Atomic Structure and Atomic Models:

The materials available either in solid, liquid or gaseous form are made up of atoms. Atoms of the same element are identical to each other in weight, size and all properties, whereas atoms of different elements differ in weight, size and other characteristics. A material which consists just one type of atoms is called element like Nitrogen, carbon, hydrogen, aluminium, copper, gold, iron etc. Group of atoms which tend to exist together in a stable form are called molecules.

The atom is considered to be made up of a heavy nucleus, consisting of protons and neutrons, surrounded by highly structured configurations of electrons, revolving around the nucleus in shells or orbits at a relatively greater distance from nucleus.

Electrons are universal constituent of all matter. This is supported by the following facts:

- The electrons have identical effects when used for any applications, e.g., radio and television (electromagnetic waves), X-ray applications, producing fluorescence effects, producing photoelectric effect, etc.
- Electrons obtained from any source possess the same charge, e (-1.602×10^{-19} C), same rest mass, m_0 (= 9.109×10^{-31} kg, equivalent energy = 0.51 MeV), same effective radius, re (= 4.6×10^{-6} nanometer). The mass of the electron, m, is usually taken as 9.1 x 10–31 kg. When electrons move with very high velocity, approaching to the velocity of light, c, the mass of the electron varies in accordance with the relation :

$$m = \frac{m_o}{\sqrt{1 - v^2 c^2}}$$

when v = 0, m = m_o. Hence m_0 is called the rest mass. The mass of the electron is negligible compared to that of protons and neutrons. The mass of the electron is 1/1836 th of the mass of the proton.

The electrons revolve round the nucleus in various shells and orbits. The electrons which are in the outermost shell or orbit account for most of the engineering properties of materials, e.g., bonding with other atoms, electrical and optical properties, chemical reactivity, etc.

Protons:

The nucleus of hydrogen atom is called the proton. A proton has a unit positive charge of same magnitude as that of electron (= 1.602×10^{-19} C). The mass of a proton is (1.672×10^{-27}) kg. The proton and the neutron are considered to be two different charge states of the same particle which is called a nucleon. The number of protons in a nucleus is called the charge Z of the given nucleus, or the charge number.

Neutrons:

These are electrically neutral particles and 1.008 times heavier than protons. The mass of each neutron is 1.675×10^{-27} kg. Each neutron is composed of one proton and one electron, i.e.

$$\text{Neutron} = \text{Proton} + \text{Electron}$$

Atomic Number (Z)

This is a fundamental property of the atom and denoted by Z. The atomic number of an element is numerically equal to the number of protons present in the nucleus, i.e., the value of positive charge on the nucleus. We must note that all the atoms of the same element possess the same atomic number which identifies the position of the element in the periodic table of elements. A normal atom is electrically neutral and hence the number of protons and electrons are equal. For example, an iron atom contains 26 protons (Z = 26) and hence the balancing electrons are also 26. Obviously, 26 specifies the position of the iron element in the periodic table of elements.

Atomic weight and mass number

The atomic weight of an element is the average relative weight of its atom as compared to the weight of one atom of oxygen which is taken to be 16, i.e. it is the ratio between the weight of one atom of the element and 1/16 th of the weight of an atom of oxygen. The mass number is equal to the sum of the number of protons and neutrons. The mass number is usually denoted by A.

$$A = \text{Number of protons} + \text{Number of neutrons}$$

For example chlorine atom has 17 protons and 18 neutrons in its nucleus. Obviously, mass number of chlorine is 35. The mass of the nucleus is directly proportional to the mass number.

Atomic models

Several atomic models about atomic structure have been advanced over the years after obtaining quantitative measurements on electrons and positive rays. These models include the models proposed by Sir J.J. Thomson, Rutherford, and modern atomic model.

Thomson's atomic models

Thomson in 1911 proposed an atomic model known as plum-pudding model. According to this model,

- The electron is a constituent of all matter
- The electron has a negative charge of 1.602×10^{-19} C and a rest mass of 9.1085×10^{-31} kg
- Atoms are uniform spheres in which electrons were distributed along with positive charges, like plums in a pudding (Fig. 1). The atom is electrically neutral.
- The electrons possess vibratory motion about their equilibrium position and cause emission of light.

Thomson, by using various methods of spectroscopy also computed the total number of electrons in an atom.

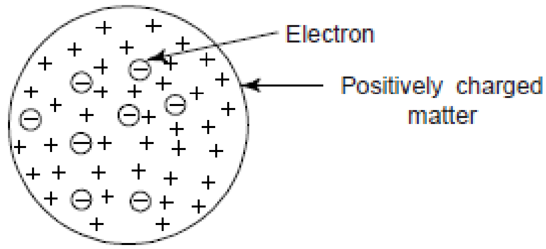

Figure 1

Thomson established that the same value is always obtained for the charge to mass (e/m) ratio of the electron. This clearly support the statement that the electron is a constituent of all matter. Thomson's model could account for the periodicity in elements, spectral lines existence of ions and kinetic theory of gases. Thomson's model failed to explain:

- The scattering of ∝-particle incident on thin gold foil (Rutherford's experiment)
- The emission of spectral series by the atoms.

Thomson's model of atom had finally to be given up with the development of Rutherford's alpha particle scattering experiments.

Rutherford's nuclear atomic models

Rutherford and coworkers in 1911 performed differential scattering experiments and proposed a new atomic model. Rutherford directed ∝-particle emitted from a radioactive source on a thin gold foil 4×10^{-6} m thick. He observed that some ∝-particle passed through the film, while others were scattered all around. Those ∝-particle passing through the thin gold film also scattered over a wide area, and produced luminescence on a fluorescent screen of zinc Sulphide (Fig.2). Very small number of ∝-particle were deflected through large angles, i.e. about 1 in 10,000 particles suffered a deflection of more than 90°. Only very rarely a ∝-particle reversed back along its own path, i.e. suffered a deflection through 180°. (Fig. 3)

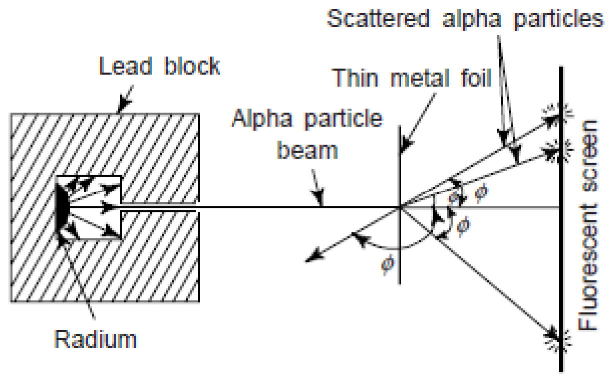

Figure 2

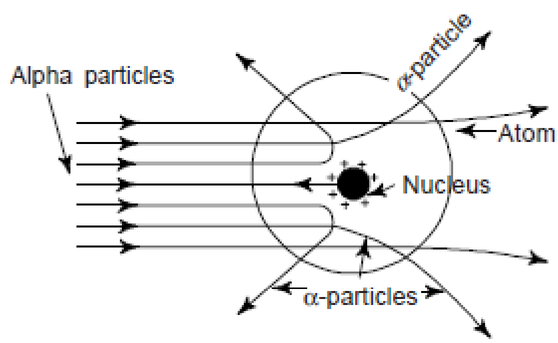

Figure 3

Rutherford ∝-particle scattering experiments established the incorrectness of the uniform distribution of positive charge in a sphere of atomic dimensions in the Thomson's atomic model. Rutherford's results can be explained only if it is assumed that the positive charge in an sphere or atom is concentrated in the center and the negatively charged particles surround it loosely, leaving enough space for ∝-particle to pass through, i.e. atoms must have a large empty space.

The large angle ∝-scattering observed can be explained on the basis that an electron is too light a particle, to cause any appreciable deflection of ∝-particle. It could only be possible if an ∝-particle has something equally or even more massive than itself, i.e. if the entire positive charge of an atom and the whole of its mass are concentrated in a small core, which Rutherford called the nucleus of the atom having very small dimensions. One can summarize the Rutherford's observations as,

- The entire positive charge and mass of an atom are concentrated at the centre of the atom in a nucleus of very small dimensions.
- The diameter of the nucleus is about 10^{-15} m whereas the diameter of an atom is about 10^{-10} m. Obviously, the nucleus of an atom occupies a volume which is a million-millionth part of an atom. Thus there is a lot of empty space in the atom.

Rutherford, in 1911 proposed the following model of an atom:

- The atom consist of a small nucleus in which the enter all the positive charge (protons) and almost the whole mass of the atom.
- The nucleus occupies a very small space as compared to the size of the atom, he proposed that the atom was mostly empty space.
- The electrons revolve around the nucleus in various orbits just as planets revolve around the sun.
- The charge on the electron is negative and is equal in magnitude to the charge on the proton. Therefore, the atom as a whole is electrically neutral.

In Rutherford's model, the force of attraction between the electrons and the nucleus was balanced by the centrifugal force attained by the electrons due to their motion in orbits round the nucleus.

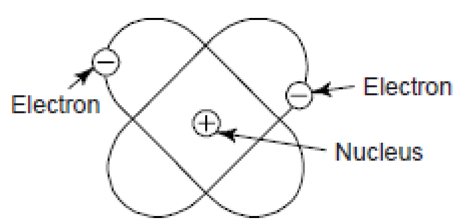

Figure 4

Electrostatic Attraction Force (Fe): If the electron moves in a circular orbit of radius r with a constant linear velocity v round the nucleus, then it will be subjected to two forces: (i) one acting inwards will be the force of electrostatic attraction given by Coulomb's law:

$$F = \frac{q_1 q_2}{4\pi\varepsilon_o r^2} = \frac{Ze \cdot 2e}{4\pi\varepsilon_o r^2}$$

Where

e : Negative electron charge = coulomb (C).

Z: Atomic number, Z =1 for hydrogen.

ε_o: Permittivity of free space = 8.849x10^{-12} farad / meter (F/m).

r: Radius of the orbit, in meter (m).

Centripetal force: mv^2/r, This force is resulting from the circular motion of the electron, (Fig. 2.5).

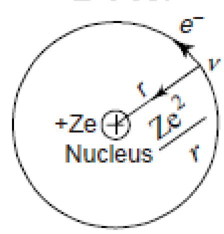

Figure 5