

Chapter = 20



Atomic Spectra

Spectroscopy:

The branch of physics which deals with the investigation of wavelengths and intensities of electromagnetic radiations emitted or absorbed by atoms is called spectroscopy.

Types of spectra:

1) : Continuous spectrum:

A radiation spectrum consisting of a continuously distributed over a frequency range without being broken up into lines or bands is called a continuous spectrum.

Black body radiation spectrum is an example of continuous spectra.

2) : Band spectra:

A spectrum which consists of a number of bands or closely

spaced lines of emitted or absorbed radiations is called a band spectrum.

Molecular spectra are the examples of band spectra.

Discrete or Line spectra:

A line spectrum which consists of discrete lines corresponding to single wavelength or frequency of emitted or absorbed radiation is called discrete or line spectrum.

Atomic spectra are the examples of discrete or line spectra.

Continuous spectrum

Line spectrum.

Band spectrum.

Different types of spectra



(i) Continuous spectrum



(ii) Line spectrum



(iii) Band spectrum

20.1 Atomic spectra

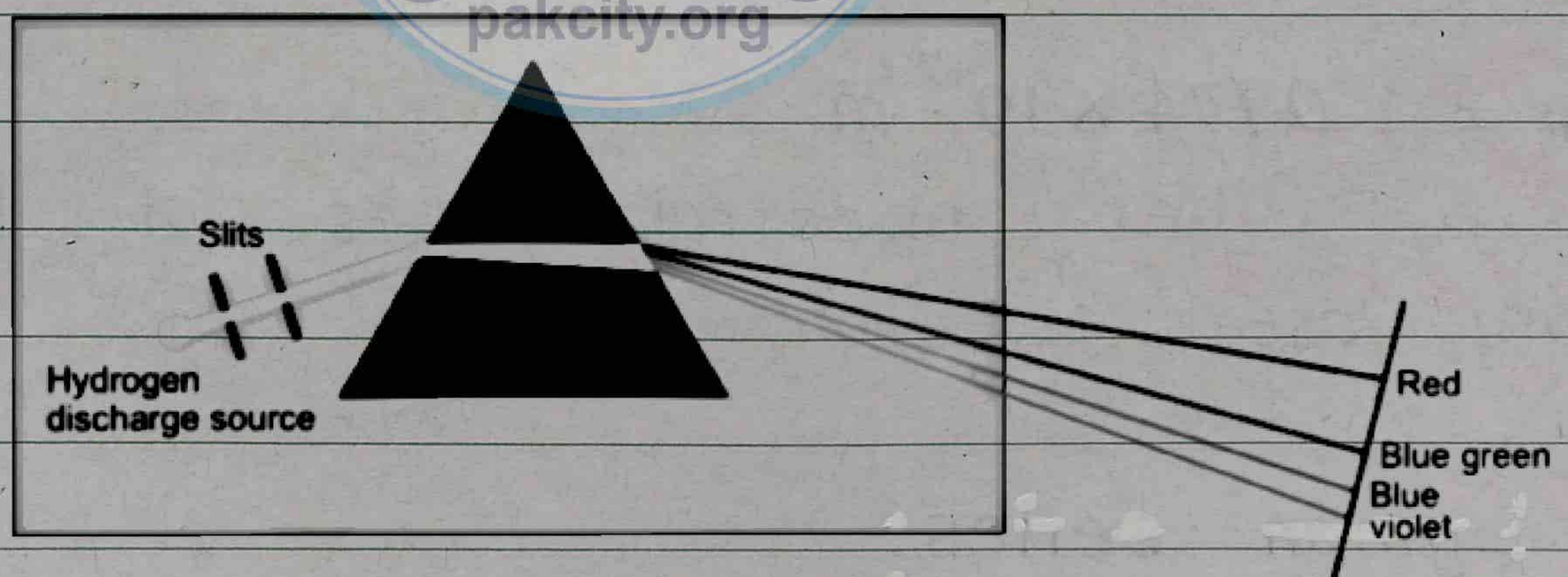
Definition:

When atomic gas or vapour at low pressure is excited by passing an electric discharge through it, the emitted radiations of certain specific wavelengths are called atomic spectra.

An experimental arrangement to observe such atomic spectra is shown in fig. For better results, a spectrometer with diffraction grating is used.

Line spectrum:

If the slit "S" in front of the source is narrow rectangle then the print on the plate is in the form of line. Due to this reason, this spectrum is called line spectrum.



Spectral series:

The spectrum of any

element contains wavelengths that show definite arrangements. It was used to identify different elements in the second half of the 19th century.

1 ; Balmer series :

It is in the visible region of the electromagnetic spectrum.

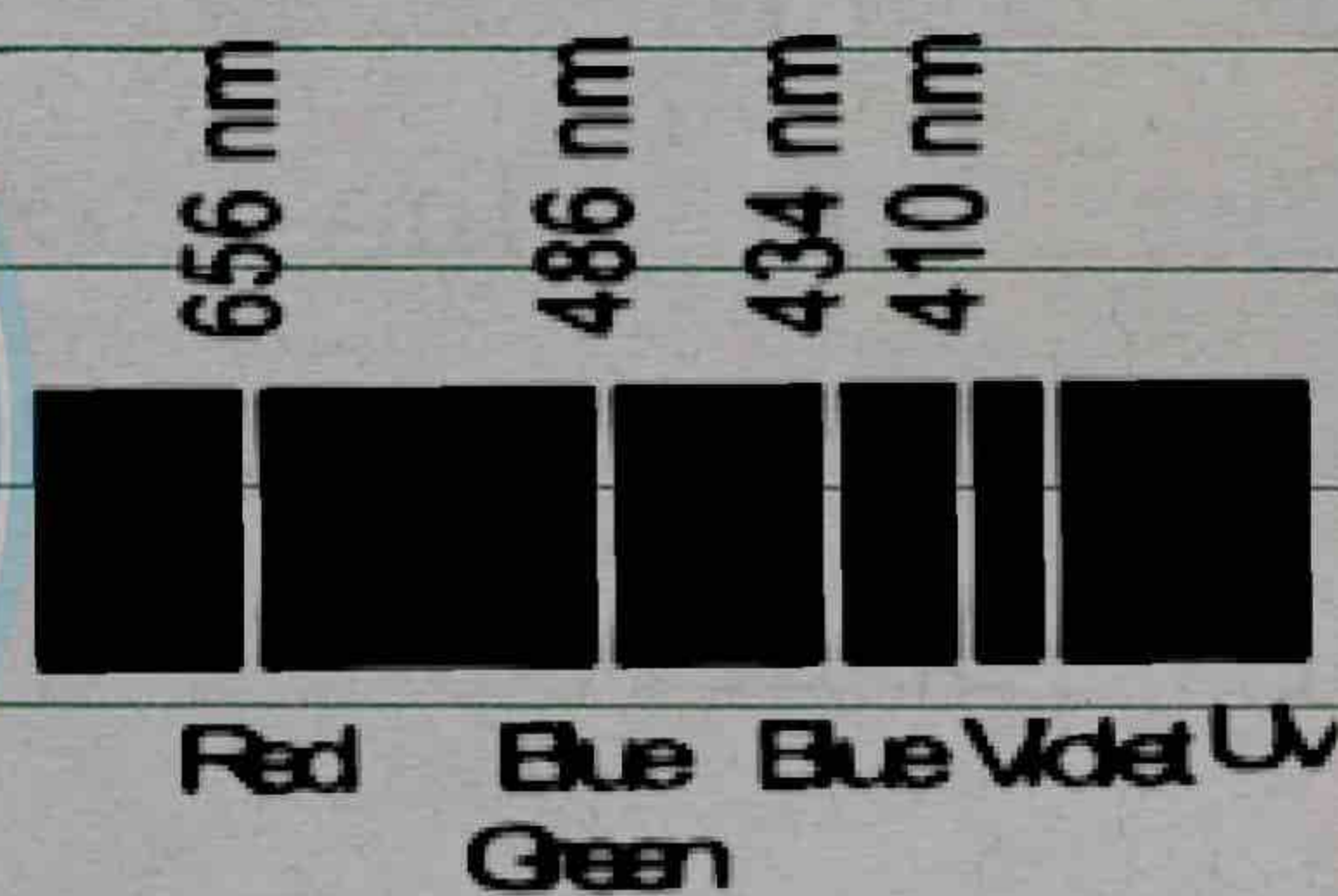
In 1885 Balmer identified this series in the spectrum of Hydrogen so, it is called Balmer series.

It is shown in fig. In 1896, J.R Rydberg, expressed the results obtained by the Balmer in the mathematical form.

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

Where $n = 3, 4, 5, 6, \dots$

R_H = Rydberg's constant.



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

Other spectral series of Hydrogen atom are as follows.

★ : Lyman series :

In the ultraviolet region, the Lyman series contains the wavelen-

gths given by the formula.



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

where $n = 2, 3, 4, \dots$

★ : Pachen series:

The wavelength of its various lines is given by the formula.

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

where $n = 4, 5, 6, \dots$

★ : Broket series:

The wavelengths of its various lines is given by the formula.

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

where $n = 5, 6, 7, \dots$

★ : Pfund series:

The wavelengths of its various lines is given by the formula.

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

where $n = 6, 7, 8, \dots$

All these series can be expressed by single formula.

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

where $p = 1, 2, 3, 4, 5$ and $n = p + 1, p + 2, p + 3, \dots, p + \infty$.



20.2 Bohr's Model of Hydrogen

atom

In 1913 Neils Bohr gave his model of Hydrogen atom. This theory is a mixture of classical ideas and modern idea of Planck's Quantum Theory. So it is a semi-classical theory.

It is based on following Postulates.

Postulates:

1); An electron can revolve in those fixed or allowed orbits for which its angular momentum is integral multiple of $\frac{h}{2\pi}$, where h is planck's constant.

$$mvr = n \cdot \frac{h}{2\pi}$$

n = Principal Quantum Number.

$n = 1, 2, 3, \dots$

Allowed orbits are also called stationary states.

2) ; The total energy of an electron in its allowed orbit remains constant, as long as it remains in the same orbit. It does not radiate energy.

3) ; When an electron jumps from a higher energy state E_n to a lower energy state E_p , it radiates energy in the form of a photon of energy " hf ".

$$E_n - E_p = hf$$

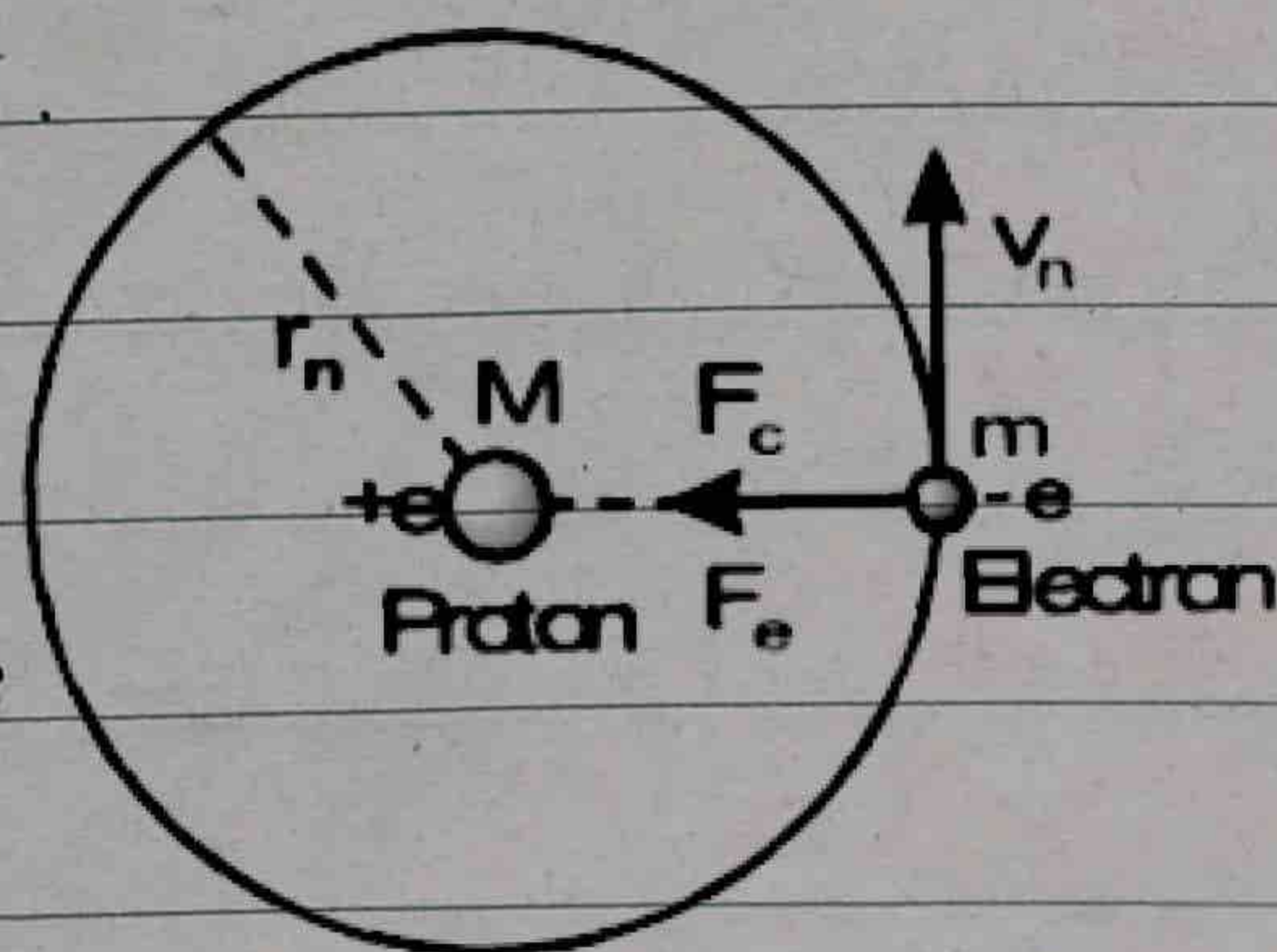
Quantized Radii:

Consider a Hydrogen atom in which an electron of charge e ($-e$) and mass " m " is revolving in a circular orbit around the nucleus (Proton) of charge $(+e)$.

r_n = Radius of Bohr orbit.

v_n = Velocity of electron.

Necessary centripetal force



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

is provided by electrostatic force.

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

$$\therefore F_e = k \frac{q_1 q_2}{r_n^2} = \frac{k(e)(e)}{r_n^2}$$

$$F_c = F_e$$

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

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

$$r_n = \frac{ke^2}{mv_n^2} \rightarrow (1)$$

By the first Postulate.

$$mv_n r_n = n \frac{h}{2\pi}$$



$$v_n = \frac{nh}{2\pi m r_n}$$

Taking sq.

$$v_n^2 = \frac{n^2 h^2}{4\pi^2 m^2 r_n^2} \rightarrow (2)$$

eq. (2) put in eq (1).

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

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

$$1 = \frac{ke^2 \cdot 4\pi^2 m \cdot r_n}{n^2 h^2}$$

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

This shows that radii are quantized.

r_n = Radius of n^{th} orbit.

where $n = 1, 2, 3, \dots$



Radius of first orbit:

If $n = 1$ then we get the radius of first orbit i.e.

$$r_1 = \frac{h^2}{4\pi^2 k m e^2} \longrightarrow (3)$$

So, $r_n = n^2 r_1 \longrightarrow (4)$

The value of r_1 can be calculated by using the values of the constant.

$$r_1 = \frac{(6.63 \times 10^{-34} \text{ J}\cdot\text{s})^2}{4(3.14)^2 \times (9.1 \times 10^{-31} \text{ kg}) \times (9 \times 10^9 \text{ Nm}^2\text{C}^{-2}) \times (1.6 \times 10^{-19} \text{ C})^2}$$

$$r_1 = 5.3 \times 10^{-11} \text{ m} = 0.053 \times 10^{-9} \text{ m}$$

$$r_1 = 0.053 \text{ nm}$$

Speed of Electron:

By the first postulate.

$$m v_n r_n = \frac{n h}{2\pi}$$

$$v_n = \frac{n h}{2\pi m r_n}$$

Put the value r_n

$$v_n = \frac{n h}{2\pi m \left(\frac{n^2 h^2}{4\pi^2 m k e^2} \right)}$$

$$V_n = \frac{n\hbar}{2\pi m} \times \frac{24\pi^2 m k e^2}{n^2 \hbar^2}$$

$$V_n = \frac{2\pi k e^2}{nh}$$

$$V_n \propto \frac{1}{n}$$

For higher orbits ($n = 1, 2, 3, 4, \dots$)
 n increases, so, V_n decreases.

Quantized energies:

The total energy E_n of an electron in the Bohr's orbit is the sum of its K.E and P.E.

$$E_n = \text{K.E} + \text{P.E} \quad \rightarrow (5)$$

As,

$$F_c = F_e$$

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

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

$$\frac{1}{2} mv_n^2 = \frac{1}{2} \frac{ke^2}{r_n}$$

$$\text{K.E} = \frac{1}{2} \frac{ke^2}{r_n}$$

$$\text{P.E} = U = \frac{kq_1q_2}{r_n} = \frac{k(+e)(-e)}{r_n} = -\frac{ke^2}{r_n}$$

Put the values of K.E and P.E in eq.(5)

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

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

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

$$E_n = - \frac{ke^2}{2 \left(\frac{n^2 h^2}{4\pi^2 m k e^2} \right)}$$

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

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

$$E_n = - \frac{1}{n^2} (E_0)$$

$$E_n = - \frac{E_0}{n^2}$$

$$E_1 = - \frac{E_0}{1^2}$$

$$E_2 = - \frac{E_0}{2^2}$$

$$E_2 = - \frac{E_0}{4}$$

$$E_3 = - \frac{E_0}{3^2} = - \frac{E_0}{9}$$

$$E_n = - \frac{E_0}{1} - \frac{E_0}{4} - \frac{E_0}{9} \dots \dots \dots$$

So, Energies are quantized.

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

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

$$E_0 = + \frac{2\pi^2 m k^2 e^4}{h^2}$$

$$\pi = 3.14$$

$$m = 9.1 \times 10^{-31} \text{ kg}$$

$$k = 9 \times 10^9 \text{ NmC}^{-2}$$

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

$$h = 6.63 \times 10^{-34} \text{ Js}$$

So,

$$E_0 = 13.6 \text{ eV}$$

pakcity.org

$$E_3 = - \frac{13.6}{9} = -1.51 \text{ eV}$$

Hydrogen emission spectrum:

Suppose an electron jumps from high energy state E_n to a low energy state E_p . The difference of energy is emitted as a photon of frequency f and energy hf .

$$hf = E_n - E_p \longrightarrow (b)$$

$$\therefore E_n = - \frac{E_0}{n^2}$$

$$hf = - \frac{E_0}{n^2} - \left(- \frac{E_0}{p^2} \right)$$

$$E_p = - \frac{E_0}{p^2}$$

$$hf = - \frac{E_0}{n^2} + \frac{E_0}{p^2}$$

$$hf = \frac{E_0}{p^2} - \frac{E_0}{n^2}$$



$$hf = E_0 \left(\frac{1}{p^2} - \frac{1}{n^2} \right)$$

$$\therefore \text{As, } f\lambda = c$$

$$h \frac{c}{\lambda} = E_0 \left(\frac{1}{p^2} - \frac{1}{n^2} \right)$$

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

$$\frac{1}{\lambda} = \frac{E_0}{hc} \left(\frac{1}{p^2} - \frac{1}{n^2} \right)$$

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

Where,

$$R_H = \frac{E_0}{hc} = 1.0974 \times 10^7 \text{ m}^{-1}$$

The above formula reduces to

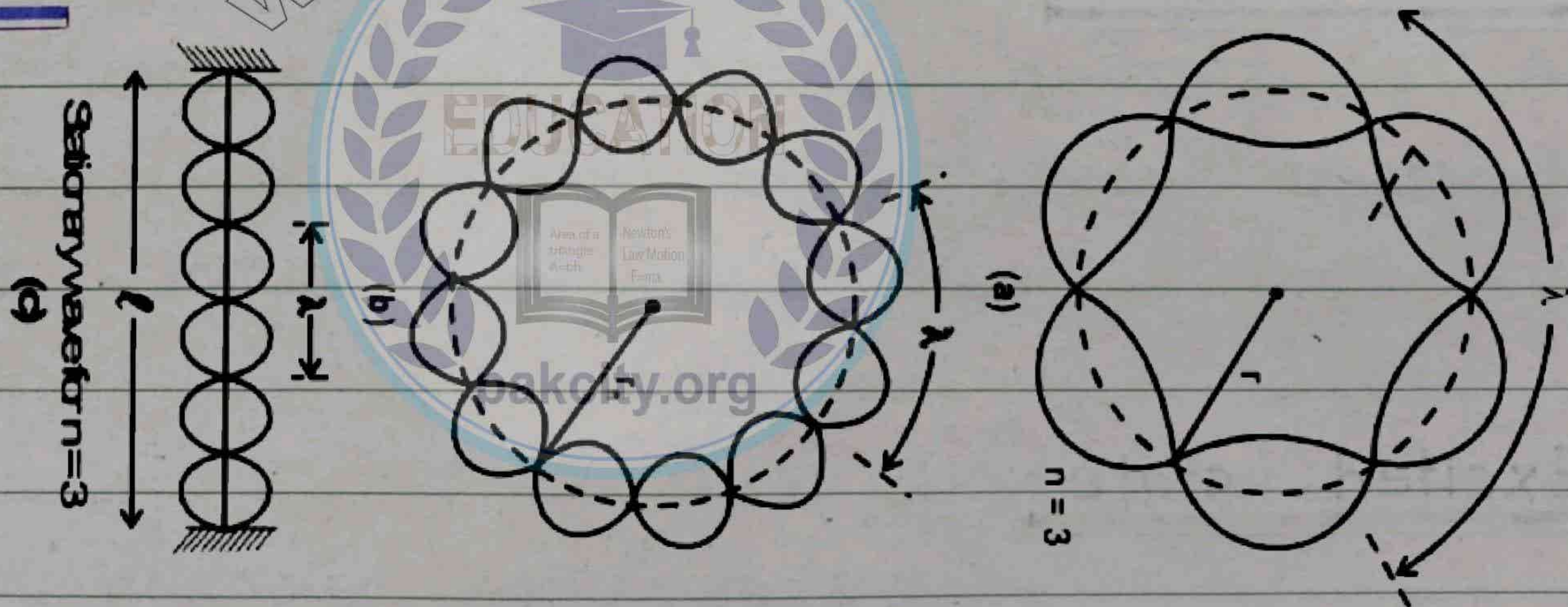
Rydbergs Formula for Balmer series when we put $p = 2$, $n = 3, 4, 5, \dots$

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

De - Broglies interpretation of Bohr's orbit:

At the time of formulation of Bohr's theory, there was no justification for the first two postulates, while postulate (III) had some roots in planck's Hypothesis. Later on with the development of de Broglie's Hypothesis some justification could be seen in postulate (I) as explained below.

Explanation:



Consider a string of length " l " as shown in fig. If this string is put into stationary vibrations, we must have $(l = n\lambda)$ where n is an integer.

Suppose that the string is bent

into circle of radius "r" for $n=3$ and $n=6$ as shown in fig.

$$l = n\lambda$$

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

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

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

From de-Broglies Hypothesis

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

$$\frac{2\pi r}{n} = \frac{h}{mv}$$



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

This is Bohr's Postulate.

Ground state:

Normally the electron in the Hydrogen atom is in the lowest energy state is called Ground state or Normal state.

Excited state:

When the electron is in the first Bohr orbit it is said to be in the ground state. When it is in the higher orbit it is said to be in the excited state.

Excitation Potential:

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 its ground state to some higher state is called **excitation potential**.



Ionization energy:

The energy required to remove completely an electron from the first Bohr orbit is called **ionization energy**. It is equal to 13.6 eV.

The ionization energy to the electron may be provided by collision with an external electron.

Ionization Potential:

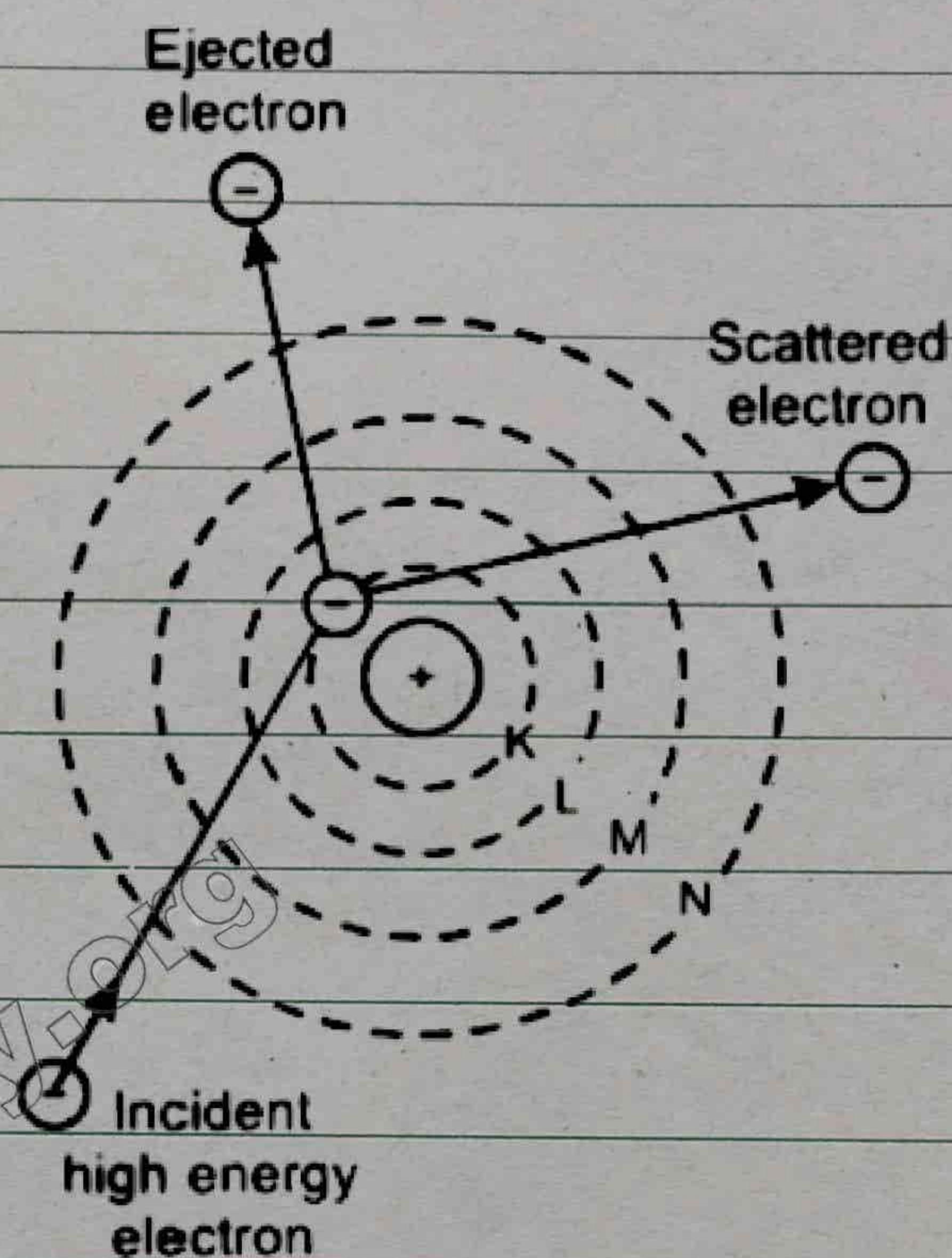
The minimum potential through which the external electron should be accelerated, so that it can supply the required ionization energy is called **ionization potential**.

For Hydrogen its value is 13.6 volts.

20.3 Inner shell Transitions and

Characteristic X-Rays

The transition of electrons in the hydrogen or other light elements causes the emission of spectral lines, in the infrared, visible or ultraviolet region of electromagnetic spectrum due to small energy difference in energy levels.



In Heavy Atoms, the electrons are arranged in concentric shells called K, L, M, N, O etc. K-shell is the closest to the nucleus, the L-shell next and so on.

The inner shell electrons are tightly bound and large amount of energy is required for their displacement from their normal energy levels.

X-Rays:

After excitation when an atom (of heavy element) returns to its normal state, photons of larger energy are emitted.

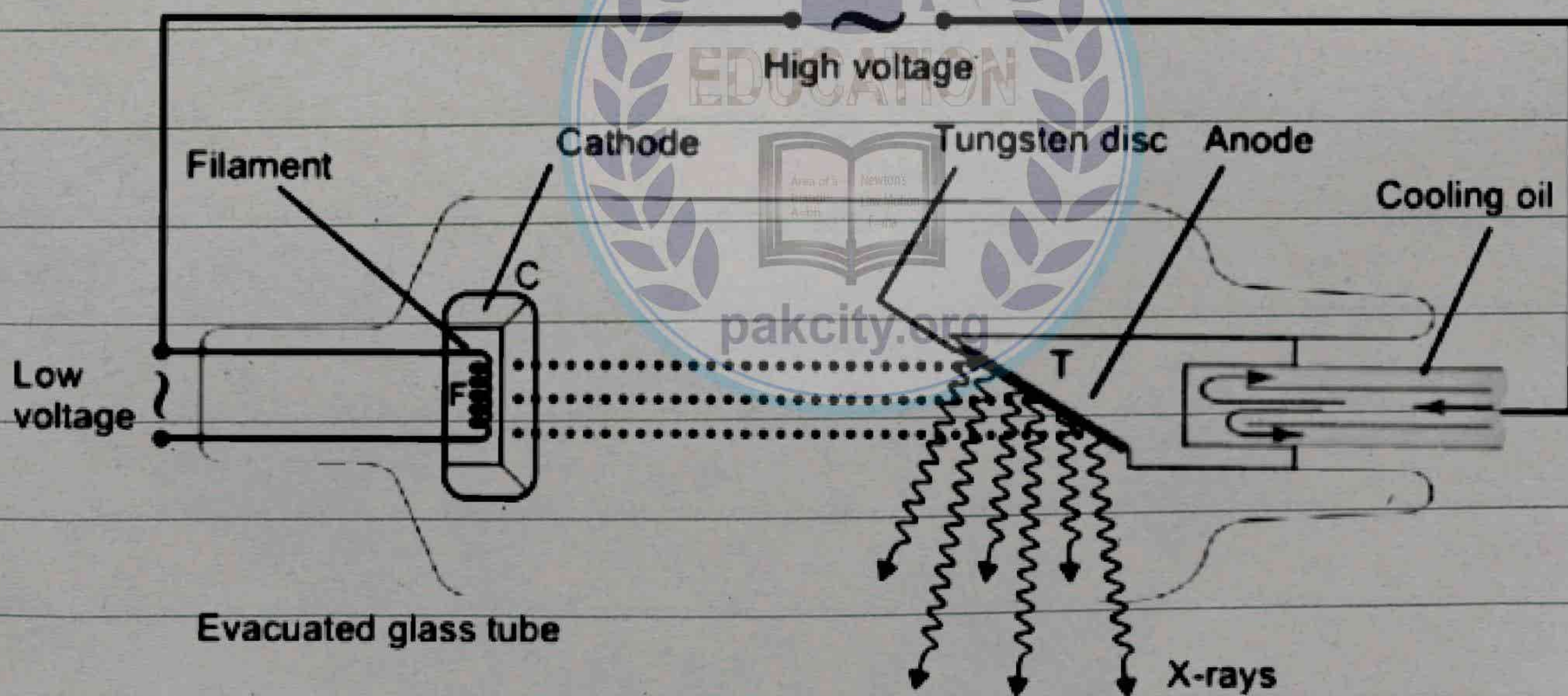
Result :

The transition of inner shell electrons in heavy atoms gives rise to the emission of high energy photons or X-Rays.

Characteristic X-Rays :

X-Rays consist of series of specific wavelengths or frequencies and called Characteristic X-Rays.

(a) Production of X-Rays :



X-Rays :

When high energy electrons

strike a metal surface, highly penetrating radiations called X-Rays are emitted.

These were discovered by Rontgen in 1895.

Construction of X-Ray Tube:

- i); A high vacuum tube called X-Ray tube.
- ii); A source of electrons cathode plate C.
- iii); A system to supply high potential difference to accelerate electrons.
- iv); A target T of tungsten or cadmium. It serves as Anode.

Operation:

When the cathode plate C is heated by the filament F, it emits electrons which are accelerated towards the anode T.

If v is the potential difference between cathode C and Target T, the K.E with which electrons strike the target is given by.

$$K.E = Ve$$

e = charge of electron

K_α X-Ray:

When the fast moving electrons of energy V_e strike a target made of cadmium or any other heavy element, suppose one K-shell electron is removed from the atom. Vacancy or hole is produced in K-shell.

The electron from L-shell jumps to occupy the hole in K-shell. A photon of energy $hf_{K\alpha}$ called K_α X-Ray is emitted

$$hf_{K\alpha} = E_L - E_K \longrightarrow (1)$$

K_β X-Ray:

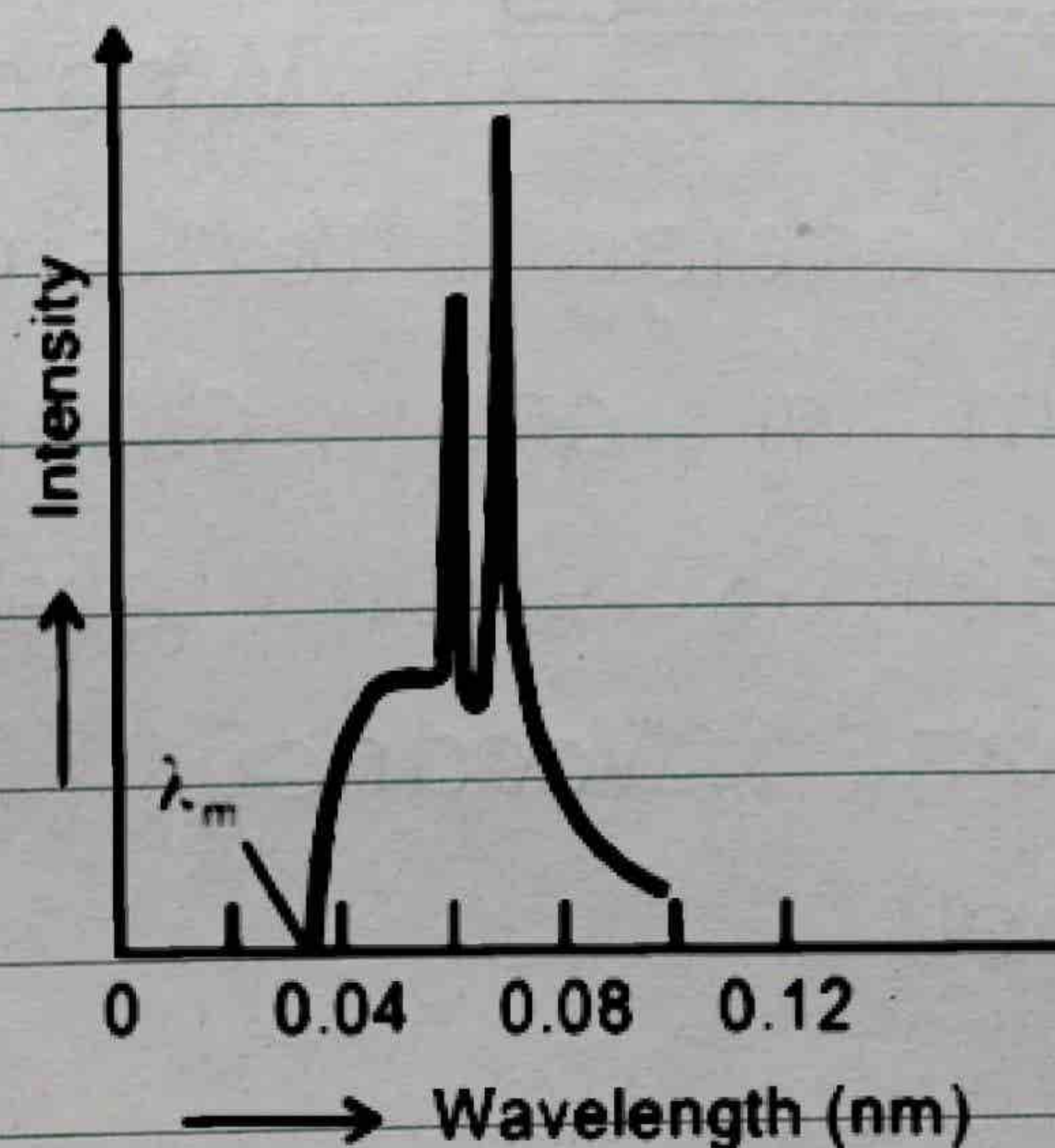
It is also possible that an electron from M-shell, might jump to occupy hole in K-shell. The photons emitted are K_β X-Rays with energies $hf_{K\beta}$.

$$hf_{K\beta} = E_M - E_K \longrightarrow (2)$$

Characteristic X-Rays:

The photons emitted in the inner shell transitions are called characteristic X-Rays. because their energies depend upon the type of target material. The

characteristic X-Rays appear as discrete lines on a continuous spectrum as shown in fig.



b) Continuous X-Ray

Spectrum:

The continuous spectrum is due to an effect called Bremsstrahlung or Breaking Radiation.

When the fast moving electrons bombard the target they are suddenly slowed down on impact with the target. These colliding electrons emit radiations as they are strongly decelerated by the target.

Since the rate of deceleration is so large, the emitted radiations have short wavelength (high frequency), so the bremsstrahlung is in the X-Ray region.

In the case when the electrons lose all their K.E in the first collision, the total K.E appears as energy of X-Ray photon $hf_{\max}$.

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

$$V_e = hf_{\max} = \frac{hc}{\lambda_{\min}}$$

So,

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

The wavelength $\lambda_{\min}$ in the fig. corresponds to frequency $f_{\max}$.

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 produce photons of smaller energy or X-Rays of longer wavelength. So, the continuous spectrum is obtained due to deceleration of colliding electrons.

C) Properties and Uses of X-Rays:

Properties:

1) : X-Rays are electromagnetic radiations of frequencies greater than the Ultra-violet light.

2) : They have no charge, so they are not effected by electric and magnetic fields.

3): They travel with the speed of light
 $C = 3 \times 10^8 \text{ ms}^{-1}$.

4): They are diffracted by crystals.

5): X-Rays produce photoelectric process when incident on a metal surface.

6): They produce ionization in gases and this property is used to find out the intensity of X-Rays.

7): They can damage living tissues, if they are exposed to them for longer duration of time.

8): X-Rays are highly penetrating radiations. They can penetrate those materials which are opaque to ordinary light. They can pass through flesh.

Uses of X-Rays:



1): X-Ray diffraction is used to study the crystal structure.

2): X-Rays are used for security

checking at the air-ports and banks etc.

3): X-Rays are used to destroy cancer cells.

4): In industry, X-Rays are used to reveal hidden flaws in metal casting and welding joints.



CAT_Scanner:

It is an improved X-Ray method. CAT stands for "Computerized axial tomography." The instrument is called CAT Scanner.

The X-Ray source produces a thin fan-shaped beam which 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-Rays 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 difference of the order of one percent can be detected with CAT-scans.

Tumors and other anomalies much too small to be scan with other techniques can be detected.



Biological Effects of X-Rays:

- 1): X-Rays can cause damage to living tissues.
- 2): Young and rapid growth cells are particularly susceptible.
- 3): Excessive X-Rays radiations exposure can cause changes in their reproductive system that will effect the organism's offsprings.
- 4): X-Rays are useful for selective destruction of cancer cells. On the other

a cell may be damaged by radiation but survive, continue dividing and produce generation of defective cells.

5): Molecular bonds in tissues may break up due to X-Rays. As a result of which highly reactive radicals like H and OH are produced. These disturb the working and structure of protein and especially genetic materials.



20.4 Uncertainty within the atom

Due to the dual nature of matter (Particle nature and wave nature), There is always an uncertainty in the measurement of position and momentum of a particle at the same time (simultaneously). By Heisenberg's Uncertainty principle.

$$\Delta P \Delta x \geq \frac{h}{2\pi} \quad \text{or} \quad \Delta P \Delta x \approx h$$

1: Electron is not present inside the nucleus:

Size of a nucleus $\Delta x \approx 10^{-14} \text{ m}$

$$\Delta P \Delta x \approx h$$

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

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

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

$$\Delta V = \frac{6.63 \times 10^{-34} \text{ Js}}{9.1 \times 10^{-31} \text{ Kg} \times 10^{-14} \text{ m}} = 7.3 \times 10^{10} \text{ ms}^{-1}$$

$$7.3 \times 10^{10} \text{ ms}^{-1} > 3 \times 10^8 \text{ ms}^{-1}$$

$$\Delta V > c$$

It means that the

speed of electron is greater than the speed of light, which is not possible.

Result:

An electron can never be found inside the nucleus.

2: Electron can reside inside the atom:

Radius of Hydrogen atom is

$$\Delta x = 5 \times 10^{-11} \text{ m}$$

$$\Delta V = \frac{h}{m \Delta x} = \frac{6.63 \times 10^{-34} \text{ J.s}}{9.1 \times 10^{-31} \text{ kg} \times 5 \times 10^{-11} \text{ m}}$$

$$\Delta V = 1.46 \times 10^7 \text{ ms}^{-1}$$

$$3 \times 10^8 \text{ ms}^{-1} > 1.46 \times 10^7 \text{ ms}^{-1}$$

$$c >$$

$$\Delta V$$



So, the speed of electron is less than the speed of light, which is possible.

Result:

An electron can exist in the atom but outside the nucleus.

20.5 Laser

Laser:

Laser is the acronym for light Amplification by Stimulated Emission of Radiation. Laser produces an intense monochromatic unidirectional and coherent beam of visible light.

Working of Laser:

It involves two terms.

- i; Spontaneous and Stimulated Emission.
- ii; Population inversion and laser action.

Spontaneous and Stimulated emission:

Consider

a sample of free atoms.

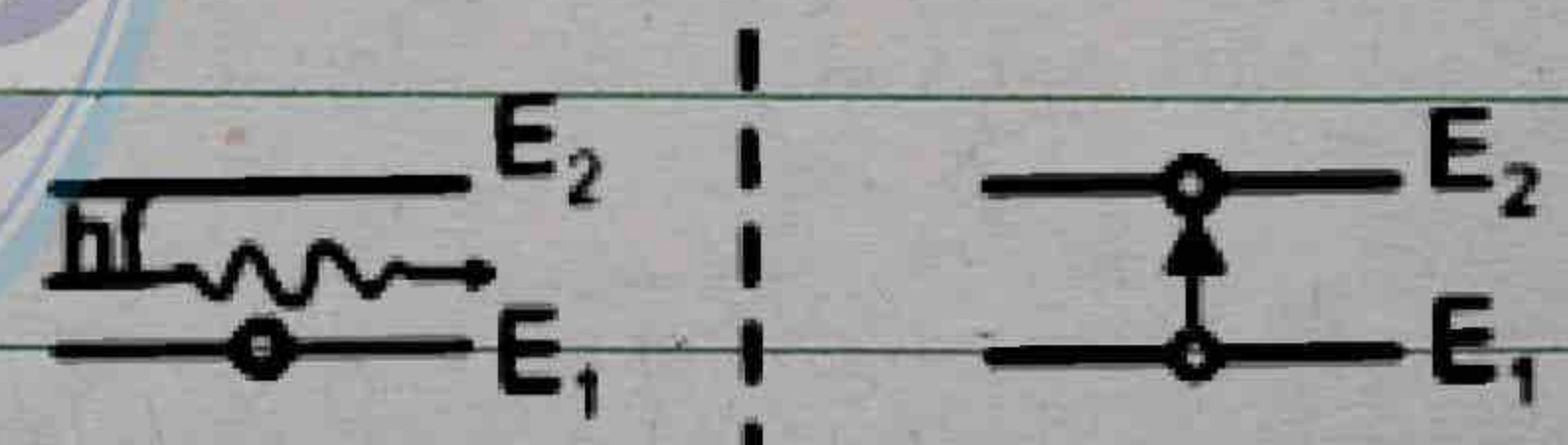
Some atoms are in the ground state E_1 .

Some atoms are in the excited state E_2 .

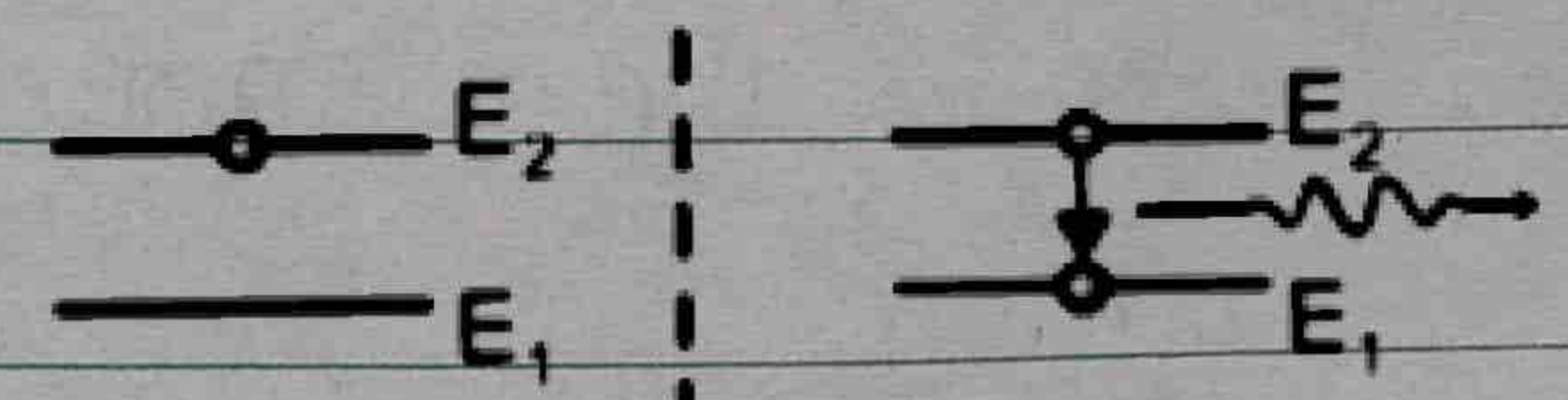
The photons of energy $hf = E_2 - E_1$ are incident on this sample.

The incident photons can interact with the atoms of the sample in two different ways.

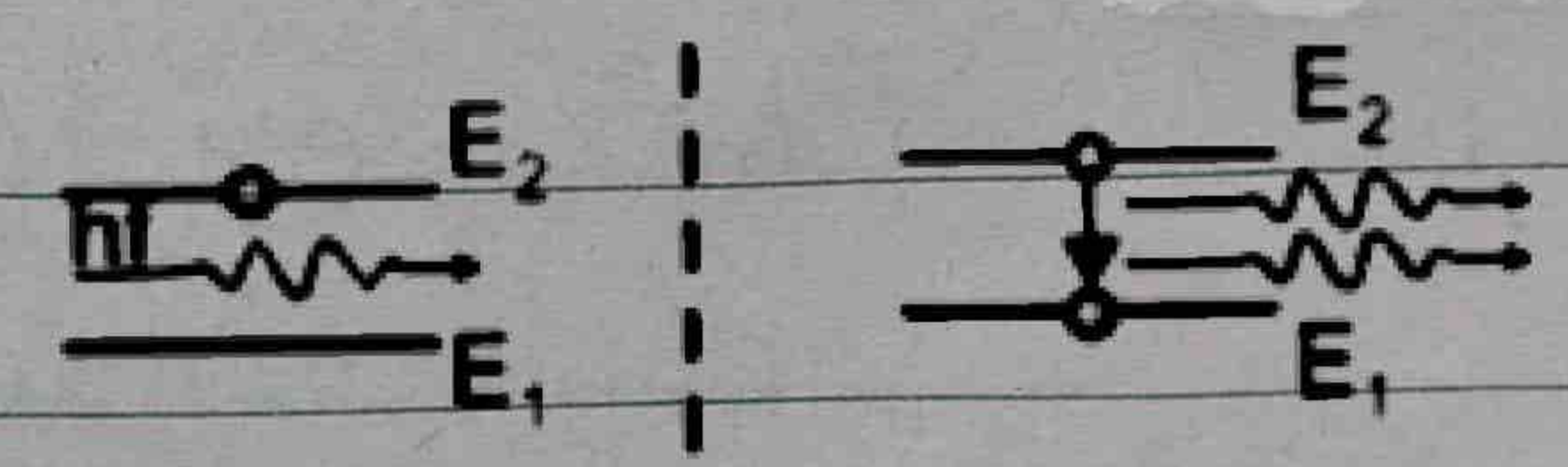
In fig (a) the incident photon is absorbed



(a) Induced absorption



(b) Spontaneous emission



(c) Induced emission

by the atoms in the ground state E_1 . As a result atom is raised to the excited state E_2 . This process is called stimulated absorption or induced absorption.

When the atoms are in the excited state E_2 , two things can happen to the atom.

i, Spontaneous Emission:

The atom can decay by spontaneous emission as shown in fig (b). Here the atom emits a photon of energy $hf = E_2 - E_1$ in any arbitrary direction.

ii, Stimulated emission:

The other alternative for the atom in the excited state E_2 is to decay by stimulated emission or induced emission as shown in fig (c). In this case, the emitted photon of energy $E_2 - E_1 = hf$ is moving in the direction of incident photon. It means that for every single incident photon, two photons will be moving in the same direction.

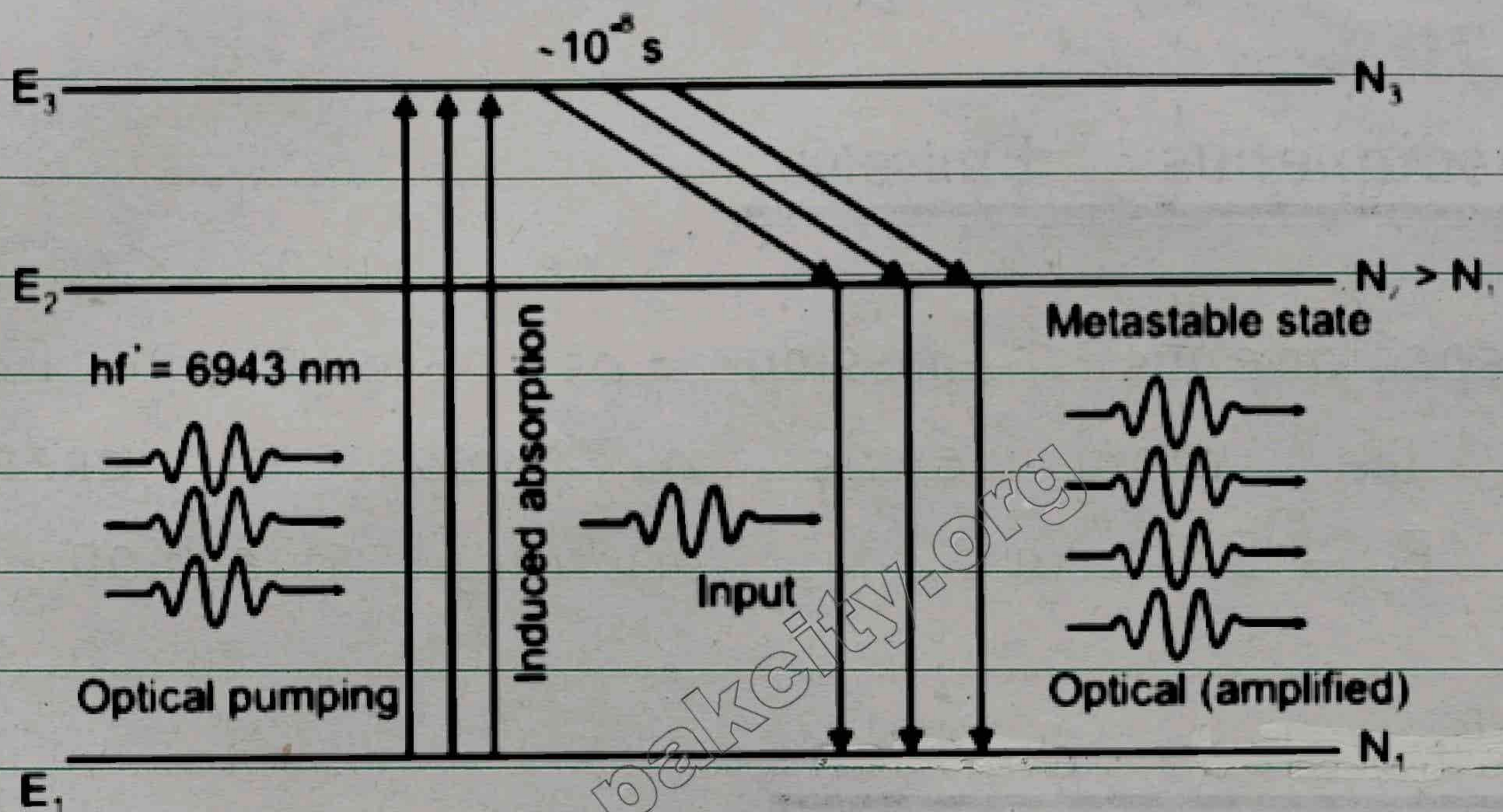
So, now we have achieved two thing

★ : Amplified.

★ : An unidirectional coherent beam.

This is only possible if there more stimulated emissions than spontaneous emissions. This can be achieved as follows.

Population inversion and Laser action:



Consider a material whose atoms can have three energy states.

E_1 = Ground state.

E_3 = Excited state in which an electron can stay for 10^{-8} s . It has very short life.

E_2 = Metastable state

It is an excited state in which an electron can stay for relatively long time 10^{-3} s . It has a longer life.

From metastable state electrons

spontaneously fall to a lower state after a relatively longer time. The transition from or to the metastable state is difficult as compared to the other excited states. So, instead of excited to higher energy level. From the higher energy level the electrons spontaneously fall to the metastable state.

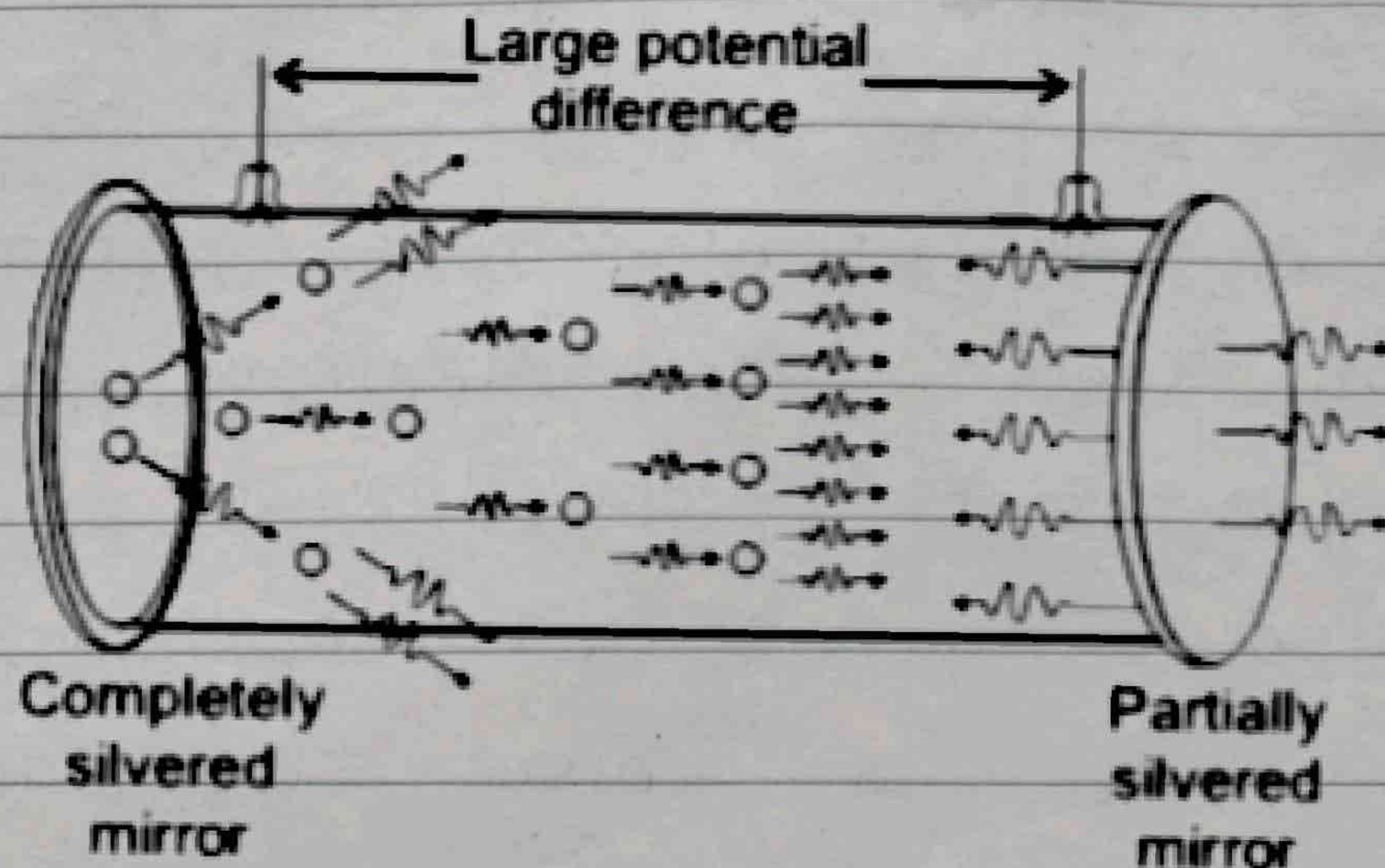
Also assume that incident photon of energy $E_3 - E_1 = hf$ raises the atom from ground state E_1 to excited state E_3 , but excited atoms do not decay back to E_1 . So, the only alternative for the atoms in the excited state E_3 is to decay spontaneously to state E_2 much faster than they leave the state E_2 . As a result, we have a situation in which the state E_2 contains more atoms than state E_1 . This situation is called Population Inversion ($N_2 > N_1$)

Laser action:

The atoms in the metastable state E_2 are bombarded by photons of energy $E = hf = E_2 - E_1$, resulting in the stimulated (induced) emission, giving an intense and coherent beam in the direction of the incident photon.

The emitted photons must be

confined in an assembly of atoms long enough to stimulate other photons.



This is done 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. In this way the resulting radiations become more and more intense and coherent as compared to ordinary visible light.

Helium Neon Lasers:

It is a most common type of laser used in physics laboratories. It is a discharge tube which contains **85%** Helium and Neon is the lasing material or

(15% Neon gas) active medium in the tube.

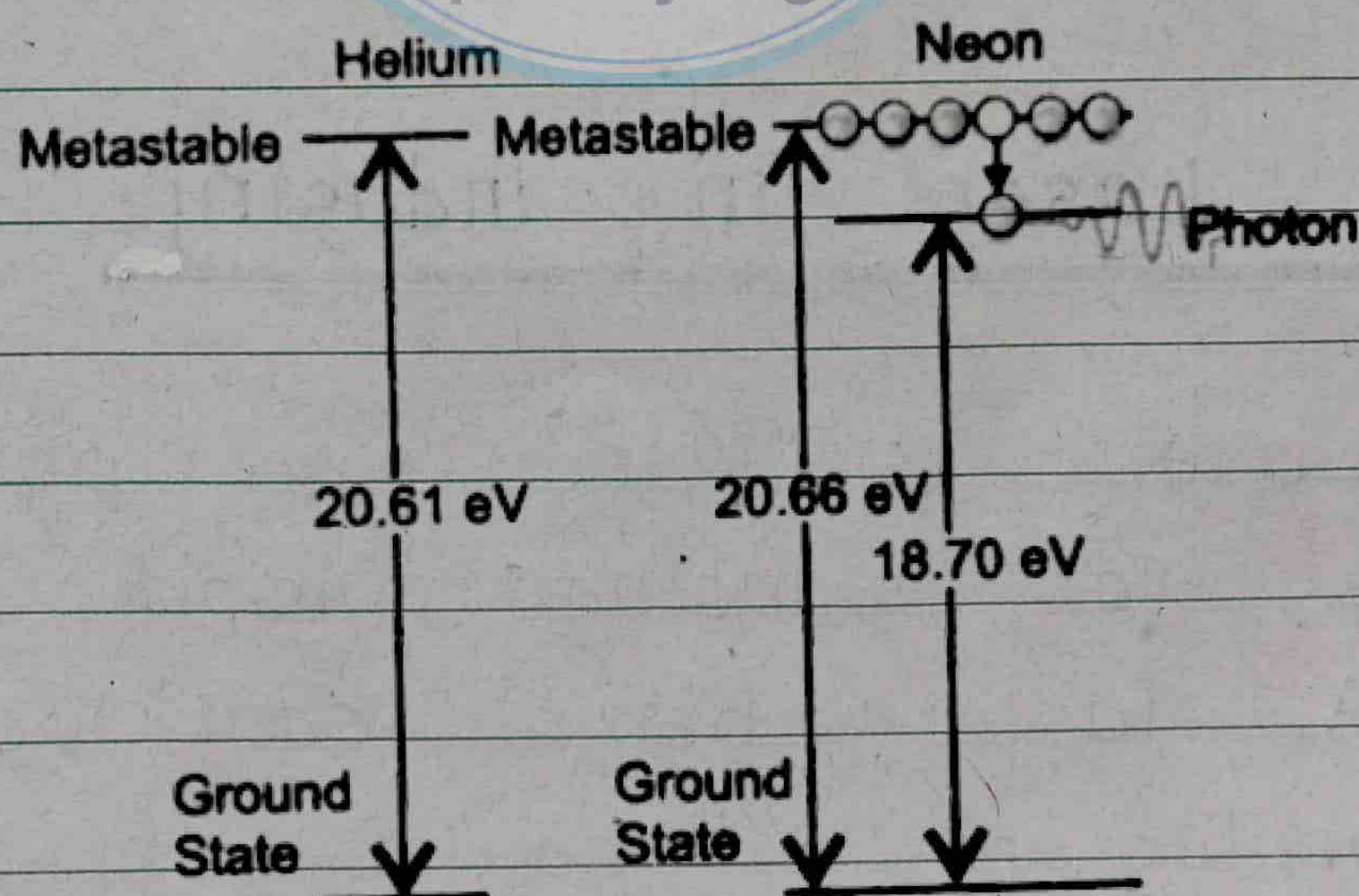
Helium and Neon have nearly identical metastable state.

For Helium it is 20.61 eV.

For Neon it is 20.66 eV.

A 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 K.E. from the moving atom. As a result the electrons in Neon atoms are raised to 20.66 eV state. So population inversion is kept in the Neon gas relative to an energy level of 18.70 eV.

Spontaneous emission from Neon atoms



start laser action and stimulated emission causes electrons in the Neon to drop from 20.66 eV to the 18.70 eV level and red light of wavelength 632.8 nm corresponding to 1.96 eV energy is generated.

Uses of Laser in medicine:

- ★ ; Laser beams are used as surgical tool for welding detached retina.
- ★ ; The narrow intense beam of laser can be used to destroy tissue in a localized area.
- ★ ; A finely focussed laser beam can be used to destroy cancerous and pre-cancerous cells.
- ★ ; Laser can be used for telecommunication along optical fibres.
- ★ ; Lasers are used to break the stone in human kidney.

Uses of Laser in industry:



- ★ ; Laser is used as potential energy source for inducing fusion reaction.
- ★ ; A laser beam can be used for the photographic recording of output data

of a computer.

★ ; The lasers can be used as very sensitive detectors of pollution in the atmosphere.

★ ; A laser beam can be used as range finder over large distances.

★ ; Lasers also have military application as laser guided missiles can destroy aircrafts and tanks.



Chapter = 20



Questions

Question = 1

Answer:

Yes,

According to the Bohr's postulate, electron does not radiate energy when it revolves in a fixed allowed orbit.

But according to the classical physics a revolving electron is an accelerated charge which must radiate energy.

So both are opposite to each other.

Question = 2

Answer:

When an electron jumps from a higher to lower orbit, a set of particular frequency is emitted. A series of lines so produced is called a line spectrum.

Line spectrum is produced for an isolated atom.

Each element has its own

characteristic line spectrum, which can be used to identify the element.

Question = 3

Answer:

Ionization energy of electron in the ground state of Hydrogen atom = 13.6 eV .

A photon of energy 13.6 eV will ionize the atom and is absorbed.

A photon of energy greater than 13.6 eV will also ionize the atom and is absorbed. The surplus energy will appear as the K.E of the electron.

Question = 4

Answer:

Although the Hydrogen atom contains a single electron, however there are so many different energy levels produce different lines in the spectrum.

So Hydrogen spectrum contains many lines.

Question = 5

Answer:

Yes,

energy is conserved. It is according to the law of conservation of energy.

The difference in energy between two energy levels is emitted as the energy of photon

$$E_2 - E_1 = hf \text{ (photon)}$$

Question = 6



Answer:

A glowing gas gives only certain wavelength because in an element there are definite energy states. The transitions between wavelengths.

When light having the same wavelengths absorbed and the atoms are excited.

Other wavelength cannot excite the atoms because of definite energy states.

So they pass through the gas and the gas is transparent to the wavelength.

Question = 7

Answer:

When a proper amount of energy is supplied to the electron of an atom, it is lifted up to one of the higher energy states.

Now, we say that the atom is excited.

Question = 8



Answer:

Yes,

X-rays are electromagnetic waves of smaller wavelength and greater frequency.

So, they can be reflected, refracted, different and polarized just like other waves.

Question = 8

Answer:

Advantages of laser light over ordinary light are;

- i) It is monochromatic
- ii) It has high intensity

- iii) It is unidirectional
iv) It is phase coherent.

Question = 10

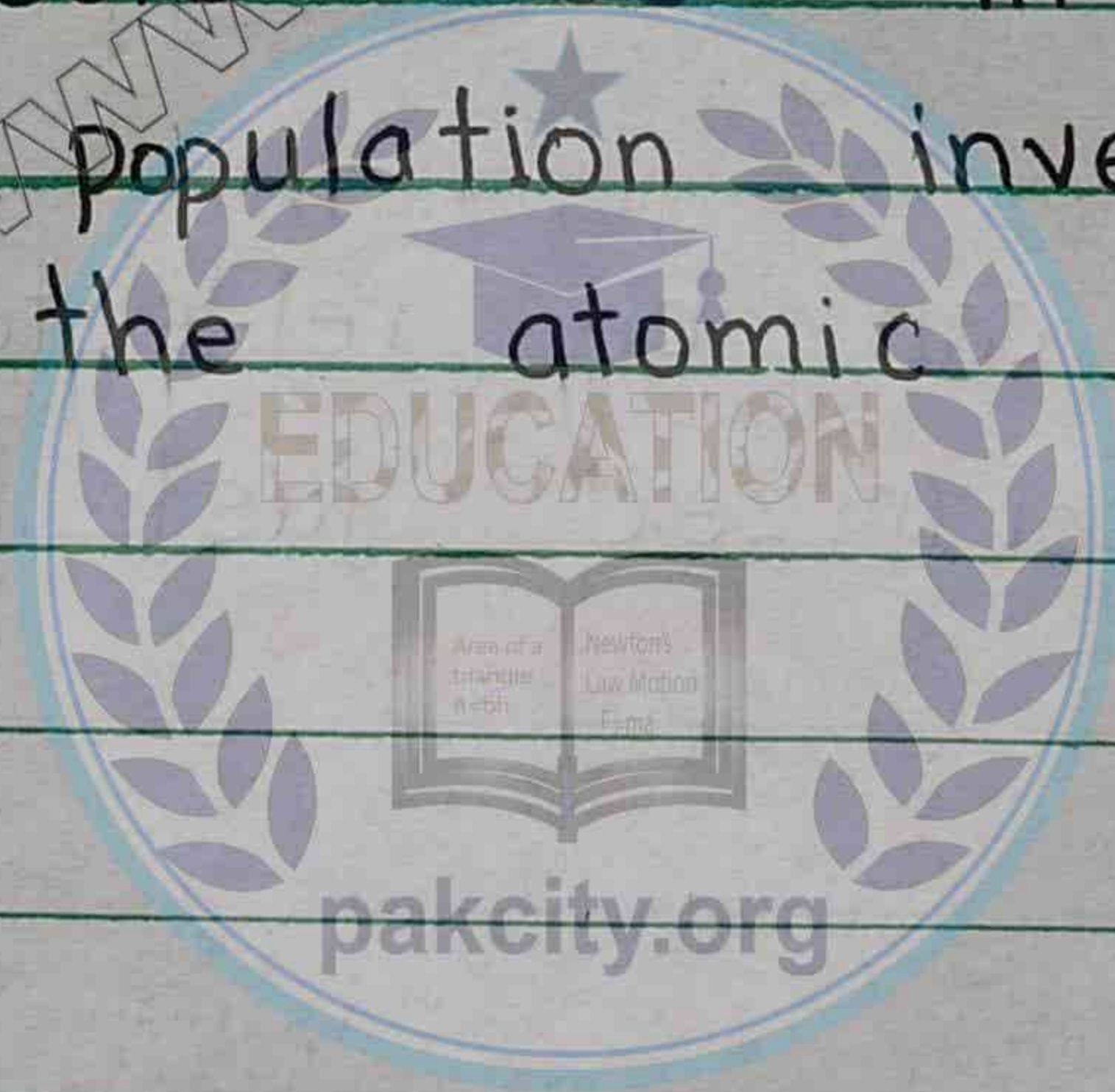


Answer

Population Inversion:

No. of atoms in the excited state $>$ No. of atoms in the ground state.

- * Laser light is produced due to stimulated emission.
- * For stimulated emission most of the electrons should be in the excited state.
So, population inversion is necessary between the atomic levels.



Chapter 20ProblemsProblem 20.1Solution

$n = 1$ (for ground state)

(a) $r_1 = ?$

(b) $p_1 = ?$

(c) $L_1 = ?$

(d) $KE = ?$

(e) $PE = ?$

(f) $E_1 = ?$

(a)

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

$$r_1 = \frac{h^2}{4 \pi^2 m k e^2}$$

$$n = 1$$

$$r_1 = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})^2}{4(3.14)^2 (9.1 \times 10^{-31} \text{ kg}) (9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}) (1.6 \times 10^{-19} \text{ C})^2}$$

$$r_1 = 5.3 \times 10^{-11} \text{ m}$$

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

$$= 0.529 \times 10^{-10}$$

$$= 0.053 \times 10^{-9} \text{ m}$$

or

$$r_1 = 53 \times 10^{-12} \text{ m}$$

$$r_1 = 0.053 \text{ nm}$$

$$r_1 = 53 \text{ pm}$$

(b)

$$V_n = \frac{2\pi k e^2}{nh}$$

$$V_1 = \frac{2\pi k e^2}{h}$$

$$n=1$$

x by m both sides

$$m v_1 = \frac{2\pi m k e^2}{h}$$

$$P_1 = \frac{2\pi m k e^2}{h}$$

$$P_1 = \frac{2 \times (3.14) (9.1 \times 10^{-31} \text{ kg}) (9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}) (1.6 \times 10^{-19} \text{ C})^2}{6.63 \times 10^{-34} \text{ J} \times \text{s}}$$

$$P_1 = 1.99 \times 10^{-24} \text{ kg} \cdot \text{m/s}$$

(c)

$$m v_n r_n = \frac{n h}{2 \pi}$$

$$n=1$$

$$m_1 v_1 r_1 = \frac{h}{2 \pi}$$

$$L_1 = \frac{h}{2 \pi}$$



$$L_1 = \frac{6.63 \times 10^{-34} \text{ J} \times \text{s}}{2 \times 3.14}$$

$$L_1 = 1.05 \times 10^{-34} \text{ J} \times \text{s}$$

(d)

$$K.E = \frac{1}{2} \frac{ke^2}{r_n}$$

$$n=1$$

$$K.E = \frac{1}{2} \frac{ke^2}{r_1}$$

$$K.E = \frac{1}{2} \cdot \frac{(9 \times 10^9 \text{ Nm}^2/\text{C}^2)(1.6 \times 10^{-19} \text{ C})^2}{0.053 \times 10^{-9}}$$

$$K.E = 2.17 \times 10^{-18} \text{ J}$$

$$K.E = \frac{2.17 \times 10^{-18}}{1.6 \times 10^{-19}} \text{ eV}$$

$$K.E = 13.6 \text{ eV}$$



(e)

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

$$n=1$$

$$PE = - \frac{ke^2}{r_1}$$

$$PE = - \frac{(9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2})(1.6 \times 10^{-19} \text{ C})^2}{(0.053 \times 10^{-9} \text{ m})}$$

$$PE = -4.34 \times 10^{-18} \text{ J}$$

$$PE = - \frac{4.34 \times 10^{-18}}{1.6 \times 10^{-19}} \text{ eV}$$

$$PE = -27.2 \text{ eV}$$

(f)

$$\text{Total Energy} = E_n$$

$$E_n = K.E + P.E$$

$$E_1 = 13.6 \text{ eV} - 27.2 \text{ eV}$$

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

Problem 20.2



Solution

$$E = ?$$

$$\text{For } \lambda = 400 \text{ nm}$$

$$E = hf$$

$$f\lambda = c$$

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

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

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{400 \times 10^{-9}}$$

$$E = 4.97 \times 10^{-19} \text{ J}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$E = \frac{4.97 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV}$$

$$E = 3.10 \text{ eV}$$

For $\lambda = 500 \text{ nm}$



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

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{500 \times 10^{-9}}$$

$$E = 3.978 \times 10^{-19} \text{ J}$$

$$E = \frac{3.978 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV}$$

$$E = 2.49 \text{ eV}$$

For $\lambda = 700 \text{ nm}$

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

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{700 \times 10^{-9}}$$

$$E = 2.84 \times 10^{-19} \text{ J}$$

$$E = \frac{2.84 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV}$$

$$\boxed{E = 1.77 \text{ eV}}$$

Problem 20.3



Solution

$$\lambda = ?$$

$$E_i = -3.5 \times 10^{-19} \text{ J}$$

$$E_f = -1.20 \times 10^{-18} \text{ J}$$

$$E = E_i - E_f$$

$$= -3.5 \times 10^{-19} - (-1.20 \times 10^{-18})$$

$$E = 1.2 \times 10^{-18} - 3.5 \times 10^{-19}$$

$$E = 8.5 \times 10^{-19}$$

As

$$E = hf$$

$$f\lambda = c$$

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

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

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

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{8.5 \times 10^{-19}}$$

$$\lambda = 2.34 \times 10^{-7}$$

$$\lambda = 234 \times 10^{-9} \text{ m}$$

$$\lambda = 234 \text{ nm}$$

Problem 20.4

pakcity.org

Solution

$$\lambda = ?$$

$$n = 6$$

$$p = 3$$

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

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

$$\frac{1}{\lambda} = R_H \left(\frac{1}{3^2} - \frac{1}{6^2} \right)$$

$$\frac{1}{\lambda} = R_H \left(\frac{1}{9} - \frac{1}{36} \right)$$

$$\frac{1}{\lambda} = R_H \left(\frac{4-1}{36} \right)$$

$$\frac{1}{\lambda} = R_H \left(\frac{3}{36} \right)$$

$$\frac{1}{\lambda} = R_H \left(\frac{1}{12} \right)$$

$$\lambda = \frac{R_H}{12}$$

$$\lambda = \frac{12}{R_H}$$

$$\lambda = \frac{12}{R_H}$$

$$\lambda = \frac{12}{1.0974 \times 10^7 \text{ m}^{-1}}$$

$$\lambda = 1.093 \times 10^{-6} \text{ m}$$

$$\lambda = 1093 \times 10^{-9} \text{ m}$$

$$\lambda = 1093 \text{ nm}$$

Problem 20.5



Solution

For Balmer series

$$\frac{1}{\lambda} = R_H \left(\frac{1}{2^2} - \frac{1}{n^2} \right) \quad n = 3, 4, 5, \dots$$

$\lambda = ?$ (shortest wavelength) i.e.
largest frequency
for shortest wave length

$$n = \infty$$

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

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

$$\frac{1}{\lambda} = R_H \left(\frac{1}{4} - 0 \right)$$

$$\frac{1}{\lambda} = \frac{R_H}{4}$$

$$\lambda = \frac{4}{R_H}$$

$$\lambda = \frac{4}{1.0974 \times 10^7 \text{ m}^{-1}}$$

$$\lambda = 3.645 \times 10^{-7} \text{ m}$$

pakcity.org

$$\lambda = 364.5 \times 10^{-9} \text{ m}$$

$$\lambda = 364.5 \text{ nm}$$

Problem 20.6

Solution:

$$\lambda = ? \quad (\text{longest})$$

For paschen series

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

$$n = 4, 5, 6, \dots$$

For Longest wavelength

i.e shortest frequency

$$n = 4$$



$$\frac{1}{\lambda} = R_H \left(\frac{1}{3^2} - \frac{1}{4^2} \right)$$

$$\frac{1}{\lambda} = R_H \left(\frac{1}{9} - \frac{1}{16} \right)$$

$$\frac{1}{\lambda} = R_H \times \left(\frac{16-9}{9 \times 16} \right)$$

$$\frac{1}{\lambda} = R_H \left(\frac{7}{9 \times 16} \right)$$

$$\lambda = \frac{1}{R_H} \times \frac{9 \times 16}{7}$$

$$\lambda = \frac{1}{1.0974 \times 10^7 \text{ m}^{-1}} \times \frac{9 \times 16}{7}$$

$$\lambda = 1.874 \times 10^{-6} \text{ m}$$

$$\lambda = 1874 \times 10^{-9} \text{ m}$$

$$\lambda = 1874 \text{ nm}$$

Problem 20.7Solution

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

$$\lambda = ? \text{ (minimum) frequency} = \text{Max}$$

$$E = hf$$

$$V_e = hf$$

$$V_e = h \frac{c}{\lambda}$$

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

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

$$\lambda = \frac{(6.63 \times 10^{-34} \text{ J}\cdot\text{s})(3 \times 10^8 \text{ m/s})}{3000 \text{ V} \times 1.6 \times 10^{-19} \text{ C}}$$

$$\lambda = 4.14 \times 10^{-10} \text{ m}$$

Problem 20.8Solution

$$\lambda = 1.377 \times 10^{-10} \text{ m}$$

$$\Delta E = ?$$

$$\Delta E = hf$$

$$f\lambda = c$$

$$\Delta E = h \frac{c}{\lambda}$$

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

$$\Delta E = \frac{(6.63 \times 10^{-34} \text{ J}\cdot\text{s})(3 \times 10^8 \text{ m/s})}{1.377 \times 10^{-10} \text{ m}}$$

$$\Delta E = 1.44 \times 10^{-15} \text{ J}$$

$$\therefore 1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$\Delta E = \frac{1.44 \times 10^{-15}}{1.6 \times 10^{-19}} \text{ eV}$$

$$= 9.027 \times 10^3 \text{ eV}$$

$$\Delta E = 9.03 \text{ keV}$$

$$\Delta E = 9027 \text{ eV}$$

Problem 20.9solution

$$V = 40 \text{ kV}$$

$$V = 40 \times 10^3 \text{ V}$$

$$\lambda = ? \text{ (shortest)}$$

$$E = hf$$

$$eV = hf$$

$$eV = h \frac{c}{\lambda}$$

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

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8 \text{ m/s}}{40 \times 10^3 \text{ V} \times 1.6 \times 10^{-19} \text{ C}}$$

$$\lambda = 3.1 \times 10^{-11} \text{ m}$$

$$\lambda = 0.31 \times 10^{-10} \text{ m}$$

Problem 20.10Solution

$$v_n = 5.456 \times 10^5 \text{ m/s}$$

(a) $n = ?$

(b) $r_n = ?$

(c) $E_n = ?$

(a)

$$v_n = \frac{2\pi k e^2}{nh}$$

$$n = \frac{2\pi k e^2}{v_n \times h}$$

$$n = \frac{2 \times 3.14 \times (9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}) (1.6 \times 10^{-19} \text{ C})}{5.456 \times 10^5 \text{ m/s} \times 6.63 \times 10^{-34} \text{ Js}}$$

$$n = 4$$

(b)

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

$$r_4 = \frac{(4)^2 h^2}{4\pi^2 m k e^2}$$

$$r_4 = \frac{16 \times (6.63 \times 10^{-34} \text{ J s})^2}{4(3.14)^2 \times (9.1 \times 10^{-31} \text{ kg}) \left(9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}\right) (1.6 \times 10^{-19} \text{ C})^2}$$

$$r_4 = 8.464 \times 10^{-10} \text{ m}$$

$$r_4 = 0.846 \times 10^{-9} \text{ m}$$

$$r_4 = 0.85 \text{ nm}$$



(C)

$$E_n = \frac{-2\pi^2 m K^2 e^4}{n^2 h^2}$$

$$E_4 = \frac{-2(3.14)^2 (9.1 \times 10^{-31} \text{ kg})^2 \left(9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}\right) (1.6 \times 10^{-19} \text{ C})^4}{(4)^2 \times (6.63 \times 10^{-34} \text{ J s})^2} \quad n=4$$

$$E_4 = -1.36 \times 10^{-19} \text{ J}$$

$$E_4 = - \frac{1.36 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV}$$

$$E_4 = 0.85 \text{ eV}$$



Chapter 20



Examples

Example 20.1

Solution:

$$V_n = \frac{2\pi k e^2}{nh}$$

$$V_1 = \frac{2\pi k e^2}{h} \quad n=1 \text{ for first Bohr orbit}$$

$$V_1 = \frac{2 \times 3.14 \times 9 \times 10^9 \text{ Nm}^2 \text{C}^{-2} \times (1.6 \times 10^{-19} \text{ C})^2}{6.63 \times 10^{-34} \text{ Js}}$$

$$V_1 = 2.19 \times 10^6 \text{ ms}^{-1}$$