COMPREHENSIVE ANSWER KEY

Journey Inside the Atom

Revision – 2 • Class IX Science • High Difficulty Level

Q1. Explain why the discovery of sub-atomic particles established that an atom is divisible. Compare the relative charge and mass of an electron, proton, and neutron.

Atomic Divisibility: Dalton's Atomic Theory postulated that atoms are indivisible and indestructible ultimate particles of matter. However, the discovery of sub-atomic particles—electrons (J.J. Thomson, 1897), protons (E. Goldstein canal rays, 1886 / Rutherford), and neutrons (J. Chadwick, 1932)—demonstrated that an atom is a complex structural entity composed of even smaller fundamental constituents, proving that atoms can indeed be divided.

Sub-atomic Particle	Symbol	Absolute Mass	Relative Mass	Relative Charge	Discovered By
Electron	e^{-}	9.109×10^{-31} kg	1/1840 u (~ 0)	−1	J.J. Thomson
Proton	p^{+}	1.673×10^{-27} kg	1 u	+1	E. Goldstein
Neutron	n^{0}	1.675×10^{-27} kg	1 u	0 (Neutral)	J. Chadwick

Q2. An atom is electrically neutral although it contains charged particles. Explain how the presence of protons and electrons accounts for this neutrality.

- Each proton carries an elementary positive charge of **$+1.602 \times 10^{-19}$ C** (+1 unit).
- Each electron carries an equal and opposite negative charge of **-1.602×10^{-19} C** (−1 unit).
- Neutrons have zero electrical charge.
- In any neutral atom, the **number of protons is exactly equal to the number of electrons** (Atomic Number Z = Number of Protons = Number of Electrons). Consequently, the total positive nuclear charge completely balances the total negative electronic charge, rendering the atom electrically neutral overall (Net Charge = 0).

Q3. State the main features of Thomson's model of the atom. Why was this model unable to explain the results of later experiments?

- **Main Features (Plum Pudding / Watermelon Model):**
  1. An atom consists of a positively charged sphere in which electrons are embedded like seeds in a watermelon or dry fruits in a plum pudding.
  2. The negative and positive charges are equal in magnitude, so the atom as a whole is electrically neutral.
- **Why it failed:** Thomson's model assumed that positive charge and mass were spread uniformly throughout the atomic volume. It could not explain the results of Rutherford’s α-particle scattering experiment, where high-energy α-particles experienced sharp, large-angle deflections and complete rebounds (180°). A diffuse sphere of positive charge could never exert an electrostatic repulsive force concentrated enough to deflect massive α-particles backwards.

Q4. Describe Rutherford's α-particle scattering experiment. State the three major observations and the conclusions drawn from each observation.

Experiment: High-energy α-particles (doubly charged helium ions, He^{2+}) emitted from a radioactive source were directed at an extremely thin gold foil (~1000 atoms thick, ~100 nm). Deflections were recorded on a circular fluorescent zinc sulphide (ZnS) screen.

Observation	Conclusion Drawn
1. Most of the α-particles (> 99%) passed straight through the foil without any deflection.	Most of the space inside the atom is completely **empty**.
2. A small fraction of α-particles were deflected by small and moderate angles.	The **positive charge** is not distributed uniformly, but is concentrated in an extremely small region that exerts strong electrostatic repulsion.
3. A very tiny fraction (approx. 1 in 12,000) rebounded back along their path (> 90° or nearly 180°).	The entire positive charge and nearly all the **mass** of the atom are concentrated in an extremely dense, compact central volume called the **nucleus** (nuclear radius ≈ 10^{-15} m vs atomic radius ≈ 10^{-10} m).

Q5. Most α-particles passed straight through the gold foil, while a very small number were deflected through large angles. Explain why these observations were significant for understanding atomic structure.

- **Significance of straight passage:** It overturned Thomson's model of a solid, uniformly filled atom, proving that matter is mostly empty void at the sub-atomic level.
- **Significance of large-angle deflections:** Because an α-particle has a mass of 4 u and moves at high velocity, only a concentrated center with intense positive charge and substantial mass could provide the enormous Coulombic repulsive force needed to turn it around. This directly led to the conceptual discovery of the **atomic nucleus**.

Q6. State the main features of Rutherford's nuclear model of the atom. How did it differ from Thomson's model?

- **Main Features of Nuclear Model:**
  1. There is a positively charged, highly dense center in an atom called the **nucleus**, where nearly all mass resides.
  2. The electrons revolve around the nucleus in circular paths called **orbits** (analogous to planets revolving around the Sun).
  3. The size of the nucleus is extremely small compared to the total size of the atom (about 10^5 times smaller).
- **Comparison with Thomson's Model:**
  - *Positive charge:* Thomson considered it a diffuse, uniform sphere filling the whole atom; Rutherford showed it is concentrated entirely in a tiny central nucleus.
  - *Electrons:* Thomson saw them embedded statically; Rutherford proposed they orbit dynamically around the nucleus.
  - *Space:* Thomson modeled the atom as a solid mass; Rutherford revealed it is mostly empty space.

Q7. Rutherford's model could not explain the stability of the atom. Explain this limitation using the behaviour of a moving charged particle.

- According to Maxwell's classical electromagnetic theory, any accelerated charged particle must continuously radiate energy in the form of electromagnetic radiation.
- An electron revolving in a circular orbit undergoes continuous centripetal acceleration (due to continuous change in direction).
- Therefore, the revolving electron should constantly radiate energy. Losing kinetic energy, its orbital radius would shrink progressively, causing the electron to spiral inward and crash into the nucleus in approximately **10^{-8} seconds**.
- In reality, atoms are exceptionally stable and do not collapse. Rutherford's model could not reconcile this contradiction.

Q8. State the main postulates of Bohr's model of the atom. How did Bohr's model overcome the major limitation of Rutherford's model?

- **Postulates of Bohr's Model:**
  1. Only certain special orbits known as **discrete orbits (or energy levels)** of electrons are allowed inside the atom.

2. While revolving in these discrete orbits, electrons **do not radiate energy**. These non-radiating states are called *stationary orbits*.
3. These orbits or shells are represented by letters **K, L, M, N...** or principal quantum numbers **n = 1, 2, 3, 4...**

- **How it overcame Rutherford's limitation:** By postulating that energy radiation does not happen continuously, but is strictly quantized and forbidden during orbital motion in permitted stationary orbits, the electron does not lose energy or spiral inward, thereby guaranteeing atomic stability.

Q9. Explain the meaning of a stationary orbit in Bohr's model. Why does an electron not continuously lose energy while moving in such an orbit?

- A **stationary orbit** refers to a fixed, permissible quantum energy state in which an electron possesses a fixed, defined amount of energy without radiating or absorbing electromagnetic waves. (The term "stationary" means the *energy* of the orbit is fixed and constant, not that the electron is at rest).
- **Why no continuous energy loss:** Bohr integrated Planck's quantum concept. Energy exchange in an atom is quantized—it cannot happen continuously in arbitrary amounts. Since no accessible lower quantum state exists below a given stationary state (unless an allowed transition occurs), the electron remains dynamically stable without electromagnetic decay.

Q10. An electron moves from a lower energy orbit to a higher energy orbit. What must happen to its energy? What happens when it returns to a lower energy orbit?

- **Lower to Higher Orbit (Excitation):** The electron must **absorb a discrete packet of energy (a photon)** exactly equal to the difference between the two levels: $\Delta E = E_{higher} - E_{lower} = h\nu$.
- **Higher to Lower Orbit (De-excitation):** The electron **emits/radiates energy** in the form of electromagnetic radiation (light/photon) corresponding precisely to the energy difference: $\Delta E = E_{higher} - E_{lower}$.

Q11, Q12 & Q13. Assertion and Reason Questions

11. Assertion: Rutherford concluded that most of the atom is empty space. **Reason:** Most α-particles passed through the gold foil without any deflection.
→ **Correct Option: A** **(Both Assertion and Reason are true, and Reason is the correct explanation of Assertion.)**

12. Assertion: Rutherford's model could not explain the stability of an atom. **Reason:** A moving charged particle should continuously lose energy according to classical theory.
→ **Correct Option: A** **(Both Assertion and Reason are true, and Reason is the correct explanation of Assertion.)**

13. Assertion: Bohr proposed that electrons can revolve only in certain permitted orbits. **Reason:** Electrons in these permitted orbits possess definite energies and do not radiate energy continuously.
→ **Correct Option: A** **(Both Assertion and Reason are true, and Reason is the correct explanation of Assertion.)**

Q14. CASE-BASED: In an experiment, a beam of α-particles is directed towards a very thin metal foil. Most particles pass through, some are slightly deflected and a very few are strongly deflected. Identify the experiment, state its conclusions, and explain which atomic model was proposed from it.

- **Identification: Rutherford's Alpha-Particle Scattering Experiment (1911)** (performed by Geiger and Marsden using gold foil).
- **Conclusions:**
  1. Most of the space inside the atom is empty (due to undeflected passage).
  2. A concentrated positive charge occupies a tiny fraction of the atom's volume (slight deflections).
  3. Almost the entire mass and positive charge reside in a tiny, dense core—the **nucleus** (sharp rebounds).
- **Atomic Model Proposed: Rutherford's Nuclear Model of the Atom** (planetary model with central nucleus and orbiting electrons).

Q15. Compare Thomson's, Rutherford's, and Bohr's models with respect to the distribution of positive charge, position of electrons, and explanation of atomic stability.

Feature	Thomson's Model (1898)	Rutherford's Model (1911)	Bohr's Model (1913)
Distribution of Positive Charge	Uniformly distributed throughout the entire spherical volume of the atom.	Concentrated in an extremely dense, compact central core (the nucleus).	Concentrated in the dense nucleus at the center of the atom.
Position of Electrons	Embedded statically within the positive sphere like seeds in a watermelon.	Revolving around the central nucleus in circular orbits (planetary motion).	Revolving only in discrete, non-radiating stationary orbits (shells: K, L, M, N...).
Explanation of Atomic Stability	Assumed stable electrostatically due to balance of equal positive and negative charges; proved incorrect dynamically.	Failed to explain stability; classical electrodynamics predicted inward spiral collapse of accelerated electrons.	Successfully explained stability: electrons in quantized stationary orbits do not radiate energy continuously.

Q16. MASTER CHALLENGE: "Rutherford discovered the nucleus, but Bohr explained why electrons could remain around it without the atom collapsing." Examine this statement critically. Mention the contribution and limitation of each model.

Critical Examination: The statement is profoundly accurate and captures the historical evolution of atomic physics. Rutherford provided the true physical framework of the atom by establishing the existence of the nucleus via experimental scattering, but his reliance on classical Newtonian and Maxwellian physics created an unsolvable stability paradox. Bohr resolved this paradox by introducing quantum principles to the nuclear model, creating the foundation for modern quantum chemistry.

Scientist / Model	Key Historical Contribution	Major Limitation
Ernest Rutherford (Nuclear Model, 1911)	• Discovered the **atomic nucleus** via α-scattering. • Showed the atom is mostly empty space. • Established that positive charge and mass are concentrated in the nucleus, with electrons moving around it.	• Could not explain the **dynamic stability** of the atom under classical Maxwellian electrodynamics (predicting radiative collapse). • Could not explain the discrete line spectra of elements or electronic distribution.
Niels Bohr (Quantum Model, 1913)	• Solved the stability paradox by postulating **quantized, non-radiating stationary orbits**. • Accurately explained and calculated the **hydrogen line emission spectrum**. • Introduced principal quantum numbers (shells K, L, M, N) and energy quantization.	• Failed to explain spectra of multi-electron atoms (atoms other than hydrogen). • Could not account for fine spectral splitting (Zeeman effect in magnetic fields, Stark effect in electric fields). • Ignored the wave nature of electrons (de Broglie) and Heisenberg's uncertainty principle (assumed flat, 2D circular orbits).