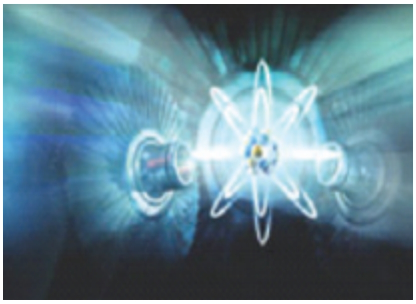

# 8

# MODELS OF THE ATOM

**OBJECTIVES**

At the end of the topic, students should be able to:

- state and discuss with chemical evidence that there is existence of atoms;
- state and discuss with experimental evidence believing that matter is electrical in nature;
- describe the Bohr-Rutherford model of the atom;
- explain the existence of line spectral in terms electron transitions between atomic energy levels;
- explain the similarity in the behaviour of the elements in terms of their electronic configuration.

## Build up to modern atomic concept

The idea that matter is composed of atoms can be traced to the early Greeks. Democritus, around 400 BC, proposed that matter consists of tiny hard particles, which are difficult to see. He also believed that these tiny particles have shape, size and mass. He called the tiny particles making up matter **atom.** According to Democritus, atom is indivisible.

The idea that matter is composed of atoms was abandoned for lack of evidence. John Dalton, a school headmaster and a chemist, proposed his atomic theory in the year 1800. Dalton atomic theory states that:

- Elements are composed of tiny particles called atoms.
- Atoms cannot be divided, destroyed or created.
- Atoms of the same element are identical in mass, density, charge, etc. but atoms of different elements are different.
- Atoms of different elements combine in simple whole number ratios to form compounds.

Gay-Lussac and Avogadro showed that in a chemical reaction, elements combine in simple whole number ratio. In forming water (a compound), two volumes of hydrogen combine with one volume of oxygen to form two volumes of water.

| 2 volumes of | + 1 volume of | = 2 volumes of |
|---|---|---|
| Hydrogen | Oxygen | Water |

$$2H_2 + O_2 = 2H_2O$$

In a chemical reaction, atoms are rearranged to form new elements. This is the evidence that matter is composed of atoms. The study of gas behaviours (Boyleâ€™s law, Charlesâ€™s law, Gay-Lussac law and the general gas law) can be explained by assuming that gases consist of molecules.

Matter is electrical in nature. If glass is rubbed with silk, it becomes charged with positive charges. This is called positive electricity. Ebonite rod produces negative electricity if rubbed with fur or wool. The electrification of matter shows that matter, apart from containing atoms, is electrical in nature.

## Atomic models

Matter consists of atoms. An atom consists of electrically charged particles called electrons and protons. Different models have been proposed by different scientists based on their understanding of the atom. When new truths about an atom are gained through experiments, scientists change their model of atom to suit the new facts. In this section, we will discuss different models, which lead to our present concept of atom.

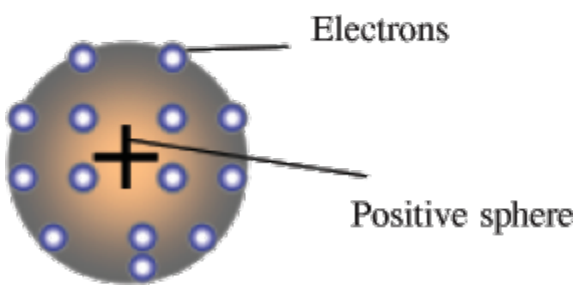


*Figure 8.1: J. J. Thomson model*

## Thomson atom

J.J. Thomson proposed that an atom is a positively charged sphere with electrons embedded on it. The electrons arrange themselves in regular pattern on the positively charged sphere, like a plum on pudding. This is shown in Figure 8.1. The number of electrons balances the number of protons making the atom electrically neutral.

The plum pudding model of the atom proposed by Thomson was successful in explaining why:

- a normal atom is electrically neutral;
- ions are formed. Ions are formed by atom gaining or losing electrons;

The model however could not explain:

- the scattering of alpha-particles by gold foil in Geiger and Marsden experiment.
- existence of line spectra of hydrogen atom and other complex gases.

## Alpha scattering experiment

Ernest Rutherford was not happy with the Thomsonâ€™s proposition of an atom. He decided to conduct experiment to test the correctness of the model. He asked Geiger and

Marsden, students under him to bombard gold foil with high energy alpha particles and see if some of the alpha particles could be scattered through large angles (Î¸>90Â°). Thomson model predicts no scattering or scattering through small angles.

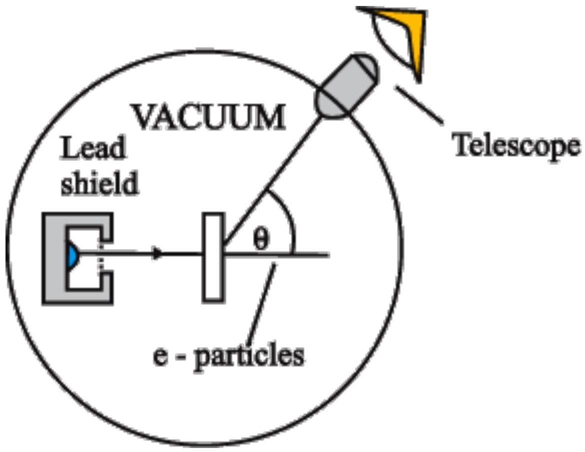


*Figure 8.2: Geiger and Marsden – scattering experiment*

The apparatus used by Geiger and Marsden is shown in Figure 8.2; it consists of a source of alpha particles, a metal foil in evacuated vessel and a microscope to see the scattered alpha particles at different angles.

A beam of alpha particles is directed towards a gold foil and are scattered at various angles. Geiger and Marsden showed that most of the alpha particles passed through the gold foil with little or no deviation. They were able to observe some alpha particles (1 out of 8000) deflected through very large angles (Î¸ > 90Âº).

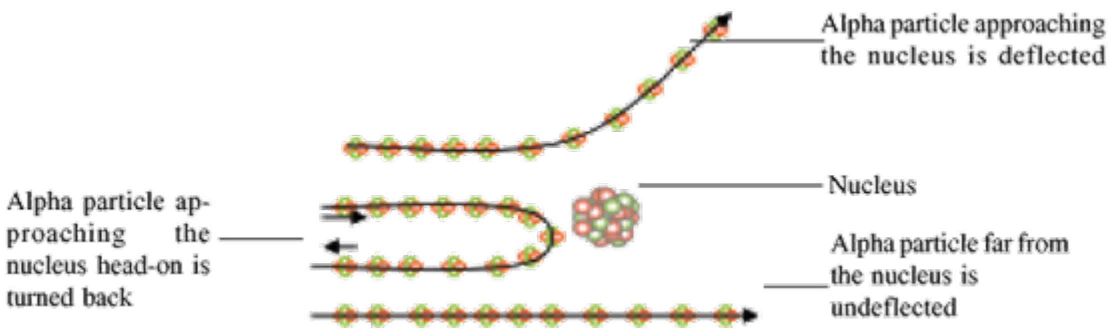


*Figure 8.3: Scattering of alpha — particles through large angles*

The plum pudding model of Thomson could not explain the scattering of alpha particles through large angles. Rutherford proposed a new model of an atom in 1911, which explains the scattering of alpha particles by gold foil. The model is called **nuclear** or **planetary model of an atom.**

## Rutherford atom

The **nuclear** or **Rutherford atom** states that an atom consists of a solid core called the **nucleus** which is positively charged. The **electrons** move round the nucleus at **definite orbit** at a great speed. ***The mass of an atom is concentrated at the nucleus.*** Rutherford made the assumption to explain why most of the alpha particles could pass through the gold foil without deflection by the positively charged nucleus.

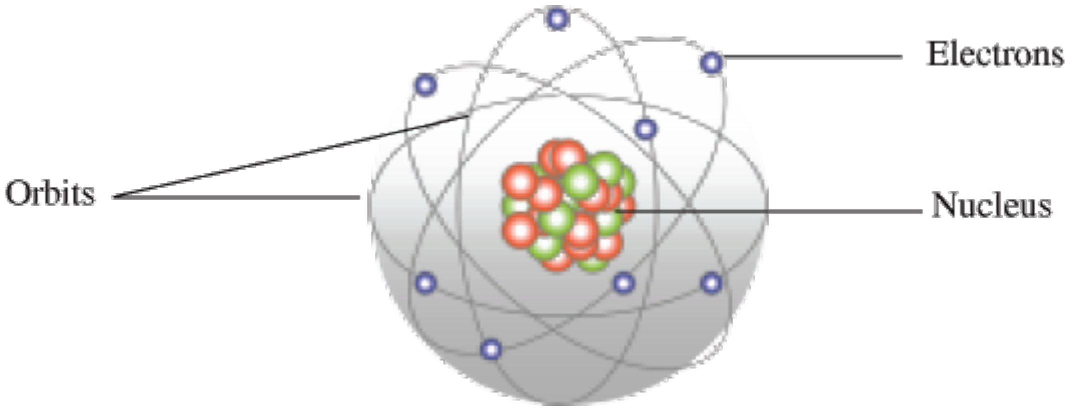


*Figure 8.4 Rutherford nuclear model not drawn to scale*

Large angle scattering occurs when an alpha particle is passed close to the gold nucleus as shown in Figure 8.3. The atom must be an empty space to explain why most of the alpha particle could pass through the gold foil without deflection.

## Limitation of Rutherford atom

- The model could not explain why electrons moving round the nucleus at high speed, do not emit electromagnetic radiation. Newtonian physics predicts that such an atom will emit radiation.
- It predicts an unstable atom. An electron moving round the nucleus at a high speed, will radiate energy, slows down and spirals into the nucleus. If this happens, the atom will collapse but everyday experience shows that atoms are stable.
- It predicts that atoms will emit radiation containing all frequencies but in practice, only some frequencies are allowed. Gases instead of producing continuous spectra as predicted by the Rutherford model, produce line spectra.

## The quantum idea

Energy and matter are not continuous as predicted by Newtonian physics. Max Planck introduced the quantum concept when he was trying to reconcile experiment and theory in black body radiation. According to quantum theory, hot bodies radiate energy in small burst or unit at a time called **wave packet.** A **burst of energy** or **wave packet** is said to be **quantized** (not continuous) and is called a **quantum of energy.**

***A quantum of energy is proportional to the frequency (f) of the source of the radiation.*** The energy of each burst or quantum is given by:

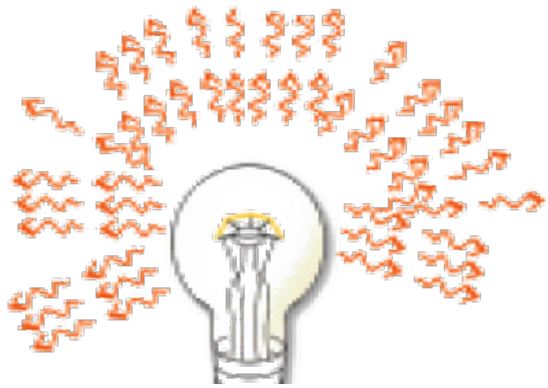

*Figure 8.5 Light is emitted as an electromagnetic burst with frequency f*

$$E = hf$$

*E* = quantum of energy or wave packet
*f* = frequency of the electromagnetic radiation
*h* = Planckâ€™s universal constant (h=6.6 Ã— $10^{-34}$Js).

Einstein developed the quantum idea of matter and energy further by extending it to light and electromagnetic radiations. Einstein proposed that an atom or other source of light radiates small bursts or electromagnetic energy. The electromagnetic burst of energy, he called **photon.**

***A photon is a concentration of wave burst (packet) or electromagnetic energy travelling in only one direction.***

A wave burst of energy is given out or radiated at a time as illustrated in Figure 8.5.


*Figure 8.6*

**Light and all electromagnetic radiation are emitted from a source as burst of energy, travel through space as wave, and are absorbed as photons.** A photon is represented in Figure 8.6.

## Bohr atom

Neil Bohr in 1913, modified Rutherford model of an atom by introducing the quantum idea in the atom. **According to Bohrâ€™s model, electrons have definite energy which corresponds to certain orbits.** As long as an electron is in one of this allowed orbit, it will not radiate energy. Bohr gave two **rules** or **postulates** as follows:

- **The orbit at which an electron will move without radiating energy is such that its angular momentum is quantized.**

  This means that the electron is not free to move in all orbits; only few orbits are allowed. The orbit an electron is permitted to move is given by the equation below.

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

$mvr$ = angular momentum

$m$ = mass of the electron

$v$ = speed of the electron round the nucleus

$r$ = radius of the orbit where the electron is moving

$n$ = principal quantum number which determines the orbit allowed. (n = 1, 2, 3 â€¦).

- **An electron will radiate energy if it jumps from higher orbital or energy to a lower orbital or energy.**

The energy radiated is given by:

$$E_i - E_f = hf$$

$E_i - E_f$ = Î”E = energy radiated when an electron jumps from initial energy level to a final energy level.

$h$ = Planckâ€™s universal constant

$f$ = frequency.

Bohrâ€™s view of the atom is illustrated in Figure 8.7. The first allowed orbit the electron can move is called the **ground state** energy level. Electrons in the ground state energy level are **stable.** When the electron in the ground state energy level absorbs enough energy, it moves to higher energy levels. Electrons in the higher energy levels are said to be **excited** and **unstable.** The excited electron loses their excess energy when they jump from the excited *radiated when an electron jumps from* energy level to a lower energy level. This is illustrated in figure 8.7.

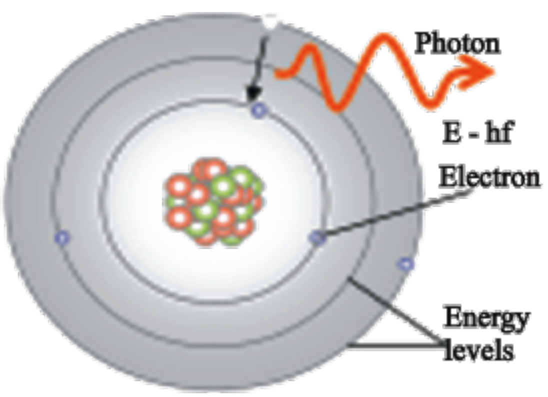


*Figure 8.7 Bohr atom; energy is radiated when an electron jumps from higher to lower energy levels*

Bohr model of an atom was very successful in;

- calculating the radius of the allowed orbit and the total energy of the electron in each allowed orbit of hydrogen atom.
- predicting the bright spectral lines of glowing hydrogen atoms.
- explaining the quantized energy state of photon in photoelectric effect.

## Limitations of Bohr atom

- It could not explain the bright spectral lines of complex atoms like oxygen.
- It looks at electrons as particles moving round the nucleus at definite orbits. Experiments show that electrons could behave like waves or particles.
- It is based on assumptions which are not supported by theory.

## Line spectra of hydrogen atom

Bohr model of an atom predicts that light or electromagnetic radiation is emitted anytime an electron jumps from higher orbit to a lower one. The frequency (wavelength) of light or electromagnetic radiation given out depends on the difference between the initial and final energy levels of the electron.

Transition from other higher energy levels to the lowest energy level emits radiation in the ultra-violet region. The ultra-violet radiation emitted is called **Lyman series.** Transition from other energy levels to the first excited energy level (n = 2) emits radiation in the visible region called **Balmer series.**

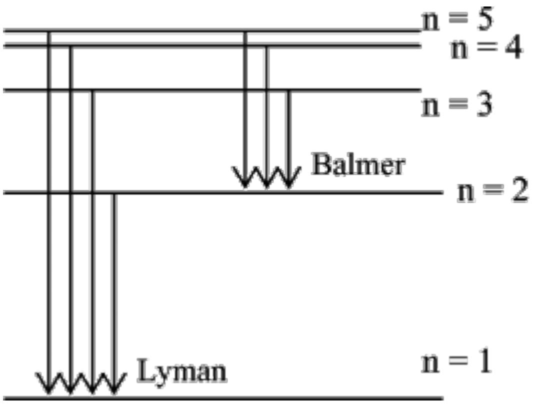


*Figure 8.8: Emission spectra of hydrogen gas*

## Electron cloud model

SchrÃ¶dinger and Heisenberg in 1925 independently developed a new mechanics called **wave mechanics.** In the new mechanics, an electron is treated as both a particle and a wave moving at some distance from the nucleus and with definite energy. Electron could be found anywhere but there are more chances that it could be found near the nucleus (i.e. the exact position of the electron cannot be predicted, as it does not move on a fixed orbit as proposed by Bohr).

The electron cloud model sees an atom as having a tiny nucleus of radius of approximately 10-15m with the electrons moving round it. The electron spends most of its time in the high-density region where they are likely to be found than in the low-density region as shown in Figure 8.9.

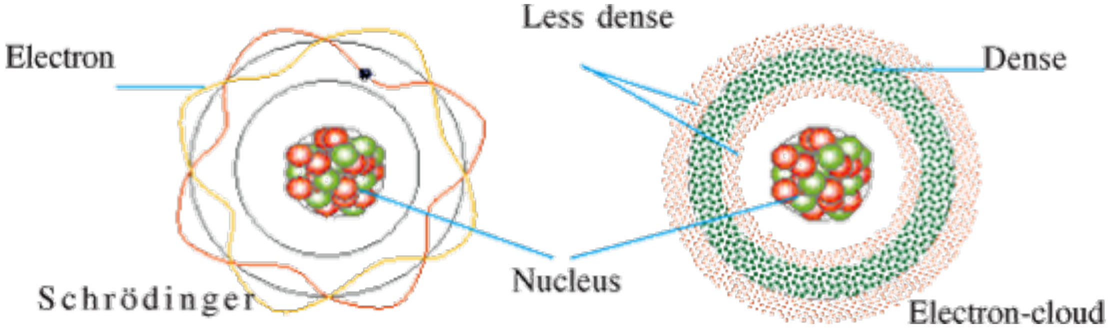


*Figure 8.9 : SchrÃ¶dinger atom and electron-cloud model*

## Electronic configuration and behaviour of elements

The electrons are moving round the nucleus at definite orbits. The orbits are called shells and are assigned specific energy. The number of electrons in an atom is determined by the atomic number (Z). The way electrons arrange themselves in an element is called **electronic configuration.** Electronic configuration determines the behaviour of the element. The first shell is filled first and takes maximum of two electrons. The next shell takes up to 8 electrons and the third shell takes up to 18 electrons. The maximum number of electrons each shell can contain is given by $2n^2$, where $n$ is the quantum number.

For sodium atom, $^{23}_{11}Na$, the first shell takes 2 electrons, the second shell takes up to 8 electrons and the third shell takes the remaining one electron. The electronic configuration of sodium element is given by: 2, 8, 1.

The number of electrons in the outermost shell is important because it determines the chemical behaviour of the element. When the sodium atom loses the outermost electron, it becomes an ion. *The number of electrons gained or lost by an atom to become an ion is called its* **valency.**

Electronic configuration, particularly the number of valence electrons, determines how the element reacts chemically. Elements with the same valence electrons are arranged into groups. The reactivity of the elements in each group increases as we move down the group. Along the rows, elements are arranged according to their atomic numbers. The pattern obtained by arranging elements in rows and columns as described above is called the **periodic table.**

## Periodic table and chemical properties of elements

Elements with similar chemical properties are put into the same group. Eight such groups exist: 1, 2, 3, 4, 5, 6, 7, and 0.

Group 1 elements (alkali metals)

### Chemical properties

| Atomic number (Z) | Symbol of element | Electronic configuration |
|---|---|---|
| 3 | Li | 2,1 |
| 11 | Na | 2,8,1 |
| 19 | K | 2,8,8,1 |

- They are very reactive. They react easily with the air to form oxide.
- The rate of reaction increases down the group.
- They form positive ion by giving out the outermost single electron.

Group 7 elements (halogens)

### Chemical properties

| Atomic number (Z) | Symbol of element | Electronic configuration |
|---|---|---|
| 9 | F | 2,7 |
| 17 | Cl | 2,8,7 |
| 35 | Br | 2,8,18,7 |

- They are very reactive. They react easily with metals to form chloride.
- The rate of reaction increases down the group.

- They form negative ion by accepting a single electron to complete the outermost shell.

## Summary

- Matter is made up tiny particles called **atoms.** New elements are formed in a chemical reaction if the atoms are rearranged.
- Matter is electrical in nature. An atom consists of electrically charged particles called electrons and protons. The protons are positively charged while the electrons are negatively charged.
- Thomson atom is a positively charged sphere with electrons embedded on it. The charge of the electrons balances the charge of the protons making an atom electrically neutral.
- The nuclear or Rutherford atomic model states that an atom consists of a solid core called the **nucleus** which is positively charged. The **electrons** move round the nucleus at definite orbit at a great speed.
- Quantum theory states that energy is radiated at a time by hot bodies in small burst or unit called **wave packet.** A quantum of energy is proportional to the frequency (f) of the source of the radiation.
- Einstein proposed that a small burst or electromagnetic energy radiated by an atom or other source of light is proportional to frequency and is called photon.
- A photon is a concentration of wave burst (packet) or electromagnetic energy travelling in only direction.
- Bohrâ€™s atomic model proposed that electrons have definite energy which corresponds to certain orbits. As long as an electron is in one of this allowed orbit, it will not radiate energy.
- The SchrÃ¶dinger atom, an electron is treated as both a particle and a wave moving at some distance from the nucleus having a definite energy.
- The electron cloud model looks at an atom as having a tiny nucleus of radius of about $10^{-15}$ m with the electrons moving round it not at definite orbit as proposed by Bohr. The electrons are likely to be found in the region where the electron waves peak. This region is called a high density region.

## Practice Questions 8

1.What is an atom? State **three** evidences to support the existence of atom.

2.(a) Describe Thomsonâ€™s atom.

(b)State **one** success and **two** limits of Thomsonâ€™s atomic model.

3.Describe an alpha particle scattering experiment and explain how it led to the **planetary model** of an atom.

4.(a) Describe the structure of an atom proposed by Rutherford. (b) State two successes and two limits of the Rutherford atom.

5.(a) State Bohrâ€™s postulates of hydrogen atom.

(b)State the successes of Bohr atom and give limitations of the model.

(c)How does Bohrâ€™s model of an atom explain:

(i) the emission of electromagnetic radiation?

(ii) the excitation of an atom?

6.(a) Describe the electron cloud or the wave mechanical model of an atom. (b) What makes the model different from Bohrâ€™s model of an atom?

7.Explain how the valence electrons determine the chemical properties of an element.

## Past Questions

1. Which of the following gives rise to line spectra observed in atoms?

   A. Kinetic energy of a moving atom.

   B. Potential energy of an electron inside an atom.

   C. Change of an electron from a higher to a lower level in the atom.

   D. Disturbed proton in the nucleus.

   E. Excitation of an electron in the atom.

WAEC

2. Which of the following is/are essential properties of Bohrâ€™s model of an atom?

   I. The electrons in the orbits have discrete values of angular momentum.

   II. When the electrons jump from one orbit to another, they emit discrete energy packets or quanta.

   III. The energy emitted by the electrons in their orbits, contain all possible wavelengths.

   A. I only.

   B. I and II only

   C. II and III only

   D. I and III only

   E. I, II and III.

WAEC

3. When an atom is in the ground state, it is said to be

   A. grounded.

   B. excited.

   C. stable.

   D. ionized.

   E. radiating.

WAEC

4. J.J. Thomsonâ€™s model of an atom was abandoned because

   A. it could not explain the scattering of alpha particles through large angles.

   B. it did not account for the neutrons.

C. it did not account for the size of the atom.

D. it was known as plum-pudding model.

E. the model was not similar to any observable phenomena.

NECO

5. Bohrâ€™s atomic model proves successful for the explanation of the:

I. structure of the hydrogen atom;

II. line spectra of the hydrogen atom;

III. multi-electron atoms.

Which of the statements above is/are correct?

A. I only.

B. II only.

C. I and II only.

D. I and III only.

WASSCE

6. Which statement is **NOT** correct about Rutherfordâ€™s model of the atom?

A. The diameter of the nucleus is of the order of $10^{-15}$ m.

B. The mass of an atom is concentrated in the nucleus.

C. The model is applicable to atoms with one electron in the outer shell.

D. The nucleus of an atom is positively charged.

E. The nucleus is surrounded by an electron cloud.

NECO

7. Bohrâ€™s theory provides evidence for the

A. structure of the atom.

B. positive charge of an electron.

C. existence of energy levels in the atom.

D. positive charge on a proton.

WASSCE

8. In the Rutherford scattering experiment, a beam of alpha particles was fired at a thin gold film with some of the particles being considerably deflected. This shows that

A. a gold nucleus contains protons, neutrons and electrons uniformly distributed in a tiny volume.

B. the gold nucleus is positively charged and concentrated in a tiny volume.

C. the gold nucleus is emitted alpha particles.

D. the gold nucleus is concentrated in a tiny volume and contains alpha particles.

JAMB

9. Which of the following particles determine the mass of the atom?

A. Protons and electrons

B. Neutrons and protons

C. Electrons and neutrons

D. Neutrons and photons

WASSCE

10. What happens when excited electrons in an atom return to lower energy level?

A. They absorb photons.

B. They emit protons

C. They emit photons.

D. They absorb neutrons.

11. State two (i) postulates of Rutherfordâ€™s model of the atom, (ii) limitations of the model.

NECO