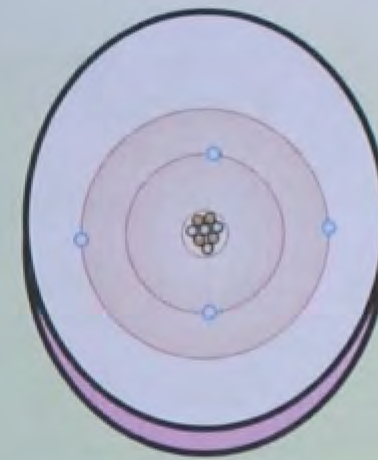
2 STRUCTURE OF AN ATOM



In This Chapter You Will Learn :

- Composition of an atom
- Arrangement of electrons in orbits or shells
- Atomic mass and relative atomic mass
- Definition of valency
- Types of valency
- Fundamental particles of an atom
- Structure of an atom
- Combination of atoms to form molecules
- Valence electrons and valence shell
- Writing a chemical formula

A. Structure of an Atom

INTRODUCTION

The word **atom** comes from the word **'atomos'** meaning indivisible coined by a Greek philosopher Democritus (460-361 B.C.). He forwarded the idea that the universe was made up of tiny indivisible particles called atoms. In 1808, John Dalton an English scientist suggested that, an atom is the basic unit of matter. Each chemical element is made up of identical atoms and elements are different because they are each made up of different kinds of atoms. According to Dalton an atom is the smallest particle exhibiting all the properties of a particular element.

Originally it was thought that atoms of an element can not be divided further, but studies in the early twentieth century showed that, an atom is itself made up of even smaller particles known as fundamental particles or subatomic particles. They are

- Electrons,
- Protons and
- Neutrons.

Electrons : Electrons are the negatively charged particles present in an atom. An electron has one unit negative charge, *i.e.*, $1{\cdot}602 \times 10^{-19}$ coulombs. An electron has a mass of $9{\cdot}1 \times 10^{-28}$ grams which is 1/1837 of the mass of one hydrogen atom. Therefore electrons are considered to have negligible mass. Evidences show that electrons are essential components of all atoms.

Protons : Protons are the positively charged particles present in an atom. They are equal in number to electrons present in an atom. They have one unit positive charge, *i.e.*, $1{\cdot}602 \times 10^{-19}$ coulombs. A proton has mass equal to one atomic mass unit (amu) which is

Table 2.1 : Symbol, charge and mass of sub-atomic particles

Particles	Symbol	Charge in coulombs	Mass in grams
1. ELECTRON	$_{-1}e^0$ or e^-	$1{\cdot}602 \times 10^{-19}$ C	$9{\cdot}1 \times 10^{-28}$ gms
2. PROTON	$_1H^1$ or p^+	$1{\cdot}602 \times 10^{-19}$ C	$1{\cdot}6 \times 10^{-24}$ gms
3. NEUTRON	$_0n^1$ or n^0	0	$1{\cdot}6 \times 10^{-24}$ gms

$1{\cdot}6 \times 10^{-24}$ grams. The number of protons in an atom of an element determines the properties of that element and distinguishes it from the atoms of other elements.

Neutrons : *Neutrons are particles with no electrical charge, so they are neutral.* A neutron has mass equal to **one atomic mass unit**, which is almost equal to the mass of a proton, *i.e.*, $1{\cdot}6 \times 10^{-24}$ grams.

- Sir J.J. Thomson in 1897 discovered the electrons.
- Robert Millikan in 1909 determined the negative charge on an electron.
- Goldstein discovered protons
- Earnest Rutherford in 1911 discovered that, an atom has a nucleus.
- Neil Bohr in 1913 discovered electron shells.
- James Chadwick in 1932 discovered neutrons in an atom.

Do You Know ?

The electrons, protons and neutrons that make up an atom are just three of more than 200 subatomic particles.

2.2 ATOM — ITS STRUCTURE

The three sub-atomic particles *i.e.*, protons, electrons and neutrons, are of great importance in understanding the structure of an atom. Various models were put forth to arrange these particles in an atom.

According to the modern standard model, an atom consists of two structural parts :

(i) **Nucleus :** It is the central part of an atom which contains protons and neutrons.

(ii) **Shells or orbits :** It is the imaginary path in the empty space of an atom surrounding the nucleus in which electrons revolve around the nucleus. There are a number of orbits in an atom and each orbit is associated with a fixed amount of energy.

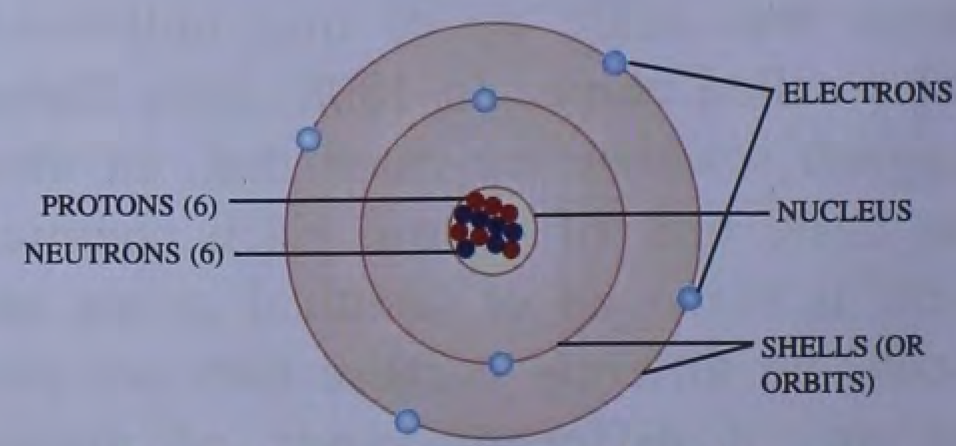


Fig. 2.1 The structure of carbon atom.

An atom of hydrogen (protium) contains only one proton and one electron but no neutron. All other atoms have all the three particles.

In comparison to the overall size of the atom the nucleus is very small. If we consider a circular stadium as an atom, then its nucleus is no more than a cricket ball.

The nucleus makes up most of the mass of an atom because it contains both protons and neutrons and they are much heavier than electrons.

The nucleus is positively charged due to the protons present in it. Neutrons are also located in the nucleus but being neutral, they do not affect the positive charge of the protons.

Protons and neutrons present in the nucleus are together called '*nucleons*'.

2.3 AN ATOM IS ELECTRICALLY NEUTRAL

The number of protons and the number of electrons in an atom are found to be equal. Protons are positively charged and electrons are negatively charged particles, thus we can say that they have equal and opposite electrical charges. Therefore, an atom, as a whole, is electrically neutral.

The stability of an atom : We know that there exists a force of attraction between particles with opposite electrical charges. Thus, there is a force of attraction between the *negatively* charged electrons and the *positively* charged protons, present in an atom.

Electrons revolve rapidly round the nucleus in fixed circular paths called energy levels or shells. It is expected that electrons being charged, light and in motion, would gradually come closer to the nucleus and eventually fall into it, resulting in the structural collapse of the atom. But this does not happen, because electrons revolve around the nucleus at a very high speed, in the shells or orbits associated with a fixed amount of energy also called as energy levels.

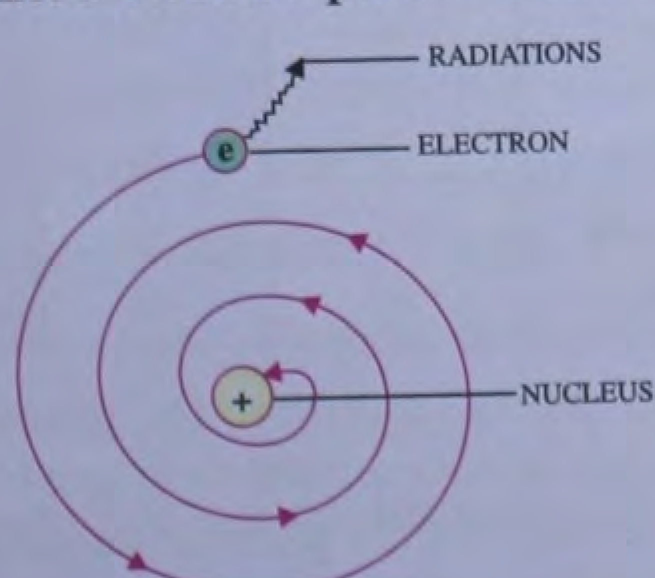


Fig. 2.2 Collapse of an atom

> The speed of an electron is about 1/10th the speed of light*.

Atoms neither lose nor gain energy until an external force is applied to them. As a result, electrons do not fall into nucleus making the atom structurally stable.

Atomic number : *Atomic number refers to the number of protons present in an atom.* It is denoted by the alphabet Z.

Atomic number (Z) = number of protons

Example **:** An atom of oxygen contains 8 protons. Therefore, its atomic number is 8.

In an electrically neutral atom, the number of protons is equal to the number of electrons. Therefore, in such an atom

Z = number of protons = number of electrons

Mass number : *Mass number is the sum of the number of protons and neutrons present in the nucleus of an atom.* It is denoted by the alphabet A.

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

Example **:** An atom of carbon contains 6 protons and 6 neutrons.

Therefore, its mass number is 6 + 6 = 12.

** The speed of light is about 3 lakh km/sec*

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

$$^{\text{Mass number}}_{\text{Atomic number}}\text{Symbol of element}$$

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

Characteristics of an atom according to the modern concept :

1. The atoms of all elements are made up of three fundamental particles : electrons, protons and neutrons [except hydrogen].
2. The nucleus is the centrally located part of an atom. It contains protons and neutrons. Most of the mass of an atom lies in it. This is because electrons have negligible mass and protons and neutrons are much heavier, contributing to the mass of an atom.
3. Electrons are found outside the nucleus, revolving around it in fixed orbits or shells.
4. The nucleus is positively charged, since protons have positive charge and neutrons have no charge.
5. Electrons are negatively charged particles.
6. The number of electrons is equal to the number of protons, which means that the atom as a whole is electrically neutral.
7. Atoms differ from each other due to the difference in their **atomic numbers**.

2.4 ATOMIC MASS (OR) RELATIVE ATOMIC MASS

The mass of an atom is known as its ***atomic mass***. Since the atom is a very small unit, it is not possible to measure its mass in grams. Therefore, the mass of light atoms, like that of hydrogen, 1/12th of carbon or 1/16th of oxygen, is taken as a standard unit. The mass of an atom of any other element is compared with these standard units. The carbon atom is the most suitable and the most widely accepted standard unit for the measurement of atomic mass. Therefore :

Relative atomic mass of an element is the number of times one atom of an element is heavier than 1/12th of the mass of an atom of carbon-12.

Relative atomic mass (RAM)

$$= \frac{\text{Mass of 1 atom of an element}}{\text{1/12 of the mass of carbon - 12}}$$

Table 2.2 : Atomic numbers, mass numbers and relative atomic masses of some common elements

Element	*Atomic number*	*Mass number*	*Relative atomic mass*
Hydrogen	1	1	1
Helium	2	4	4
Lithium	3	7	6·941
Beryllium	4	9	9
Boron	5	11	10·81
Carbon	6	12	12
Nitrogen	7	14	14
Oxygen	8	16	16
Fluorine	9	19	19
Neon	10	20	20·18
Sodium	11	23	22·99
Magnesium	12	24	24·31
Aluminium	13	27	26·98
Silicon	14	28	28
Phosphorus	15	31	30·97
Sulphur	16	32	32
Chlorine	17	35	35·5
Argon	18	40	39·95
Potassium	19	39	39·1
Calcium	20	40	40

Note : Mass number is always a whole number but relative atomic mass can be fractional as it is the average weight taken for the different isotopes of an element compared to the standard unit.

It tells us how many times the atom of an element is heavier, compared to the standard unit.

Example : The relative atomic mass of a sodium atom is 23. This means that an atom of sodium is 23 times as heavy as 1/12th of the mass of a carbon atom.

Earlier atomic mass unit was abbreviated as '*amu*', but according to the latest IUPAC recommendation, it is now written as '*u*' — unified mass.

2.5 ARRANGEMENT OF ELECTRONS AROUND THE NUCLEUS OF AN ATOM [ELECTRONIC CONFIGURATION]

Electrons revolve around the nucleus in imaginary paths called orbits or shells. The orbit closest to the nucleus is called the *first orbit*, the next orbit is called the *second orbit* and so on. They are labelled as :

K, L, M, N, ... or

1, 2, 3, 4, ...

Each of these shells contain different number of electrons depending upon the amount of energy associated with them. *The shell closest to the nucleus has the lowest amount of energy and hence contains the least number of electrons.*

The following rules are followed for writing the number of electrons in different energy levels or shells :

(1) The maximum number of electrons in each shell or orbit is determined by a formula $2n^2$, where n is the number of shell. Therefore :

K shell, $n = 1$, no. of electrons $= 2 \times 1^2 = 2$

L shell, $n = 2$, no. of electrons $= 2 \times 2^2 = 8$

M shell, $n = 3$, no. of electrons $= 2 \times 3^2 = 18$

N shell, $n = 4$, no. of electrons $= 2 \times 4^2 = 32$

Note : $2n^2$ is known as Bohr-Bury scheme as it was given by scientists Bohr and Bury.

Table 2.3 : Electronic configuration of elements with atomic number

Element	*At. number*	*Electronic configuration*			
		K	*L*	*M*	*N*
Hydrogen	1	1			
Helium	2	2			
Lithium	3	2	1		
Beryllium	4	2	2		
Boron	5	2	3		
Carbon	6	2	4		
Nitrogen	7	2	5		
Oxygen	8	2	6		
Fluorine	9	2	7		
Neon	10	2	8		
Sodium	11	2	8	1	
Magnesium	12	2	8	2	
Aluminium	13	2	8	3	
Silicon	14	2	8	4	
Phosphorus	15	2	8	5	
Sulphur	16	2	8	6	
Chlorine	17	2	8	7	
Argon	18	2	8	8	
Potassium	19	2	8	8	1
Calcium	20	2	8	8	2

Thus, the maximum number of electrons in the first orbit is 2, in the second 8, in the third 18 and in the fourth 32. ***However, the outermost orbit of an electrically neutral atom cannot have more than 8 electrons.***

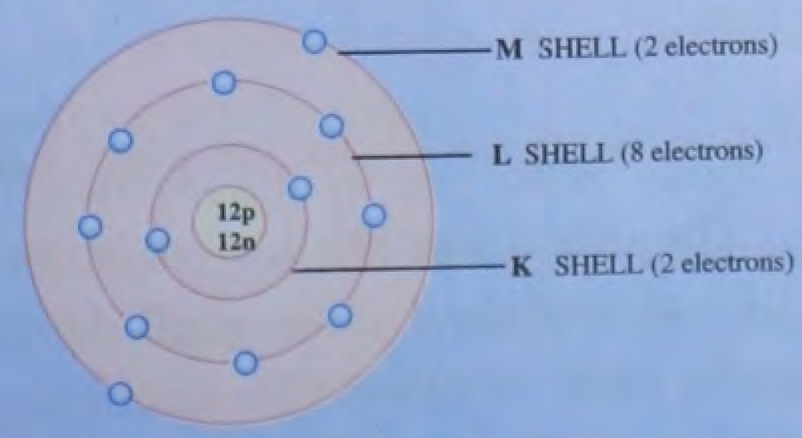


Fig. 2.3 The arrangement of electrons in a magnesium atom.

Fig. 2.4 Atomic diagrams of elements with atomic number (1-10) to show arrangement of electrons in different shells.

(2) If the number of electrons in the outermost orbit is 8, the atom is chemically stable and inert, but any number less than 8 makes it chemically unstable and reactive.

Exception : Hydrogen cannot have more than 2 electrons as it has only one shell.

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

Valence shell and valence electrons

The outermost shell of an atom is known as its *valence shell*. This shell determines the valency of an element. The electrons present in a valence shell are called *valence electrons.*

ISOTOPES : Isotopes are the atoms of same element with same atomic number but different mass number. They differ due to the number of neutrons present in them.

Example : Hydrogen element has three isotopes.

- Protium • Deuterium and • Tritium.

All the three have same atomic number, *i.e.*, one but their mass number are one, two and three respectively. This is because Protium has no neutron, Deuterium has one neutron and Tritium has two neutrons.

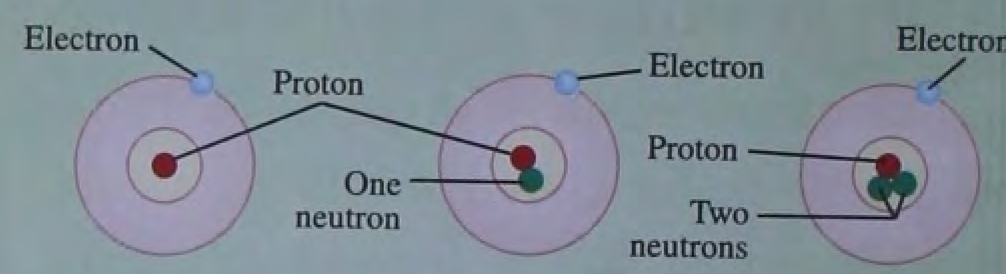


Fig. 2.5

Protium (^1_1H)	**Deuterium (^2_1H or D)**	**Tritium (^3_1H or T)**
At No. : 1	At No. : 1	At No. : 1
Mass number : 1	Mass No. : 2	Mass No. : 3
No. of electron = 1	No. of electron = 1	No. of electron = 1
No. of proton = 1	No. of proton = 1	No. of proton = 1
No. of neutron = 0	No. of neutron = 1	No. of neutron = 2

Other examples are :

(i) Carbon $^{12}_{6}C$ and $^{14}_{6}C$

(ii) Chlorine $^{35}_{17}Cl$ and $^{37}_{17}Cl$.

Application of isotopes

(1) An isotope of uranium is used as a fuel in nuclear reactors.

(2) An isotope of cobalt is used in the treatment of cancer.

(3) An isotope of iodine is used in the treatment of goitre.

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

Example : $^{40}_{20}Ca$, $^{40}_{18}Ar$

EXERCISE – I

1. Define the following terms :
   (a) Atomic number (b) Mass number
   (c) Relative atomic mass
   (d) Valence shell (e) Valence electrons.
2. Answer the following questions in short :
   (a) Name the fundamental particles present in an atom.
   (b) Give the charge and the mass of an electron, proton and neutron.
   (c) Name the particles present in the nucleus of an atom ? What are they collectively known as ?
   (d) What are the two main parts of which an atom is made of ?
   (e) Where is the nucleus of an atom situated?
   (f) What are orbits or shells ?
   (g) Name the particles which revolve around the nucleus.
   (h) What are the maximum number of electrons present in
   (i) first shell (ii) second shell
   (iii) third shell (iv) fourth shell and
   (v) valence shell of an atom.
   (i) Give the formula on which arrangement of electrons in an atom is based.
   (j) Why are orbits also known as shells or energy levels ?
3. State the main characteristics of an atom according to the modern concept.
4. Write electronic configuration and draw atomic diagrams of oxygen, fluorine, sodium, silicon, argon.
5. What are isotopes ? Name the three isotopes of hydrogen. Also give their atomic number and mass number.

B. Chemical Bonding, Valency and Chemical Formulae

The knowledge of atom can be applied to understand how molecules of elements and compounds are formed.

You have already studied that when the atoms of same element combine with one another a molecule of that element is formed and when the atom of different elements combine a molecule of a compound is formed.

Example : (i) Two atoms of oxygen combine to form a molecule of oxygen element. (ii) Two atoms of hydrogen and one atom of oxygen combine to form a molecule of water.

Why do atoms combine to form the molecules?

Atoms combine to form molecules so as to attain chemical stability.

The maximum number of electrons present in the outermost orbit of a stable atom is 8 except Helium which has two electrons. If an atom has 8 electrons in its outermost orbit, it acquires a stable structure and does not combine with the atoms of any other element.

Most of the atoms known to us have electrons less than 8 in number in their outermost shells. Therefore, they are chemically unstable, and so they tend to combine with other atoms to complete their *octet* and attain stability.

Do You Know ?

All the inert or noble gases, except helium have 8 electrons in their outermost orbits. This condition is called **octet**. Only helium has 2 electrons which has only one orbit with a maximum capacity of 2 electrons. This condition is called **duplet**.

Therefore, all inert gases are chemically stable and they do not combine with the atoms of any other element.

HOW DO ATOMS COMBINE ?

Atoms combine either by transfer of electrons or by sharing of electrons between the atoms.

HOW ARE THE ATOMS HELD IN A MOLECULE ?

Atoms are held together in a molecule by a force of attraction known as chemical bond.

A chemical bond is the binding force between two or more atoms present in a molecule.

FORMATION OF CHEMICAL BOND BY TRANSFER OF ELECTRONS [ELECTROVALENT BOND]

Transfer of electrons takes place between the atoms of metals and non-metals to form molecules.

Metallic atoms have electrons varying from 1 to 3 in their outermost shell, so they donate or lose these electrons to other atoms in order to become chemically stable by making their next complete inner shell as their outermost shell. After donating their valence electrons, they are left with greater number of protons and a lesser number of electrons. Therefore the atoms no more remain neutral. They become positively charged.

On the other hand non-metallic atoms have electrons varying from 4 to 7 in their outermost shell. So they accept or gain electrons from other atoms in order to complete their outermost shell and become stable. After gaining electrons these atoms have an excess of electrons over protons, therefore they become negatively charged.

These charged atoms are called ions.

*An atom which becomes charged by losing or gaining electrons is called an **ion**.*

*A positively charged ion is called a **cation** and a negatively charged ion is called an **anion**.*

A group of atoms carrying a charge is known as polyatomic ion.

The two oppositely charged ions are held together in the molecule by a strong electrostatic force of attraction which leads to the formation of electrovalent bond. These ions balance each other and therefore the molecule as a whole remains neutral.

The chemical bond formed due to complete transfer of electrons from one atom to another is called electrovalent or ionic bond.

The compounds formed by the ions are called ionic compounds.

The formation of ionic compound can be better understood by the following example :

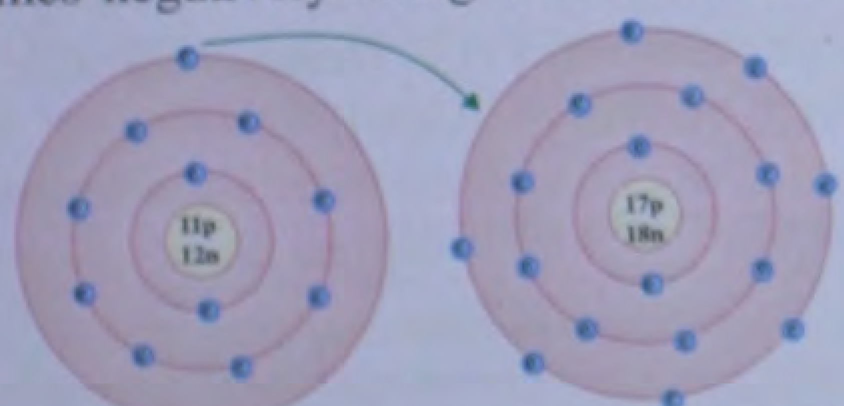
A molecule of compound sodium chloride is formed when one atom of sodium combines with one atom of chlorine. As we know, sodium has only one electron in its outermost shell. So,

Table 2.4 : Arrangement and transfer of electrons between sodium and chlorine.

Element	*Atomic number*	*Number of protons*	*Number of electrons*	*Arrangement of electrons*			*Number of electrons left after transfer of electrons*	*Charge*
				Ist shell	*IInd shell*	*IIIrd shell*		
Sodium	11	11	11	2	8	1	10	+1
Chlorine	17	17	17	2	8	7	18	–1

it donates this electron to the chlorine atom and becomes a positively charged ion (Na^+) with 11 protons and 10 electrons in all. The second orbit now becomes the outermost, with 8 electrons in it (*octet*). Thus, the sodium atom becomes chemically stable by acquiring stable electronic configuration.

The chlorine atom has 7 electrons in its outermost orbit, so, it accepts one electron from the sodium atom to complete its *octet* and becomes chemically stable. But, at the same time, it now has one extra electron, *i.e.*, 18 electrons and 17 protons in all. Therefore, it becomes negatively charged chlorine ion (Cl^-).

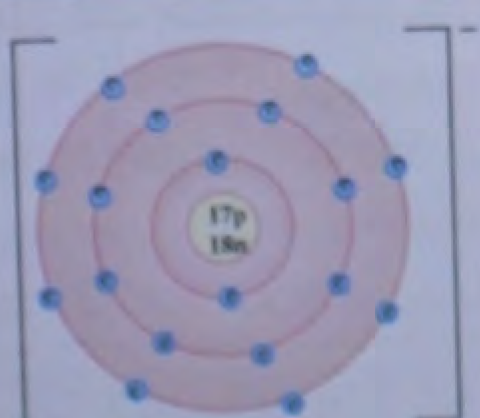


Number of electrons = 11 [2, 8, 1]
Sodium atom donates 1 electron

Number of electrons = 17 [2, 8, 7]
Chlorine atom accepts 1 electron

Other examples of ionic compounds are calcium oxide, magnesium chloride, potassium oxide, *etc*.

No. of electrons = 10 [2, 8]
A sodium ion (Na^+)



No. of electrons = 18 [2, 8, 8]
A chloride ion (Cl^-)

The oppositely charged sodium and chloride ions attract each other and bind together to form a molecule of sodium chloride (a compound). The positive charge on the sodium ion balances the negative charge on the chloride ion. As a result, the molecule of sodium chloride is chemically stable, *i.e.*, electrically neutral.

FORMATION OF CHEMICAL BOND BY SHARING OF ELECTRONS (COVALENT BOND)

When the atoms of different non-metals combine, they share their electrons to acquire stability. They neither donate nor accept electrons and hence no ions are formed. *Such a bond is called covalent bond.*

Some examples are : Water, carbon-dioxide, hydrogen chloride, oxygen molecule, hydrogen molecule, *etc*.

2.6 VALENCY

Valency denotes the combining capacity of an atom of an element.

The valency of an element is the number of electrons donated or accepted or shared by its 'atom' during chemical combination so as to acquire 8 electrons in its outermost orbit and attain chemical stability.

You have already studied that, during the formation of sodium chloride,

(i) the sodium atom donates one electron to the chlorine atom from its valence shell. Therefore, *the valency of sodium is* 1.

(ii) the chlorine atom accepts one electron from the sodium atom into its valence shell [in order to complete its octet]. Therefore, *the valency of chlorine is also* 1.

The atom that donates electrons is said to have a **positive valency,** whereas the atom that accepts electrons has a **negative valency.**

1. **Positive valency :** All metals [and hydrogen] have electrons numbering between 1 and 3 in their valence shells. During chemical combination, they donate their electrons and become positively charged. Depending upon the number of electrons donated, these elements are monovalent (Na^{+}), bivalent (Mg^{2+}) and trivalent (Al^{3+}).

2. **Negative valency :** All non-metals have negative valency. The number of electrons in their valence shells varies between 4 and 7. During chemical combination, they accept electrons and become negatively charged. Depending upon the number of electrons accepted, they are monovalent (Cl^{-}), bivalent (O^{2-}) and trivalent (N^{3-}).

Valency is always a whole number. There is a simple rule to determine the valency of an atom.

- When the number of valence electrons is less than 4

  Valency = Number of valence electrons.

- When the number of valence electrons is equal to or more than 4

  Valency = 8 – Number of valence electrons.

3. **Variable valency :** There are some elements with more than one valency. They are said to have variable valency.

   Example : iron, copper, tin, lead, sulphur, phosphorus, etc.

   For example, iron forms two compounds with chlorine : $FeCl_2$ (ferrous chloride) and $FeCl_3$ (ferric chloride).

Table 2.5 : Symbols and valencies of some common elements

Valency	*Positive valencies*			*Negative valencies*		
	Element	*Symbol*	*Ion*	*Element/ radical*	*Symbol*	*Ion*
Monovalent (valency 1)	Hydrogen Sodium Potassium Lithium	H Na K Li	H^{+} Na^{+} K^{+} Li^{+}	Chlorine/Chloride Bromine/Bromide Iodine/Iodide	Cl Br I	Cl^{-} Br^{-} I^{-}
Bivalent (valency 2)	Magnesium Calcium Zinc Barium	Mg Ca Zn Ba	Mg^{2+} Ca^{2+} Zn^{2+} Ba^{2+}	Oxygen/Oxide Sulphur/Sulphide	O S	O^{2-} S^{2-}
Trivalent (valency 3)	Aluminium Chromium	Al Cr	Al^{3+} Cr^{3+}	Nitrogen/Nitride	N	N^{3-}

Table 2.6 : Elements with variable valency

Element	*Symbol*	*Lower valency state*	*Higher valency state*
Copper	Cu	Cu^+ or Cu(I) [Cuprous]	Cu^{2+} or Cu (II) [Cupric]
Iron	Fe	Fe^{2+} or Fe (II) [Ferrous]	Fe^{3+} or Fe (III) [Ferric]
Silver	Ag	Ag^+ or Ag (I) [Argentous]	Ag^{2+} or Ag (II) [Argentic]
Lead	Pb	Pb^{2+} or Pb (II) [Plumbous]	Pb^{4+} or Pb (IV) [Plumbic]
Tin	Sn	Sn^{2+} or Sn (II) [Stannous]	Sn^{4+} or Sn (IV) [Stannic]
Mercury	Hg	Hg^+ or Hg (I) [Mercurous]	Hg^{2+} or Hg (II) [Mercuric]

In the first case, the suffix ***'ous'*** is used with the name of the element showing the lower valency and in the second case the suffix ***'ic'*** is used indicating the higher valency. Thus, $FeCl_2$ is named ferrous chloride, and $FeCl_3$, is named ferric chloride. The modern way of writing the names of these two compounds is iron (II) chloride and iron (III) chloride, which clearly indicates the valency of iron in these compounds.

2.7 RADICALS

The molecule of a compound is usually made up of two parts which are known as ***radicals***. These radicals are charged. *For example,* in sodium chloride, sodium ion and chloride ion are radicals. Sodium ion is positive and chloride ion is negative radical.

A radical may consist of one atom or group of non-metallic atoms that react as a single unit and keep their identity in many reactions.

The charge shown on these radicals also shows their valency (see table 2.7).

It can be said that a radical does not have independent existence. It exists in combination with another radical or element.

An example is the sulphate radical. The sulphate radical has the formula SO_4^{2-}, and a negative valency of 2. It cannot exist independently. It combines with other radicals. For example, with sodium ion, it forms sodium sulphate (Na_2SO_4).

Table 2.7 : Representation of some radicals

Name of radical	*Representation*	*Valency*
Ammonium	NH_4^+	1
Nitrate	NO_3^-	1
Nitrite	NO_2^-	1
Bisulphate	HSO_4^-	1
Bisulphite	HSO_3^-	1
Bicarbonate	HCO_3^-	1
Hydroxide	OH^-	1
Acetate	CH_3COO^-	1
Sulphate	SO_4^{2-}	2
Sulphite	SO_3^{2-}	2
Sulphide	S^{2-}	2
Carbonate	CO_3^{2-}	2
Dichromate	$Cr_2O_7^{2-}$	2
Phosphate	PO_4^{3-}	3

Another example, the nitrate radical, is represented as NO_3^-. It contains one atom of nitrogen (N), three atoms of oxygen (O) and one negative charge. It combines with Na^+ ion to form a compound, sodium nitrate ($NaNO_3$).

MOLECULAR FORMULA OF COMPOUNDS

Each compound is represented by a chemical formula with the help of symbols and valency of different atoms present in it. Since that formula represents the molecule of a compound, therefore it is more commonly known as its molecular formula.

> A molecular formula of a compound is the symbolic representation of its (one) molecule. It shows the number of atoms of each element present in it. These atoms combine in whole number to form the molecule.

For example : A molecule of sulphur dioxide gas is represented as SO_2. It indicates that one molecule of SO_2 is formed by one atom of element sulphur and two atoms of element oxygen.

2.8 WRITING THE CHEMICAL FORMULA OF A COMPOUND

To write the chemical formula of a compound, the following information should be available :

(i) Symbols of the elements or the radicals that constitute the compound.

(ii) Valencies of the elements or the radicals.

Step-by-step method for writing the formulae of chemical compounds.

I. Write the symbols

On the left hand side	*On the right hand side*
Positive ion Ca	Negative ion CI

II. Write the valency of the symbols

At the top right corner	*At the top right corner*
Positive ion Ca^{2+}	Negative ion Cl^{1-}

III. Interchange the valency number

(ignore the (+) and (–) signs)

Ca^{2+} ⟶ 2 ; Cl^{1-} ⟶ 1

Ca^{2+} Cl^{1-}
1 ⟵ ⟶ 2

IV. Write the interchanged numbers at the base

but ignore the + and the – signs

Ca_1 Cl_2

V. Write the formula of the compound

(ignore base number if it is 1)

$CaCl_2$

I. Write the radicals

On the left hand side	*On the right hand side*
Positive radical NH_4	Negative radical Cr_2O_7

II. Write the valency of the radicals

At the top right corner	*At the top right corner*
Positive radical NH_4^{1+}	Negative radical $Cr_2O_7^{2-}$

III. Interchange the valency number

(ignore the (+) and (–) signs)

NH_4^{1+} $Cr_2O_7^{2-}$
2 ⟵ ⟶ 1

IV. Write the interchanged numbers at the base

but ignore the + and the – signs

$NH_{4\ 2}$ $Cr_2O_{7\ 1}$

V. Write the formula of the compound

(radicals are placed in brackets when they are two or more in number)

$(NH_4)_2Cr_2O_7$

Note : The number 1 with Ca is not written in the formula because the symbol itself represents one atom.

One more example of writing molecular formula is in which valency number of positive and negative ion are divided by a common number.

Eg : Calcium oxide

Step I : Write the symbols and valencies.

Symbols	
Calcium	Oxide
Ca	O

Valencies	
Calcium	Oxide
2^+	2^-

Step II : Ca^{2+} ⨯ O^{2-}

Step III : Ca^2 O^2 ⟶ Ca_2O_2

Step IV : Reduce the valency numbers to the lowest ratio, if possible.

∴ the formula is, **CaO**

More examples :

(1) Formula of hydrogen sulphide :

Symbol H S

Valency 1 2

Formula : H_2S

(2) Formula of aluminium oxide :

Symbol Al O

Charge 3^+ 2^-

Formula : Al_2O_3

(3) Formula of Calcium hydroxide :

Symbol Ca OH

Valency 2^+ 1^-

Formula : $Ca(OH)_2$

Significance of molecular formula

The molecular formula of a compound gives us the following information :

(i) It represents one molecule of a compound.

(ii) The number of each kind of atoms present, *i.e.*, the ratio in which the atoms are present in one molecule.

(iii) The mass of one molecule of that compound.

Example :

- A molecule of sulphuric acid is represented by the formula H_2SO_4.
- The elements present in it are hydrogen, sulphur and oxygen.
- One molecule of sulphuric acid has two atoms of hydrogen, one atom of sulphur and four atoms of oxygen. The ratio in which atoms of hydrogen, sulphur and oxygen are present is 2 : 1 : 4.
- If the masses of all the atoms present in the molecule is added, the molecular mass of sulphuric acid is obtained.

Note : We can represent the number of molecules of a compound by writing a number before the formula.
For example: $2H_2SO_4$ represents two molecules of sulphuric acid.
5NaCl represents five molecules of sodium chloride.

Table 2.8 : Molecular formula of some metallic oxides

Metallic oxides	*Formula*
1. Magnesium oxide	MgO
2. Calcium oxide	CaO
3. Iron oxide	FeO
4. Copper oxide	CuO
5. Zinc oxide	ZnO
6. Lead oxide	PbO

Table 2.9 : Molecular formula of some metallic sulphides

Metallic sulphides	*Formula*
1. Magnesium sulphide	MgS
2. Calcium sulphide	CaS
3. Iron sulphide	FeS
4. Copper sulphide	CuS
5. Zinc sulphide	ZnS
6. Lead sulphide	PbS

Table 1.10 : Molecular formulae, the elements present and the state of some common compounds

Name of Compounds	*Formula*	*Elements present*	*State*
1. Common salt	$NaCl$	Sodium & chlorine	Solid
2. Sugar	$C_{12}H_{22}O_{11}$	Carbon, hydrogen & oxygen	Solid
3. Glucose	$C_6H_{12}O_6$	Carbon, hydrogen & oxygen	Solid
4. Baking soda	$NaHCO_3$	Sodium, hydrogen, carbon & oxygen	Solid
5. Washing soda	$Na_2CO_3 \cdot 10H_2O$	Sodium, carbon, oxygen & hydrogen	Solid
6. Marble & chalk [calcium carbonate]	$CaCO_3$	Calcium, carbon & oxygen	Solid
7. Sand [silica]	SiO_2	Silicon & oxygen	Solid
8. Calcium hydroxide	$Ca(OH)_2$	Calcium, oxygen and hydrogen	Solid
9. Sodium hydroxide	$NaOH$	Sodium, oxygen & hydrogen	Solid
10. Copper-sulphate	$CuSO_4$	Copper, sulphur & oxygen	Solid
11. Water	H_2O	Hydrogen & oxygen	Liquid
12. Acetic acid	CH_3COOH	Carbon, hydrogen & oxygen	Liquid
13. Hydrochloric acid	HCl	Hydrogen & chlorine	Liquid
14. Sulphuric acid	H_2SO_4	Hydrogen, sulphur & oxygen	Liquid
15. Nitric acid	HNO_3	Hydrogen, nitrogen & oxygen	Liquid
16. Carbon dioxide	CO_2	Carbon and oxygen	Gas
17. Carbon monoxide	CO	Carbon and oxygen	Gas
18. Sulphur dioxide	SO_2	Sulphur and oxygen	Gas
19. Sulphur trioxide	SO_3	Sulphur and oxygen	Gas
20. Ammonia	NH_3	Nitrogen and hydrogen	Gas
21. Hydrogen sulphide	H_2S	Hydrogen and sulphur	Gas
22. Nitrogen dioxide	NO_2	Nitrogen and oxygen	Gas
23. Nitric oxide	NO	Nitrogen and oxygen	Gas
24. Nitrous oxide	N_2O	Nitrogen and oxygen	Gas
25. Phosphorous pentoxide	P_2O_5	Phosphorus and oxygen	Solid

RECAPITULATION

- The atom is divisible. It consists of a nucleus and an extra-nuclear part.
- The three fundamental particles present in the atom are protons, electrons and neutrons. Protons are positively charged, each with 1 unit mass 1 unit positive charge. Electrons are negatively charged, and with one unit negative charge negligible mass. Neutrons are neutral with zero charge (no charge) *i.e.* electrically neutral, but they too have 1 unit mass.
- Atoms of different elements differ from one another because they contain a different number of protons in their respective nuclei.
- Chemically stable atoms are electrically neutral.
- Electrons are arranged in orbits around the nucleus of the atom.
- The number of electrons in the outermost orbit of a chemically stable atom cannot exceed 8.
- Atoms donate or accept or share electrons to combine chemically and attain chemical stability.
- The resultant combination of atoms gives a molecule.
- Valency is the number of electrons donated or accepted by the valence shell of an atom during chemical combination.
- Valency can be positive or negative.
- Some elements exhibit variable valency.
- The molecule of a compound is usually made up of two parts which are separately known as ***radicals***.
- Radicals are group of atoms that react as single unit and keep their identity in many reactions.
- Molecular formula is the representation of molecules with the help of the symbols and the valencies of its constituting atoms.

EXERCISE – II

1. Define the following terms :

(a) Ions (b) Chemical bond

(c) Molecular formula (d) Valency

2. Write the names of the elements present in the following compounds.

(a) Common salt (b) Ammonia

(c) Sulphuric acid (d) Glucose

(e) Sodium hydroxide (f) Acetic acid

3. What does each of the following represent ?

(a) $2CO_2$ (b) $2H_2S$

(c) $5H_2SO_4$ (d) $6NaNO_3$

4. Write the symbols and valencies of :

(a) Magnesium (b) Ammonium

(c) Carbonate (d) Nitrate

(e) Oxide (f) Bisulphate

(g) Aluminium

5. Name the following radicals :

(a) SO_4^{2-} (b) CO_3^{2-}

(c) OH^- (d) $Cr_2O_7^{2-}$

6. (a) Name one ion for each of the valencies +1, +2 and +3.

(b) Name one ion for each of the valencies –1, –2 and –3.

7. Elements X and Y have 1 and 7 electrons in their outermost shell respectively.

(a) Which of the element will lose electron ?

(b) Which of the element will gain electron ?

(c) Which will form positive ion ?

(d) Which will form negative ion ?

(e) What will be the formula of the compound formed when elements X and Y combine ?

(f) What will be the charge present on the molecule so formed ?

8. Magnesium and sulphur combine to form a molecule of a compound magnesium sulphide.
   (a) What is the number of electrons donated by a magnesium atom and number of electrons accepted by sulphur atoms ?
   (b) How many units of charge are developed on each of them ?
   (c) What is the number of electrons after the transfer of electrons in magnesium and sulphur atoms ?
   (d) Diagrammatically represent the transfer of electrons.
9. The valency of calcium is 2. Write the valencies of other radical in the following :
   (a) CaO (b) $Ca(OH)_2$
   (c) $CaCO_3$ (d) $CaCl_2$
   (e) Ca_3N_2
10. Write the names of the following compounds :
   (a) $(NH_4)_2SO_4$ (b) $Ca(NO_3)_2$
   (c) FeS (d) Na_3PO_4
   (e) NH_4OH (f) $CuCO_3$
   (g) HgO (h) $ZnCl_2$
   (i) ZnS (j) H_2S.
11. Write the molecular formulae of :
   (a) Sodium sulphide
   (b) Magnesium oxide
   (c) Calcium chloride
   (d) Hydrogen chloride
   (e) Sulphuric acid
   (f) Iron (II) sulphide
   (g) Iron (III) chloride
   (h) Nitric acid
   (i) Potassium hydroxide
   (j) Sodium chloride
12. The valency of sodium is one, write the molecular formula for the following compounds of sodium.
   (a) sodium oxide
   (b) sodium sulphate
   (c) sodium carbonate
   (d) sodium hydroxide
   (e) sodium nitrate
13. Give two example for each of the following types of compounds :
   (a) Ionic compounds
   (b) Covalent compounds
14. What is variable valency ? Give two examples of elements showing variable valency.
15. Complete the following table

Atomic number	Mass number	Number of neutrons	Number of protons	Number of electrons	Name of the atomic species
9	—	10	—	—	—
16	32	—	—	—	Sulphur
—	24	—	12	—	—
—	2	—	1	—	—
—	1	0	1	0	—

OBJECTIVE TYPE QUESTIONS

1. Fill in the blanks :
   (a) Atoms are ....
   (b) An ion with positive charge is called ....
   (c) An ion with negative charge is called ....
   (d) The outermost shell of an unstable atom.................. or .... electrons during chemical combination.
   (e) Protons and neutrons taken together are called ....
   (f) Metals have .... valency.
   (g) Non-metals have .... valency.
   (h) A group of non-metals possessing positive charge or negative charge is called ....
   (i) The number of electrons present in the outermost shell of an atom is called ....
   (j) A chemical formula represents a ....

2. Tick (√) the correct answer.

(a) A proton has
(i) positive charge
(ii) negative charge
(iii) no charge

(b) The atomic number of an element means the number of
(i) electrons (ii) neutrons
(iii) protons

(c) The mass of a neutron is equal to the mass of
(i) an electron (ii) a proton
(iii) a nucleus

(d) Atoms transfer electrons to become
(i) unstable (ii) stable
(iii) neutral

(e) The valency of iron in Fe_2O_3 is
(i) 1 (ii) 2
(iii) 3

(f) Which of the following has valency 4 ?
(i) aluminium (ii) oxygen
(iii) carbon (iv) phosphorus

(g) The sulphate radical is written as SO_4^{2-}. What is the formula of calcium sulphate ?
(i) $Ca(SO_4)_2$ (ii) $Ca_2(SO_4)$
(iii) $Ca(SO_4)_3$ (iv) $CaSO_4$

(h) The number of electrons present in the valence shell of sodium is
(i) 2 (ii) 1
(iii) 7 (iv) 3

(i) Which of the following exhibit variable valency ?
(i) calcium (ii) copper
(iii) carbon (iv) chlorine

3. Write *"true"* or *"false"*.

(a) The number of protons and electrons in an atom is the same. ....

(b) The maximum number of electrons in the outermost orbit of an atom is 6. ....

(c) An atom has positive charge. ....

(d) The nucleus of an atom has positive charge. ....

(e) Metal atoms accept electrons to attain stability. ....

4. Give one word for the following :

(a) The number of atoms present in a molecule of an element. ....

(b) The symbolic representation of a molecule. ....

(c) The force which holds the atoms together in a molecule. ....

(d) A group of atoms that react as a single unit. ....

(e) The arrangement of electrons in the shells of an atom. ....

GROUP ACTIVITY

Play a game for writing formula

Example : Make playcards with symbols and valencies of the elements separately. Each student should hold two placards, one with the symbol in the right hand and the other with the valency in the left hand. Keeping the symbols in place, students should criss-cross their valencies to form the formula of a compound.