Chapter 20

ATOMIC SPECTRA

LEARNING OBJECTIVES

At the end of this chapter the students will be able to:

- Know experimental facts of hydrogen spectrum.
- Describe Bohr's postulates of hydrogen atom.
- Explain hydrogen atom in terms of energy levels.
- Describe de-Brogle's interpretation of Bohr's orbits.
- Understand excitation and ionization potentials.
- Describe uncertainty regarding position of electron in the atom.
- Understand the production, properties and uses of X-rays.
- Describe the terms spontaneous emission, stimulated emission, metastable states and population inversion.
- Understand laser principle.
- Describe the He-Ne gas laser.
- Describe the application of laster including holography.

Q.1 Define spectroscopy.

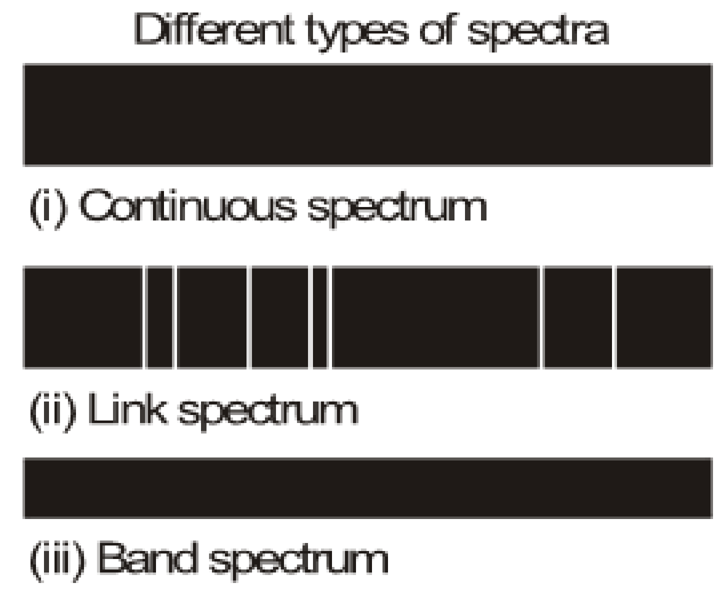
Ans. **SPECTROSCOPY**

The branch of physics which deals with the investigation of wavelengths and intensities of electromagnetic radiations emitted or absorbed by atoms. There are three types

(i) Continuous spectra

(ii) Band spectra

(iii) Line spectra or discrete spectra



(i) Continuous Spectra

The electromagnetic radiation emitted by the black body is an example of continuous spectra.

(ii) Band Spectra

The molecular spectra are the example of band spectra.

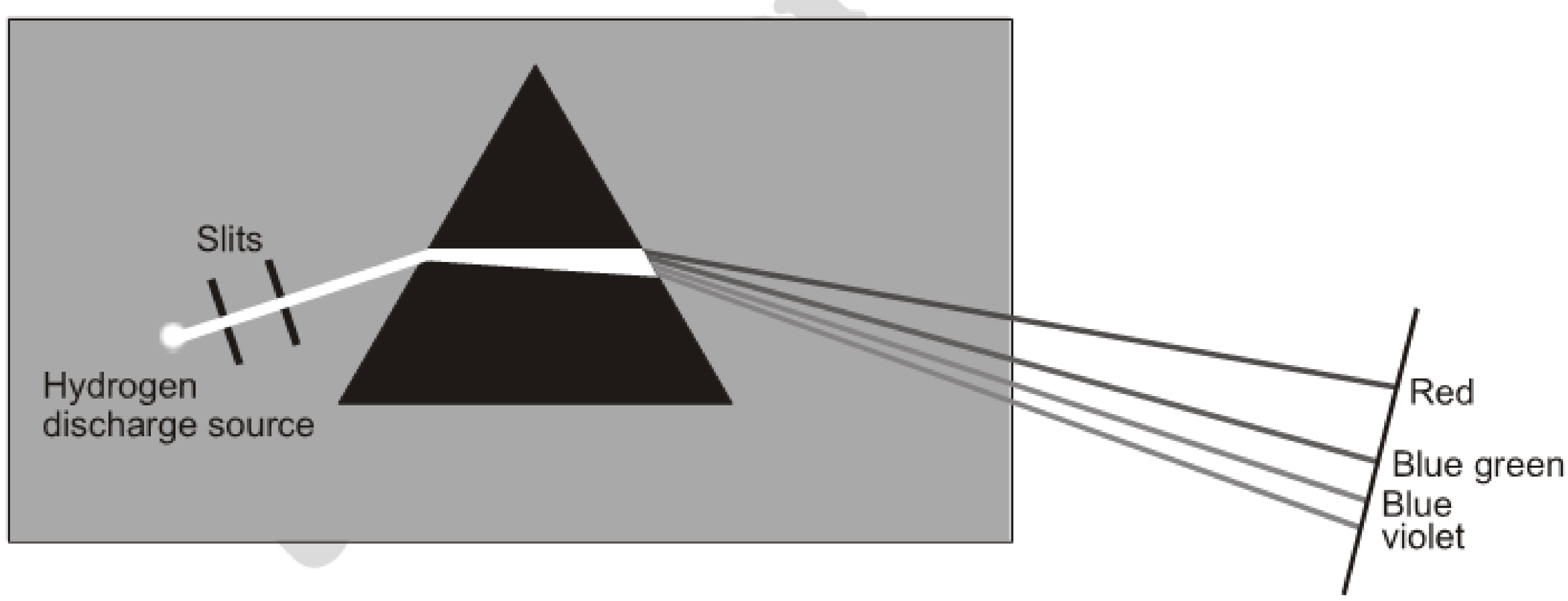
(iii) Line Spectra

The atomic spectra are the example of line spectra.

Q.2 What is atomic spectrum / spectra?

Ans. ATOMIC SPECTRUM / SPECTRA

When an atomic gas or vapour at much less than atmospheric pressure is suitably excited, usually by passing an electric current through it, the emitted radiation has a spectrum, which contains certain specific wavelengths only. An idealized arrangement for observing such atomic spectra is shown in figure. Actual spectrometer uses diffraction grating for better results. The impression on the screen is in the form of lines if the slit in front of the source S is narrow rectangle. It is for this reason that the spectrum is referred to as line spectrum. The fact that the spectrum of any element contains wavelengths that exhibit definite regularities was utilized in the second half of the 19^{th} century in identifying different elements.



These regularities were classified into certain groups called the spectral series. The first such series was identified by J.J Balmer in 1885 in the spectrum of hydrogen. This series, called the Balmer series, is shown in figure, and is in the visible region of the electromagnetic spectrum.

The results obtained by Balmer were expressed in 1896 by J.R Rydberg in the following mathematical form

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \qquad \text{...... (i)}$$

where R_H is the Rydberg's constant. Its value is $1.0974 \times 10^7\ m^{-1}$. Since then many more series have been discovered and proved helpful in predicting the arrangement of the electrons in different atoms.

Atomic Spectrum of Hydrogen

The Balmer series contain wavelengths in the visible portion of the hydrogen spectrum. The spectral lines of hydrogen in the ultraviolet and infrared regions fall into several other series. In the ultraviolet region, the Lyman series contains the wavelengths given by the formula

$$\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \qquad \ldots\ldots \text{(ii)}$$

where n = 2, 3, 4, ……

In the infrared region, three spectral series have been found whose lines have the wavelengths specified by the formulae:

Paschen series

$$\frac{1}{\lambda} = R_H\left(\frac{1}{3^2} - \frac{1}{n^2}\right) \qquad \ldots\ldots$$

(iii)

where n = 4, 5, 6, ……

Brackett series

$$\frac{1}{\lambda} = R_H\left(\frac{1}{4^2} - \frac{1}{n^2}\right) \qquad \ldots\ldots$$

(iv)

where n = 5, 6, 7, ……

Pfund series

$$\frac{1}{\lambda} = R_H\left(\frac{1}{5^2} - \frac{1}{n^2}\right) \qquad \ldots\ldots \text{(v)}$$

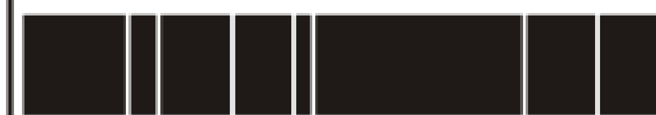
where n = 6, 7, 8, ……

The existence of these regularities in the hydrogen spectrum together with similar regularities in the spectra of more complex elements, proposes a definite test for any theory of atomic structure.

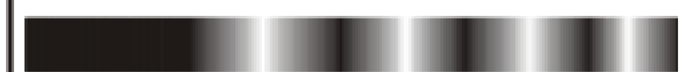
Do You Know?

Different types of spectra

(a) Continuous spectrum

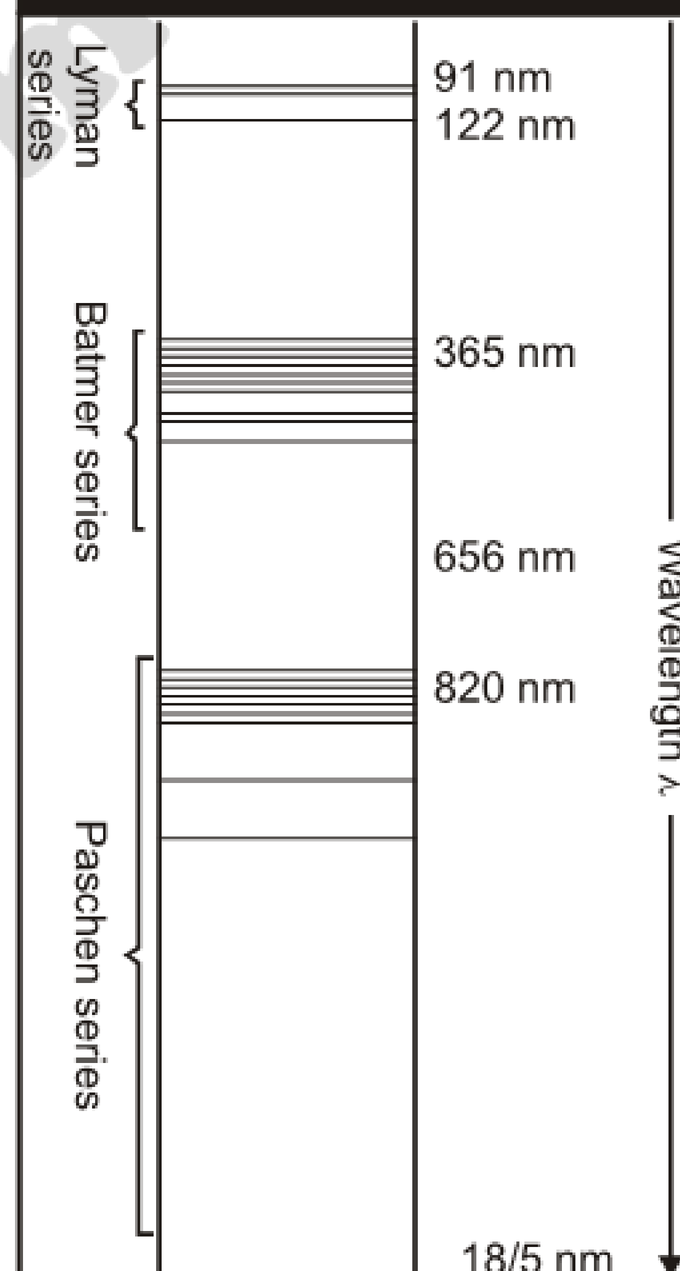


(b) Link spectrum



(c) Band spectrum

For Your Information



Line spectrum of atomic hydrogen. Only the Balmer series lies in the visible region of the electromagnetic spectrum.

Q.3 Write Bohr's second pastulate and find out formula for Bohr quantized radii.

Ans. BOHR'S MODEL OF THE HYDROGEN ATOM

In 1913 Bohr formulated a model of hydrogen atom based on classical physics and Planck's Quantum Theory. His atomic model based on the following three postulates

- An electron bound to the nucleus in an atom can moves around the nucleus in certain stationary orbits without radiating energy, these orbits are called discrete stationary states of the atom.

- Only these stationary orbits are allowed for which the angular momentum is equal to an integral multiple of $\frac{h}{2\pi}$ i.e.,

$$mvr = \frac{nh}{2\pi}$$

where n = 1, 2, 3, …… and n is called principle quantum number, m and v are the mass and velocity of the orbiting electron respectively and h is the Planck, constant.

- Whenever, an electron jumps from higher energy state E_n to the lower energy state E_p, a photon of energy hf is emitted, so that

$$hf = E_n - E_p$$

where $f = \frac{c}{\lambda}$ is the frequency of the radiation emitted.

de-Broglie's Interpretation of Bohr's Orbits

Do You Know?

At the time of formulation of Bohr theory there was no justification for the first two postulates. But postulates (III) have some roots / justification in Planck's theory. Later on, postulate (II) proved by de-Broglie. Consider a string of length l as shown in figure. If this string is put into stationary vibrations i.e., $l = n\lambda$. Suppose that, the string is bent into circle of radius r then,

$$l = 2\pi r = n\lambda$$

$$2\pi r = n\lambda$$

$$\lambda = \frac{2\pi r}{n}$$

By using de-Broglie equation

$$P = \frac{h}{\lambda}$$

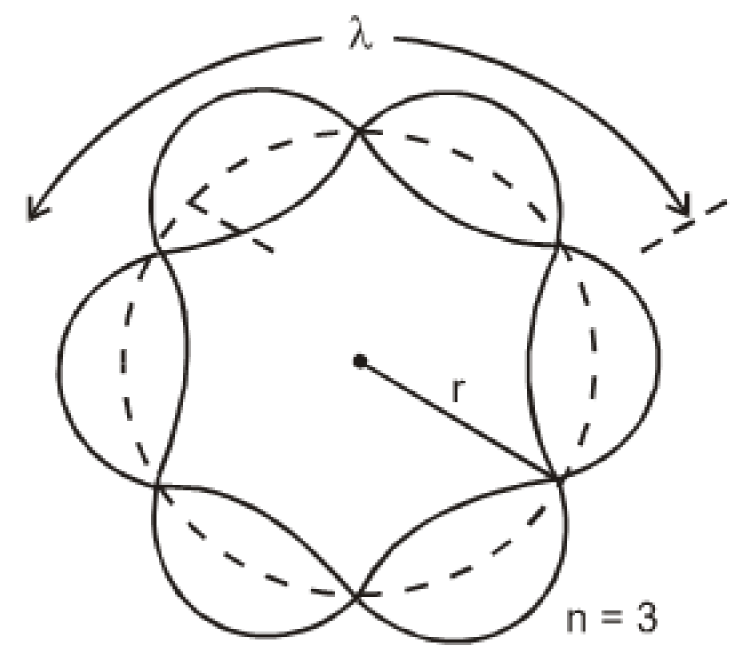
$$P = \frac{h}{2\pi r/n}$$

$$P = \frac{nh}{2\pi r}$$

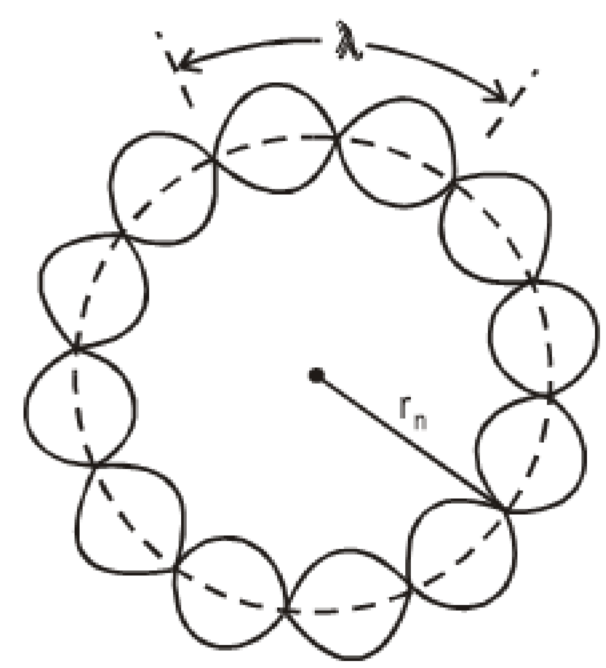
$$mv = \frac{nh}{2\pi r}$$

$$mvr = \frac{nh}{2\pi}$$

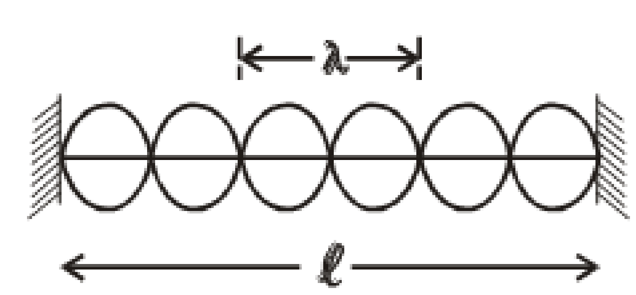
Which is postulate 1.



(a)



(b)



Stationary wave for n=3
(c)

Q.4 Define spectroscopy. Derive expression for radii of quantized orbit.

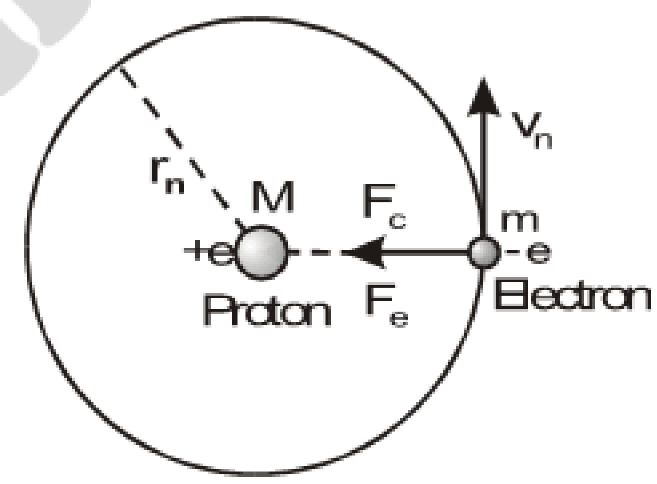
Ans. QUANTIZED RADII

Consider, a hydrogen atom in which electron is moving with velocity V_n in stationary circular orbit of radius r_n then, by using Bohr's second postulate.

$$mv_nr_n = \frac{nh}{2\pi}$$

$$v_n = \frac{nh}{2\pi mr_n} \quad \text{...... (i)}$$

In this condition the centripetal force is provided by the Coulomb's force. Therefore,



$$F_c = F_e$$

$$\frac{mv_n^2}{r_n} = \frac{ke^2}{r_n^2}$$

$$mv_n^2 = \frac{ke^2}{r_n}$$

$$r_n = \frac{ke^2}{mv_n^2} \quad \text{...... (ii)}$$

Putting the values of v_n in this equation

$$r_n = \frac{ke^2}{m\left(\frac{nh}{2\pi mr_n}\right)^2}$$

$$r_n = \frac{ke^2}{m} \times \frac{4\pi^2m^2r_n^2}{n^2h^2}$$

$$r_n = \frac{4\pi^2ke^2mr_n^2}{n^2h^2}$$

$$= \frac{4\pi^2ke^2mr_n}{n^2h^2}$$

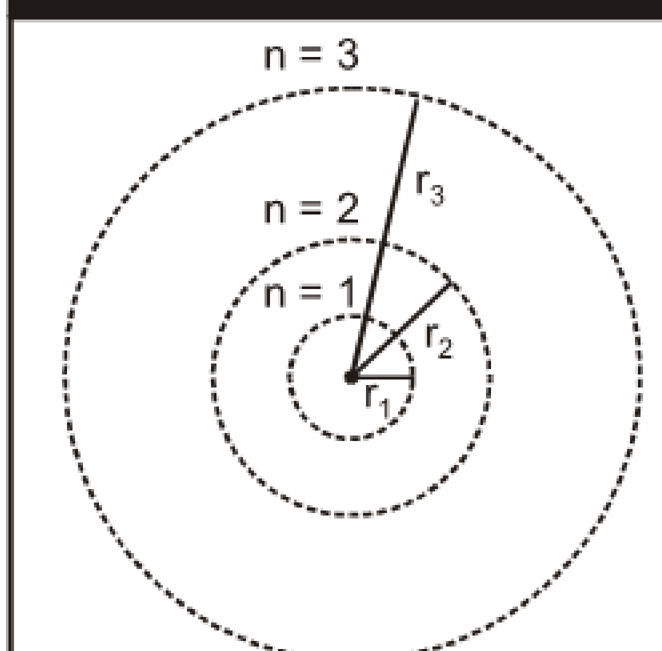
$$r_n = \frac{n^2h^2}{4\pi^2ke^2m}$$

where, $r_1 = \frac{h^2}{4\pi^2ke^2m} = 0.053 \text{ nm}$

So, $r_n = n^2r_1$

This agrees with experimental measured value and is called first Bohr's orbit radius of the H-atom.

For Your Information



The first Bohr orbit in the hydrogen atom has a radius $r_1 = 5.3 \times 10^{-11}$ m. The second and third Bohr orbits have radii $r_2 = 4r_1$ and $r_3 = 9r_1$ respectively.

This according to Bohr theory the radii of different stationary orbit of the electron in H-atom are given by

$$r_n = r_1, 4r_1, 9r_1, 16r_1, \ldots\ldots$$

Putting value of r_n from eq. (ii) in eq. (i)

$$\therefore \quad V_n = \frac{nh}{2\pi m \dfrac{ke^2}{mV_n^2}}$$

$$V_n = \frac{nhV_n^2}{2\pi ke^2}$$

$$\therefore \quad V_n = \frac{2\pi ke^2}{nh}$$

This gives speed of electron in nth orbit.

QUANTIZED ENERGY

Let us calculate the total energy E_n of the electron which is the sum of K.E and P.E that is

$$E_n = K.E + P.E \qquad \ldots\ldots \text{(i)}$$

Consider a hydrogen atom in which electron moving with velocity V_n is in stationary circular orbit of radius r_n. For this

$$F_c = F_e$$

$$\frac{mV_n^2}{r_n} = \frac{ke^2}{r_n^2}$$

$$mV_n^2 = \frac{ke^2}{r_n}$$

Multiply both sides by 1/2

$$\therefore \quad \frac{1}{2}mV_n^2 = \frac{ke^2}{2r_n}$$

$$\therefore \quad K.E. = \frac{ke^2}{2r_n}$$

and its P.E is

$$P.E = \frac{-ke^2}{r_n}$$

$$w = \frac{-ke^2}{r_n}$$

This work is stored as P.E.

$$P.E = \frac{-ke^2}{r_n}$$

$\therefore$ eq. (i) becomes

$$E_n = \frac{1}{2}\frac{ke^2}{r_n} + \left(-\frac{ke^2}{r_n}\right)$$

$$= \frac{ke^2}{2r_n} - \frac{ke^2}{r_n}$$

$$E_n = -\frac{1}{2}\frac{ke^2}{r_n}$$

But, $$r_n = \frac{n^2h^2}{4\pi^2ke^2m}$$

Then, $$E_n = -\frac{ke^2}{2 \times \frac{n^2h^2}{4\pi^2ke^2m}}$$

$$E_n = -\frac{ke^2}{2} \times \frac{4\pi^2ke^2m}{n^2h^2}$$

$$E_n = -\frac{1}{n^2}\left[\frac{2\pi^2k^2e^4m}{h^2}\right]$$

Where, $$\frac{2\pi^2 (ke^2)^2 m}{h^2} = \text{Constant} = E_o$$

So, $$E_n = -\frac{E_o}{n^2} = \frac{-13.6 \text{ eV}}{n^2}$$

Here $$E_o = 13.6 \text{ eV}$$

As electric potential due to a charge q at a distance r is $V = \frac{kq}{r}$.

From definition of potential difference a

$$V = \frac{W}{q'}$$

$$W = Vq'$$

$$\therefore \quad W = \frac{kqq'}{r}$$

$$= \frac{k(e)(-e)}{r}$$

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

This work is converted in P.E.

$$\therefore \quad P.E = -\frac{ke^2}{r_n}$$

Which is the energy required to completely remove an electron from the first Bohr orbit. This is called **Ionization Energy**. The ionization energy may be provided to the electron by collision with an external electron. The minimum potential through which this external electron should be accelerated so that it supply the requisite ionization energy is known as **ionization potential**.

Thus, for n = 1, 2, 3, ……

Then $$E_n = -E_o, \frac{-E_o}{4}, \frac{-E_o}{9}, \ldots\ldots$$

The experimentally measured value of the binding energy of the electron in H-atom is in perfect agreement with the value predicted by Bohr theory.

Normally the electron in the hydrogen atom is in the lowest energy state corresponding to n = 1 and this state is called the **ground state or normal state**. When it is in higher orbit, it is said to be in the excited state. The atom may be excited by collision with externally accelerated electron. The potential through which an electron should be accelerated so that, on collision it can lift the electron in the atom from the ground state to some higher state, is known as excitation potential. The potential through which an electron should be accelerates so that it can supply the requisite ionization energy is known as **ionization potential**.

Q.5 What is hydrogen emission spectrum?

Ans. HYDROGEN EMISSION SPECTRUM

Do You Know?

Photon must have energy exactly equal to the energy difference between the two shells for excitation of an atom but an electron with KE greater that the required difference can excite the gas atoms.

The results derived above for the energy levels along with postulate III can be used to arrive at the expression for the wavelength of the hydrogen spectrum. Suppose that the electron in the hydrogen atom is in the excited state n with energy E_n and makes a transition to a lower state p with energy E_p, where $E_p < E_n$, then

$$hf = E_n - E_p$$

where $$E_n = -\frac{E_o}{n^2} \quad \text{and} \quad E_p = -\frac{E_o}{p^2}$$

Hence $$hf = -E_o\left(\frac{1}{n^2} - \frac{1}{p^2}\right)$$

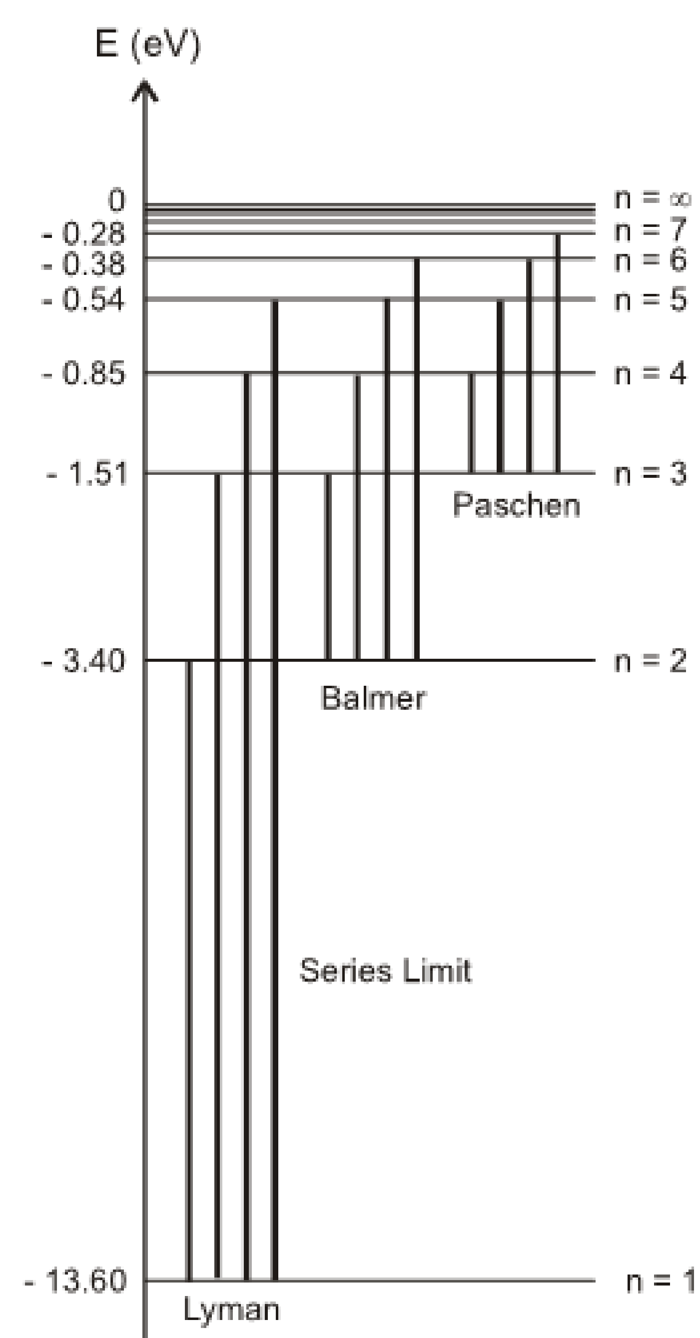
Substituting for $f = \dfrac{c}{\lambda}$

$$\frac{hc}{\lambda} = -E_o\left(\frac{1}{n^2} - \frac{1}{p^2}\right)$$

$$\frac{1}{\lambda} = \frac{E_o}{hc}\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

or $$\frac{1}{\lambda} = R_H\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

Where $R_H = \dfrac{E_o}{hc}$ and is constant called Rydberg constant. Its value is $1.0974 \times 10^7 \text{ m}^{-1}$ which agrees well with the latest measured value of H-atom.

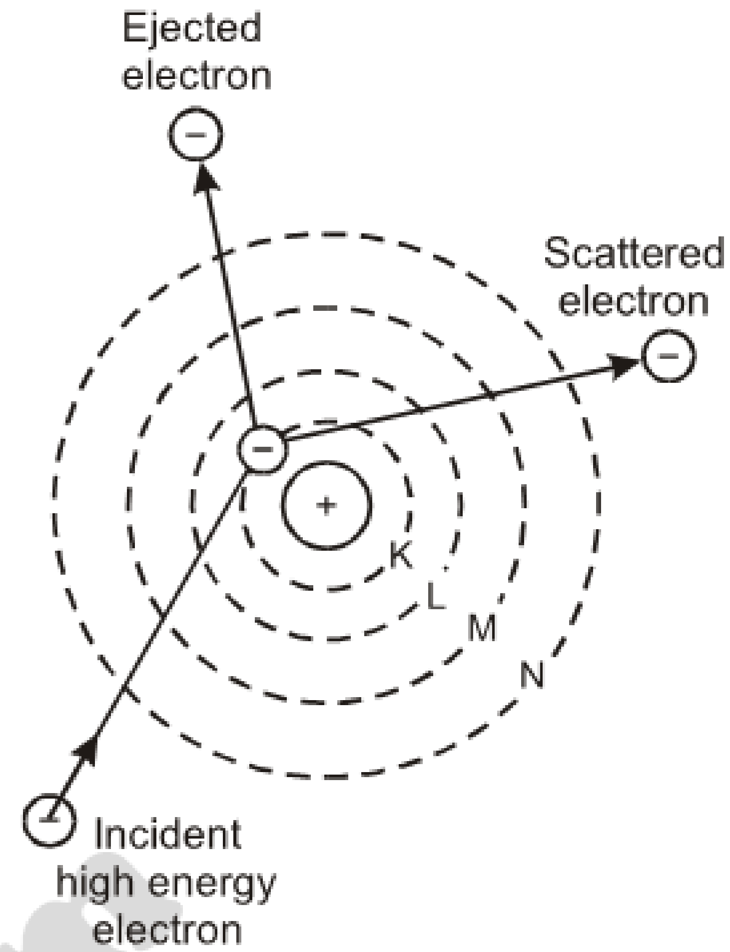


Energy level diagram for the H-atom.

Q.6 What are X-rays? How are they produced?

Ans. INNER-SHELL TRANSITIONS AND CHARACTERISTIC X-RAYS

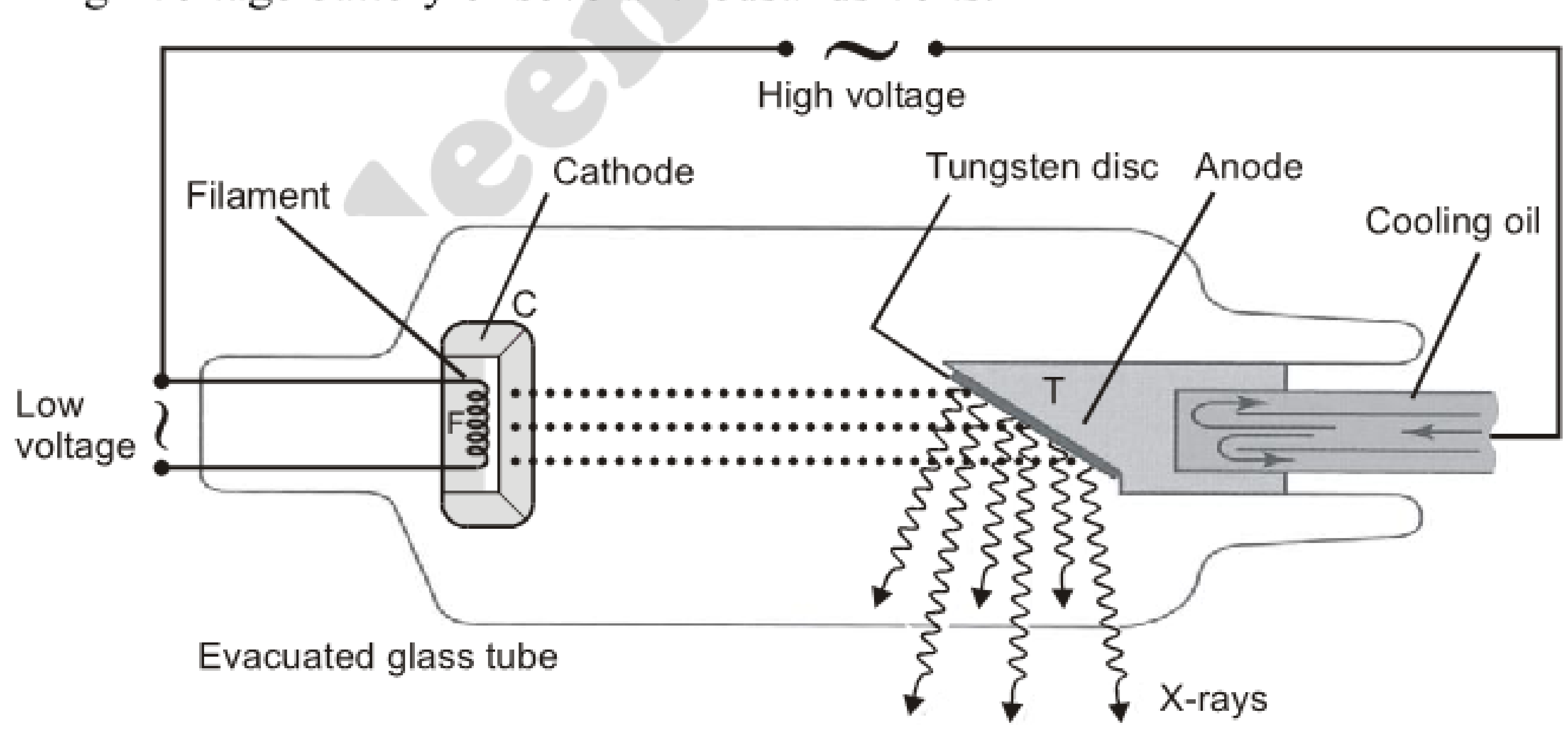
The transitions of electrons in the hydrogen or other light elements results in the emission of spectral lines in the infrared, visible or ultraviolet region of electromagnetic spectrum due to small energy difference in the transition levels. In heavy atoms, the electrons are supposed to be arranged in concentric shells named as K, L, M, N, O. The K-shell being closed to the nucleus, next is L shell and so on. The inner shell electron are tightly bounded and large amount of energy is required to excite them. After excitation, when an atom returns to the ground state photons of larger energy are emitted. Thus, transition of inner shell electron in heavy atoms gives rise to the emittion of light energy or photons or X-rays. These X-rays consist of series of wavelengths or frequencies and hence are called characteristics X-rays. The study of characteristic X-rays spectra has played a very important role in the study of atomic structure and the periodic table of elements.



Production of X-rays

The figure shows an arrangement for production of X-rays which consists of X-rays are electromagnetic radiation of short wavelength (10^{-9} m – 10^{-11} m). X-rays were discovered by Rontgen in 1895 when he was investigating cathode rays.

- An evacuated glass tube or high vacuum tube called X-rays tube.
- A source of electron, filament is used as source of electron.
- A target, usually tungsten is used as target.
- A high voltage battery of several thousands volts.



Q.7 *Explain characteristics X-rays and continuous X-ray spectra. Also write two uses of X-rays.*

Ans. **WORKING**

When the cathode is heated by filament F it emits electrons which are accelerated towards the anode T. If V is the potential difference between cathode and anode, the K.E with which the electron strikes the target is given by

$$K.E = Ve$$

Suppose that these fast moving electrons strike a target of heavy atom. It is possible that the electrons from K shell will be knocked out. Suppose that, one of the electron in the K-shell is removed creating a hole in that shell. The electron from L-shell jumps to occupy the space / hole in K-shell, emitting a photon of energy $hf_{K\alpha}$ is called **K_α, X-rays** given by

$$hf_{K\alpha} = E_L - E_K$$

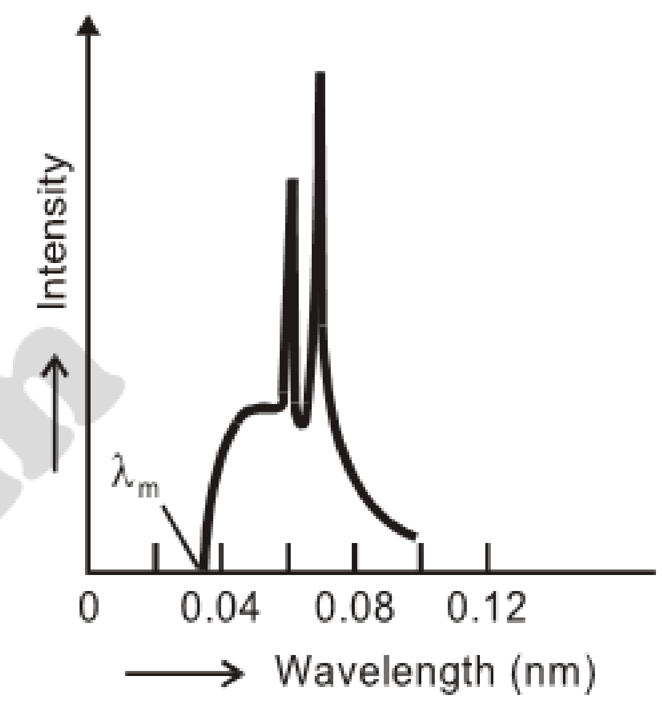
It is also possible that the electron from the M shell might also jump to occupy the hole in the K shell. The photons emitted are K_β X-ray with energies

$$hf_{K\beta} = E_M - E_K$$

these photons give rise to K_β X-ray and so on.

The photons emitted in such transitions i.e., inner shell transitions are called characteristic X-rays, because their energies depend upon the type of target material.

The holes created in the L and M shells are occupied by transitions of electrons from higher states creating more X-rays. The characteristic X-rays appear as discrete lines on a continuous spectrum as shown.



Continuous X-rays

The continuous spectrum is due to an effect known at bremsstranhlung or braking radiation. When the fast moving electrons bombared the target, they are suddenly slowed down on impact with the target. We know that an accelerating charge emits electromagnetic radiation. Hence, these impacting electrons emit radiation as they are strongly decelerated by the target. Since the rate of deceleration is so large, the emitted radiation correspond to short wavelength and so the bremsstrahlung is in the X-ray region. In the case when the electrons lose all their kinetic energy in the first collision, the entire kinetic energy appears as a X-ray photon of energy hf_{max}, i.e.,

$$K.E. = hf_{max}$$

The wavelength λ_{min} corresponds to frequency f_{max} is as shown. Other electrons do not lose all their energy in the first collision. They may suffer a number of collisions before coming to rest. This will give rise to photons of smaller energy or X-rays of longer wavelength. Thus the continuous spectrum is obtained due to deceleration of impacting electrons.

Properties and Uses of X-rays

Properties

- They are not deflected by electric and magnetic field, so, this shows that they are chargeless.
- They are diffracted by crystals.
- They cause ionization in gases.
- X-rays can cause photoelectric effect on striking some metal surface.
- X-rays are highly penetrating radiations. So, they can pass many substances.
- Since X-rays are electromagnetic waves, they exhibit wave properties such as diffraction, interference.

Uses

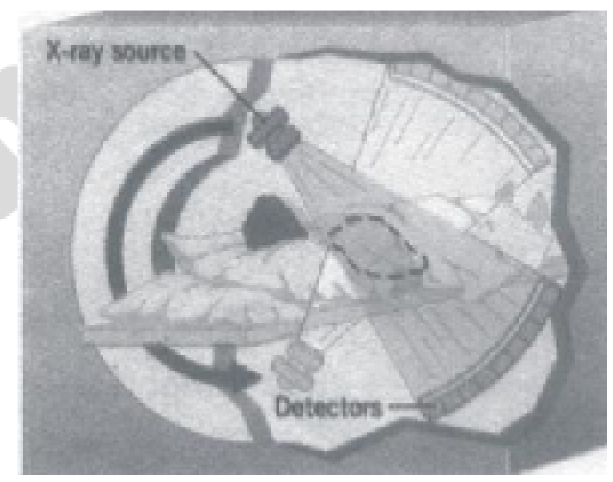
- High energy X-rays are used to destroy cancer cells with in the body.
- X-rays are used at custom and security posts to detect arms.
- X-rays are widely use in industry e.g., X-rays photographs show hidden flaws such as cracks.
- X-rays are most useful in medical treatment.
- X-rays have many practical application in medicine and industry.

Q.8 What is CAT-Scanner?

Ans. **CAT-SCANNER**

In the recent past, several vastly improved X-ray techniques have been developed. One widely used system is computerized axial tomography; the corresponding instrument is called CAT-Scanner. The X-ray source produces a thin fan-shaped beam that is detected on the opposite side of the subject by an array of several hundred detectors in a line. Each detector measures absorption of X-ray along a thin line through the subject. The entire apparatus is rotated around the subject in the plane of the beam during a few seconds. The changing reactions of the detector are recorded digitally; a computer processes this information and reconstructs a picture of different densities over an entire cross section of the subject. Density differences of the order of one percent can be detected with CAT-Scans. Tumors, and other anomalies much too small to be seen with older techniques can be detected.

Interesting Information



In CAT scanning a "fanned-out" array of X-ray beams is directed through the patient from a number of different orientations.

Q.9 What is the biological effects of X-rays?

Ans. **BIOLOGICAL EFFECTS OF X-RAYS**

X-rays cause damage to living tissue. As X-ray photons are absorbed in tissues, they break molecular bonds and create highly reactive free radicals (such as H and OH), which in turn can disturb the molecular structure of the proteins and especially the genetic material. Young and rapidly growing cells are particularly susceptible; hence X-rays are useful for selective destruction of cancer cells. On the other hand a cell may be damaged by radiation but survive, continue dividing and produce generation of defective cells. Thus X-rays can cause cancer. Even when the organism itself shows no apparent damage, excessive radiation exposure can cause changes in their productive system that will affect the organism's offspring.

Q.10 Explain the uncertainty within the atom.

Ans. **UNCERTAINTY WITH IN THE ATOM**

One of the characteristics of dual nature of atom is a fundamental limitations in the accuracy of the measurement of the position and momentum of a particle. Heisenberg showed that this is given by the equation

$$\Delta P \,.\, \Delta x \simeq h$$

or

$$\Delta P \,.\, \Delta x \geq h$$

Q. However, these limitations are significant within the atom. Whether the electron are present in a nucleus.

Ans. As the typical nuclei are less than 10^{-14} m in diameter for an electron to be confined within such a nucleus, the uncertainty in the position is of the order of 10^{-14} m. Thus the uncertainty in the electron's momentum is

$$\Delta P \geq \frac{h}{\Delta x}$$

$$\Delta P \geq \frac{6.63 \times 10^{-34}}{10^{-14}}$$

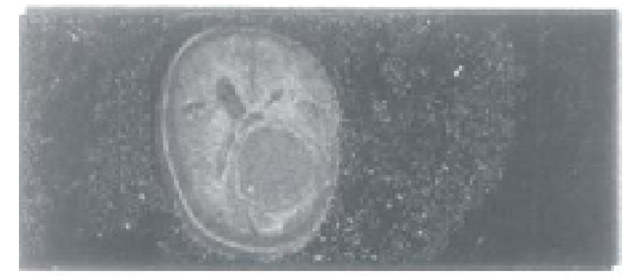
Therefore, $$m\Delta V \geq \frac{6.63 \times 10^{-34}}{10^{-14}}$$

$$\Delta V \geq \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^{-14}}$$

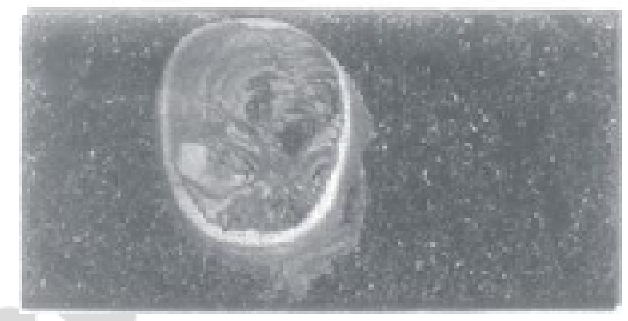
$$\Delta V \geq 7.3 \times 10^{10} \text{ m/sec.}$$

Hence, for the electron to be confined to a nucleus, its speed is greater than 10^{10} m/sec. That is greater than the speed of light. Because, this is impossible. So, we must conclude that an electron can never be inside the nucleus.

Do You Know?



(a)



(b)

(a) This two-dimensional CAT scan of a brain reveals a large intracranial tumor (colored purple). (b) Three-dimensional CAT scans are now available and this example reveals an arachnoid cyst (colored yellow) within a skull. In both photographs the colors are artificial having been computer generated to aid in distinguishing anatomical features.

Q. Can an electron reside inside the atom?

Ans. To find this we have to calculate the speed of electron by considering the radius of the H-atom, that is 5×10^{-11} m. Thus by using uncertainty principle

$$\Delta P \geq \frac{h}{\Delta x}$$

$$m\Delta V \geq \frac{h}{\Delta x}$$

$$\Delta V \geq \frac{h}{m\Delta x}$$

$$\Delta V \geq \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 5 \times 10^{-11}}$$

$$\Delta V \geq 1.46 \times 10^{7} \text{ m/sec.}$$

This speed of the electron is less than the speed of light. Therefore, the electron can exist in the atom but outside the nucleus.

Q.11 What does the word laser stand for? Write any four uses of laser.

Ans. **LASER**

The word laser stands for light amplification by the stimulated emission of radiation. A laser is the device which produces very narrow beam of light having the following properties.

- It is a monochromatic.

- It is a phase coherent.
- It is a uni-directional.

There are some requirements necessary for laser action which are:

(i) Laser active medium.

(ii) Population inversion.

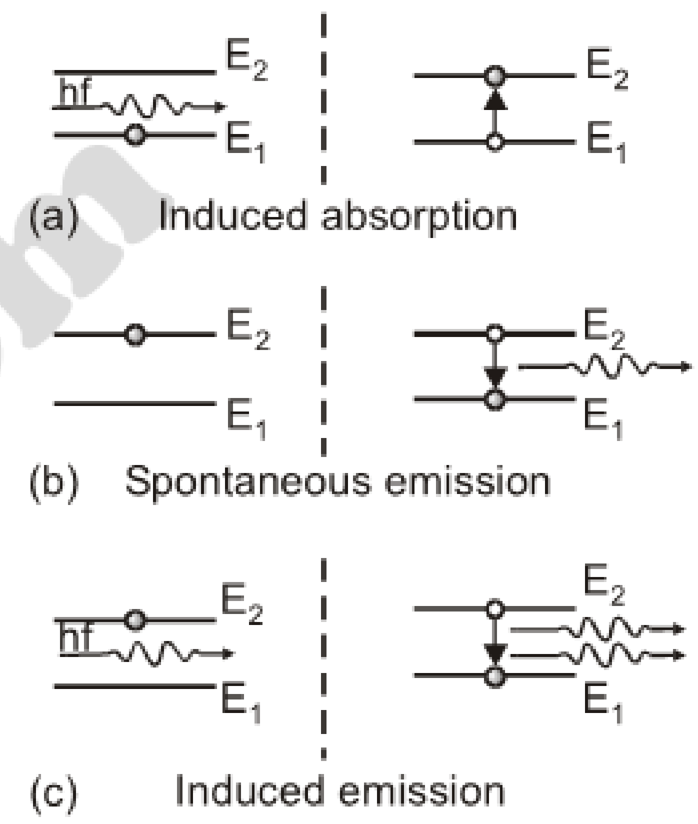
(iii) Existence of metastable state.

(iv) Stimulated emission.

(v) Resonators or reflecting mirrors.

Spontaneous and Stimulated Emissions

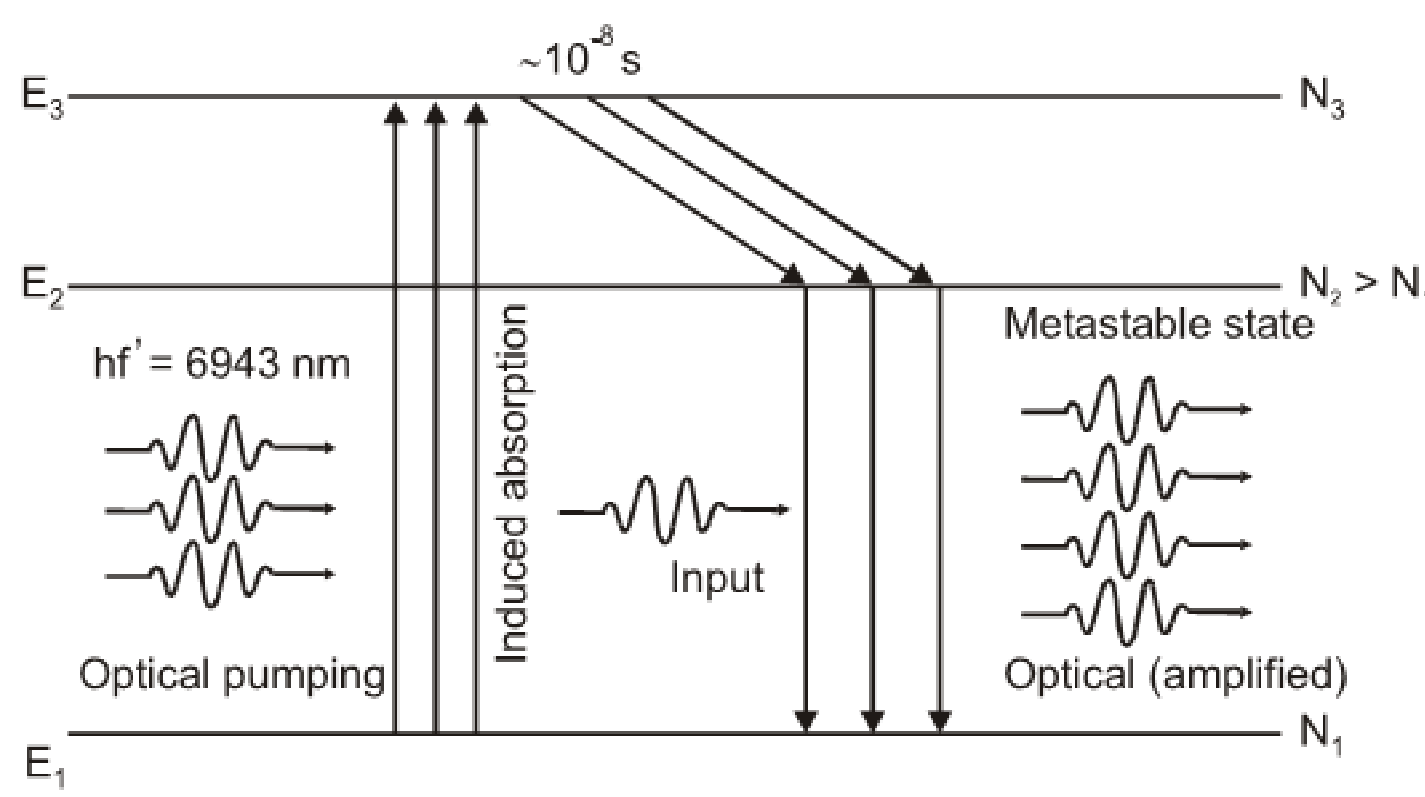
Consider a sample of free atoms some of which are in the ground state with energy E_1 and some in the excited state E_2 as shown in figure. The photons of energy $hf = E_2 - E_1$ are incident on this sample. These incident photons can interact with atoms in two different ways. In figure (a) the incident photon is absorbed by an atom in the ground state E_1, thereby leaving the atom in the excited state E_2. This process is called simulated or induced absorption. Once in the excited state, two things can happen to the atom. (i) It may decay by spontaneous emission as shown in figure (b), in which the atom emits a photon of energy $hf = E_2 - E_1$ in any arbitrary direction.



The other alternative for the atom in excited state E_2 is to decay by stimulated or induced emission as shown in figure (c). In this case the incident photon of energy $hf = E_2 - E_1$ induces the atom to decay by emitting a photon that travels in the direction of the incident photon. For each incident photon we will have two photons going in the same direction thus we have accomplished two things; an amplified as well as a unidirectional coherent beam. From a practical point this is possible only if there is more stimulated or induced emission than spontaneous emission.

Population Inversion and Laser Action

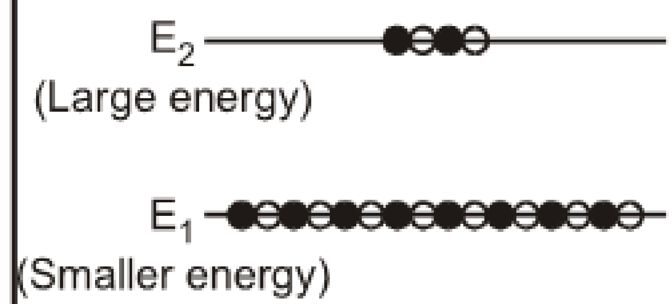
Let us consider a simple case of a material whose atoms can reside in three different states as shown in figure, state E_1 which is ground state; the excited state E_3, in which the atoms can reside only for 10^{-8} s and the metastable state E_2, in which the atoms can reside of ~ 10^{-3} s, much longer than 10^{-8} s. A metastable state is an excited state in which an excited electron is unusually stable and from which the electron spontaneously falls to lower state only



after relatively longer time. The transition from or to this state are difficult as compared to other excited states. Hence, instead of direct excitation to this state, the electrons are excited to higher level for spontaneous fall to metastable state. Let us assume that the incident photons of energy $hf = E_1 - E_3$ raise the atom from the ground state E_1 to the excited state E_3, but the excited atoms do not decay back to E_1. Thus the only alternative for the atoms in the excited state E_3 is to decay spontaneously to state E_2, the atoms reach state E_2 much faster than they leave state E_2. This eventually leads to the situation that the state E_2 contains more atoms than state E_1. This situation is known as population inversion.

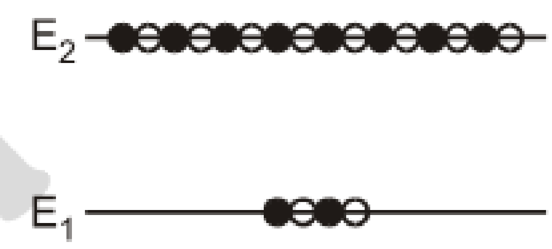
Once the population inversion has been reached, the lasing action of a laser is simple to achieve. The atoms in the metastable state E_2 are bormbarded by photons of energy $hf = E_2 - E_1$, resulting in an induced emission, giving an intense, coherent beam in the direction of the incident photon.

Do You Know?



(a) Normal population

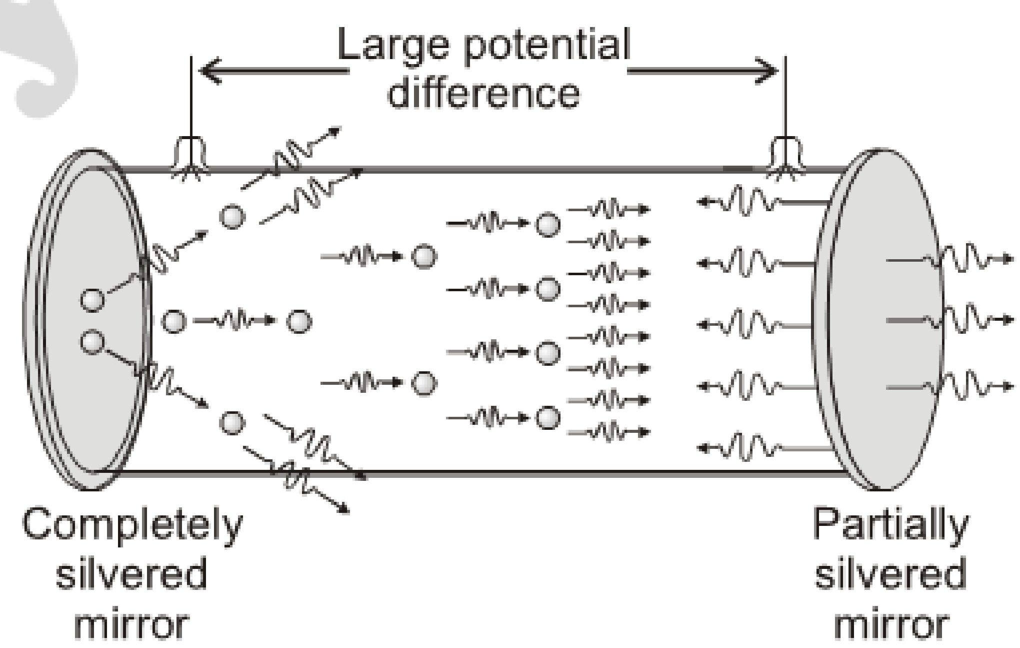
A normal population of atomic energy state, with more atomic in the lower energy state E_1 than in the excited state E_2.



(b) Population inversion

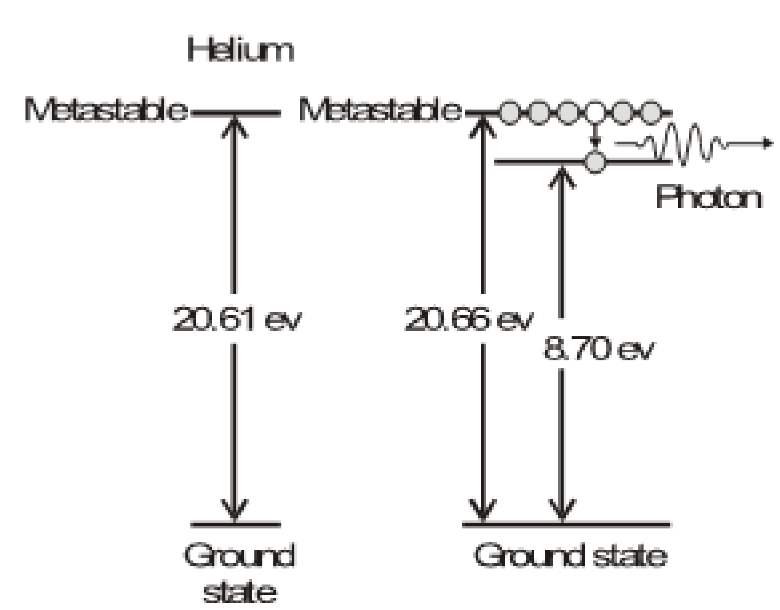
A population inversion, in which the higher energy state has a greater population than the lower energy state.

The emitted photons must be confined in the assembly long enough to stimulate further emission from other excited atoms. This is achieved by using mirrors at the two ends of the assembly. One end is made totally reflecting, and the other end is partially transparent to allow the laser beam to escape. As the photons move back and forth between the reflecting mirrors they continue to stimulate other excited atoms to emit photons. As the process continuous the number of photons multiply, and the resulting radiation is, therefore, much more intense and coherent than light from ordinary sources.



Helium-Neon Laser

It is a most common type of lasers used in physics laboratories. Its discharge tube is filled with 85% helium and 15% neon gas. The neon is the lasing or active medium in this tube. By chance, helium and neon have nearly identical metastable states, respectively located 20.61 eV and 20.66 eV level. The high voltage electric discharge excites the electrons in some of the helium atoms to the 20.61 eV state. In this laser, population inversion in neon is achieved by direct collisions with same energy electrons of helium atoms. Thus excited helium atoms collide with neon atoms, each transferring its own 20.61 eV of energy to an electron in the neon atom along with 0.05 eV of K.E. from the moving atom. As a result, the electrons in neon atoms are raised to the 20.66 eV state. In this way, a population inversion is sustained in the neon gas relative to an energy level of 18.70 eV. Spontaneous emission from neon atoms initiate laser action and stimulated emission causes electrons in the neon to drop from 20.66 eV to the 18.70 eV level and red laser light of wavelength 632.8 nm corresponding to 1.96 eV energy is generated.



Uses of Laser

(1) Laser beams are used as surgical tool, for welding detached retina.

(2) Narrow intense beam of laser can be used to destroy tissue in a localized area.

(3) Lasers are used to break the stone in human kidney.

(4) Laser can be used for telecommunication along optical fibres.

(5) A laser beam can be used to drill tiny holes in the hardest materials.

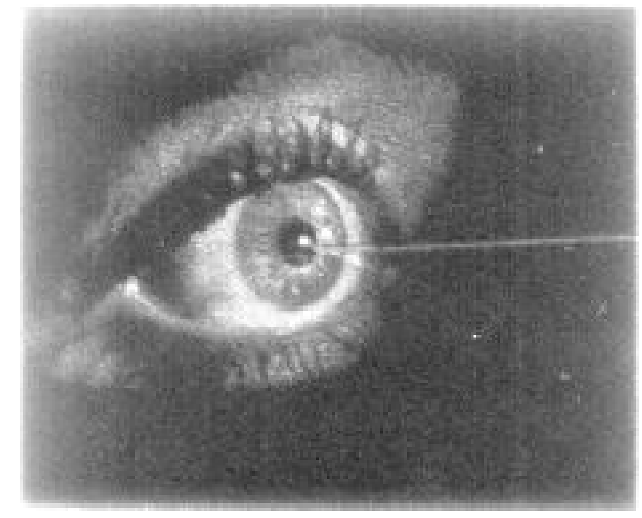
(6) Laser also have military applications and laser guided missile.

(7) A laser beam can be used to develop hidden finger print.

(8) A laser can be used for the photographic recording of output data of a computer.

(9) It can be used to generate three-dimensional images of objects in a process called **holography**.

Do You Know?



The helium-neon laser beam is being used to diagnose diseases of the eye. The use of laser technology in the field of ophthalmology is widespread.

Types of Laser

Lasers are classified into three kinds depending on the nature of the laser active medium.

(i) **Solid Laser:** In solid laser, a fluorescent crystal such as ruby, glass or a semiconductor is used as laser active medium.

(ii) **Liquid Laser:** In liquid laser, a dye dissolved in methanol is used as light amplifying substance.

(iii) **Gas Laser:** In gas laser, a mixture of gases is used as light amplifying substance. e.g., Helium-neon laser, CO_2 laser.

SOLVED EXAMPLES

EXAMPLE 20.1

Find the speed of the electron in the first Bohr orbit.

SOLUTION

By formula

$$v_n = \frac{2\pi ke^2}{hn} \qquad \text{where} \qquad n = 1$$

$$v_1 = 2 \times 3.14 \times (9 \times 10^9) \times \frac{(1.6 \times 10^{-19})^2}{6.63 \times 10^{-34}}$$

$$v_1 = 2.19 \times 10^6 \text{ ms}^{-1}$$

Result

Speed of electron $= v_1 = 2.19 \times 10^6 \text{ ms}^{-1}$