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5

ATOMIC STRUCTURE

In lesson 3, you have studied about atoms and molecules as the constituents of matter. You have also learnt that the atoms are the smallest constituents of matter. In lesson 4 you studied about the chemical reactions, their types and the ways to represent them. You know that according to Dalton's atomic theory, the atoms of different elements are different and in chemical reactions the atoms are rearranged between different reacting substances. However, today we know that the atom is not indivisible as it was thought by Dalton. The atom has a structure and contains smaller constituents in it. In this unit, we would attempt to find out the answers to some of the questions like, "What is the structure of an atom?", "What are the constituents of atoms?", "Why the atoms of different elements are different?" and so on.

We will begin this unit with the study of the discoveries of sub-atomic particles such as electron, proton etc. Then, we will take up various atomic models proposed on the basis of these discoveries. We will discuss how various models for the structure of atom were developed and also explain the success as well as the shortcomings of these models. This will be followed by the description of the arrangement or the distribution of electrons in the atom. This arrangement is known as *electronic configuration*. These electronic configurations are useful in explaining various properties of the elements. These also determine the nature of chemical bonds formed by it. This aspect is dealt with in lesson 7 on chemical bonding.

OBJECTIVES

After completing this lesson, you will be able to:

- *recall the evidences showing the presence of charged particles in matter;*
- *describe the discovery of electron and proton;*
- *explain Dalton's atomic theory and its failure;*
- *discuss Thomson's and Rutherford's models of atom and explain their limitations;*

- *explain the Bohr's model of atom (in brief);*
- *describe the discovery of neutron;*
- *compare the characteristic properties of proton, electron and neutron;*
- *explain various rules for filling of electrons and write the distribution of electrons in different shells upto atomic number 20;*
- *define valency and correlate the electronic configuration of an atom with its valency;*
- *define atomic number and mass number of an atom;*
- *describe isotopes and isobars;*
- *define and compute average atomic mass and explain its fractional value.*

5.1 CHARGED PARTICLES IN ATOM

You have read about Dalton's atomic theory in lesson 3. The theory proposed in the year 1803 considered the atom to be the smallest indivisible constituent of all matter. The Dalton's theory could explain the law of conservation of mass, law of constant composition and law of multiple proportions known at that time. However, towards the end of nineteenth century, certain experiments showed that an atom is neither the smallest nor indivisible particle of matter as stated by Dalton. It was shown to be made up of even smaller particles. These particles were called electrons, protons and neutrons. The electrons are negatively charged whereas the protons are positively charged. The neutrons on the other hand are uncharged in nature. You will now learn about the discovery of the charged subatomic particles.

5.1.1 Discovery of Electron

In 1885, Sir William Crookes carried out a series of experiments to study the behaviour of metals heated in a vacuum using cathode ray tubes. A cathode ray tube

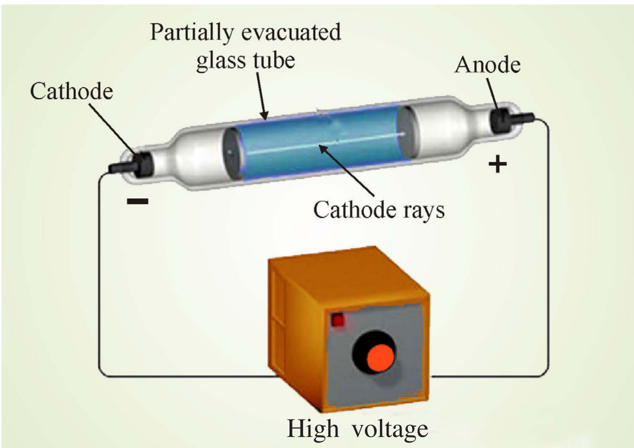


Fig. 5.1: *A cathode ray tube; cathode rays are obtained on applying high voltage across the electrodes in an evacuated glass tube*

consists of two metal electrodes in a partially evacuated glass tube. An evacuated tube is the one from which most of the air has been removed. The negatively charged electrode is called cathode whereas the positively charged electrode is called anode. These electrodes are connected to a high voltage source. Such a cathode ray tube has been shown in Fig. 5.1.

It was observed that when very high voltage was passed across the electrodes in evacuated tube, the cathode produced a stream of particles. These particles were shown to travel from cathode to anode and were called **cathode rays**. In the absence of external magnetic or electric field these rays travel in straight line. In 1897, an English physicist Sir J.J. Thomson showed that the rays were made up of a stream of negatively charged particles. This conclusion was drawn from the experimental observations when the experiment was done in the presence of an external electric field. Following are the important properties of cathode rays:

- Cathode rays travel in straight line
- The particles constituting cathode rays carry mass and possess kinetic energy
- The particles constituting cathode rays have negligible mass but travel very fast
- Cathode ray particles carry negative charge and are attracted towards positively charged plate when an external electric field is applied (Fig. 5.2)
- The nature of cathode rays generated was independent of the nature of the gas filled in the cathode ray tube as well as the nature of metal used for making cathode and anode. In all the cases the charge to mass ratio (e/m) was found to be the same.

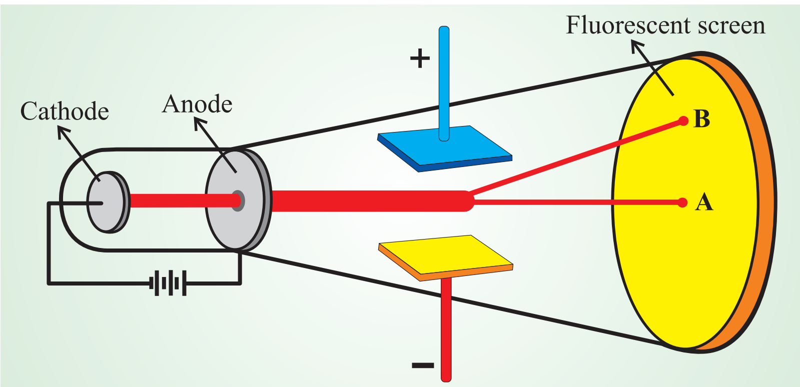


Fig. 5.2: *The cathode rays are negatively charged; these travel in straight line from cathode to the anode (A), however in the presence of an external electrical field these bend towards the positive plate (B)*

These particles constituting the cathode rays were later called **electrons**. Since it was observed that the nature of cathode rays was the same irrespective of the metal used for the cathode or the gas filled in the cathode ray tube. This led Thomson to conclude that all atoms must contain electrons. *This meant that the atom is not indivisible as was believed by Dalton and others*. In other words, we can say that the Dalton's theory of atomic structure failed partially.

This conclusion raised a question, "If the atom was divisible, then what were its constituents?". Today a number of smaller particles are found to constitute atoms. These particles constituting the atom are called **subatomic particles**. You have learnt above that electron is one of the constituents of the atom, let us study the next section to learn about another constituent particle present in an atom. As the atom is neutral, we expect the presence of positively charged particles in the atom so as to neutralise the negative charge of the electrons.

5.1.2 Discovery of Proton

Much before the discovery of electron, Eugen **Goldstein** (in 1886) performed an experiment using a perforated cathode (a cathode having holes in it) in the discharge tube filled with air at a very low pressure. When a high voltage was applied across the electrodes in the discharge tube, a faint red glow was observed behind the perforated cathode. Fig. 5.3

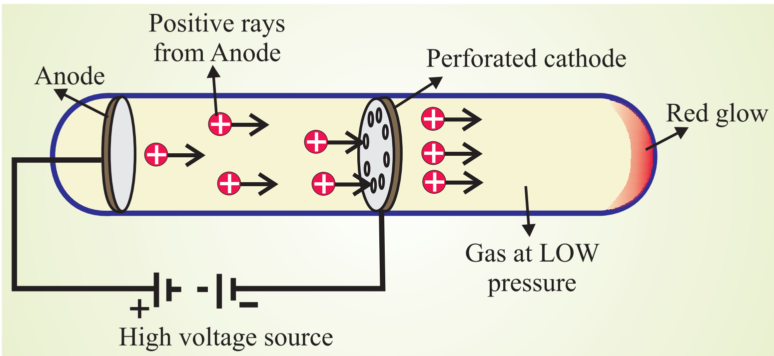


Fig. 5.3 *Goldstein's cathode ray tube with perforated cathode*

This glow was due to another kind of rays flowing in a direction opposite to that of the cathode rays. These rays were called as **anode rays** or positive rays. These were positively charged and were also called **canal rays** because they passed through the holes or the canals present in the perforated cathode. The following observations were made about anode rays (canal rays):

- Like cathode rays, the anode rays also travel in straight lines.
- The particles constituting anode rays carry mass and have kinetic energy.
- The particles constituting canal rays are much heavier than electrons and carry positive charges

- The positive charge on the particles was whole number multiples of the amount of charge present on the electron.
- The nature and the type of the particles constituting the anode rays were dependent on the gas present in the discharge tube.

The origin of anode rays can be explained in terms of interaction of the cathode rays with the gas present in the vacuum tube. It can be explained as given below:

The electrons emitted from the cathode collide with the neutral atoms of the gas present in the tube and remove one or more electrons present in them. This leaves behind positive charged particles which travel towards the cathode. When the cathode ray tube contained hydrogen gas, the particles of the canal rays obtained were the lightest and their charge to mass ratio (e/m ratio) was the highest. Rutherford showed that these particles were identical to the hydrogen ion (hydrogen atom from which one electron has been removed). These particles were named as **protons** and were shown to be present in all matter. Thus, we see that the experiments by Thomson and Goldstein had shown that an atom contains two types of particle which are oppositely charged and an atom is electrically neutral. What do you think is the relationship between the numbers of these particles in a given atom?

In addition to the two charged particles namely the electron and the proton, a neutral particle called neutron was also discovered about which you would learn later in this lesson. Now, it is the time to check your understanding. For this, take a pause and solve the following intext questions:

INTEXT QUESTIONS 5.1

1. Name two charged particles which constitute all matter.
2. Describe a cathode ray tube.
3. Name the negatively charged particles emitted from the cathode in the cathode ray tube?
4. Why do the canal rays obtained by using different gases have different e/m values?

> In addition to the discovery of electrons and protons as the constituents of atom, the phenomenon of **radioactivity** that is the spontaneous emission of rays from atoms of certain elements also proved that the atom was divisible.

5.2 EARLIER MODELS OF ATOM

In section 5.1 you have learnt that the atom is divisible and contains three smaller particles in it. The question that arises is, "In what way are the subatomic particles arranged in the atom?". On the basis of experimental observations, different models have been proposed for the structure of an atom. In this section, we will discuss two such models namely Thomson model and Rutherford model.

5.2.1 Thomson Model

In lesson 3 you have learnt that all matter is made of atoms and all the atoms are electrically neutral. Having discovered electron as a constituent of atom, Thomson concluded that there must be an equal amount of positive charge present in an atom. On this basis he proposed a model for the structure of atom. According to his model, atoms can be considered as a large sphere of uniform positive charge with a number of small negatively charged electrons scattered throughout it, Fig. 5.4. This model was called as **plum pudding** model. The electrons represent the plums in the pudding made of negative charge. This model is similar to a water-melon in which the pulp represents the positive charge and the seeds denote the electrons. However, you may note that a water melon has a large number of seeds whereas an atom may not have as many electrons.

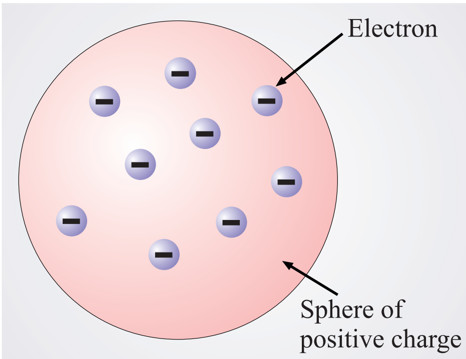


Fig. 5.4: *Thomson's plum-pudding model*

5.2.2 Rutherford's model

Ernest Rutherford and his co-workers were working in the area of radioactivity. They were studying the effect of alpha (α) particles on matter. The alpha particles are helium nuclei, which can be obtained by the removal of two electrons from the helium atom. In 1910, Hans Geiger (Rutherford's technician) and Ernest Marsden (Rutherford's student) performed the famous α-ray scattering experiment. This led to the failure of Thomson's model of atom. Let us learn about this experiment.

α-Ray scattering experiment

In this experiment a stream of α particles from a radioactive source was directed on a thin (about 0.00004 cm thick) piece of gold foil. On the basis of Thomson's model it was expected that the alpha particles would just pass straight through the gold foil and could be detected by a photographic plate placed behind the foil. However, the actual results of the experiment, Fig. 5.5, were quite surprising. It was observed that:

(i) Most of the α-particles passed straight through the gold foil.

(ii) Some of the α-particles were deflected by small angles.

(iii) A few particles were deflected by large angles.

(iv) About 1 in every 12000 particles experienced a rebound.

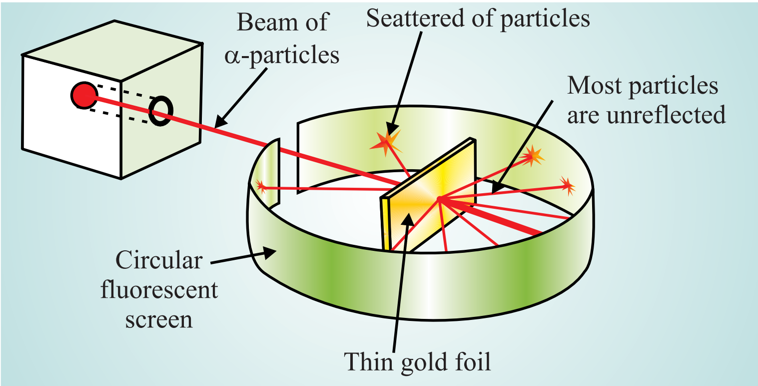
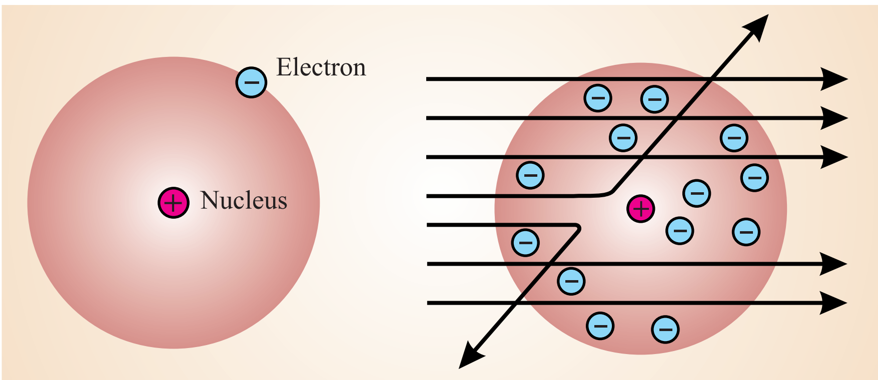


Fig. 5.5: *The experimental set-up and observations in the α- ray scattering experiment performed by Geiger and Marsden*

The results of α-ray scattering experiment were explained by Rutherford in 1911 and another model of the atom was proposed. According to Rutherford's model, Fig. 5.6(a).

- An atom contains a dense and positively charged region located at its centre; it was called as **nucleus**,
- All the positive charge of an atom and most of its mass was contained in the nucleus,
- The rest of an atom must be empty space which contains the much smaller and negatively charged electrons,



(a) (b)

Fig 5.6: *(a) Rutherford's model of atom (b) Explanation of the results of scattering experiment by Rutherford's model.*

On the basis of the proposed model, the experimental observations in the scattering experiment could be explained. This is illustrated in Fig. 5.6(b). The α particles passing through the atom in the region of the electrons would pass straight without any deflection. Only those particles that come in close vicinity of the positively charged nucleus get deviated from their path. Very few α-particles, those that collide with the nucleus, would face a rebound.

On the basis of his model, Rutherford was able to predict the size of the nucleus. He estimated that the radius of the nucleus was at least 1/10000 times smaller than that of the radius of the atom. We can imagine the size of the nucleus with the following analogy. If the size of the atom is that of a cricket stadium then the nucleus would have the size of a fly at the centre of the stadium.

INTEXT QUESTIONS 5.2

1. Describe Thomson's model of atom. What is it called?
2. What would have been observed in the α-ray scattering experiment if the Thomson's model was correct?
3. Who performed the α-ray scattering experiment and what were the observations?
4. Describe the model of atom proposed by Rutherford.

5.3 DRAWBACKS OF RUTHERFORD'S MODEL

According to Rutherford's model the negatively charged electrons revolve in circular orbits around the positively charged nucleus. However, according to Maxwell's electromagnetic theory (about which you may learn in higher classes), if a charged particle accelerates around another charged particle then it would continuously lose energy in the form of radiation. The loss of energy would slow down the speed of the electron. Therefore, the electron is expected to move in a spiral fashion around the nucleus and eventually fall into it as shown in Fig. 5.7. In other words, the atom will not be stable. However, we know that the atom is stable and such a collapse does not occur. Thus, Rutherford's model is unable to explain the stability of the atom. You know that an atom may contain a number of electrons. The Rutherford's model also does not say anything about the way the electrons are distributed around the nucleus. Another drawback of the Rutherford's model was its inability to explain the

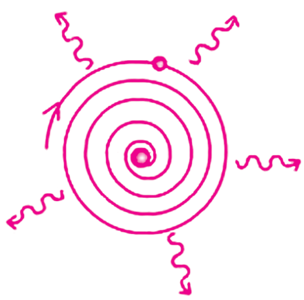


Fig. 5.7: *The electron in the Rutherford's model is expected to spiral into the nucleus*

relationship between the atomic mass and atomic number (the number of protons). This problem was solved later by Chadwick by discovering neutron, the third particle constituting the atom. You would learn about it in section 5.5.

The problem of the stability of the atom and the distribution of electrons in the atom was solved by Neils Bohr by proposing yet another model of the atom. This is discussed in the next section.

5.4 BOHR'S MODEL OF ATOM

In 1913, Niels Bohr,a student of Rutherford proposed a model to account for the shortcomings of Rutherford's model. Bohr's model can be understood in terms of two postulates proposed by him. The postulates are:

Postulate 1: *The electrons move in definite circular paths of fixed energy around a central nucleus*; just like our solar system in which different planets revolve around the Sun in definite trajectory. Similar to the planets, only certain circular paths around the nucleus are allowed for the electrons to move. These paths are called **orbits**, or **energy levels**. The electron moving in the orbit does not radiate. In other words, it does not lose energy; therefore, these orbits are called **stationary orbits or stationary states**. The bold concept of stationary state could answer the problem of stability of atom faced by Rutherford's model.

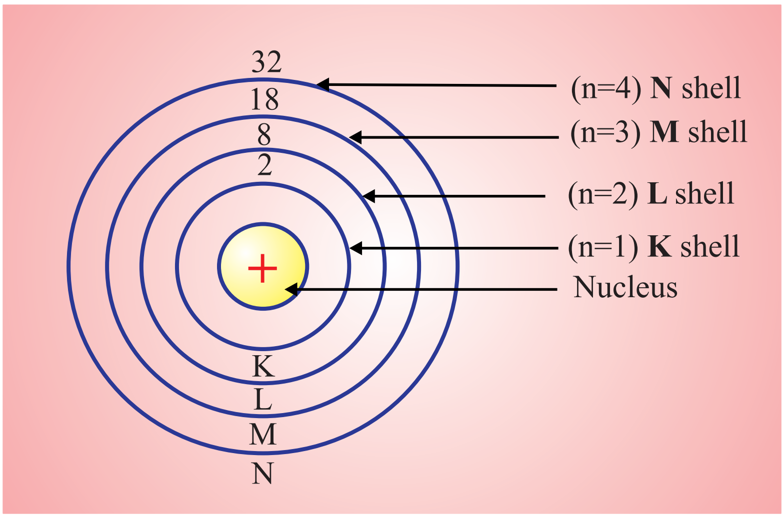


Fig. 5.8: *Illustration showing different orbits or the energy levels of fixed energy in an atom according to Bohr's model*

It was later realised that the concept of circular orbit as proposed by Bohr was not adequate and it was modified to energy shells with definite energy. While a circular orbit is two dimensional, a shell is a three dimensional region. The shells of definite energy are represented by letters (K, L, M, N etc.) or by positive integers (1, 2, 3, ... etc.) Fig. 5.8. The energies of the shells increase with the number n; n = 1, level is of the lowest energy. Further, the maximum number of electrons that can be accommodated in each shell is given by $2n^2$, where n is the number of the level. Thus, the first shell (n=1) can have a maximum of two electrons whereas the second shell can have 8 electrons and so on. Each shell is further divided into various sublevels called **subshells** about which you would study in your higher classes.

Postulate 2: The electron can change its shells or energy level by absorbing or releasing energy. An electron at a lower state of energy E_i can go to a final higher state of energy E_f by absorbing a single photon of energy given by:

$$E = h\nu = E_f - E_i$$

Similarly, when electron changes its shell from a higher initial level of energy E_i to a lower final level of energy E_f, a single photon of energy $h\nu$ is released (Fig. 5.9).

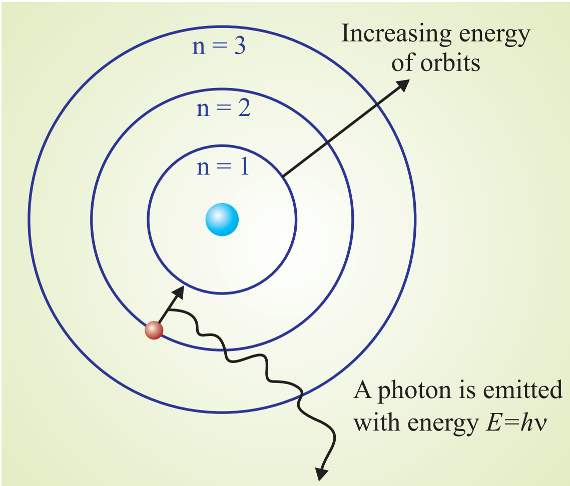


Fig. 5.9: *The electrons in an atom can change their energy level by absorbing suitable amounts of energy or by emitting energy.*

INTEXT QUESTIONS 5.3

1. Give any two drawbacks of Rutherford's model of atom.
2. State the postulates of Bohr's model.
3. How does Bohr model of an atom explain the stability of the atom?

Thus, the Bohr's model of atom removes two of the limitations of Rutherford's model. These are related to the stability of atom and the distribution of electrons around the nucleus. You would recall that the third limitation of Rutherford's model was its inability to explain the relationship between the atomic mass, and the atomic number (the number of protons) of an atom. Let us learn how this problem was solved with the discovery of neutron.

5.5 DISCOVERY OF NEUTRON

You would recall that when we discussed about the failure of Rutherford's model we mentioned that it was unable to explain the relationship between the atomic mass and the atomic number (the number of protons). According to the Rutherford's model, the mass of helium atom (containing 2 protons) should be double that of a hydrogen atom (with only one proton). [Ignoring the mass of electron as it is very light]. However, the actual ratio of the masses of helium atom to hydrogen atom is 4:1. It was suggested that there must be one more type of subatomic particle present in the nucleus which may be neutral but have mass.

Such a particle was discovered by James Chadwick in 1932. This was found to be electrically neutral and was named **neutron**. Neutrons are present in the nucleus of all atoms, except hydrogen. A neutron is represented as 'n' and is found to have a mass slightly higher than that of a proton. Thus, if the helium atom contained 2 protons and 2 neutrons in the nucleus, the mass ratio of helium to hydrogen (4:1) could be explained. The characteristics of the three fundamental particles constituting the atom are given in Table 5.1.

Table 5:1 Characteristics of the fundamental subatomic particles

Particle	Symbol	Mass (in kg)	Actual Charge (in Coulombs)	Relative charge
Electron	e	$9.109\,389 \times 10^{-31}$	$1.602\,177 \times 10^{-19}$	–1
Proton	p	$1.672\,623 \times 10^{-27}$	$1.602\,177 \times 10^{-19}$	1
Neutron	n	$1.674\,928 \times 10^{-27}$	0	0

INTEXT QUESTIONS 5.4

1. What is a neutron and where is it located in the atom?
2. How many neutrons are present in the α-particle?
3. How will you distinguish between an electron and a proton?

5.6 ATOMIC NUMBER AND MASS NUMBER

You have learnt that the nucleus of atom contains positively charged particles called protons and neutral particles called neutrons. **The number of protons in an atom is called the atomic number and is denoted by the symbol 'Z'**. All atoms of an element have the same atomic number. The electrons occupy the space outside the nucleus. In order to account for the electrically neutral nature of the atom, the number of protons in the nucleus is exactly equal to the number of electrons. Thus,

Atomic number = number of protons = number of electrons

You would recall that according to Dalton's theory, the atoms of different elements are different from each other. We can now say that this difference is due to difference in the numbers of protons present in the nucleus of the element. In other words, different elements differ in terms of their **atomic number**. For example, the atoms of hydrogen and helium are different because hydrogen has one proton in its nucleus whereas the nucleus of helium atom contains two protons. Their atomic numbers are 1 and 2, respectively. You have learnt in the Rutherford's model that the mass of the atom is concentrated in its nucleus. This is due to the presence of two heavy particles namely protons and neutrons in the nucleus. These particles are called **nucleons**. *The number of nucleons in the nucleus of an atom is called its* ***mass number***. It is denoted by 'A' and is equal to the total number of protons and neutrons present in the nucleus of an element. Thus,

Mass number (A) = number of protons(Z) + number of neutrons(n)

Atomic number and mass number are represented on the symbol of an element. An element, X with an atomic number, Z and the mass number, A is denoted as follows:

$$^{A}_{Z}X$$

For example, $^{12}_{6}C$ means that the carbon has an atomic number of 6 and the mass number of 12. This can be used to compute the number of different fundamental particles in the atom. Let us calculate it for carbon.

As the atomic number is 6 this means:

Number of protons = number of electrons = 6

As Mass number = number of protons + number of neutrons

$\Rightarrow$ 12 = 6 + number of neutrons

$\Rightarrow$ number of neutrons = 12 – 6 = 6

Thus, an atom of $^{12}_{6}C$ has 6 protons, 6 electrons and 6 neutrons.

INTEXT QUESTIONS 5.5

1. A sodium atom has an atomic number of 11 and a mass number of 23. Calculate the number of protons, electrons and neutrons in a sodium atom.

2. What is the mass number of an atom which has 7 protons and 8 neutrons?
3. Calculate the number of electrons, protons and neutrons in $^{40}_{18}Ar$ and $^{49}_{19}K$.

5.7 ELECTRONIC CONFIGURATION: DISTRIBUTION OF ELECTRONS IN DIFFERENT ORBITS

As discussed in section 5.4, the electrons move in definite paths called orbits or shells around a central nucleus. These orbits or shells have different energies and can accommodate different number of electrons in them. The question arises that how are the electrons distributed amongst these shells? The answer to this question was provided by Bohr and Bury. According to their scheme, the electron distribution is governed by the following rules:

I. These orbits or shells in an atom are represented by the letters K, L, M, N,… or the positive integral numbers, n = 1,2,3,4,….

II. The orbits are arranged in the order of increasing energy. The energy of M shell is more than that of the L shell which in turn is more than that of the K shell.

III. The maximum number of electrons present in a shell is given by the formula $2n^2$, where 'n' is the number of the orbit or the shell. Thus, the maximum number of electrons that can be accommodated in different shells are as follows:

Maximum number of electrons in K shell (or n = 1 level) = $2n^2 = 2 \times (1)^2 = 2$

Maximum number of electrons in L shell (or n = 2 level) = $2n^2 = 2 \times (2)^2 = 8$

Maximum number of electrons in M shell (or n = 3 level) = $2n^2 = 2 \times (3)^2 = 18$ and so on. See table 5.2

Table 5.2: Electron accommodation capacity of different shells

Value of n	Shell name	Maximum capacity
1	K-Shell	2
2	L- Shell	8
3	M- Shell	18
4	N- Shell	32

IV. The shells are occupied in the increasing order of their energies.

V. Electrons are not accommodated in a given shell, unless the inner shells are completely filled.

The arrangement of electrons in the various shells or orbits of an atom of the element is known as electronic configuration. Keeping these points in mind, let us now study the filling of electrons in various shells of atoms of different elements.

- Hydrogen (H) atom has only one electron. It would occupy the first shell and electronic configuration of hydrogen can be represented as 1.
- The next element helium (He) has two electrons in its atom. Since the first shell can accommodate two electrons; hence, this second electron will also be placed in the first shell. The electronic configuration of helium is written as 2.
- The third element, Lithium (Li) has three electrons. Now the two electrons occupy the first shell whereas the third electron goes to the next shell of higher energy level, i.e. second shell. Thus, the electronic configuration of Li is 2, 1.

Similarly, the electronic configurations of other elements can be written. The structures of the atoms of elements with atomic number 1 to 18 are given in Fig. 5.10.

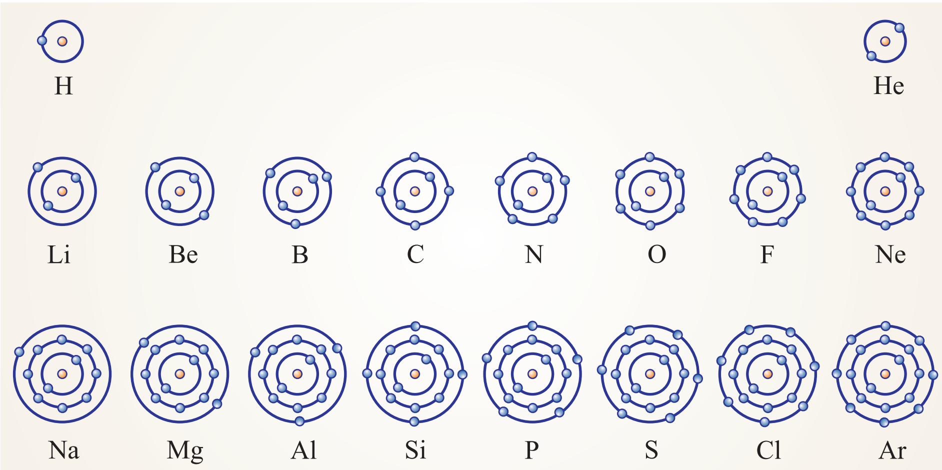


Fig. 5.10: *The structures, according to Bohr's model of atoms, of elements with atomic number 1 to 18.*

5.7.1 Concept of Valence or Valency

We have just discussed the electronic configuration of first 18 elements. You can see from the Fig. 5.10 that different elements have different number of electrons in the outermost or the valence shell. These electrons in the outermost shell are known as valence electrons. **The number of valence electrons determines the combining capacity of an atom in an element.** Valence is the number of chemical bonds that an atom can form with univalent atoms. Since hydrogen is a univalent atom, the valence of an element can be taken by the number of atoms of hydrogen with which one atom of the element can combine. For example, in H_2O, NH_3, and CH_4 the valencies of oxygen, nitrogen and carbon are 2, 3 and 4 respectively.

The elements having a completely filled outermost shell in their atoms show little or no chemical activity. In other words, their combining capacity or valency is zero. The elements with completely filled valence shells are said to have stable electronic configuration. The main group elements can have a maximum of eight electrons in their valence shell. This is called **octet rule**; you will learn more about it in lesson 7. You will learn that the combining capacity or the tendency of an atom to react with other atoms to form molecules depends on the ease with which it can achieve octet in its outermost shell. The valencies of the elements can be calculated from the electronic configuration by applying the octet rule. It can be seen as follows:

- If the number of valence electrons is four or less then the valency is equal to the number of the valence electrons.
- In cases when the number of valence electrons is more than four then generally the valency is equal to 8 minus the number of valence electrons.

Thus,

Valency = Number of valence electrons (for 4 or lesser valence electrons)

Valency = 8 - Number of valence electrons (for more than 4 valence electrons)

The composition and electronic configuration of the elements having the atomic numbers from 1 to 18, along with their valencies is given in Table 5.3.

Table 5.3: The composition, electron distribution and common valency of the elements with atomic number from 1 to 18

Name of Element	Symbol	Atomic Number	Number of Protons	Number of Neutrons	Number of Electrons	Distribution of Electrons				Valency
						K	L	M	N	
Hydrogen	H	1	1	–	1	1	–	–	–	1
Helium	He	2	2	2	2	2	–	–	–	0
Lithium	Li	3	3	4	3	2	1	–	–	1
Beryllium	Be	4	4	5	4	2	2	–	–	2
Boron	B	5	5	6	5	2	3	–	–	3
Carbon	C	6	6	6	6	2	4	–	–	4
Nitrogen	N	7	7	7	7	2	5			3
Oxygen	O	8	8	8	8	2	6	–	–	2
Fluorine	F	9	9	10	9	2	7	–	–	1
Neon	Ne	10	10	10	10	2	8	–	–	0
Sodium	Na	11	11	12	11	2	8	1		1
Magnesium	Mg	12	12	12	12	2	8	2	–	2
Aluminium	Al	13	13	14	13	2	8	3	–	3
Silicon	Si	14	14	14	14	2	8	4	–	4
Phosphorus	P	15	15	16	15	2	8	5	–	3, 5
Sulphur	S	16	16	16	16	2	8	6	–	2
Chlorine	Cl	17	17	18	17	2	8	7	–	1
Argon	Ar	18	18	22	18	2	8	8	–	0

In next lesson, you will study about the importance of electronic configurations in understanding the periodic arrangement of elements. These electronic configurations are also helpful in studying the nature of bonding between various elements which will be dealt with in lesson 7.

INTEXT QUESTIONS 5.6

1. How many shells are occupied in the nitrogen (atomic number =7) atom?
2. Name the element which has completely filled first shell.
3. Write the electronic configuration of an element having atomic number equal to 11.

WHAT HAVE YOU LEARNT

- According to Dalton's atomic theory, the atom is considered to be the smallest indivisible constituent of all matter. This theory could explain the law of conservation of mass, law of constant composition and law of multiple proportions. However, certain experiments towards the end of nineteenth century showed that the atom is neither the smallest nor indivisible particle of matter. It was shown to be made up of even smaller particles called electrons, protons and neutrons.
- Sir J.J.Thomson discovered that when very high voltage was passed across the electrodes in the cathode ray tube, the cathode produced rays that travel from cathode to anode and were called **cathode rays**. It showed that the rays were made up of a stream of negatively charged particles called electrons. The discovery of electrons *meant that the atom is not indivisible as was believed by Dalton and others*.
- Eugen **Goldstein** discovered anode rays by using a perforated cathode (a cathode having holes in it) in the discharge tube filled with air at a very low pressure. The discovery of anode rays established the presence of positively charged proton in the atom.
- According to Thomson's plum-pudding model, atoms can be considered as a large sphere of uniform positive charge with a number of small negatively charged electrons scattered throughout it.
- The α-ray scattering experiment performed by Geiger and Marsden led to the failure of Thomson's model of atom. In this experiment, a stream of α-particles from a radioactive source was directed on a thin piece of gold foil. Most of the α-particles passed straight through the gold foil, some α-particles were deflected by small angles, a few particles by large angles and very few experienced a rebound.

- The results of α-ray scattering experiment were explained in terms of Rutherford's model. According to which the atom contains a dense and positively charged region called **nucleus** at its centre and the negatively charged electrons move around it. All the positive charge and most of the mass of atom is contained in the nucleus.
- The Rutherford's model however failed as it could not explain the stability of the atom, the distribution of electrons and the relationship between the atomic mass and atomic number (the number of protons).
- The problem of the stability of the atom and the distribution of electrons in the atom was solved by Neils Bohr in terms of Bohr's model of the atom. Bohr's model can be understood in terms of two postulates, the first being, '*The electrons move in definite circular paths of fixed energy around a central nucleus*' and the second, '*The electron can change its orbit or energy level by absorbing or releasing energy*.'
- In 1932, James Chadwick discovered an electrically neutral particle in atom and named it as **neutron**.
- The number of protons in an atom is called the atomic number and is denoted as 'Z'. On the other hand the number of nucleons(protons plus neutrons) in the nucleus of an atom is called its mass number and is denoted as 'A'
- The electrons are distributed in different shells in the order of increasing energy. The distribution is called electronic configuration. The maximum number of electrons present in a shell is given by the formula $2n^2$, where 'n' is the number of the orbit or the shell.
- The valence is the number of chemical bonds that an atom can form with univalent atoms. If the number of valence electrons is four or less, then the valency is equal to the number of the valence electrons. On the other hand, if the number of valence electrons is more than four, then generally the valency is equal to 8 minus the number of valence electrons.

TERMINAL EXERCISE

1. How did J.J.Thomson discover the electron? Explain his "plum pudding" model of the atom.
2. What made Thomson conclude that all atoms must contain electrons?
3. Identify the following subatomic particles:
   (a) The number of these in the nucleus is equal to the atomic number
   (b) The particle that is not found in the nucleus
   (c) The particle that has no electrical charge
   (d) The particle that has a much lower mass than the others subatomic particles

4. Which of the following are usually found in the nucleus of an atom?
   (a) Protons and neutrons only
   (b) Protons, neutrons and electrons
   (c) Neutrons only
   (d) Electrons and neutrons only
5. Describe Ernest Rutherford's experiment with alpha particles and gold foil. How did this lead to the discovery of the nucleus?
6. What does the atomic number tell us about an atom?
7. What is the relationship between the numbers of electrons and protons in an atom?
8. How did Neils Bohr revise Rutherford's atomic model?
9. What is understood by a stationary state?
10. What is a shell? How many electrons can be accomodate in L-shell?
11. State the rules for writing the electronic configuration of elements.

ANSWERS TO INTEXT QUESTIONS

5.1

1. Electrons and protons
2. A cathode ray tube consists of two metal electrodes in a partially evacuated glass tube. The negatively charged electrode is called cathode while the positively charged electrode is called anode. These electrodes are connected to a high voltage source.
3. Electron
4. When the electrons emitted from the cathode collide with the neutral atoms of the gas present in the tube, these remove one or more electrons present in them. This leaves behind positive charged particles which travel towards the cathode. As the atoms of different gases have different number of protons present in them, these give positively charged ions with different e/m values.

5.2

1. According to Thomson's model, atoms can be considered as a large sphere of uniform positive charge with a number of small negatively charged electrons scattered throughout it. This model was called as **plum pudding** model.

2. If the Thomson's model was correct, then most of the α-particles in the α-ray scattering experiment would have passed straight through the atom

3. The α-ray scattering experiment was performed by Geiger and Marsden. When a stream of α-particles from a radioactive source was directed on a thin piece of gold foil, most of the α-particles passed straight through the gold foil, some α-particles were deflected by small angles, a few particles by large angles and very few experienced a rebound.

4. According to Rutherford's model, the atom contains a dense and positively charged region called **nucleus** at its centre and the negatively charged electrons move around it. All the positive charge and most of the mass of atom is contained in the nucleus.

5.3

1. The Rutherford's model could not explain the stability of the atom, the distribution of electrons and the relationship between the atomic mass and atomic number (the number of protons).

2. The two postulates of Bohr's model are :

   I. The electrons move in definite circular paths of fixed energy around a central nucleus.

   II. The electron can change its orbit or energy level by absorbing or releasing energy.

3. The Bohr's model explains the stability of atom by proposing that the electron does not lose energy when present in a given energy level.

5.4

1. It is a neutral subatomic particle present in the nucleus of the atom.

2. An α-particle contains two neutrons.

3. The electron and proton can be distinguished in terms of their charge and mass. While the electron is negatively charged, the proton is positively charged. Secondly, the proton is much heavier than the electron; it is about 1840 times heavier.

5.5

1. No of protons = 11

   No. of electrons = 11

   No. of neutrons = 12

2. Mass number = number of protons + number of neutrons

   Therefore, mass number = 7 + 8 = 15

3. $^{40}_{18}Ar$: Number of protons = atomic number = 18

   Number of electrons = number of protons = 18

   Number of neutrons = mass number – number of protons = 40 – 18 = 22

   $^{40}_{19}K$ Number of protons = atomic number = 19

   Number of electrons = number of protons = 19

   Number of neutrons = mass number – number of protons = 40 – 19 = 21

5.6

1. The electronic configuration of nitrogen is 2, 5. Thus, two shells are occupied. The first shell (capacity = 2) is completely filled while the second shell (capacity = 8) is partially filled.
2. Helium
3. The electronic configuration of an element having atomic number 11 is 2, 8, 1.