CH – 4 STRUCTURE OF ATOM

Structure of Atom

The existence of different kinds of matter is due to different atoms constituting them. Two questions arise:

(i) What makes the atom of one element different from the atom of another element? and

(ii) Are atoms really indivisible, or are there smaller constituents inside the atom?

One of the first indications that atoms are not indivisible, comes from studying static electricity and the condition under which electricity is conducted by different substances.

Charged Particles in Matter

Many scientists contributed in revealing the presence of charged particles in an atom. It was known by 1900 that the atom was not a simple, indivisible particle but contained at least one sub-atomic particle – the electron identified by J.J. Thomson.

E. Goldstein in 1886 discovered the presence of new radiations in a gas discharge and called them canal rays. These rays were positively charged radiations which ultimately led to the discovery of another sub-atomic particle. This sub-atomic particle had a charge, equal in magnitude but opposite in sign to that of the electron. Its mass was approximately 2000 times as that of the electron. It was given the name of proton. In general, an electron is represented as 'e–' and a proton as 'p+'. The mass of a proton is taken as one unit and its charge as plus one. The mass of an electron is considered to be negligible and its charge is minus one.

The Structure of an Atom

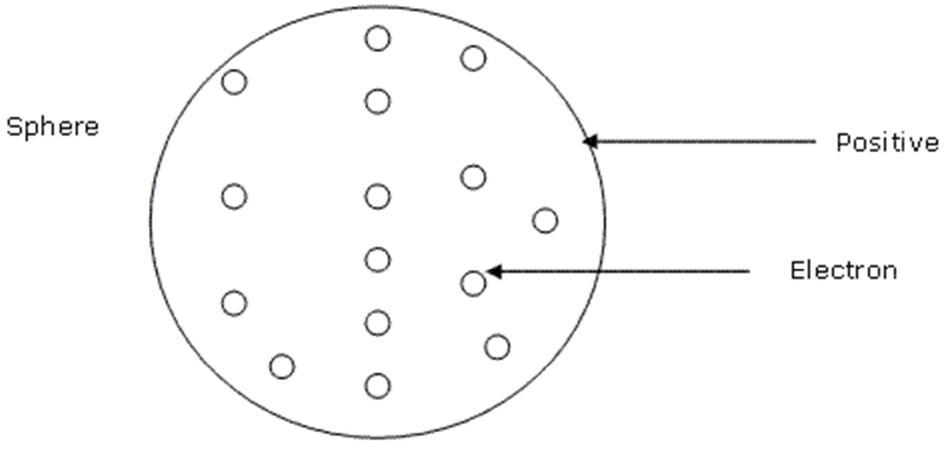
J.J. Thomson was the first one to propose a model for the structure of an atom.

THOMSON’S MODEL OF AN ATOM

Thomson proposed 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. 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.



Thomsan’s model of and atom.

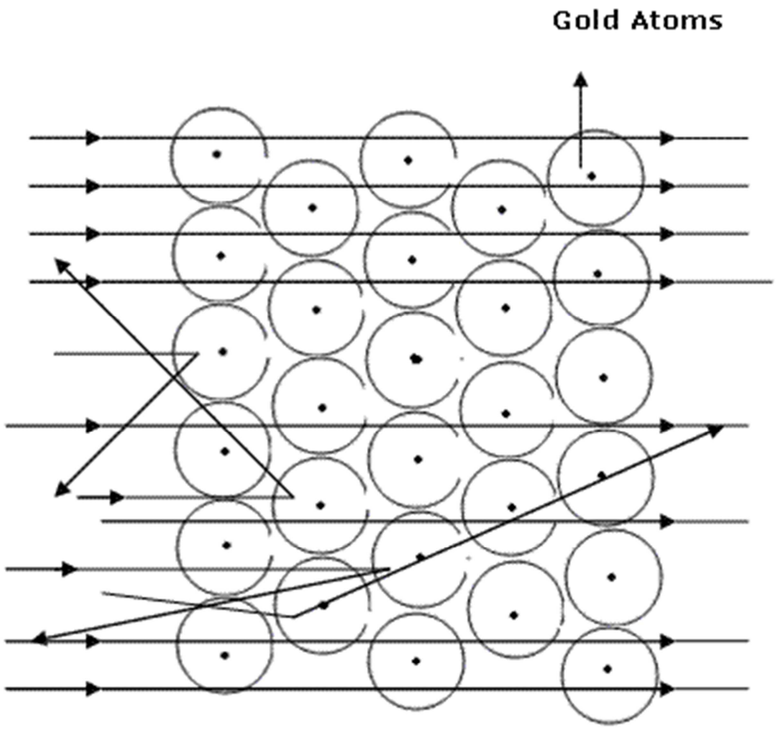
RUTHERFORD’S MODEL OF AN ATOM

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.



Scattering of α particles by a Gold foil

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.

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 well-defined orbits.

(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

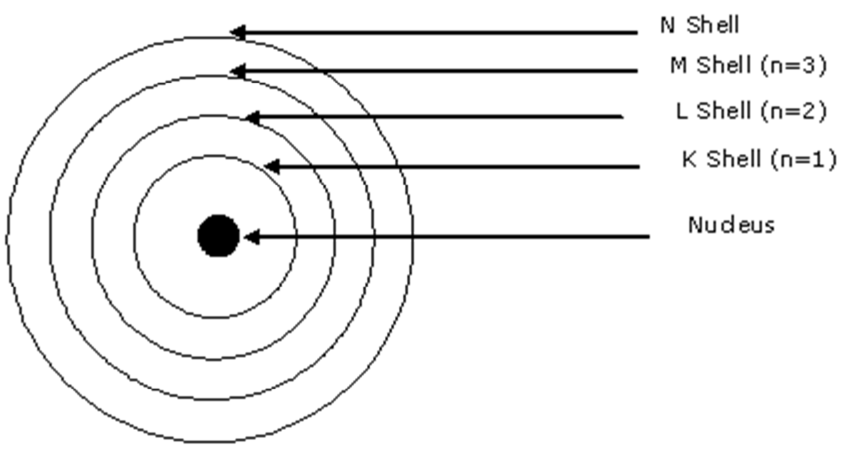
The orbital revolution of the electron is not expected to be stable. Any particle in a circular orbit would undergo acceleration. During acceleration, charged particles would radiate energy. Thus, the revolving electron would lose energy and finally fall into the nucleus. If this were so, the atom should 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

In order to overcome the objections raised against Rutherford's model of the 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.



A few energy levels in an Atom

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.

How are Electrons Distributed in Different Orbits (Shells)?

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 2n2, 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 = $2 \times 1^2 = 2$,

second orbit or L-shell will be = $2 \times 2^2 = 8$,

third orbit or M-shell will be = $2 \times 3^2 = 18$,

fourth orbit or N-shell will be = $2 \times 4^2 = 32$, 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 present in the outermost shell of an atom are known as the valence electrons. Valency or valency number, is a measure of the number of chemical bonds formed by the atoms of a given element.

According to Bohr-Bury, outermost shell of an atom can have two electrons in its outermost shell and all other elements have atoms with eight electrons in the outermost shell. 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 was thus explained as an attempt to attain a fully-filled outermost shell. An outermost-shell, which had eight electrons was said to possess an octet. Atoms would thus react, so as to achieve an octet in the outermost shell. This was done by sharing, gaining or losing electrons. The number of electrons gained, lost or shared so as to make the octet of electrons in the outermost shell, gives us directly the combining capacity of the element.

For example, hydrogen/lithium/sodium atoms contain one electron each in their outermost shell, therefore each one of them can lose one electron. So, they are said to have valency of one. If the number of electrons in the outermost shell of an atom is close to its full capacity, then valency is determined in a different way. For example, the fluorine atom has 7 electrons in the outermost shell, and its valency could be 7. But it is easier for fluorine to gain one electron instead of losing seven electrons. Hence, its valency is determined by subtracting seven electrons from the octet and this gives a valency of one for fluorine. Valency can be calculated in a similar manner for oxygen. Therefore, an atom of each element has a definite combining capacity, called its valency.

Atomic Number and Mass Number

ATOMIC NUMBER- The number of protons in the nucleus of an atom determines an element's atomic number. Each element has a unique number that identifies how many protons are in one atom of that element. For example, all hydrogen atoms, and only hydrogen atoms, contain one proton and have an atomic number of 1. All carbon atoms, and only carbon atoms, contain six protons and have an atomic number of 6. Oxygen atoms contain 8 protons and have an atomic number of 8. The atomic number of an element never changes, meaning that the number of protons in the nucleus of every atom in an element is always the same.

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 aluminum is 27 u (13 protons+14 neutrons). The mass number is defined as the sum of the total number of protons and neutrons present in the nucleus of an atom.

All atoms have a mass number which is derived as follows.

Number of Neutrons + Number of Protons = Mass Number