# Atoms

## Multiple Choice Questions

***Choose and write the correct option(s) in the following questions.***

1. **The potential energy of an electron in the second excited state in hydrogen atom is** *[CBSE 2023 (55/4/1)]*

   (*a*) –3.4 eV  (*b*) –3.02 eV
   (*c*) –1.51 eV  (*d*) –6.8 eV

**2. To explain his theory, Bohr used**

(*a*) conservation of linear momentum

(*b*) quantisation of angular momentum

(*c*) conservation of quantum

(*d*) none of these

**3. Taking the Bohr radius as $a_0 = 53$ pm, the radius of $Li^{++}$ ion in its ground state, on the basis of Bohr's model, will be about** [*NCERT Exemplar*]

(*a*) 53 pm (*b*) 27 pm (*c*) 18 pm (*d*) 13 pm

**4. The ratio of energies of the hydrogen atom in its first to second excited state is**

(*a*) 1 : 4 (*b*) 4 : 1 (*c*) – 4 : – 9 (*d*) $-\frac{1}{4} : -\frac{1}{9}$

**5. The binding energy of a H-atom, considering an electron moving around a fixed nuclei (proton), is $B = -\frac{me^4}{8n^2\varepsilon_0^2h^2}$ ($m$ = electron mass).**

**If one decides to work in a frame of reference where the electron is at rest, the proton would be moving arround it. By similar arguments, the binding energy would be**

$B = -\frac{me^4}{8n^2\varepsilon_0^2h^2}$ **(M = proton mass)** [*NCERT Exemplar*]

**This last expression is not correct because**

(*a*) $n$ would not be integral

(*b*) Bohr-quantisation applies only to electron

(*c*) the frame in which the electron is at rest is not inertial

(*d*) the motion of the proton would not be in circular orbits, even approximately

**6. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because** [*NCERT Exemplar*]

(*a*) of the electrons not being subject to a central force

(*b*) of the electrons colliding with each other

(*c*) of screening effects

(*d*) the force between the nucleus and an electron will no longer be given by Coulomb's law

**7. The ratio of the speed of the electrons in the ground state of hydrogen to the speed of light in vacuum is**

(*a*) 1/2 (*b*) 2/237 (*c*) 1/137 (*d*) 1/237

**8. For the ground state, the electron in the H-atom has an angular momentum = $\hbar$, according to the simple Bohr model. Angular momentum is a vector and hence there will be infinitely many orbits with the vector pointing in all possible directions. In actuality, this is not true,** [*NCERT Exemplar*]

(*a*) because Bohr model gives incorrect values of angular momentum.

(*b*) because only one of these would have a minimum energy.

(*c*) angular momentum must be in the direction of spin of electron.

(*d*) because electrons go around only in horizontal orbits.

**9. $O_2$ molecule consists of two oxygen atoms. In the molecule, nuclear force between the nuclei of the two atoms** [*NCERT Exemplar*]

(*a*) is not important because nuclear forces are short-ranged.

(*b*) is as important as electrostatic force for binding the two atoms.

(*c*) cancels the repulsive electrostatic force between the nuclei.

(*d*) is not important because oxygen nucleus have equal number of neutrons and protons.

10. **In the following transitions of the hydrogen atom, the one which gives an absorption line of highest frequency is**

(*a*) $n = 1$ to $n = 2$ (*b*) $n = 3$ to $n = 8$

(*c*) $n = 2$ to $n = 1$ (*d*) $n = 8$ to $n = 3$

11. **Hydrogen atom initially in the ground state, absorbs a photon which excites it to $n = 5$ level. The wavelength of the photon is** *[CBSE 2023 (55/1/1)]*

(*a*) 975 nm (*b*) 740 nm (*c*) 523 nm (*d*) 95 nm

12. **Two H atoms in the ground state collide inelastically. The maximum amount by which their combined kinetic energy is reduced is** *[NCERT Exemplar]*

(*a*) 10.20 eV (*b*) 20.40 eV (*c*) 13.6 eV (*d*) 27.2 eV

13. **When an electron in an atom goes from a lower to a higher orbit, its**

(*a*) kinetic energy (*KE*) increases, potential energy (*PE*) decreases

(*b*) *KE* increases, *PE* increases

(*c*) *KE* decreases, *PE* increases

(*d*) *KE* decreases, *PE* decreases

14. **A hydrogen atom makes a transition from $n = 5$ to $n = 1$ orbit. The wavelength of photon emitted is $\lambda$. The wavelength of photon emitted when it makes a transition from $n = 5$ to $n = 2$ orbit is** *[CBSE 2023 (55/2/1)]*

(*a*) $\frac{8}{7}\lambda$ (*b*) $\frac{16}{7}\lambda$ (*c*) $\frac{24}{7}\lambda$ (*d*) $\frac{32}{7}\lambda$

15. **If an electron in a hydrogen atom jumps from the 3rd orbit to the 2nd orbit, it emits a photon of wavelength $\lambda$. 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*) $\frac{20}{13}\lambda$

16. **Hydrogen H, deuterium D, singly-ionised helium $He^+$ and doubly-ionised lithium $Li^{++}$ all have one electron around the nucleus. Consider $n = 2$ to $n = 1$ transition. The wavelengths of the emitted radiations are $\lambda_1, \lambda_2, \lambda_3$, and $\lambda_4$ respectively. Then approximately**

(*a*) $\lambda_1 = 2\lambda_2 = 2\sqrt{2}\lambda_3 = 3\sqrt{2}\lambda_4$ (*b*) $\lambda_1 = \lambda_2 = 2\lambda_3 = 3\lambda_4$

(*c*) $\lambda_1 = \lambda_2 = 4\lambda_3 = 9\lambda_4$ (*d*) $4\lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$

17. **The Bohr model for the spectra of a H-atom** *[NCERT Exemplar]*

(*a*) will not be applicable to hydrogen in the molecular from.

(*b*) will not be applicable as it is for a He-atom.

(*c*) is valid only at room temperature.

(*d*) predicts continuous as well as discrete spectral lines.

18. **Let $E_n = \frac{1}{8\varepsilon_0^2}\frac{me^4}{n^2h^2}$ be the energy of the $n$th level of H-atom. If all the H-atoms are in the ground state and radiation of frequency $(E_2 - E_1)/h$ falls on it,** *[NCERT Exemplar]*

(*a*) it will not be absorbed at all.

(*b*) some of atoms will move to the first excited state.

(*c*) all atoms will be excited to the $n = 2$ state.

(*d*) no atoms will make a transition to the $n = 3$ state.

19. **If $\nu_1$ is the frequency of the series limit of Lyman series, $\nu_2$ is the frequency of the first line of Lyman series and $\nu_3$ is the frequency of the series limit of the Balmer series. Then** *[HOTS]*

(*a*) $\nu_1 - \nu_2 = \nu_3$ (*b*) $\nu_1 + \nu_2 = \nu_3$

(*c*) $\frac{1}{\nu_2} = \frac{1}{\nu_1} + \frac{1}{\nu_3}$ (*d*) $\frac{1}{\nu_2} = \frac{1}{\nu_1} - \frac{1}{\nu_3}$

**20. Which of the following statements is not correct according to Rutherford model?** [*CBSE 2020 (55/1/1)*]

(*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 the model.

**21. In Bohr's model of hydrogen atom, the total energy of the electron in $n^{th}$ discrete orbit is proportional to** [*CBSE 2020 (55/3/1), 2023 (55/1/1)*]

(*a*) $n$ (*b*) $\frac{1}{n}$

(*c*) $n^2$ (*d*) $\frac{1}{n^2}$

**22. Paschen series of atomic spectrum of hydrogen gas lies in** [*CBSE 2020 (55/4/1)*]

(*a*) Infrared region

(*b*) Ultraviolet region

(*c*) Visible region

(*d*) Partly in ultraviolet and partly in visible region

**23. Which state of triply ionised beryllium ($Be^{+++}$) has the same orbital radius as that of the ground state of hydrogen?**

(*a*) $n = 1$ (*b*) $n = 2$

(*c*) $n = 3$ (*d*) $n = 4$

## Answers

| | | | | | | |
|---|---|---|---|---|---|---|
| **1.** (*b*) | **2.** (*b*) | **3.** (*c*) | **4.** (*d*) | **5.** (*c*) | **6.** (*a*) | **7.** (*c*) |
| **8.** (*a*) | **9.** (*a*) | **10.** (*a*) | **11.** (*d*) | **12.** (*a*) | **13.** (*c*) | **14.** (*d*) |
| **15.** (*c*) | **16.** (*c*) | **17.** (*a*), (*b*) | **18.** (*b*), (*d*) | **19.** (*a*) | **20.** (*d*) | **21.** (*d*) |
| **22.** (*a*) | **23.** (*b*) | | | | | |

# Assertion-Reason Questions

***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

**(a)** ***Both A and R are true and R is the correct explanation of A.***

**(b)** ***Both A and R are true but R is not the correct explanation of A.***

**(c)** ***A is true but R is false.***

**(d)** ***A is false and R is also false.***

**1. Assertion(*A*)** : Paschen series lies in the infrared region.

**Reason (*R*)** : Paschen series corresponds to the wavelength given by $\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$, where $n = 4, 5, 6, ..., \infty$.

**2. Assertion(*A*)** : The electrons have orbital angular momentum.

**Reason (*R*)** : Electrons have well-defined quantum states.

**3. Assertion(*A*)** : Large angle of scattering of α-particles led to the discovery of atomic nucleus.

**Reason (*R*)** : Entire positive charge of atom is concentrated in the central core.

4. **Assertion (A)** : Bohr's postulate states that the electrons in stationary orbits around the nucleus do not radiate.

**Reason (R)** : According to classical physics, all moving electrons radiate.

5. **Assertion (A)** : In the Bohr model of the hydrogen, atom, $v$ and $E$ represent the speed of the electron and the total energy of the electron respectively. Then $v/E$ is proportional to the quantum number $n$ of the electron.

**Reason (R)** : $v \propto n$ and $E \propto n^{-2}$

6. **Assertion (A)** : When a hydrogen atom emits a photon in transiting for $n = 4$ to $n = 1$, its recoil speed is about 4 m/s.

**Reason (R)** : $v = \frac{p}{m} = \frac{E}{mc} = \frac{13.6 \times \left(1 - \frac{1}{16}\right) \text{eV}}{1.67 \times 10^{-27} \text{ kg} \times 3 \times 10^{8} \text{ m/s}}$

7. **Assertion (A)** : Electrons in the atom are held due to coulomb forces.

**Reason (R)** : The atom is stable only because the centripetal force due to Coulomb's law is balanced by the centrifugal force.

8. **Assertion (A)** : Bohr's postulate states that the stationary orbits are those for which the angular momentum is some integral multiple of $\frac{h}{2\pi}$.

**Reason (R)** : Linear momentum of the electron in the atom is quantised.

9. **Assertion (A)** : The total energy of an electron revolving in any stationary orbit is negative.

**Reason (R)** : Energy can have positive or negative values.

10. **Assertion (A)** : Hydrogen atom consists of only one electron but its emission spectrum has many lines.

**Reason (R)** : Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

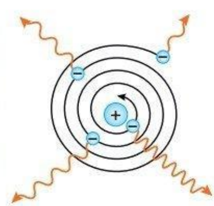
## Answers

**1.** (*a*) **2.** (*b*) **3.** (*b*) **4.** (*a*) **5.** (*c*) **6.** (*c*) **7.** (*a*)
**8.** (*c*) **9.** (*c*) **10.** (*b*)

# Case-based/Passage-based Questions

***Read the passages given below and answer the questions that follow:***

**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 in a 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.

(*a*) 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.

(*b*) 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*) $2\pi h$
(*b*) $\pi h$
(*c*) $h/\pi$
(*d*) $2h/\pi$

**OR**

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

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

## Explanations

(*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

$$L = 2\left(\frac{h}{2\pi}\right) = \frac{h}{\pi} = \frac{6.6\times10^{-34}\,\text{Js}}{22/7} = 2.1 \times 10^{-34}\ \text{Js}$$

(*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.

## CONCEPTUAL QUESTIONS

**Q. 1. Write the expression for Bohr's radius in hydrogen atom.** [*CBSE Delhi 2010*]

**Ans.** Bohr's radius, $r_1 = \dfrac{\varepsilon_0 h^2}{\pi m e^2} = \mathbf{0.529 \times 10^{-10}\,m}$

**Q. 2. In the Rutherford scattering experiment the distance of closest approach for an α-particle is $d_0$. If α-particle is replaced by a proton, how much kinetic energy in comparison to α-particle will it require to have the same distance of closest approach $d_0$?** *[CBSE (F) 2009]*

**Ans.** $E_k = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{d_0}$ (for α-particle, $q = 2e$)

$E'_k = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{d_0}$ (for proton, $q = e$)

$\frac{E'_k}{E_k} = \frac{1}{2} \quad \Rightarrow \quad \mathbf{E'_k = \frac{E_k}{2}}$

That is $KE$ of proton must be half on comparison with $KE$ of α-particle.

**Q. 3. What is the ratio of radii of the orbits corresponding to first excited state and ground state in a hydrogen atom?** *[CBSE Delhi 2010]*

**Ans.** $r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m e^2} \propto n^2$

For $1^{st}$ excited state, $n = 2$

For ground state, $n = 1$

$\therefore \quad \mathbf{\frac{r_2}{r_1} = \frac{4}{1}}$

**Q. 4. Find the ratio of energies of photons produced due to transition of an electron of hydrogen atom from its:**

**(i) second permitted energy level to the first level, and**

**(ii) the highest permitted energy level to the first permitted level.** *[CBSE (AI) 2010]*

**Ans.** $E_I = Rhc\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = \frac{3}{4}Rhc$

$E_{II} = Rhc\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = Rhc$

Ratio, $\frac{E_I}{E_{II}} = \mathbf{\frac{3}{4}}$

**Q. 5. State Bohr's quantisation condition for defining stationary orbits.** *[CBSE (F) 2010]*

**Ans. Quantum Condition:** The stationary orbits are those in which angular momentum of electron is an integral multiple of $\frac{h}{2\pi}$ *i.e.*,

$$mvr = n\frac{h}{2\pi} \qquad n = 1, 2, 3, ...$$

Integer $n$ is called the **principal quantum number**. This equation is called Bohr's quantum condition.

**Q. 6. The radius of innermost electron orbit of a hydrogen atom is $5.1 \times 10^{-11}$ m. What is the radius of orbit in the second excited state?** *[CBSE Delhi 2010]*

**Ans.** In ground state, $n = 1$

In second excited state, $n = 3$

As $\quad r_n \propto n^2$

$\therefore \quad \frac{r_3}{r_1} = \left(\frac{3}{1}\right)^2 = 9$

$r_3 = 9r_1 = 9 \times 5.1 \times 10^{-11}$ m $= \mathbf{4.59 \times 10^{-10}}$ **m**

**Q. 7. What is the value of angular momentum of electron in the second orbit of Bohr's model of hydrogen atom?** [*CBSE Sample Paper 2021*]

**Ans.** According to Bohr,

The angular momentum of an orbiting electron = $\frac{nh}{2\pi}$

Here, $n = 2$

Angular momentum = $\frac{2 \times h}{2\pi} = \frac{h}{\pi}$

**Q. 8. 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?** [*NCERT Exemplar*] [*HOTS*]

**Ans.** This is because electrons interact only electromagnetically.

**Q. 9. 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 $e = 1.6 \times 10^{-19}$ C? Give reasons for your answer.** [*NCERT Exemplar*] [*HOTS*]

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

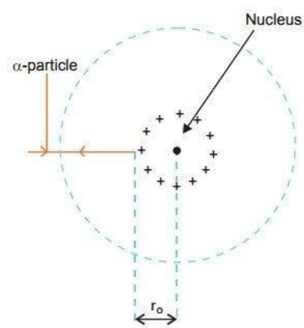
**Q. 10. Consider two different hydrogen atoms. The electron in each atom is in an excited state. Is it possible for the electrons to have different energies but the same orbital angular momentum according to the Bohr model?** [*NCERT Exemplar*] [*HOTS*]

**Ans.** No, because according to Bohr model, $E_n = -\frac{13.6}{n^2}$, and electrons having different energies belong to different levels having different values of $n$. So, their angular momenta will be different, as $mvr = \frac{nh}{2\pi}$.

## Very Short Answer Questions

***Each of the following questions are of 2 marks.***

**Q. 1. Define the distance of closest approach. An α-particle of kinetic energy '*K*' is bombarded on a thin gold foil. The distance of the closest approach is '*r*'. What will be the distance of closest approach for an α-particle of double the kinetic energy?** [*CBSE Delhi 2017, 2022 (55/1/1), Term-2*]




**Ans.** Distance of closest approach is the distance of charged particle from the centre of the nucleus, at which the entire initial kinetic energy of the charged particles gets converted into the electric potential energy of the system.

Distance of closest approach ($r_o$) is given by

$$r_o = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{K}$$

If '*K*' is doubled, $r_o$ becomes $\frac{r_o}{2}$.

**Q. 2. Consider two different hydrogen atoms. The electron in each atom is in an excited state. Is it possible for the electrons to have different energies but same orbital angular momentum according to the Bohr model? Justify your answer.** [*CBSE Sample Paper 2022, Term-2*]

**Ans.** No

Because according to Bohr's model,

$E_n = -\frac{13.6}{n^2}$ and electrons having different energies belong to different levels having different values of $n$.

So, their angular momenta will be different, as

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

**Q. 3. Define ionization energy. How would the ionization energy change when electron in hydrogen atom is replaced by a particle of mass 200 times than that of the electron but having the same charge?** *[CBSE Central 2016]*

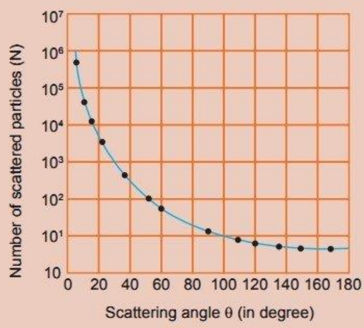
**Ans.** The minimum energy required to free the electron from the ground state of the hydrogen atom is known as ionization energy.

$$E_0 = \frac{me^4}{8\varepsilon^2 h^2}, \quad i.e., E_0 \propto m$$

Therefore, ionization energy will become 200 times.

**Q. 4. Draw the graph showing the variation of the number (*N*) of scattered alpha particles with scattering angle (θ) in Geiger – Marsden experiment. Infer two conclusions from the graph.** *[CBSE 2022 (55/1/1), Term-2]*

**Ans. Graph:**

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(Give full credit if axis are marked and values are not given)

**Conclusions**

- Most of the alpha particles pass undeviated through the gold foil.
- A few alpha particles, get deflected through 90° or more.
- Only about 0.14% of the incident alpha particles are reflected by large angle. ½ + ½
- A very few alpha particles retrace their path.

(Any other two conclusions) *[CBSE Marking Scheme 2022 (55/1/1), Term-2]*

**Q. 5. 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?** *[CBSE 2023 (55/1/1)]*

**Ans.** For ground state, Energy ($E$) = –13.6 eV

For third excited state, $n = 4$,

$$E_4 = \frac{-13.6}{n^2} = \frac{-13.6}{4^2} = -0.85 \text{ eV}$$

$\therefore \quad K.E = -E = -(-0.85) = \mathbf{0.85\ eV}$

and $\quad P.E = -2K.E = -2 \times 0.85 = \mathbf{-1.7\ eV}$.

**Q. 6. Use Bohr's model of hydrogen atom to obtain the relationship between the angular momentum and the magnetic moment of the revolving electron.** *[CBSE 2020 (55/5/1)]*

**Ans.** According to Bohr's model,

$$L = \text{Angular momentum} = mvr = \frac{nh}{2\pi} \qquad \tfrac{1}{2}$$

$$\mu = \text{Magnetic moment} = \text{current} \times \text{area of the orbit} \qquad \tfrac{1}{2}$$

$$\mu = \frac{|e| \times v}{2\pi r} \times \pi r^2 = \frac{|e| vr}{2} \qquad \left[I = \frac{ev}{2\pi r}\right] \qquad \tfrac{1}{2}$$

Now, $\dfrac{L}{\mu} = \dfrac{mvr \times 2}{|e| vr} = \dfrac{2m}{|e|}$

$$\therefore \quad \mu = \frac{|e|}{2m} L \qquad \tfrac{1}{2}$$

*[CBSE Marking Scheme 2020 (55/5/1)]*

**Q. 7. When is $H_\alpha$ line in the emission spectrum of hydrogen atom obtained? Calculate the frequency of the photon emitted during this transition.** *[CBSE North 2016]*

**Ans.** The line with the longest wavelength of the Balmer series is called $H_\alpha$.

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

where $\lambda$ = wavelength

$$R = 1.097 \times 10^7\ \text{m}^{-1}\ \text{(Rydberg constant)}$$

When the electron jumps from the orbit with $n = 3$ to $n = 2$,

We have

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

The frequency of photon emitted is given by

$$\nu = \frac{c}{\lambda} = c \times \frac{5}{36} R$$

$$= 3 \times 10^8 \times \frac{5}{36} \times 1.097 \times 10^7\ \text{Hz}$$

$$= \mathbf{4.57 \times 10^{14}\ Hz}$$

**Q. 8. A difference of 2.3 eV separates two energy levels in an atom. What is the frequency of radiation emitted when the atom makes transition from the upper level to the lower level?** *[NCERT]*

**Ans.** According to Bohr's postulate

$$E_1 - E_2 = h\nu$$

$\therefore$ Frequency of emitted radiation

$$\nu = \frac{E_1 - E_2}{h} = \frac{2.3\ \text{eV}}{h}$$

$$= \frac{2.3 \times 1.6 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J-s}} = \mathbf{5.55 \times 10^{14}\ Hz}$$

**Q. 9. 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?**

**[*CBSE 2020 (55/3/1)*]**

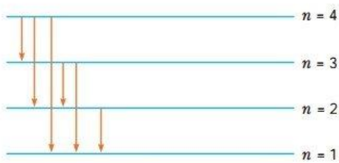
**Ans.** (*a*) For third excited state, $n = 4$

For ground state, $n = 1$

Hence, the possible transitions are

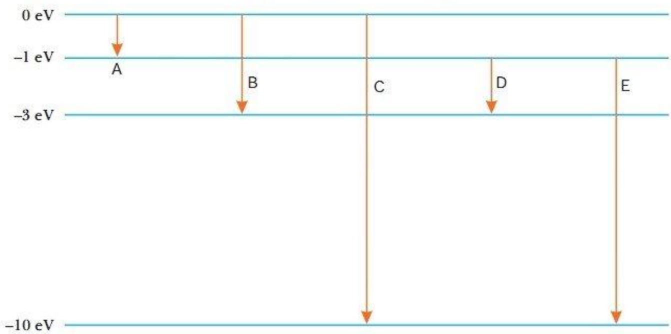
$$n_i = 4 \text{ to } n_f = 3, 2, 1$$
$$n_i = 3 \text{ to } n_f = 2, 1$$
$$n_i = 2 \text{ to } n_f = 1$$

$\therefore$ Total number of transitions = 6, as shown in figure.




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

**Q. 10. The energy levels of an atom are given below in the diagram.**




**Which of the transitions belong to Lyman and Balmer series? Calculate the ratio of the shortest wavelengths of the Lyman and the Balmer series of the spectra.**

**[*CBSE Chennai 2015, CBSE 2019 (55/2/3)*]**

**Ans.** Transition *C* and *E* belong to Lyman series.

**Reason:** In Lyman series, the electron jumps to lowest energy level from any higher energy levels.

Transition *B* and *D* belong to Balmer series.

**Reason:** The electron jumps from any higher energy level to the level just above the ground energy level.

The wavelength associated with the transition is given by

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

Ratio of the shortest wavelength

$$\lambda_L : \lambda_B = \frac{hc}{\Delta E_L} : \frac{hc}{\Delta E_B}$$

$$= \frac{1}{0-(-10)} : \frac{1}{0-(-3)} = \mathbf{3:10}$$

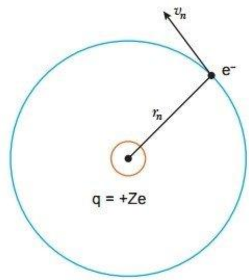
**Q. 11. Using Bohr's atomic model, derive the expression for the radius of $n^{th}$ orbit of the revolving electron in a hydrogen atom.** *[CBSE 2020 (55/1/1), 2023 (55/3/1)]*

**Ans.** Centripetal force required by electron to revolve = Electrostatic attraction of nucleus and electron

$$F_C = F_E$$

$$\Rightarrow \quad \frac{mv_n^2}{r_n} = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{(Ze)(e)}{r_n^2} \qquad (m = \text{mass of electron})$$

$$\Rightarrow \quad mv_n^2 r_n = \frac{e^2}{4\pi\varepsilon_0} \qquad [\because Z = 1 \text{ for H-atom}] \qquad ...(i)$$




According to Bohr's second postulate,

Angular momentum of electron, $L = mv_n r_n = \frac{nh}{2\pi}$ ...(ii)

From (ii) $v_n = \frac{nh}{2\pi m r_n}$

From (i), we have

$$\Rightarrow \quad mr_n\left(\frac{nh}{2\pi m r_n}\right)^2 = \frac{e^2}{4\pi\varepsilon_0}$$

$$\Rightarrow \quad r_n = \frac{n^2h^2\varepsilon_0}{m\pi e^2}$$

**Q. 12. A photon emitted during the de-excitation of electron from a state *n* to the first excited state in a hydrogen atom, irradiates a metallic cathode of work function 2 eV, in a photo cell, with a stopping potential of 0.55 V. Obtain the value of the quantum number of the state *n*.** *[CBSE 2019 (55/2/1)]*

**Ans.** From photoelectric equation,

$$h\nu = \phi_0 + eV_s$$

$$= 2 + 0.55 = 2.55 \text{ eV}$$

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

The energy difference, $\Delta E = -3.4 - (-2.55)$ eV $= -0.85$ eV

$$-\frac{13.6}{n^2} = -0.85$$

$$\therefore \quad n = \mathbf{4}$$

**Q. 13. The energy of hydrogen atom in an orbit is –1.51 eV. What are kinetic and potential energies of the electron in this orbit?** *[CBSE 2022 (55/3/3), Term–2]*

**Ans.**

From Bohr's postulate, we have.
We have

$$\frac{Ke^2}{r^2} = \frac{mv^2}{r}$$ [1st postulate]

[electrostatic force applies the required centripetal force]

$K = \frac{1}{4\pi\varepsilon_0} = 9\times10^9$

$e \Rightarrow$ charge of electron
$r \Rightarrow$ radius of orbit
$m \Rightarrow$ mass of electrons
$v \Rightarrow$ velocity of electrons in the orbit.

$\Rightarrow mv^2 = \frac{Ke^2}{r}$

Now Kinetic energy of electron in an orbit (KE) $= \frac{1}{2}mv^2 = \boxed{\frac{Ke^2}{2r}} = KE$

Potential energy of electron in the orbit (PE) $= \frac{K(e)(-e)}{r} = \boxed{\frac{-Ke^2}{r}} = P.E.$

Total energy of electron (TE) = PE + KE

$\Rightarrow TE = -\frac{Ke^2}{r} + \frac{Ke^2}{2r}$

$\boxed{TE = -\frac{Ke^2}{2r}}$

Given that energy of electron in Hydrogen atom is $= -1.5\,eV = -\frac{Ke^2}{2r}$

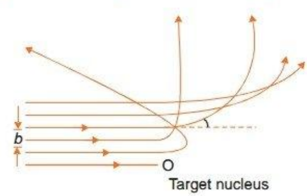
$\Rightarrow \frac{Ke^2}{r} = 3.02\,eV$

$\therefore PE = -\frac{Ke^2}{r} = -3.02\,eV$, $KE = \frac{Ke^2}{2r} = +1.51\,eV$

Ans. Thus, $\boxed{\begin{array}{l} KE = +1.51\,eV \\ PE = -3.02\,eV \end{array}}$

**[*Topper's Answer 2022*]**

**Q. 14. The trajectories, traced by different α-particles, in Geiger-Marsden experiment were observed as shown in the figure.** **[*CBSE 2020 (55/2/1)*]**



(*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?**

**Ans.** (*a*) The symbol '*b*' represents **impact parameter** and 'θ' represents the **scattering angle**.

(*b*) (*i*) When $\theta = 0°$, the **impact parameter** will be maximum and represent the **atomic size.**

(*ii*) When $\theta = \pi$ radians, the impact parameter '*b*' will be minimum and represent the nuclear size.

**Q. 15. Which is easier to remove: orbital electron from an atom or a nucleon from a nucleus?** [*HOTS*]

**Ans.** 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 electron volt energy while the removal of a nucleon from a nucleus requires nearly 8 MeV energy.

**Q. 16. Write shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model.** [*CBSE 2020 (55/5/1)*]

**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.

**Q. 17. Find the ratio of the longest and the shortest wavelengths amongst the spectral lines of Balmer series in the spectrum of hydrogen atom.** [*CBSE 2020 (55/4/1)*]

**Ans.** For shortest wave length,

$$\frac{1}{\lambda_S} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right)$$

$$\frac{1}{\lambda_S} = \frac{R}{4} \qquad \ldots(i) \qquad ½$$

For longest wave length,

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

$$= R\left(\frac{1}{4} - \frac{1}{9}\right)$$

$$= R\left(\frac{5}{36}\right) \qquad \ldots(ii) \qquad ½$$

Dividing equation (*i*) by equation (*ii*) we get,

$$\frac{\left(\frac{1}{\lambda_S}\right)}{\left(\frac{1}{\lambda_L}\right)} = \frac{\left(\frac{R}{4}\right)}{\left(\frac{5R}{36}\right)} \qquad ½$$

$$\therefore \quad \frac{\lambda_L}{\lambda_S} = \frac{9}{5} \quad \Rightarrow \quad \lambda_L : \lambda_S = 9:5 \qquad ½$$

[*CBSE Marking Scheme 2020 (55/4/1)*]

## Short Answer Questions

***Each of the following questions are of 3 marks.***

**Q. 1. (*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?** [*CBSE (F) 2016*]

**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

$$h\nu = E_i - E_f$$

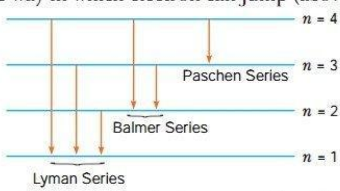
where $E_i$ and $E_f$ are the energies of the initial and final states and $E_i > E_f$.

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

$\therefore$ Maximum number of spectral lines can be

$$^4C_2 = \frac{4!}{2!2!} = \frac{4 \times 3}{2} = 6$$

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).

**Q. 2. 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.**

[*CBSE 2020 (55/5/1)*]

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

$$E_I = \frac{13.6}{2^2}\text{eV} = 3.4\text{ eV} = -3.4 \times 1.6 \times 10^{-19}\text{J} = -5.44 \times 10^{-19}\text{J} \qquad \tfrac{1}{2} + \tfrac{1}{2}$$

Associated kinetic energy $= -E_1$ ½

$$K = 5.44 \times 10^{-19}\text{J} \qquad \tfrac{1}{2}$$

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

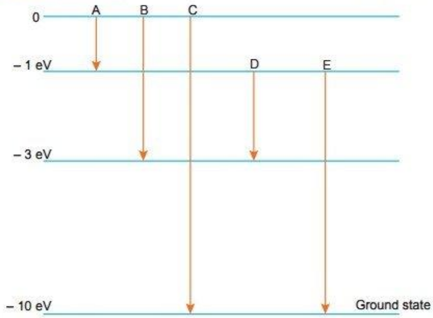
$$\lambda = \frac{h}{\sqrt{2mK}} = \frac{6.63 \times 10^{-34}}{(2 \times 9.1 \times 10^{-31} \times 5.44 \times 10^{-19})^{1/2}}\text{ m} \qquad \tfrac{1}{2}$$

$$= \frac{6.63 \times 10^{-34}}{(99.008)^{1/2} \times 10^{-25}}\text{ m}$$

$$\approx 0.663 \times 10^{-9}\text{ m} = 0.663\text{ nm} = 6.63\text{ Å} \qquad \tfrac{1}{2}$$

[*CBSE Marking Scheme 2020 (55/5/1)*]

**Q. 3. The energy levels of an atom of element $X$ are shown in the diagram. Which one of the level transitions will result in the emission of photons of wavelength 620 nm? Support your answer with mathematical calculations.** *[CBSE Sample Question Paper 2018]*




**Ans.** Eergy of Photon, $E = \frac{hc}{\lambda}$

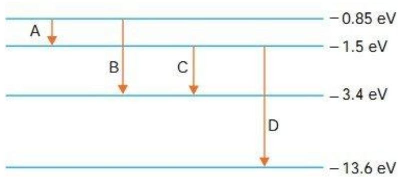
$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{620 \times 10^{-9}}$$

$$= 3.2 \times 10^{-19}\,\text{J}$$

$$= \frac{3.2 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{2\ eV}$$

This corresponds to the transition '$D$'. Hence level transition $D$ will result in emission of wavelength 620 nm.

**Q. 4. The energy level diagram of an element is given below. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm.** *[CBSE Delhi 2008]*




**Ans.** We have, $\Delta E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{102.7 \times 10^{-9}}\,\text{J}$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{102.7 \times 10^{-9} \times 1.6 \times 10^{-19}}\,\text{eV}$$

$$= \frac{66 \times 3000}{1027 \times 16} = 12.04\ \text{eV}$$

Now, $\Delta E = |-13.6 - (-1.50)|$

$$= \mathbf{12.1\ eV}$$

Hence, transition shown by arrow $D$ corresponds to emission of $\lambda = 102.7$ nm.

**Q. 5. 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.** [*CBSE Ajmer 2015*]

**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

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

or
$$r = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Ze^2}{K}$$

$$= \frac{9\times10^9\times2\times80\,e^2}{4.5\,\text{MeV}} = \frac{9\times10^9\times2\times80\times(1.6\times10^{-19})^2}{4.5\times10^6\times1.6\times10^{-19}}$$

$$= \frac{9\times160\times1.6}{4.5}\times10^{-16} = 512\times10^{-16}\,\text{m}$$

$$= \mathbf{5.12\times10^{-14}\ m}$$

**Q. 6. 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.** [*CBSE Sample Paper 2022, Term–2*]

**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

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

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

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

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

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

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

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

**Q. 7. 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.** [*CBSE (AI) 2017*]

**Ans.**

$E_1 = -13{\cdot}6\,\text{eV}$

$E_i = -1{\cdot}51\,\text{eV}$

$E_f = -3{\cdot}4\,\text{eV}$

change in energy $= E_i - E_f = -1{\cdot}51\,\text{eV} - 3{\cdot}4\,\text{eV}$

$= 3{\cdot}4\,\text{eV} - 1{\cdot}51\,\text{eV}$

$= 1{\cdot}89\,\text{eV}$

$h\nu = 1{\cdot}89\,\text{eV}$

$h\dfrac{c}{\lambda} = 1{\cdot}89\times1{\cdot}6\times10^{-19}\,\text{J}$

$\lambda = \dfrac{hc}{1{\cdot}89\times1{\cdot}6\times10^{-19}\,\text{J}} = \dfrac{6{\cdot}636\times10^{-34}\times3\times10^{8}\ \text{m s}^{-1}\,\text{kg m}^2\text{s}^{-1}}{1{\cdot}89\times1{\cdot}6\times10^{-19}\ \text{kg m}^2\text{s}^{-2}}$

$$\frac{19.908 \times 10^{-26}}{30.24 \times 10^{-1} \times 10^{-19}} \text{ m}$$

$$\frac{19.908 \times 10^{-26}}{3.024 \times 10^{-19}} \text{ m}$$

$$= 6.58 \times 10^{-7} \text{ m}$$

$$= 6.58 \times 10^{-7} \text{ m}$$

It belongs to visible light and hence it belongs to Balmer series of Hydrogen spectrum

Since 658 nm belongs to 400 nm to 700 nm.

[*Topper's Answer 2017*]

**Q. 8. A hydrogen atom initially in its ground state absorbs a photon and is in the excited state with energy 12.5 eV. Calculate the longest wavelength of the radiation emitted and identify the series to which it belongs.**

**[Take Rydberg constant $R = 1.1 \times 10^7\ m^{-1}$]** [*CBSE East 2016*]

**Ans.** Let $n_i$ and $n_f$ are the quantum numbers of initial and final states, then we have

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

The energy of the incident photon = 12.5 eV.

Energy of ground state = –13.6 eV

∴ Energy after absorption of photon can be –1.1 eV.

This means that electron can go to the excited state $n_i = 3$. It emits photon of maximum wavelength on going to $n_f = 2$, therefore,

$$\frac{1}{\lambda_{max}} = \left\{\frac{1}{2^2} - \frac{1}{3^2}\right\}R$$

$$\lambda_{max} = \frac{36}{5R} = \frac{36}{5 \times 1.1 \times 10^7} = 6.545 \times 10^{-7} \text{ m} = \mathbf{6545\ Å}$$

It belongs to Balmer Series.

**Q. 9. A 12.5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelengths and the corresponding series of the lines emitted.**[*CBSE (AI) 2017*]

**Ans.** It is given that the energy of the electron beam used to bombard gaseous hydrogen at room temperature is 12.5 eV.

Also, the energy of the gaseous hydrogen in its ground state at room temperature is –13.6 eV.

When gaseous hydrogen is bombarded with an electron beam, the energy of the gaseous hydrogen becomes –13.6 + 12.5 eV = –1.1 eV.

Orbital energy related to orbit level ($n$) is

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

For $n = 3$,

$$E = \frac{-13.6}{(3)^2} \text{eV} = \frac{-13.6}{9} \text{eV} = -1.5 \text{ eV}$$

This energy is approximately equal to the energy of gaseous hydrogen.

This implies that the electron has jumped from $n = 1$ to $n = 3$ level.

During its de-excitation, electrons can jump from $n = 3$ to $n = 1$ directly, which forms a line of the Lyman series of the hydrogen spectrum.

Relation for wave number for the Lyman series is

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

For first member $n = 3$

$$\therefore \quad \frac{1}{\lambda_1} = R\left[\frac{1}{1^2} - \frac{1}{(3)^2}\right] = R\left[\frac{1}{1} - \frac{1}{9}\right]$$

$$\therefore \quad \frac{1}{\lambda_1} = 1.097 \times 10^7\left[\frac{9-1}{9}\right] \quad \text{(where Rydberg constant } R = 1.097 \times 10^7 \text{ m}^{-1}\text{)}$$

$$\therefore \quad \frac{1}{\lambda_1} = 1.097 \times 10^7 \times \frac{8}{9} \quad \Rightarrow \quad \boldsymbol{\lambda_1 = 1.025 \times 10^{-7} \text{ m}}$$

For $n = 2$,

$$\therefore \quad \frac{1}{\lambda_2} = R\left[\frac{1}{1^2} - \frac{1}{(2)^2}\right] = R\left[\frac{1}{1} - \frac{1}{4}\right]$$

$$\therefore \quad \frac{1}{\lambda_2} = 1.097 \times 10^7\left[\frac{4-1}{4}\right]$$

$$\therefore \quad \frac{1}{\lambda_2} = 1.097 \times 10^7 \times \frac{3}{4} \quad \Rightarrow \quad \boldsymbol{\lambda_2 = 1.215 \times 10^{-7} \text{m}}$$

Relation for wave number for the Balmer series is

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

For first member, $n = 3$

$$\therefore \quad \frac{1}{\lambda_3} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = 1.097 \times 10^7 \times \left[\frac{1}{4} - \frac{1}{9}\right]$$

$$\Rightarrow \quad \boldsymbol{\lambda_3 = 6.56 \times 10^{-7} \text{ m}}$$

**Q. 10. Obtain the first Bohr's radius and the ground state energy of a muonic hydrogen atom, *i.e.*, an atom where the electron is replaced by a negatively charged muon ($\mu^-$) of mass about 207 $m_e$ that orbits around a proton.**

**(Given for hydrogen atom, radius of first orbit and ground state energy are $0.53 \times 10^{-10}$ m and – 13.6 eV respectively)** ***[CBSE 2019 (55/5/1)]***

**Ans.** In Bohr's Model of hydrogen atom the radius of $n$th orbit is given by

$$r_n = \frac{n^2h^2}{4\pi^2e^2m_e} \qquad \text{[for H-atom, } Z = 1\text{]}$$

$$r_1 \propto \frac{1}{m_e} \qquad (\because n = 1)$$

Similarly,

$$r_\mu \propto \frac{1}{m_\mu}$$

$$\frac{r_\mu}{r_e} = \frac{m_e}{m_\mu} = \frac{1}{207} \quad \Rightarrow \quad r_\mu = \frac{1}{207} r_e = \frac{0.53 \times 10^{-10}}{207} = 2.56 \times 10^{-13} \text{m}$$

Energy of electron in $n$th orbit,

$$E_n = -\frac{Z^2 me^4}{8E_0 h^2 n^2} \qquad \Rightarrow E_n \propto m \qquad (\because n = 1)$$

and
$$\frac{E_\mu}{E_e} = \frac{m_\mu}{m_e} = 207$$

$\therefore$
$$E_\mu = 207\, E_e = -207 \times 13.6 \text{ eV}$$
$$= -2.8 \textbf{ keV}$$

**Q. 11. A hydrogen atom initially in the ground state absorbs a photon, which excites it to the $n$=4 level. Determine the wavelength and frequency of photon.** [*NCERT*]

**Ans.** The energy levels of H-atom are given by $E_n = -\frac{Rhc}{n^2}$

For given transition $n_1 = 1$, $n_2 = 4$

$\therefore$
$$E_1 = -\frac{Rhc}{1^2}, \quad E_2 = -\frac{Rhc}{4^2}$$

$\therefore$ Energy of absorbed photon

$$\Delta E = E_2 - E_1 = Rhc\left(\frac{1}{1^2} - \frac{1}{4^2}\right)$$

or
$$\Delta E = \frac{15}{16} Rhc$$

$\therefore$ Wavelength of absorbed photon $\lambda$ is given by

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

$\therefore$
$$\frac{hc}{\lambda} = \frac{15}{16} Rhc \quad \Rightarrow \quad \lambda = \frac{16}{15R}$$

or
$$\lambda = \frac{16}{15 \times 1.097 \times 10^7} \text{m} = \mathbf{9.72 \times 10^{-8}\ m}$$

Frequency,
$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{9.72 \times 10^{-8}} = \mathbf{3.09 \times 10^{15}\ Hz}$$

## Long Answer Questions

***Each of the following questions are of 5 marks.***

**Q. 1. Draw a schematic arrangement of Geiger-Marsden experiment for studying α-particle scattering by a thin foil of gold. Describe briefly, by drawing trajectories of the scattered α-particles. How this study can be used to estimate the size of the nucleus?** [*CBSE Delhi 2010*]

**OR**

**Describe Geiger-Marsden experiment. What are its observations and conclusions?**

**Ans.** At the suggestion of Rutherford, in 1911, H. Geiger, and E. Marsden performed an important experiment called Geiger-Marsden experiment (or Rutherford's scattering experiment). It consists of

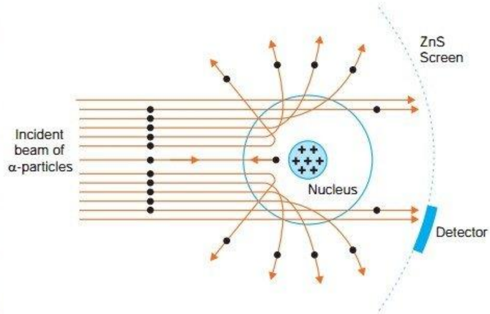
1. **Source of α-particles:** The radioactive source polonium emits high energetic alpha (α) particles. Therefore, polonium is used as a source of α-particles. This source is placed in an enclosure containing a hole and a few slits $A_1$, $A_2$, ..., etc., placed in front of the hole. This arrangement provides a fine beam of α-particles.

2. **Thin gold foil:** It is a gold foil of thickness nearly $10^{-6}$ m, α-particles are scattered by this foil. The foil taken is thin to avoid multiple scattering of α-particles, *i.e.*, to ensure that α-particle be deflected by a single collision with a gold atom.
3. **Scintillation counter:** By this the number of α-particles scattered in a given direction may be counted. The entire apparatus is placed in a vacuum chamber to prevent any energy loss of α-particles due to their collisions with air molecules.

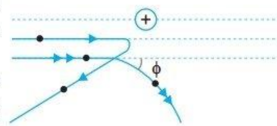
**Method:** When α-particle beam falls on gold foil, the α-particles are scattered due to collision with gold atoms. This scattering takes place in all possible directions. The number of α-particles scattered in any direction is counted by scintillation counter.

**Observations and Conclusions**

(*i*) Most of α-particles pass through the gold foil undeflected. This implies that "most part of the atom is hollow."




(*ii*) α-particles are scattered through all angles. Some α-particles (nearly 1 in 2000), suffer scattering through angles more than 90°, while a still smaller number (nearly 1 in 8000) retrace their path. This implies that when fast moving positively charged α-particles come near gold-atom, then a few of them experience such a strong repulsive force that they turn back. On this basis Rutherford concluded that whole of positive charge of atom is concentrated in a small central core, called the nucleus.




The distance of closest approach of α-particle gives the estimate of nuclear size. If $Ze$ is charge of nucleus, $E_k$–kinetic energy of α particle, $2e$–charge on α-particle, the size of nucleus $r_0$ is given by

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

Calculations show that the size of nucleus is of the order of $10^{-14}$ m, while size of atom is of the order of $10^{-10}$m; therefore the size of nucleus is about $\frac{10^{-14}}{10^{-10}} = \frac{1}{10,000}$ times the size of atom.

(*iii*) The negative charges (electrons) do not influence the scattering process. This implies that nearly whole mass of atom is concentrated in nucleus.

**Q. 2. Using the postulates of Bohr's model of hydrogen atom, obtain an expression for the frequency of radiation emitted when atom make a transition from the higher energy state with quantum number $n_i$ to the lower energy state with quantum number $n_f$ ($n_f < n_i$).** [*CBSE (AI) 2013, (F) 2012, 2011*]

**OR**

**Using Bohr's postulates, obtain the expression for the total energy of the electron in the stationary states of the hydrogen atom. Hence draw the energy level diagram showing how the line spectra corresponding to Balmer series occur due to transition between energy levels.** [*CBSE Delhi 2013, Guwahati 2015*]

**OR**

**Using Rutherford model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron?** [*CBSE (AI) 2014*]

**Ans.** Suppose $m$ be the mass of an electron and $v$ be its speed in $n$th orbit of radius $r$. The centripetal force for revolution is produced by electrostatic attraction between electron and nucleus.

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2} \qquad \text{[from Rutherford model]} \qquad ...(i)$$

or, $$mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

So, Kinetic energy $[K] = \frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$

Potential energy $= \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(-e)}{r} = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$

Total energy, $E = KE + PE = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r} + \left(-\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}\right) = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r}$

For $n$th orbit, $$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2r_n} \qquad ...(ii)$$

Negative sign indicates that the electron remains bound with the nucleus (or electron-nucleus form an attractive system)

From Bohr's postulate for quantization of angular momentum

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi mr}$$

Substituting this value of $v$ in equation ($i$), we get

$$\frac{m}{r}\left[\frac{nh}{2\pi mr}\right]^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2} \quad \text{or} \quad r = \frac{\varepsilon_0 h^2 n^2}{\pi m Ze^2}$$

or, $$r_n = \frac{\varepsilon_0 h^2 n^2}{\pi m Ze^2}$$

For Bohr's radius, $n = 1$, *i.e.*, for $K$ shell $r_B = \frac{\varepsilon_0 h^2}{\pi Zme^2}$

Substituting value of $r_n$ in equation ($ii$), we get

$$E_n = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{2\left(\frac{\varepsilon_0 h^2 n^2}{\pi m Ze^2}\right)} = -\frac{mZ^2e^4}{8\varepsilon_0^2 h^2 n^2}$$

or, $$E_n = -\frac{Z^2Rhc}{n^2}, \text{ where } R = \frac{me^4}{8\varepsilon_0^2 ch^3}$$

$R$ is called Rydberg constant.

For hydrogen atom $Z=1$, $E_n = \frac{-Rhc}{n^2}$

If $n_i$ and $n_f$ are the quantum numbers of initial and final states and $E_i$ & $E_f$ are energies of electron in H-atom in initial and final state, we have

$$E_i = \frac{-Rhc}{n_i^2} \text{ and } E_f = \frac{-Rch}{n_f^2}$$

If $\nu$ is the frequency of emitted radiation, we get

$$\nu = \frac{E_i - E_f}{h} \Rightarrow \nu = \frac{-Rc}{n_i^2} - \left(\frac{-Rc}{n_f^2}\right) \Rightarrow \nu = Rc\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$$

For Balmer series $n_f = 2$, while $n_i = 3, 4, 5, ...\infty$.

**Q. 3. Derive the expression for the magnetic field at the site of a point nucleus in a hydrogen atom due to the circular motion of the electron. Assume that the atom is in its ground state and give the answer in terms of fundamental constants.** *[CBSE Sample Paper 2016]*

**Ans.** To keep the electron in its orbit, the centripetal force on the electron must be equal to the electrostatic force of attraction. Therefore,

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} \quad \text{(For H atom, } Z = 1) \qquad ...(i)$$

From Bohr's quantisation condition

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{h}{2\pi mr} \quad \text{(For } K \text{ shell, } n=1) \qquad ...(ii)$$

From (*i*) and (*ii*), we have

$$\frac{m}{r}\left(\frac{h}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$\frac{m}{r}\frac{h^2}{4\pi^2m^2r^2} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} \Rightarrow r = \frac{\varepsilon_0 h^2}{\pi me^2} \qquad ...(iii)$$

From (*ii*) and (*iii*), we get, $v = \frac{h \times \pi me^2}{2\pi m\varepsilon_0 h^2} = \frac{e^2}{2\varepsilon_0 h}$

Magnetic field at the centre of a circular loop, $B = \frac{\mu_0 I}{2r}$

$\therefore \qquad I = \frac{ev}{2\pi r} \qquad \left[\because I = \frac{Charge}{Time} \text{ and } Time = \frac{2\pi r}{v}\right]$

So, $\qquad B = \frac{\mu_0 ev}{2r \times 2\pi r} = \frac{\mu_0 ev}{4\pi r^2} \qquad ...(iv)$

From (*ii*), (*iii*) (*iv*), we have

$$B = \frac{\mu_0 e.e^2\pi^2m^2e^4}{2\varepsilon_0 h \times 4\pi \times \varepsilon_0^2 h^4} \Rightarrow B = \frac{\mu_0 e^7\pi m^2}{8\varepsilon_0^3 h^5}$$

## Questions for Practice

**1. Choose and write the correct option in the following questions.**

(*i*) As per Bohr model, the minimum energy (in eV) required to remove an electron from the ground state of doubly-ionised Li atom (Z = 3) is

(*a*) 1.51 (*b*) 13.6 (*c*) 40.8 (*d*) 122.4

(*ii*) The ratio of kinetic energy to the total energy of an electron in a Bohr orbit of the hydrogen atom, is

(*a*) 1 : 1 (*b*) 1 : –1 (*c*) 2 : –1 (*d*) 1 : –2

(*iii*) The ratio of maximum frequency and minimum frequency of light emitted in Balmer series of hydrogen spectrum, in Bohr's model is *[CBSE 2023 (55/3/1)]*

(*a*) $\frac{11}{9}$ (*b*) $\frac{9}{5}$ (*c*) $\frac{11}{7}$ (*d*) $\frac{16}{7}$

(*iv*) In which region of the electromagnetic spectrum does the Lyman series of hydrogen lie?

(*a*) Ultraviolet (*b*) Infra-red (*c*) Visible (*d*) X-ray

(*v*) What is the relation between orbit radius '*r*' and orbit number '*n*' of electron in an atom according to Bohr's theory?

(*a*) $r \propto n^{-1}$ (*b*) $r \propto n$ (*c*) $r \propto n^{-2}$ (*d*) $r \propto n^2$

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***
   ***(a) Both A and R are true and R is the correct explanation of A.***
   ***(b) Both A and R are true but R is not the correct explanation of A.***
   ***(c) A is true but R is false.***
   ***(d) A is false and R is also false.***

   **Assertion** (*A*) **:** Hydrogen atom consists of only one electron but its emission spectrum has many lines.

   **Reason** (*R*) **:** Only Lyman series is found in the absorption spectrum of hydrogen atom whereas in the emission spectrum, all the series are found.

3. When electron in hydrogen atom jumps from energy state $n_i = 4$ to $n_f = 3, 2, 1$, identify the spectral series to which the emission lines belong.

4. The energy of electron in *n*th orbit of H-atom is $E_n = -\frac{13.6}{n^2}$ eV. What is the energy required for transition from ground state to first excited state?

5. Define ionisation energy. What is its value for a hydrogen atom? ***[CBSE 2023 (55/2/1)]***

6. 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.

7. (*i*) Define the terms : 'impact parameter' and distance of closest approach for an α-particle in Geiger-Marsden scattering experiment.

   (*ii*) What will be the value of the impact parameter for scattering angle (*a*) $\theta = 0°$ (*b*) $\theta = 180°$?

   ***[CBSE 2022 (55/2/1), Term–2]***

8. Draw graph to show the variation of the number of scattered particlea s detected (*N*) in Geiger-Marsden experiment as a function of scattering angle (θ). ***[CBSE 2023 (55/3/1)]***

9. The ground state energy of hydrogen atom is – 13.6 eV. If an electron makes a transition from an energy level – 0.85 eV to –3.4 eV, calculate the wavelength of the spectral line emitted. To which series of hydrogen spectrum does this wavelength belong?

10. 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. ***[CBSE Sample Paper 2021]***

11. Suppose you are given a chance to repeat the alpha particle scattering experiment using a thin sheet of solid hydrogen in place of gold foil (hydrogen is a solid at temperature below 14 K). What results do you expect? ***[NCERT]***

12. The ground state energy of hydrogen atom is –13.6 eV. What is the kinetic and potential energies of the electron in the ground and second excited state? ***[CBSE (AI) 2010, 2011, Bhubaneshwar 2015]***

13. The radius of innermost orbit of a hydrogen atom is $5.3 \times 10^{-11}$ m. What are the radii of $n=2$ and $n=3$ orbits? ***[NCERT]***

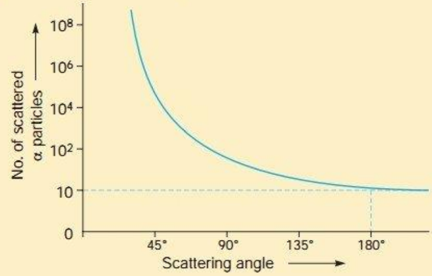
14. In accordance with Bohr's model, find the quantum number, that characterises the earth's revolution around the sun in an orbit of radius $1.5 \times 10^{11}$ m with orbital speed $3 \times 10^4$ m/s. ***[NCERT]***
    (Mass of earth = $6.0 \times 10^{24}$ kg)

15. Write two important limitations of Rutherford nuclear model of the atom. ***[CBSE Delhi 2017]***

16. Find out the wavelength of the electron orbiting in the ground state of hydrogen atom. ***[CBSE Delhi 2017]***

**17.** In an experiment on α-(particles) scattering by a thin foil of gold, draw a plot showing the number of particles scattered versus the scattering angle θ.

Why is it that a very small fraction of the particles are scattered at $\theta > 90°$? *[CBSE (F) 2013]*




**18.** A hydrogen atom in the ground state is excited by an electron beam of 12.5 eV energy. Find out the maximum number of lines emitted by the atom from its excited state. *[CBSE 2019 (55/2/1)]*

**19.** A 12.5 eV electron beam is used to excite a gaseous hydrogen atom at room temperature. Determine the wavelengths and the corresponding series of the lines emitted.

**20.** The spectrum of a star in the visible and the ultraviolet region was observed and the wavelength of some of the lines that could be identified were found to be:

824 Å, 970 Å, 1120 Å, 2504 Å, 5173 Å, 6100 Å

Which of these lines cannot belong to hydrogen atom spectrum? (Given Rydberg constant $R = 1.03 \times 10^7\ m^{-1}$ and $\frac{1}{R} = 970$ Å). Support your answer with suitable calculations.

**21.** State Bohr's postulate to explain stable orbits in a hydrogen atom. Prove that the speed with which the electron revolves in $n$th orbit is proportional to $(1/n)$. *[CBSE 2022 (55/3/1), Term–2]*

**22.** Given the ground state energy $E_0 = -13.6$ eV and Bohr radius $a_0 = 0.53$ Å. Find out how the de Broglie wavelength associated with the electron orbiting in the ground state would change when it jumps into the first excited state.

**23.** A 12.3 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited?
Calculate the wavelengths of the second member of Lyman series and second member of Balmer series. *[CBSE Delhi 2014]*

**24.** The short wavelength limit for the Lyman series of the hydrogen spectrum is 913.4 Å. Calculate the short wavelength limit for Balmer series of the hydrogen spectrum. *[CBSE (AI) 2017]*

## Answers

**1.** (*i*) (*d*) (*ii*) (*b*) (*iii*) (*b*) (*iv*) (*a*) (*v*) (*d*)

**2.** (*a*) **4.** 10.2 eV **6.** $3.646 \times 10^{-7}$ m

**9.** 4853 Å **11.** 2.4 MeV **12.** 13.6 eV, –27.2 eV [For $n = 1$], 1.51eV, –3.02 eV [For $n = 3$]

**13.** $2.12 \times 10^{-10}$m, $4.77 \times 10^{-10}$m,

**14.** $2.57 \times 10^{74}$ **16.** 3.32 Å **18.** 3 **19.** $6.54 \times 10^{-7}$m

**23.** $n = 3$, 102.5 nm, 486 nm. **24.** 3653.6 Å