



CHAPTER

2

CHEMICAL BONDING

We have learnt in previous classes that the smallest particle of an element or compound that is capable of an independent existence and shows all the properties of that substance is called a **molecule**. Molecules are made up of atoms. Molecule of an element is composed of atoms of the same kind. For example, a molecule of hydrogen consists of two atoms of hydrogen, two atoms of oxygen unite to form a molecule of oxygen etc. Atoms of different elements combine together in definite proportions to form molecules of compounds. For example, hydrogen chloride is a compound whose molecules are made up of one atom of hydrogen and one atom of chlorine. Similarly, a molecule of water contains two atoms of hydrogen and one atom of oxygen. When atoms of elements combine to form molecules, a force of attraction is developed between the combining atoms which holds them together. This force is called **chemical bond**. Thus, a **chemical bond is one which holds the atoms together in a molecule**.

2.1. ATTAINMENT OF A STABLE ELECTRONIC CONFIGURATION

How do atoms combine together to form molecules and why do atoms form bonds ? The molecule formed must be more stable than the individual atoms or molecules would not be formed. It means that the process must be energetically favourable and lead to a minimum energy.

In the previous class, we have studied the structure of atom. We have also learnt that the chemical properties of elements depend upon the number of electrons present in the outermost shell of the atom or **valence electrons**. It is a well known fact that atoms of the noble gases do not normally react with any other atoms and their molecules are mono-atomic, that is, they contain only one atom. The lack of reactivity indicates that these atoms are extremely stable and their energy is so favourable that it cannot be further minimised by compound

formation. They must be having a complete outer shell of electrons, so that we conclude that this is a very stable electronic arrangement or configuration. The electronic configuration of these elements are given below (Table 2.1).

Table 2.1. Electronic configuration of noble gas atoms

Element	Atomic Number	Number of electrons in various shells						Valence electrons
		K	L	M	N	O	P	
Helium (He)	2	2						2
Neon (Ne)	10	2	8					8
Argon (Ar)	18	2	8	8				8
Krypton (Kr)	36	2	8	18	8			8
Xenon (Xe)	54	2	8	18	18	8		8
Radon (Rn)	86	2	8	18	32	18	8	8

We can see from the above table that all the atoms of noble gases (with the exception of helium) have eight electrons in the valence shell. Helium, on the other hand, has two electrons in its first and the only energy level (K-shell) which cannot hold more than two electrons. *Two electrons in the first (K-shell) and the only shell of helium (He) and eight electrons in the outermost shells of other noble gases give a stable configuration of electrons.* We can therefore, conclude that atoms having eight electrons in their outermost shells (two in case there is K-shell) are very stable and unreactive. Eight electrons in the outermost shell of an atom is called **octet** of electrons. Two electrons in the outermost shell of helium is called **duplet** of electrons. Thus, eight electrons in the outermost shell of an atom makes the atom stable. When there is only K-shell, in an atom, two electrons in this shell make the atom stable.

All atoms other than noble gases have less than eight electrons in their outermost shells. In other words, the outermost shells of the atoms of these elements do not have stable configurations. Therefore, **atoms combine with each other or with other atoms to acquire stable nearest noble gas electronic configurations. The principle of attaining eight electrons in the valence shell of atoms is called octet rule.** However, it may be noted that for hydrogen and lithium atoms, the stable configuration means two (duplet) electrons which corresponds to the nearest noble gas helium. This is called **duplet rule**.

In the light of octet rule, Kossel and Lewis, in 1916 developed an important theory of chemical combination between atoms known as **Electronic Theory of Valency**. According to this theory, atoms combine to acquire the nearest noble gas electronic configuration by losing, gaining or sharing electrons. This leads to the formation of chemical bonds between the combining atoms.

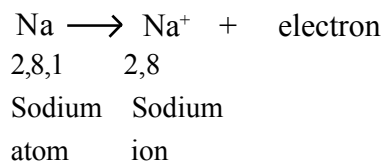
There are three common types of bonds. These are

- (i) Electrovalent or ionic bond
- (ii) Covalent bond
- (iii) Co-ordinate bond.

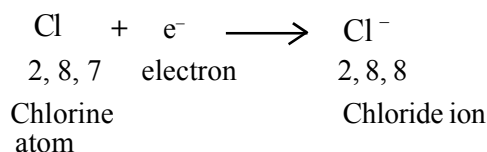
2.1.1. Electrovalent or Ionic Bond

In the previous chapter, we have seen that elements can be divided into (a) metals or electropositive elements, whose atoms give up one or more electrons fairly readily, and (b) non-metals or electronegative elements which take up electrons.

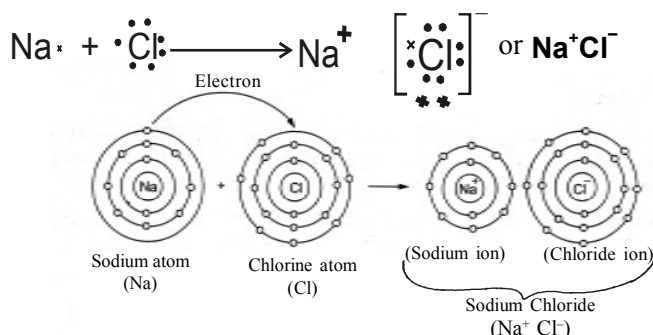
An ionic or electrovalent bond is formed when an electropositive element combines with an electronegative element. Let us consider the sodium atom (atomic number 11), which has the electronic configuration 2, 8, 1. The first and second shells of electrons are full, but the third shell contains only one electron. When this atom reacts, it will do so in such a way that a stable electron configuration is attained. The nearest noble gas neon has the configuration 2,8. If the sodium atom can lose one electron from its outer shell, it will attain this configuration except that sodium atom becomes sodium ion with a net charge of +1. This is because there are eleven positive charges on the nucleus and only ten electrons. When supplied with energy sodium atoms tend to do this, so sodium is an electropositive element.



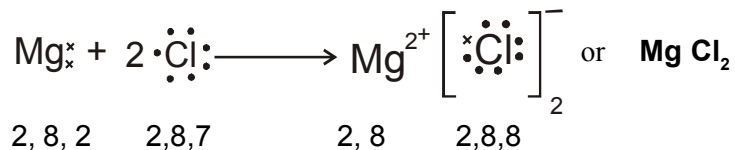
Chlorine atom has the electronic configuration 2, 8, 7. It is only one electron short of the stable inert gas configuration of argon, 2, 8, 8. Chlorine atoms tend to react and gain electrons that is they are electronegative. By gaining one electron, the electrically neutral chlorine atom becomes a chloride ion with a net charge of -1.



When sodium and chlorine react together, the outer electron of the sodium atom is transferred to the chlorine atom to produce sodium ion Na^+ and chloride ion Cl^- . The two ions (Na^+ and Cl^-), being oppositely charged, are now held together by the electrostatic force of attraction. Since both sorts of atoms attain a very stable inert gas configuration, the process is energetically favourable and sodium chloride, Na^+Cl^- is formed readily. This may be illustrated diagrammatically using dots and crosses to represent the valence electrons only as follows:

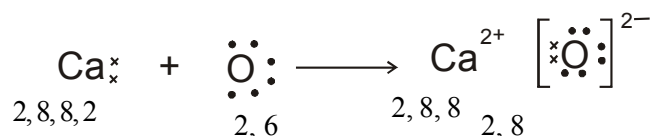


In a similar way, an atom of magnesium (Mg) can combine with two atoms of chlorine (Cl) to form magnesium chloride MgCl_2 . The electronic configuration of Mg (atomic number 12) is 2, 8, 2. It has 2 electrons in its outermost shell. Thus the Mg atom transfers its two valence electrons to two Cl atoms and changes into a stable magnesium ion (Mg^{2+}), with a stable octet of electrons in its outer shell. The positively charged magnesium ion (Mg^{2+}) and negatively charged chloride ions (Cl^-) are now held together by the electrostatic force of attraction.



It should be noted that two chlorine atoms are needed to take up the two electrons coming from a single magnesium atom.

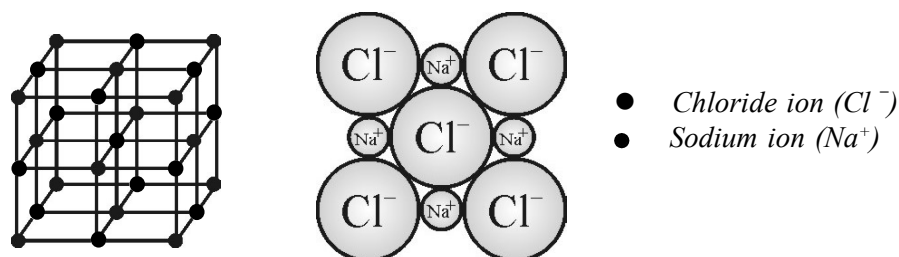
Combination of calcium (Ca) and oxygen (O) atoms to form calcium oxide (CaO) can be explained in a similar way. The atomic numbers of Ca and O are 20 and 8 respectively. So, their electronic configurations are 2, 8, 8, 2 and 2, 6, respectively, so that, Ca atom has two valence electrons, whereas the O atom has 6. When the two atoms combine, the two valence electrons of Ca are transferred to the valence shell of oxygen. In doing so, calcium, as well as oxygen atom, achieve a stable octet of electrons and thus attain stable noble gas configuration. Ca atom acquires two positive charges and becomes calcium ion (Ca^{2+}) and oxygen atom, two negative charges and becomes oxide (O^{2-}) ion. The two oppositely charged ions (Ca^{2+} and O^{2-}) are now held together by electrostatic force of attraction forming calcium oxide $\text{Ca}^{2+}\text{O}^{2-}$ or CaO.



In the above examples, we find that the stable structure like that of the noble gases is attained by combining atoms by the transfer of one or more electrons from one atom to another. **The type of combination between atoms which depend upon the transfer of electrons and in which oppositely charged ions are held together by electrostatic force of attraction, is called electrovalent or ionic bond.** *The number of electrons lost or gained by an atom to attain the stable electronic configuration is known as the electrovalency of the atom.* The compounds formed by electrovalent or ionic bonds are called electrovalent or ionic compounds.

Characteristics of Ionic or Electrovalent Compounds

- (a) **Ionic compounds are generally crystalline in nature.** X-rays studies of these compounds have shown that they do not exist as single molecules but as ions which are arranged in a well defined geometric pattern. This is because of the fact that the forces of attraction are not restricted to a single unit, such as one Na^+ and one Cl^- , but due to uniform electric field around an ion, each ion is attracted to a large number of other ions. The ionic bond is **non-directional**. This results into a three dimensional aggregate of the oppositely charged ions arranged in a regular manner. For example, the arrangement of ions in sodium chloride is such that each Na^+ ions is surrounded by six Cl^- ions and each Cl^- ion is surrounded by six Na^+ ions.



The arrangement of ions in sodium chloride crystal.

The right hand side diagram shows the relative size of ion.

The left hand side diagram shows only the arrangement of ion, but not their relative sizes.

Fig. 2.1. Formation of aggregates in ionic crystals.

- (b) **Ionic compounds have high melting and boiling points.** This is due to the strong electrostatic force of attraction between the oppositely charged ions. As a result of this, large amount of energy is needed to break the bond and hence melting and boiling points are high.
- (c) **They conduct electricity in molten state and in their aqueous solution.** Solid ionic compounds do not conduct electricity as the ions are fixed at particular positions and are not free to move. However, when these are melted or dissolved in water, the ions become free and, therefore, conduct electricity.
- (d) **Ionic compounds are usually soluble in water and other polar solvents** but insoluble in organic solvents such as benzene, ether, carbon tetrachloride, kerosene etc.

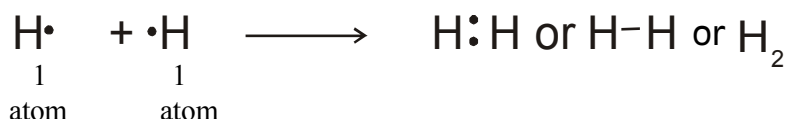
Let us answer these.

1. Which electronic configuration favour inert or noble behaviour of elements ?
2. Why do most of the elements form ions ?
3. What kind of elements form cation ? Support your answer by two examples?
4. What kind of elements form anions ? Support you answer by two examples.
5. Sodium atom reacts vigorously with water, but sodium ion does not. Why ?
6. What is an ionic bond ? State at least three conditions for its formation.
7. A metal A (atomic number 19) burns in chlorine to produce a white solid chloride ACl. By means of diagrams, show the arrangement of electrons in A before and after the reaction.
8. Give reasons of the following : (a) Ionic compounds have high melting and boiling points. (b) Ionic compounds are good conductors of electricity in fused state or aqueous solution.

2.1.2. Covalent Bond

The formation of ionic bond cannot explain the chemical combination between identical atoms or atoms of similar chemical nature to form molecules. Thus it cannot account for the formation of molecules like H_2 , O_2 , Cl_2 , CO_2 ; and also for the organic molecules like methane (CH_4), carbon tetrachloride (CCl_4) etc. In such cases, the combining atoms attain the stable noble gas configuration by sharing electrons. The sharing always occurs in pairs and in each pair of shared electrons, one electron is contributed by each atom. **The bond formed by mutual sharing of electrons between the combining atoms is called covalent bond.** Sharing of one pair of electrons form a **single bond**, two pairs a **double bond** and three pairs a **triple bond**.

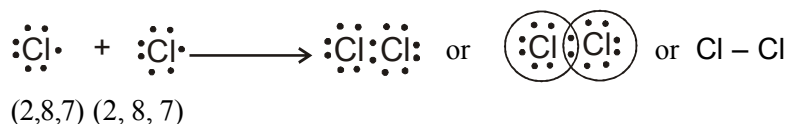
Let us consider the formation of hydrogen molecule (H_2) from two atoms of hydrogen. The nucleus of hydrogen has one proton and the only one electron revolves in the K-shell which is also the valence shell. In the formation of hydrogen molecule, H_2 , when the two hydrogen atoms approach each other, the single electron of both the atoms form a shared pair. This electron pair revolve around the two nuclei of H-atoms i.e., the two H-nuclei are bound together by the electron pair. It is contained in the electron shells of both the atoms and each hydrogen atom attain the electronic configuration of the nearest inert gas helium. In the conventional system of writing the structural formula of molecules, a single covalent bond is represented by a dash (–) between the combining atoms. This may be represented as follows.



Pictorially hydrogen molecule may be represented as . Once the bond is formed, both the atoms have a stable configuration of the noble gas helium.

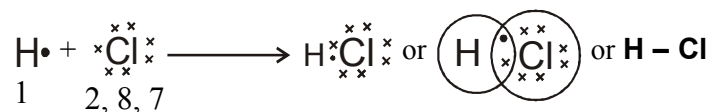
Formation of Chlorine molecule (Cl_2)

The atomic number of chlorine is 17. The electronic configuration of the Cl atom is 2, 8, 7. Thus, a Cl atom needs one electron to complete its octet. The two combining atoms of chlorine gives one of its electrons to be shared between them and constitute a shared pair of electrons. The two shared electrons are counted for both the atoms. Thus, each Cl atom in a chlorine molecule (Cl_2) acquires a stable configuration. Showing the outer (valence) electrons only, this may be represented as follows:



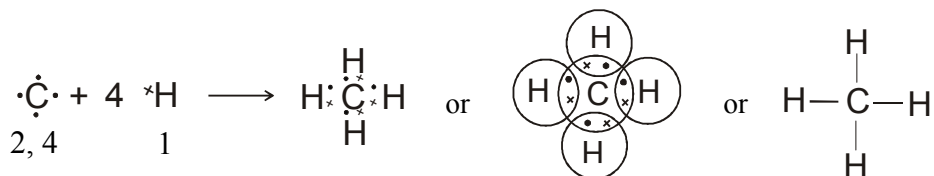
Formation of hydrogen chloride (HCl) molecule

Hydrogen atom has only one electron and chlorine atom has seven electrons in its valence shell. Hence, by mutual sharing of electron pair between them, both the atoms acquire nearest noble gas configurations. Hydrogen atoms acquire stable electronic configuration (duplet) of helium whereas chlorine atoms acquire stable electronic configuration (octet) of argon.



Formation of methane (CH₄) molecule

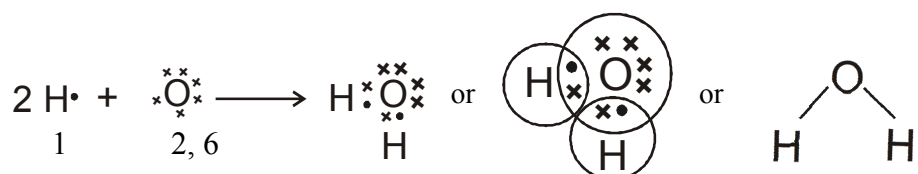
A carbon atom has four electrons in its valence shell. It shares its valence electrons with those of four H atoms. Thus, an atom of carbon forms four single covalent bonds with four H atoms.



In a molecule of methane, the carbon atom and each of the four H atoms acquire the stable electronic configurations of neon and helium respectively. In methane, we have four carbon-hydrogen (C–H) single bonds. Thus, a methane molecule has four pairs of shared electrons.

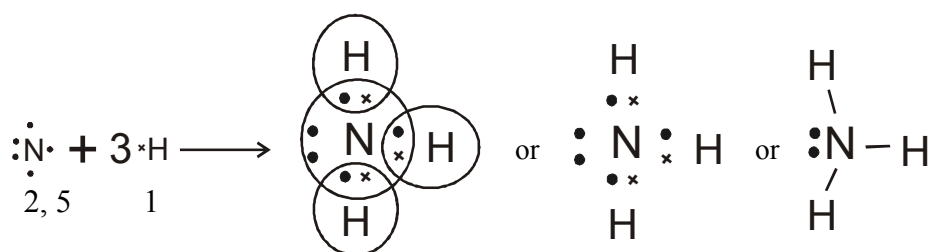
Formation of water (H₂O) molecule

A molecule of water is made up of one oxygen atom and two hydrogen atoms. An oxygen atom is two electrons short and hydrogen atoms are one electron short of a noble gas structure. Thus one atom of oxygen shares two of its electrons with two hydrogen atoms, thus attaining a stable configuration.



Formation of ammonia (NH₃) molecule

A molecule of ammonia is formed by the combination of one atom of nitrogen with three atoms of hydrogen. There are five electrons in the valence shell of nitrogen atom. So, it has three electrons short of to complete its octet and to be stable. When it shares three of its electrons with three H atoms, the stable electronic configuration of neon is achieved. The three H atoms acquire the stable helium configuration.



Multiple Covalent Bonding

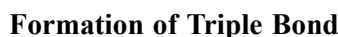
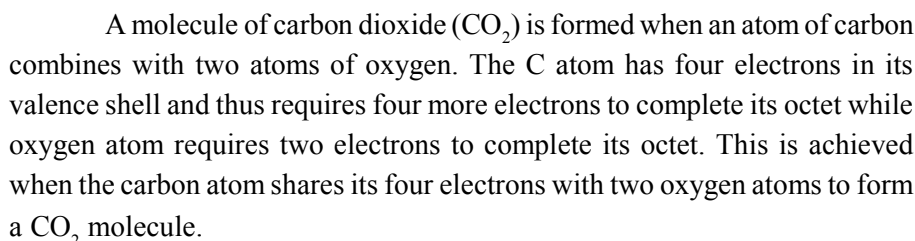
We have seen that electron pair shared between two atoms is responsible for the formation of a covalent bond. This shared pair is also called **bonding pair of electrons**. The pair of electrons which do not take part in bonding are called **lone pairs**. The bonding atoms may share more than one pair of electrons also depending upon their requirement to complete the stable electronic configuration or octet.

If the two atoms share one electrons pair, the bond is known as **single covalent bond** and is represented by one dash (–).

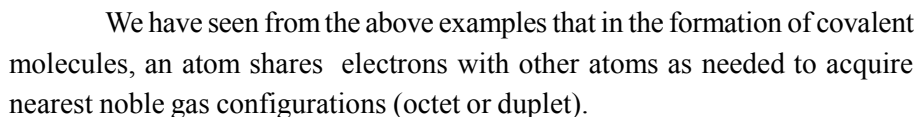
If the two atoms share two electron pairs, bond is known as **double covalent bond** and is represented by two dashes (=).

If the two atoms share three electron pairs, bond is known as **triple covalent bond** and is represented by three dashes (≡).

Two oxygen atoms combine to form an oxygen molecule(O_2) by sharing two electron pairs. We know that each oxygen atom has six electrons in the valence shell and requires two electrons to complete the octet. Therefore, in the formation of oxygen molecule, both the atoms contribute two electrons each for sharing resulting in two electron pairs. Hence there is double bond between the two oxygen atoms.



In the formation of nitrogen molecule (N_2), each of the two nitrogen atoms having five valence electrons, provides three electrons to form three electron pairs for sharing. Thus a triple bond is formed between the two atoms.



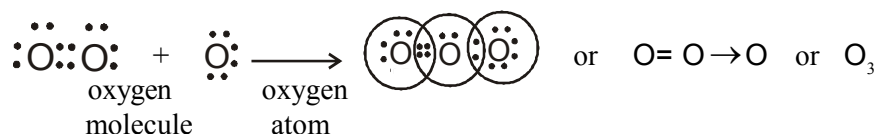
The type of combination between atoms which results from the mutual sharing of pair of electrons between the combining atoms is called **covalent bond** and the molecules formed are called **covalent molecules**. The number of electrons contributed by an atom for sharing in the formation of a covalent molecule is known as **covalency**. Thus, the covalency

of hydrogen, oxygen and nitrogen in the above examples is one, two and three respectively.

2.1.3. Co-ordinate or Dative Bond

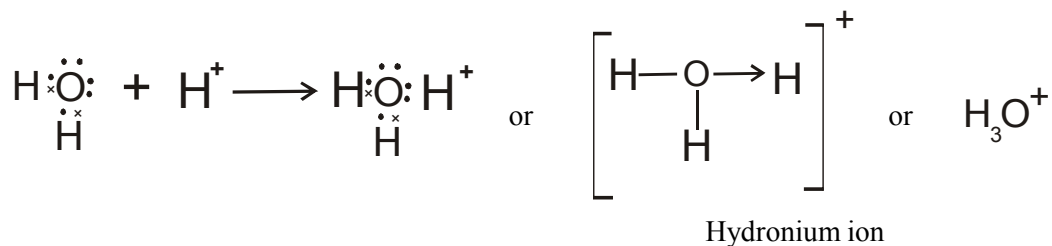
A covalent bond results from the sharing of an electron pair, where each atom contributes one electron to the bond, as seen above. It is also possible to have an electron pair bond in which both the electrons of the shared pair came originally from one of the atoms. Such type of bond is formed between atoms, one of which is deficient in at least two electrons while the other has already acquired a stable configuration (or octet). The atom which contributes the electron pair is called the *donor* while the other which only shares the electron pair is known as *acceptor*. Such bonds are called **co-ordinate covalent or dative bonds**. The usual representation of co-ordinate bond is to point an arrow ($\rightarrow$) from donor to the acceptor.

Let us consider the formation of ozone (O_3) molecule. A molecule of oxygen (O_2) contains two atoms of oxygen joined by covalent double bond so that each atom has stable octet configuration. In O_2 molecule, each oxygen atom has two pairs of unused valence electrons. Such pairs of electrons which are not involved in bond formation are called **lone pairs**. Now, if an atom of oxygen having six valence electrons comes close to O_2 molecule, the new atom may share a lone pair of electrons of one of the oxygen atoms of O_2 molecule. It gives rise to the formation of a co-ordinate covalent bond.

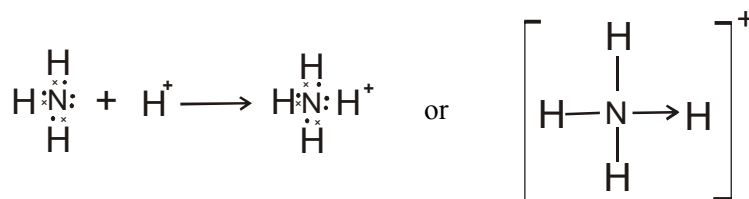


Formation of hydronium ion (H_3O^+) and ammonium (NH_4^+) ion

Water, H_2O has lone pair of electrons on oxygen atom while hydrogen ion (H^+) has empty K-shell thereby can accommodate two electrons. Thus, oxygen in H_2O can easily provide two electrons while H^+ ion can accept these electrons to form a co-ordinate bond between them.



Similarly ammonium ion (NH_4^+) is formed by co-ordinate bond between ammonia (NH_3) molecule and hydrogen ion (H^+).



Ammonium ion

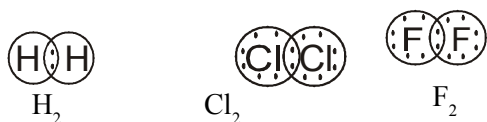
Characteristics of Covalent substances

Covalent substances show the following characteristic properties.

- (a) **Physical state :** The covalent compounds do not exist as ions but they exist as molecules. There are weak inter molecular forces between the molecules. Hence, generally they exist as liquids or gases at room temperature.
- (b) **Low melting and boiling points:** Since the forces between the molecules are weak, a comparatively small amount of heat energy is required to overcome these forces. Hence covalent compounds generally have low melting and boiling points.
- (c) **Solubility:** In general, they are sparingly soluble in polar solvents like water but soluble in non-polar solvents like benzene, carbon tetrachloride, kerosene, etc.
- (d) **Conductivity :** They do not conduct electricity. This is because they are made up of neutral molecules, not ions.

2.1.4. Do covalent bonds show partial ionic character ?

If we consider a covalent bond between similar atoms, the shared pair of electrons is equally attracted by the two atoms. As a result of this, it is situated exactly in between the two identical nuclei. The common examples are H_2 , F_2 , Cl_2 etc.

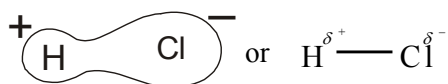


These are examples of pure covalent bonds.

However, if the atoms forming bonds are different, the electron attracting tendency of the two atoms may differ. *The relative tendency of an atom to attract shared electrons to itself when combined in a compound is termed as the electronegativity of the atom.* As a result of the difference in electronegativity, the shared electron pair will be displaced towards the atom with more electron attracting tendency or electronegativity. For example, the compound hydrogen chloride is formed by sharing a pair of electrons between the hydrogen and the chlorine atom.



Of the two nuclei, the attraction exerted on the shared pair of electrons by the chlorine nucleus is more than that by the hydrogen nucleus. In the hydrogen chloride molecule, therefore, the shared electron pair would be attracted more towards the chlorine end of the molecule. So the chlorine end of the molecule will be slightly negative and the hydrogen end slightly positive, these are represented as δ^+ and δ^- charges.



In other words, the hydrogen chloride molecule develops a partial ionic character even though it is a covalent molecule. Such molecules are said to be **partially polar**. Almost all covalent bonds between unlike atoms are partially polar. They are thus **polar covalent compounds**.

Similarly, the molecules of HF and H₂O are polar covalent compounds.



Unlike the covalent bond in the HF and HCl molecule, the water (H₂O) molecule contains two covalent bonds between the oxygen and hydrogen atoms. These two bonds are not symmetrically arranged, and H₂O molecule is V-shaped. This results in the polar character of water. Hence water is a polar solvent.

Let us answer these.

1. Using dots (•) and crosses (×) to represent valence electrons, show the formation of covalent bonds in CO_2 and CCl_4 .
2. Why does carbon tetrachloride not conduct electricity ?
3. How does a co-ordinate bond differ from a normal covalent bond ?
4. Why does H_2 molecule exist while He_2 does not exist ?
5. Why is HF polar while H_2 and F_2 are not polar.

2.3. BONDING IN METALS

We know that metals are generally hard solids and they are made up of atoms. It has been established that the atoms in metals are closely packed together.

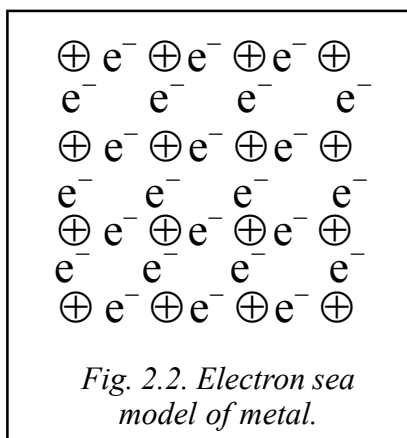


Fig. 2.2. Electron sea model of metal.

What force holds the atoms in metals closely together ? What type of bonding exist between the atoms of metals ? We have learnt that metal atoms can easily lose electrons to form positively ions and they are good conductors of electricity. This implies that the valence electrons of metal atoms are loosely held by the nucleus and can move freely.

To account for the bonding in metals, Lorentz has proposed a model known as *electron sea model*. According to this model, a metal lattice consists of positively charged **kernels** arranged in a regular way surrounded by loosely held valence electrons. Kernels are metal nuclei and other electrons except valence electrons. Alternatively, it can be assumed that there is a sea of valence electrons in which positively charged **kernels** are immersed. It is for this reason that it is called **electron sea model**. *The simultaneous force of attraction between the positively charged kernel and the mobile electrons which binds the metal atoms together is called metallic bond.*

Let us consider lithium metal. The electronic configuration of lithium is 2, 1; it has one valence electron. Without the valence electron, the kernel is Li^+ . The arrangement of kernel of lithium atom, $\oplus$ and valence electrons (e^-) in its metal lattice is shown in Fig.2.2.

SUMMARY

- The interaction between two or more atoms or groups of atoms holding the atoms together is called chemical bond.
- Noble gas atoms have stable electronic configurations.
- The type of combination which depends upon the transfer of electrons and in which oppositely charged ions are held together by electrostatic force of attraction is called electrovalent or ionic bond.
- Atoms which can lose electrons and form positive ions (cations) are said to be electropositive and the elements are called electropositive elements. Metals are generally electropositive.
- Atoms which can gain electrons and form negative ions (anions) are said to be electronegative and the elements are called electronegative elements. Non-metals are generally electronegative.
- The number of electrons gained or lost by an atom in the formation of ionic bonds is equal to its electrovalency.
- Covalent bonds are formed by mutual sharing of electrons between the combining atoms.
- Compounds formed by covalent bonds are called covalent compounds.
- The number of electrons contributed by an atom for sharing in the formation of covalent bonds to attain stable configuration is known as its covalency.
- A co-ordinate covalent bond is formed by sharing of electrons between two atoms where both the electrons of the shared pair come originally from one atom and none from the other .
- The force that holds the atoms closely together by simultaneous force of attraction between the positively charged kernel and the mobile valence electrons in a metal is known as the metallic bond.

EXERCISES

1. Define the terms 'valence shell' and 'valence electrons'.
2. Why do elements combine chemically ?
3. What is an electrovalent bond and how is it formed ?

4. What is a covalent bond and how is it formed ?
5. How does an ionic bond differ from a covalent bond ? Illustrate your answer with two examples of each type of bond.
6. What is a polar molecule ? Give example.
7. Give electron dot representation for the following molecules.
 F_2 , HF and H_2O .
8. State four properties each of electrovalent and covalent compounds.
9. The elements w , x , y and z have atomic numbers 7, 9, 10 and 11 respectively. Write the formula of the molecules that would be formed between the following pairs of elements and indicate the type of the bonding present using dots ($\cdot$) and crosses ($\times$) to represent valence electrons.
(a) w and x (b) x and x (c) w and z (d) y and y .

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