

CHAPTER – 5



Structure of the atom

In the previous chapters, we have already learnt that matter is made up of molecules which in turn are made up of atoms. The existence of different kinds of matter is due to differences in atoms constituting them.

Then, what makes the atom of one element different from the atom of another element?

Are atoms really indivisible as proposed by Dalton, or are there smaller constituents inside the atom?

5.1. Charged particles in matter:

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

Activity 5.1.

- A. (i) Take a glass or ebonite rod and rub it with a silk or fur cloth.
(ii) Immediately bring the rod near an inflated balloon.
(iii) Observe what happens.
- B. (i) With a plastic comb, comb your hair (dry hair), and bring it near small pieces of paper.
(ii) Does the comb then attract small pieces of paper?

From the above activities, we can conclude that on rubbing two objects together, they become electrically charged.

Where does this charge come from?

In 1830, Michael Faraday showed that chemical changes occur when electricity is passed through certain solutions called electrolytes. For example, when electricity is passed through water containing a little acid, it is decomposed into hydrogen and oxygen gas. He could calculate the mass of a substance produced by a given quantity of electricity. Thus, Faraday for the first time established relationship between electricity and matter. He stated that electricity is made up of particles called "atoms of electricity". In 1874 G.J. Stoney suggested the name *electron* for the atoms of electricity. However the real credit for the discovery of electron goes to J.J. Thomson.

5.1.1. Discovery of electron:

In 1878, William Crookes, noted that gases are ordinarily poor conductors of electricity. However, when a high voltage charge from an induction coil is applied to tubes filled with gases at very low pressure, it resulted in the production of new kinds of rays. Since these rays travel *from the cathode towards the anode*, they are called cathode rays. Later J. J. Thomson studied the characteristics and the constituents of cathode rays. The apparatus used by him is shown in Fig. 5.1 and the tube used is called a *discharge tube* or a *cathode ray tube*. The cathode rays were found to possess the following characteristic properties (Fig. 5.2, 5.3, 5.4).

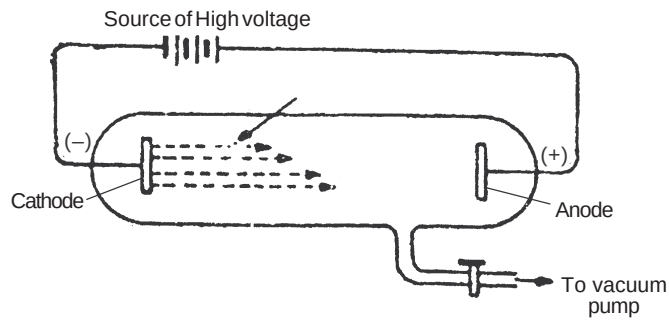


Fig. 5.1. Production of cathode rays

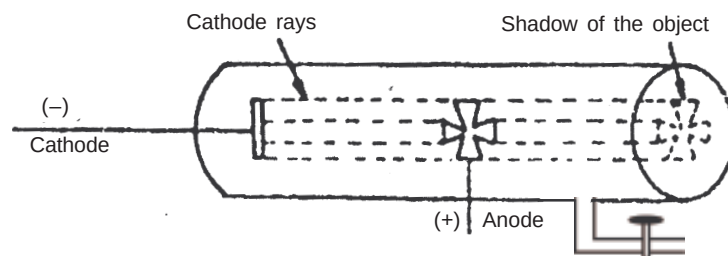


Fig. 5.2. An object in the path of beam of Cathode rays cast a shadow.

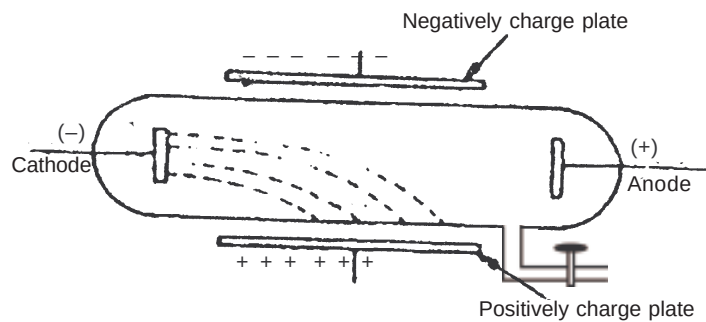


Fig. 5.3. Deflection of the Cathode rays towards a positively charged plate shows that these rays are negatively charged.

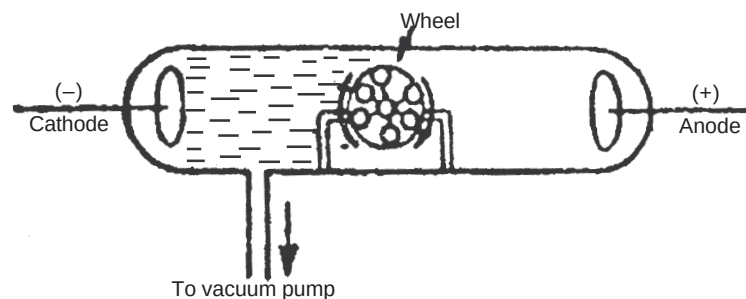


Fig. 5.4. Cathode rays moves a wheel. It shows that the rays consists of particles.

The cathode rays, like light, travelled in a straight line, cast shadows of obstacles but, unlike light, could be bent by electric and magnetic fields. It was thus clear that these rays consisted of charged particles.

Where did these particles come from?

The rays (particles) are emitted from the cathode irrespective of the nature of the metal electrode or the nature of the gas contained in the tube.

Thomson concluded that these negatively charged particles, now called *electrons* are an integral part of all atoms.

Electrons have both definite mass and definite electric charge. It has been found that the mass of the electron is nearly $1/1837$ of the mass of hydrogen atom. However, this mass is very small and for all practical purposes, it may be taken as negligible.

The charge of the electron is the smallest known electrical charge. For convenience, this charge has been assigned a value of -1 .

5.1.2. Discovery of Proton:

The formation of cathode rays has shown that all the atoms contain negatively charged particles called electrons. Now, since an atom is electrically neutral, it must contain some positively charged particles to balance the negative charge of electrons. It has actually been found by experiments that all the atoms contain positively charged particles called *protons*.

In 1886, E. Goldstein repeated the cathode ray tube experiment, using a perforated cathode. He demonstrated that positive rays were produced simultaneously with cathode rays. These rays travelled in opposite direction to the cathode (Fig. 5.5). He called these rays *Positive rays* or *Anode rays*.

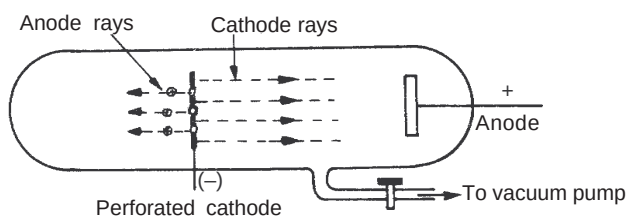


Fig. 5.5

Anode rays consist of positively charged particles. The mass and charge of the anode ray particles depend on the nature of the gas taken in the discharge tube. Different gases give different types of anode rays which contain positively charged particles having different masses and different charges.

Hydrogen gas is the lightest gas and hydrogen atom is the lightest atom. So, the positive particles obtained from hydrogen gas are the lightest and have the smallest charge. These particles were called *Protons*. Goldstein explained that a proton is formed by the removal of the electron from a hydrogen atom. Proton is also a fundamental particle found in the atoms of all the elements. It has been observed that positively charged particles obtained from gases other than hydrogen are multiples of protons.

This means that atoms of other gases consist of more than one proton.

It has been found that the proton is actually a hydrogen atom which has lost its electron. Since the mass of an electron is very small, we can say that the mass of a proton is equal to the mass of a hydrogen atom. But the mass of a hydrogen atom is 1 u, therefore, the relative mass of a proton is 1 u.

The charge carried by a proton has been found to be equal in magnitude but opposite in sign to that of an electron i.e., it has one unit positive charge (+1).

5.1.3. Discovery of the Nucleus (Rutherford's Experiment):

In 1896, Henry Becquerel while conducting experiments with uranium salts found that these salts gave out penetrating radiations spontaneously. The radiation was capable of passing through paper, or even thin sheets of metals, and affected a photographic plate. The phenomenon was called *radioactivity* and the element was called radioactive element.

Soon afterwards, scientists were able to show that three types of radiations called *alpha*, *beta* and *gamma* rays are emitted from radioactive elements. Alpha (α) and (β) were streams of positively and negatively charged particles whereas γ -rays carried no charge at all.

Ernest Rutherford was interested in knowing how the protons and electrons are arranged within an atom. In 1911, he directed a stream of alpha particles from a radioactive source towards a very thin gold foil (Fig. 5.6). (He selected a gold foil because he wanted as thin a layer as possible). Alpha particles are doubly – charged helium ions with mass 4 u.

The following observations were made from his experiment:

- (i) Most of the alpha (α) particles (nearly 99%) passed through the gold foil undeflected.
- (ii) A few of them got deflected through small angles.
- (iii) Very few (about one in 100,000) did not pass through the foil at all but suffered large deflections (more than 90 degrees) or even returned back in the direction from which they came.

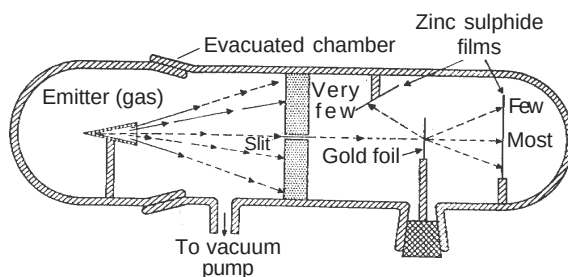


Fig.5.6. A schematic representation of several experiments in which gold foil was bombarded with a beam of alpha particles. Zinc sulphide emits a flash of light when struck by an alpha particle.

Can you correlate these facts and frame theories to explain these observations regarding structure of atom?

Rutherford explained these observations as follows:

- (i) Gold is a dense solid. It can hardly be compressed. It means that the atoms of gold actually touch one another (closely packed).
- (ii) Since most of the α -particles pass through the gold foil undeflected, there must be a very large empty space within the atom.
- (iii) Alpha particles are positively charged and have considerable mass. They can be deflected only if they come close to some heavy, positively charged mass, due to the force of repulsion. Since most of the α -particles are deflected to certain angles, it implies that there is a heavy, positively charged mass present in the atom. Moreover, this mass must be occupying a very small space within the atom because only a few particles suffered large deflections. The positively charged core in which the mass of the atom is concentrated and occupies a small volume in an atom is called the *nucleus*.
- (iv) The strong deflections, bouncing or even bouncing back of α -particles from the foil were explained to be the result of a direct collision with the positively charged nucleus of the atom.
- (v) The atoms themselves appear to be neutral, since gold is neither attracted nor repelled by charged bodies. It means that in each atom there are just enough electrons outside the positive nucleus to provide a balance of positive and negative charges.

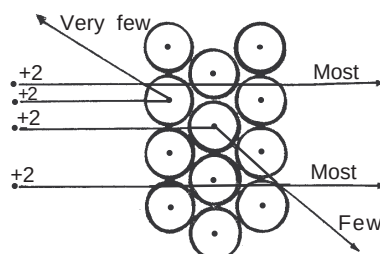


Fig. 5.7. Deflection of α -particles by gold atoms. Rutherford evolved the idea of an atom as a particle that has a definite radius and is mostly empty space, but has a tiny, massive, positive nucleus. The tiny dots at the left represent alpha particles, the spheres represent gold atoms, the tiny dots in the centre of each sphere is the nucleus of the atom.

Rutherford pictured the model of an atom (Fig. 5.7). He put forward the nuclear model of the atom which has the following features:

- (i) There is a tiny positively charged centre in an atom called the nucleus. Nearly all the mass of an atom is concentrated in the nucleus. The positive charge of the nucleus is due to the protons. The electrons revolve around the nucleus in well-defined orbits and forms the outside surface (extra nuclear part) of the atom.
- (ii) Between the nucleus and the outer electrons is empty space except for other electrons.

(iii) The size of the nucleus is very small compared to the size of the atom.

Present information, obtained largely from x-ray investigations, have indicated that the diameter of an atom is about 10^{-8} cm and that of the nucleus is about 10^{-13} cm, or only 1/100,000 that of the atom.

5.1.4. Atomic number:

Moseley, in 1913 tried to determine the exact number of positive charges present in the nucleus of an atom by studying the nature of the x-rays emitted when different elements were bombarded with cathode rays. (You will learn the details of the process in higher classes). Moseley stated that the "*number of positive charges on the nucleus increases from atom to atom by a single electronic unit*". The number of positive charges is now called the *atomic number* which is 1 for hydrogen, 2 for helium, 3 for lithium, and so on.

Since the subatomic positive particle is, the proton, and as each proton carries one unit positive charge, the *atomic number, then, is the number of protons in the nucleus of an atom*. Since the atom, on the whole, is neutral, the number of protons in the nucleus is equal to the number of electrons outside the nucleus. The atomic number is denoted by Z.

Thus the atomic number (Z) = Nuclear charge or number of protons.
= Number of electrons.

5.1.5. Discovery of Neutron:

Until 1920, an atom was supposed to consist of two fundamental particles i.e., electrons and protons only. Since electrons have negligible mass, the entire mass of the atom was regarded as the mass of protons in the nucleus. This means that the nucleus must contain protons equal to the mass of the atom (atomic mass). But, the number of protons is equal to the atomic number. This means that atomic mass should be equal to the atomic number. However, it has been found that for all atoms *except hydrogen, the atomic mass is more than the atomic number*. For example, the atomic number of helium is two and, thus, it should have two protons in the nucleus and two extra-nuclear electrons. Therefore, the helium atom should have a mass twice that of the hydrogen atom. However, its mass has been found to be 4 times that of the hydrogen atom (atomic mass of He = 4 u). To solve this problem, Rutherford predicted the presence of some *neutral* particle in the nucleus of the atom.

The neutral particle called *neutron*, was discovered by James Chadwick in 1932 when he bombarded a thin foil of beryllium metal with α -particles.

The neutral particle (neutron) was found to have a mass which is nearly the same as that of hydrogen but no charge.

The discovery of neutrons made it clear that the nucleus of the atom consists of protons and neutrons. Since the electrons have negligible mass, the entire mass of the atom is mainly due to protons and neutrons present in the nucleus. They are collectively called **nucleons*. *The sum of the number of protons and neutrons present in the nucleus of an atom is called the mass number*. The mass number is denoted by (A).

* A few other particles like positrons, mesons, neutrinos etc. were also found to be present in the nucleus at a later stage. But since they have negligible mass, the mass of the nucleus is due to protons and neutrons only.

Thus mass number (A) = No. of protons + No. of neutrons.

It may be noted that the mass number of an element is nearly same as its atomic mass but the latter has certain units of measurements. However, whereas the mass number is always a whole number, the atomic mass of the element may not be whole number always.

From the above studies, it can be summed up that an atom consists of three fundamental particles — electrons, protons and neutrons. Their masses and charges are given in Table 5.1.

Table 5.1. Fundamental Particles of an Atom

Particle	Mass		Charge (unit charge is 1.062×10^{-19} coulombs)
	in gram	in u (amu)	
Electron	9.110×10^{-28}	0.00055	– 1
Proton	1.673×10^{-24}	1.00728	+ 1
Neutron	1.675×10^{-24}	1.00866	No charge

If we know the atomic number and the mass number of an element, we can calculate the number of protons, electrons and neutrons present in the atom.

Example 5.1

The atomic number and the mass number of the element aluminium (Al) is 13 and 27 respectively. How many protons, electrons and neutrons are present in the atom?

Solution:

We know that,

$$\text{Atomic no.} = \text{No. of protons} = \text{No. of electrons}$$

$$\therefore \text{No. of protons} = 13$$

$$\text{No. of electrons} = 13$$

$$\text{Mass no.} = \text{No. of protons} + \text{No. of neutrons}$$

$$\therefore \text{Number of neutrons} = 27 - 13$$

$$= 14.$$

The atomic number and mass number of the first twenty elements are given in Table 5.2.

It is customary to designate an atom by its symbol for the element with the atomic number (Z) at the lower left and the mass number (A) written at the upper left. For example, the element carbon C with mass number 12 and atomic number 6 may be written as

$$\text{Mass number} \rightarrow 12$$

$$\text{Atomic number} \rightarrow 6^{\text{C}}$$

Table 5.2. Atomic numbers (Z) and mass numbers (A) of first twenty elements.

Atomic No.	Element	Mass No.	Notation
1	H	1	${}^1_1\text{H}$
2	He	2	${}^4_2\text{He}$
3	Li	7	${}^7_3\text{Li}$
4	Be	9	${}^9_4\text{Be}$
5	B	11	${}^{11}_5\text{B}$
6	C	12	${}^{12}_6\text{C}$
7	N	14	${}^{14}_7\text{N}$
8	O	16	${}^{16}_8\text{O}$
9	F	19	${}^{19}_9\text{F}$
10	Ne	20	${}^{20}_{10}\text{Ne}$
11	Na	23	${}^{23}_{11}\text{Na}$
12	Mg	24	${}^{24}_{12}\text{Mg}$
13	Al	27	${}^{27}_{13}\text{Al}$
14	Si	28	${}^{28}_{14}\text{Si}$
15	P	31	${}^{31}_{15}\text{P}$
16	S	32	${}^{32}_{16}\text{S}$
17	Cl	35	${}^{35}_{17}\text{Cl}$
18	Ar	39	${}^{39}_{18}\text{Ar}$
19	K	39	${}^{39}_{19}\text{K}$
20	Ca	40	${}^{40}_{20}\text{Ca}$

5.1.6. Isotopes and Isobars:

One of the postulates of Dalton's atomic theory states that atoms of the same element are identical in all respects. But later investigations by scientists have shown that there are elements in which atoms have the same number of protons but different number of neutrons. This means that the atoms have the same atomic number but different mass numbers.

The atoms of the same element having the same atomic number but different mass numbers are called isotopes of the element.

Many isotopes were discovered with the help of an instrument called *mass spectrometer*. Hydrogen has been found to have three isotopes known as *protium* (ordinary hydrogen), *deuterium* and *tritium* having mass numbers 1, 2 and 3 respectively. The first isotope contains one proton only ($Z = 1$, $A = 1$), the second contains 1 proton and 1 neutron ($Z = 1$, $A = 2$), and the third has one proton and two neutrons ($Z = 1$, $A = 3$). The term "hydrogen" is strictly used only for the first isotope (${}^1_1\text{H}$) while Deuterium (${}^2_1\text{D}$) and Tritium (${}^3_1\text{T}$) are used to refer to the second and third isotopes respectively. These may be shown as:

Subatomic particles	ISOTOPES		
	${}^1_1\text{H}$ (hydrogen)	${}^2_1\text{H}$ or ${}^2_1\text{D}$ (deuterium)	${}^3_1\text{H}$ or ${}^3_1\text{T}$ (tritium)
Proton	1	1	1
Neutron	0	1	2
Electron	1	1	1

Each of them has only one proton and one electron, but differs in the number of neutrons.

The isotopes of other elements do not have special names. They are indicated by giving mass numbers (A value) on the symbol of the element. For example, ${}^{12}\text{C}$ and ${}^{14}\text{C}$ are the isotopes of carbon, they are known as carbon -12 and carbon -14 respectively. ${}^{235}\text{U}$, ${}^{238}\text{U}$ and ${}^{239}\text{U}$ are the isotopes of uranium having mass numbers 235, 238 and 239 respectively.

Many elements consists of atoms which are isotopes, that is, elements are made up of a mixture of isotopes. The chemical properties of isotopes are similar since they have the same number of protons and electrons. Their electronic arrangements are same.

However, the physical properties of the isotopes of an element may be slightly different due to difference in their mass numbers.

When an element has isotopes, question arises, what should be the atomic mass of the element? For example, chlorine occurs in nature in two isotopic forms, with masses 35 u and 37 u in the ratio of 3:1. The mass of an atom of any natural element is taken as the average mass of all the naturally occurring atoms (Isotopes) of that element.

The average atomic mass of chlorine atom on the basis of the above data will be

$$\left[\left(35 \times \frac{75}{100} \right) + \left(37 \times \frac{25}{100} \right) \right] \text{ or } \frac{35 \times 3 + 37 \times 1}{4} \text{ or } 35.5 \text{ u.}$$

It does not mean that any one atom of chlorine has a fractional mass of 35.5 u. It means that if we take a certain amount of chlorine, it will contain both isotopes of chlorine and the average mass is 35.5 u.

Since the chemical properties of all the isotopes of an element are the same, normally we are not concerned about taking a mixture.

However, there are two types of isotopes. One type of isotopes are stable but another type is unstable. The unstable isotopes emit various types of radiations and penetrating particles. They are called *radioactive isotopes* or just *radioisotopes*. Depending on their special properties, some isotopes are found useful in various fields. Examples include:

- (i) Use of an isotope of uranium known as Uranium-235 as fuel in nuclear reactors.
- (ii) An isotope of cobalt known as cobalt-60 is used in the treatment of cancer.
- (iii) An isotope of iodine (iodine-131) finds application in the treatment of diseases like goitre.

Isobars:

Atoms of different elements i.e., atoms having different atomic numbers may have the same mass number. These atoms are called *isobars*. For example, $^{14}_6\text{C}$ and $^{14}_7\text{N}$ do not have the same atomic number, but they have the same mass number. Hence they are isobars of each other. $^{40}_{18}\text{Ar}$, $^{40}_{19}\text{K}$, $^{40}_{20}\text{Ca}$ are also isobars.

Let us answer these:

- Who proposed the atomic theory?
- From which electrode do the cathode rays originate?
- What happens to cathode rays when they are subjected to an electric field?
- What is the charge of an electron?
- Where is the mass of an atom concentrated?
- What are the particles present in the nucleus of an atom?
- Where are the electrons in an atom found?
- Which atom contains only two fundamental particles?
- What led Rutherford to discover the existence of nucleus?
- Define:
 - atomic number and
 - mass number.
- What are isotopes? Give one example.
- What are cathode rays and how do they differ from positive rays?
- Give experimental evidence to show that:
 - the entire mass of an atom is practically concentrated in the nucleus.
 - the nucleus of an atom is positively charged.
- Derive a relationship between atomic number, mass number and number of neutrons in an atom.
- How many protons, electrons and neutrons are there in the following atoms?
 $^{14}_7\text{N}$, $^{12}_6\text{C}$, $^{14}_6\text{C}$, $^{14}_8\text{O}$, $^{16}_8\text{O}$, $^{40}_{19}\text{K}$, $^{40}_{18}\text{Ar}$
 Which of these are
 - isotopes and
 - isobars.

5.2. Models of atom:

Dalton's atomic theory had suggested that the atom was indivisible and indestructible. Now at least three fundamental particles (electrons, protons and neutrons) have been discovered to be present inside the atom.

How far Dalton's atomic theory will be tenable in respect of this postulate?

It is considered necessary to find out how electrons, protons (and neutrons) are arranged within an atom. For explaining this, many scientists proposed various atomic models.

5.2.1. Thomson's Model:

An atom is electrically neutral. It contains positive charges (due to the presence of protons), as well as, negative charges (due to the presence of electrons). Hence, J. J. Thomson assumed that *an atom is a uniform sphere of positive charges with electrons embedded in it.**

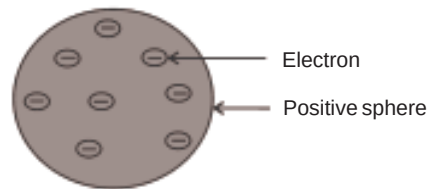


Fig. 5.8 Thomson's model of an atom.

Thus, the atom may be visualised as a pudding or cake of positive charge with raisins (electrons) embedded into it (Fig. 5.8).

This model of atom explains the electrical neutrality of atom, but it failed to stand for a long time as it was not consistent with the experimental results obtained by Rutherford.

5.2.2. Rutherford's model:

With the discovery of the nucleus, Rutherford proposed an atomic model similar to the structure of solar system. Just as in the solar system, the sun is at the centre (having the maximum mass) and the planets revolve around it, in an atom, the nucleus contains the main mass and the electrons revolve around it in orbits or shells.

The outward (centrifugal) force acting on the electrons balances the inward (centripetal) force of attraction exerted on them by the nucleus. This accounts for the stability of an atom.

The Rutherford's model of atom suffers from the following defects:

Any particle in a circular orbit would undergo acceleration. According to the electromagnetic theory, if a charged particle (electron) is accelerated around an oppositely charged particle (nucleus), the electron would continuously radiate or lose energy. So, the revolving electron continuously losing energy will gradually come closer to the nucleus 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 now. But, in reality, this does not happen, we know that atoms are quite stable.

5.2.3. Bohr's model of atom:

In order to remove the drawbacks of Rutherford's model of the atom, Niels Bohr proposed a theory for the structure of atom. According to this theory:

- (i) The nucleus is situated at the centre of the atom.
- (ii) The electrons revolve around the nucleus in definite circular fixed orbits. These orbits are associated with definite energies and are called *energy shells* or *energy levels*.

* At Thomson's time, no neutron was discovered. Hence, this model of atom later became known as the "raisin pudding" model.

(iii) The orbits or shells are numbered as 1, 2, 3, 4etc. (from the nucleus) or alternatively these are designated as K, L, M, N.....etc. shells (Fig. 5.9).

(iv) As long as electron remains in a particular orbit, it does not lose or gain energy. This means that the energy of the electron in a particular energy level shall remain constant. Therefore, these orbits are also called *stationary states*.

(v) To change from one orbit to another the electron must absorb or emit a quantity of energy exactly equal to the difference in energy between the two orbits.

This model of the atom explains satisfactorily the stability of the atom.

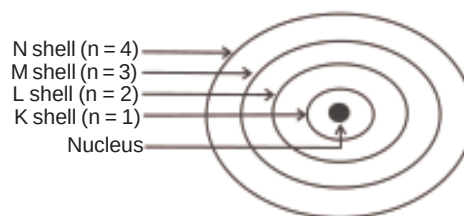


Fig. 5.9. A few energy levels in an atom.

Let us answer these:

1. Which subatomic particle was not present in Thomson's model of the atom?
2. State one drawback of Rutherford's model of atom.
3. Why is an atom neutral inspite of the presence of charged particles in it?
4. How did Neils Bohr explain the stability of the atom?
5. What are the various letters used in Bohr's model to represent electron shells in an atom?
6. Draw a sketch of Bohr's model of an atom with three shells.

5.3. How are electrons distributed in different orbits (shells)?

Based on several experimental observations, Bohr and Bury suggested a scheme for the distribution of electrons in different orbits or shells (energy levels). The scheme consists of the following rules.

- (i) The maximum number of electrons that can be present in a shell is given by the formula $2n^2$, where 'n' is the orbit number or energy level index, 1, 2, 3.....

Thus,

For the first orbit ($n = 1$) or K-shell, maximum number of electrons = $2 \times 1^2 = 2$.

For the 2nd orbit ($n = 2$) or L-shell, maximum number of electrons = $2 \times 2^2 = 8$.

For the 3rd orbit ($n = 3$) or M-shell, maximum number of electrons = $2 \times 3^2 = 18$.

For the 4th orbit ($n = 4$) or N-shell, maximum number of electrons = $2 \times 4^2 = 32$, and so on.

- (ii) The maximum number of electrons that can be accommodated in the outermost orbit is 8 and the next to outermost known as penultimate orbit cannot have more than 18 electrons.
- (iii) It is not necessary for an orbit to be completed before the next orbit starts filling. In fact, a new orbit begins when the previous orbit gets 8 electrons.

5.3.1. Electronic configuration of atoms (Elements):

The hydrogen atom, the lightest of all atoms has one proton in the nucleus and one electron revolving around it. The electron occupy K-shell. A helium atom has a nucleus containing 2 protons and 2 neutrons. Both the electrons revolving around the nucleus are accommodated in the K-shell according to the $2n^2$ rule. (Fig. 5.10).

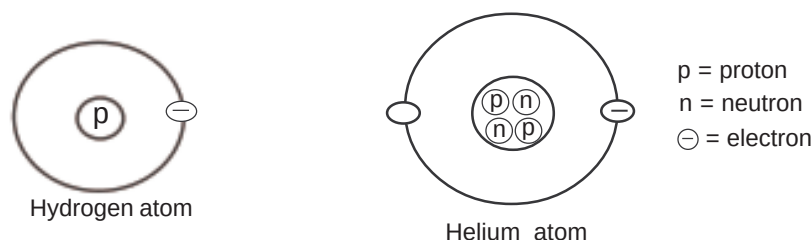
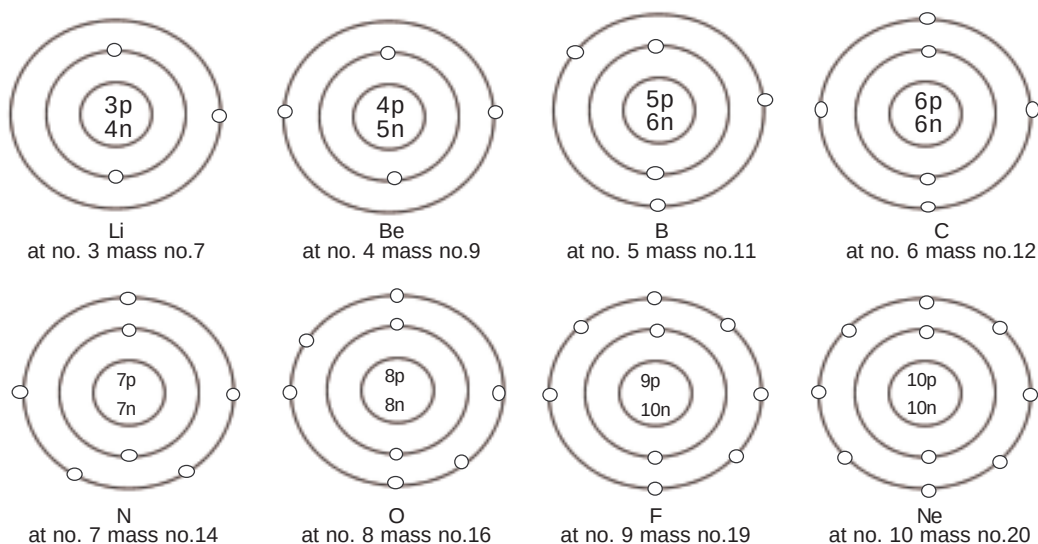


Fig. 5.10.

The distribution of electrons in various shells of an atom is known as its electronic configuration. The precise details of the electronic configuration of atoms will only be dealt in higher classes.

Atomic structures of Lithium to Neon:

For lithium ($Z=3$), the atom contains 3 electrons. The first 2 electrons are accommodated in the K-shell since it can take in a maximum of 2 electrons only according to the $2n^2$ rule. Now the third electron is naturally accommodated in the L-shell. The electronic structure of the atoms of elements from Li to Ne are shown below



After neon, the next electron goes to the third orbit. The electronic structure of sodium (at.no.11) to Argon (at.no.18) may be shown as follows:

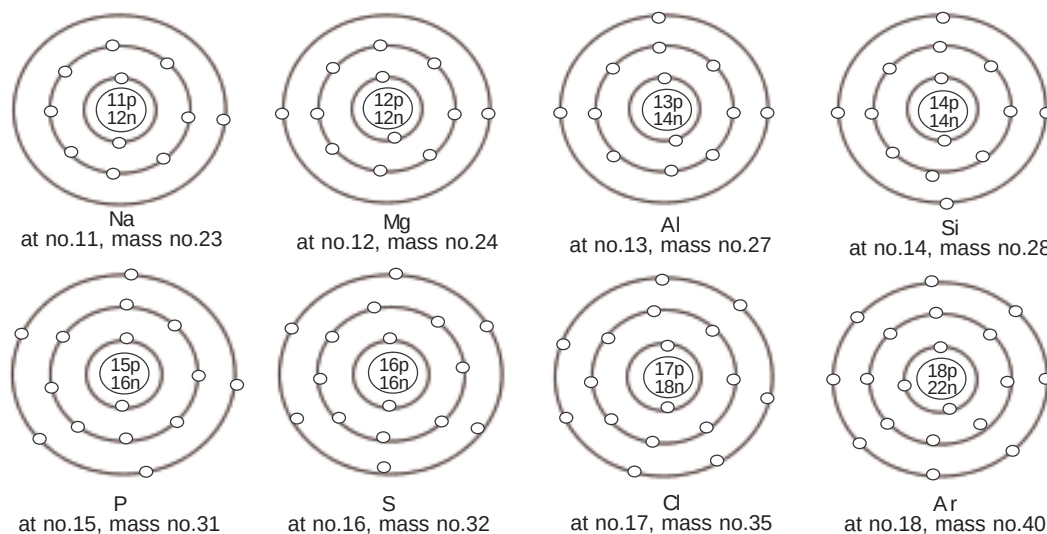


Fig. 5. 11

Exercise:

Write the electronic configurations of potassium ($Z = 19$) and Calcium ($Z = 20$)

Solution:

Element	Symbol	At no.	Electrons in shells K, L, M, N			
Potassium	K	19	2	8	8	1
Calcium	Ca	20	2	8	8	2

Let us answer these:

1. Write the distribution of electrons in oxygen and sodium atoms.
2. An atom has 2 and 7 electrons in the K and L shells respectively, then what would be the atomic number of the element? Name the element.

5.4. Valence electrons

We have learnt that atoms combine to form molecules. At what part of the atom will the combination take place? Naturally, it will be the outermost shell of an atom. The outermost electron shell of an atom is known as *valence shell*. *The electrons present in the outermost shell of an atom are known as valence electrons because they determine the combining capacity or valency of the atom.* Only the valence electrons of an atom take part in chemical combinations because they have more energy than the inner electrons of the atom.

From Bohr-Bury scheme, we know that the outermost shell of an atom can accommodate a maximum of 8 electrons except when the outermost shell is K-shell and it can hold a maximum of 2 electrons only. It has been observed that the atoms of elements, having a completely filled outermost shell i.e. 8 electrons show little chemical activity. An

outermost shell, which had eight electrons was said to possess an octet in the outermost shell. In other words, the valency of the atoms having octet in their valence shells are zero. These elements are known as *inert* or *noble elements*. Helium, neon, argon, krypton, xenon are inert elements. Since they are all gases, they are also known as inert or noble gas elements. Of these inert elements, the helium atom has two electrons in its outermost shell i.e. K-shell for which it represents full or stable structure.

The combining capacity of the atoms of an element is the tendency to react or form molecules with other atoms of the same or different elements. It was thus explained as the tendency to attain a fully filled outermost shell or stable structure, i.e. octet of electrons in the outermost shell (except Helium structure).

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 or valency of the element.

Example:5.1. What will be the valency of lithium, sodium and potassium?

Solution:

Lithium ($Z = 3$), sodium ($Z = 11$) and potassium ($Z = 19$) atoms contain one electron in each of their outermost orbit or shell (Valence shell).

Li ($Z = 3$): K-2, L-1.

Na ($Z = 11$): K-2, L-8, M-1.

K ($Z = 19$): K-2, L-8, M-8, N -1.

Each one of them can lose one electron to achieve stable structure.

They have valency of one.

Example 5.2. What will be the valency of Magnesium and Aluminium?

Solution:

Electronic arrangement (configuration) of:

Mg ($Z = 12$) atom is K-2, L= 8, M = 2. and Al ($Z = 13$) atom is K-2, L = 8, M = 3.

The valence electrons of Mg and Al are 2 and 3 respectively.

Hence, the valency of Mg and Al will be 2 and 3 respectively.

If the number of electrons in the outermost shell of an atom is close to its full capacity, i.e., octet, then the valency is determined in a different way.

Example 5.3. What will be the valency of fluorine ($Z = 9$)?

Solution:

Fluorine (at.no. 9) has the configuration: K = 2, L = 7. Fluorine atom has 7 electrons in the outermost (valence) shell. It is easier for fluorine to gain one electron instead of losing seven electrons.

Hence, the valency of fluorine is determined by subtracting seven electrons from the octet and gives us a valency of 1 for fluorine.

Valency can be calculated in a similar manner for atoms having outermost shell (valence shell) close to its full capacity (octet).

Example 5.4

What will be the valency of oxygen?

Solution:

The electric configuration of oxygen ($Z = 8$) is : $K = 2, L = 6$.

Oxygen has 6 valence electrons, short of 2 electrons to get octet.

Hence, valency of oxygen = $(8 - 6) = 2$.

Therefore, an atom of each element has a definite combining capacity, called valency. The valency is related to the number of electrons in the outermost orbit or shell of an atom.

Electronic arrangement in various shells (or electronic configuration of atoms) and the composition of the first twenty elements and their valencies are given in Table 5.3.

Table 5.3. Composition of atoms of the first twenty elements with electron distribution in various shells and their valency.

Sl No.	Element	Symbol	Atomic no.	No. of Protons	No. of neutrons	No. of electron	Distribution of electrons				Valency
							K	L	M	N	
1	Hydrogen	H	1	1		1	1				1
2	Helium	He	2	2	2	2	2				0
3	Lithium	Li	3	3	4	3	2	1			1
4	Beryllium	Be	4	4	5	4	2	2			2
5	Boron	B	5	5	6	5	2	3			3
6	Carbon	C	6	6	6	6	2	4			4
7	Nitrogen	N	7	7	7	7	2	5			3
8	Oxygen	O	8	8	8	8	2	6			2
9	Fluorine	F	9	9	10	9	2	7			1
10	Neon	Ne	10	10	10	10	2	8			0
11	Sodium	Na	11	11	12	11	2	8	1		1
12	Magnesium	Mg	12	12	12	12	2	8	2		2
13	Aluminium	Al	13	13	14	13	2	8	3		3
14	Silicon	Si	14	14	14	14	2	8	4		4
15	Phosphorous	P	15	15	16	15	2	8	5		3,5
16	Sulphur	S	16	16	16	16	2	8	6		2
17	Chlorine	Cl	17	17	18	17	2	8	7		1
18	Argon	Ar	18	18	22	18	2	8	8		0
19	Potassium	K	19	19	20	19	2	8	8	1	1
20	Calcium	Ca	20	20	20	20	2	8	8	2	2

Let us answer these:

1. The nucleus of an atom has 7 protons 8 neutrons. What would be the
 - (i) atomic number
 - (ii) mass number,
 - (iii) the number of electrons, and
 - (iv) the number of valence electrons?
2. What is the general name of the elements having 8 electrons in the outermost shells of their atoms?
3. The atomic number of an element X is 15.
 - (i) Write down the electronic configuration of X.
 - (ii) What will be the valency of X?
4. How will you find the valency of chlorine, potassium and sulphur?

SUMMARY

1. Credit for the discovery of electron and proton in an atom goes to J.J. Thomson and E. Goldstein respectively.
2. The relative charge of an electron is, -1 while that of proton is, $+1$.
3. The relative mass of a proton is taken as $1u$ while that of an electron is taken negligible.
4. Neutron was discovered by J. Chadwick. It has no charge but has a mass of $1u$.
5. The three fundamental particles of an atom are electron, proton and neutrons.
6. J. J. Thomson proposed that electrons are embedded in a sphere of positive charge so that the atom as a whole is neutral.
7. Rutherford's alpha-particle scattering experiment led to the discovery of a tiny positively charged nucleus in the centre of the atom.
8. Rutherford's model of an atom proposed that electrons revolve around the nucleus in definite orbits or shells. The stability of the atom could not be explained by this model.
9. Neils Bohr's model of the atom could successfully explain the stability of the atom and many other phenomena. He proposed that electrons revolve rapidly around the nucleus in discrete energy levels or shells. Each shell can accommodate only a fixed number of electrons.
10. The electron orbits or shells of an atom are represented by numbers 1, 2, 3, 4....etc or designated as K, L, M, N,etc.
11. The number of positive charges or the number of protons present in the nucleus of an atom is known as the atomic number of the element.
12. The mass number of an element (atom) is equal to the sum of the no. of protons and neutrons present in the nucleus (or the number of nucleons) of the atom.
13. Elements are identified by the number of protons (atomic number) they possess.
14. Isotopes are atoms of the same element but have different mass numbers.

15. Isobars are atoms having the same mass number but different atomic numbers. They are atoms of different elements having same mass number.
16. Bohr and Bury scheme gives certain rules for the distribution of electrons into different orbits (shells) of an atom.
17. The electrons present in the outermost shell of an atom are called valence electrons and the outermost shell is known as valence shell.
18. Valence electrons determine the valency of an element.

EXERCISES

1. Name the three subatomic particles present in an atom and compare their properties.
2. What atom does not contain neutron?
3. Describe the Rutherford's model of an atom. What are its limitations?
4. Describe Bohr's model of the atom.
5. Explain with examples (i) Atomic number (ii) Mass number (iii) Isotopes and (iv) Isobars. Give any two uses of isotopes.
6. The mass number of an element is 40. It contains 19 electrons. What is the number of protons and neutrons in it? What is the atomic number of the element?
7. Write the electronic configuration of potassium atom. ($Z = 19$).
8. Explain why, sodium ion, Na^+ , has completely filled K and L shells.
9. If both K and L shells of an atom are full, what is the total number of electrons in the atom?
10. If bromine atom is available in the form of two isotopes $^{79}_{35}\text{Br}$ (49%) and $^{81}_{35}\text{Br}$ (51%), calculate the average atomic mass of bromine atom.
11. Composition of the nuclei of two atomic species x and y are as follows:

X	Y
No. of protons = 15	15
No. of neutrons = 15	16

Give the mass numbers of X and Y. What is the relation between the two species?

12. What is the relation between the valency of an element and the number of valence electrons in its atom. Explain with examples
13. Complete the following table:

Atomic Number	Mass Number	Number of Protons	Number of Neutrons	Number Of Electrons	Name of the Atomic species
11	.....	.....	12	.....	.....
.....	.....	11	12	10	.....
17	35	.....	.....	.....	.....
17	35	.....	.....	18	.....
.....	27	13	.....	.....	.....