the higher energy level (E_2) and during the transition from higher energy level (E2) to lower energy level (E_1) the light is emitted from the atoms or molecules.

Let us consider an atom exposed to light photons of energy $E_2 - E_1 = h\nu$, three distinct processes take place.

a. **Absorption**
b. **Spontaneous emission**
c. **Stimulated Emission**

Induced Absorption of Radiation:

An atom in the lower energy level or ground state energy level E_1 absorbs the incident photon radiation of energy hν and goes to the higher energy level or excited level E_2 as shown in figure.



This process is called absorption

If there are many numbers of atoms in the ground state then each atom will absorb the energy from the incident photon and goes to the excited state. Then,

The rate of absorption (R_{12}) is proportional to the following factors.

$$R_{12} \propto \text{Energy Density of incident radiation } (\rho_\nu)$$

$$R_{12} \propto \text{No. of atoms in the ground state} (N_1)$$

Therefore,

$$R_{12} \propto \rho_\nu N_1$$

$$R_{12} = B_{12}\rho_\nu N_1 \dots\dots\dots\dots\dots\dots\dots.(1)$$

Where B_{12} is a constant which gives the probability of absorption of absorption transition per unit time.

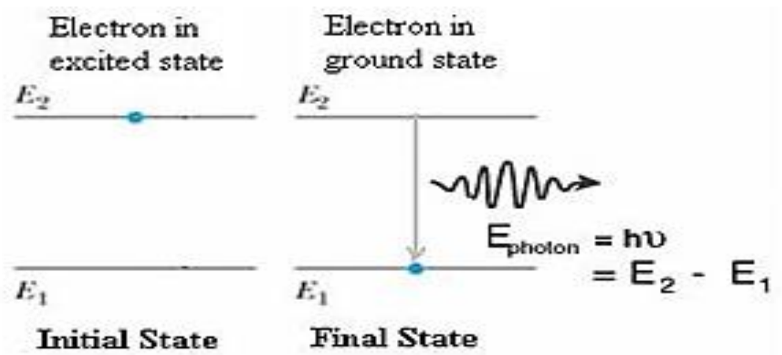
Normally, the atoms in the excited state will not stay there for a long period of time , rather it comes to ground state by emitting a photon of energy E=hν Such an emission takes place by one of the following two methods.

Spontaneous emission:

The atom in the excited state returns to the ground state by emitting a photon of energy

$$E = (E_2 - E_1) = h\nu$$

Spontaneously without any external triggering as shown in the figure.



This process is known as spontaneous emission. Such an emission is random and is independent of incident radiation. If N1 and N2are the numbers of atoms in the ground state (E1) and excited state (E2) respectively, then

The rate of spontaneous emission is

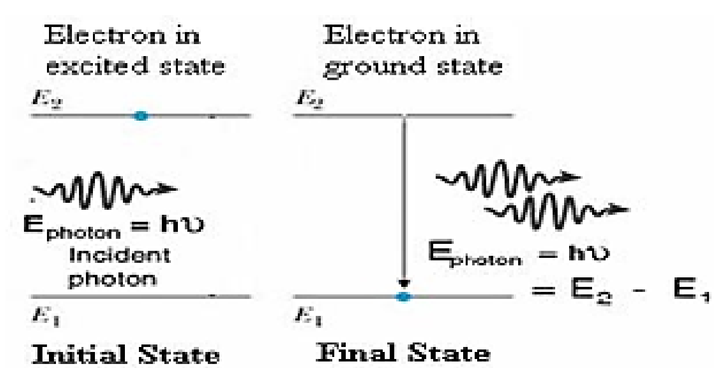
$$R_{21(sp.)} \propto N_2$$

$$R_{21(sp.)} = A_{21}N_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Where A21 is a constant which gives the probability of spontaneous emission transitions per unit time.

Stimulated Emission:

The atom in the excited state can also return to the ground state by external triggering or inducement of photon thereby emitting a photon of energy equal to the energy of the incident photon, known as stimulated emission. Thus results in two photons of same energy, phase difference and of same directionality as shown.



Therefore, the rate of stimulated emission is given by

$$R_{21(st.)} \propto \rho_\nu N_2$$

$$R_{21(st.)} = B_{21}\rho_\nu N_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

Where B_{21} is a constant which gives the probability of stimulated emission transitions per unit time.

Einstein's theory (Relationship between Einstein's A and B Coefficient):

Einstein's theory of absorption and emission of light by an atom is based on Planck's theory of radiation. Also under thermal equilibrium, the population of energy levels obeys the Boltzmann distribution law

Under thermal equilibrium

The rate of absorption = the rate of emission

$$R_{12} = R_{21}$$

$$R_{12} = R_{21(sp)} + R_{21(st)}$$

$$\therefore\ B_{12}\rho_\nu N_1 = A_{21}N_2 + B_{21}\rho_\nu N_2$$

$$B_{12}\rho_\nu N_1 - B_{21}\rho_\nu N_2 = A_{21}N_2$$

$$\rho_\nu(B_{12}N_1 - B_{21}N_2) = A_{21}N_2$$

$$\rho_\nu = \frac{A_{21}N_2}{(B_{12}N_1 - B_{21}N_2)}$$

$$\rho_\nu = \frac{A_{21}}{\left(B_{12}\frac{N_1}{N_2} - B_{21}\right)}$$

$$\rho_\nu = \frac{A_{21}}{B_{21}}\frac{1}{\left(\frac{B_{12}}{B_{21}}\frac{N_1}{N_2} - 1\right)} \ldots\ldots\ldots\ldots\ldots(4)$$

We know that from Boltzmann Distribution Law

$$N_1 = N_o e^{-E_1/K_B T}$$

$$N_2 = N_o e^{-E_2/K_B T}$$

Where K_B is the Boltzmann Constant and T is the absolute temperature.

Therefore

At equilibrium, we can write the ratio of population levels as follows.

$$\frac{N_1}{N_2} = e^{(E_2 - E_1)/K_B T}$$

Since

$$h\nu = (E_2 - E_1)$$

Then

$$\frac{N_1}{N_2} = e^{h\nu/K_B T} \ldots\ldots\ldots\ldots\ldots(5)$$

Substituting the value of $\frac{N_1}{N_2}$ from equation 5 in equation 4, we have

$$\rho_\nu = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{B_{12}}{B_{21}} e^{h\nu/K_B T} - 1\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

This equation has a very good agreement with Planck's Radiation Law

i.e.

$$\rho_\nu = \frac{8\pi h\nu^3}{c^3} \frac{1}{\left(e^{h\nu/K_B T} - 1\right)} \ldots\ldots\ldots\ldots\ldots\ldots..(7)$$

Comparing equation 6 and 7

We get

1. $\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$, The ratio of spontaneous emission and stimulated emission is proportional to v^3 this implies that the probability of spontaneous emission dominates over induced emission more and more as the energy difference between the two states increases.
2. $\frac{B_{12}}{B_{21}} = 1$; $B_{12} = B_{21}$, The probability of spontaneous emission is same as that of induced absorption. This means that if these two processes will occur at equal rates, so that no population inversion can be attained in a two-level system.

Ratio of magnitudes of Stimulated to Spontaneous emission rates

From equations (2) and (3) we have

$$\frac{R_{21(st)}}{R_{21(sp)}} = \frac{B_{21}\rho_\nu N_2}{A_{21}N_2}$$

$$\frac{R_{21(st)}}{R_{21(sp)}} = \frac{B_{21}\rho_\nu}{A_{21}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

From equation 6

$$\frac{B_{21}}{A_{21}}\rho_\nu = \frac{1}{\left(\frac{B_{12}}{B_{21}} e^{h\nu/K_B T} - 1\right)}$$

Since $B_{12} = B_{21}$, we have

$$\frac{1}{\left(e^{h\nu/K_B T} - 1\right)} = \frac{B_{21}}{A_{21}}\rho_\nu \ldots\ldots\ldots\ldots..(9)$$

From equation 8 and 9, we get

$$\frac{R_{21(st)}}{R_{21(sp)}} = \frac{1}{\left(e^{h\nu/K_B T} - 1\right)} = \frac{B_{21}}{A_{21}}\rho_\nu$$

In a simpler way the ratio can be written as,

$$R = \frac{B_{21}}{A_{21}}\rho_\nu$$

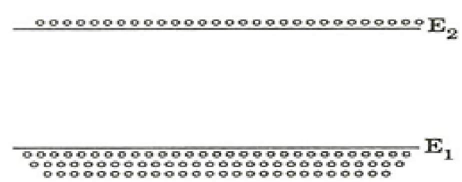
Generally Spontaneous emission is more predominant in the optical region (Ordinary light). To increase the number of coherent photons stimulated emission should dominate over spontaneous emission. To achieve this, an artificial condition called **Population Inversion is necessary.**

Differences between Stimulated and spontaneous emission of radiation

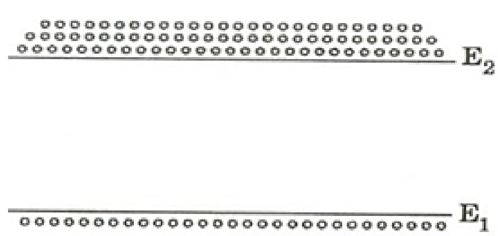
S.no	Stimulated Emission	Spontaneous emission
1.	An atom in the excited state is induced to return to the ground state , thereby resulting in two photons of same frequency and energy is called Stimulated emission	The atom in the excited state returns to the ground state thereby emitting a photon, without any external inducement is called Spontaneous emission.
2.	The emitted photons move in the same direction and is highly directional	The emitted photons move in all directions and are random
3.	The radiation is highly intense , monochromatic and coherent	The radiation is less intense and is incoherent.
4.	The photons are in phase, there is a constant phase difference.	The photons are not in phase (i.e.) there is no phase relationship between them.
5.	The rate of transition is given by $R_{21}(St) = B_{21}\rho_v N_2$	The rate of transition is given by $R_{21}(SP) = A_{21}N_2$

Population Inversion:

Population Inversion creates a situation in which the number of atoms in higher energy state is more than that in the lower energy state. Usually at thermal equilibrium, the number of atoms N_2 i.e., the population of atoms at higher energy state is much lesser than the population of the atoms at lower energy state N_1 that is $N_1 > N_2$. The Phenomenon of making $N_2 > N_1$ is known as Population Inversion.



The Phenomenon of making $N_2 > N_1$ is known as Population Inversion.



Conditions of Population inversion.

1. There must be at least two energy levels E2 > E1.
2. There must be a source to supply the energy to the medium.
3. The atoms must be continuously raised to the excited state.

Meta stable States:

An atom can be excited to a higher level by supplying energy to it. Normally, excited atoms have short life times and release their energy in a matter of nano seconds (10-9) through spontaneous emission. It means atoms do not stay long to be stimulated. As a result, they undergo spontaneous emission and rapidly return to the ground level; thereby population inversion could not be established. In order to do so, the excited atoms are required to 'wait' at the upper energy level till a large number of atoms accumulate at that level. In other words, it is necessary that excited state have a longer lifetime. A Meta stable state is such a state. Metastable can be readily obtained in a crystal system containing impurity atoms. These levels lie in the forbidden gap of the host crystal. There could be no population inversion and hence no laser action, if metastable states do not exist.

Such a state, which single-photon emission is impossible, has an unusually long time and is called a metastable state. Therefore, the metastable state allows accumulation of a large number of excited atoms at that level. The metastable state population can exceed the population at a lower level and establish the condition of population inversion in the lasing medium. It would be impossible to create the state of population inversion without a metastable state.

Pumping Schemes

Two Level Pumping System

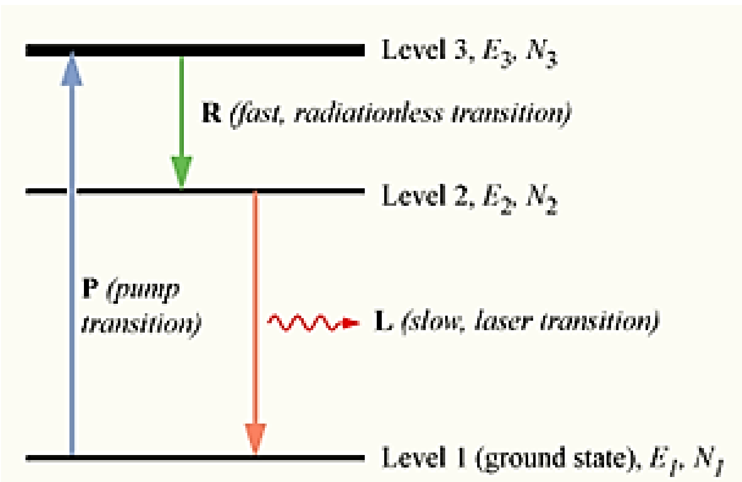
In a simple two-level system, it is not possible to obtain a population inversion with optical pumping because the rate of absorption becomes equal to rate of emission.

Three Level Pumping Scheme

Laser action can be achieved achieving population inversion between two levels of energy E1 and E2 with $E_2>E_1$, so that more atoms are in the level 2 than in the level 1.

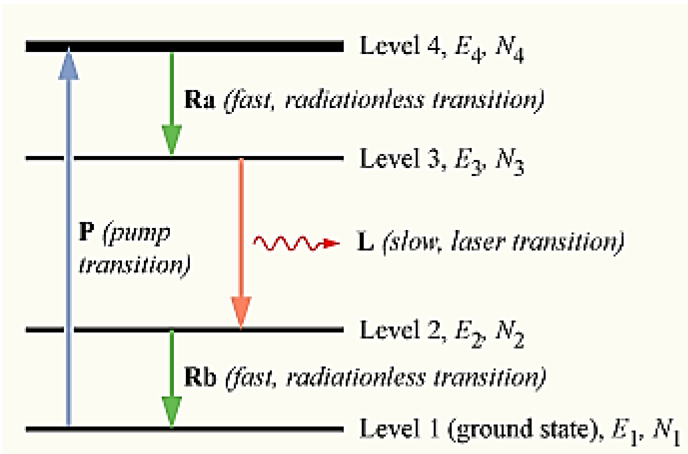
"Pumping" is done to achieve the condition of inversion. In the three-level lasers. The three levels in an atom such that $E_3>E_2>E_1$, Incident radiation frequency v is used to raise atoms from the level 1(ground state) to level 3(excited state).

Atom at level 3 decays rapidly to level 2(metastable state) through a non-radiative transition, hence population inversion is obtained between levels 2 and 1. A chance spontaneous emission will result in stimulated emission and laser action is achieved between levels



Four Level Pumping Scheme:

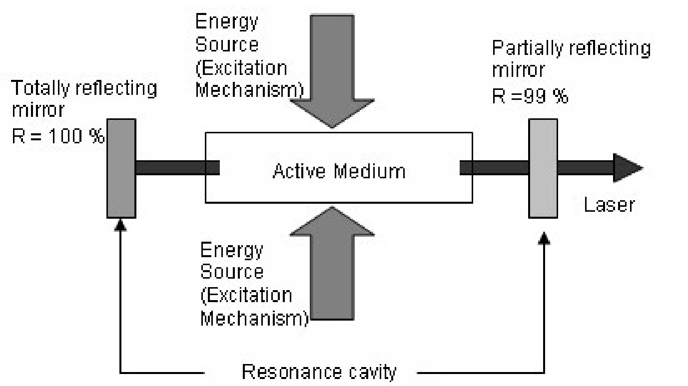
It is difficult to produce a continuous beam of laser in 3 level pumping scheme as at a time either pumping or laser action exists. An easier approach is to use a four-level system and population inversion is achieved between two excited levels. We start with all the atoms in the ground state1, and none in the excited states 2,3 and 4 (E2<E3<E4) . Atom are pumped from level 1 to Level 4(excited state) from there they fast decay to level 3(metastable state) through a non-radiative transition, and population inversion is achieved between levels 3 and 2. A chance spontaneous emission will result in stimulated emission and laser action is achieved between level 3 and 2. level 2 is chosen so that it has a fast decay to the ground state.



Principal and Components of Laser

Principle: Due to stimulated emission the photons multiply in each step-giving rise to an intense beam of photons that are coherent and moving in the same direction. Hence the light is amplified by Stimulated Emission of the Radiation. Termed LASER.

Components of Lasers



Active Medium:

The main component of a laser is a certain medium in the form of a solid, liquid or gas called **active medium**. A medium in which population inversion can be achieved is known as active medium.

Active Center:

Active mediums contain atoms which can produce more stimulated emission than spontaneous emission and cause amplification they are called "Active Centers". The material in which the atoms are raised to the excited state to achieve Population Inversion is called Active Center.

Energy Source (Excitation Mechanism):

Energy Source (Excitation mechanisms) pumps the active centers from ground state to excited state to achieve population inversion. The pumping by energy source can be optical, electrical or chemical depending on the active medium. It is an external source of energy which provides the necessary energy to the active medium to produce a state of population inversion, essential for lasing action.

Methods of pumping action:

1. Optical pumping (Excitation by Photons)
2. Electrical discharge method (Excitation by electrons)
3. In elastic atom – atom collision between atoms
4. Direct conversion
5. Chemical Reaction

Optical pumping:

When the atoms are exposed to light radiations energy hν , atoms in the lower energy state absorb these radiations and they go to the excited state. This method is called Optical pumping. It is used in solid state lasers like ruby laser and Nd-YAG laser. In ruby laser, xenon flash lamp is used as pumping source.

Electrical discharge method (Excitation by electrons):

In this method, the electrons are produced in an electrical discharge tube. These electrons are accelerated to high velocities by a strong electrical field. These accelerated electrons collide with the gas atoms. By the process, energy from the electrons is transferred to gas atoms. Some atoms gain energy and they go to the excited state. This results in population inversion. This method is called Electrical discharge method.

It is represented by the equation

$$e^* + A = A^* + e$$

Where A →gas atom in the ground state, A*→same gas atom in the excited state e* →Electrons with higher Kinetic energy and e → same electron with lesser energy.

This method of pumping is used in gas lasers like argon and CO_2 Laser.

In elastic atom – atom collision:

In this method, a combination of two gases (Say A and B are used). The excited states of A and B nearly coincides in energy.

In the first step during the electrical discharge atoms of gas A are excited to their higher energy state A* (metastable state) due to collision with the electrons .

$$e^* + A = A^* + e$$

Now A* atoms at higher energy state collide with B atoms in the lower state. Due to inelastic atom - atom collision B atoms gain energy and they are excited to a higher state B* . Hence, A atoms lose energy and return to lower state.

$$A^* + B = A + B^*$$

Direct Conversion:

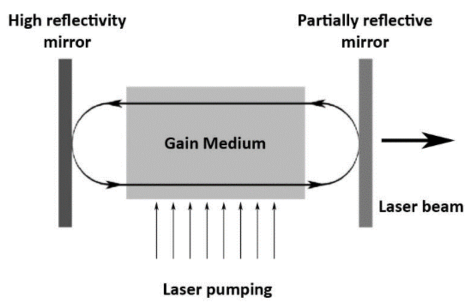
In this method, due to electrical energy applied in direct band gap semiconductor like Ga As, recombination of electrons and holes takes place. During the recombination process, the electrical energy is directly is converted into light energy.

Chemical pumping:

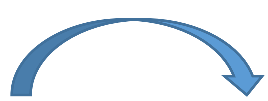
Chemical reaction may also result in excitation and hence creation of population inversion in few systems. Examples of such systems are HF and DF lasers.

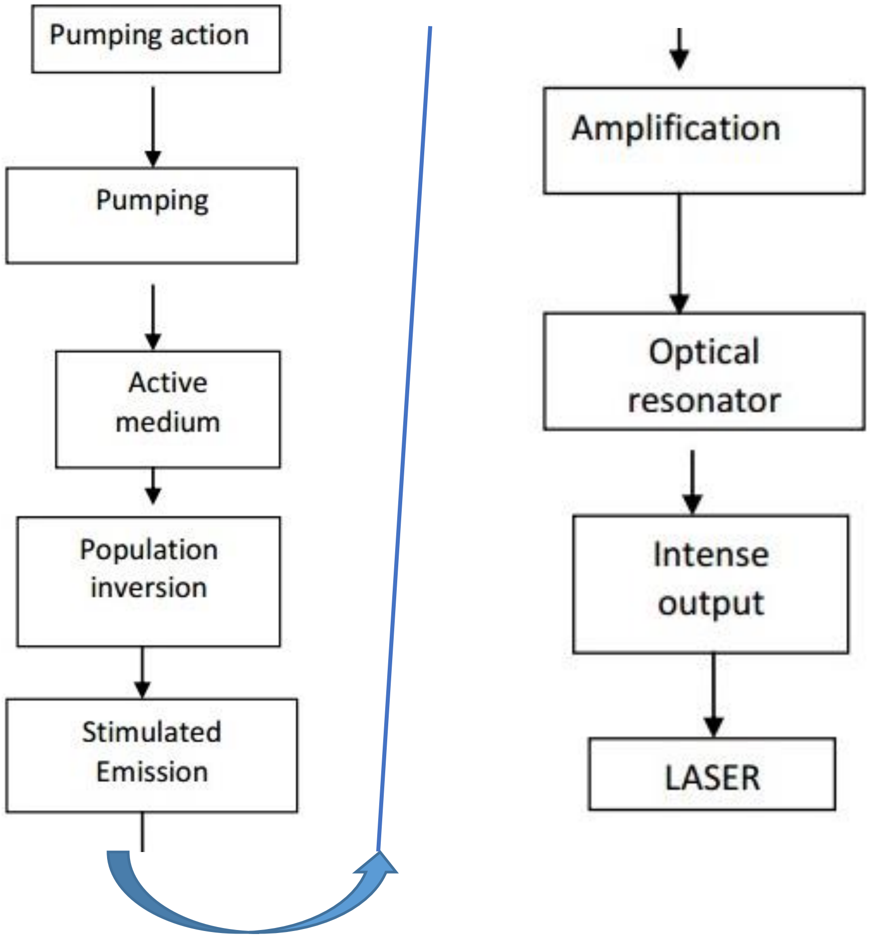
Optical resonator:

An optical resonator consists of a pair of reflecting surfaces in which one is fully reflecting (R_1) and the other is partially reflecting (R_2). The active material is placed in between these two reflecting surfaces. The photons generated due to transitions between the energy states of active material are bounced back and forth between two reflecting surfaces.



Flow Chart of Laser action:





Helium Neon Laser:

The helium-neon laser was the first continuous wave (CW) laser ever constructed. It was built in 1961 by Ali Javan, Bennett, and Herriott. He-Ne stands for Helium-Neon. The He-Ne laser active medium consists of two gases which do not interact form a molecule. Therefore He-Ne laser is one type of atomic gas lasers.

In Helium Neon Laser

Active Medium (gas): A mixture of helium and neon gas (10:1)

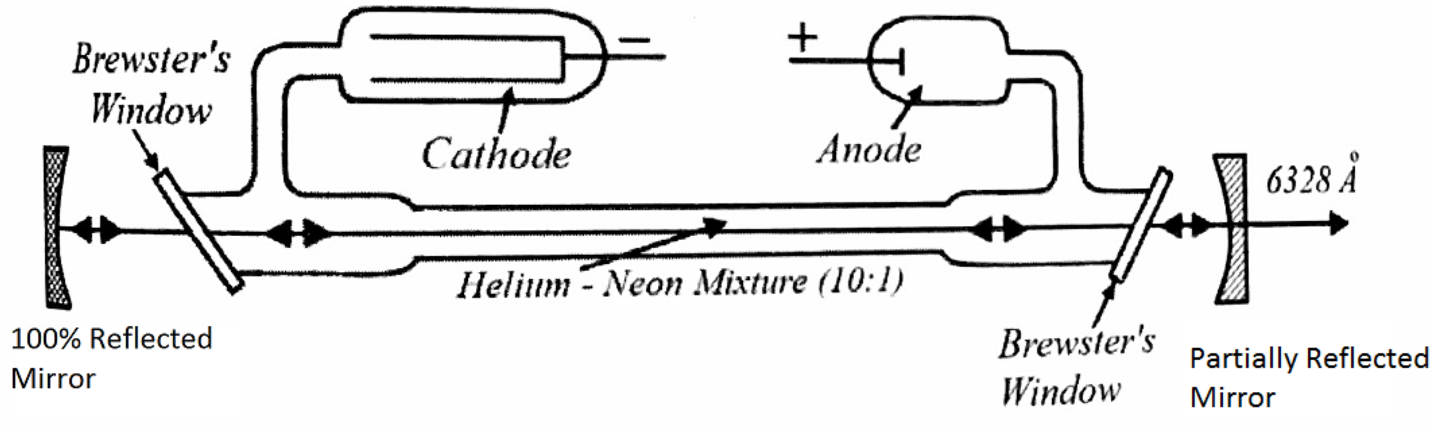
Pumping Mechanism: Electric discharge method

Resonant Cavity: The reflectors (plane or concave) R_1 and R_2 placed outside the tube.

Principle:

This laser is based on the principle of stimulated emission, produced in the active medium of gas. Here, the population inversion achieved due to the interaction between the two gases which have closer higher energy levels.

Construction of He-Ne Lasers



The gas laser consists of a fused quartz tube with small diameter. This tube filled with a mixture of neon (Ne) gas under a pressure of 0.1mm of mercury and helium (He) gas under a pressure of 1 mm of mercury. There is majority of helium atoms and minority of neon atoms.

In this method, two gases Helium & Neon were mixed in the ratio 10:1 in a discharge tube.

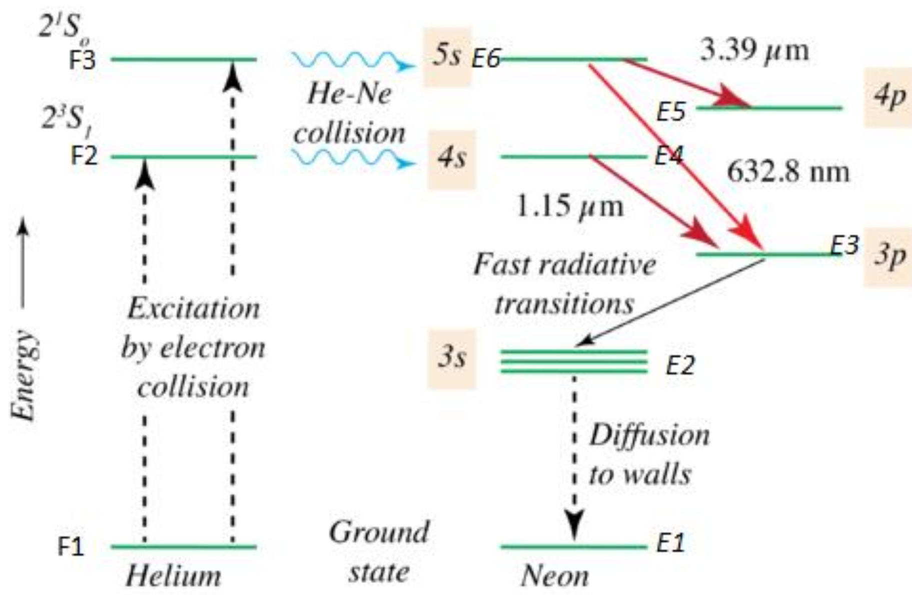
The end faces of the discharge tube are inclined at the polarizing angle so that laser light is plane polarized. Such arrangement is known as Brewster window.

At one end of the tube, there is a perfect reflector (100%) while other end is a partial reflector (<100%). These reflecting surfaces form an optical resonator.

The active material is excited by means of a high frequency generator (R.F Generator) with a frequency od several tens of MHz and an input of about 50 watt.

Working:

- When the electric discharge (fast moving electrons) is passing through the gas mixture, the electrons collide with the He gas atoms excites into higher levels F2 and F3 form F1 by absorbing the electrons energy.
- In He atoms higher levels F2 and F3, the life time of He atoms is more.
- Since F2 and F3 states are acting as metastable states, so the He atom cannot return to ground level through spontaneous emission.
- So there is a maximum possibility of energy transfer between He and Ne atoms through atomic collisions.



- When He atoms present in the levels F_2 and F_3 collide with Ne atoms present ground state E_1, the Ne atoms gets excitation into higher levels E_4 and E_6.
- Due to the continuous excitation of Ne atoms, we can achieve the population inversion between the higher levels E_4 (E_6) and lower levels E_3 (E_5).
- The various transitions $E_6 \rightarrow E_5$ and $E_6 \rightarrow E_3$leads to the emission of wavelengths 3.39µm,1.15µm and 6328Å
- The first two corresponding to the infrared region while the last wavelength is corresponding to the visible region.
- The Ne atoms present in the E_3 level are de-excited into E_2 level, by spontaneously emitting a photon of around wavelength 6000Å.
- When a narrow discharge tube is used, the Ne atoms present in the level E2 collide with the walls of the tube and get de-excited to ground level E1.
- The excitation and de-excitation of He and Ne atoms is a continuous process and thus it gives continuous laser radiations.

Characteristics of He-Ne Laser:

- Type: It is four energy levels (3 in Ne and 1 in He) laser.
- Active Medium: It uses a mixture of helium and neon gases as the active medium
- Pumping Method: Electric discharge method is used for pumping action, i.e. for achieving population inversion.
- Optical Resonator: A pair of plane mirrors facing each other is used as optical resonator.
- Frequency Output: The frequency of output beams is about 4.7×10^{14} Hz.
- Wavelength Output: The wavelength of laser output is 6328Å
- Nature of Output: The nature of output is continuous wave.
- Power Output: The power output of laser beam is 0.5-50 miliwatts.

Advantages of He-Ne Laser

- He-Ne laser has very good coherence property
- He-Ne laser can produce three wavelengths that are 1.152µm, 3.391 µm and 632.8nm, in which the 632.8nm is most common because it is visible usually in red color.
- He-Ne laser tube has very small length approximately from 10 to 100cm and best life time of 20.000 hours.
- Cost of He-Ne laser is less from most of other lasers.
- Construction of He-Ne laser is also not very complex.
- He-Ne laser provide inherent safety due to low power output.

Disadvantages of He-Ne Laser

- It is relatively low power device means its output power is low.
- He-Ne laser is low gain system/ device.
- To obtain single wavelength laser light, the other two wavelengths of laser need suppression, which is done by many techniques and devices. So it requires extra technical skill and increases the cast also.
- High voltage requirement can be considered its disadvantage.
- Escaping of gas from laser plasma tube is also its disadvantage.

Applications / Uses of He-Ne Laser

- He-Ne lasers are produced in large quantities from many years.
- Many schools / colleges / universities use this type of laser in their science programs and experiments.
- He-Ne lasers also used in super market checkout counters to read bar codes and QR codes.
- He-Ne lasers also used by newspapers for reproducing transmitted photographs.
- He-Ne lasers can be used as an alignment tool.
- It is also used in Guns for targeting.

Semi-Conductor Laser

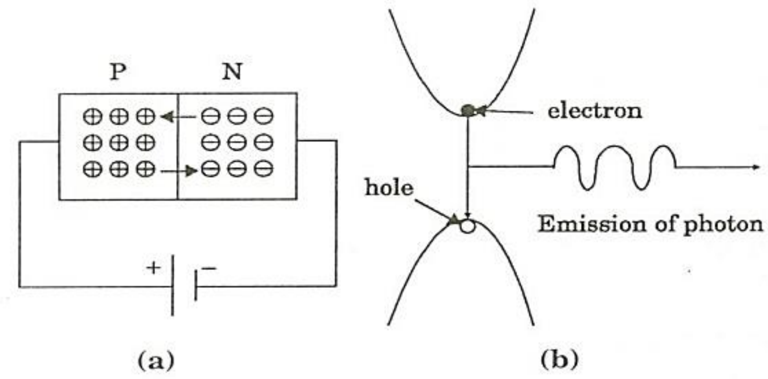
It is specifically fabricated p-n junction diode. This diode emits laser light when it is forward biased.

Principle:

When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombine with each other.

During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductors like Ga-As. This light radiation is known as recombination radiation.

The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.



Construction:

Figure shows the basic construction of semiconductor laser. The active medium is a p-n junction diode made from the single crystal of gallium arsenide (GaAs). This crystal is cut in the form of a platter having thickness of 0.5µm.

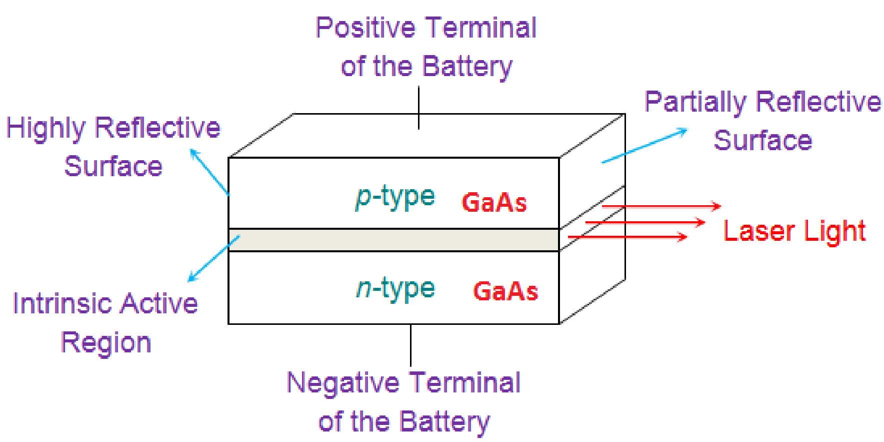


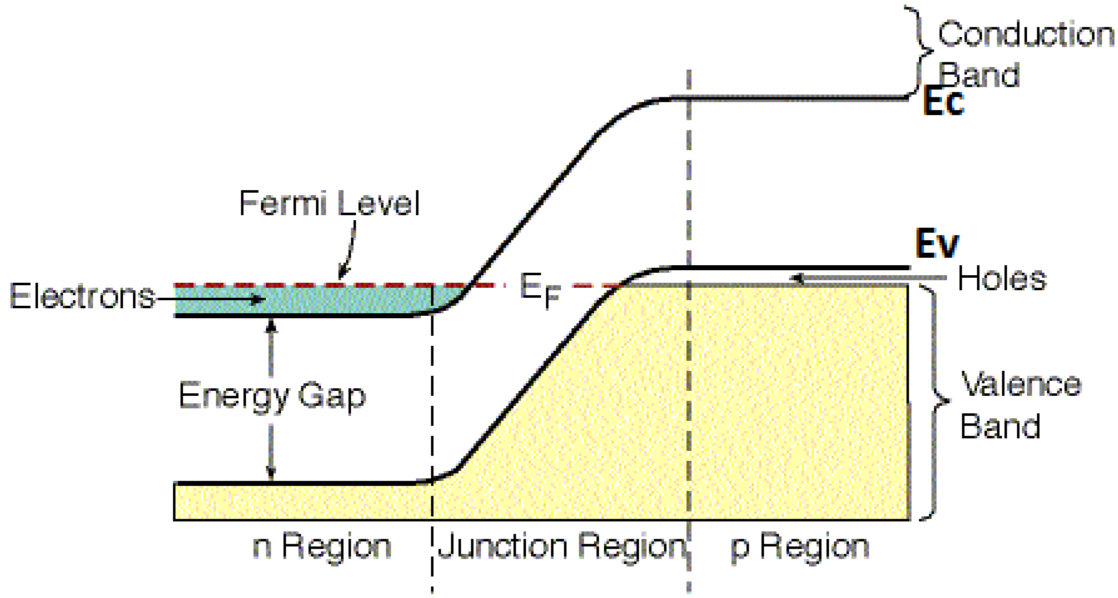
Figure **Semiconductor Laser**

The platelet consists of two parts having an electron conductivity (n-type) and hole conductivity (p-type). The photon emission is stimulated in a very thin layer of PN junction (in order of few microns). The electrical voltage is applied to the crystal through the electrode fixed on the upper surface.

The end faces of the junction diode are well polished and parallel to each other. They act as an optical resonator through which the emitted light comes out.

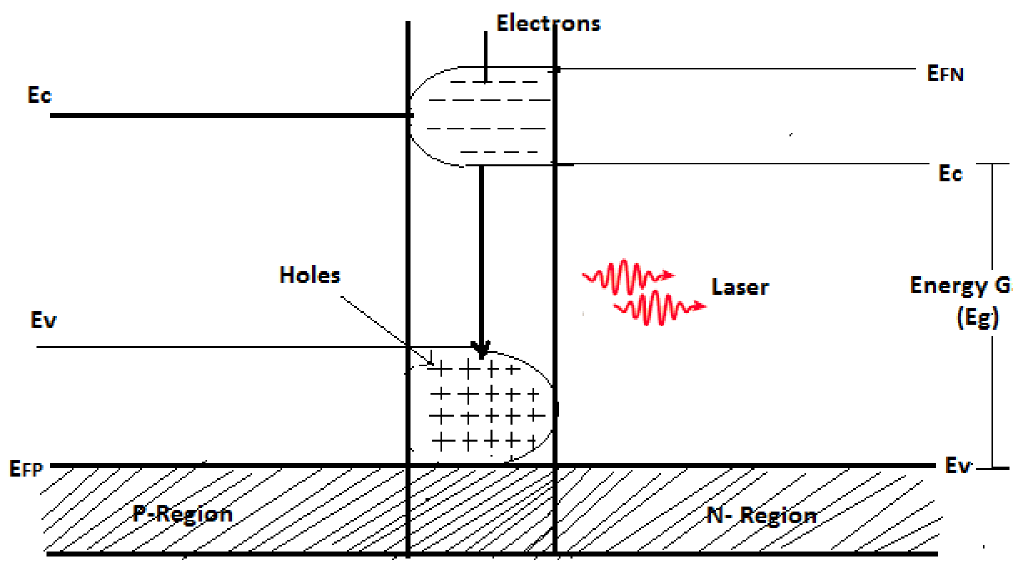
Working:

The energy band diagram of a P-N junction diode having highly doped P and N regions is shown in fig.



When a small forward bias is applied, electrons flow from conduction band on N- side to the vacant sides on P - side and hole flow to N-side. Therefore, the carriers are pumped by the applied voltage. At this state, the electron – hole recombination causes spontaneous emission.

Let us consider that the P-N junction diode is forward biased with large applied voltage. The energy level diagram in this situation shown in fig.



When applied voltage high enough, the current reaches a threshold value and in the vicinity of junction and active region is developed.

In active region, a large concentration of electrons in conduction band and a large concentration of holes in valence band gets developed. This is the of population inversion. The narrow region where the population inversion is achieved is called inversion region or active region. When electrons and holes recombine with each other, the recombination produce radiation in form of light (photons).

The photons that propagates in the junction plane, induce the conduction electrons to jump into the vacant states of valence band. The stimulated electron –hole recombination cause emission of coherent radiation. The photons moving at the plane of junction travels back and forth by reflection between two sides placed parallel and opposite to each other and flow in strength. After getting enough strength, it gives out laser beam. The wavelength of laser light is given by

$$E_g = h\nu = h\frac{c}{\lambda}$$

$$\lambda = \frac{E_g}{hc}$$

Where Eg is the band gap energy in joule

Characteristics:

1. **Type**: It is a solid state semiconductor laser.
2. **Active medium**: A P-N junction diode made from single crystal of gallium arsenide is used as an active medium.
3. **Pumping method**: The direct conversion method is used for pumping action.
4. **Power output:** The power output from this laser is 1mW.
5. **Nature of output:** The nature of output is continuous wave or pulsed output.
6. **Wavelength of Output:** gallium arsenide laser gives infrared radiation in the wavelength 6000Å to 11200 Å.

Advantages:

1. It is very small in dimension. The arrangement is simple and compact.
2. It exhibits high efficiency.
3. The laser output can be easily increased by controlling the junction current.
4. It is operated with lesser power than ruby and CO_2 laser.
5. It requires very little auxiliary equipment
6. It can have a continuous wave output or pulsed output.

Disadvantages:

1. It is difficult to control the mode pattern and mode structure of laser.
2. The output is usually from 5 degree to 15 degree i.e., laser beam has large divergence.
3. The purity and monochromacity are poor than other types of laser.
4. Threshold current density is very large (400A/mm2).
5. It has poor coherence and poor stability.

Application:

1. It is widely used in fiber optic communication
2. It is used to heal the wounds by infrared radiation

3. It is also used as a pain killer

4. It is used in laser printers and CD writing and reading

Applications of Laser in Engineering:

- **Welding and Cutting:** The highly collimated beam of a laser can be focused to a microscopic dot of extremely high energy density for welding and cutting. The automobile industry makes extensive use of carbon dioxide lasers with powers up to several kilowatts for computer controlled welding on auto assembly lines.
- **Communication:** The lasers have significant advantages in communication because they are more nearly monochromatic and this allows the pulse shape to be maintained better over long distances when used in optical fiber.
- **Barcode Scanner:** Supermarket scanners typically use helium-neon lasers to scan the universal barcodes to identify products. The laser beam bounces off a rotating mirror and scans the code, sending a modulated beam to a light detector and then to a computer which has the product information stored.
- **Laser Printing:** The laser printer has in a few years become the dominant mode of printing in offices. The laser is focused and scanned across a photoactive selenium coated drum where it produces a charge pattern which mirrors the material to be printed. This drum then holds the particles of the toner to transfer to paper which is rolled over the drum in the presence of heat.
- **CD's and Optical Discs:** The detection of the binary data stored in the form of pits on the compact disc is done with the use of a semiconductor laser.
- Surveying and Ranging: Helium-neon and semiconductor lasers have become standard parts of the field surveyor's equipment. A fast laser pulse is sent to a corner reflector at the point to be measured and the time of reflection is measured to get the distance.
- **Laser cooling:** The use of lasers to achieve extremely low temperatures has advanced to the point that temperatures of 10-9 K have been reached
- **Laser Spectroscopy:** Laser spectroscopy has led to advances in the precision with which spectral line frequencies can be measured, and this has fundamental significance for our understanding of basic atomic processes.
- **Holography:** Holography is "lens less photography" in which an image is captured not as an image focused on film, but as an interference pattern at the film.

Applications of Laser in Medical Science

- Lasers are used for bloodless surgery.

- Lasers are used to destroy kidney stones.
- Lasers are used in cancer diagnosis and therapy.
- Lasers are used for eye lens curvature corrections.
- Lasers are used in fiber-optic endoscope to detect ulcers in the intestines.
- The liver and lung diseases could be treated by using lasers.
- Lasers are used to study the internal structure of microorganisms and cells.
- Lasers are used to produce chemical reactions.
- Lasers are used to create plasma.
- Lasers are used to remove tumors successfully.
- Lasers are used to remove the caries or decayed portion of the teeth.
- Lasers are used in cosmetic treatments such as acne treatment, cellulite and hair removal.

Application in Science

- Since the laser beam can stay on at a single frequency, it can be modulated to transmit large number of messages at a time in radio, television and telephone.
- The semiconductor laser is the best light source for optical fiber communication.
- Narrow angular spread of the laser beam makes it a very useful tool for microwave communication. Communication with earth satellites and in rocketry.
- Laser is also used in accurate range finders for detecting the targets.
- The earth-moon distance has been measured with the help of lasers.
- It is used in laser Raman Spectroscopy.
- Laser beam can determine precisely the distance, velocity and direction as well as the size and form of the objects by means of the reflected signal as in radar.