

## ATOMIC SPECTRA

**Q1:** What is spectrum? How the spectrum of light is obtained? Distinguish among continuous spectrum, band spectrum and line spectrum. (ETEA 2013)

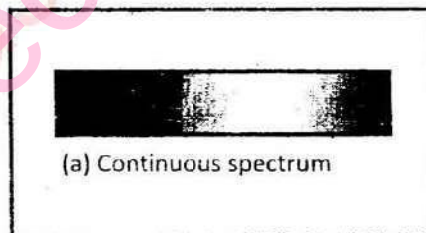
**Answer:** Spectrum:

"The particular arrangement of colours, wavelengths or frequencies of electromagnetic radiations is known as spectrum"

The spectrum of light can be obtained when light is allowed to pass through a certain device called prism.

**1. Continuous Spectrum:**

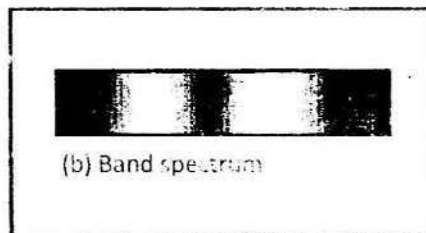
"The spectrum which is continuously distributed over a frequency region without being broken up into lines or bands is known as continuous spectrum."



**Example:** The spectrum of black body radiations is the example of continuous spectrum.

**2. Band Spectrum:**

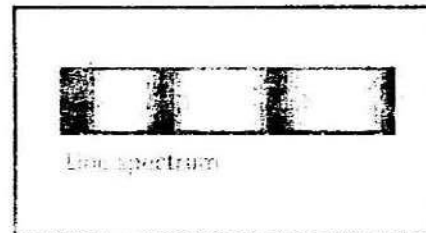
"The spectrum which consists of groups or bands of closely spaced lines is called band spectrum."



**Example:** The spectrum of molecules of gases and chemical compounds is the example of band spectrum.

**3. Line Spectrum:**

"The spectrum which consists of discrete values of energy or frequencies is known as line spectrum."



**Example:** Atomic spectra is the example of line spectrum.

**Q2: Discuss the spectrum of H-atom. Discuss its various features. Write a formula for representing the different series of H-atoms.**

Answer:

The atom of hydrogen is the simplest atom in nature. It consists of one proton and one electron.

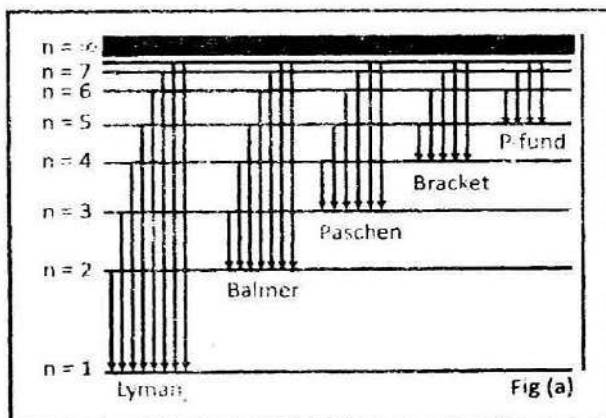
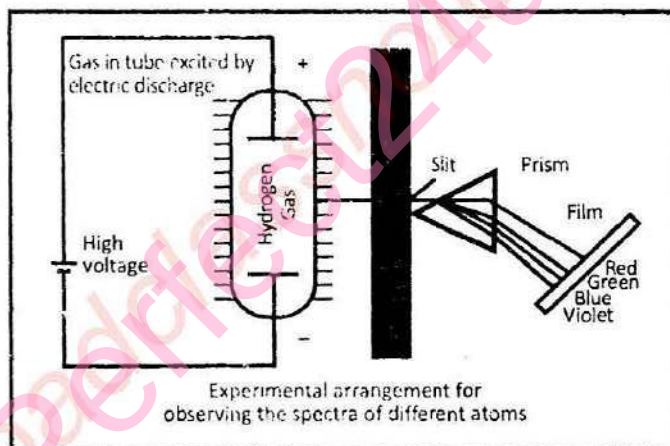
In order to get the spectrum of H-atom, consider a hydrogen gas is filled in a discharge tube as shown in the figure.

Now due to very high voltage, the hydrogen gas becomes excited. The beam of excited hydrogen is then allowed to pass through a slit and then falls on the prism. The prism disperse the beam into a spectrum of various colours ranging from violet,....., and ends at red colours as shown in the figure.

The spectrum of H-atom was first studied by Balmer in 1885. He derived a general formula for various spectral series of H-atom, which is given below:

$$\frac{1}{\lambda_n} = R \left[ \frac{1}{n_i^2} - \frac{1}{n_f^2} \right] \quad (1)$$

In equation (1) "R" is called Rydberg constant. Its value is  $1.097 \times 10^7 \text{ m}^{-1}$ . "n<sub>i</sub>" represents the lower orbit and "n<sub>f</sub>" represents the higher orbit. The spectrum of H-atom consists of the following series:



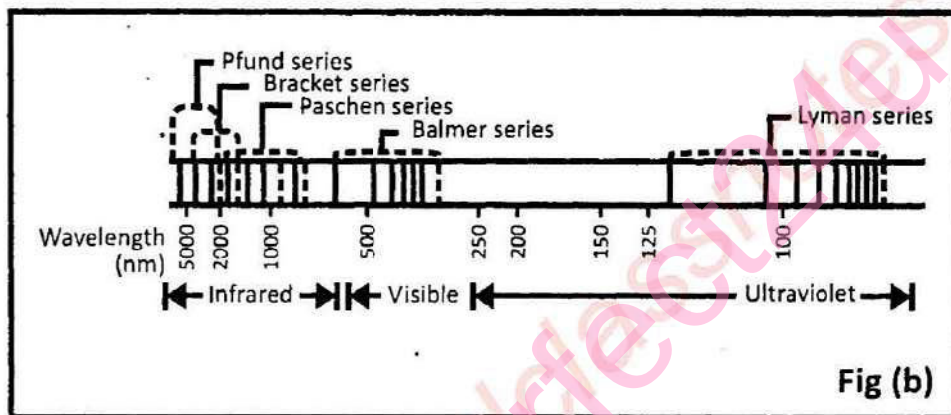
### 1. Lyman Series:

This series lies in the ultraviolet region of hydrogen spectrum. In case of Lyman series, the electrons jump from outer orbits to first orbit, as shown in the figure (a). Thus we have,

$$n_i = 1 \text{ and } n_f = n = 2, 3, 4, 5, \dots$$

thus equation (1)  $\Rightarrow$

$$\frac{1}{\lambda_n} = R \left[ \frac{1}{1^2} - \frac{1}{n^2} \right]$$



### 2. Balmer Series:

The Balmer series lies in the visible region of H-spectrum. In case of Balmer series, the electrons jump from outer orbits to 2<sup>nd</sup> orbit, as shown in the figure. Thus we have,  $n_i = 2$ ,  $n_f = n = 3, 4, 5, 6, \dots$  so equation (1)  $\Rightarrow$

Formula:

$$\begin{array}{ccccc} L & B & P & B & P \\ 1 & 2 & 3 & 4 & 5 \end{array}$$

$$\frac{1}{\lambda_n} = R \left[ \frac{1}{2^2} - \frac{1}{n^2} \right]$$

### 3. Paschen Series:

This series lies in the infrared region of H-spectrum. In case of Paschen series the electron jumps from outer orbits to 3<sup>rd</sup> orbit, as shown in the figure. Thus we have,  $n_i = 3$  and  $n_f = n = 4, 5, 6, 7, \dots$  so equation (1)  $\Rightarrow$

$$\frac{1}{\lambda_n} = R \left[ \frac{1}{3^2} - \frac{1}{n^2} \right]$$

#### 4. Bracket Series:

This series lies in the infrared region of H-spectrum. In case of bracket series, the electron jumps from outer orbits to the fourth orbit, as shown in the figure. Thus we have,  $n_i = 4$ ,  $n_f = n = 5, 6, 7, \dots$  so equation (1)  $\rightarrow$

$$\frac{1}{\lambda_n} = R \left[ \frac{1}{4^2} - \frac{1}{n^2} \right]$$

#### 5. Pfund Series:

This series lies in the far infrared region of H-spectrum. In case of pfund series, the electron jumps from outer orbits to the fifth orbit, as shown in the figure. Thus we have,  $n_i = 5$  and  $n_f = n = 6, 7, 8, 9, \dots$  so equation (1)  $\Rightarrow$

$$\frac{1}{\lambda_n} = R \left[ \frac{1}{5^2} - \frac{1}{n^2} \right]$$

Q3: Discuss the Bohr's model of H-atom. (OR)

Discuss the Bohr's postulates about hydrogen atom.

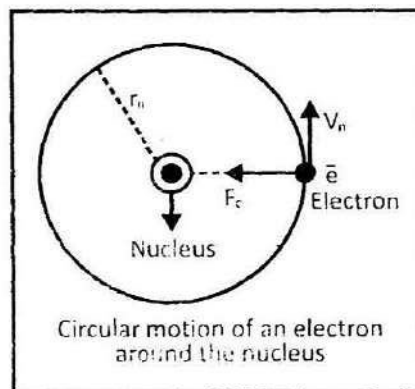
Answer: Bohr's Model of H-Atom: (ETEA 2008-10)

In 1913, Bohr presented his atomic model, which consists of the following postulates:

1. There is electrostatic force of attraction between electrons and the nucleus.
2. The electrons revolve around the nucleus only in those orbits, for which the angular momentum of electron is given by,

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

3. The electrons revolve around the nucleus in specific orbits. Its energy remains the same as far as it remains in its specific orbit.
4. When the electron jumps from higher energy orbit " $E_h$ " to lower energy orbit " $E_l$ ", it emits energy which is equal to the energy of photon i.e.



$$E = E_h - E_L \Rightarrow hf = E_h - E_L$$

**Q4: Using Bohr's theory, find an expression for the radii of a quantized orbit. (ETEA 2015)**

**Answer: Radii of the Quantized Orbit:**

According to Bohr's postulate, there is electrostatic force of attraction between proton and electron of H-atom. So we have,

$$F_e = k \frac{e \cdot e}{r_n^2} \Rightarrow F_e = k \frac{e^2}{r_n^2} \quad (1)$$

- The electrostatic force compels the electron to perform circular motion. So this force acts as centripetal force i.e.

$$F_e = F_c$$

$$\Rightarrow F_e = \frac{mv_n^2}{r_n} \quad (2)$$

Comparing equations (1), (2), we get,

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

$$\Rightarrow \frac{Ke^2}{r_n} = mv_n^2$$

$$\Rightarrow \frac{r_n}{Ke^2} = \frac{1}{mv_n^2}$$

$$\Rightarrow r_n = \frac{Ke^2}{mv_n^2} \quad (3)$$

From Bohr's 2<sup>nd</sup> postulate, we have,

$$mv_n r_n = \frac{nh}{2\pi} \Rightarrow v_n = \frac{nh}{2\pi m r_n} \quad (4)$$

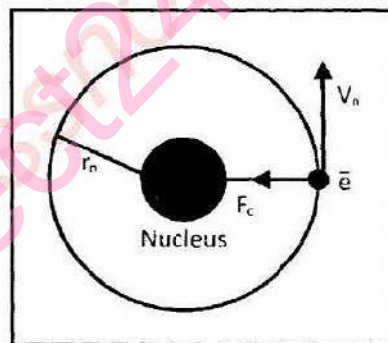
Putting equation (4) in equation (3), we get,

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

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

$$\Rightarrow 1 = \left( \frac{4\pi^2 Ke^2 m}{n^2 h^2} \right) r_n$$

$$\Rightarrow r_n = \frac{n^2 h^2}{4\pi^2 Ke^2 m} \quad (5)$$



Putting the values of  $h$ ,  $k$ ,  $e$  and  $m$  in equation (5), we get,

$$r_n = n^2 \left[ \frac{(6.63 \times 10^{-34})^2}{(4 \times (3.14)^2 \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2 \times 9.1 \times 10^{-31})} \right]$$

$$\Rightarrow r_n = n^2 \times 0.53 \times 10^{-10} \text{ m} \quad (6)$$

As  $10^{-10} \text{ m} = 1 \text{ \AA}$ , so equation (6)

$$r_n = n^2 \times 0.53 \text{ \AA} \quad (7)$$

Equations (6), (7) represent the radii of any orbit. In equation (7) "n" is an integer and is called quantum number. Equations (6), (7) show that the orbits of electrons are quantized. In case of H-atom, we put  $n = 1$ , so equation (7)

$$r_1 = (1)^2 \times 0.53 \text{ \AA}$$

$$\Rightarrow r_1 = 0.53 \text{ \AA} \quad (8)$$

Putting equation (8) in equation (7), we get,

$$r_n = n^2 \times r_1 \quad (9)$$

In general, the radii of different stationary orbits of the electron in hydrogen atom can be written as,

$$r_n = r_1, 4r_1, 9r_1, 16r_1, 25r_1, \dots$$

**Q5:** Using Bohr's theory, find an expression for the energy of electron in quantized orbit.

**Answer:** Energy of Electron in Quantized Orbit: (ETEA 2012)

The energy of an electron in a certain orbit is equal to the sum of K.E and P.E, so we have,

$$E_n = K.E + P.E \quad (1)$$

We know that,

$$K.E = \frac{1}{2} m v_n^2 \quad (2)$$

The P.E of an electron in a certain orbit " $r_n$ " is given by,

$$P.E = \frac{-K e^2}{r_n} \quad (3)$$

Putting equations (2), (3) in equation (1), we get,

$$E_n = \frac{1}{2} m v_n^2 - \frac{K e^2}{r_n} \quad (4)$$

According to Bohr's 1<sup>st</sup> postulate, we have,

$$\begin{aligned}
 F_c &= F_e \\
 \Rightarrow \frac{Ke^2}{r_n^2} &= \frac{mV_n^2}{r_n} \\
 \frac{Ke^2}{r_n} &= mV_n^2 \\
 \Rightarrow V_n^2 &= \frac{Ke^2}{r_n m} \quad \text{--- (5)}
 \end{aligned}$$

Putting equation (5) in equation (4), we get,

$$\begin{aligned}
 E_n &= \frac{1}{2} m \frac{Ke^2}{r_n m} - \frac{Ke^2}{r_n} \\
 \Rightarrow E_n &= \frac{Ke^2}{2r_n} - \frac{Ke^2}{r_n} \\
 \Rightarrow E_n &= \frac{(Ke^2 - 2Ke^2)}{2r_n} \\
 \Rightarrow E_n &= \frac{-Ke^2}{2r_n} \quad \text{--- (6)}
 \end{aligned}$$

We know that the radii of quantized orbit is given by,

$$r_n = \frac{n^2 h^2}{4\pi^2 K e^2 m} \quad \text{--- (7)}$$

Putting equation (7) in equation (6), we get,

$$\begin{aligned}
 E_n &= -Ke^2 \times \frac{4\pi^2 K e^2 m}{2 \times n^2 h^2} \\
 \Rightarrow E_n &= -\frac{1}{n^2} \left[ \frac{2\pi^2 K^2 e^4 m}{h^2} \right] \quad \text{--- (8)}
 \end{aligned}$$

Putting the values of K, e, m and h in equation (8), we get,

$$\begin{aligned}
 E_n &= -\frac{1}{n^2} \left[ \frac{2 \times (3.14)^2 \times (9 \times 10^9)^2 \times (1.6 \times 10^{-19})^4 \times 9.1 \times 10^{-31}}{(6.63 \times 10^{-34})^2} \right] \\
 \Rightarrow E_n &= -\frac{1}{n^2} [2.17 \times 10^{-18} \text{ J}] \quad \text{--- (9)}
 \end{aligned}$$

$$\text{or } E_n = -\frac{1}{n^2} \left[ \frac{2.17 \times 10^{-18}}{1.6 \times 10^{-19}} \right] \text{ eV} \quad [1\text{eV} = 1.6 \times 10^{-19} \text{ J}]$$

The electron revolves around the nucleus due to electrostatic force of attraction of the nucleus. So the nucleus do work on electron which appears in the form of P.E in the electrons. Now work = F · r

$$\Rightarrow P.E = F \cdot r$$

$$\Rightarrow P.E = \frac{Ke^2}{r^2} \cdot r$$

$$\Rightarrow P.E = \frac{Ke^2}{r}$$

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

The negative sign shows that the electrons is directed towards the nucleus.

$$\Rightarrow E_n = -\frac{1}{n^2} \times (13.6) \text{ eV} \quad \text{---(10)}$$

Using equations (9), (10), we can calculate the energy of electron in any quantized orbit. In case of H-atom, we put  $n = 1$ , so equation (10)  $\Rightarrow$

$$E_1 = -13.6 \text{ eV} \quad \text{---(11)}$$

Putting equation (11) in equation (10), we get,

$$E_n = \frac{E_1}{n^2} \quad \text{---(12)}$$

In general, the energy of electron in any quantized orbit can be written as,

$$E_n = E_1, \frac{E_1}{4}, \frac{E_1}{9}, \frac{E_1}{16}, \text{ [where } E_1 = -13.6 \text{ eV]}$$

**Q6: Discuss hydrogen emission spectrum? (OR)**

**Show that the Bohr's theory satisfies the Balmer empirical formula.**

**Answer: Hydrogen Emission Spectrum:**

We can use Bohr's theory to derive an expression for the wavelength of hydrogen spectrum. According to Bohr's fourth postulate, we have,

$$hf = E_h - E_L \quad \text{---(1)}$$

Let the electron is in excited state "n" and make transition to a lower state "p", then we replace " $E_h$ " by " $E_n$ " and " $E_L$ " by " $E_p$ ", so equation (1) becomes,

$$hf = E_n - E_p \quad \text{---(2)}$$

We know that,  $E_n = \frac{E_1}{n^2}$  and  $E_p = \frac{E_1}{p^2}$  so equation (2) becomes,

$$hf = \frac{E_1}{n^2} - \frac{E_1}{p^2}$$

$$\Rightarrow hf = E_1 \left[ \frac{1}{n^2} - \frac{1}{p^2} \right]$$

$$\Rightarrow hf = -E_1 \left[ \frac{1}{p^2} - \frac{1}{n^2} \right]$$

$$\Rightarrow \frac{hc}{\lambda} = -E_1 \left[ \frac{1}{p^2} - \frac{1}{n^2} \right]$$

$$\Rightarrow \frac{1}{\lambda} = -\frac{E_1}{hc} \left[ \frac{1}{p^2} - \frac{1}{n^2} \right] \quad (3)$$

In equation (3),  $\frac{-E_1}{hc}$  = Rydberg constant = R, so eq. (3) becomes

$$\frac{1}{\lambda} = R \left[ \frac{1}{p^2} - \frac{1}{n^2} \right] \quad (4)$$

We know that the Balmer empirical formula is given by,

$$\frac{1}{\lambda} = R \left[ \frac{1}{n_i^2} - \frac{1}{n_f^2} \right] \quad (5)$$

Now if we compare equations (4), (5), we get the same result. Thus the Bohr's theory satisfies the Balmer empirical formula. Thus we can use the Bohr's theory to compute the energies or wave-length of the transitions which are involved in the various emission series.

**Q7: Discuss the energy-level diagram for H-atom.**

**Answer: Energy-Level Diagram:**

We know that the radii of quantized orbit is given by,

$$r_n = n^2 \times r_1 \quad (1)$$

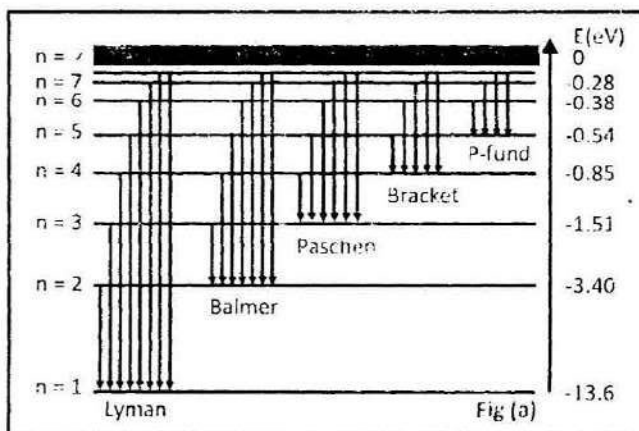
While the energy of quantized orbit is given by,

$$E_n = \frac{E_1}{n^2} \quad (2) \quad [E_1 = -13.6 \text{ eV}]$$

Now if  $n \rightarrow \infty$ , then equations (1), (2) becomes,

$$r_n \rightarrow \infty \text{ and } E_n \rightarrow 0$$

Under such conditions, the atom becomes ionized and the electrons become free from the nucleus. The energy of quantized states of the atom can be represented on energy level diagram, as shown in the figure.



The horizontal lines represent the energy levels " $E_n$ " of the atom. While the vertical arrows represent the transitions between energy levels. At  $n = \infty$  level, the electron becomes free from the atom and is at rest. Under such conditions, the P.E and K.E of electrons are zero.

The energy level diagram can be used to illustrate the origin of various spectral series observed in the emission spectrum of H-atom.

1. The transition from various energy levels to the lowest level ( $n = 1$ ) gives rise to Lyman series.
2. The transition from various energy levels to the second energy level ( $n = 2$ ) gives rise to Balmer series.
3. The transition from various energy levels to the 3<sup>rd</sup> energy level ( $n = 3$ ) gives rise to Paschen series.
4. The transition from various energy levels to the fourth energy level ( $n = 4$ ) gives rise to Brackett series.
5. The transition from various energy levels to the fifth energy level ( $n = 5$ ) gives rise to pfund series.

**Q8: Discuss the De-Broglie interpretation of Bohr's orbit.**

**Answer: De-Broglie Waves and Hydrogen Atom: (ETEA 2009)**

Consider a string of length " $l$ " is excited into its stationary vibrations, as shown in the figure. Under such conditions, we have,

$$l = n\lambda \quad (1)$$

Now if the string is bent to form a circular shape of radius " $r$ ", then,

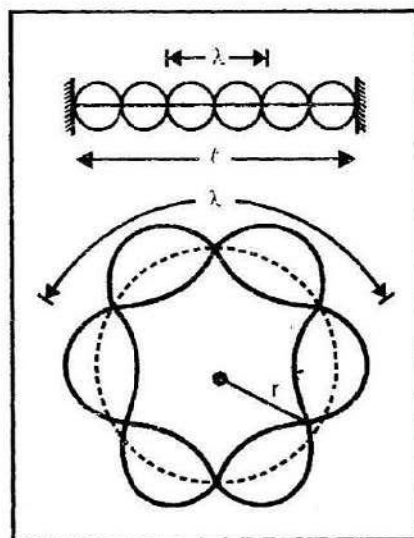
$$l = 2\pi r \quad (2)$$

Comparing equations (1), (2), we get,

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

$$\Rightarrow \lambda = \frac{2\pi r}{n} \quad (3)$$

Now according to De-Broglie hypothesis, we have,



$$\lambda = \frac{h}{mv} \quad (4)$$

Comparing equations (3), (4), we get,

$$\begin{aligned} \frac{h}{mv} &= \frac{2\pi r}{n} \\ \Rightarrow \frac{mv}{h} &= \frac{n}{2\pi r} \\ \Rightarrow \boxed{mvr} &= \frac{nh}{2\pi} \quad (5) \end{aligned}$$

Equation (5) represents the Bohr's 2<sup>nd</sup> postulate. Thus the De-Broglie hypothesis is in agreement with Bohr's 2<sup>nd</sup> postulate. This is known as the De-Broglie interpretation of Bohr's orbit.

**Q9: Discuss the success and failure of Bohr's theory. (ETE 2014-15)**

**Answer: 1. Success of Bohr's Theory:**

The Bohr's theory is successful in many aspects. For example,

1. It presents a physical model for an atom.
2. It gives the accurate values of wavelengths of different spectral lines of H-atom.
3. It gives the accurate value about the size of an atom.
4. It determines the value of Rydberg's constant.
5. It gives us the concept of photons.
6. It can be used to determine the energy of quantized orbits.
7. It can be used to determine the radii of quantized orbits.

**2. Limitations of Bohr's Theory [Failure of Bohr's Theory]:**

1. It cannot explain the energy levels of complex atom.
2. It cannot explain the fine structure of the spectral lines of H-atom.
3. It cannot explain the existence of non-radiating stationary electron orbits.

**Q10: Define and explain the following terms:**

- a) Excitation energy and excitation potential
- b) Ionization energy and ionization potential

**Answer: a) Excitation Energy and Excitation Potential:**

"The energy required by an electron to go to excited state from

ground is known as excitation energy."

While "the voltage applied to accelerate the electron from ground state to the excited state is known as excitation potential."

The state  $n = 1$  is called ground state while the states with  $n = 2, 3, 4, \dots$  are called excited state. The first excitation energy of H-atom is given by,

$$\text{First excitation energy} = \frac{E_1}{n^2} - E_1 = \frac{E_1}{2^2} - E_1 = \frac{E_1}{4} - E_1$$

$$\Rightarrow \text{First excitation energy} = \frac{-3E_1}{4} = \frac{-3(-13.6)\text{eV}}{4} = 10.2\text{eV}$$

$$\Rightarrow \boxed{\text{First excitation energy} = 10.2\text{eV}}$$

Similarly, the 2<sup>nd</sup> excitation energy is given by,

$$2^{\text{nd}} \text{ excitation energy} = \frac{E_1}{3^2} - E_1 = \frac{-8E_1}{9} = \frac{-8(-13.6)\text{eV}}{9}$$

$$\Rightarrow \boxed{2^{\text{nd}} \text{ excitation energy} = 12.1\text{eV}}$$

The value of 1<sup>st</sup> excitation potential is 10.2eV.

The value of 2<sup>nd</sup> excitation potential is 12.1eV.

#### **b) Ionization Energy and Ionization Potential:**

"The minimum energy required to remove an electron from its ground state is called ionization energy."

While "the voltage applied to accelerate the electron from ground state and remove from the atom is called ionization potential."

If an atom absorbs sufficient energy, then the electron may be raised to a level  $n = \infty$ . At this stage, the electron becomes free from the attractive force of the nucleus. In other words we say that the electron is removed from the atom and the atom is said to be ionized. The energy of final ionized state of an atom is zero. So the ionization energy of an atom is given by,

$$\text{Ionization energy} = 0 - E_1 = 0 - (-13.6)\text{eV}$$

$$\Rightarrow \boxed{\text{Ionization energy} = 13.6\text{eV}}$$

**Q11: Explain how the inner-shell transitions of electrons give rise to characteristics x-rays?**

**Answer: Inner Shell Transition and Characteristic X-rays:**

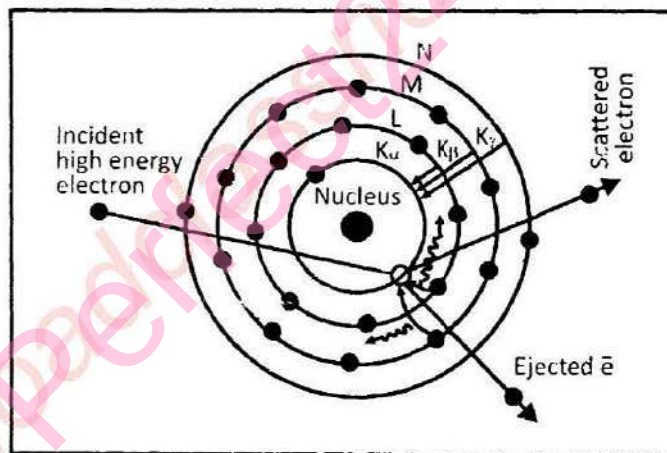
The x-rays are emitted when high energy electrons are bombarded on a metal target. The spectrum of x-rays consists of a broad con-

continuous band and a series of intense sharp lines which depend on the nature of target material. These discrete lines are called characteristics x-rays which were discovered in 1908.

We know that the electrons are revolving around the nucleus in circular orbits or shells. These shells are represented by K, L, M, N, O etc. In each shell, there are specific numbers of electrons. For example, there are two electrons in K-shell, eight electrons in L-shell and so on.

The characteristics x-rays are produced when a high energy electron is bombarded on another electron in an inner shell of target atom and knockout it from the atom.

Let the electron to K-shell is knockout from the atom due to bombarding electron. In this way, a vacancy is created in K-shell. Then an electron of L, or M or N-shell will jump down quickly to fill the vacancy in K-shell. In doing so the jumping electrons emit its excess energy in the form of photons which is known as characteristics x-rays.



- The photon emitted due to transition of electron from L-shell to K-shell is called K<sub>α</sub> characteristic x-rays.
- The photon emitted due to transition of electron from M-shell to K-shell is called K<sub>β</sub> characteristics x-rays.
- The photon emitted due to transition of electron from N-shell to K-shell is called K<sub>γ</sub> characteristics x-rays.

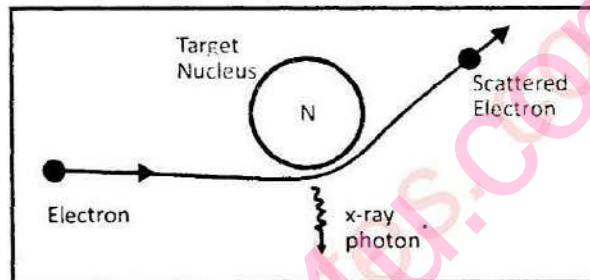
**Q12: Discuss the production of continuous x-rays.**

**Answer: Continuous X-rays: (ETEA 2010-11)**

Consider a high energy electron is allowed to pass in the strong field of a heavy target nucleus. When it enters in the field of the nucle-

us, it experience strong coulomb's force of attraction. As a result, it deviate from its original path and losses some K.E. This K.E appears in the form of photon which is known as continuous x-ray.

The frequency of photon depends upon the closeness of electron towards nucleus. i.e. the closer the electron passes a nucleus, greater will be the loss in its K.E and hence greater will be the frequency of emitted photon and vice versa.



If the incoming electron losses its K.E in a single encounter, then we have,

$$(K.E)_{max} = hf_{max} \quad (1)$$

If "V" is the accelerating potential and "e" is the charge on electron, then work done on electron will be equal to "Ve". This work appears in the form of K.E in the electron, so we have,

$$(K.E)_{max} = Ve \quad (2)$$

Comparing equations (1), (2), we get,

$$hf_{max} = Ve \Rightarrow \boxed{f_{max} = \frac{Ve}{h}} \quad (3)$$

Equation (3) represents the frequency of emitted x-ray photon. We also know that,

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

$$\Rightarrow \lambda_{min} = \frac{c}{f_{max}} \quad (4)$$

Putting equation (3) in equation (4), we get,

$$\boxed{\lambda_{min} = \frac{ch}{Ve}} \quad (5)$$

Equation (5) represents the wavelength of emitted x-ray photon. Equation (3), (5) shows that the frequency and wavelength of x-

ray photon depends upon the accelerating potential " $V$ ". i.e. greater the value of " $V$ ", greater will be " $f$ " and smaller will be " $\lambda$ " and vice versa.

During this process, the energy lost by the electron depends only on how close it comes to the nucleus, so x-rays of various wavelengths are emitted. Thus due to number of series, we get a spectrum which is known as continuous x-rays spectrum.

**Q13: Discuss the production, properties and uses of x-rays.**

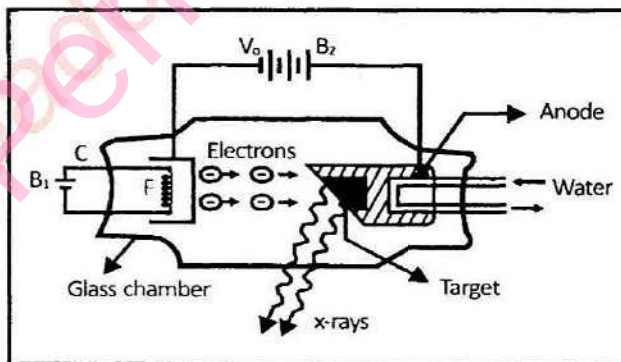
**Answer: X-rays:**

**Definition:** The x-rays are high power penetrating radiations which are emitted from metal surface due to bombardment of high energy electrons.

**Production of X-rays: (ETEA 2011)**

The production of x-rays is the reverse process of photoelectric effect. For the production of x-rays, an evacuated tube is used which consists of a filament [cathode], a target material like tungsten [anode] etc as shown in the figure.

The filament " $F$ " is heated by a battery " $B_1$ " due to which electrons are emitted from the filament. These electrons are then accelerated towards anode [target] by applying very high P.D " $V_0$ " between anode and cathode with the help of battery " $B_2$ ", as shown in the figure.



When these electrons strike the target, they loss some of their K.E in the form of heat and some in the form of x-rays photon. Due to heat, the target becomes warm which can be cool down by water behind it.

The energy of x-ray photon is " $hf$ " which is equal to the K.E loss by electron. So we have,

$$(K.E)_{\text{max}} = hf \quad (1)$$

=====

We also know that,

$$(K.E)_{\max} = V_0 e \quad (2)$$

In equation (2) " $V_0$ " represents the accelerating potential and " $e$ " the charge on electron. Comparing equation (1), (2), we get,

$$\boxed{hf = V_0 e} \quad (3)$$

The intensity of x-rays photon depends upon the number of electrons hitting the target. While the frequency of x-rays photon depends upon the accelerating voltage " $V_0$ ".

The x-rays having large penetrating power is called hard x-rays. While x-rays having small penetrating power are called soft x-rays.

### Properties of X-rays: (ETEA 2010)

1. They are neutral radiations.
2. These radiations cannot be deflected by an electric and magnetic fields.
3. They can travel with velocity of light.
4. They possess very high penetrating power.
5. They have low ionization effect.
6. They can eject electron from metal surface.
7. They can produce fluorescence in many substances.
8. They can damage living tissues.
9. They can be diffracted by crystals.
10. They can affect the photographic plate.

### Uses of X-rays: (ETEA 2011)

#### 1. Scientific Applications:

- a) The diffraction of x-rays at crystals gave birth to x-ray crystallography.
- b) The diffraction pattern of x-rays can be used to determine the internal structure of the crystals.
- c) It can be used to determine the spacing and disposition of the atoms of a crystal accurately.

#### 2. Industrial Applications:

- a) X-rays possess high penetrating power. So they can be used in industry for testing of materials.
  - b) They can detect the defects in metallic structures in big ma-
- =====

chines, railway tracks and bridges.

- c) They can be used to analyze the structure and composition of alloys, rubber and plastics etc.

### 3. Medical Applications:

- a) They are used in hospitals for the detection of fractures in bones of human body.  
b) They are used for curing malignant tissues of the body.  
c) X-ray therapy is used for the treatment of cancer diseases.  
d) Beside these, x-rays can be used for the detection of arms explosive materials and other precious materials in detection departments.  
e) They are also used in agriculture department for various purposes.

**Q14: What is CT scanner? Discuss the structure and working in details.**

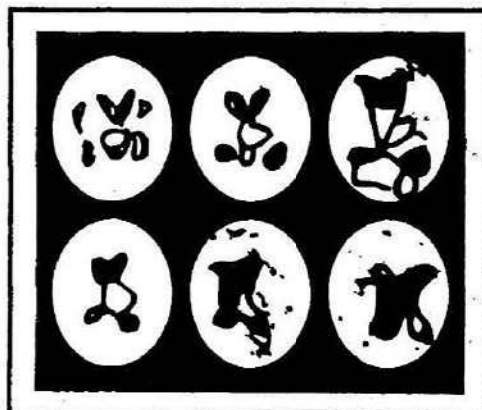
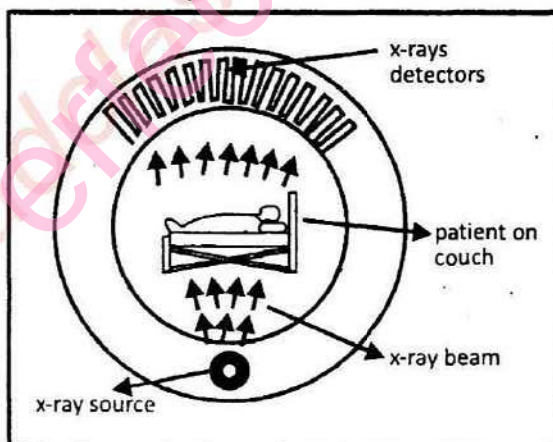
**Answer: CT Scanner:**

CT scans is a machine which gives high quality images. These images help us in identifying the internal structures of various parts of human body.

#### Structure and Working:

CT scans machine is 3D machine with computer model. It consists of a single x-ray source and large number of detectors. The source and detectors are mounted in a large ring-shaped machine.

The patient is placed inside on a couch, as shown in the figure. Each detector records an image and then the source and detectors are rotated around the patient to give images from different directions. The image is called a tomogram.



The couch and patient are then moved along the axis of the machine and another set of images is taken. The large numbers of images are then combined by a computer to give a composite detailed 3D image of the organs under investigations.

#### Uses of CT Scanner:

1. It is used in the diagnosis of bone diseases like bone tumor, bone tuberculosis, osteoarthritis etc.
2. It is used in the diagnosis of brain diseases like brain hemorrhage, brain tumor etc.
3. It is used in the diagnosis of kidney diseases like kidney tumor, polycystic kidney diseases etc.
4. It is used in the diagnosis of liver diseases like liver tumor, liver cysts, liver cirrhosis etc.
5. It is used in the diagnosis of lung diseases like lung tumor, lung tuberculosis and other lung diseases.

Q15: 1. What is a LASER?

2. Explain the concept of LASER.

#### Answer: 1. LASER:

The word "LASER" for Light Amplification Stimulated Emission of Radiation. The discovery of LASER led to a new field of physics known as photonics.

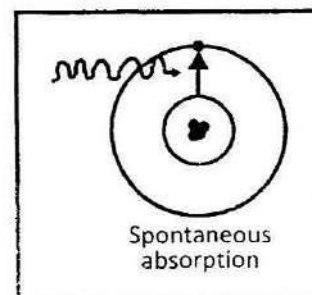
#### 2. Concept of LASER:

The idea of LASER was first given by Einstein. He suggested that there are three processes that involved interaction of radiations with matter or interaction of photons with atom. These processes are given below:

##### (a) Absorption:

Consider an atomic system of two states " $E_1$ " and " $E_2$ " such that  $E_2 > E_1$ .

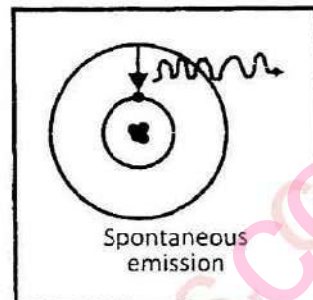
Let the atom is initially in state " $E_1$ " and a photon of energy " $E_2 - E_1 = hf$ " approaches it. Then the photon will be absorbed by the atom or it will be disappear and the atom will



jump from state " $E_1$ " to " $E_2$ ". This process is called absorption.

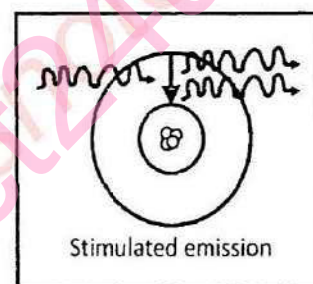
**(b) Spontaneous Emission:**

If the atom is in upper state " $E_2$ " and there is no radiation nearby, then after a mean time " $\tau$ ", the isolated atomic system jumps on its own accord to lower energy state " $E_1$ " and during this process it emits a photon of energy " $hf = E_2 - E_1$ ". Such process is called spontaneous emission.



**(c) Stimulated Emission: (ETEA 2007)**

If an atomic system is in a state " $E_2$ " and a photon of energy " $hf = E_2 - E_1$ " strike with it, then it comes down to state " $E_1$ " without any further delay. During this process, it emits an identical photon of energy " $hf = E_2 - E_1$ ". Thus two identical photons become available. Such process is called stimulated emission.



**Q16: Explain (a) Metastable state**

**(b) Population inversion**

**(c) Laser action**

**Answer: (a) Metastable State: (ETEA 2007)**

Normally an atom stays in an excited state for a very short interval of time [about  $10^{-8}$  sec] but it is found that there are few excited states of some atoms in which it stay for a longer period of about  $10^{-3}$  sec and in some cases upto 1sec. Such excited states are called metastable state.

**(b) Population Inversion: (ETEA 2011)**

If the excited state is a metastable state, then atoms reaching there stay for a longer period. During this time other atoms can be pumped from ground state to the metastable state and after sometime, a situation may arise when number of atoms in metastable state may become greater than that in ground state. Such a situation is called "population inversion".

### (c) LASER Action:

#### Condition for LASER Action:

The laser action takes place when a system satisfies the following conditions:

1. One of the excited states of the system is metastable state.
2. The system is in state of population inversion.
3. The emitted photons are confined in the assembly longer enough to stimulate de-excitation of another atom which are in metastable state.

**Explanation:** Consider an atomic system having three energy states  $E_1$ ,  $E_2$  and  $E_3$  such that

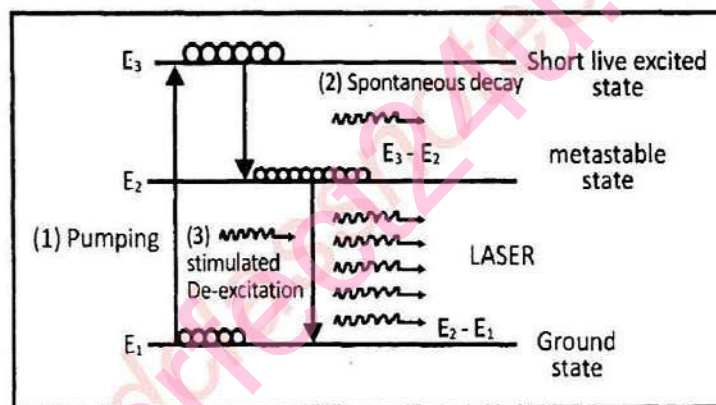
$E_3 > E_2 > E_1$ . " $E_1$ " represents the ground state, " $E_2$ " is metastable excited state and " $E_3$ " is the next short lived excited state.

The laser action takes place in the following three steps:

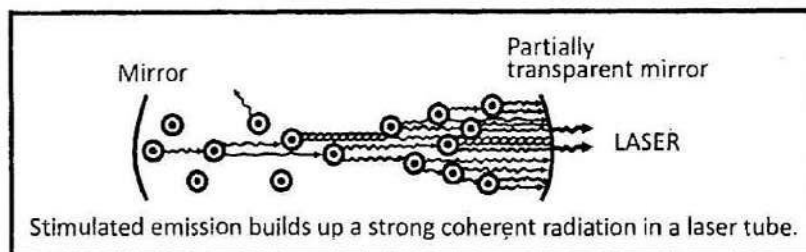
**STEP-1:** First the atoms are pumped from ground state " $E_1$ " to state " $E_3$ " by some source such as a flash lamp.

**Step-2:** Some of the free atoms directly come back to " $E_1$ " from " $E_3$ ". They are again pumped to " $E_1$ ". But some atoms decay spontaneously to metastable state " $E_2$ " and emit a photon of energy " $E_3 - E_2$ ". As " $E_2$ " is metastable state, so population inversion will be attained between " $E_2$ " and " $E_1$ " after sometime.

**STEP-3:** In this step, any stray photon of a " $E_2 - E_1$ " trigger laser action. It stimulates de-excitation of an atom from " $E_2$ " to " $E_1$ " by resulting an emission of an identical photon. These two photons de-excite other two atoms.



In this way, very large numbers of identical photons are produced by



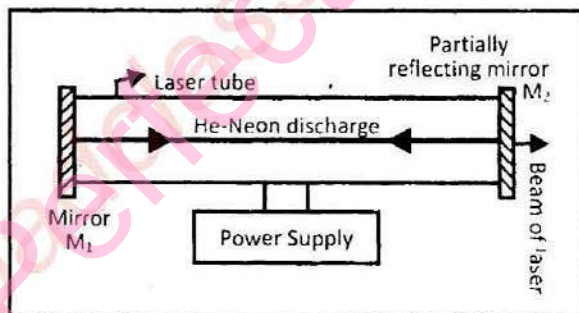
stimulation. Some of them escape from assembly in the form of laser beam.

**Q17: Write a note on Helium-Neon laser.**

**Answer: Helium-Neon Laser:**

The apparatus used for the He-Ne laser consists of a quartz discharge tube about one meter in length. The tube is filled with a mixture of 85% "He" and 15% "Ne" at a pressure of 7mm of Hg i.e. 1 torr.

The "He" acts as pumping while "Ne" acts as active medium. There are four energy states  $E_1$ ,  $E_2$ ,  $E_3$  and  $E_4$  involved in laser action of this system.



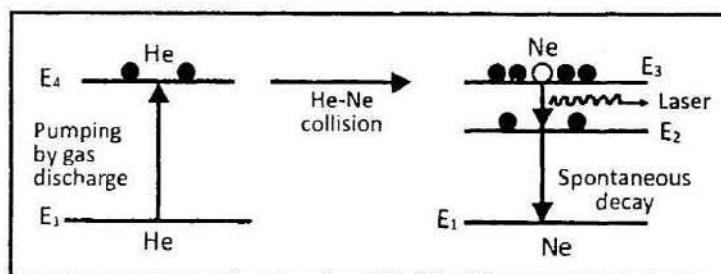
" $E_1$ " represents the ground states of "He" and "Ne". " $E_4$ " is the excited state of "He" which is metastable state. " $E_2$ " and " $E_3$ " are the short lived excited states of "Ne".

$E_4 = 20.61\text{eV}$  state of "He" and

$\begin{bmatrix} \text{He} \rightarrow \text{Helium} \\ \text{Ne} \rightarrow \text{Neon} \end{bmatrix}$

$E_3 = 20.66\text{eV}$  state of "Ne" are very close to each other.

First the He-atoms are excited from  $E_1$  to  $E_4$  by collision of free electrons with them. When these excited atoms of "He" col-



lide with "Ne" atoms, they loss their energy to neon atoms and make them to jump from  $E_1$  to  $E_3$ .

In this way, " $E_3$ " state becomes highly populated. Red laser beam is emitted due to decay of "Ne" atom from  $E_3$  to  $E_2$  state. Spontaneous decay of "Ne" atom also takes place from  $E_2$  to  $E_1$  and from  $E_3$  to  $E_1$ . But the stimulated emission from  $E_3$  to  $E_2$  state is dominant.

The assembly of He-Ne laser source is fitted with two mirrors " $M_1$ " and " $M_2$ " on opposite sides as shown in the figure. " $M_1$ " is perfectly reflecting and " $M_2$ " is partially transparent. These mirrors are used to confine the emitted photons in the assembly so that they can stimulate de-excitation of other atoms while moving back and forth between the two mirrors.

In this way, large numbers of identical and coherent photons are produced. Some fraction of these photons escapes from partially transparent mirror " $M_2$ " in the form of laser beam.

**Q18: Discuss the properties and uses of laser.**

**Answer: a) Properties of Laser:**

1. It is monochromatic in nature. Thus laser photons posses same frequency and same wavelength.
2. Laser is highly coherent i.e. the phase difference between two waves in laser does not change during their propagation. It is due to their monochromatic nature.
3. It is highly intense and unidirectional. It is because, the photons of laser light are emitted from its source parallel to each other. Thus laser beam can travel over long distance with negligible deviations.
4. As the laser photons are emitted parallel from its source, so it can be focused at a point sharply with the help of convex lens.

**b) Uses of Laser:**

1. Laser beam is used in electrical devices.
2. It is used for drilling, welding and cutting purposes.
3. It is used in surgical instruments.

4. It vapourize any thing which comes in its way.
5. It is used for crushing of kidney's stone.
6. It can induce nuclear reaction.
7. It can be used as ranger finder over large distance.
8. It can be used to develop hidden finger prints.
9. It can be used as detector of pollutants in the atmosphere.
10. It can be used for photographic reading of output data of computers.
11. It can be used in telecommunication along optical fibers.

### SOLUTIONS OF EXAMPLES & ASSIGNMENTS

#### EXAMPLE 19-1:

The Balmer series for hydrogen atom corresponds to electronic transitions that terminate in the state of quantum number  $n = 2$ . Find the (a) shortest and (b) longest wavelength of photon emitted in the Balmer's series of hydrogen atom?

Solution:

Given Data:

a) For shortest wavelength, we have,

Energy level =  $n_i = 2$

Energy level =  $n_f = \infty$

Rydberg constant =  $R_H = 1.0974 \times 10^7 \text{ m}^{-1}$

b) For longest wavelength, we have

Energy level =  $n_i = 2$

Energy level =  $n_f = 3$

Required:

a) Shortest wavelength =  $\lambda_s = ?$

b) Longest wavelength =  $\lambda_L = ?$

Calculation:

a) We know that,

$$\frac{1}{\lambda} = R \left[ \frac{1}{n_i^2} - \frac{1}{n_f^2} \right] = R \left[ \frac{1}{2^2} - \frac{1}{\infty^2} \right]$$

$$\Rightarrow \frac{1}{\lambda_s} = R \left[ \frac{1}{4} - 0 \right] = \frac{R}{4}$$

$$\Rightarrow \frac{1}{\lambda_s} = \frac{4}{R}$$

$$\Rightarrow \lambda_s = \frac{4}{R} = \left( \frac{4}{1.0974 \times 10^7} \right) \text{m} = 3.645 \times 10^{-7} \text{m}$$

$$\Rightarrow \boxed{\lambda_s = 364.5 \times 10^{-9} \text{m}}$$

or  $\boxed{\lambda_s = 364.5 \text{nm}}$

b) For longest wavelength, we have,  $n_i = 2$ ,  $n_f = 3$ , we get,

$$\frac{1}{\lambda} = R \left[ \frac{1}{n_i^2} - \frac{1}{n_f^2} \right] = R \left[ \frac{1}{2^2} - \frac{1}{3^2} \right]$$

$$\Rightarrow \frac{1}{\lambda_L} = R \left[ \frac{1}{4} - \frac{1}{9} \right] = R \left[ \frac{9-4}{36} \right] = \frac{5R}{36}$$

$$\Rightarrow \frac{1}{\lambda_L} = \frac{5R}{36} \Rightarrow \lambda_L = \frac{36}{5R}$$

$$\Rightarrow \lambda_L = \left( \frac{36}{5 \times 1.0974 \times 10^7} \right) \text{m} = 6.561 \times 10^{-7} \text{m}$$

$$\Rightarrow \boxed{\lambda_L = 656.1 \times 10^{-9} \text{m}} \text{ or } \boxed{\lambda_L = 656.1 \text{nm}}$$

#### ASSIGNMENT 19-1:

The Lyman series for hydrogen atom corresponds to electronic transitions that terminate in the state of quantum number  $n = 1$ . Find the (a) shortest and (b) longest wavelength of photon emitted in the Lyman's series of hydrogen atom?

Solution:

Given Data:

a) For shortest wavelength in Lyman series, we have,

Energy level =  $n_i = 1$

Energy level =  $n_f = \infty$

b) For longest wavelength, we have,

Energy level =  $n_i = 1$

Energy level =  $n_f = 2$

Required:

a) Shortest wavelength =  $\lambda_s = ?$

b) Longest wavelength =  $\lambda_L = ?$

**Calculation:**

a) We know that,

$$\frac{1}{\lambda} = R \left[ \frac{1}{n_i^2} - \frac{1}{n_f^2} \right] \text{-----(1)}$$

For Lyman series equation (1) becomes,

$$\frac{1}{\lambda_s} = R \left[ \frac{1}{1^2} - \frac{1}{n_f^2} \right]$$

For shortest wavelength we put  $n_f = 2$ , so we get,

$$\frac{1}{\lambda_s} = R \left[ \frac{1}{1^2} - \frac{1}{2^2} \right] = R \left[ \frac{1}{1} - \frac{1}{4} \right] = R \left[ \frac{4-1}{4} \right]$$

$$\Rightarrow \frac{1}{\lambda_s} = \frac{3R}{4} \Rightarrow \lambda_s = \frac{4}{3R}$$

$$\Rightarrow \lambda_s = \left( \frac{4}{3 \times 1.0974 \times 10^7} \right) m = 1.215 \times 10^{-7} m$$

$$\Rightarrow \boxed{\lambda_s = 121.5 \times 10^{-9} m} \text{ or } \boxed{\lambda_s = 121.5 nm}$$

b) Now for longest wavelength we put  $n_i = 1$ ,  $n_f = \infty$  in equation (1)

$$\frac{1}{\lambda_L} = R \left[ \frac{1}{1^2} - \frac{1}{\infty^2} \right] = R [1 - 0]$$

$$\Rightarrow \frac{1}{\lambda_L} = R \Rightarrow \lambda_L = \frac{1}{R}$$

$$\Rightarrow \lambda_L = \left( \frac{1}{1.0974 \times 10^7} \right) m = 0.911 \times 10^{-7} m$$

$$\Rightarrow \boxed{\lambda_L = 91.1 \times 10^{-9} m} \text{ or } \lambda_L = 91.1 nm$$

or

$$\boxed{\lambda_L = 91 nm}$$

**EXAMPLE 19.2:**

A tungsten target is struck by electrons that have been accelerated from rest through a 40.0 kV potential difference. Find the shortest wavelength of the radiation emitted.

**Solution:**

**Given Data:**

Applied voltage = "V" = 40.0 kV = 40.0 × 10<sup>3</sup> V

Plank's constant = "h" = 6.626 × 10<sup>-34</sup> Js

Charge on electron = " $q_e$ " =  $1.6 \times 10^{-19} \text{ C}$

Speed of light =  $c = 3 \times 10^8 \text{ ms}^{-1}$

Required:

Shortest wavelength =  $\lambda = ?$

Calculation:

We know that,

$$\lambda = \frac{hc}{qV} \Rightarrow \lambda_{\min} = \frac{hc}{q_e V}$$

$$\Rightarrow \lambda_{\min} = \left( \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 40 \times 10^3} \right) \text{ m}$$

$$\Rightarrow \lambda_{\min} = (0.311 \times 10^{-34+8+19-3}) \text{ m}$$

$$\Rightarrow \lambda_{\min} = 0.311 \times 10^{-10} \text{ m}$$

$$\Rightarrow \lambda_{\min} = 0.0311 \times 10^{-9} \text{ m}$$

$$\Rightarrow \lambda_{\min} = 0.0311 \text{ nm}$$

#### ASSIGNMENT 19.2:

What is the wavelength of the second line of paschen series?

Solution:

Given Data:

In case of paschen series, the electron jumps from outer orbits to  $3^{\text{rd}}$  orbit, so we have,  $n_i = 3$ ,  $n_f = 4, 5, 6, 7, \dots$

Now for 2<sup>nd</sup> line we put  $n_i = 5$

Required:

Wavelength of 2<sup>nd</sup> line =  $\lambda_2 = ?$

Calculation:

We know that,

$$\frac{1}{\lambda} = R \left[ \frac{1}{n_i^2} - \frac{1}{n_f^2} \right] \text{ ————— (1)}$$

Putting the values of  $R$ ,  $n_i$  and  $n_f$  in equation (1), we get,

$$\frac{1}{\lambda} = R \left[ \frac{1}{3^2} - \frac{1}{5^2} \right] = R \left[ \frac{1}{9} - \frac{1}{25} \right]$$

$$\Rightarrow \frac{1}{\lambda} = R \left[ \frac{25 - 9}{225} \right] = \frac{16R}{225}$$

$$\Rightarrow \lambda = \frac{225}{16R} = \left( \frac{225}{16 \times 1.0974 \times 10^7} \right) \text{m} = 12.8143 \times 10^{-7} \text{m}$$

$$\Rightarrow \boxed{\lambda = 1281.43 \times 10^{-7} \text{m}} \text{ or } \boxed{\lambda = 1281.43 \text{nm}}$$

### ASSIGNMENT 19.3:

Electrons in an x-ray tube are accelerated through a potential difference of 3000V. If these electrons were slowed down in a target, what will be the minimum wavelength of x-rays produced?

Solution:

Given Data:

Potential difference =  $V = 3000\text{V}$

Charge on electron =  $q_e = 1.6 \times 10^{-19} \text{C}$

Plank's constant =  $h = 6.63 \times 10^{-34} \text{Js}$

Speed of light =  $c = 3 \times 10^8 \text{m/sec}$

Required:

Minimum wavelength =  $\lambda_{\min} = ?$

Calculation:

We know that,

$$\lambda_{\min} = \frac{hc}{q_e V} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 3000} = 4.14 \times 10^{-10} \text{m}$$

$$\Rightarrow \boxed{\lambda_{\min} = 0.414 \times 10^{-9} \text{m}}$$

OR

$$\boxed{\lambda_{\min} = 0.414 \text{nm}}$$

## Exercise

Choose the best possible answer:

1. Which of the following series of hydrogen spectra lies in the visible region of the spectrum?
  - a) Lyman
  - b) Balmer✓
  - c) Paschen
  - d) Brachett
2. The longest wavelength in Balmer's series with wavelength is 656.2nm corresponds to:
  - a)  $n = 3$ ✓
  - b)  $n = 4$
  - c)  $n = 5$
  - d)  $n = \infty$
3. If 13.6eV energy is required to ionize the hydrogen atom, then the required energy to remove an electron from  $n = 2$  is:
  - a) 10.2eV
  - b) 0eV
  - c) 3.4eV✓
  - d) 6.8eV

Solution:

$$E_n = \frac{E_1}{n^2} \Rightarrow E_2 = \frac{13.6\text{eV}}{2^2}$$

$$\Rightarrow E_2 = \frac{13.6\text{eV}}{4} \Rightarrow \boxed{E_2 = 3.4\text{eV}}$$

4. If an atom exists in excited state  $n = 5$ , the maximum number of transitions that take place is:
  - a) 3
  - b) 5
  - c) 10✓
  - d) 25

Solution:

$$\frac{n(n-1)}{2} \quad \text{For } n = 5$$

$$\frac{5(5-1)}{2} = \frac{20}{2} = 10$$

5. The energy of the electron in the excited state  $n = 4$  in hydrogen atom is:
  - a) -13.6eV
  - b) -3.4eV
  - c) -0.85eV✓
  - d) -1.5eV

Solution:

$$E_n = \frac{-13.6}{n^2} \quad \text{put } n = 4$$

$$\Rightarrow E_n = -0.85 \text{ eV}$$

- a) 3                      b) 6  
c) 9✓                    d) 16

$$\Rightarrow r_3 = 3^2 \times r_1 \Rightarrow \boxed{r_3 = 9 \times r_1}$$

- a) Compton effect  
b) Photoelectric effect ✓  
c) Pair production  
d) Pair annihilation

- a)  $10^{-3} \text{ s}$       b)  $10^{-6} \text{ s}$   
c)  $10^{-8} \text{ s}$       d)  $10^{-10} \text{ s}$

- a) Blue      b) Green  
c) Red✓      d) White

- a) 50% "He" and 50% "Ne"
- b) 15% "He" and 85% "Ne"
- c) 85% "He" and 15% "Ne" ✓
- d) 99% "He" and 1% "Ne"

- a)  $20.66\text{eV}$                       b)  $18.70\text{eV}$   
c)  $39.36\text{eV}$                       d)  $1.96\text{eV}$  ✓

$$E_1 = 18.70 \text{ eV}, E_2 = 20.66 \text{ eV}$$

$$\text{Energy of photon} = E_2 - E_1 = 20.66 \text{ eV} - 18.70 \text{ eV} = 1.96 \text{ eV}$$

12. In connection with inner shell transition the symbol  $L_{\beta}$  refers to x-ray emission associated with an electron going from:

- a)  $n = 3$  to  $n = 1$       b)  $n = 4$  to  $n = 1$  ✓  
c)  $n = 4$  to  $n = 2$       d)  $n = 5$  to  $n = 3$

13. In laser the pumping is performed to:

- a) Produce meta-stable states  
b) Produce stimulated emission  
c) Achieve population inversion ✓  
d) Achieve coherency in photons

14. Linear momentum of an electron in Bohr orbit of H-atom (principal quantum number  $n$ ) is proportional to:

- a)  $n$  ✓      b)  $1/n$   
c)  $n^2$       d)  $1/n^2$

Solution:

$$mvr = \frac{nh}{2\pi} \Rightarrow mv = \frac{nh}{2\pi r}$$
$$\Rightarrow p = \frac{nh}{2\pi r} \Rightarrow \boxed{p \propto n} \quad \left[ \text{put } \frac{h}{2\pi r} = \text{constant} \right]$$

### ◀ CONCEPTUAL QUESTIONS ▶

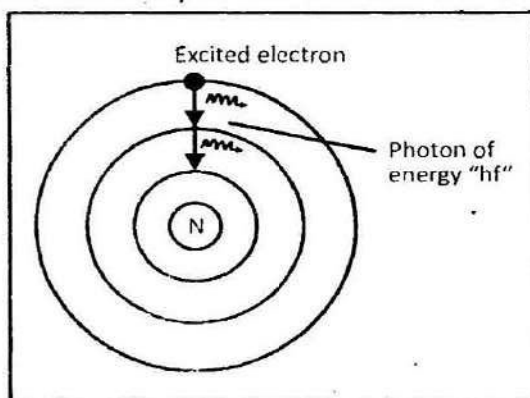
**Q1:** Why does the spectrum of hydrogen consists of many lines even though a hydrogen atom has only a single electron?

Answer:

The spectrum of hydrogen consists of many lines even though it has only one electron.

Reason and Explanation:

When energy is supplied to the hydrogen atom, it will be excited. The single electron of hydrogen atom jumps to higher state from ground state. This electron goes back towards ground state through several jumps. During each jump, the electron emits energy whose frequency and wave-



length depends upon the difference of energies between the levels. In this way, several spectral lines are produced during the de-excitation of a single electron.

**Q2: Why do solid give rise to continuous spectrum while hot gases give rise to line spectrum?**

Answer:

The solid gives rise to continuous spectrum while hot gases give rise to line spectrum.

Reason and Explanation:

In solids, the constituent atoms are so close to each other that their energy levels overlap to form an energy band. In this energy band, all transitions are possible. Each transition corresponds to a particular frequency and wavelength. Therefore in solids, the spectrum formed is continuous due to the fact that radiations of all wavelengths are emitted.

On the contrary, gas molecules are not as close to each other as the atoms in solids. The distance between molecules of a hot gas is larger as compared to their average size. Also the energy levels of gas molecules are discrete. Therefore, their spectrum is also discrete, containing lines of particular wavelength. Each line corresponds to a specific transition. Thus spectrum of solids is continuous while that of hot gases is discrete.

**Q3: Can the electron in the ground state of hydrogen absorb a photon of energy (a) less than 13.6eV (b) greater than 13.6eV?**

Answer:

Yes the electron can absorb a photon of energy less than 13.6eV or greater than 13.6eV in the ground state.

Reason and Explanation:

1. When energy is less than 13.6eV:

When energy is less than 13.6eV, then atoms will absorb this energy and will go to the excited state. It will go back to ground state by emitting photon of the same energy. It should be noted that the atom will absorb those photon whose energy is exactly equal to the excitation energy i.e. photon of energy 10.2eV, 12.75eV, 13.22eV etc.

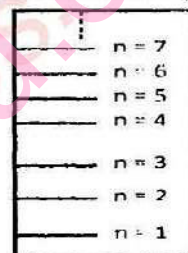
2. When energy is greater than 13.6eV:

When the energy is greater than 13.6eV, then this energy will be absorbed by the atoms. In such a case the ionization of atoms will take place. The electron will spend energy equal to 13.6eV as ionization energy and will become free. While the remaining energy will appear in the form of K.E in the electron.

**Q4: Why do the spectral lines in the hydrogen atom become closer together farther away from the nucleus?**

Answer:

The spectral lines in the hydrogen atoms become closer together farther away from the nucleus. It is because the energy levels are closer together in the region which is far away from the nucleus.



**Q5: Why it was necessary to quantize angular momentum in Bohr's model of the atom?**

Answer:

According to Bohr's atomic model, the angular momentum of electron revolving around the nucleus is quantized. It is because the electron can revolve around the nucleus in those orbits in which the angular momentum of electron is an integral multiple of " $nh/2\pi$ ".

i.e. 
$$L = \frac{nh}{2\pi}$$

Each orbit has specific energy and electron revolves in specific orbits having specific values of angular momentum. Thus in Bohr's atomic model, the angular momentum of revolving electron is quantized.

**Q6: Why x-rays have different properties from light even though both originate from orbital transition of electron in excited atoms?**

Answer:

X-rays have different properties from light even though both originate from orbital transition of electrons in excited atoms. It is because the x-rays are produced due to inner shell transition of electrons. On the other hand, the visible light is produced due to tran-

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sition of electrons in the outermost shells. The x-rays are more energetic having high frequency and shorter wavelength due to inner shell transition. The visible lights are less energetic having low frequency and longer wavelengths. Thus the visible light have different properties from x-rays.

Q7: If the potential difference in an x-ray tube is increased, how does this affect the wavelengths of (a) Bremsstrahlung x-ray and (b) characteristics x-rays?

Answer:

a) If the potential difference in an x-ray tube is increased, the energy of electrons which strikes the x-ray tube is increased. As a result the energy of the bremsstrahlung x-ray also increases. Thus the wavelength of the bremsstrahlung x-ray decreases due to increase in its energy.

$$\left[ E = \frac{hc}{\lambda} \right]$$

b) Due to increasing potential difference and increasing energy of electron beam, the energy of characteristics x-ray also increases. As a result their wavelength decreases.

Q8: Crystal lattices can be examined with x-rays but not with ultraviolet rays, why?

Answer:

Crystal lattices can be examined with x-rays but not with ultraviolet rays. It is because the wavelength of x-rays is much smaller than that ultraviolet rays. The wavelength of x-rays is of the range of lattice parameters while the wavelength of ultraviolet rays does not match with the lattice parameters. So it cannot be use for examining crystal lattice. Only x-rays can be use for examining the crystal lattice.



## NUMERICAL QUESTIONS



**Q1:** Calculate the shortest and longest wavelength of radiations for paschen series.

Solution:

Given Data:

Rydberg constant =  $R = 1.0974 \times 10^7 \text{ m}^{-1}$

Required:

a) Shortest wavelength =  $\lambda_s = ?$

b) Longest wavelength =  $\lambda_L = ?$

Calculation:

We know that,

$$\frac{1}{\lambda} = R \left[ \frac{1}{n_i^2} - \frac{1}{n_f^2} \right] \text{-----(1)}$$

For shortest wavelength in paschen series, we put  $n_i = 3$  and  $n_f = \infty$ , so equation (1) becomes,

$$\begin{aligned} \frac{1}{\lambda} &= R \left[ \frac{1}{3^2} - \frac{1}{\infty^2} \right] = R \left[ \frac{1}{9} - 0 \right] \\ \Rightarrow \frac{1}{\lambda_s} &= \frac{R}{9} \Rightarrow \lambda_s = \frac{9}{R} = \frac{9}{1.0974 \times 10^7} \\ \Rightarrow \lambda_s &= 8.20 \times 10^{-7} \text{ m} = 820.0 \times 10^{-9} \text{ m} \\ \Rightarrow \lambda_s &= 820 \text{ nm} \end{aligned}$$

b) For longest wavelength of paschen series, we put  $n_i = 3$ ,  $n_f = 4$  so equation (1) becomes,

$$\begin{aligned} \frac{1}{\lambda_L} &= R \left[ \frac{1}{3^2} - \frac{1}{4^2} \right] = R \left[ \frac{1}{9} - \frac{1}{16} \right] \\ \Rightarrow \frac{1}{\lambda_L} &= R \left[ \frac{16 - 9}{144} \right] = R \left[ \frac{7}{144} \right] \\ \Rightarrow \lambda_L &= \frac{144}{7R} = \left( \frac{144}{7 \times 1.0974 \times 10^7} \right) \text{ m} = 18.75 \times 10^{-7} \text{ m} \\ \Rightarrow \lambda_L &= 1875.0 \times 10^{-9} \text{ m} \\ \Rightarrow \lambda_L &= 1875 \text{ nm} \end{aligned}$$

Q2: In the fifth energy level determine the radius and energy of electron for hydrogen atom.

Solution:

Given Data:

We know that the radius for  $n$ th orbit is given by,

$$r_n = n^2 \times 5.3 \times 10^{-11} \text{ m} \quad (1)$$

Similarly, the energy for  $n$ th energy level is given by,

$$E_n = \frac{-13.6 \text{ eV}}{n^2} \quad (2)$$

For fifth energy level, we put  $n = 5$  so equation (1) becomes

$$r_5 = 5^2 \times 5.3 \times 10^{-11} \text{ m} = 25 \times 5.3 \times 10^{-11} \text{ m}$$

$$\Rightarrow r_5 = 132.5 \times 10^{-11} \text{ m} = 1.325 \times 10^{-9} \text{ m}$$

$$\Rightarrow \boxed{r_5 = 1.325 \text{ nm}}$$

Put  $n = 5$  in equation (2), we get,

$$E_5 = \frac{-13.6 \text{ eV}}{5^2} = \frac{-13.6 \text{ eV}}{25} = -0.544 \text{ eV}$$

$$\Rightarrow \boxed{E_5 = -0.544 \text{ eV}}$$

$$\text{or } E_5 = -0.544 \times 1.6 \times 10^{-19} \text{ J}$$

$$\Rightarrow E_5 = -0.871 \times 10^{-19} \text{ J}$$

$$\Rightarrow \boxed{E_5 = -8.71 \times 10^{-20} \text{ J}}$$

Q3: An electron drops from the second energy level to the first energy level within an excited hydrogen atom (a) determine the energy of the photon emitted (b) calculate the frequency of the photon emitted (c) calculate the wavelength of the photon emitted.

Solution:

Given Data:

Transition from  $n = 2$  to  $n = 1$

Required:

a) Energy of emitted photon =  $E = ?$

b) Frequency =  $f = ?$

c) Wavelength =  $\lambda = ?$

Calculation:

a) We know that,

$$E_n = \frac{-13.6 \text{ eV}}{n^2} \quad (1)$$

Now for  $n = 1$ , equation (1) becomes

$$E_1 = -13.6 \text{ eV}$$

Now for  $n = 2$ , equation (1) becomes

$$E_2 = \frac{-13.6 \text{ eV}}{4} \Rightarrow E_2 = -3.4 \text{ eV}$$

Now the energy of photon must be equal to the difference in energy of the two states i.e.

$$E = E_2 - E_1 = -3.4 - (-13.6) = -3.4 + 13.6$$

$$\Rightarrow \boxed{E = 10.2 \text{ eV}} \quad [E = 10.2 \text{ eV} = 10.2 \times 1.6 \times 10^{-19} \text{ J}]$$

b) As  $E = hf \Rightarrow f = \frac{E}{h}$

$$\Rightarrow f = \frac{10.2 \times 1.6 \times 10^{-19}}{6.625 \times 10^{-34}} \Rightarrow \boxed{f = 2.5 \times 10^{15} \text{ Hz}}$$

c) As  $c = f\lambda \Rightarrow \lambda = \frac{c}{f} = \left( \frac{3 \times 10^8}{2.5 \times 10^{15}} \right) \text{ m}$

$$\Rightarrow \boxed{\lambda = 1.2 \times 10^{-7} \text{ m}}$$

Or  $\lambda = 120.0 \times 10^{-9} \text{ m} = 120 \text{ nm}$

$$\Rightarrow \boxed{\lambda = 120 \text{ nm}}$$

**Q4: Find the wavelength associated with an electron in the state  $n = 4$  of hydrogen.**

Solution:

We know that,

$$\lambda = \frac{h}{mv_n} \quad (1)$$

We also know that,

$$V_n = \frac{2\pi K e^2}{nh} \quad (2)$$

Putting equation (2) in equation (1), we get,

$$\lambda = \frac{h}{m \times \frac{2\pi K e^2}{nh}} = \frac{nh^2}{2\pi m K e^2}$$

$$\Rightarrow \lambda = \frac{nh^2}{2\pi m K e^2} \quad (3)$$

Put  $n = 4$ ,  $h = 6.63 \times 10^{-34} \text{ Js}$ ,  $\pi = 3.14$ ,  $m = 9.11 \times 10^{-31} \text{ kg}$ ,  
 $k = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$ ,  $e = 1.6 \times 10^{-19} \text{ C}$  in equation (3), we get,

$$\lambda = \frac{4 \times (6.63 \times 10^{-34})^2}{2 \times 3.14 \times 9.11 \times 10^{-31} \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2}$$

$$\Rightarrow \lambda = \left( \frac{4 \times 6.63 \times 6.63 \times 10^{-68}}{2 \times 3.14 \times 9.11 \times 10^{-31} \times 9 \times 10^9 \times 1.6 \times 1.6 \times 10^{-38}} \right) \text{ m}$$

$$\Rightarrow \lambda = (0.133 \times 10^{-68+31-9+38}) \text{ m} = 0.133 \times 10^{-8} \text{ m}$$

$$\Rightarrow \boxed{\lambda = 1.33 \times 10^{-9} \text{ m}}$$

or

$$\boxed{\lambda = 1.33 \text{ nm}}$$

**Q5:** An electron is in the first Bohr orbit of hydrogen atom. (a) Find the speed of electron, and (b) the time required for electron to circle the nucleus.

Solution:

Given Data:

For first orbit,  $n = 1$

Required:

a) Speed of electron in first orbit =  $V_1 = ?$

b) Time period for electron =  $T_1 = ?$

Calculation:

a) We know that the velocity of electron in  $n$ th orbit is given by,

$$V_n = \frac{2\pi K e^2}{nh} \quad (1)$$

Putting the values of  $n$ ,  $\pi$ ,  $K$ ,  $e$ ,  $h$  in equation (1), we get,

$$V_1 = \frac{2 \times 3.14 \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2}{1 \times 6.625 \times 10^{-34}}$$

$$\Rightarrow V_1 = 21.9 \times 10^5 \text{ m/s}$$

$$\Rightarrow \boxed{V_1 = 2.19 \times 10^6 \text{ m/s}}$$

b) We know that,  $v = r\omega$

$$\Rightarrow V_1 = r_1 \omega_1$$

$$\Rightarrow V_1 = r_1 \frac{2\pi}{T_1}$$

$$\tau = \frac{2\pi}{\omega}$$

$$\Rightarrow \omega = \frac{2\pi}{T}$$

$$\Rightarrow T_1 = \frac{2\pi r_1}{V_1}$$

$$\Rightarrow T_1 = \frac{2 \times 3.14 \times 0.53 \times 10^{-10}}{2.19 \times 10^6}$$

$$\Rightarrow T_1 = 1.52 \times 10^{-16} \text{ sec}$$

$$r_1 = 0.53 \text{ \AA}$$

$$\Rightarrow r_1 = 0.53 \times 10^{-10} \text{ m}$$

**Q6:** If the shortest wavelength produced by an x-ray tube is 0.46nm what is the voltage applied to the tube?

Solution:

Given Data:

Wavelength of x-ray =  $\lambda = 0.46 \text{ nm} = 0.46 \times 10^{-9} \text{ m}$

Plank's constant =  $h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$

Charge on electron =  $e = 1.6 \times 10^{-19} \text{ C}$

Velocity of light =  $c = 3 \times 10^8 \text{ m/sec}$

Required:

Voltage applied =  $V = ?$

Calculation:

We know that,

$$\lambda = \frac{ch}{Ve} \Rightarrow V = \frac{ch}{\lambda e}$$

$$\Rightarrow V = \left( \frac{3 \times 10^8 \times 6.63 \times 10^{-34}}{0.46 \times 10^{-9} \times 1.6 \times 10^{-19}} \right) \text{ volt} = 27.0 \times 10^{8-34+9+19}$$

$$\Rightarrow V = 27.0 \times 10^2 \text{ V} = 2.70 \times 10^3 \text{ V}$$

$$\Rightarrow V = 2.7 \text{ KV}$$

