PRACTICE PAPER 12
CHAPTER 12 ATOMS

SUBJECT: PHYSICS — **MAX. MARKS : 40**
CLASS : XII — **DURATION : 1½ hrs**

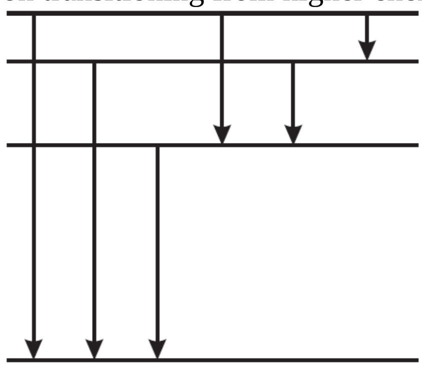
General Instructions:

(i). **All** questions are compulsory.
(ii). This question paper contains 2**0** questions divided into five Sections A, B, C, D and E.
(iii). **Section A** comprises of **10 MCQs** of **1 mark** each. **Section B** comprises of 4 questions of **2 marks** each. **Section C** comprises of 3 questions of **3 marks** each. **Section D** comprises of 1 question of **5 marks** each and **Section E** comprises of 2 Case Study Based Questions of **4 marks** each.
(iv). There is no overall choice.
(v). Use of Calculators is not permitted

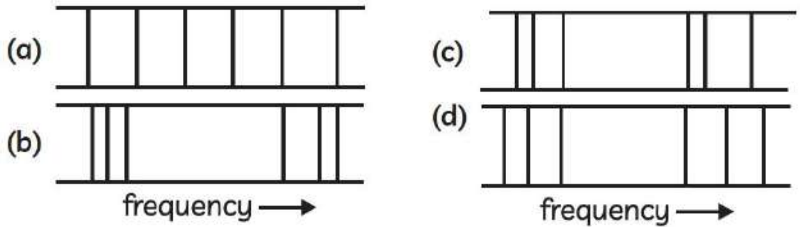
SECTION – A

Questions 1 to 10 carry 1 mark each.

1. The emission spectrum of an element is the spectrum of frequencies of EM radiations emitted due to electrons making a transition from a higher energy state to a lower energy state.
The given diagram shows electron transitioning from higher energy states to lower energy states.



Which of the following spectrums most closely corresponds to the above transitions?



2. In Balmer series of hydrogen atom, as the wavelength of spectral lines decreases, they appear:
(a) equally spaced and equally intense. (b) further apart and stronger in intensity.
(c) closer together and stronger in intensity. (d) closer together and weaker in intensity.

3. The radius (rn) of nth orbit in Bohr model of hydrogen atom varies with n as:
(a) $r_n \propto n$ (b) $r_n \propto 1/n$ (c) $r_n \propto n^2$ (d) $r_n \propto 1/n^2$

4. Specify the transition of electron in the wavelength of the line in the Bohr model of hydrogen atom which gives rise to the spectral line of highest wavelength.
(a) n = 3 to n = 1 (b) n = 3 to n = 2 (c) n = 4 to n = 1 (d) n = 4 to n = 2

5. When alpha particles are sent through a thin gold foil, most of them go straight through the foil, because:
(a) alpha particles are positively charged
(b) the mass of an alpha particle is more than the mass of an electron
(c) most of the part of an atom is empty space

(d) alpha particles move with high velocity

6. An electron with angular momentum L moving around the nucleus has a magnetic moment given by:
(a) eL/2m (b) eL/3m (c) eL/4m (d) eL/m

7. The energy of an electron in nth orbit of hydrogen atom is, $E_n = -13.6/n^2$ eV. The negative sign of energy indicates that:
(a) electron is free to move.
(b) electron is bound to the nucleus.
(c) kinetic energy of electron is equal to potential energy of electron.
(d) atom is radiating energy.

8. Which of the following statements is NOT correct according to Rutherford model?
(a) Most of the space inside an atom is empty.
(b) The electrons revolve around the nucleus under the influence of Coulomb force acting on them.
(c) Most part of the mass of the atom and its positive charge are concentrated at its centre.
(d) The stability of atom was established by this model.

In the following questions 9 and 10, a statement of assertion (A) is followed by a statement of reason (R). Mark the correct choice as:
(a) Both assertion (A) and reason (R) are true and reason (R) is the correct explanation of assertion (A).
(b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).
(c) Assertion (A) is true but reason (R) is false.
(d) Assertion (A) is false but reason (R) is true.

9. **Assertion (A):** Bohr postulated that the electrons in stationary orbits around the nucleus do not radiate energy.
Reason (R): According to classical Physics, all accelerated electrons radiate energy.

10. **Assertion (A):** According to Bohr's atomic model the ratio of angular momenta of an electron in first excited state to that in ground state is 2 : 1.
Reason (R): According to Bohr's theory the angular momentum of the electron is directly proportional to the principal quantum number.

SECTION – B

Questions 11 to 14 carry 2 marks each.

11. What is meant by ionisation energy? Write its value for hydrogen atom?

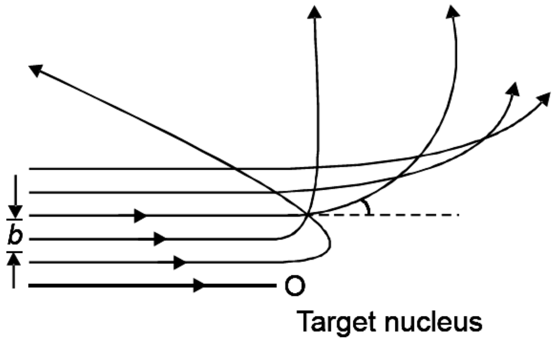
OR

The ground state energy of hydrogen atom is –13.6 eV. What is the potential energy and kinetic energy of an electron in the third excited state?

12. A hydrogen atom is in its third excited state.
(a) How many spectral lines can he emitted by it before coming to the ground state? Show these transitions in the energy level diagram.
(b) In which of the above transitions will the spectral line of shortest, wavelength be emitted?

OR

The trajectories, traced by different α-particles, in Geiger-Marsden experiment were observed as shown in the figure.



(a) What names are given to the symbols 'b' and 'θ' shown here?
(b) What can we say about the values of b for (i) $\theta = 0°$ (ii) $\theta = \pi$ radians?

13. The ground state energy of hydrogen atom is –13·6 eV. If an electron makes a transition from an energy level –1·51 eV to –3·4 eV, calculate the wavelength of the spectral line emitted and name the series of hydrogen spectrum to which it belongs.

OR

Write shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model.

14. Name the spectral series for a hydrogen atom which lies in the visible region. Find the ratio of the maximum to the minimum wavelengths of this series.

OR

An electron in a hydrogen atom makes transitions from orbits of higher energies to orbits of lower energies.
(a) When will such transitions result (i) Lyman, (ii) Balmer series?
(b) Find the ratio of the longest wavelength in Lyman series to the shortest wavelength in Balmer series.

SECTION – C

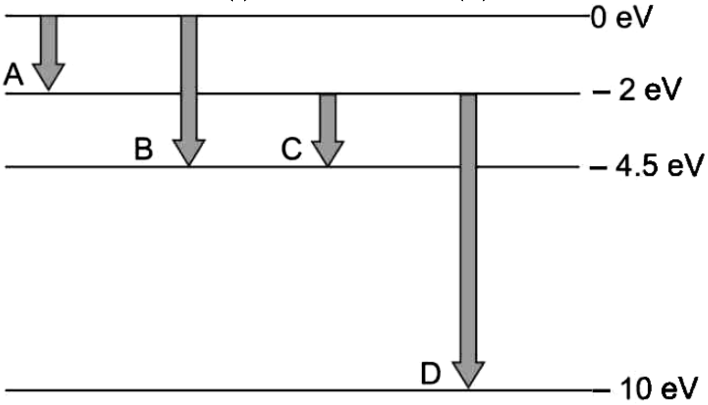
Questions 15 to 17 carry 3 marks each.

15. Calculate the de-Broglie wavelength associated with the electron revolving in the first excited state of hydrogen atom. The ground state energy of the hydrogen atom is –13.6 eV.

OR

(i) State Bohr postulate of hydrogen atom that gives the relationship for the frequency of emitted photon in a transition.
(ii) An electron jumps from fourth to first orbit in an atom. How many maximum number of spectral lines can be emitted by the atom? To which series these lines correspond?

16. The energy levels of a hypothetical atom are shown alongside. Which of the shown transitions will result in the emission of a photon of wavelength 275 nm? Which of these transitions correspond to emission of radiation of (i) maximum and (ii) minimum wavelength?



OR

Determine the distance of closest approach when an alpha particle of kinetic energy 4.5 MeV strikes a nucleus of Z = 80, stops and reverses its direction.

17. Draw the graph showing variation of scattered particles detected (N) with the scattering angle (θ) in Geiger-Marsden experiment. Write two conclusions that you can draw from this graph. Obtain the expression for the distance of closest approach in this experiment.

OR

Derive an expression for the frequency of radiation emitted when a hydrogen atom de-excites from level *n* to level (*n* – 1). Also show that for large values of n, this frequency equals to classical frequency of revolution of an electron.

SECTION – D

Questions 18 carry 5 marks.

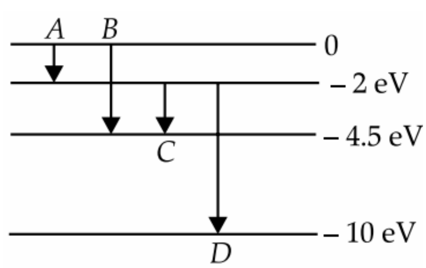
18. Draw a schematic arrangement of the Geiger-Marsden experiment. How did the scattering of α-particles of a thin foil of gold provide an important way to determine an upper limit on the size of the nucleus? Explain briefly.

OR

(a) State Bohr's postulate to define stable orbits in hydrogen atom. How does de Broglie's hypothesis explain the stability of these orbits?

(b) A hydrogen atom initially in the ground state absorbs a photon which excites it to the n = 4 level. Estimate the frequency of the photon.

(c) The energy levels of a hypothetical atom are given below. Which of the shown transitions will result in the emission of photon of wavelength 275 nm?

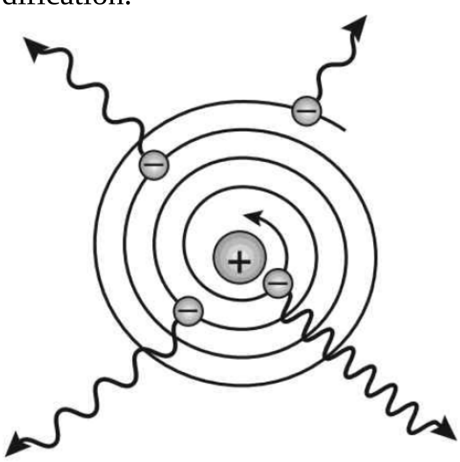


SECTION – E (Case Study Based Questions)

Questions 19 to 20 carry 4 marks each.

19. Case-Study 1: Read the following paragraph and answer the questions.

The Bohr Atom: Rutherford's model of the atom, although strongly supported by evidence for the nucleus, is inconsistent with classical physics. An electron moving ina circular orbit round a nucleus is accelerating and according to electromagnetic theory it should emit radiation continuously and so lose energy. If this happened the radius of the orbit would decrease and the electron would spiral into the nucleus. Evidently either this model of the atom or the classical theory of radiation requires modification.



In 1913, in an effort to overcome this paradox, Bohr, drawing inspiration from the success of the quantum theory in solving other problems involving radiation and atoms, made two revolutionary suggestions.

Electrons can revolve round the nucleus only in certain 'allowed orbits' and while they are in these orbits they do not emit radiation. An electron in an orbit has a definite amount of energy. It possesses kinetic energy because of its motion and potential energy on account of the attraction of the nucleus. Each allowed orbit is therefore associated with a certain quantity of energy, called the 'energy of the orbit', which equals the total energy of an electron in it.

An electron can 'jump' from one orbit of energy E_2 to another of lower energy E_1 and the energy difference is emitted as one quantum of radiation of frequency f given by Planck's equation

$E_2 - E_1 = hf$.

(*i*) According to Bohr's model of hydrogen atom, an electron can revolve round a proton indefinitely, if its path is

(*a*) a perfect circle of any radius (*b*) a circle of constantly decreasing radius

(*c*) a circle of an allowed radius (*d*) an ellipse

(*ii*) In Bohr model of hydrogen atom, which of the following is quantised?

(*a*) Linear velocity of electron (*b*) Angular velocity of electron

(*c*) Linear momentum of electron (*d*) Angular momentum of electron

(*iii*) For an electron in the second orbit of hydrogen, what is the moment of momentum as per the Bohr's model?

(*a*) 2p*h* (*b*) p*h* (*c*) *h*/p (*d*) 2*h*/p

OR

An electron orbiting in H atom has energy level –3.4 eV. Its angular momentum will be

(*a*) 2.1×10^{-34} Js (*b*) 2.1×10^{-20} Js (*c*) 4×10^{-20} Js (*d*) 4×10^{-34} Js

(*iv*) The Bohr's model is applicable to which kind of atoms?

(*a*) Having one electron only (*b*) Having two electrons

(*c*) Having eight electrons (*d*) Having more than eight electrons

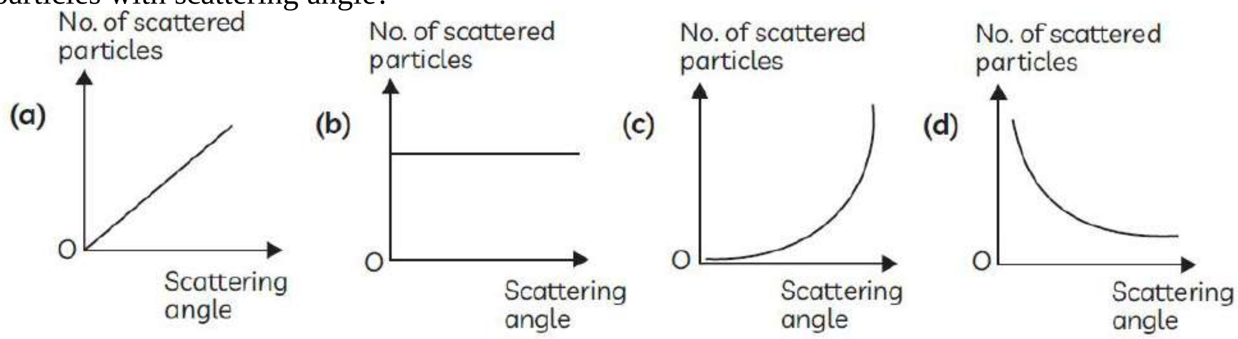
20. J. J. Thomson's "plum pudding" model was unable to account for some scientific findings about the atomic structure of elements. As a result, British scientist Ernest Rutherford conducted an experiment in 1909 and, based on the results, developed the Rutherford atomic model and the atomic structure of the elements. At the time, there was still no clear model that defined atoms. He conducts an experiment in which he bombards a thin sheet of gold with alpha particles, observing the interactions between the particles and the foil as well as their route.

First, he noticed that the majority of α-particles that are fired at the gold sheet pass through the foil without being deflected, indicating that the majority of the space is vacant.

The fact that some of the α-particles were partially deflected through the gold sheet at extremely small angles indicates that the positive charge in an atom is not spread uniformly. In an atom, the positive charge is confined to a relatively small volume. Only a very small percentage of the alpha particles (1–2%) were redirected, meaning that only a very small fraction of α-particles deflected nearly 180 degrees. This demonstrates that, in comparison to the entire volume of an atom, the positively charged particles' volume is extremely small.

(i) Which of the following was not a conclusion drawn by Rutherford?
(a) Most of the mass of atoms is concentrated at their center and it is known as the nucleus.
(b) Nucleus consists of protons and neutrons (only the particles with significant mass).
(c) Electrons revolve around the positively charged nucleus in parabolic orbits.
(d) Coulomb's force provides the necessary centripetal acceleration for the electron.

(ii) Which of the following graph correctly represents the variation of number of scattered particles with scattering angle?



(iii) Which of the following is a limitation of Rutherford's model?
(a) It cannot explain the charge distribution of the atom.
(b) It cannot explain the stability of atoms.
(c) It cannot explain the presence of electronic orbits.
(d) It cannot explain the existence of a nucleus.

(iv) According to the Bohr's model of hydrogen atom, which of the following orbit will not be available for electron to revolve in?
(a) Orbit A in which electrons have an angular momentum of $2h/\pi$.
(b) Orbit B in which electrons have an angular momentum of $h/3\pi$
(c) Orbit C in which electrons have an angular momentum of $3h/\pi$
(d) Orbit D in which electrons have an angular momentum of $h/2\pi$

PRACTICE PAPER 12
CHAPTER 12 ATOMS (ANSWERS)

SUBJECT: PHYSICS | **MAX. MARKS : 40**
CLASS : XII | **DURATION : 1½ hrs**

General Instructions:

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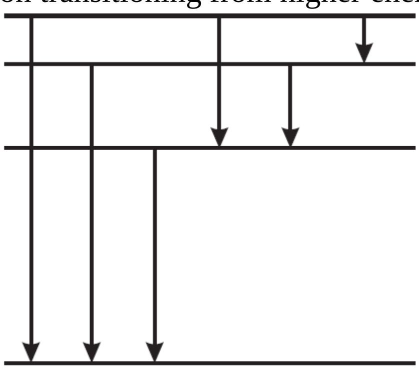
(iv). There is no overall choice.
(v). Use of Calculators is not permitted

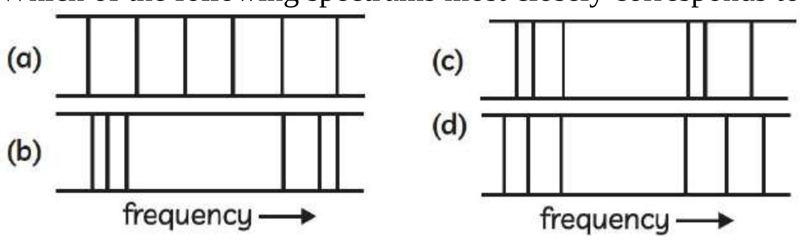
SECTION – A

Questions 1 to 10 carry 1 mark each.

1. The emission spectrum of an element is the spectrum of frequencies of EM radiations emitted due to electrons making a transition from a higher energy state to a lower energy state.
The given diagram shows electron transitioning from higher energy states to lower energy states.



Which of the following spectrums most closely corresponds to the above transitions?



Ans. (c)
The transitions given belong to Lyman, Balmer and Paschen series. The figure (c) correctly depicts these transitions.

2. In Balmer series of hydrogen atom, as the wavelength of spectral lines decreases, they appear:
(a) equally spaced and equally intense.
(b) further apart and stronger in intensity.
(c) closer together and stronger in intensity.
(d) closer together and weaker in intensity.
Ans. (d) closer together and weaker in intensity.
As wavelength of spectral lines in Balmer series decreases, energy increases. The spectral lines are emitted when electron transitions from higher energy level to lower energy level. Higher energy levels are closer together. Hence, as wavelength decreases the spectral lines converge together.
Since electrons in higher levels vary rarely compared to lower level. Intensity of the spectral lines decreases as wavelength decreases.

3. The radius (rn) of nth orbit in Bohr model of hydrogen atom varies with n as:
(a) $r_n \propto n$ (b) $r_n \propto 1/n$ (c) $r_n \propto n^2$ (d) $r_n \propto 1/n^2$
Ans. (c) $r_n \propto n^2$

4. Specify the transition of electron in the wavelength of the line in the Bohr model of hydrogen atom which gives rise to the spectral line of highest wavelength.
(a) n = 3 to n = 1 (b) n = 3 to n = 2 (c) n = 4 to n = 1 (d) n = 4 to n = 2
Ans. (b) n = 3 to n = 2
In the Bohr model of the hydrogen atom, the spectral line of highest wavelength is the Lyman-alpha line, which corresponds to the transition of an electron from the n = 2 energy level to the n = 1 energy level.
When an electron in a hydrogen atom transits from a higher energy level to a lower energy level, it releases energy in the form of a photon with a specific wavelength. The wavelength of the photon is determined by the energy difference between the two energy levels involved in the transition.

5. When alpha particles are sent through a thin gold foil, most of them go straight through the foil, because:
(a) alpha particles are positively charged
(b) the mass of an alpha particle is more than the mass of an electron
(c) most of the part of an atom is empty space
(d) alpha particles move with high velocity
Ans. (c) most of the part of an atom is empty space
As the majority of an atom is empty space, the majority of alpha particles that are delivered through a thin metal foil, pass straight through the foil.

6. An electron with angular momentum L moving around the nucleus has a magnetic moment given by:
(a) eL/2m (b) eL/3m (c) eL/4m (d) eL/m
Ans. (a) eL/2m

7. The energy of an electron in nth orbit of hydrogen atom is, $E_n = -13.6/n^2$ eV. The negative sign of energy indicates that:
(a) electron is free to move.
(b) electron is bound to the nucleus.
(c) kinetic energy of electron is equal to potential energy of electron.
(d) atom is radiating energy.
Ans. (b) electron is bound to the nucleus.
The negative sign means that the energy of the electron in the atom is lower than the energy of a free electron at rest. A free electron at rest is an electron that is infinitely far away from the nucleus and is assigned the energy value zero.

8. Which of the following statements is NOT correct according to Rutherford model?
(a) Most of the space inside an atom is empty.
(b) The electrons revolve around the nucleus under the influence of Coulomb force acting on them.
(c) Most part of the mass of the atom and its positive charge are concentrated at its centre.
(d) The stability of atom was established by this model.
Ans. (d) The stability of atom was established by this model.
The Rutherford model of the atom fails to explain atomic stability. When an electron moves in a circular path, it should accelerate and emit energy. As a result, the electron would lose energy continuously and eventually collapse into the nucleus.

In the following questions 9 and 10, a statement of assertion (A) is followed by a statement of reason (R). Mark the correct choice as:
(a) Both assertion (A) and reason (R) are true and reason (R) is the correct explanation of assertion (A).
(b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).
(c) Assertion (A) is true but reason (R) is false.
(d) Assertion (A) is false but reason (R) is true.

9. **Assertion (A):** Bohr postulated that the electrons in stationary orbits around the nucleus do not radiate energy.
Reason (R): According to classical Physics, all accelerated electrons radiate energy.
Ans. (b) Both assertion (A) and reason (R) are true but reason (R) is not the correct explanation of assertion (A).
Bohr postulate that the electrons in stationary orbits around the nuclear do not radiate energy to give stable atomic model.

10. **Assertion (A):** According to Bohr's atomic model the ratio of angular momenta of an electron in first excited state to that in ground state is 2 : 1.
Reason (R): According to Bohr's theory the angular momentum of the electron is directly proportional to the principal quantum number.
Ans. (a) Both Assertion and Reason are true and Reason is the correct explanation of Assertion.

SECTION – B

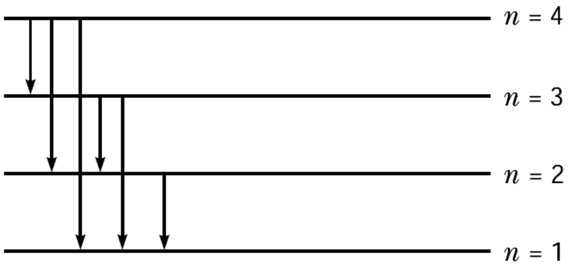
Questions 11 to 14 carry 2 marks each.

11. What is meant by ionisation energy? Write its value for hydrogen atom?
Ans. Ionization energy is the minimum amount of energy required to remove an electron from an isolated gaseous atom or ion. In other words, it is the energy required to overcome the attractive forces between an electron and its nucleus to completely remove the electron from the atom.
The ionization energy of hydrogen atom is 1312 kJ/mol or 13.6 eV (electron volts). This means that to completely remove an electron from a hydrogen atom in its ground state, a minimum of 13.6 eV of energy must be supplied to the atom.

OR

The ground state energy of hydrogen atom is –13.6 eV. What is the potential energy and kinetic energy of an electron in the third excited state?
Ans. For ground state, Energy (E) = –13.6 eV
For third excited state, n = 4, $E_4 = \frac{-13.6}{n^2} = \frac{-13.6}{4^2} = -0.85 eV$
$\therefore K.E = -E = -(-0.85) = \mathbf{0.85\ eV}$
and $P.E = -2K.E = -2 \times 0.85 = \mathbf{-1.7\ eV}$.

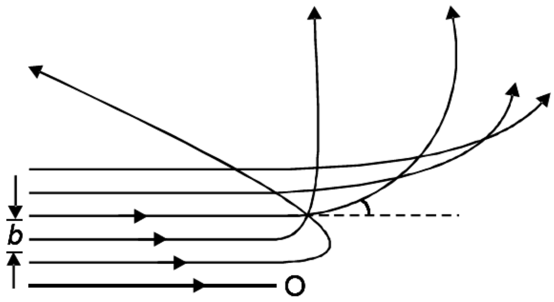
12. A hydrogen atom is in its third excited state.
(a) How many spectral lines can he emitted by it before coming to the ground state? Show these transitions in the energy level diagram.
(b) In which of the above transitions will the spectral line of shortest, wavelength be emitted?
Ans. (a) For third excited state, $n = 4$
For ground state, $n = 1$
Hence, the possible transitions are
$n_i = 4$ to $n_f = 3, 2, 1$
$n_i = 3$ to $n_f = 2, 1$
$n_i = 2$ to $n_f = 1$
$\therefore$ Total number of transitions = 6, as shown in figure.



(*b*) The shortest wavelength corresponds to the transition when e^- jumps from $n = 4$ to $n = 1$.

OR

The trajectories, traced by different α-particles, in Geiger-Marsden experiment were observed as shown in the figure.



(a) What names are given to the symbols 'b' and 'θ' shown here?
(b) What can we say about the values of b for (i) θ = 0° (ii) θ = π radians?
Ans. (a) The symbol 'b' represents impact parameter and 'θ' represents the scattering angle.
(b) (i) When θ = 0°, the impact parameter will be maximum and represent the atomic size.
(ii) When θ = π radians, the impact parameter 'b' will be minimum and represent the nuclear size.

13. The ground state energy of hydrogen atom is –13·6 eV. If an electron makes a transition from an energy level –1·51 eV to –3·4 eV, calculate the wavelength of the spectral line emitted and name the series of hydrogen spectrum to which it belongs.
Ans. $E_1 = -13.6\ eV$, $E_i = -1.51\ eV$, $E_f = -3.4\ eV$
Change in energy $= E_i - E_f = -1.51\ eV - (-3.4\ eV)$
$\Rightarrow E = 3.4\ eV - 1.51\ eV \Rightarrow E = 1.89\ eV \Rightarrow h\nu = 1.89\ eV$

$$\Rightarrow \frac{hc}{\lambda} = 1.89\times1.6\times10^{-19} J \Rightarrow \lambda = \frac{hc}{1.89\times1.6\times10^{-19}}$$

$$\Rightarrow \lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.89\times1.6\times10^{-19}} = 6.58\times10^{-7} m$$

It belongs to visible light and hence to belongs to Balmer series of hydrogen spectrum.
Since, 658 nm belongs to 400 nm to 700 nm.

OR

Write shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model.
Ans. 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.
Bohr's postulates overcome these limitations by:
(i) Bohr stated that negatively charged electrons revolve around positively charged nucleus in certain orbits called stationary orbits. The electrons does not radiate energy when in stationary orbits.

(ii) The quantum of energy is released or absorbed when an electron jumps from one stationary orbit to another.

14. Name the spectral series for a hydrogen atom which lies in the visible region. Find the ratio of the maximum to the minimum wavelengths of this series.

Ans. All of the wavelength in the Balmer series are in the visible region of the electromagnetic spectrum (400 nm to 740 nm).

When electrons does transition from higher energy state (n_h = 3, 4, 5, 6, 7, ...) to lower energy states (n_i = 2), the Balmer series appears.

Shortest wavelength, $n_1 = 2$ and $n_2 = \infty$

$$\frac{1}{\lambda_1} = R\left(\frac{1}{2^2} - 0\right) \Rightarrow \lambda_1 = \frac{4}{R}$$

Largest wavelength, $n_1 = 2$ and $n_2 = 3$

$$\frac{1}{\lambda_2} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) \Rightarrow \lambda_2 = \frac{36}{5R}$$

∴ Required ratio, $\frac{\lambda_1}{\lambda_2} = \frac{\frac{4}{R}}{\frac{36}{5R}} = \frac{5}{9}$

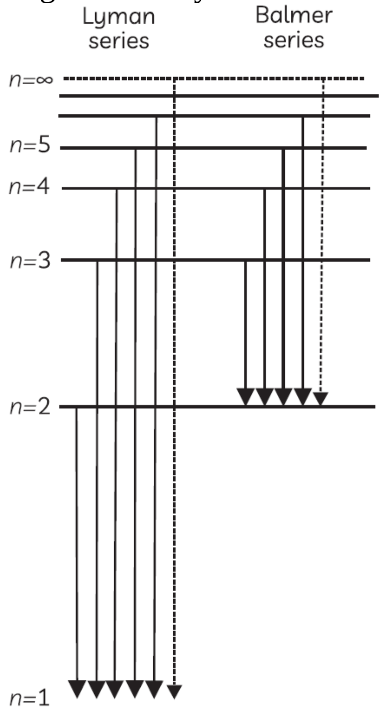
OR

An electron in a hydrogen atom makes transitions from orbits of higher energies to orbits of lower energies.

(a) When will such transitions result (i) Lyman, (ii) Balmer series?

(b) Find the ratio of the longest wavelength in Lyman series to the shortest wavelength in Balmer series.

Ans. (a) Emission spectrum of Hydrogen atom: Lyman and Balmer series



(i) Lyman Series: When electron will jump from a higher energy orbit to n = 1 orbit.

(ii) Balmer Series: When electron will jump from a higher energy orbit to n = 2 orbits.

(b) Longest wavelength of Lyman series:

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

Shortest wavelength of Balmer series:

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

Now, required ratio is: $\frac{\lambda_L}{\lambda_B} = \frac{\frac{4}{3}}{\frac{4}{1}} = \frac{1}{3}$

SECTION – C

Questions 15 to 17 carry 3 marks each.

15. Calculate the de-Broglie wavelength associated with the electron revolving in the first excited state of hydrogen atom. The ground state energy of the hydrogen atom is –13.6 eV.

Ans. Energy of the electron in the first excited state,

$$E_1 = \frac{13.6}{2^2}\text{eV} = 3.4\text{ eV} = -3.4 \times 1.6 \times 10^{-19}\text{J} = -5.44 \times 10^{-19}\text{J}$$

Associated kinetic energy $= -E_1$

$$K = 5.44 \times 10^{-19}\text{J}$$

$\therefore$ de-Broglie wavelength, $\lambda = h/p$

$$\lambda = \frac{h}{\sqrt{2mK}} = \frac{6.63\times10^{-34}}{(2\times9.1\times10^{-31}\times5.44\times10^{-19})^{1/2}}\text{m} = \frac{6.63\times10^{-34}}{(99.008)^{1/2}\times10^{-25}}\text{m}$$

$$\approx 0.663 \times 10^{-9}\text{ m} = 0.663\text{ nm} = 6.63\text{ Å}$$

OR

(i) State Bohr postulate of hydrogen atom that gives the relationship for the frequency of emitted photon in a transition.

(ii) An electron jumps from fourth to first orbit in an atom. How many maximum number of spectral lines can be emitted by the atom? To which series these lines correspond?

Ans. (*i*) **Bohr's third postulate:** It states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states.

The frequency of the emitted photon is given by

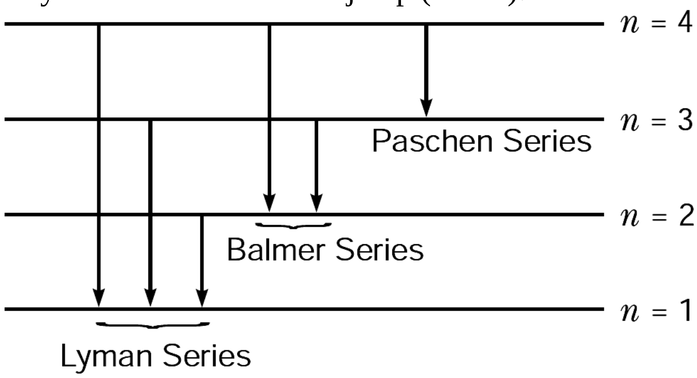
$$h\nu = E_i - E_f$$

where E_i and E_f are the energies of the initial and final states and $E_i > E_f$.

(*ii*) Electron jumps from fourth to first orbit in an atom

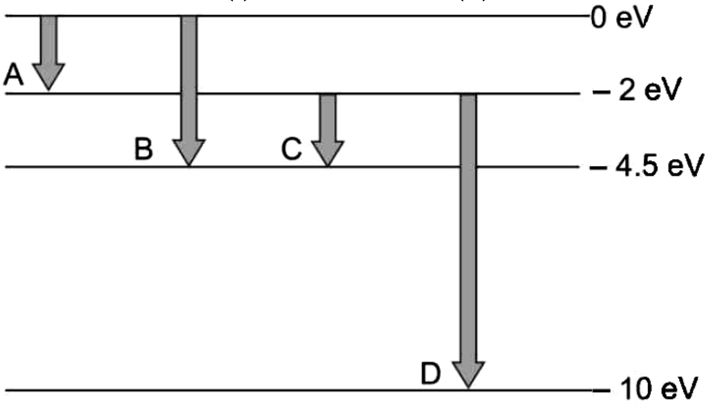
$\therefore$ Maximum number of spectral lines can be $^4C_2 = \frac{4!}{2!2!} = \frac{4\times3}{2} = 6$

In diagram, possible way in which electron can jump (above).



The line responds to Lyman series (e^- jumps to 1st orbit), Balmer series (e^- jumps to 2nd orbit), Paschen series (e^- jumps to 3rd orbit).

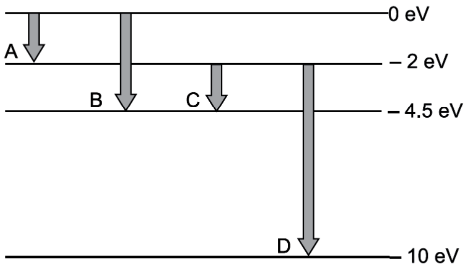
16. The energy levels of a hypothetical atom are shown alongside. Which of the shown transitions will result in the emission of a photon of wavelength 275 nm? Which of these transitions correspond to emission of radiation of (i) maximum and (ii) minimum wavelength?



Ans:

Energy of photon wavelength 275 nm

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{275 \times 10^{-9} \times 1.6 \times 10^{-19}} \text{ eV} = 4.5 \text{ eV}.$$



This corresponds to transition '*B*'.

(*i*) $\Delta E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{\Delta E}$

For maximum wavelength ΔE should be minimum. This corresponds to transition A.

(*ii*) For minimum wavelength ΔE should be maximum. This corresponds to transition D.

OR

Determine the distance of closest approach when an alpha particle of kinetic energy 4.5 MeV strikes a nucleus of Z = 80, stops and reverses its direction.

Ans. Let *r* be the centre to centre distance between the alpha particle and the nucleus (Z = 80). When the alpha particle is at the stopping point, then

$$K = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r}$$

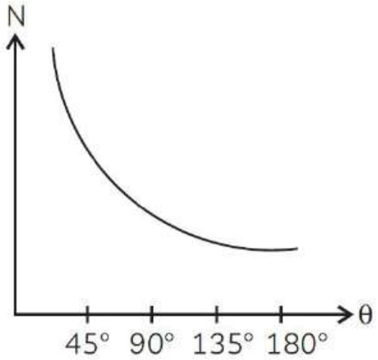
$$\text{or} \quad r = \frac{1}{4\pi\varepsilon_0}.\frac{2Ze^2}{K} = \frac{9\times 10^9 \times 2 \times 80\, e^2}{4.5\,\text{MeV}}$$

$$= \frac{9\times 10^9 \times 2 \times 80 \times (1.6\times 10^{-19})^2}{4.5 \times 10^6 \times 1.6 \times 10^{-19}}$$

$$= \frac{9 \times 160 \times 1.6}{4.5} \times 10^{-16} = 512 \times 10^{-16}\text{m} = \mathbf{5.12 \times 10^{-14}\ m}$$

17. Draw the graph showing variation of scattered particles detected (N) with the scattering angle (θ) in Geiger-Marsden experiment. Write two conclusions that you can draw from this graph. Obtain the expression for the distance of closest approach in this experiment.

Ans. The graph showing the variation of scattered particles (N) versus the scattering angle (θ) is given by



The conclusion drawn from this graph are :
(i) Very few particles are reflected back at θ = 180º because almost all the mass of the foil is concentrated on certain points (nuclei) of atoms.
(ii) Most of the α-particles pass undeviated through the gold foil.
Let the distance of closest approach be r then coulombic repulsion experienced by a-particle must overcome its kinetic energy.

$$\text{i.e. } \frac{Ze^2}{4\pi\varepsilon_0 r} = \frac{1}{2}mv^2 \Rightarrow r = \frac{2Ze^2}{4\pi\varepsilon_0 mv^2}$$

OR

Derive an expression for the frequency of radiation emitted when a hydrogen atom de-excites from level n to level $(n - 1)$. Also show that for large values of n, this frequency equals to classical frequency of revolution of an electron.
Ans. From Bohr's theory, the frequency f of the radiation emitted when an electron de – excites from level n_2 to level n_1 is given as

$$f = \frac{2\pi^2 mk^2 Z^2 e^4}{h^3}\left[\frac{1}{n_1^2 - n_2^2}\right]$$

Given $n_1 = n - 1$, $n_2 = n$, derivation of it

$$f = \frac{2\pi^2 mk^2 Z^2 e^4}{h^3} \frac{(2n-1)}{(n-1)^2 n^2}$$

For large n, $2n - 1 = 2n$, $n - 1 = n$ and $Z = 1$.

Thus, $$f = \frac{4\pi^2 mk^2 e^4}{n^3 h^3}$$

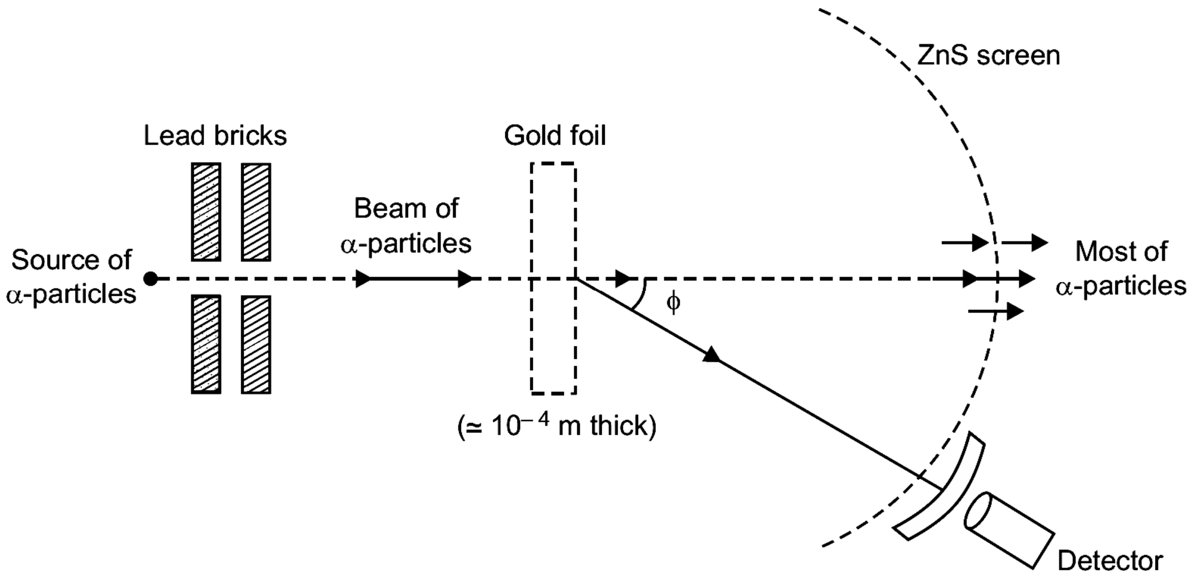
which is same as orbital frequency of electron in n^{th} orbit.

$$f = \frac{v}{2\pi r} = \frac{4\pi^2 mk^2 e^4}{n^3 h^3}$$

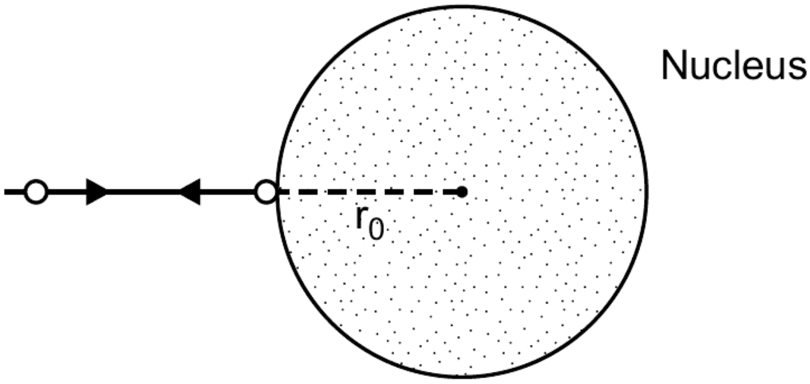
SECTION – D

Questions 18 carry 5 marks.

18. Draw a schematic arrangement of the Geiger-Marsden experiment. How did the scattering of α-particles of a thin foil of gold provide an important way to determine an upper limit on the size of the nucleus? Explain briefly.
Ans:
The Schematic arrangement of Geiger-Marsdon Experiment (also known as Rutherford Scattering Experiment) is shown in fig.



Observations: (i) Only a small fraction of number of a-particles rebound back. This shows that the number of a-particles undergoing head on collision is very small. The conclusion is that the entire positive charge of atom is concentrated in a small volume called the **nucleus.**



At the distance of head on approach, the entire kinetic energy of a-particle is converted into electrostatic potential energy. This distance of head on approach gives an upper limit of the size of nucleus (denoted by r_0) and is given by

$$E_k = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r_0}$$

$$\Rightarrow r_0 = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{E_k}$$

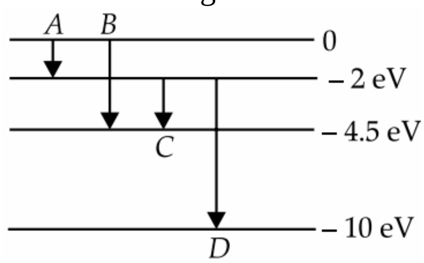
This is about 10^{-14} m.

OR

(a) State Bohr's postulate to define stable orbits in hydrogen atom. How does de Broglie's hypothesis explain the stability of these orbits?

(b) A hydrogen atom initially in the ground state absorbs a photon which excites it to the n = 4 level. Estimate the frequency of the photon.

(c) The energy levels of a hypothetical atom are given below. Which of the shown transitions will result in the emission of photon of wavelength 275 nm?



Ans: (a) Bohr's postulate, for stable orbits, states
"The electron, in an atom, revolves around the nucleus only in those orbits for which its angular momentum is an integral multiple of h/2π (h = Planck's constant)."

As per de Broglie's hypothesis, $\lambda = \frac{h}{p} = \frac{h}{mv}$

For a stable orbit, we must have circumference of the orbit= nλ (n=1,2,3,…….)

$\therefore\ 2\pi r = \frac{nh}{mv} \Rightarrow mvr = \frac{nh}{2\pi}$

Thus de-Broglie showed that formation of stationary pattern for integral 'n' gives rise to stability of the atom.

This is nothing but the Bohr's postulate.

(b) Energy in the n = 4 level = $-E_o/4^2 = -E_o/16$

∴ Energy required to take the electron from the ground state, to the

$$n = 4 \text{ level} = \left(-\frac{E_0}{16}\right) - (-E_0)$$

$$= \left(\frac{-1+16}{16}\right)E_0 = \frac{15}{16}E_0$$

$$= \frac{15}{16} \times 13.6 \times 1.6 \times 10^{-19}\ \text{J}$$

Let the frequency of the photon be ν, we have

$$h\nu = \frac{15}{16} \times 13.6 \times 1.6 \times 10^{-19}$$

$$\therefore \quad \nu = \frac{15 \times 13.6 \times 1.6 \times 10^{-19}}{16 \times 6.63 \times 10^{-34}}\ \text{Hz}$$

$$= \mathbf{3.07 \times 10^{15}\ Hz}$$

(c) Energy of photon $= \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{275 \times 10^{-9} \times 1.6 \times 10^{-19}}\ \text{eV} = 4.5\ \text{eV}$

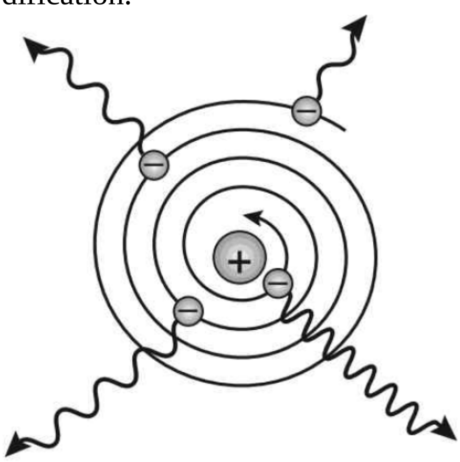
The corresponding transition is B.

SECTION – E (Case Study Based Questions)

Questions 19 to 20 carry 4 marks each.

19. Case-Study 1: Read the following paragraph and answer the questions.

The Bohr Atom: Rutherford's model of the atom, although strongly supported by evidence for the nucleus, is inconsistent with classical physics. An electron moving ina circular orbit round a nucleus is accelerating and according to electromagnetic theory it should emit radiation continuously and so lose energy. If this happened the radius of the orbit would decrease and the electron would spiral into the nucleus. Evidently either this model of the atom or the classical theory of radiation requires modification.



In 1913, in an effort to overcome this paradox, Bohr, drawing inspiration from the success of the quantum theory in solving other problems involving radiation and atoms, made two revolutionary suggestions.

Electrons can revolve round the nucleus only in certain 'allowed orbits' and while they are in these orbits they do not emit radiation. An electron in an orbit has a definite amount of energy. It possesses kinetic energy because of its motion and potential energy on account of the attraction of the nucleus. Each allowed orbit is therefore associated with a certain quantity of energy, called the 'energy of the orbit', which equals the total energy of an electron in it.

An electron can 'jump' from one orbit of energy E_2 to another of lower energy E_1 and the energy difference is emitted as one quantum of radiation of frequency f given by Planck's equation
$E_2 - E_1 = hf$.

(*i*) According to Bohr's model of hydrogen atom, an electron can revolve round a proton indefinitely, if its path is
(*a*) a perfect circle of any radius (*b*) a circle of constantly decreasing radius
(*c*) a circle of an allowed radius (*d*) an ellipse

(*ii*) In Bohr model of hydrogen atom, which of the following is quantised?
(*a*) Linear velocity of electron (*b*) Angular velocity of electron
(*c*) Linear momentum of electron (*d*) Angular momentum of electron

(*iii*) For an electron in the second orbit of hydrogen, what is the moment of momentum as per the Bohr's model?
(*a*) 2p*h* (*b*) p*h* (*c*) *h*/p (*d*) 2*h*/p

OR

An electron orbiting in H atom has energy level –3.4 eV. Its angular momentum will be
(*a*) 2.1×10^{-34} Js (*b*) 2.1×10^{-20} Js (*c*) 4×10^{-20} Js (*d*) 4×10^{-34} Js
(*iv*) The Bohr's model is applicable to which kind of atoms?
(*a*) Having one electron only (*b*) Having two electrons
(*c*) Having eight electrons (*d*) Having more than eight electrons

Ans. (*i*) (*c*) In Bohr's model of hydrogen atom, an electron can revolve around nucleus only in a circle of allowed radius.
(*ii*) (*d*) In Bohr model of hydrogen atom, angular momentum of electron is quantised.
(*iii*) (*c*) In second orbit of hydrogen, $n = 2$

$$L = 2\left(\frac{h}{2\pi}\right) = \frac{h}{\pi}$$

OR

(*a*) The electron revolving in second orbit ($n = 2$) has energy equal to –3.4 eV. Therefore, its angular momentum is

$$L = 2\left(\frac{h}{2\pi}\right) = \frac{h}{\pi} = \frac{6.63\times10^{-34}}{22/7} = 2.1\times10^{-34}\ Js$$

(*iv*) (*a*) Bohr's model is applicable to hydrogen - like species *i.e.*, atoms having one electron only. Such species are also called hydrogen like species.

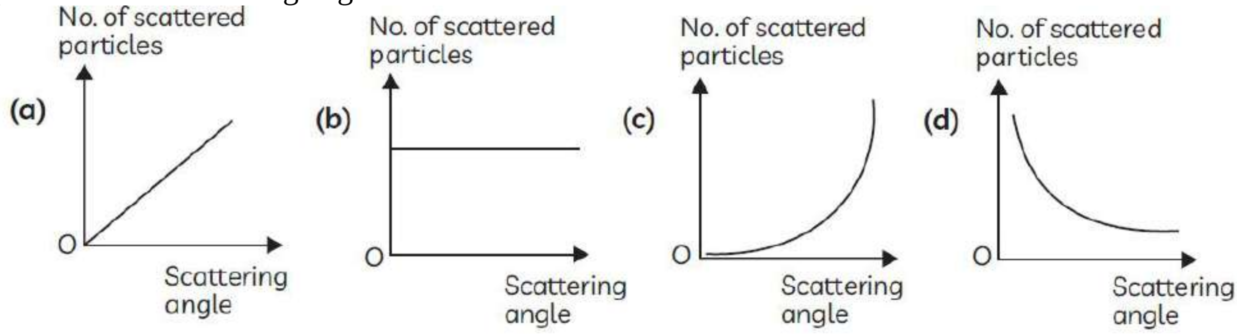
20. J. J. Thomson's "plum pudding" model was unable to account for some scientific findings about the atomic structure of elements. As a result, British scientist Ernest Rutherford conducted an experiment in 1909 and, based on the results, developed the Rutherford atomic model and the atomic structure of the elements. At the time, there was still no clear model that defined atoms. He conducts an experiment in which he bombards a thin sheet of gold with alpha particles, observing the interactions between the particles and the foil as well as their route.

First, he noticed that the majority of α-particles that are fired at the gold sheet pass through the foil without being deflected, indicating that the majority of the space is vacant.

The fact that some of the α-particles were partially deflected through the gold sheet at extremely small angles indicates that the positive charge in an atom is not spread uniformly. In an atom, the positive charge is confined to a relatively small volume. Only a very small percentage of the alpha particles (1–2%) were redirected, meaning that only a very small fraction of α-particles deflected nearly 180 degrees. This demonstrates that, in comparison to the entire volume of an atom, the positively charged particles' volume is extremely small.

(i) Which of the following was not a conclusion drawn by Rutherford?
(a) Most of the mass of atoms is concentrated at their center and it is known as the nucleus.
(b) Nucleus consists of protons and neutrons (only the particles with significant mass).
(c) Electrons revolve around the positively charged nucleus in parabolic orbits.
(d) Coulomb’s force provides the necessary centripetal acceleration for the electron.

(ii) Which of the following graph correctly represents the variation of number of scattered particles with scattering angle?



(iii) Which of the following is a limitation of Rutherford’s model?
(a) It cannot explain the charge distribution of the atom.
(b) It cannot explain the stability of atoms.
(c) It cannot explain the presence of electronic orbits.
(d) It cannot explain the existence of a nucleus.

(iv) According to the Bohr's model of hydrogen atom, which of the following orbit will not be available for electron to revolve in?
(a) Orbit A in which electrons have an angular momentum of $2h/\pi$.
(b) Orbit B in which electrons have an angular momentum of $h/3\pi$
(c) Orbit C in which electrons have an angular momentum of $3h/\pi$
(d) Orbit D in which electrons have an angular momentum of $h/2\pi$

Ans. (i) (c) Electrons revolve around the positively charged nucleus in parabolic orbits.
Electrons revolve around the nucleus in circular orbits according to Rutherford.

(ii) (d)
The mass in gold foil is concentrated at the nuclei of sizes of a few femtometers. The alpha particle will mostly pass through the foil without any deflection. The few particles that encounter a nucleus will scatter but only slightly. Rarely, an alpha particle will approach a nucleus head on and bounce back to its original path at an angle of 180°. The variation of number of scattered particles with scattering angle is given in (d).
(iii) (b) It cannot explain the stability of atoms.
Objects moving in circular paths always have a positive acceleration. Also, accelerating charged particles should radiate energy. Accordingly, the electron in Rutherford's atomic model should radiate energy continuously and it should collapse on the nucleus when its energy is expanded, disturbing the charge configuration of the nucleus and making it unstable. According to the calculations, Rutherford's atom should collapse in about 10^{-8} seconds.
(iv) (b) Orbit B in which electrons have an angular momentum of $h/3\pi$