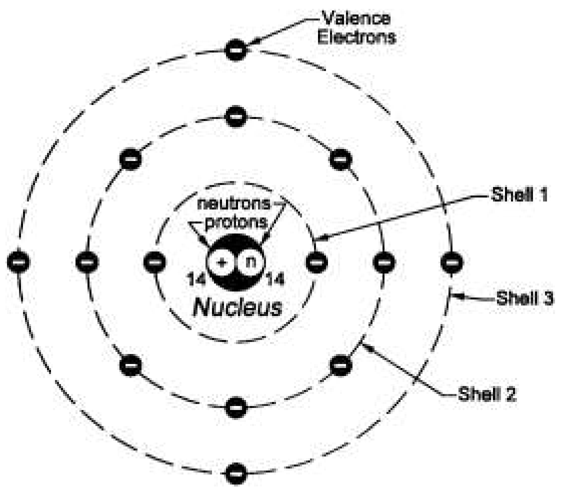
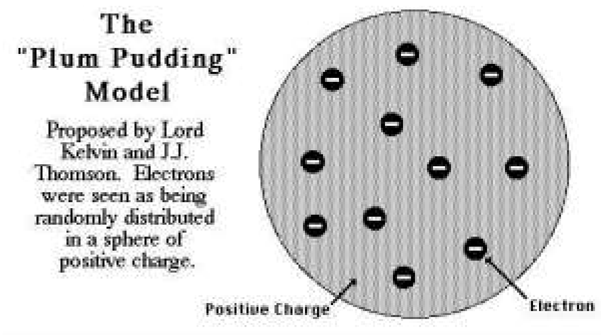
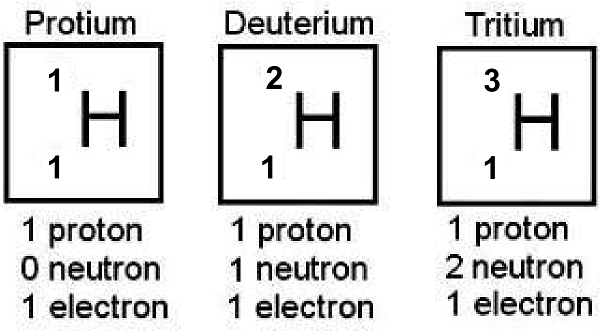
# Journey Inside the Atom

## Chapter Outline

- Discovery of fundamental particles
- Atomic Models
  - (i) Thomson's Model
  - (ii) Rutherford's Model
  - (iii) Bohr's Model
- Valency and Valence Electrons
- Atomic number & Mass number
- Electronic Configuration
- Iso terms



## INTRODUCTION

Maharishi Kanad an ancient Indian philosopher proposed the term parmanu (reported in vedas) as the smallest particle of matter which cannot be further divided. Later on the term 'Atom' was used by Greek philosophers to describe the ultimate particle of matter. Atom is a Greek word which means indivisible. Several other western philosophers like Plato, Aristotle, Lucretius, Democritus etc. believed that matter is composed of extremely small and indivisible particles called atoms.

**Particles present in atom :**

The atoms of elements are electrically neutral and do not carry any charge. At the end of nineteenth century, several evidences indicated that atom can be subdivided and contains certain charged particles. Among these particles, the most important ones are electron and proton. Later on discovery of isotopes led to the fact that the atom also contains neutral particles called neutron. Electrons, protons and neutrons are collectively known as fundamental particles of atom.

Dalton's model could not explain why atoms of an element differ in their masses. This led to the discovery of three sub atomic particles mainly electron, proton and neutron which are now recognized to be the constituents of atom. The modern atomic concept is based on the following discoveries :

1. Cathode rays by William Crookes (1879) and J.J. Thomson, (1897).
2. Positive rays by Goldstein (1886).
3. Nucleus by Rutherford (1909).
4. Atomic number by Moseley (1913).
5. Bohr's model and atomic spectra of H-atom (1913).
6. Neutron by Chadwick (1932).
7. The Bohr-Bury scheme of electronic arrangement (1921).
8. The Term electron is coined by J. Stoney (1891)

## DISCOVERY OF ELECTRON

Electrons are the fundamental particles of all substances. Electron was identify as a particle in 1897 by J.J. Thomson and the name 'electron' is given by Johnstone Stoney in 1891.

**Characteristics of Electron :**

The two important characteristics of electron are given below :

1. **The mass of electron :** The mass of electron is $\frac{1}{1837}$ of the mass of one hydrogen atom. The mass of one hydrogen atom is 1u.

   So, the relative mass of an electron is $\frac{1}{1837}$ u.

   1 u = $1.6605 \times 10^{-24}$ gram

   Therefore,

   Mass of an electron in gm is = $9.109 \times 10^{-28}$ gm

   Since the mass of electron is very, very small, its mass is ignored while calculating the atomic mass of an element.

2. **Charge of an electron :** An electron carries negative charge. The absolute value of the negative charge is $1.6 \times 10^{-19}$ Coulomb. It is the smallest negative charge. All the negatively charged particles possess charge which is an integral multiple of $1.6 \times 10^{-19}$ Coulomb.

   The relative charge of an electron is –1. Thus, the negative charge on all the negatively charged particles is an integral multiple of –1. The relative charge of a negative particle may be –1, –2, –3 unit etc, but it can not be in fractions like –1.5, –2.3, –3.1 units etc.

## DISCOVERY OF PROTON

We know that all the atoms contain negatively charged particles called electrons. Since an atom is electrically neutral, therefore an atom must contain positively charged particles to balance the negative charge of electrons. It has been shown that all the atoms contain positively charged particles called protons. Proton was discovered by Goldstein (1886).

**Note :** The name 'proton' was given by Rutherford in 1911.

**Characteristics of proton :**

The two important characteristics of proton are given below :

1. **Mass of proton :** Hydrogen atom contains one electron and one proton. Since mass of electron is very, very small and it may be ignored, therefore mass of proton may be taken equal to the mass of ordinary hydrogen atom. We know that mass of hydrogen atoms is 1 u or $1.6605 \times 10^{-24}$ gram. Therefore, relative mass of proton is 1 u and its absolute mass is $1.6 \times 10^{-24}$ gram. The mass of proton is 1837 times that of an electron.
2. **Charge of proton :** The magnitude of charge on a proton and an electron is equal but their sign are opposite to each other.
   The absolute value of positive charge of proton is $1.6 \times 10^{-19}$ Coulomb. It is the smallest positive charge that can be had by a positively charged particle. No positively charged particle can possess positive charge less than $1.6 \times 10^{-19}$ Coulomb. Thus, relative charge of proton is + 1 unit. All the positively charged particles possess charge which is an integral multiple of $1.6 \times 10^{-19}$ Coulomb or + 1 unit. The relative positive charge a particle may be +1, + 2, + 3 unit etc. But it can not be in fractions like + 1.7, + 2.1, + 3.8 unit etc.

## DISCOVERY OF NEUTRON

It is a fact that the mass of an atom cannot be explained on the basis of protons only (mass of electron is ignored being negligible). For example, a carbon atom contains 6 protons. Therefore, the atomic mass of carbon should be 6u. But the atomic mass of carbon is 12 u. Now the problem is how do we explain this extra mass of 6 units ? This problem was solved by the discovery of another sub-atomic particle called neutron.

In 1932, James Chadwick bombarded the element beryllium with $\alpha$ - particles.

**Characteristics of neutron :**

The two important characteristics of proton are given below :

1. **Mass of neutron:**
   The mass of neutron is equal to the mass of a proton. The relative mass of a neutron is 1 u. The absolute mass of a neutron is $1.6 \times 10^{-24}$ gm.
2. **Charge of neutron :**
   Neutron has no charge. It is electrically neutral.

**Note :** It is important to know that all the protons and neutrons of an atom are present in the nucleus whereas the electrons are present in the outer region. Except ordinary hydrogen atom, all the atoms of other elements contain neutrons.

Thus, important sub-atomic particles of an atom are electron, proton and neutron.

| Property | Electron | Proton | Neutron |
|---|---|---|---|
| Discovery | J.J. Thomson | E. Goldstein | James Chadwick |
| Symbol | e | p | n |
| Nature | Negatively charged | Positively charged | Neutral |
| Relative charge | -1 | +1 | 0 |
| Absolute charge | $-1.602 \times 10^{-19}$ C | $+ 1.602 \times 10^{-19}$ C | 0 |
| Relative mass | $\frac{1}{1837}$ u | 1 u | 1 u |
| Absolute mass | $9.109 \times 10^{-28}$ g | $1.6725 \times 10^{-24}$ g | $1.6748 \times 10^{-24}$ g |

## THE STRUCTURE OF AN ATOM

Various atomic models have been suggested to explain the stability of the atom and to find out how the three sub-atomic particles (electrons, protons and neutrons) are arranged in an atom. These atomic models are being discussed below :

**Thomson's Model of an Atom: (Plum Pudding Model)**

Thomson proposed that :

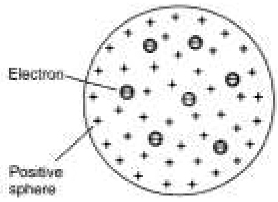
(1) An atom consists of positively charged sphere and the electrons are embedded in it.

(2) The negative and positive charges are equal in magnitude. So, the atom as a whole is electrically neutral.

It is important to know that neutron was not discovered when Thomson proposed the atomic model.

Thomson's model of atom can be compared to watermelon. The red and edible part of watermelon represents the sphere of positive charge whereas the black seeds embedded in watermelon are like the electrons.

In the following figure, the shaded area in the sphere (or ball) represents the positive charge of the atom. The negatively charged electrons are embedded into it in such a way to give most stable electrostatic arrangement. Thomson's atomic model is similar to that of Christmas pudding. The electrons embedded in a sphere of positive charge are like the currents (dry fruits) in a spherical Christmas pudding.




**Thomson's model of an atom**

**Objections to Thomson's Model :**

(1) Thomson's model explained that atoms are electrically neutral, but it could not explain the results of Rutherford's alpha rays scattering experiment.

(2) There were no practical evidence in support of model.

Therefore, Thomson's atomic model was rejected.

**Rutherford's α-rays Scattering Experiment (Discovery of Nucleus)**

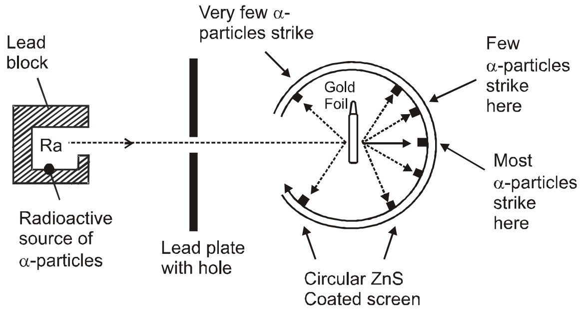
Before explaining Rutherford's experiment, it is necessary to explain a few terms used in this experiment.

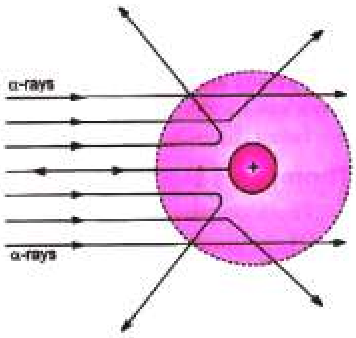
**Alpha particle:** Alpha particle is a positively charged particle which has 2 units of positive charge and 4 units of mass. It is represented as $He^{2+}$.

**Boost your knowledge**

- Helium atom contains 2 electrons, 2 protons and 2 neutrons and its atomic mass is 4u. When the 2 electrons present in the outer region of the helium atom are removed, the positively charged particle $He^{2+}$ are formed that contain 2 units of positive charge and 4 units of mass. $He^{2+}$ or α-particle is the nucleus of helium gas which contains 2 protons and 2 neutrons.

**Experiment :** Fast moving alpha particles are allowed to strike the thin gold foil kept in vacuum. It was expected that α-particles would be deflected by the sub-atomic particles in the gold atoms. Since the α-particles are much heavier than the protons, the large deflections were not expected.




**Rutherford's α-ray scattering experiment**

But the α-particle scattering experiment gave totally unexpected results. It was found that -

(1) Most of the α-particles passed through the gold foil without any deflection from their original path.

(2) A small fraction of the α-particles got deflected by small angles. Some α-particles got deflected by large angles.

(3) A very few α-particles (one out of every 12000 α-particles) appeared to rebound and got reflected back to their original path, i.e., deflected by 180º.

**Explanation :** Gold foil is made up of atoms. If the atoms are completely solid, then every alpha particle striking the solid atoms of gold should have changed its path and got deflected. But this did not happen. This shows that atoms are not completely solid. The solid part of the atom should be very, very small. It is because only one alpha particle out of 12000 $\alpha$-particle comes back to its original path.
Therefore, there must be large empty space in an atom.

**Rutherford concluded the $\alpha$-particle scattering experiment that :**

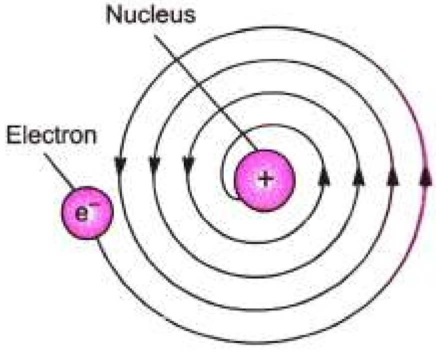
(1) Since most of the $\alpha$-particles pass through the gold foil without any deflection, it shows that most of the space inside the atom is empty.
(2) The positively charged $\alpha$-particle are expected to be repelled by another positively charged body. Since some of the $\alpha$-particles get deflected by small or large angles, it shows that there is centre of positive charge of the atoms occupies vary little space. This centre of the positive charge in the atom is called nucleus.
(3) A very small fraction of $\alpha$-particles get deflected by 180°, i.e., the $\alpha$-particles get retraced their original part. It shows that there should be something massive in the atom, colliding with which the alpha particles rebounded on their path.
(4) Since the nucleus of the atom is very dense, whole of the positive charge and almost whole of the mass is concentrated in it.

The size of the nucleus is negligible as compared to the size of whole atom. It was also concluded that the radius of the nucleus is about $10^5$ times less than the radius of whole atom.
From Rutherford's alpha-particle scattering experiment, it was concluded that an atom is made up of two parts :
(i) Nucleus and (ii) Outer region.

**Rutherford's Model of an Atom :**
It is based on Rutherford's alpha particle scattering experiment. It is also called nuclear atomic model. According to this model -

(1) An atom consists of positively charged, hard, dense and rigid small nucleus. All the protons and neutrons of the atom are present in the nucleus. Whole of the positive charge and almost whole of the mass is concentrated in this small nucleus. The positive charge of the nucleus is due to protons.
(2) The nucleus is surrounded by negatively charged electrons. Electrons are present in the empty space around nucleus. Electrons revolve around the nucleus in circular paths at very high speeds. The circular path of the revolving electrons is called orbits or shells.
(3) There is electrostatic force of attraction among the positively charged nucleus and negatively charged electrons. This electrostatic force of attraction holds the atom together.
(4) The size of the nucleus is very small as compared to the size of the atom.
(5) There is large empty space around the nucleus.

**Drawbacks of Rutherford's Model of the Atom :**
The important drawback of Rutherford's atomic model is that it does not explain the stability of the atom as explained below.
Rutherford's atomic model is against the laws of electrodynamics. A moving charged particle loses energy continuously in the form of electromagnetic radiations. Thus, energy of the electron decreases continuously. This will result in the decrease of electron path. Electrons come closer and closer to the nucleus and will ultimately jump into the nucleus. This will destroy the atom. But this never happens because an atom is a stable system. Thus, Rutherford's atomic model does not explain the stability of the atom.




**Continuous loss of energy by revolving electron**

**Note :** In the neutral atom the total number of protons in the nucleus is equal to the total number of electrons revolving around the nucleus.

**Bohr's Model of Atom:**

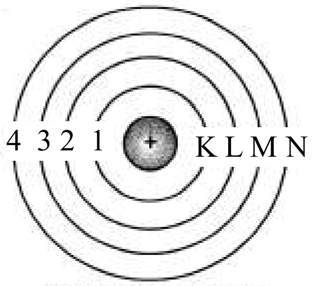
In order to explain the stability of the atom and to overcome the objections raised against Rutherford's atomic model, Neils Bohr gave another model of atom. Following are the important postulates of Bohr's atomic model-

(1) Electrons in an atom revolve around the nucleus in certain circular orbits which are associated with definite energies. These are called stationery orbits or energy levels.

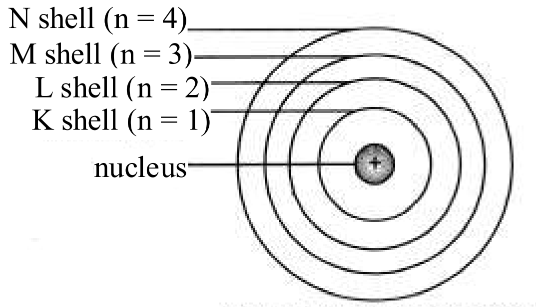
(2) When an electron revolves in discrete orbits (energy levels), it does not radiate energy.

(3) Each orbit (energy level) is associated with a definite amount of energy.

(4) When an electron jumps from higher energy level to lower energy level, it loses energy and when it jumps from lower energy level to higher energy level it gains energy.




Bohr's circular orbits




A few energy levels in an atom

(5) The energy level are represented in two ways :
   (i) Either they are represented by the numbers 1, 2, 3, 4, 5, 6 …….
   (ii) Or energy levels are represented by the letters K, L, M, N, O, P ……
   (iii) The energy levels are counted from the centre onwards.

**Explanation of Stability of Atom :**

According to Bohr's atomic theory, electrons revolve around the nucleus in definite energy levels without losing any energy. While revolving, the energy and velocity of electron does not decrease. The electron do not come close to the nucleus. The spiral path of the electrons does not get shortened and the electron does not fall into the nucleus. Therefore, atom remains stable.

## VALENCE ELECTRON AND VALENCY

Electrons of the outermost shell are called valence electrons. The valency of an atom depends on the number of its valence electrons. It is because the electrons present in the outermost shell (valence shell) take part in chemical reactions.

We can say that valence electrons are those electrons which take part in chemical bonding and are located in the outermost shell of the atom.

**Number of valence electrons in an atom**

| Elements | Number of valence electrons | Valency |
|---|---|---|
| H, Li, Na, K | 1 | 1 |
| He, Be, Mg, Ca | 2 | 2 |
| B, Al | 3 | 3 |
| C, Si | 4 | 4 |
| N, P | 5 | 3 |
| O, S | 6 | 2 |
| F, Cl | 7 | 1 |
| Ne, Ar | 8 | 0 |

It is important to know that the number of valence electrons can easily be determined by simply writing the electronic configuration of the elements. The number of electrons present in the outermost shell are the valence electrons.

**Ex.1** What is the number of valence electrons of an element having atomic number (a) 11 and (b) 17.

**Sol.** (a) The electronic configuration of element having atomic number 11 is : 2, 8, 1. Therefore, the number of valence electrons is one.

(b) The electronic configuration of element having atomic number 17 is : 2, 8, 7. Therefore, the number of valence electrons is 7.

When atoms of one element combine with the atoms of another element, compounds are formed. The atoms of elements combine in fixed numbers to form the compounds. It is called the combining capacity of the element.

"Valency is defined as the combining capacity of an element."

For example, valency of hydrogen is one and that of carbon is 4. Thus, one hydrogen atom can combine with one carbon atom whereas one carbon atom can combine with 4 hydrogen atoms. The formula of methane is given below :

$$\begin{array}{ccc} & H & \\ & | & \\ H - & C & - H \\ & | & \\ & H & \end{array}$$

In methane molecule one hydrogen atom is linked to one carbon atom whereas one carbon atom is linked to 4 hydrogen atoms.

In $NH_3$ molecule, one N-atom is linked to three H-atoms. Therefore, valence of N is 3. In $PCl_5$, one phosphorus atom is linked to five Cl-atoms. Therefore, valency of phosphorus is 5. In H-F, the valency of both the atoms is one.

"Valency may also be defined as the number of electrons lost, gained or shared by an atom."

For example, sodium atom can lose one electron to form the cation $Mg^{2+}$. Therefore, valency of magnesium is 2. Chlorine atom can gain one electron to form chloride anion ($Cl^-$). Therefore, valency of chlorine atom is one. Oxygen atom can gain 2 electrons to from the oxide anion ($O^{2-}$). Therefore, the valency of oxygen atom is 2.

## RELATION BETWEEN VALENCY AND VALENCE ELECTRONS

It is important to know that valency of an atom depends upon the number of its valence electrons, that is number of electrons in the outermost shell of electrons.

The valency of an element is equal to -

(i) Either the number of its valence electrons.

(ii) Or number of electrons required to complete its octet (octet means 8 electrons in the outermost shell).

The valency of an element = number of valence electrons (when number of valence electrons are from 1 to 4)

The valency of an element = 8– number of valence electrons. (when number of valence electrons are more than 4)

**For example :**

Na has 1 valence electron, thus, its valency is 1.

Cl has 7 valence electrons, thus, its valency is 8 –7 = 1.

## ATOMIC NUMBER (Z)

(i) The number of protons in the nucleus of an atom of given element is called the atomic number of that element.

or

Atomic number is the number of protons present in the atom of an element. It is denoted by "Z".

(ii) Atomic number = Number of protons = Number of electrons (in a neutral atom)

Atomic number = Number of protons (in an ion)

(iii) The atomic number is represented on the LHS of the symbol of the element as subscript.

**E.g.** $_{11}$**Na**

- Atomic number of sodium is 11.
- Nucleus of sodium has 11 protons.
- Nucleus of sodium has 11 units of positive charge.
- There are 11 electrons, revolving around the nucleus of sodium.

**Boost your knowledge**

- Each element has a unique atomic number which is its identity.

## MASS NUMBER (A)

(i) An atom contains electrons, protons and neutrons. Since the mass of electrons is very, very small and is ignored, the actual mass of an atom is determined by the number of protons and neutrons only.

(ii) Mass number (A) of an element is equal to the sum of protons and neutrons present in the nucleus of one atom.

Mass number (A) = Number of protons + Number of neutrons

The mass number of an element is denoted by the letter A.

**Ex.1** One atom of nitrogen contains 7 protons, 7 electrons and 7 neutrons. What is the mass number of nitrogen atom ?

**Sol.** Mass number = Number of protons + Number of neutrons.

$= 7 + 7 = 14$

**Ex.2** One atom of sodium contains 11 protons and 12 neutrons. What is the mass number of Sodium atom ?

**Sol.** Mass number = Number of protons + Number of neutrons.

$= 11 + 12 = 23$

Relation between mass number (A) and atomic number (Z)

Mass number (A) = No. of protons + No. of neutrons.

$\because$ Atomic number (Z) = no. of protons

Mass number (A) = Atomic number (Z) + No. of neutrons (n)

$A = Z + n$

## SYMBOL OF AN ELEMENT

The atomic number (Z) and mass number (A) of the element can be shown on the symbol of an element. The atomic number (Z) is written on the lower left side of the symbol of the element whereas mass number (A) is written on the upper left side of the symbol of the element.

For example the lower figure 11 in the symbol of sodium shows the atomic number whereas the upper figure 23 shows the mass number of sodium.

Mass number / Atomic number $\boxed{\text{Symbol of element}}$ or ${}^{A}_{Z}\boxed{\text{Symbol of element}}$ ${}^{23}_{11}\boxed{\text{Na}}$

## DISTRIBUTION OF ELECTRONS IN AN ATOM

Electrons revolve around the nucleus in definite energy levels. These energy levels are also called orbits or shells. These orbits or shells are represented by the numbers 1, 2, 3, 4, … or by the letters K, L, M, N, … . The K shell having the minimum energy is nearest to the nucleus. L shell has little more energy and is a bit farther away from the nucleus and so on. The energy of the outermost shell of an element is the highest.

Different orbits can accommodate a fixed number of electrons.

(1) The maximum number of electrons which can be present in any orbit is given by the formula $2n^2$. Here, n is the number of that orbit or energy level for which number of maximum electrons is to be calculated.

| | |
|---|---|
| Maximum number of electrons in first orbit (n = 1) is | : $2n^2 = 2$ |
| Maximum number of electrons in second orbit (n = 2) is | : $2n^2 = 2(2)^2 = 8$ |
| Maximum number of electrons in third orbit (n = 3) is | : $2n^2 = 2(3)^2 = 18$ |
| Maximum number of electrons in fourth orbit (n = 4) is | : $2n^2 = 2(4)^2 = 32$ |

**Maximum number of electrons in a shell**

| Number of shell | Name of shell | Maximum number of electrons |
|---|---|---|
| 1 | K | 2 |
| 2 | L | 8 |
| 3 | M | 18 |
| 4 | N | 32 |

(2) The maximum number of electrons that can be accommodated in the outermost orbit of the atom is 8, even if this orbit has the capacity to accommodate more electrons as power rule (1), i.e.., $2n^2$.

**Boost your knowledge**

- If first orbit is the last orbit of the atom, then it can accommodate at the maximum 2 electrons.

(3) Electrons in an atom are not filled in the new shell unless all the inner shells are completely filled with electrons. Thus, the shells are filled in a step wise manner. Therefore, electrons are first filled in K shell, then L and shell, M shell, and so on. It is important to know that there are many exceptions to rule (2) and rule (3) which you will study in higher classes.

## ELECTRONIC CONFIGURATION

Electrons are distributed in various shells (energy levels) of an atom.

"The distribution of electrons in the various shells of an atom of the element is called its electronic configuration."

For example, electronic configuration of carbon (Z = 6) and oxygen (Z = 8) is 2, 4 and 2, 6 respectively whereas that of sodium (Z = 11) is 2, 8, 1. To know the electronic configuration of an element or an ion, the total number of electrons present in it should be known.

**Ex.1** Write the electronic configuration of nitrogen, oxygen, fluorine and neon. Their atomic numbers are 7, 8, 9 and 10 respectively.

**Sol.** The first, orbit can accommodate 2 electrons.

The electrons left in nitrogen, fluorine and neon are 5, 6, 7 and 8 respectively.

These electrons will be accommodated in second orbit (L shell).

Electronic configuration of nitrogen : 2, 5

Electronic configuration of oxygen : 2, 6

Electronic configuration of oxygen : 2, 7

Electronic configuration of neon : 2, 8

**Ex.2** Write the electric configuration of sodium and magnesium. Atomic Number of sodium is 11 and that of magnesium is 12.

**Sol.** The first orbit can accommodate 2 electrons. The second orbit can accommodate 8 electrons. Thus, total electrons accommodated in K and L shell are 2 + 8 = 10.

Electrons left to be accommodated in sodium = 11 – 10 = 1

Electrons left to be accommodated in magnesium = 12 – 10 = 2

These electrons are accommodated in M shell.

| | K | L | M |
|---|---|---|---|
| Electronic configuration of sodium : | K | L | M |
| | 2 | 8 | 1 |
| Electronic configuration of magnesium : | K | L | M |
| | 2 | 8 | 2 |

It is better to avoid the letters K, L, M etc. and write the electronic configuration simply as given below :

Electronic configuration of sodium : 2, 8, 1

Electronic configuration of magnesium : 2, 8, 2

**Electronic configuration of first Thirty elements**

| Atomic Number | Symbols of the element | Name of the element | Electronic configuration |
|---|---|---|---|
| 1. | H | Hydrogen | 1 |
| 2. | He | Helium | 2 |
| 3. | Li | Lithium | 2,1 |
| 4. | Be | Berylium | 2,2 |
| 5. | B | Boron | 2,3 |
| 6. | C | Carbon | 2,4 |
| 7. | N | Nitrogen | 2,5 |
| 8. | O | Oxygen | 2,6 |
| 9. | F | Fluorine | 2,7 |
| 10. | Ne | Neon | 2,8 |
| 11. | Na | Sodium | 2,8,1 |
| 12. | Mg | Magnesium | 2,8,2 |
| 13. | Al | Aluminium | 2,8,3 |
| 14. | Si | Silicon | 2,8,4 |
| 15. | P | Phosphorus | 2,8,5 |
| 16. | S | Sulphur | 2,8,6 |
| 17. | Cl | Chlorine | 2,8,7 |
| 18. | Ar | Argon | 2,8,8 |
| 19. | K | Potassium | 2,8,8,1 |
| 20. | Ca | Calcium | 2,8,8,2 |
| 21. | Sc | Scandium | 2,8,9,2 |
| 22. | Ti | Titanium | 2,8,10,2 |
| 23. | V | Vanadium | 2,8,11,2 |
| 24. | Cr | Chromium | 2,8,13,1 |
| 25. | Mn | Manganese | 2,8,13,2 |
| 26. | Fe | Iron | 2,8,14,2 |
| 27. | Co | Cobalt | 2,8,15,2 |
| 28. | Ni | Nickle | 2,8,16,2 |
| 29. | Cu | Copper | 2,8,18,1 |
| 30. | Zn | Zinc | 2,8,18,2 |

**Boost your knowledge**

- The maximum number of electrons that can be accommodated in a shell is given by the formula $2n^2$ (where n = number of shell i.e. 1, 2, 3 –)

  Electronic Configuration

| Shell | N | $2n^2$ | Max. no. of $e^-$ |
|---|---|---|---|
| K | 1 | $2(1)^2$ | 2 |
| L | 2 | $2(2)^2$ | 8 |
| M | 3 | $2(3)^2$ | 18 |
| N | 4 | $2(4)^2$ | 32 |

  Each energy level is further divided into subshells designated as s, p, d, f.

  $1^{st}$ shell (K) contains 1 subshell (s)

  $2^{nd}$ shell (L) contains 2 subshells (s, p)

  $3^{rd}$ shell (M) contains 3 subshells (s,p,d)

  $4^{th}$ shell (N) contains 4 subshells (s, p, d, f)

## ISOTOPES

(a) The isotopes of an element have the same atomic number but different atomic masses.

Isotopes have the same number of protons and electrons. The difference in their masses is due to the presence of different number of neutrons.

**E.g.**

**(i) Isotopes of hydrogen :**

| Characteristics | Protium $^1_1H$ | Deuterium $^2_1H$ | Tritium $^3_1H$ |
|---|---|---|---|
| 1. Atomic number | 1 | 1 | 1 |
| 2. No. of protons | 1 | 1 | 1 |
| 3. No. of electrons | 1 | 1 | 1 |
| 4. No. of neutrons | 0 | 1 | 2 |
| 5. Mass number | 1 | 2 | 3 |

**(ii) Isotopes of oxygen :**

| Characteristics | $^{16}_8O$ | $^{17}_8O$ | $^{18}_8O$ |
|---|---|---|---|
| 1. Atomic number | 8 | 8 | 8 |
| 2. No. of protons | 8 | 8 | 8 |
| 3. No. of electrons | 8 | 8 | 8 |
| 4. No. of neutrons | 8 | 9 | 10 |
| 5. Mass number | 16 | 17 | 18 |

**(b) Characteristics of Isotopes :**

**(i)** The physical properties of the isotopes of an element are different. This is due to the fact that isotopes have different numbers of neutrons in their nuclei. Hence mass, density and other physical properties of the isotopes of an element are different.

**(ii)** All the isotopes of an element contain the same number of electrons. So, they have the same electronic configuration with the same number of valence electrons. Since the chemical properties of an element are determined by the number of valence electrons in its atom, so all the isotopes of an element have identical chemical properties.

**(c) Reason for the fractional atomic masses of elements :**

The atomic masses of many elements are in fraction and not whole number. The fractional atomic masses of elements are due to the existence of their isotopes having different masses.

Average atomic mass can be calculated as :

$$\overline{M} = M_1\frac{X_1}{100} + M_2\frac{X_2}{100} \text{ ----------- } + M_n\frac{X_n}{100}$$

Or $\overline{M} = \dfrac{M_1r_1 + M_2r_2 - - - - - + M_nr_n}{r_1 + r_2 - - - - - + r_n}$

Or $\overline{M} = M_1P_1 + M_2P_2$ ---------+ $M_nP_n$

Where

$M_1, M_2, M_3$ ----- are the masses of isotopes

$X_1, X_2, X_3$ ----- are the % abundance of isotopes

$P_1, P_2, P_3$ ------- are probabilities of isotopes

**E.g. :** The atomic mass of chlorine is 35.5 u. Chlorine has two isotopes and with abundance of 75% and 25% respectively. Thus the average mass of a chlorine atom will be 75% of Cl-35 and 25% of Cl-37, which is 35.5 u.

i.e., average atomic mass of chlorine

$= 35 \times \frac{75}{100} + 37 \times \frac{25}{100} = \frac{2625}{100} + \frac{925}{100} = 26.25 + 9.25 = \mathbf{35.5\ u.}$

Thus, the average atomic mass of chlorine is 35.5 u.

**(d) Applications of Radioactive isotopes :**

**(i) In agriculture :** Certain elements such as boron, cobalt, copper, manganese, zinc and molybdenum are necessary in very minute quantities for plant nutrition.

**Note :** By radioactive isotopes we can identify the presence and requirements of these element in the nutrition of plants.

**(ii) In industry :** Coating of radium on the arm of clock to see in dark. To identify the cracks in metal casting.

**(iii) In medicine :** Thyroid, bone diseases, brain tumours and cancer are diagnosed, controlled or destroyed with the help of radioactive isotopes like

- The isotope, cobalt-60 is used for destroying malignant cells in patients suffering from cancer.
- The isotope, iodine-131 is used for studying disorders of the thyroid gland.
- The isotope, sodium-24 is used for examining the circulation of blood.

**(iv) Determination of the mechanism of chemical reaction :** by replacing an atom or molecule by its isotope.

e.g. Esterification

$$CH_3COOH + C_2H_5OH \xrightarrow{H^+} CH_3COOC_2H_5 + H_2O$$

(acetic acid) (ethyl alcohol) (ethyl acetate)

Here, radioactive oxygen determines that oxygen of $CH_3COOH$ take part in the reaction.

**(v) In carbon dating :** Willard Libby (1960) developed the technique of radiocarbon dating to determine the age of plants, fossils and archaeological samples.

Estimating the age of a carbon-containing object by measuring the concentration (or activity) of ${}^{14}_{6}C$ in it is called radiocarbon dating.

Radioactive carbon-14 (${}^{14}_{6}C$) gets converted to radioactive carbon dioxide $^{14}CO_2$. This radioactive $^{14}CO_2$ is taken up by plants during photosynthesis. ${}^{14}_{6}C$ is radioactive and decays by β-emission.

$${}^{14}_{6}C \longrightarrow {}^{14}_{7}N + \underset{(\beta-\text{particle})}{{}^{0}_{-1}e}$$

$^{14}_{6}C$ is being continuously formed in the higher atmosphere and consumed due to β-emission decay. As a result, an equilibrium concentration of $^{14}_{6}C$ is maintained in all the living plants. However, when a plant dies, it can no longer fix up radioactive $^{14}CO_2$. As a result, the concentration of $^{14}_{6}C$ in it starts decreasing. The half-life of $^{14}_{6}C$ is 5760 years. Thus, in 5760 years, the concentration of $^{14}_{6}C$ is lowered to half (50%) of its initial concentration, and another 5760 years, its concentration gets lowered to 25% (50% of the 50%) of the initial concentration. Thus, in 11,520 years, the $^{14}_{6}C$ concentration is reduced to one-fourth of its initial concentration. Thus, by measuring the concentration of $^{14}_{6}C$ in a dead carbon-containing object, and knowing the concentration of $^{14}_{6}C$ in a living plant, we can estimate the age of the object (the age of the object means the number of years ago when the plant would have died).

**Note :** Isotopes (Like Uranium-235) are used in nuclear reactors to produce energy and power.

## ISOBARS

The atoms of different elements with different atomic numbers, but same mass number are called isobars.

e.g. $^{14}_{6}\mathbf{C}$ and $^{14}_{7}\mathbf{N}$ are isobars, $^{40}_{20}\mathbf{Ca}$ and $^{40}_{18}\mathbf{Ar}$ are isobars.

| **Characteristics** | $^{40}_{18}Ar$ | $^{40}_{20}Ca$ |
|---|---|---|
| 1. Atomic number | 18 | 20 |
| 2. Mass number | 40 | 40 |
| 3. No. of electrons | 18 | 20 |
| 4. No. of protons | 18 | 20 |
| 5. No. of neutrons | 22 | 20 |
| 6. Electronic configuration | 2, 8, 8 | 2, 8, 8, 2 |

**Note :** Isobars contain different number of electrons, protons and neutrons.

## ISOTONES

The isotones may be defined as the atoms of different elements containing same number of neutrons.

e.g. $^{13}_{6}C$ and $^{14}_{7}N$

Number of neutrons (n) = A – Z

For $^{13}_{6}C$, number of neutrons = 13 – 6 = 7

For $^{14}_{7}N$, number of neutrons = 14 – 7 = 7

Other example $^{30}_{14}Si$, $^{31}_{15}P$ and $^{32}_{16}S$

## ISOELECTRONIC SPECIES

Ion or atom or molecule which have the same number of electrons are called as isoelectronic species.

e.g. $F^-$, Ne, $Na^+$, $H_2O$, $H_3O^+$, $CH_3^-$ all have 10 electrons.