Chapter – 04 STRUCTURE OF THE ATOM

The Structure of an Atom :- For explaining the atomic structure, many scientists proposed various atomic models. J.J. Thomson was the first one to propose a model for the structure of an atom.

Thomson's model of an atom :- Thomson proposed the model of an atom to be similar to that of a Christmas pudding. The electrons, in a sphere of positive charge, were like currants (dry fruits) in a spherical Christmas pudding. We can also think of a watermelon, the positive charge in the atom is spread all over like the red edible part of the watermelon, while the electrons are studded in the positively charged sphere, like the seeds in the watermelon

Thomson proposed that -
(i) An atom consists of a positively charged sphere and the electrons are embedded in it.
(ii) The negative and positive charges are equal in magnitude. So, the atom as a whole is electrically neutral.

Drawbacks :-
Although Thomson's model explained that atoms are electrically neutral, the results of experiments carried out by other scientists could not be explained by this model.

Rutherford's model of an atom :- Ernest Rutherford was interested in knowing how the electrons are arranged within an atom. Rutherford designed an experiment for this.
In this experiment, fast moving alpha (α)-particles were made to fall on a thin gold foil.

- He selected a gold foil because he wanted as thin a layer as possible. This gold foil was about 1000 atoms thick.
- α-particles are doubly-charged helium ions. Since they have a mass of 4 u, the fast-moving α-particles have a considerable amount of energy.
- It was expected that α-particles would be deflected by the sub-atomic particles in the gold atoms. Since the α-particles were much heavier than the protons, he did not expect to see large deflections.

But, the α-particle scattering experiment gave totally unexpected results. The following observations were made:

(i) Most of the fast moving α-particles passed straight through the gold foil.
(ii) Some of the α-particles were deflected by the foil by small angles.
(iii) Surprisingly one out of every 12000 particles appeared to rebound.

Rutherford concluded from the α-particle scattering experiment that–

(i) Most of the space inside the atom is empty because most of the α-particles passed through the gold foil without getting deflected.
(ii) Very few particles were deflected from their path, indicating that the positive charge of the atom occupies very little space.
(iii) A very small fraction of α-particles were deflected by 1800, indicating that all the positive charge and mass of the gold atom were concentrated in a very small volume within the atom.

From the data he also calculated that the radius of the nucleus is about 10^5 times less than the radius of the atom. On the basis of his experiment, Rutherford put forward the nuclear model of an atom, which had the following features -

(i) There is a positively charged centre in an atom called the nucleus. Nearly all the mass of an atom resides in the nucleus.
(ii) The electrons revolve around the nucleus in circular paths.
(iii) The size of the nucleus is very small as compared to the size of the atom.

Drawbacks of Rutherford's model of the atom :- The revolution of the electron in a circular orbit is not expected to be stable. Any particle in a circular orbit would undergo acceleration. During acceleration, charged particles would radiate energy. Thus, the revolving electron would lose energy and finally fall into the nucleus. If this were so, the atom should be highly unstable and hence matter would not exist in the form that we know. We know that atoms are quite stable.

Bohr's model of atom :- Neils Bohr put forward the following postulates about the model of an atom:

(i) Only certain special orbits known as discrete orbits of electrons, are allowed inside the atom.
(ii) While revolving in discrete orbits the electrons do not radiate energy.

These orbits or shells are called energy levels. These orbits or shells are represented by the letters K,L,M,N,… or the numbers, n=1,2,3,4,….

NEUTRONS :- In 1932, J. Chadwick discovered another subatomic particle which had no charge and a mass nearly equal to that of a proton. It was eventually named as neutron. Neutrons are present in the nucleus of all atoms, except hydrogen. In general, a neutron is represented as 'n'. The mass of an atom is therefore given by the sum of the masses of protons and neutrons present in the nucleus.

Distribution of electrons into different orbits :- The distribution of electrons into different orbits of an atom was suggested by Bohr and Bury. The following rules are followed for writing the number of electrons in different energy levels or shells

(i) The maximum number of electrons present in a shell is given by the formula $2n^2$, where 'n' is the orbit number or energy level index, 1,2,3,…. Hence the maximum number of electrons in different shells are as follows:
first orbit or K-shell will be = 2 × 12 = 2,
second orbit or L-shell will be = 2 × 22 = 8,
third orbit or M-shell will be = 2 × 32 = 18,
fourth orbit or N-shell will be = 2 × 42= 32, and so on.

(ii) The maximum number of electrons that can be accommodated in the outermost orbit is 8.

(iii) Electrons are not accommodated in a given shell, unless the inner shells are filled. That is, the shells are filled in a step-wise manner.

Valency :- The electrons in an atom are arranged in different shells/orbits. The electrons present in the outermost shell of an atom are known as the valence electrons.

The combining capacity of the atoms of other elements, that is, their tendency to react and form molecules with atoms of the same or different elements, is an attempt to attain a fully-filled outermost shell.

An outermost-shell, which had eight electrons was said to possess an octet. Atoms react to achieve an octet in the outermost shell. This was done by sharing, gaining or losing electrons.

An atom of each element has a definite combining capacity, called its valency.

Atomic number :- Protons are present in the nucleus of an atom. It is the number of protons of an atom, which determines its atomic number. It is denoted by 'Z'. All atoms of an element have the same atomic number, Z. Elements are defined by the number of protons they possess.

For hydrogen, Z = 1, because in hydrogen atom, only one proton is present in the nucleus.
Similarly, for carbon, Z = 6.

The atomic number is defined as the total number of protons present in the nucleus of an atom.

Mass number :- Mass of an atom is practically due to protons and neutrons alone. These are present in the nucleus of an atom. Hence protons and neutrons are also called nucleons. Therefore, the mass of an atom resides in its nucleus.

For example, mass of carbon is 12 u because it has 6 protons and 6 neutrons, 6 u + 6 u = 12 u.

Similarly, the mass of aluminium is 27 u (13 protons+14 neutrons).

The mass number is defined asthe sum of the total number of protons and neutrons present in the nucleus of an atom.

In the notation for an atom, the atomic number, mass number and symbol of the element are to be written as:

Mass Number
$\boxed{\text{Symbol of element}}$
Atomic Number

For example, nitrogen is written as ${}^{14}_{7}N$.

Isotopes :- In nature, a number of atoms of some elements have been identified, which have the same atomic number but different mass numbers.
For example, hydrogen atom has three atomic species, namely protium (${}^{1}_{1}H$), deuterium (${}^{2}_{1}H$ or D) and tritium (${}^{3}_{1}H$ or T).
The atomic number of each one is 1, but the mass number is 1, 2 and 3, respectively. Other such examples are
(i) carbon, ${}^{12}_{6}C$ and ${}^{14}_{6}C$, (ii) chlorine, ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$, etc.

On the basis of these examples, isotopes are defined as the atoms of the same element, having the same atomic number but different mass numbers. Many elements consist of a mixture of isotopes. Each isotope of an element is a pure substance. The chemical properties of isotopes are similar but their physical properties are different.
Chlorine occurs in nature in two isotopic forms, with masses 35 u and 37 u in the ratio of 3:1.

Applications :- Since the chemical properties of all the isotopes of an element are the same, normally we are not concerned about taking a mixture. But some isotopes have special properties which find them useful in various fields. Some of them are :

(i) An isotope of uranium is used as a fuel in nuclear reactors.
(ii) An isotope of cobalt is used in the treatment of cancer.
(iii) An isotope of iodine is used in the treatment of goiter.

Isobars :- Atoms of different elements with different atomic numbers, which have the same mass number, are known as isobars.

Calcium, atomic number 20, and argon, atomic number 18. The number of electrons in these atoms is different, but the mass number of both these elements is 40. That is, the total number of nucleons is the same in the atoms of this pair of elements.