Chapter = 18

"ATOMIC SPECTRA"

Atomic Spectroscopy:

The branch of physics which deals with the measurement of the wavelength and intensities of electromagnetic radiation emitted or absorbed by atoms is called Atomic spectroscopy.

Series of hydrogen spectrum:

Electron emits its energy in the form of electromagnetic radiation when it jumps from higher energy level to lower energy level. Frequency of emitted EM radiation depends upon the difference in energy between these energy levels.

These frequencies belong to the different regions of EM spectrum depending upon in which energy state electron is after losing its energy. This phenomenon gives rise to the different series of hydrogen spectrum. These series are given below

1. **Lyman Series:**

   If an electron falls from higher energy level to the ground state (n=1) it emits radiation which are in the ultra violet region of EM spectrum. $|\bar{v}|$ for Lyman series is written as

$$|\bar{v}| = \frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{n_i^2}\right)$$

2. **Balmer Series:**

   If an electron falls from higher energy level to the 1st exited state (n=2) it emits radiation which are in the visible region of EM spectrum. $|\bar{v}|$ for Balmer series is written as

$$|\bar{v}| = \frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n_i^2}\right)$$

3. **Paschen Series:**

   If an electron falls from higher energy level to the 2nd exited state (n=3) it emits radiation which are in the infrared region of EM spectrum. $|v|$ for Paschen series is written as

$$|\bar{v}| = \frac{1}{\lambda} = R_H\left(\frac{1}{3^2} - \frac{1}{n_i^2}\right)$$

4. **Brackett Series:**

   If an electron falls from higher energy level to the 3rd exited state (n=4) it emits radiation which are in the far infrared region of EM spectrum. $|\bar{v}|$ for Brackett series is written as

$$|\bar{v}| = \frac{1}{\lambda} = R_H\left(\frac{1}{4^2} - \frac{1}{n_i^2}\right)$$

5. **Pfund Series:**

   If an electron falls from higher energy level to the 4th exited state (n=5) it emits radiation which are in the far infrared region of EM spectrum. $|\bar{v}|$ for Pfund series is written as

$$|\bar{v}| = \frac{1}{\lambda} = R_H\left(\frac{1}{5^2} - \frac{1}{n_i^2}\right)$$

Bohr Atomic Model of hydrogen:

In order to develop a quantitative theory for the spectrum off the hydrogen atom, Bohr put forward the following postulates.

1. Total energy of the electron remains constant as long as it remains in the same orbit.
2. If an electron jumps from higher energy level (orbit) of energy E_i to the lower energy level (orbit) of energy E_f i-e ($E_i < E_f$), a photon of is emitted. whose frequency is given by

$$\boxed{f = \frac{E_i - E_f}{h}}$$

3. An electron moves only in those circular orbits for which its orbital angular momentum L is an integral multiple of $\hbar\left(\frac{h}{2\pi}\right)$.

$$\boxed{L = n\hbar = \frac{nh}{2\pi}}$$

Determination of Atomic Radii:

Consider a hydrogen atom as shown in figure as the electron revolving around the nucleus. Since the electro is positively charged and the nucleus is consisting of a single proton there is a columbic attractive force between

Squaring on both sides we get

$$v^2 = \frac{n^2\hbar^2}{m_e^2\, r^2}$$

Putting above in equation (a) we get

$$\frac{ke^2}{r^2} = \frac{m_e}{r} \times \frac{n^2\hbar^2}{m_e^2\, r^2}$$

$$ke^2 = \frac{n^2\hbar^2}{m_e r}$$

Separating for r we get

$$r = n^2\left(\frac{\hbar^2}{m_e k e^2}\right)$$

$$\boxed{r = n^2 a_o}$$

Where a_o is called Bohr radius and its value is given by

$$a_o = \frac{\hbar^2}{m_e k e^2}$$

$$a_o = \frac{(1.05459 \times 10^{-34})^2}{9.11 \times 10^{-31} \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2}$$

$$\boxed{a_o = 0.53\text{Å}}$$

n is called principle quantum number and it represents orbit number for the electron.

For ground state ($n = 1$) radius r_1 of orbit will be

$$r_1 = (1)^2 \times 0.53\text{Å}$$

$$r_1 = 0.53\text{Å} = a_o$$

There for Bohr radius can be defined as

"It is the radius of obit of electron in of a hydrogen atom in ground state."

Determination of the Energy of an Electron in a "Stationary State":

According to Bohr atomic theory electron does not radiate energy as long as it remains in the same orbit or energy level.

The total energy E of the electron can be written as

$$\boxed{E = K.E + P.E}$$

Kinetic Energy:

$$K.E = \frac{1}{2} m_e v^2$$

$$\frac{ke^2}{r^2} = \frac{m_e v^2}{r}$$

$$\frac{ke^2}{r} = m_e v^2$$

Separating for v^2 we get

$$v^2 = \frac{ke^2}{m_e r}$$

Putting in expression for kinetic energy we get

$$K.E = \frac{1}{2} \cancel{m_e} \frac{ke^2}{\cancel{m_e} r}$$

$$\boxed{\boldsymbol{K.E = \frac{ke^2}{2r}}}$$

Potential Energy:

Expression for electric potential is

$$V = \frac{W}{e}$$

$$P.E = -W$$

$$V = -\frac{P.E}{e}$$

$$P.E = -eV$$

Now Since

$$V = \frac{ke}{r}$$

Now potential energy can be written as

$$P.E = -e\frac{ke}{r}$$

$$\boxed{\boldsymbol{P.E = -\frac{ke^2}{r}}}$$

Total Energy:

Total energy can be written as

$$\boldsymbol{E = K.E + P.E}$$

$$E = \frac{ke^2}{2r} - \frac{ke^2}{r}$$

$$E = \frac{ke^2}{r}\left(\frac{1}{2} - 1\right)$$

$$\boxed{\boldsymbol{E = -\frac{ke^2}{2r}}}$$

Putting the value of $\boldsymbol{r}$ in above expression we get.

$$\boldsymbol{E_n = -\frac{ke^2}{2n^2 a_o}}$$

$$\boldsymbol{E_n = -\frac{1}{n^2}\left(\frac{ke^2}{2a_o}\right)}$$

Now putting values of constant and converting in to Electron-Volts we get

$$\frac{ke^2}{2a_o} = 13.6eV$$

Putting the values in expression for E_n we get

$$\boxed{E_n = -\frac{13.6eV}{n^2}}$$

Hydrogen Spectrum:

According to Bohr Atomic theory when an electron jumps from higher energy level (orbit) of energy E_i to the lower energy level (orbit) of energy E_f i-e $(E_i < E_f)$, a photon of is emitted Whose frequency is given by

$$f = \frac{E_i - E_f}{h}$$

Here

$$E_i = -\frac{1}{n_i^2}\frac{ke^2}{2a_o}$$

$$E_f = -\frac{1}{n_f^2}\frac{ke^2}{2a_o}$$

Putting values we get

$$f = \frac{1}{h}\left[-\frac{1}{n_i^2}\frac{ke^2}{2a_o} - \left(-\frac{1}{n_f^2}\frac{ke^2}{2a_o}\right)\right]$$

$$f = \frac{1}{h}\left(\frac{1}{n_f^2}\frac{ke^2}{2a_o} - \frac{1}{n_i^2}\frac{ke^2}{2a_o}\right)$$

$$f = \frac{ke^2}{2ha_o}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Now since

$$c = \lambda f$$

$$f = \frac{c}{\lambda}$$

Putting in above we get

$$\frac{c}{\lambda} = \frac{ke^2}{2ha_o}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$\frac{1}{\lambda} = \frac{ke^2}{2cha_o}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) - - - (b)$$

Now here

$$\frac{1}{\lambda} = |\bar{\nu}|$$

$|\bar{\nu}|$ is called wave number and

$$\frac{ke^2}{2hca_o} = R_H$$

Where R_H is called Rydberg constant and its numerical value is

$$\boldsymbol{R_H = 1.0970 \times 10^7 m^{-1}}$$

Now equation (b) will become

$$|\bar{v}| = \frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

X-Rays:

X-rays are high frequency (short wavelength) electromagnetic radiation. Frequency range of X-ray is from $10^{16}\,Hz$ to $10^{20} Hz$.

Frequency Range

The frequency range of these x-rays is from 30 x 10^{15} Hz to 30 x 10^{18} Hz.

Wavelength range

The wavelength range of x-rays is from 0.001 nm to 1nm.

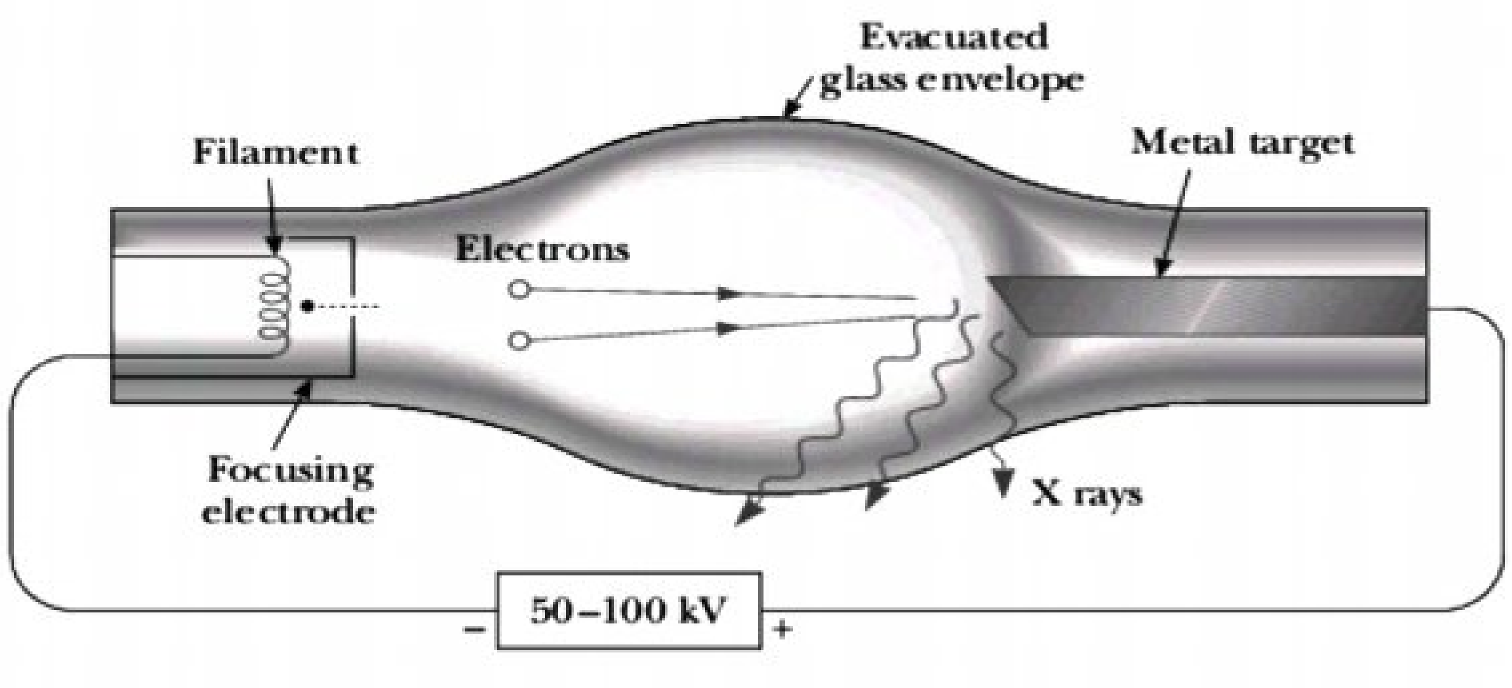
Properties of X-rays

1. X-rays have very short wavelength of the order of the same size as that diameter of an atom.
2. X-rays causes ionization in atoms or molecules.
3. They affect photographic film in the same way as visible light.
4. X-rays are stopped by metal and human bones when incident on them.
5. X-rays are not deflected by electric or magnetic field.
6. They posses high penetrating power.
7. X-rays can penetrate through optically opaque objects such as paper, wood, glass, etc.
8. X-rays travel in the straight line with a speed equal to the speed of light.
9. They can be diffracted by the crystal lattice.
10. X-rays can destroy the living cell and tissues.

Generation of X-rays:

X-rays are generated by accelerating electron to high velocity and then suddenly stopping them by collision with a solid body of atomic number greater than 10.

Typical apparatus used for X-ray generation is shown in figure.



High amount of current is passed through highly resistive filament at cathode. Cathode emits electron by thermionic emission .These electrons are accelerated to high speed by high potential difference between anode and cathode. These high speed electrons collide with Anode (of high atomic number). If potential difference is of several thousand of volt X-rays are emitted out of the anode.

Derivation:

X-rays are produced when electron strike a metal surface. These electrons are release from the heating filament and accelerated by a high voltage towards the metal target. When the electrons collide with the atoms and nuclei of the metal surface, these highly energetic particles are decelerated by the atoms and some of the kinetic energy is converted into electromagnetic energy and x-rays are produced. If the incident electrons losses the kinetic energy in more than one collision than less energetic x-rays are produced, called soft x-rays. If the incident electrons losses all the kinetic energy in one collision than high energetic x-rays are formed, called hard x-rays. If one electron completely loss its kinetic energy and photon is emitted then

Loss in kinetic energy = energy of a single photon

$$(V)(e) = (h)(\mathbf{v}_{max})$$

$$[\mathbf{v}_{max} = (c/\lambda_{min})]$$

$$(V)(e) = (h)(c/\lambda_{min})$$

$$\lambda_{min} = \frac{hc}{Ve}$$

X-Ray Spectra:

Spectral analysis of X-ray shows that

i. X-rays have continuous spectrum also called X-ray Bremsstrahling.
i. Under certain condition there is an additional line spectrum called Characteristic spectrum.

X-Ray Continuous Spectra (X-ray Bremsstrahling):

In ordinary condition, a continuous spectrum is emitted with maximum frequency directly proportional to the acceleration voltage and is nearly independent of material of which electrodes are made off.

Explanation:

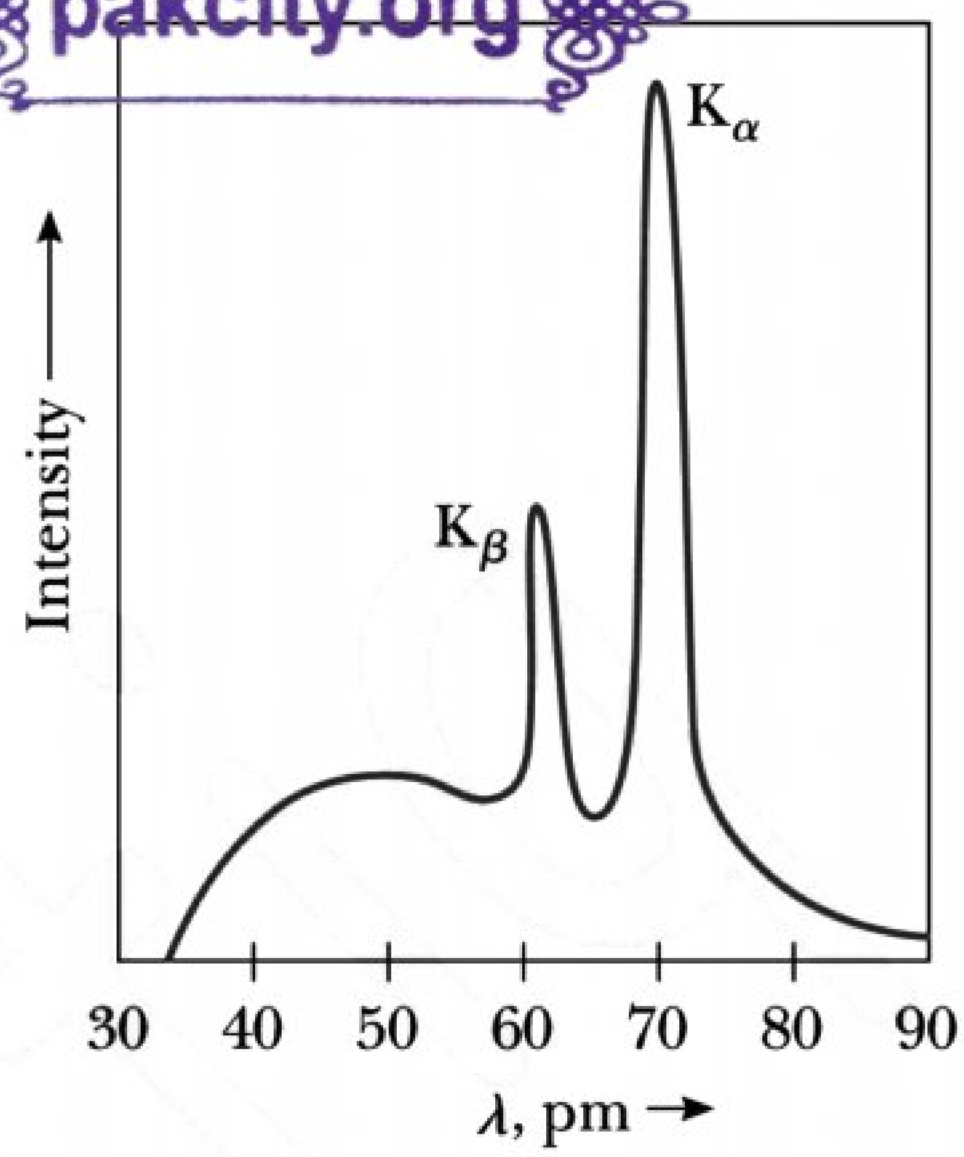
When fast moving electron from cathode passes near to the nucleus of atoms in anode nucleus attracted it toward itself by columbic force but due to the high speed of electron it passes away with some deflection due to this scattering process electron transfer some of its momentum to atom (or lose energy). Since electron can lose any amount of energy (from zero to its maximum energy eV) and therefore Continuous spectrum is obtain and whole process can be described by the equation

$$\boxed{Atom + e^- \ (fast) \longrightarrow Atom + e^-(slow) + \ hf}$$

here; hf is the energy of emitted X-ray photon.

X-ray line spectra (Characteristic Spectra):

In X-Ray spectra certain peaks high intensity peaks appear that are called X-ray line spectra (Characteristic Spectra).



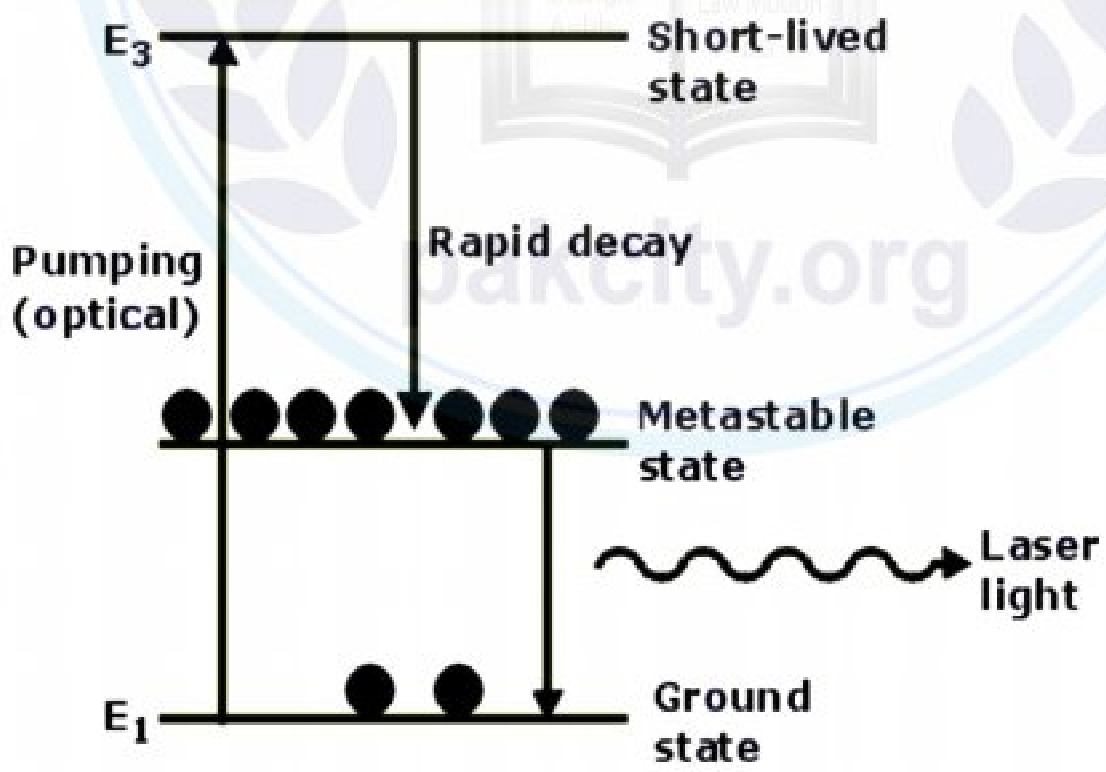
Explanation:

The process of emission of characteristic spectra takes place as follows. When a highly energetic incident electron knocks an electron from the k-shell, a vacancy occurs in that shell. This vacancy is filled by the arrival of an electron from outside the k-shell, emitting excess amount of energy in the form of photon.

If the electron jumps only one shell and returns with the emission of X-rays to Y shell, then X-rays are termed as 'Y_α' X-rays. If the electron jumps two shells and returns with emission of X-rays to suppose 'Y' shell, then X-rays are termed as 'Y_β' rays and so on, where Y may be K, L, M,......

LASER

LASER stands for *Light Amplification by Stimulated Emission of Radiation.* Laser is a device used to produce very intense, highly directional, coherent and monochromatic beam of light.



Basic Conditions to Produce Laser

1. There must be a Meta stable state in the system.
2. The system must achieve population inversion.
3. The photons emitted must be confined in the system for a time to allow them further stimulated emission.

Principle of Laser

The principle of laser production is based on the fact that atoms of a material have a number of energy levels in which at least one is Meta stable state.

The laser operation

The understand the laser operation we have to study the following processes and definitions

1. Optical pumping of atoms
2. Spontaneous emission
3. Population inversion
4. Metastable state
5. Stimulated emission
6. Amplification

Explanation:

Consider a three level atomic system having energies E_1, E_2 and E_3 respectively. Let the atoms are at ground state E_1. If photons interact with an atom in ground state, the atom absorbs the photon and reaches the excited state E_3 . We know that the excited state is an unstable state, therefore, electron must return back to ground state E_1 but such transitions are not allowed and the electron first reach the state E_2. Atoms in the state E_3 which has a life time of about 10^{-8} sec decay spontaneously from state E_3 to state E_2 which is Meta stable and has life time of 10^{-3}sec. This means that the atoms reach state E_2 much faster than they leave state E_2. This results in an increase in number of atoms in state E_2, and hence population inversion is achieved. After achieving population inversion it is exposed to a beam of photons which causes induced emission of photons and a beam of laser is produced.

Characteristics of laser light

1. Laser produces an intense beam of light.
2. Laser beam is highly monochromatic i.e. single wavelength.
3. Laser light is unidirectional.
4. It is coherent beam of visible light i.e. all parts of beam are in phase.
5. It can be focused very sharply.

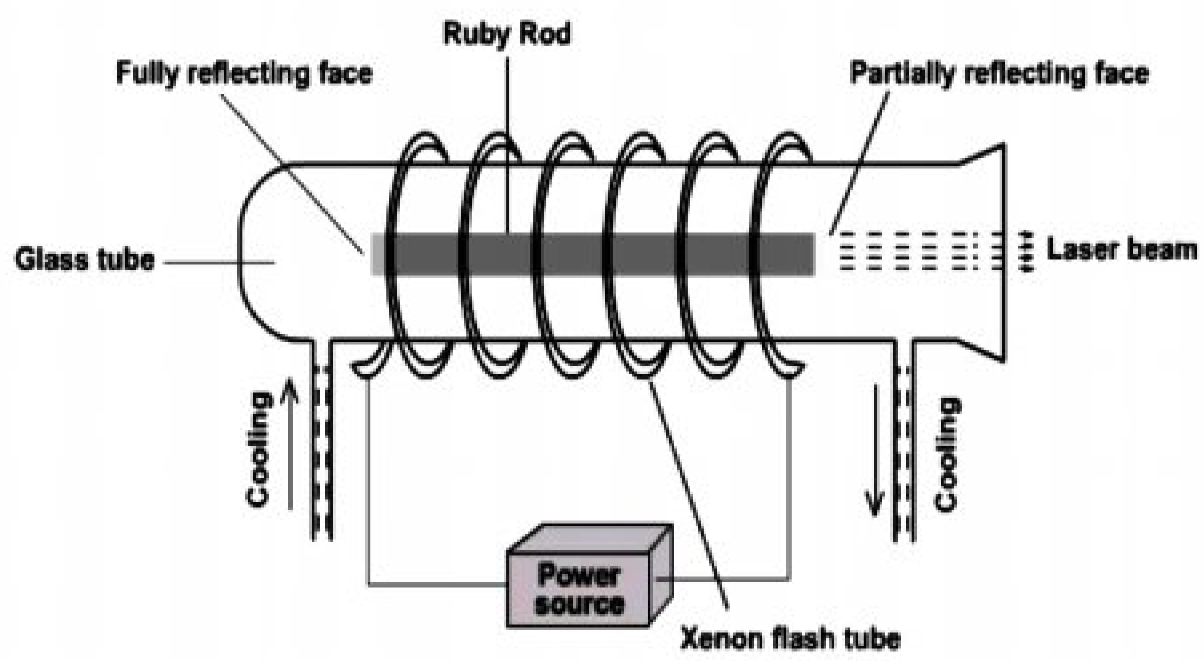
Applications of laser light

1. The laser light is used in holography in which three dimensional images of objects are formed.
2. It is used as a surgical tool for welding detached retina
3. Laser is used as a sensor to measure the distance.
4. It is used as a potential energy source including nuclear fusion reaction.
5. It is used in communication along optical fibers.
6. It is used to drill tiny holes in solid materials and for precise cutting of metals.
7. This focused beam of light is used to destroy cancerous and pre-cancerous cell.
8. The narrow intense beam of laser is used to destroy tissue in localized area.

RUBY LASER:

Construction:

Ruby is a crystal of Al_2O_3, a small number of whose Al atoms are replaced by Cr^{+3} ions. A high intensity helical flash lamp surrounding the ruby rod is used as light source to raise **Cr** atoms from state E_1 to E_3.



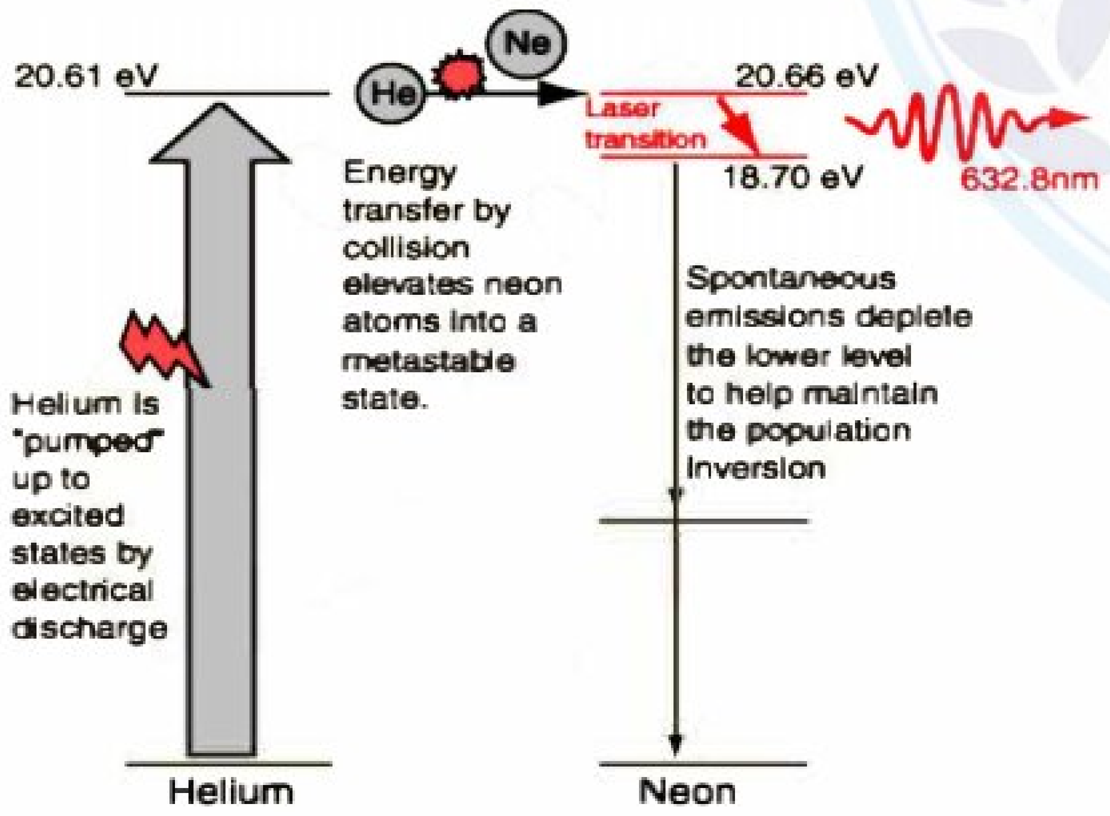
The ruby laser is a cylindrical rod with parallel, flat reflecting ends. One end is partially reflecting. The flash light is attached with the high voltage.

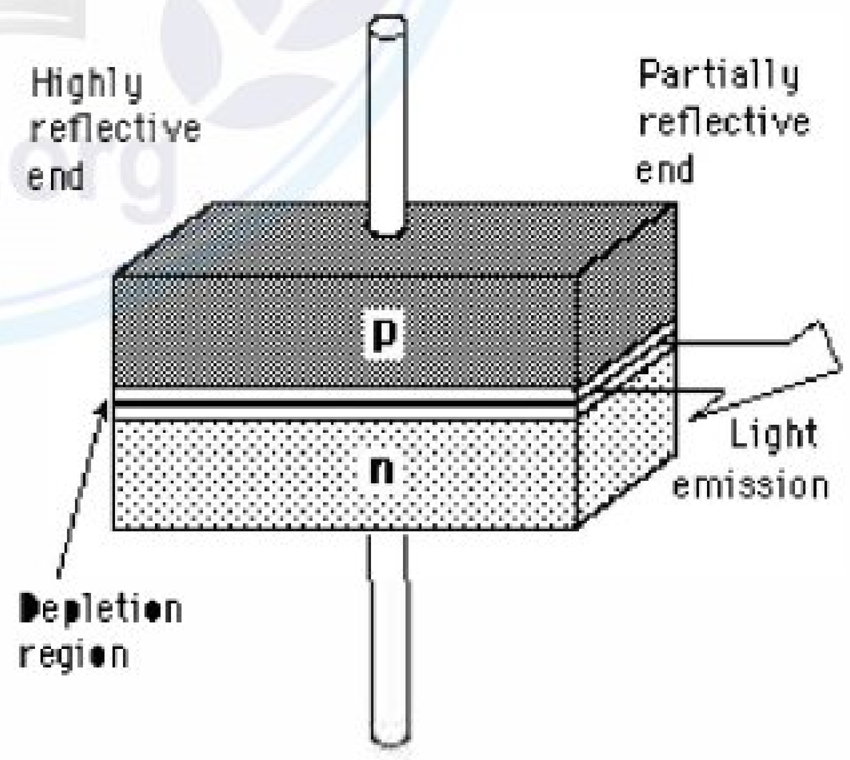
Working:

1. Electrons are raised from ground state E_1 to Excited state E_3 (optical pumping) which has a life time 10^{-8} sec.
2. The atoms from the state E_3 make transition to state E_2. Since E_2 is meta-stable state having life time equal to 10^{-3} sec.
3. As atoms reach state E_2 much faster than they leave state E_2. This results in an increase in the number of atoms in state E_2 and hence population inversion is achieved.
4. In this process few Cr atoms make spontaneous transition from E_2 to E_1 and emitted photons stimulate further transition. In this way we obtain an intense, coherent, monochromatic beam of red laser.

Helium Neon Laser

Helium Neon laser is a gas type laser and its discharge tube is filled with 85% helium gas which is used to be pumped up to excited state by electrical discharge and 15% neon gas which is used to be produce lasing action in the range 632.8 nanometer in the visible spectrum. The Metastable state of helium gas is 20.61ev and that of neon gas is 20.66ev. The high voltage electric discharge excites the electrons in helium atoms to the 20.61ev. The excited atoms of helium collide with the neon atoms and transfer its energy 20.61ev to neon atoms along with the kinetic energy of 0.05ev of moving atoms. Now the electrons in the neon gas raised to the 20.66ev state. Stimulated in the neon gas de-excite the electrons from energy level 20.66ev to an energy level 18.70ev and red laser light of wavelength 632.8 nm corresponding to energy 1.96 is produced.





The Diode Laser:

Laser action can be achieved in a p-n junction formed by two doped gallium arsenide layers. The two ends of the structure need to be optically flat and parallel with one end mirrored and one partially reflective. The length of the junction must be precisely related to the wavelength of the light to be emitted. The junction is forward biased and the recombination process produces light as in the LED (incoherent). Above a certain current threshold the photons moving parallel to the junction can stimulate emission and initiate laser action.