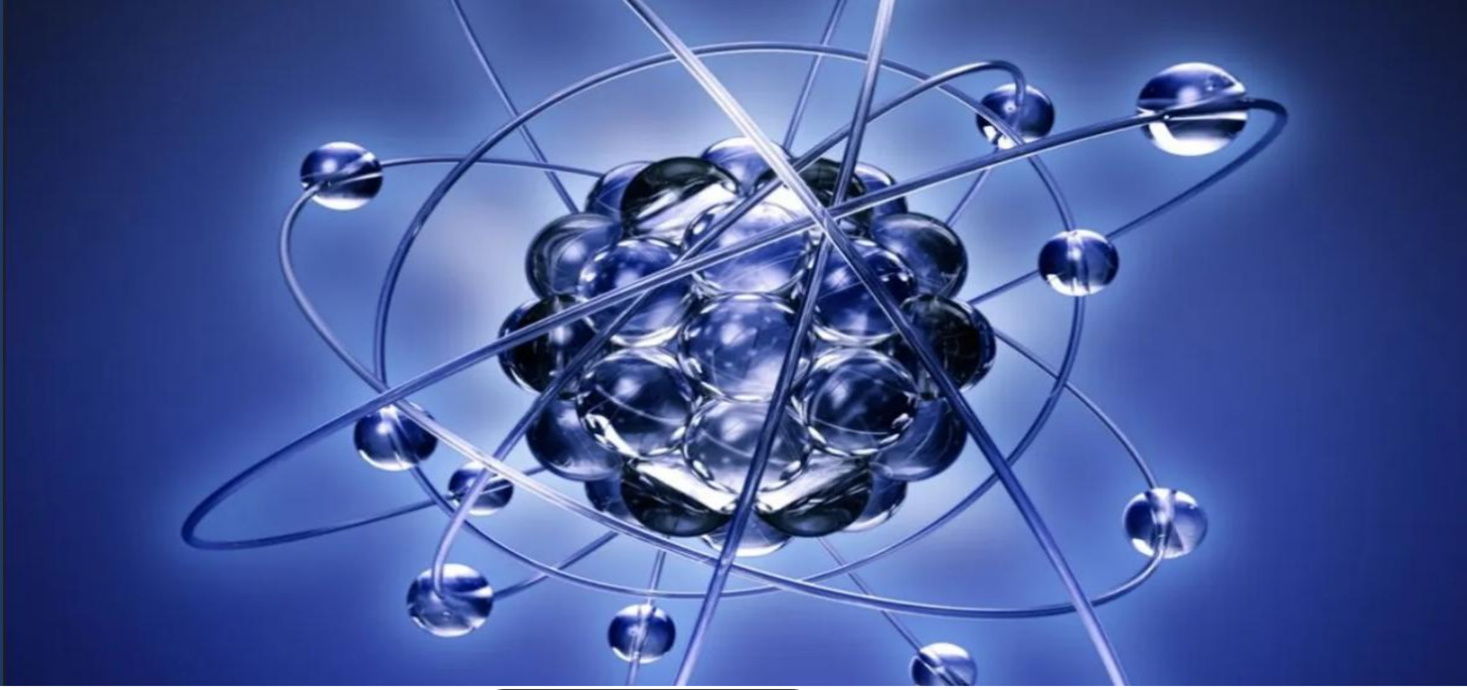
ATOMS



CHAPTER – 12

ATOMS

Various Models For Structure Of Atom

Dalton's Theory

Every material is composed of minute particles known as atom. Atom is indivisible i.e. it cannot be subdivided. It can neither be created nor be destroyed. All atoms of same element are identical (Physically as well as chemically), whereas atoms of different elements are different in properties. The atoms of different elements are comparable to hydrogen atoms. (The radius of the heaviest atom is about 10 times that of hydrogen atom and its mass is about 250 times that of hydrogen). The atom is stable and electrically neutral.

Thomson's Atom Model

The atom as a whole is electrically neutral because the positive charge present on the atom (sphere) is equal to the negative charge of electrons present in the sphere. Atom is a positively charged sphere of radius 10^{-10} m. in which electron are embedded in between. The positive charge and the whole mass of the atom is uniformly distributed throughout the sphere.

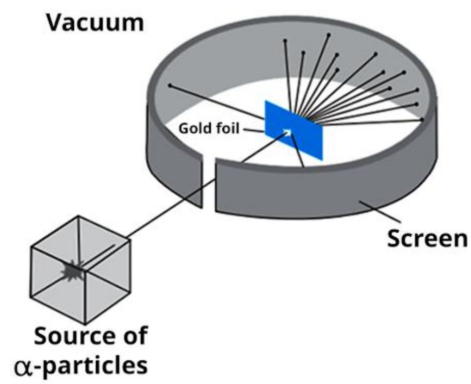
Shortcomings of Thomson's model

(i) The spectrum of atoms cannot be explained with the help of this model.

(ii) Scattering of α-particles cannot be explained with the help of this model.

Rutherford experiments on scattering of α-particles by thin gold foil

The experimental arrangement is shown in figure. α-particles are emitted by some radioactive material (polonium), kepi inside a thick lead box. A very fine beam of a-particles pass through a small hole in the lead screen. This well collimated beam is then allowed to fall on a thin gold foil. While passing through the gold foil, α-particles are scattered through different angles. A zinc sulphide screen was placed on the other side of the gold foil. This screen was movable, so as to receive the a-particles, scattered from the gold foil at angles varying from 0° to 180°. When an α-particle strikes the screen, it produces a flash of light and it is observed by the microscope. It was found that :



(i) Most of the α-particles went straight through the gold foil and produced flashes on the screen as if there were nothing inside gold foil. Thus, the atom is hollow.

(ii) Few particles collided with the atoms of the foil which have scattered or deflected through considerable large angles. Few particles even turned back towards source itself.

(iii) The entire positive charge and almost whole mass of the atom is concentrated in small center called a nucleus.

(iv) The electrons could not deflect the path of a α-particles i.e., electrons are very light.

(v) Electrons revolve round the nucleus in circular orbits.

So, Rutherford 1911, proposed a new type of model of the atom. According to this model, the positive charge of the atom, instead of being uniformly distributed throughout a sphere of atomic dimension is concentrated in a very small volume (Less than 10^{-13} cm is diameter) at it center. This central core, now called nucleus, is surrounded by clouds of electron makes the entire atom electrically neutral.

According to Rutherford scattering formula, the number of α-particle scattered at an angle e by a target are given by

$$N_\theta = \frac{N_0 nt(2\,Ze^2)^2}{4(4\pi\varepsilon_0)^2 r^2 (mv_0^2)^2} \times \frac{1}{sin^4\frac{\theta}{2}}$$

Where N₀ = number of α-particles that strike the unit area of the scatter

n = number of target atom per m^3

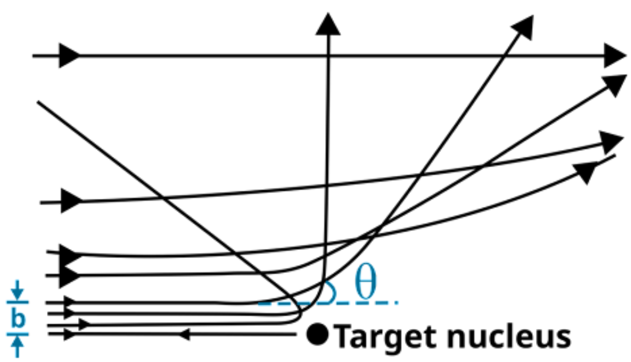
t = thickness of target

Ze = charge on the target nucleus

2e = charge on α-particle

r = distance of the screen from target

v_0 = initial velocity of α-particles



Now closest approach distance is $(r_0) = \frac{1}{4\pi\varepsilon_0} \times \frac{(2\,Ze)^2}{\left[\frac{1}{2}mv_0^2\right]} = \frac{1}{4\pi\epsilon_0}\frac{(2Ze)^2}{E_K}$

Where E_K = K.E. of α-particle

Failure of Rutherford's Atomic model:

(i) It couldn't explain the stability of atom.

(ii) It couldn't explain discrete nature of hydrogen spectra.

Bohr's Theory Of Hydrogen Atom

Bohr's theory of hydrogen atom is based on the following assumption

An electron in an atom moves in a circular orbit about the nucleus under the influence of coulomb's force of attraction between the electron and nucleus As the atom as a whole is stable the coulombian force of attraction provides necessary centripetal force:

$$\frac{e^2}{4\pi\varepsilon_0 r^2} = \frac{mv^2}{r} \qquad .....(i)$$

Only those orbits are possible for which the angular momentum of the electron is equal to an integral multiple of $\frac{h}{2\pi}$ i.e.

$$mvr = n\frac{h}{2\pi} \qquad .....(ii)$$

Where h is Planck's constant.

The electron moving in such allowed orbits does not radiate electromagnetic radiations. Thus, the total energy of the electron revolving in any of the stationary orbits remains constant.

Electromagnetic radiations are emitted if an electron jumps from stationary orbit of higher energy E_2 to another stationary orbit of lower energy, E_1. The frequency v of the emitted radiation is related by the equation.

$E_2 - E_1 = hv$ .... (iii)

Shortcomings of Bohr's model

This model could not explain the fine structure of spectral lines, Zeeman effect and Stark effect.

This model is valid only for single electron systems. (Cannot explain electron-electron interaction)

This model is based on circular orbits of electrons whereas in reality there is no orbit.

Electron is presumed to revolve round the nucleus only whereas in reality motion of electron cannot be described.

This model could not explain the intensity of spectral lines.

It could not explain the doublets obtained in the spectra of some of the atoms.

Bohr's model is semi quantum model, it means, it includes two quantum numbers (E and L) but unfortunately it considers circular motion of electron.

Q. In the Bohr model of a hydrogen atom, the centripetal force is furnished by the coulomb attraction between the proton and the electron. If a_0 is the radius of the ground state orbit, m is the mass and e is the charge on the electron and e_0 is the vacuum permittivity, then determine the speed of the electron.

Sol. Centripetal force = force of attraction of nucleus on electron

$$\frac{mv^2}{a_0} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{a_0^2} \Rightarrow v = \frac{e}{\sqrt{4\pi\varepsilon_0 a_0 m}}$$

Characteristics Of Bohr Model

Radii Of Orbits

From equation $v = \frac{nh}{2\pi mr}$, Here n is number of orbits

Substituting value of v in equation $\frac{e^2}{4\pi\varepsilon_0 r^2} = \frac{m}{r}\left[\frac{nh}{2\pi mr}\right]^2 \Rightarrow r = \frac{mn^2h^2.4\pi\varepsilon_0 r^2}{4\pi^2 m^2 r^2 e^2} = \frac{n^2h^2\varepsilon_0}{\pi me^2}$

In general, $r_n = \frac{n^2h^2\varepsilon_0}{\pi me^2}$ .... (iv)

equation (iv) shows that the radii of the permitted orbits vary as the square of n. For the smallest orbit n = 1substituting the values of h, ε_0, m and e we have radius of first orbit $r_1 = 0.529 \times 10^{-10}$m = 0.529 Å

This calculation shows that the atom is about 10^{-10} meter in diameter.

Velocity of Revolving Electron

To obtain the velocity of the revolving electron, we substitute the value of r from eq. (iv) in eq. (ii), we have

$$mv\left[\frac{n^2h^2\varepsilon_0}{\pi me^2}\right] = n\frac{h}{2\pi}$$

$$\Rightarrow \quad v = \frac{nh}{2\pi}\cdot\frac{\pi me^2}{n^2h^2\varepsilon_0}\cdot\frac{1}{m} = \frac{e^2}{2nh\varepsilon_0}$$

This expression shows that the velocity of the electron is inversely proportional to n i.e., the electron in the inner most orbit has the highest velocity.

Frequency of Electron in an orbit

Frequency of electron is given by

$$v = \frac{1}{T} = \frac{v}{2\pi r}$$

$$\Rightarrow v = \frac{e^2}{2nh\varepsilon_0}\times\frac{1}{2\pi}\times\frac{\pi\mu\varepsilon^2}{n^2h^2\varepsilon_0} = \frac{me^4}{4\varepsilon_0^2h^3n^3} \quad \text{....(vi)}$$

This expression shows that the frequency of an electron is inversely proportional to the cube of n.

Electron Energy

The electron energy consists of two types:

(i) Kinetic energy and (ii) Potential energy

(i) Kinetic energy is due to the motion of electron and its value is $\frac{1}{2}$ mv^2 where v is the velocity of the electron,

$$\therefore \text{K.E.} = \frac{1}{2}\text{mv}^2 = \frac{1}{2}\text{m}\left[\frac{\text{e}^2}{2\text{nh}\varepsilon_0}\right]^2 \text{ from equation}$$

$$\therefore \text{K.E.} = \frac{\text{me}^4}{8\text{n}^2\text{h}^2\varepsilon_0^2}$$

(ii) Potential energy is due to the fact that electron lies in. the electric field of positive nucleus. We know that potential at a distance r from the nucleus is: $v = \frac{e}{4\pi\varepsilon_0 r}$

The potential energy of election of charge e is P.E.= $V\times(-e) = \frac{-e^2}{4\pi\varepsilon_0 r} = \frac{-e^2\times\pi me^2}{4\pi\varepsilon_0 n^2h^2\varepsilon_0} = \frac{-me^4}{4n^2h^2\varepsilon_0^2}$

So, Total energy in nth orbit, E_n = K.E. + P.E.

$$\Rightarrow \quad E_n = \frac{me^4}{8n^2h^2\varepsilon_0^2} - \frac{me^4}{4n^2h^2\varepsilon_0^2}$$

$$\Rightarrow \quad E_n = \frac{-me^4}{8n^2h^2\varepsilon_0^2}$$

Frequency of Emitted Radiation

The frequency of emitted radiations can be found from the following relation when electron jumps from higher orbit n_2 to lower orbit n_1.

$$hv = E_{n_2}E_{n_1} \qquad \Rightarrow v = \frac{me^4}{8\varepsilon_0^2h^3}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$$

..... (viii)

$\frac{1}{\lambda} = \frac{me^4}{8\varepsilon_0^2h^3c}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$ Where R $=\frac{me^4}{8\varepsilon_0^2h^3c}$;

R = Rydberg's constant = 10.97 × 10^6 m^{-1} ≈ 1.1 × 7 m^{-1}

$$\bar{v} = \frac{1}{\lambda} = R\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$$

ELECTRON ENERGY LEVELS IN HYDROGEN ATOM

Energy of an electron revolving in nth orbit is given by

$$E_n = \frac{-me^4}{8\varepsilon_0^2h^2n^2} = -\frac{(9.11\times10^{-31})(1.6\times10^{-19})^4}{8(8.854\times10^{-12})^2(6.62\times10^{-34})^2n^2}$$

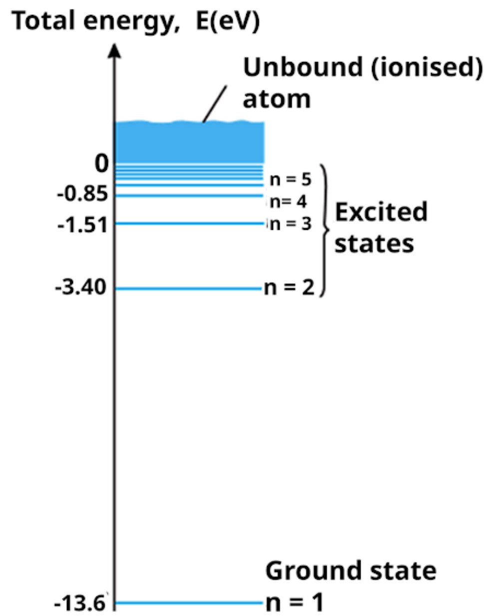
$$= -\frac{21.7\times10^{-19}}{n^2}joule = -\frac{21.7\times10^{-19}}{1.6\times10^{-19}}\times\frac{1}{n^2}eV$$

(∵ 1eV = 1.6 × 10^{-19} J)

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

The negative sign in energy shows that is thus electron is bound to the nucleus by attractive forces and to separate the electron from the nucleus energy must be supplied to it. Giving different values to n, we can calculate the energy of the electron in different orbits.

E_1 = –13.6 eV when n = 1 (K-shell)
E_2 = – 3.4 eV n = 2 (K-shell)
E_3 = –1.5 eV n = 3 (M-shell)
E_∞ = 0eV n = ∞ (Limiting case)



	Energy of electron	Binding energy or Ionization energy
n = ∞	0	0
n = 4	–0.85 eV	+0.85 eV
n = 3	–1.51 eV	+1.51 eV
n = 2	–3.4 eV	+3.4 eV
n = 1	–13.6 eV	+13.6 eV

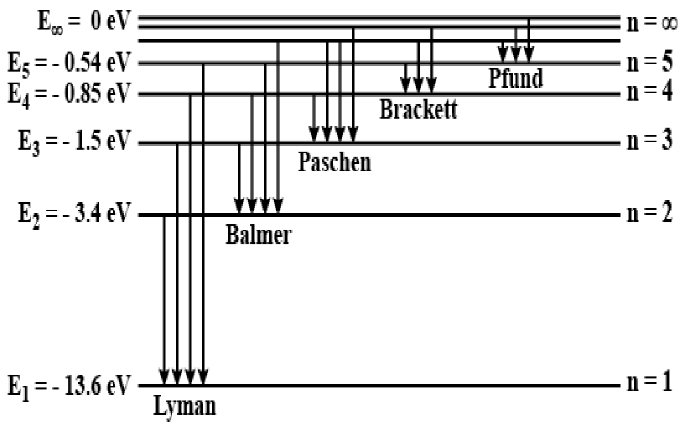
The diagram is known as energy level diagram. The lowest energy level (n = 1) corresponds to normal unexcited state of hydrogen. This state is also called as ground state. In energy level diagram the lower energy (more negative) are at the bottom while higher energies (Less negative) are at the top. By such a consideration the various electron jumps between allowed orbit will be vertical arrows between different energy level. The energy of radiated photon is greater when the length of arrow is greater.

Spectral Series of Hydrogen Atom

It has been shown that the energy of the outer orbit is greater than the energy of the inner ones. When the Hydrogen atom is subjected to external energy, the electron jumps from lower energy State i.e., the hydrogen atom is excited. The excited state is not stable hence the electron returns to its ground state in about 10^{-8} seconds. The excess of energy is now radiated in the form of radiations of different wavelength. The different wavelength constitutes spectral series. Which is characteristic of atom emitting, then the wavelength of different members of series can be found from the following relations.

$$\bar{v} = \frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

This relation explains the complete spectrum of hydrogen. A detailed account of the important radiations is listed below.



Energy level diagram for hydrogen atom

Lyman Series:

The series consist of wavelength which are emitted when electron jumps from an outer orbit to the first orbit i.e., the electron jumps to K orbit give rise to Lyman series.

Here $n_1 = 1$ and $n_2 = 2, 3, 4, \ldots\ldots\ \infty$.

Balmer Series

This series is consisting of all wavelengths which are emitted when an electron jumps from an outer orbit to the second orbit i. e. the electron jumps to L orbit give rise to Balmer series.

Here $n_1 = 2$ and $n_2 = 3, 4, 5 \ldots\ldots\ \infty$

Paschen Series

This series consist of all wavelengths are emitted when an electron jumps from an outer orbit to the third orbit i.e., the electron jumps to M orbit give rise to Paschen series.

Here $n_1 = 3$ and $n_2 = 4, 5, 6 \ldots\ldots\ \infty$

Brackett Series

This series is consisting of all wavelengths which are emitted when an electron jumps from an outer orbit to the fourth orbit i.e., the electron jumps to N orbit give rise to Brackett series.

Here $n_1 = 4$ and $n_2 = 5, 6, 7, \ldots\ldots\ \infty$

Pfund series

The series consist of all wavelengths which are emitted when an electron jumps from an outer orbit to the fifth orbit i.e., the electron jumps to O orbit give right to Pfund series.

Here $n_1 = 5$ and $n_2 = 6, 7, 8 \ldots\ldots\ \infty$

Q. An electron makes a transition from orbit n = 4 to the orbit n = 2 of a hydrogen atom. What is the wavelength of the emitted radiations? (R = Rydberg's constant)

Sol. Transition of hydrogen atom from orbit n_1 = 4 to n_2 = 2.

Wave number $= \frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] = R\left[\frac{1}{(2)^2} - \frac{1}{(4)^2}\right]$

$= R\left[\frac{1}{4} - \frac{1}{16}\right] = R\left[\frac{4-1}{16}\right] = \frac{3R}{16} \Rightarrow \lambda = 16/3R$

Q. Ionization potential of hydrogen atom is 13.6 eV. Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. According to Bohr's theory, the which spectral lines will be emitted by hydrogen.

Sol. Ionization potential of hydrogen atom is 13.6 eV. Energy required for exciting the hydrogen atom in the ground state to orbit n is given by

$E = E_n - E_1$

i.e., $12.1 = -\frac{13.6}{n^2} - \left(\frac{-13.6}{1^2}\right) = -\frac{13.6}{n^2} + 13.6$

or, $-1.5 = \frac{-13.6}{n^2}$ or, $n^2 = \frac{13.6}{1.5} = 9$ or, $n = 3$

Number of spectral lines emitted $= \frac{n(n-1)}{2} = \frac{3\times 2}{2} = 3$

De Broglie's Explanation Of Bohr's Second Postulate Of Quantization

De Broglie came up with an explanation for why the angular momentum might be quantized in the manner Bohr assumed it was. De Broglie realized that if you use the wavelength associated with the electron, and assume that an integral number of wavelengths must fit in the circumference of an orbit, you get the same quantized angular momenta that Bohr did.

The circumference of the circular orbit must be an integral number of wavelengths:

$2\pi r = n\lambda = \frac{nh}{p}$ $\left(\lambda = \frac{h}{p}\right)$

The momentum, p, is simply mv as long as we're talking about non-relativistic speeds, so this becomes:

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

Rearranging this a little gives the Bohr relationship:

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

SUMMARY

- **Thomson's Model of an Atom:**
  An atom consists of positively charged matter in which the negatively charged electrons are uniformly embedded like plums in a pudding. This model could not explain scattering of alpha-particles through thin foils and hence discarded.
- **Rutherford's Model of an Atom:**
  Geiger and Marsden in their experiment on scattering of alpha-particles found that most of the alpha-particles passed undeviated through thin foils but some of them were scattered through very large angles.
  From the results of these experiments, Rutherford proposed the following model of an atom:

(a) An atom consists of a small and massive central core in which the entire positive charge and almost the whole mass of the atom are concentrated. This core is called the nucleus.

(b) The nucleus occupies a very small space as compared to the size of the atom.

(c) The atom is surrounded by a suitable number of electros so that their total negative charge is equal to the total positive charge on the nucleus and the atom as a whole is electrically neutral.

(d) The electrons revolve around the nucleus in various orbits just as planets revolve around the sun.

(e) The centripetal force required for their revolution is provided by the electrostatic attraction between the electrons and the nucleus.

- **Draw-back of Rutherford Model:**
  This model could not explain in stability of the atom because according to classical electromagnetic theory the electron revolving around the nucleus must continuously radiate energy revolving around the nucleus must continuously radiate energy in the form of electromagnetic radiate energy in the form of electromagnetic radiation and hence it should fall into the nucleus.
- **Distance of Closest Approach:**
  When an alpha-particle of mass m and velocity v moves directly towards a nucleus of atomic number Z, its initial energy E, which is just the kinetic energy K gets completely converted into potential energy U at stopping point. This stopping point happens to be at a distance of closest approach d from the nucleus.

$$E = \frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{2eZe}{d} = \frac{2Ze^2}{4\pi\varepsilon_0 d}d = \frac{2Ze^2}{4\pi\varepsilon_0 k}$$

Hence,

$$d = \frac{2Ze^2}{4\pi\varepsilon_0 K}$$

- **Impact Parameter:**

(a) It is defined as the perpendicular distance of the velocity of the alpha-particle from the central of the nucleus, when it is far away from the atom.

(b) The shape of the trajectory of the scattered alpha-particle depends on the impact parameter b and the nature of the potential field.

(c) Rutherford deduced the following relationship between the impact parameter b and the scattering angle θ:

$$b = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Ze^2 \cot\frac{\theta}{2}}{E}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{Ze^2 \cot\frac{\theta}{2}}{\frac{1}{2}mv^2}$$

- **Quantization or Discretisation:**
  The quantization or discretisation of a physical quantity means that it cannot very continuously to have any arbitrary value but can change only discontinuously to take certain specific values.
- **Bohr's Model for the Hydrogen Atom:**
  Basic postulates:

(a) Nuclear concept:
An atom consists of a small massive central called nucleus around which planetary electrons revolve. The centripetal force required for their rotation is provided by the electrostatic attraction between the electrons and the nucleus.

(b) Quantum condition:
Of all the possible circular orbits allowed by the classical theory, the electrons are permitted to circulate only in such orbits in which the angular momentum of an electron is an integral multiple of h/2π , h being Planck's constant.

$$L = mvr = \frac{nh}{2\pi}, n = 1, 2, 3.....$$

where n is called principal quantum number.

(c) Stationary orbits:
While revolving in the permissible orbits, an electron does not radiate energy. These non-radiating orbits are called stationary orbits.

(d) Frequency condition:
An atom can emit or absorb radiation in the form of discrete energy photons only, when an electron jumps from a higher to a lower orbit or from a lower to a higher orbit. If E_1 and E_2 are the energies associated with these permitted orbits then the frequency **V** of the emitted absorbed radiation is,

$h\nu = E_2 - E_1$

(e) Radius of the orbit of an electron in hydrogen atom is,

$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$

(f) Kinetic energy K & electrostatic potential energy U of the electron in hydrogen atom:

$$K = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\varepsilon_0 r}$$

$$U = -\frac{e^2}{4\pi\varepsilon_0 r}$$

(g) Total energy E of the electron in hydrogen atom:

$$E = K + U = -\frac{e^2}{8\pi\varepsilon_0 r}$$

(h) Speed of an electron in the nth orbit is,

$$v = \frac{2\pi ke^2}{nh} = \alpha.\frac{c}{n} = \frac{1}{137}.\frac{c}{n}$$

Where $\alpha = \frac{2\pi ke^2}{ch}$ is fine structure constant.

(i) Energy of an electron in nth orbit is,

$$E_n = \frac{2\pi^2 mk^2 Z^2 e^4}{n^2 h^2} = -\frac{13.6}{n^2} eV$$

- **Failure of Bohr's Model:**

(a) This model is applicable only to hydrogen-like atoms and fails in case of higher atoms.

(b) It could not explain the fine structure of the spectral lines in the spectrum of hydrogen atom.

- **Energy Level Diagram:**
  It is a diagram in which the energies of the different stationary states of an atom are represented by parallel horizontal lines, drawn according to some suitable energy scale.
- **Spectral Series of Hydrogen Atom:**
  Whenever an electron in hydrogen atom makes a transition from a higher energy level n_2 to a lower energy level n_1, the difference of energy appears in the form of a photon of frequency **V** is given by,

$$v = \frac{2\pi^2 mk^2 e^2}{h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

- **Different Spectral Series of Hydrogen Atom:**
  These are as follows:
  a) Lyman Series. Here n_2 = 2, 3, 4,.....and n_1 = 1. This series lies in the ultraviolet region.
  b) Balmer Series. Here n_2 = 3, 4, 5,.... and n_1 = 2. This series lies in the visible region.
  c) Paschen Series. Here n_2 = 4, 5, 6,..... and n_1 = 3. This series lies in the infrared region.
  d) Brackett Series. Here n_2 = 5, 6, 7,..... and n_1 = 4. This series lies in the infrared region.
  e) P fund Series. Here n_2 = 6, 7, 8,.... and n_1 = 5. This series lies in the infrared region.
- **Excitation Energy:**
  It is defined as the energy required by an electron of an atom to jump from its ground state to any one of its existed states.
- **Ionization Energy:**
  It is defined as the energy required to remove an electron from an atom, i.e., the energy required to take an electron from its ground state to the outermost orbit ($n = \infty$)
- **Excitation Potential:**
  It is the accelerating potential which gives sufficient energy to a bombarding electron so to excite the target atom by raising one of its electrons from an inner to and outer orbit.
- **Ionization Potential:**
  It is the accelerating potential which gives to bombarding electron the sufficient energy to an outer orbit.
- **De Broglie's Hypothesis:**
  The electrons having a wavelength λ = h/mv gave an explanation for Bohr's quantized orbits by bringing in the wave particle duality. The orbits correspond to circular standing waves in which the circumference of the orbit equals a whole number of wavelengths.

MIND MAP

Atoms

Contribution

In 1898 J.J Thomson proposed the first model of atom also known as plum-pudding model

α – particle scattering experiment

- α- particle bombarded on thin gold foil
- Most of α– particle passed undeviated or with a small angle
- 1 out of 8000 α particles were deflected by scattering angle

Impact parameter

$$b = \frac{Ze^2 \cot\theta/2}{4\pi\varepsilon_0\left(\frac{1}{2}mv^2\right)}$$

Rutherford's Model

Postulates

- Atoms have a central, massive, positively charged core called nucleus around which electron revolves
- Size of nucleus $\approx$ 1 fermi $= 10^{-15}$m

Draw backs

- Doesn't explain the stability of atom
- Doesn't explain the atomic spectrum

Energy Level

Energy of electron in each stationary orbits is

Given by $E_n = -13.6\frac{Z^2}{n^2}$ eV

Where n = 1,2,3….

Z = atomic number of atom

- These stationary energy orbits are also called energy levels.
- When electron jumps from higher energy level to lower energy level it releases energy.

$$\Delta E = E_f - E_i = 13.6\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right]Z^2\text{eV}$$

Hydrogen Spectrum

Hydrogen gas heated in a sealed tube emits radiation which passes through prism

- Component of different wavelength appears
- Wavelength in each series given by

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

$n_f > n_i$

- Lyman series [U.V. region]
  $n_i = 1$, $n_f = 2,3,4….$
  $\lambda_{min} = 912$ A°, $\lambda_{max} = 1216$ A°
- Balmer series [visible region]
  $n_i = 2$ $n_f = 3, 4, 5…..$
  $\lambda_{min} = 3648$ A°, $\lambda_{max} = 6563$ A°
- Paschan series [I–R region]
  $n_i = 3$ $n_f = 4, 5, 6…..$
  $\lambda_{min} = 8208$ A°, $\lambda_{max} = 18761$ A°
- Brackett series [I R region]
  $n_i = 4$ $n_f = 5, 6, 7…$
  $\lambda_{min} = 14592$ A° $\lambda_{max} = 40533$ A°
- P –fund [I R region]
  $n_i = 5$ $n_f = 6, 7, 8……$
  $\lambda_{min} = 23850$ A° $\lambda_{max} = 74618$ A°

Bohr Model

Postulates

- Electron revolves around the nucleus in stationary orbits
- Angular momentum of electron
  $mvr_n = n \times \frac{h}{2\pi}$
  n = Integers. It is also known as principle Quantum Number
- It explains spectrum of hydrogen or hydrogen like [He^+, Li^{++}] atom

Limitations

- Fails to explain spectrum of complex atoms/ions of multi electron system
- Dosn't explain Zeeman's and Stark's effect

Radius of nth Bohr's orbit

$$R_n = \frac{\varepsilon_0 h^2}{\pi me^2}\left(\frac{n^2}{Z}\right) = 0.53\frac{n^2}{Z}\text{A°}$$

Velocity of electron in nth Bohr's orbit

$$v_n = \frac{e^2}{2\varepsilon_0 h}\left(\frac{Z}{n}\right) = 2.2 \times 10^6\frac{Z}{n}\text{ m/s}$$

Potential Energy

$$U_n = -\frac{KZe^2}{r_n} = \frac{-me^4}{4\varepsilon_0^2h^2}\left(\frac{Z^2}{n^2}\right) = \frac{-27.2Z^2}{n^2}\text{eV}$$

Kinetic Energy

$$E_k = \frac{KZe^2}{2r_n} = \frac{me^4}{8\varepsilon_0^2h^2}\frac{Z^2}{n^2} = \frac{13.6^2}{n^2}Z^2\text{eV}$$

Total Energy

$$E = U_n + E_k = -\frac{KZe^2}{2r_n} = \frac{-13.6Z^2}{n^2}\text{eV} = \frac{U_n}{2} = -E_K$$

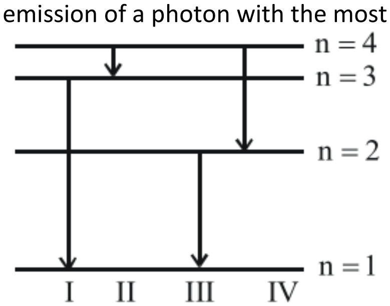
PRACTICE EXERCISE

MCQ

Q1. The potential energy associated with an electron in the orbit
(a) increases with the increases in radii of the orbit
(b) decreases with the increase in the radii of the orbit
(c) remains the same with the change in the radii of the orbit
(d) None of these

Q2. When an α-particle of mass m moving with velocity v bombards on a heavy nucleus of charge Ze, its distance of closest approach from the nucleus depends on m as
(a) $\frac{1}{m^2}$ (b) m
(c) $\frac{1}{m}$ (d) $\frac{1}{\sqrt{m}}$

Q3. The diagram shows the energy levels for an electron in a certain atom. Which transition shown represents the emission of a photon with the most energy?



(a) IV (b) III
(c) II (d) I

Q4. Electrons in a certain energy level n = n_1, can emit 3 spectral lines. When they are in another energy level, n = n_2. They can emit 6 spectral lines. The orbital speed of the electrons in the two orbits are in the ratio of
(a) 4: 3 (b) 3: 4
(c) 2: 1 (d) 1: 2

Q5. In a Rutherford scattering experiment when a projectile of charge z_1 and mass M_1 approaches a target nucleus of charge z_2 and mass M_2, the distance of closest approach is r_0. The energy of the projectile is
(a) directly proportional to $z_1 z_2$
(b) inversely proportional to z_1
(c) directly proportional to mass M_1
(d) directly proportional to $M_1 \times M_2$

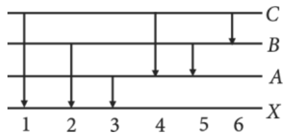
Q6. In the Bohr model an electron moves in a circular orbit around the proton. Considering the orbiting electron to be a circular current loop, the magnetic moment of the hydrogen atom, when the electron is in n^{th} excited state, is:
(a) $\left(\frac{e}{2m}\frac{n^2h}{2\pi}\right)$ (b) $\left(\frac{e}{m}\right)\frac{nh}{2\pi}$
(c) $\left(\frac{e}{2m}\right)\frac{nh}{2\pi}$ (d) $\left(\frac{e}{m}\right)\frac{n^2h}{2\pi}$

Q7. A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. It will emit:
(a) 2 lines in the Lyman series and 1 line in the Balmer series
(b) 3 lines in the Lyman series
(c) 1 line in the Lyman series and 2 lines in the Balmer series
(d) 3 lines in the Balmer series

Q8. The radius of hydrogen atom in its ground state is 5.3 x 10^{-11} m. After collision with an electron, it is found to have a radius of 21.2 x 10^{-11} m. What is the principal quantum number n of the final state of the atom
(a) n = 4 (b) n = 2
(c) n = 16 (d) n = 3

Q9. When hydrogen atom is in its first excited level, its radius is
(a) four times its ground state radius
(b) twice
(c) same
(d) half

Q10. The figure indicates the energy level diagram of an atom and the origin of six spectral lines in emission (*e.g.*, line no. 5 arises from the transition from level B to A).



Which of the following spectral lines will occur in the absorption spectrum?
(a) 4, 5, 6 (b) 1, 2, 3, 4, 5, 6
(c) 1, 2, 3 (d) 1, 4, 6

Q11. According to Bohr's principle, the relation between principal quantum number (n) and radius of orbit (r) is
(a) $r \propto \frac{1}{n}$ (b) $r \propto \frac{1}{n^2}$
(c) $r \propto n$ (d) $r \propto n^2$

Q12. Energy levels A, B and C of a certain atom corresponding to increasing values of energy *i.e.*, $E_A < E_B < E_C$. If λ_1, λ_2 and λ_3 are wavelengths of radiations corresponding to transitions C to B, B to A and C to A respectively, which of the following relations is correct?
(a) $\lambda_3 = \lambda_1 + \lambda_2$ (b) $\lambda_3 = \frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2}$
(c) $\lambda_1 + \lambda_2 + \lambda_3 = 0$ (d) $\lambda_3^2 = \lambda_1^2 + \lambda_2^2$

Q13. The ionization energy of the electron in the hydrogen atom in its ground state is 13.6 eV. The atoms are excited to higher energy levels to emit radiations of 6 wavelengths. Maximum wavelength of emitted radiation corresponds to the transition between
(a) n = 3 to n = 1 states
(b) n = 2 to n = 1 states
(c) n = 4 to n = 3 states
(d) n = 3 to n = 2 states

Q14. The energy of the ground electronic state of hydrogen atom is –13.6 eV. The energy of the first excited state will be

(a) –27.2 eV (b) –52.4 eV
(c) –3.4 eV (d) –6.8 eV

Q15. The minimum wavelength of the X-rays produced by electrons accelerated through a potential difference of V volts is directly proportional to

(a) $\frac{1}{\sqrt{V}}$ (b) $\frac{1}{V}$
(c) $\sqrt{V}$ (d) V^2

Q16. Hydrogen atoms are excited from ground state of the principal quantum number 4. Then the number of spectral lines observed will be

(a) 3 (b) 6
(c) 5 (d) 2

Q17. For which one of the following, Bohr model is not valid?

(a) Hydrogen atom
(b) Singly ionized helium atom (He^+)
(c) Deuteron atom
(d) Singly ionized neon atom (Ne^+)

Q18. The total energy of an electron in an atom in an orbit is – 3.4 eV. Its kinetic and potential energies are, respectively

(a) 3.4 eV, 3.4 eV (b) – 3.4 eV, – 3.4 eV
(c) – 3.4 eV, – 6.8 eV (d) 3.4 eV, – 6.8 eV

Q19. The ground state energy of hydrogen atom is –13.6 eV. When its electron is in the first excited state, its excitation energy is

(a) 10.2 eV (b) 0
(c) 3.4 eV (d) 6.8 eV

Q20. The interplanar distance in a crystal is 2.8 × 10^{-8} m. The value of maximum wavelength which can be diffracted

(a) 2.8 × 10^{-8} m (b) 5.6 × 10^{-8} m
(c) 1.4 × 10^{-8} m (d) 7.6 × 10^{-8} m

Q21. Hydrogen atom in ground state is excited by a monochromatic radiation of λ = 975 Å. Number of spectral lines in the resulting spectrum emitted will be

(a) 3 (b) 2
(c) 6 (d) 10

Q22. The electron in the hydrogen atom jumps from excited state (n = 3) to its ground state (n = 1) and the photons thus emitted irradiate a photosensitive material. If the work function of the material is 5.1 eV, the stopping potential is estimated to be (the energy of the electron in n^{th} state $E_n = \frac{-13.6}{n^2}$ eV)

(a) 5.1 V (b) 12.1 V
(c) 17.2 V (d) 7 V

Q23. The ionization energy of hydrogen atom is 13.6 eV. Following Bohr's theory, the energy corresponding to a transition between 3rd and 4th orbit is

(a) 3.40 eV (b) 1.51 eV
(c) 0.85 eV (d) 0.66 eV

Q24. If an electron in a hydrogen atom jumps from the 3rd orbit to the 2nd orbit, it emits a photon of wavelength λ. When it jumps from the 4th orbit to the 3rd orbit, the corresponding wavelength of the photon will be

(a) $\frac{16}{25}\lambda$ (b) $\frac{9}{16}\lambda$
(c) $\frac{20}{7}\lambda$ (d) $\frac{20}{13}\lambda$

Q25. Out of the following which one is not a possible energy for a photon to be emitted by hydrogen atom according to Bohr's atomic model?

(a) 0.65 eV
(b) 1.9 eV
(c) 11.1 eV
(d) 13.6 eV

ASSERTION AND REASONING

Directions: Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.

(a) Assertion is correct, reason is correct; reason is a correct explanation for assertion.
(b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion
(c) Assertion is correct, reason is incorrect
(d) Assertion is incorrect, reason is correct

Q1. Assertion: The force of repulsion between atomic nucleus and D-particle varies with distance according to inverse square law.
Reason: Rutherford did D-particle scattering experiment.

Q2. Assertion: According to classical theory the proposed path of an electron in Rutherford atom model will be parabolic.
Reason: According to electromagnetic theory an accelerated particle continuously emits radiation.

Q3. Assertion: Bohr had to postulate that the electrons in stationary orbits around the nucleus do not radiate.
Reason: According to classical physics all moving electrons radiate.

Q4. Assertion: Hydrogen atom consists of only one electron but its emission spectrum has many lines.
Reason: Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

Q5. Assertion: Hydrogen atom consists of only one electron but its emission spectrum has many lines.
Reason**:** Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

Q6. Assertion: The angular momentum of an electron in an atom is quantized.
Reason**:** In an atom only those orbits are permitted in which angular momentum of the electron is integral multiple of h/2π , where h is a plank's constant.

SHORT ANSWER QUESTIONS

Q1. Would the Bohr formula for the H-atom remain unchanged if proton had a charge (+4/3) e and electron had a charge (–3/4) e, where e = 1.6×10^{-19} C? Give reasons for your answer.

Q2. When an electron falls from a higher energy to a lower energy level, the difference in the energies appears in the form of electromagnetic radiation. Why cannot it be emitted as other forms of energy?

Q3. Write two important limitations of Rutherford nuclear model of the atom.

Q4. Which is easier to remove: orbital electron from an atom or a nucleon from a nucleus?

NUMERICAL TYPE QUESTIONS

Q1. Consider 3rd orbit of He^+ (Helium), using non-relativistic approach, then find the speed of electron in this orbit. [given K = 9×10^9 constant, Z = 2 and h (Planck's constant) = 6.6×10^{-34} J s]

Q2. The radius of the first permitted Bohr orbit for the electron, in a hydrogen atom equals 0.51 Å and its ground state energy equals –13.6 eV. If the electron in the hydrogen atom is replaced by muon (μ^-) [charge same as electron and mass 207 m_e], then find the first Bohr radius and ground state energy.

Q3. Monochromatic radiation emitted when electron on hydrogen atom jumps from first excited to the ground state irradiates a photosensitive material. The stopping potential is measured to be 3.57 V. Then find the threshold frequency of the material.

Q4. Given the value of Rydberg constant is $10^7\ \mathrm{m}^{-1}$, then find the wave number of the last line of the Balmer series in hydrogen spectrum.

Q5. If the orbital radius of the electron in a hydrogen atom is 4.7×10^{-11} m. Compute the kinetic energy of the electron in Kinetic energy of the electron in hydrogen atom'

Q6. It is found experimentally that 13.6 eV energy is required to separate a hydrogen atom into a proton and an electron. Then, find the velocity of the electron in a hydrogen atom.

Q7. If wavelength of the first line of the Balmer series of hydrogen is 6561Å, find the wavelength of the second line of the series.

Q8. The ratio of wavelengths of the last line of Balmer series and then last line of Lyman series.

Q9. The speed of an electron in ground state energy level is $2.6 \times 10^6\ \mathrm{ms}^{-1}$, then find its speed in third excited state.

Q10. The total energy of an electron in an atom in an orbit is –3.4eV. find Its kinetic and potential energies.

Q11. An electron of a hydrogen like atom is in excited state. If total energy of the electron is – 4.6 eV, then find de-Broglie wavelength of the electron.

HOMEWORK EXERCISE

MCQ

Q1. An electron in the hydrogen atom jumps from excited state n to the ground state. The wavelength so emitted illuminates a photosensitive material having work function 2.75 eV. If the stopping potential of the photoelectron is 10 V, the value of n is
(a) 3 (b) 4
(c) 5 (d) 2

Q2. An energy of 24.6 eV is required to remove one of the electrons from a neutral helium atom. The energy in (eV) required to remove both the electrons from a neutral helium atom is
(a) 38.2 (b) 49.2
(c) 51.8 (d) 79.0

Q3. If the atom ${}_{100}Fm^{257}$ follows the Bohr model and the radius of ${}_{100}Fm^{257}$ is n times the Bohr radius, then find n.
(a) 100 (b) 200
(c) 4 (d) ¼

Q4. An electron is moving round the nucleus of a hydrogen atom in a circular orbit of radius r. The Coulomb force $\vec{F}$ between the two is
(a) $K\frac{e^2}{r^2}\hat{r}$ (b) $-K\frac{e^2}{r^3}\hat{r}$
(c) $K\frac{e^2}{r^3}\vec{r}$ (d) $-K\frac{e^2}{r^3}\vec{r}$
$\left(\text{where } K = \frac{1}{4\pi\varepsilon_0}\right)$

Q5. The energy of He^+ in the ground state is – 54.4 eV, then the energy of Li^{++} in the first excited state will be
(a) –30.6 eV (b) 27.2 eV
(c) –13.6 eV (d) –27.2 eV

Q6. Suppose an electron is attracted towards the origin by a force $\frac{k}{r}$ where 'k' is a constant and 'r' is the distance of the electron from the origin. By applying Bohr model to this system, the radius of the n^{th} orbital of the electron is found to be 'r_n' and the kinetic energy of the electron to be 'T_n'. Then which of the following is true?
(a) $T_n \propto \frac{1}{n^2}, r_n \propto n^2$
(b) T_n independent of $n, r_n \propto n$
(c) $T_n \propto \frac{1}{n}, r_n \propto n$
(d) $T_n \propto \frac{1}{n}, r_n \propto n^2$

Q7. In Hydrogen spectrum, the wavelength of H_α line is 656 nm, whereas in the spectrum of a distant galaxy, H_α line wavelength is 706 nm. Estimated speed of the galaxy with respect to earth is
(a) 2×10^8 m/s (b) 2×10^7 m/s
(c) 2×10^6 m/s (d) 2×10^5 m/s

Q8. What is the radius of iodine atom (At. no. 53, mass no. 126)
(a) 2.5×10^{-11} m (b) 2.5×10^{-9} m
(c) 7×10^{-9} m (d) 7×10^{-6} m

Q9. When an α-particle of mass 'm' moving with velocity 'v' bombards on heavy nucleus of charge 'Ze', its distance of closest approach from the nucleus depends on m as:
(a) $\frac{1}{m}$ (b) $\frac{1}{\sqrt{m}}$
(c) $\frac{1}{m^2}$ (d) m

Q10. An electron in hydrogen atom makes a transition $n_1 \rightarrow n_2$ where n_1 and n_2 are principal quantum numbers of the two states. Assuming Bohr's model to be valid the time period of the electron in the initial state is eight times that in the final state. The possible values of n_1 and n_2 are
(a) $n_1 = 4$ and $n_2 = 2$
(b) $n_1 = 6$ and $n_2 = 2$
(c) $n_1 = 8$ and $n_2 = 1$
(d) $n_1 = 8$ and $n_2 = 2$

Q11. The spectrum obtained from a sodium vapor lamp is an example of
(a) band spectrum
(b) continuous spectrum
(c) emission spectrum
(d) absorption spectrum

Q12. Ionization potential of hydrogen atom is 13.6eV. Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. According to Bohr's theory, the spectral lines emitted by hydrogen will be
(a) three (b) four
(c) one (d) two

Q13. The largest wavelength in the ultraviolet region of the hydrogen spectrum is 122 nm. The smallest wavelength in the infrared region of the hydrogen spectrum (to the nearest integer) is
(a) 802 nm (b) 823 nm
(c) 1882 nm (d) 1648 nm

Q14. The ionization energy of hydrogen atom is 13.6 eV. Following Bohr's theory, the energy corresponding to a transition between 3^{rd} and 4^{th} orbit is
(a) 3.40 eV (b) 1.51 eV
(c) 0.85 eV (d) 0.66 eV

Q15. When an electron does transition from $n = 4$ to $n = 2$, then emitted line spectrum will be
(a) first line of Lyman series
(b) second line of Balmer series
(c) first line of Paschen series
(d) second line of Paschen series

ASSERTION AND REASONING

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(c) Assertion is correct, reason is incorrect
(d) Assertion is incorrect, reason is correct

Q1. Assertion: Large angle of scattering of a-particles led to the discovery of atomic nucleus.
Reason: Entire positive charge of atom is concentrated in the central core.

Q2. Assertion: Bohr had to postulate that the electrons in stationary orbits around the nucleus do not radiate.
Reason: According to classical physics all moving electrons radiate.

Q3. Assertion: Electrons in the atom are held due to coulomb forces. Reason The atom is stable only because the centripetal force due to Coulomb's law is balanced by the centrifugal force.

Q4. Assertion: The total energy of an electron revolving in any stationary orbit is negative.
Reason: It is bounded to the nucleus.

Q5. Assertion: Between any two given energy levels, the number of absorption transitions is always less than the number of emission transitions.
Reason: It Absorption transitions start from the lowest energy level only and may end at any higher energy level. But emission transitions may start from any higher energy level and end at any energy level below it.

SHORT ANSWER QUESTIONS

Q1. Define ionization energy. What is its value for a hydrogen atom?

Q2. When is Ha line of the Balmer series in the emission spectrum of hydrogen atom obtained?

Q3. What is the maximum number of spectral lines emitted by a hydrogen atom when it is in the third excited state?

Q4. Define ionization energy.
How would the ionization energy change when electron in hydrogen atom is replaced by a particle of mass 200 times that of the electron but having the same charge?

NUMERICAL TYPE QUESTIONS

Q1. A hydrogen atom in the ground state is excited by radiations of wavelength 975 Å. Find:
(a) the energy state to which the atom is excited.
(b) how many lines will be possible in emission spectrum

Q2. Find the atomic number of atom when given that its ionization potential is equal to 122.4 V.

Q3. Find the first and second excitation potentials of an atom when its ionization potential is 122.4 V.

Q4. Find the maximum wavelength of Brackett series of hydrogen atom.

Q5. An X-ray beam of wavelength 1.0Å is incident on a crystal of lattice spacing 2.8 Å. Calculate the value of Bragg's angle for first order diffraction.

Q6. In the experiment of Coolidge tube, wavelength of electron striking at the target is 0.01 nm. What will be value of minimum wavelength of X-rays obtained from the tube?

Q7. An X-ray tube operates at 20 kV. A particular electron loses 5% of its kinetic energy to emit an X-ray photon at the first collision. Find the wavelength corresponding to this photon.

Q8. Find out wavelength of K_α X-ray.

Q9. For the given transitions of electron, obtain the relation between λ_1, λ_2 and λ_3.

Q10. An electron in the hydrogen atom jumps from excited state n to the ground state. The wavelength so emitted illuminates a photosensitive material having work function 2.75 eV. If the stopping potential of the photoelectron is 10 V, then find the value of n.

PRACTICE EXERCISE SOLUTIONS

MCQ

S1. (b) P.E. = $\frac{-Ze^2}{4\pi\varepsilon_0 r}$. Negative sign indicates that revolving electron is bound to be positive nucleus. So, it decreases with increase in radii of orbit.

S2. (c) Distance of closest approach when an α-particle of mass m moving with velocity v is bombarded on a heavy nucleus of charge Ze, is given by

$r_0 = \frac{Ze^2}{2\pi\varepsilon_0 mv^2} \therefore r_0 \propto \frac{1}{m}$

S3. (b) $E = Rho\left[\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2}\right]$

E will be maximum for the transition for which $\left[\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2}\right]$ is maximum. Here n_2 is the higher energy level.

Clearly, $\left[\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2}\right]$ is maximum for the third transition, i.e., 2 → 1. I transition represents the absorption of energy.

S4. (a) Number of emission spectral lines

$N = \frac{n(n-1)}{2}$

$\therefore 3 = \frac{n_1(n_1-1)}{2}$, in first case.

Or $n_1^2 - n_1 - 6 = 0$ or $(n_1 - 3)(n_1 + 2) = 0$

Take positive root.

□ $n_1 = 3$

Again, $6 = \frac{n_2(n_2-1)}{2}$, in second case.

Or $n_2^2 - n_2 - 12 = 0$ or $(n_2 - 4)(n_2 + 3) = 0$.

Take velocity of electron $v = \frac{2\pi KZe^2}{nh}$

$\therefore \frac{v_1}{v_2} = \frac{n_2}{n_1} = \frac{4}{3}$.

S5. (a) Energy of the projectile is the potential energy at closest approach, $\frac{1}{4\pi\varepsilon_0}\frac{z_1 z_2}{r}$

Therefore energy $\propto z_1 z_2$

S6. (c) Magnetic moment of the hydrogen atom, when the electron is in n^th excited state, i.e., n′ = (n + 1) As magnetic moment $M_n = I_n A = I_n(\pi r_n^2)$

$i_n = eV_n = \frac{mz^2e^5}{4\varepsilon_0^2 n^3 h^3}$

$r_n = \frac{n^2h^2}{4\pi^2 kzme^2}\left(k = \frac{1}{4\pi\epsilon_0}\right)$

Solving we get magnetic moment of the hydrogen atom for n^th excited state

$Mn' = \left(\frac{e}{2m}\right)\frac{nh}{2\pi}$

S7. (a) $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{6.62\times10^{-34}\times3\times10^8}{12.5\times1.6\times10^{-19}}$

= 993Å

$\frac{1}{\lambda} = R\left(\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2}\right)$

(Where Rydberg constant, R = 1.097 × 10^7)

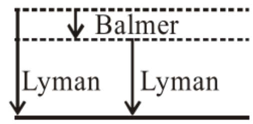
or, $\frac{1}{993\times10^{-10}} = 1.097 \times 10^7\left(\frac{1}{1^2} - \frac{1}{n_2{}^2}\right)$

Solving we get $n_2 = 3$

Spectral lines

Total number of spectral lines = 3

Two lines in Lyman series for $n_1 = 1$, $n_2 = 2$ and $n_1 = 1$, $n_2 = 3$ and one in Balmer series for $n_1 = 2$, $n_2 = 3$



n = 3   n = 2   n = 1

S8. (b) $r \propto n2$

$\therefore \frac{\text{radius of final state}}{\text{radius of initial state}} = n^2$

$\frac{21.2\times10^{-11}}{5.3\times10^{-11}} = n^2$

$\therefore n^2 = 4$ or $n = 2$

S9. (a) $R = \frac{R_0 n^2}{Z}$

Radius in ground state = $\frac{R_0}{Z}$

Radius in first excited state = $\frac{R_0\times4}{Z}(\because n=2)$

Hence, radius of first excited state is four times the radius in ground state.

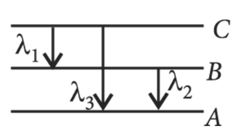
S10. (c) Absorption spectrum involves only excitation of ground level to higher level. Therefore, spectral lines 1, 2, 3 will occur in the absorption spectrum.

S11. (d) According to Bohr's principle, radius of orbit

$(r) = 4\pi\varepsilon_0 \times \frac{n^2h^2}{4\pi^2 me^2}; r \propto n^2$

where n = principal quantum number.

S12. (b)

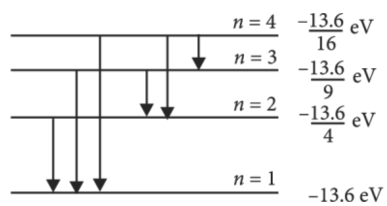


$(E_C - E_A) = (E_C - E_B) + (E_B - E_A)$

$\frac{hc}{\lambda_3} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}$ or $\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$

$\therefore \frac{1}{\lambda_3} = \frac{\lambda_1+\lambda_2}{\lambda_1\lambda_2}$ or $\lambda_3 = \frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2}$

S13. (c)



The maximum wavelength emitted here corresponds to the transition n = 4 → n = 3 (Paschen series 1st line)

S14. (c) Energy of the ground electronic state of hydrogen atom E = –13.6 eV.

We know that energy of the first excited state for second orbit (where n = 2)

$E_n = -\frac{13.6}{(n)^2} = -\frac{13.6}{(2)^2} = -3.4$ eV

S15. (b) $\frac{hc}{\lambda} = eV$ or $\lambda = \frac{hc}{eV} \propto \frac{1}{V}$

S16. (b) In the question it is said that a hydrogen atom is excited from the ground state. The principal quantum number is given to us as 4. We are asked to find the number of spectral lines when the atom is excited, we know that to find the total number of spectral lines we have an equation,

$N = \frac{n(n-1)}{2}$

where 'N' is the total number of spectral lines and 'n' is the principal quantum number.

From the question we know that n=4.

By substituting the value of 'n' in the equation, we will get

$N = \frac{4(4-1)}{2}$

$N = \frac{(16-4)}{2}$

$N = \frac{12}{2}$

N = 6

S17. (d) Bohr's atomic model is valid for single electron species only. A singly ionized neon contains more than one electron. Hence option (d) is correct.

S18. (d) Total energy of electron in n^{th} orbit, $E_n = \frac{-13.6Z^2}{n^2}$ eV

Kinetic energy of electron in n^{th} orbit, K.E. $= \frac{13.6Z^2}{n^2}$ eV

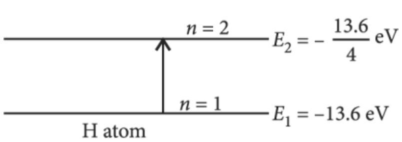
Potential energy of electron in n^{th} orbit, P.E. $= \frac{-27.2Z^2}{n^2}$ eV

Thus, total energy of electron, $E_n = -$K.E. $= \frac{\text{P.E.}}{2}$

∴ K.E. $= 3.4$ eV [Given $E_n = -3.4$ eV]

P.E. $= 2 \times -3.4 = -6.8$ eV

S19. (a)



1st excitation energy $E_{n2} - E_{n1}$ $= (-3.4 + 13.6)$ = 10.2 eV

S20. (b) $2d \sin\phi = n\lambda$; $(\sin\phi)_{\max} = 1$

i.e., $\lambda_{\max} = 2d$

⇒ $\lambda_{\max} = 2 \times 2.8 \times 10^{-8} = 5.6 \times 10^{-8}$ m.

21. (c)

Energy of the photon, $E = \frac{hc}{\lambda}$

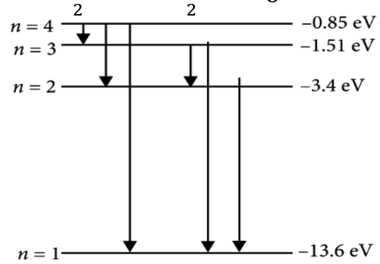
$E = \frac{6.63\times10^{-34}\times3\times10^{8}}{975\times10^{-10}}$ J

$= \frac{6.63\times10^{-34}\times3\times10^{8}}{975\times10^{-10}\times1.6\times10^{-19}}$ eV = 12.75 eV

After absorbing a photon of energy 12.75 eV, the electron will reach to third excited state of energy –0.85 eV, since energy difference corresponding to n = 1 and n = 4 is 12.75 eV.

∴ Number of spectral lines emitted

$= \frac{(n)(n-1)}{2} = \frac{(4)(4-1)}{2} = 6$



S22. (d) Energy released when electron in the atom jumps from excited state (n = 3) to ground state (n = 1) is

$E = h\upsilon = E_3 - E_1$

$= \frac{-13.6}{3^2} - \left(\frac{-13.6}{1^2}\right) = \frac{-13.6}{9} + 13.6 = 12.1$ eV

Therefore, stopping potential

$eV_0 = h\upsilon - \phi_0 = 12.1 - 5.1 = 7$ eV

$V_0 = 7$ V [∵ work function $\phi_0 = 5.1$]

S23. (d) $E = E_4 - E_3$

$= -\frac{13.6}{4^2} - \left(-\frac{13.6}{3^2}\right) = -0.85 + 1.51 = 0.66$

S24. (c) When electron jumps from higher orbit to lower orbit then, wavelength of emitted photon is given by,

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

so, $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5R}{36}$ and $\frac{1}{\lambda'} = R\left(\frac{1}{3^2} - \frac{1}{4^2}\right) = \frac{7R}{144}$

∴ $\lambda' = \frac{144}{7} \times \frac{5\lambda}{36} = \frac{20\lambda}{7}$

S25. (c) The energy of n^{th} orbit of hydrogen atom is given as

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

∴ $E_1 = -13.6$ eV; $E_2 = -\frac{13.6}{2^2} = -3.4$ eV

$E_3 = -\frac{13.6}{3^2} = -1.5$ eV; $E_4 = -\frac{13.6}{4^2} = -0.85$ eV

∴ $E_3 - E_2 = -1.5 - (-3.4) = 1.9$ eV

$E_4 - E_3 = -0.85 - (-1.5) = 0.65$ eV

ASSERTION AND REASONING

S1. (b) Rutherford confirmed that the repulsive force of Particle due to nucleus varies with distance according to inverse square law and that the positive charges are concentrated at the center and not distributed throughout the atom.

S2. (d) According to classical electromagnetic theory, an accelerated charged particle continuously emits radiation. As electrons revolving in circular paths are constantly experiencing centripetal acceleration, hence they will be losing their energy continuously and the orbital radius will go on decreasing, form spiral and finally the electron will fall in the nucleus

S3. (b) Bohr postulated that electrons in stationary orbits around the nucleus do not radiate. This is the one of Bohr's postulates, according to this the moving electrons radiates only when they go from one orbit to the next lower orbit.

S4. (b) When the atom gets appropriate energy from outside, then this electron rises to some higher energy level. Now it can return either directly to the lower energy level or come to the lowest energy level after passing through other lower energy levels hence all possible transitions take place in the source and many lines are seen in the spectrum.

S5. (b) When the atom gets appropriate energy from outside, then this electron rises to some higher energy level. Now it can return either directly to the lower energy level or come to the lowest energy level after passing through other lower energy levels, hence all possible transitions take place in the source and many lines are seen in the spectrum. At ordinary temperature, all atoms are present at their lowest energy level (n=1). Hence absorption transition can start only from n=1 (and not from n=2,3, 4,). Hence only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

S6. (a) According to Bohr's postulates, the angular momentum of an electron (mvr) is an integral multiple of h /2π Thus, mvr= nh /2π Only those orbitals are permitted which satisfy the above equation. Hence, the angular momentum of an electron in an atom is quantized.

SHORT ANSWER QUESTIONS

S1. Yes, since the Bohr formula involves only the product of the charges.

S2. This is because electrons interact only electromagnetically.

S3. Two important limitations of Rutherford Model are:

(i) According to Rutherford model, electron orbiting around the nucleus, continuously radiates energy due to the acceleration; hence the atom will not remain stable.

(ii) As electron spirals inwards; its angular velocity and frequency change continuously, therefore it should emit a continuous spectrum. But an atom like hydrogen always emits a discrete line spectrum.

S4. It is easier to remove an orbital electron from an atom. The reason is the binding energy of orbital electron is a few electron-volts while that of nucleon in a nucleus is quite large (nearly 8 MeV). This means that the removal of an orbital electron requires few electrons volt energy while the removal of a nucleon from a nucleus requires nearly 8 MeV energy.

NUMERICAL TYPE QUESTIONS

S1. Energy of electron in He^+ 3rd orbit

$E_3 = -13.6 \times \frac{Z^2}{n^2}\,\text{eV} = -13.6 \times \frac{4}{9}\,\text{eV}$

$= -13.6 \times \frac{4}{9} \times 1.6 \times 10^{-19}\,\text{J} \simeq -9.7 \times 10^{-19}\,\text{J}$

As per Bohr's model,

Kinetic energy of electron in the 3rd orbit $= -E_3$

$\therefore \quad 9.7 \times 10^{-19} = \frac{1}{2} m_e v^2$

$$v = \sqrt{\frac{2 \times 9.7 \times 10^{-19}}{9.1 \times 10^{-31}}} = 1.46 \times 10^6\ \text{m s}^{-1}$$

S2. Given, radius of first Bohr orbit for electron in a hydrogen atom, r = 0.51 Å

and its ground state energy, E_n = –13.6 eV

Charge of muon = charge of electron

Mass of muon = 207 × (mass of electron)

Therefore, when electron is replaced by muon then,

first Bohr radius, $r_1' = \frac{0.51\ \text{Å}}{207} = 2.56 \times 10^{-13}\ \text{m}$

and ground state energy, $E_1' = -\,13.6 \times 207$

= –2815.2 eV = –2.815 keV

S3. For hydrogen atom, $E_n = -\frac{13.6}{n^2}\,\text{eV}$

For ground state, $n = 1$

$\therefore \quad E_1 = -\frac{13.6}{1^2} = -13.6$ eV

For first excited state, $n = 2$

$\therefore \quad E_2 = -\frac{13.6}{2^2} = -3.4$ eV

The energy of the emitted photon when an electron jumps from first excited state to ground state is

$h\upsilon = E_2 - E_1 = -3.4\ \text{eV} - (-13.6\ \text{eV}) = 10.2\ \text{eV}$

Maximum kinetic energy,

$K_{\max} = eV_s = e \times 3.57\ \text{V} = 3.57\ \text{eV}$

According to Einstein's photoelectric equation

$K_{\max} = h\upsilon - \phi_0$

where ϕ_0 is the work function and $h\upsilon$ is the incident energy

$\phi_0 = h\upsilon - K_{\max} = 10.2\ \text{eV} - 3.57\ \text{eV} = 6.63\ \text{eV}$

Threshold frequency, $\upsilon_0 = \frac{\phi_0}{h} = \frac{6.63 \times 1.6 \times 10^{-19}\,\text{J}}{6.63 \times 10^{-34}\,\text{J s}}$

= 1.6×10^{15} Hz

S4. Here, $R = 10^7\ \text{m}^{-1}$

The wave number of the last line of the Balmer series in hydrogen spectrum is given by

$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = \frac{R}{4} = \frac{10^7}{4} = 0.25 \times 10^7\ \text{m}^{-1}$

S5. $\text{KE} = \frac{e^2}{8\pi\varepsilon_0 r}$

were, $\quad e = 1.6 \times 10^{-19}\ \text{C}, \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \text{N} - \text{m}^2\ \text{C}^{-2}$

and $r = 4.7 \times 10^{-11}$ m.

$= \frac{(9 \times 10^9\ \text{Nm}^2\text{C}^{-2})(1.6 \times 10^{-19}\ \text{C})^2}{(2)(4.7 \times 10^{-11}\text{m})}$

$= 2.45 \times 10^{-18}\ \text{J} = \frac{2.45\times10^{-18}}{1.6\times10^{-19}}\ \text{eV} = 15.3\ \text{eV}$ atom.

S6. Total energy of the electron in hydrogen atom is – 13.6 eV.

$\Rightarrow \quad E = -13.6 \times 1.6 \times 10^{-19}\ \text{J} = -2.2 \times 10^{-18}\ \text{J}$

As we know, total energy *E* of the electron in a hydrogen atom is

$E = \frac{-e^2}{8\pi\varepsilon_0 r} \Rightarrow r = \frac{-e^2}{8\pi\varepsilon_0 E}$

were, $e = 1.6 \times 10^{-19}\ \text{C}, \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \text{N} - \text{m}^2\text{C}^{-2}$

$\Rightarrow \quad r = -\frac{(9\times10^9)\times(1.6\times10^{-19})^2}{2\times(-2.2\times10^{-18})} = 5.3 \times 10^{-11}\ \text{m}$

As, electron revolves around the nucleus, by centripetal force, so the electrostatic force required to separate electron from atom should be equal to this centripetal force.

i.e., $F_c = F_e$

$\Rightarrow \quad \frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} \Rightarrow v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$

were, $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} - \text{m}^2, \text{m} = 9.1 \times 10^{-31}\ \text{kg}$

and $r = 5.3 \times 10^{-11}$m.

$\Rightarrow \quad v = \frac{1.6\times10^{-19}}{\sqrt{4\times3.14\times8.85\times10^{-12}\times9.1\times10^{-31}\times5.3\times10^{-11}}}$

$= 2.2 \times 10^6\ \text{m/s}$

S7. Wavelength of spectral line in Balmer series is given by

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

For first line of Balmer series, *n* = 3

$\Rightarrow \quad \frac{1}{\lambda_1} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5R}{36} \qquad \ldots(i)$

For second line, *n* = 4

$\Rightarrow \quad \frac{1}{\lambda_2} = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = \frac{3R}{16} \qquad \ldots(ii)$

Dividing Eq. (i) by Eq. (ii), we get

$\therefore \quad \frac{\lambda_2}{\lambda_1} = \frac{20}{27} \Rightarrow \lambda_2 = \frac{20}{27} \times \lambda_1$

$\Rightarrow \quad \lambda_2 = \frac{20}{27} \times 6561 = 4860\ \text{Å}$

S8. Wavelength of spectral lines are given by

$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

For last line of Balmer series, $n_1 = 2$ and $n_2 = \infty$

S9. According to Bohr's model, velocity

$v = \frac{2\pi ke^2 Z}{nh} \quad or \quad v \propto \frac{1}{n}$

$\therefore \quad \frac{v_A}{v_B} = \frac{n_B}{n_A} \quad \therefore \quad v_B = v_A \times \frac{n_A}{n_B}$

Given, $n_A = 1, n_B = 4$ and $v_A = 2.6 \times 10^6\ \text{ms}^{-1}$

$v_B = 2.6 \times 10^6 \times \frac{1}{4} = 6.5 \times 10^5\ \text{ms}^{-1}$

S10. According to Bohr's model, the kinetic energy of electron is given by

$\text{KE} = \frac{me^4}{8\varepsilon_0^2 n^2 h^2} \qquad \ldots(i)$

where, *h* = Planck's constant

and *n* = principal quantum number.

Similarly, potential energy is given by

$\text{PE} = -\frac{me^4}{4\varepsilon_0^2 n^2 h^2} \qquad \ldots.(ii)$

$\therefore$ Total energy, $E = \text{PE} + \text{KE} = -\frac{me^4}{8\varepsilon_0^2 n^2 h^2}$

[from Eqs. (i) and (ii)]

$\Rightarrow \quad KE = -E$ and PE = 2E

Given, $E = -3.4$ eV

$\therefore \quad \text{KE} = -(-3.4) = 3.4\ \text{eV}$

and $\text{PE} = 2\,(-3.4) = -6.8\ \text{eV}$

S11. Given, $E = -4.6$ eV

$K = -E = -(-4.6) = 4.6\ \text{eV}$

de-Broglie wavelength,

$\lambda = \frac{h}{\sqrt{2mK}} = \frac{6.6\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times4.6\times1.6\times10^{-19}}}$

$= 0.57 \times 10^{-9}\ \text{m} = 0.57\ \text{nm}$

HOMEWORK EXERCISE SOLUTIONS

MCQ

S1. (b) KE_{max} = 10eV

Φ = 2.75 eV

Total incident energy

E = Φ+KE_{max} = 12.75 eV

 Energy is released when electron jumps from the excited state n to the ground state.

∵ $E_4 - E_1$ = {-0.85-(-13.6) ev}

= 12.75eV

 Value of n = 4

S2. (d) When one e^- is removed from neutral helium atom, it becomes a one e^- species.

For one e^- species we know

$$E_n = \frac{-13.6Z^2}{n^2} \text{ Ev/atom}$$

For helium ion, Z = 2 and for first orbit n = 1.

$$\therefore \quad E_1 = \frac{-13.6}{(1)^2} \times 2^2 = -54.4\,\text{eV}$$

 Energy required to remove this e^- =+54.4 eV

 Total energy required = 54.4 + 24.6 =79 eV

S3. (d) For an atom following Bohr's model, the radius is given by

$$rm = \frac{r_0 m^2}{Z}$$ where r_0 = Bohr's radius and

m = orbit number.

For Fm, m = 5 (Fifth orbit in which the outermost electron is present)

$$\therefore \; r_m = \frac{r_0 5^2}{100} = nr_0 \,(\text{given}) \Rightarrow n = \frac{1}{4}$$

S4. (d) The charge on hydrogen nucleus

$q_1 = +e$

charge on electron, $q_2 = -e$

Coulomb force, $F = K\frac{q_1q_2}{r^2} = K\frac{(+e)(-e)}{r^2}$

$\vec{F} = -\frac{Ke^2}{r^3}\vec{r} = -\frac{Ke^2}{r^2}\hat{r}$

S5. (d) Energy of electron in n^{th} orbit is

$$E_n = -(Rch)\,\frac{Z^2}{n^2} = -54.4eV$$

For He^+ is ground state

$E_1 = -(Rch)\frac{(2)^2}{(1)^2} = -54.4 \Rightarrow Rch = 13.6$

 For Li^{++} in first excited state (n = 2)

$E' = -13.6 \times \frac{(3)^2}{(2)^2} = -30.6eV$

S6. (b) When $F = \frac{k}{r}$ = centripetal force, then

$\frac{k}{r} = \frac{mv^2}{r} \Longrightarrow$ mv^2 = constant

⟹ kinetic energy is constant

⟹ T is independent of n.

S7. (b) $\frac{1}{\lambda'} = \frac{1}{\lambda}\sqrt{\frac{c-v}{c+v}}$

Here, λ' = 706 nm, λ = 656 nm

$\therefore \frac{c-v}{c+v} = \left(\frac{\lambda}{\lambda'}\right)^2 = \left(\frac{656}{706}\right)^2 = 0.86$

$\Rightarrow \frac{v}{c} = \frac{0.14}{1.86}$

⟹ v = 0.075 × 3 × 10^8 = 2.25 × 10^7 m/s

S8. (a) 53 electrons in iodine atom are distributed as 2, 8, 18, 18, 7 n = 5

$r_n = (0.53 \times 10^{-10})\frac{n^2}{Z}$

$= \frac{0.53\times10^{-10}\times5^2}{53} = 2.5 \times 10^{-11}m$

S9. (a) At closest distance of approach, the kinetic energy of the particle will convert completely into electrostatic potential energy.

Kinetic energy K.E. $= \frac{1}{2}\text{mv}^2$

Potential energy P.E. $= \frac{KQq}{r}$

$\frac{1}{2}mv^2 = \frac{KQq}{r} \Rightarrow r \propto \frac{1}{m}$

S10. (a)

$\because T \propto n^3$

T_{n_1} = 8 T_{n_2} (given)

Hence, $n_1 = 2n_2$

S11. (c) A spectrum is observed, when light coming directly from a source is examined with a spectroscope. Therefore, spectrum obtained from a sodium vapor lamp is emission spectrum.

S12. (a) Energy of ground state 13.6 eV Energy of first excited state

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

Energy of second excited state

$= -\frac{13.6}{9} = -1.5\text{eV}$

Difference between ground state and 2^{nd} excited state = 13.6 – 1.5 = 12.1 eV So, electron can be excited up to 3^{rd} orbit No. of possible transition

1→2, 1→ 3, 2→ 3

So, three lines are possible.

S13. (b) The smallest frequency and largest wavelength in ultraviolet region will be for transition of electron from orbit 2 to orbit 1.

$\therefore \frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

$$\Rightarrow \frac{1}{122 \times 10^{-9}m} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = R\left[1 - \frac{1}{4}\right] = \frac{3R}{4}$$

$\Rightarrow R = \frac{4}{3\times122\times10^{-9}}m^{-1}$

The highest frequency and smallest wavelength for infrared region will be for transition of electron from ∞ to 3rd orbit.

$\therefore \frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \Rightarrow \frac{1}{\lambda} = \frac{4}{3\times122\times10^{-9}}\left(\frac{1}{3^2} - \frac{1}{\infty}\right)$

$\therefore \lambda = \frac{3\times122\times9\times10^{-9}}{4} = 823.5nm$

S14. (b) $E = E_4 - E_3$

$$= -\frac{13.6}{4^2} - \left(-\frac{13.6}{3^2}\right) = -0.85 + 1.51$$

= 0.66 eV

S15. (b) Jump to second orbit leads to Balmer series. The jump from 4th orbit shall give rise to second line of Balmer series.

ASSERTION AND REASONING

S1. (a) Alpha particle is positively charged, so is the nucleus, so the large angle of scattering of alpha particle shows that the nucleus is positively charged and concentrated in the central core.

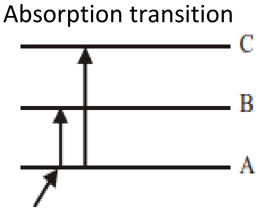
S2. (b) Bohr postulated that electrons in stationary orbits around the nucleus do not radiate. This is the one of Bohr's postulates. According to this moving electron radiates only when they go from one orbit to the next lower orbit.

S3. (c) The nature of atoms and the manner in which electrons interact and move about their nucleus. There is always a force of attraction between the electrons and nucleus. They strictly follow coulomb law and attract themselves in order to generate necessary centripetal force which will allow them to perform circular motion.

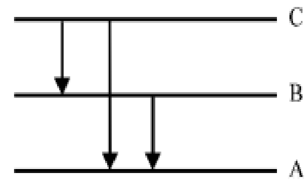
S4. (a) Electron is bound to nucleus by electrostatic force of attraction. Now, that it revolves in an orbit as well, its kinetic energy is not enough so that it can break free from the orbit. Hence the total energy of electron is negative. Therefore, both assertion and reason are correct and reason is the correct explanation of assertion.

S5. (a) Beginning from any level n to another upper energy level m, only m−n absorption transitions can be made, but since emission from m to n can involve transition between any two levels between n and m, ${}^{m-n}C_2$ transitions are possible which is always greater than m−n. Hence both statements are correct and second one is correct explanation for first.

Absorption transition



Two possibilities in absorption transition



SHORT ANSWER QUESTIONS

S1. Ionization energy: The energy required to knock out an electron from an atom is called ionization energy of the atom. For hydrogen atom it is 13.6 eV.

S2. Balmer series is obtained when an electron jumps to the second orbit ($n_1 = 2$) from any orbit $n_2 = n > 2$.

S3. For third excited state, $n_2 = 4$, and $n_1 = 3, 2, 1$ Hence there are 3 spectral lines.

S4. Ionization energy: "The minimum energy, required to free the electron from the ground state of the hydrogen atom, is known as Ionization Energy."

The ionization energy is given by:

$E_0 = m\frac{e^4}{8\epsilon_0^2h^2}$

Ionization Energy will become 200 times,

$\because$ the mass of given particle is 200 times.

NUMERICAL TYPE QUESTIONS

S1. (a) $\lambda = 975$ Å $= 975 \times 10^{-10}$ m

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

$\therefore \frac{1}{975\times10^{-10}} = 1.1\times10^7\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$ or n = 4

(b) n = 4

$\because$ Number of spectral lines (N) = $\frac{n(n-1)}{2}$

$\therefore N = \frac{4\times(4-1)}{2} = 6$

Possible transition 4→3, 4→2, 4→1, 3→2, 3→1, 2→1

S2. I.P. = 122.4 V

$E = Z^2E_H$

$\because \quad Z = \sqrt{\frac{E}{E_{H_2}}} = \sqrt{\frac{122.4}{13.6}} = 3$

S3. I.P. = 122.4 V

$E_{ex1} = 122.4 - \frac{122.4}{4} = 91.8V$

$\therefore E_{ex2} = 122.4 - \frac{122.4}{9} = 108.8V$

S4. $n_1 = n_2 = 5$

$\therefore \frac{1}{\lambda_{max}\left[\frac{1}{4^2} - \frac{1}{5^2}\right]}$

or $\lambda \frac{25\times16\times10^{10}}{9\times1.1\times10^7}{}_{max}$

S5. From Bragg's equation $2d \sin\theta = n\lambda$

$2 \times 2.8 \times 10^{-10} \times \sin\theta = l \times 10^{-10}$

$sin\,\theta = \frac{1}{5.6} \Rightarrow \sin\theta = 0.1786$ or $\theta = \sin^{-1}(0.1786)$

S6. Wavelength of a moving electron $\lambda_e = \frac{12.27}{\sqrt{V_a}}\AA$

Or V_a = accelerating potential of electron = $\frac{150}{\lambda_e^2} = \frac{150}{(0.1)^2} = 15000\ volt$

Minimum wavelength of X-rays $\lambda \frac{hc}{eV_a} \frac{6.62\times10^{-34}\times3\times10^8}{1.6\times10^{-19}\times15000}_{min}$

S7. Kinetic energy acquired by the electron = 20×10^3 eV

The energy of the photon = $\frac{5}{100} \times 20 \times 10^3 eV = 10^3 eV$

Thus, $\frac{hc}{\lambda} = 10^3 eV$ or $\lambda = \frac{hc}{10^3 eV} = \frac{12400 eV-\AA}{10^3 eV} = 12.4\AA$

S8. K_a means transition from $n_2 = 2$ to $n_1 = 2$ and b = 1 for K series

$\frac{1}{\lambda_{K\alpha}} = R(Z-1)^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ $\frac{1}{\lambda_{K\alpha}} = R(Z-1)^2\left[\frac{1}{1^2} - \frac{1}{2^2}\right]$

$\frac{1}{\lambda_{K\alpha}} = \frac{3R(Z-1)^2}{4}$

R = 1.097×10^7 m^{-1} and $\frac{1}{R} = 912\AA$

$\lambda_{K\alpha} = \frac{4}{3R(Z-1)^2}$

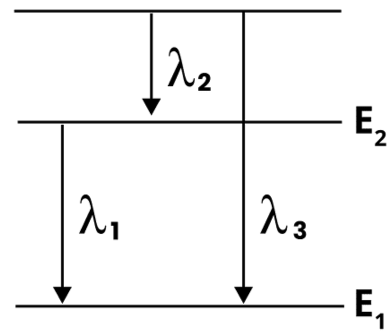
$\lambda_{K\alpha} = \frac{1216}{(Z-1)^2}\AA$

S9. For given condition $E_3 - E_1 = (E_3 - E_2) + (E_2 - E_1)$

$\Rightarrow \quad \frac{hc}{\lambda_3} = \frac{hc}{\lambda_2} + \frac{hc}{\lambda_1}$

$$\Rightarrow \quad \frac{1}{\lambda_3} = \frac{1}{\lambda_2} + \frac{1}{\lambda_1}$$

Therefore $\lambda_3 = \frac{\lambda_2\lambda_1}{\lambda_2 + \lambda_1}$



S10. Here, Stopping potential, V_0 = 10 V

Work function, W = 2.75 eV

According to Einstein's photoelectric equation

$eV_0 = h\upsilon - W$ or $h\upsilon = eV_0 + W$

= 10 eV + 2.75 eV = 12.75 eV ...(i)

When an electron in the hydrogen atom makes a transition from excited state n to the ground state $(n = 1)$, then the frequency (υ) of the emitted photon is given by

$h\upsilon = E_n - E_1 \Rightarrow h\upsilon = -\frac{13.6}{n^2} - \left(-\frac{13.6}{1^2}\right)$

[∵For hydrogen atom, $E_n = -\frac{13.6}{n^2}$ eV]

According to given problem

$-\frac{13.6}{n^2} + 13.6 = 12.75$ (Using (i))

$\frac{13.6}{n^2} = 0.85 \Rightarrow n^2 = \frac{13.6}{0.85} = 16$

or $n = 4$