

STRUCTURE OF MOLECULES

CONCEPTUAL LINKAGE

Before reading this chapter, the student must know the,

- Electronegativity concept.
- Polarity of compounds

TIME ALLOCATION

Teaching periods	= 16
Assessment periods	= 04
Weightage	= 15%

LEARNING OUTCOMES

After reading this chapter, the Student will be able to,

- Find the number of valence electrons in an atom using the Periodic table. (Applying)
- Describe the importance of noble gas electronic configuration. (Understanding)
- State the octet and duplet rules. (Remembering)
- Explain how elements attain stability. (Understanding)
- Describe the ways in which bonds may be formed. (Remembering)
- State the importance of noble gas electronic configurations in the formation of ion. (Applying)
- Describe the formation of cations from an atom of a metallic element. (Applying)
- Describe the formation of anions from an atom of a non-metallic element. (Applying)
- Describe the characteristics of an ionic bond. (Understanding)
- Recognize a compound as having ionic bond. (Analyzing)
- Identify characteristics of ionic compounds. (Understanding)
- Describe the formation of a covalent bond between two non metallic elements. (Understanding)
- Describe the characteristics of ionic and covalent compounds. (Understanding)
- Describe with examples single, double and triple covalent bonds. (Understanding)
- Draw electron cross and dot structures for simple covalent molecules containing single, double and triple bonds. (Applying)

4.0 Introduction

In chemistry the structure determination is the basic and most essential element. The properties of matter lie in the structure of compounds, and structure of the compound is largely influenced by the type of bonding in the compound. A chemical bond is the force of attraction between the atoms that constitute the molecule, this attraction results due to the electrostatic forces produced by the charged particles of atoms. The chemical bonding is associated with the sharing or transfer of electrons between the participating atoms. Molecules, crystals, and diatomic gases indeed most of the physical environment around us are held together by chemical bonds, which dictate the structure of matter. In the forth coming topics you will learn the different types of bonds that are found in the chemical compounds, and also their influences upon the nature of these compounds.

4.1 Why Do Atoms Form Chemical Bonds?

It is the basic tendency of matter to be in the lowest energy state, that is why the atoms react to form molecule or form bonds between them.

In the periodic table the most stable electronic structure is of the noble gases, so all the other atoms react to attain the electronic structure of these noble gases.

For example the Na atom has the electronic configuration, $1s^2 2s^2 2p^6 3s^1$. The nearest noble gas of this configuration is Neon with electronic configuration, $1s^2 2s^2 2p^6$.

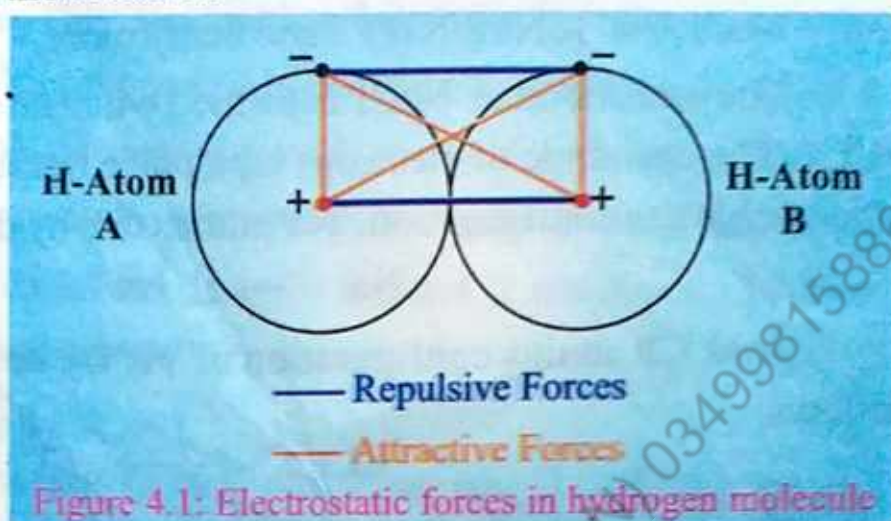
So, the Na tries to attain this configuration when it reacts with the other elements, e.g. in reaction with Cl to form NaCl, the Na losses 1 electron and attains the electronic configuration of Ne, in the same way Cl accepts 1 electron and attains the electronic configuration of his nearest noble gas Ar, during process of formation of NaCl the energy is liberated, and stable NaCl is formed after the spontaneous reaction.

4.2 The Chemical Bond

A Chemical bond is the force that binds the atoms to form the molecules. The chemical bond is the result of attractions among the atoms

caused by the electrostatic forces, (remember that opposite charges attract each other). The electrostatic forces in atoms arise from the charged particles, i.e. the proton and the electron.

These particles form the bond, when the nucleus of one creates attraction with the electrons of the other and vice versa, and hence the atoms are bonded by these forces. Due to the existence of some repulsive forces, i.e. the forces among the nucleus-nucleus and among the electrons-electrons, shown in figure 4.1.



The bond between the atoms forms when the attractive forces are stronger than the repulsive forces.

Although, it seems simple, but in reality this is not the case, and different types of compounds have different situations and the Scientists explain these in totally different ways, i.e. there is no single way to describe all the types of compounds satisfactorily. Some of the important types of bonds are described in coming pages.

4.3 Types of Chemical Bonds

Depending upon their nature there are following 4 types of chemical bonds:

- ♦ The ionic bond
- ♦ The co-valent bond
- ♦ The co-ordinate covalent/dative bond
- ♦ Metallic bond

4.3.1 Ionic Bond

This type of bond is formed when one or more electrons are completely transferred from one atom to the other, as a result of this transfer ions are formed. One of these ions is positively charged and other is negatively ions.

charged. These ions attract each other by strong electrostatic force, and hence ionic bond is formed between these ions. The examples of compounds having ionic bond are:

NaCl, CaCl₂, NaF, NH₄Cl and many more.

The ionic bond in 'NaCl' is formed when an electron transfers from 'Na' to 'Cl'. The exchange of electrons take place because both 'Na' and 'Cl' are to attain noble gas configuration. 'Na' attains this by donating an electron.



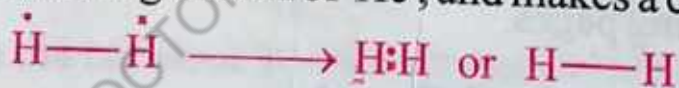
And 'Cl' attains configuration of 'Ar' by obtaining this one electron as follows:



These ions are strongly attracted by electrostatic force forming NaCl. This bond is very strong and compounds having ionic bond have high melting and boiling points.

4.3.2 Covalent Bond

This type of bond is formed when none of atoms are able to donate the electrons completely so they share the electrons, e.g. in case of 'H₂' molecule, each 'H' atom shares an electron with the other hydrogen atom, and hence each 'H' achieves noble gas configuration of 'He', and makes a covalent bond.



This can also be represented as in figure 4.2:

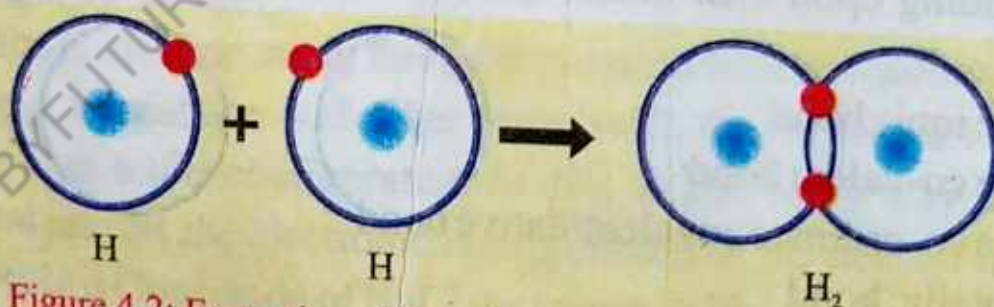


Figure 4.2: Formation of Covalent bond in hydrogen molecule

Other such covalent compounds are O₂, CO₂, H₂O, CCl₄, CH₄, HCl, SiO₂ etc.

It is to be remembered that during the formation of a covalent bond the

atoms tend to attain nearest noble gas configuration and generally they attain such electronic structure that there remains 8 electron in the valence shell of each bonded atom. This is called **octet rule**, but there are also exceptions of this rule e.g., the first period elements i.e. hydrogen gets just 2 electrons in their valence shell during covalent bond formation, this is because of the smaller size of hydrogen and availability of only first shell whose ability to carry the electrons is only limited 2 electrons, for this hydrogen this rule is called **duplet rule**.

4.3.2.1 Types of Covalent Bond

The Covalent bond can be further classified into 3 different types, depending upon the numbers of electron pairs donated. The first type of the covalent bond is the simple covalent bond which is formed by the sharing of single electron pair, this is also known as the single covalent bond. Such covalent bonds are formed between H_2 , F_2 , HCl , CH_4 , Cl_2 etc. (See figure 4.3)

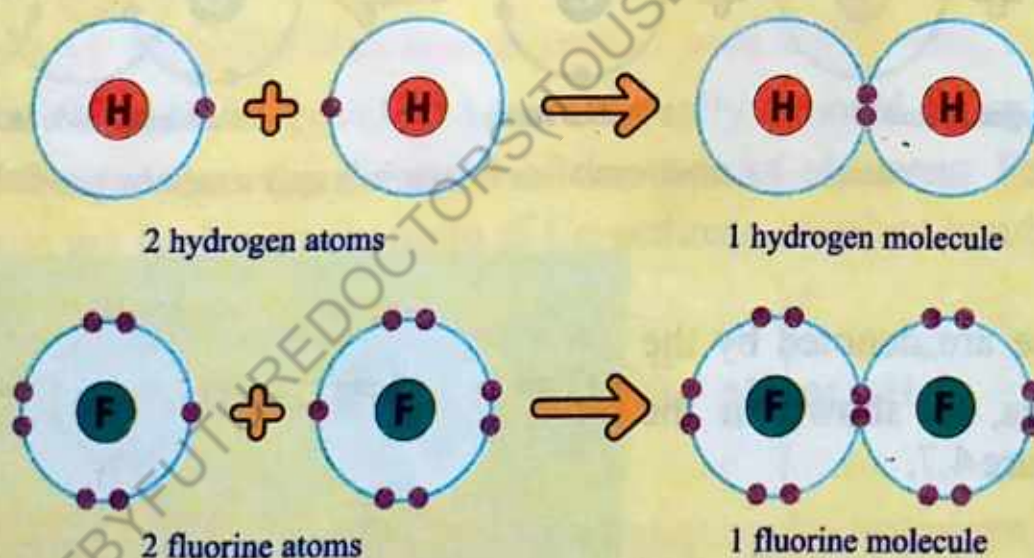


Figure 4.3: Formation of single covalent bonds in hydrogen and fluorine

For ease a single line is written between the two bonded atoms, as in figure 4.4. Or it can also be denoted by the electron cross and dot structures, as in figure 4.5. (Note that the dot and cross are used just to express the electrons of different atoms, otherwise all electrons are alike.) Such cross-dot structure of molecules are called lewis structures.

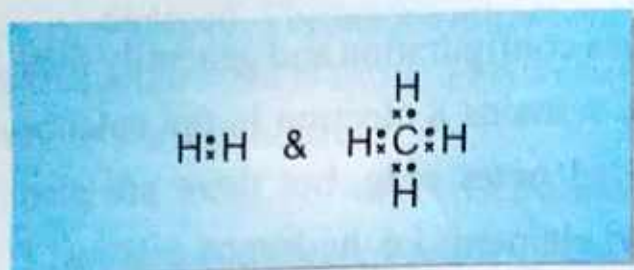


Figure 4.4: Dot and cross representation of hydrogen and methane molecules

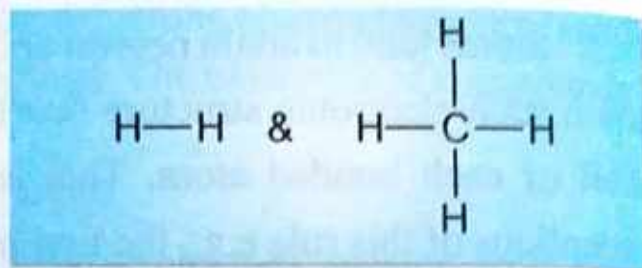


Figure 4.5: Line covalent bonding representation in hydrogen and methane molecules

The second type of covalent bond involves the sharing of two electron pairs, that is why it is called double covalent bond, e.g. in CO_2 , O_2 , C_2H_4 (ethene), see figure 4.6:

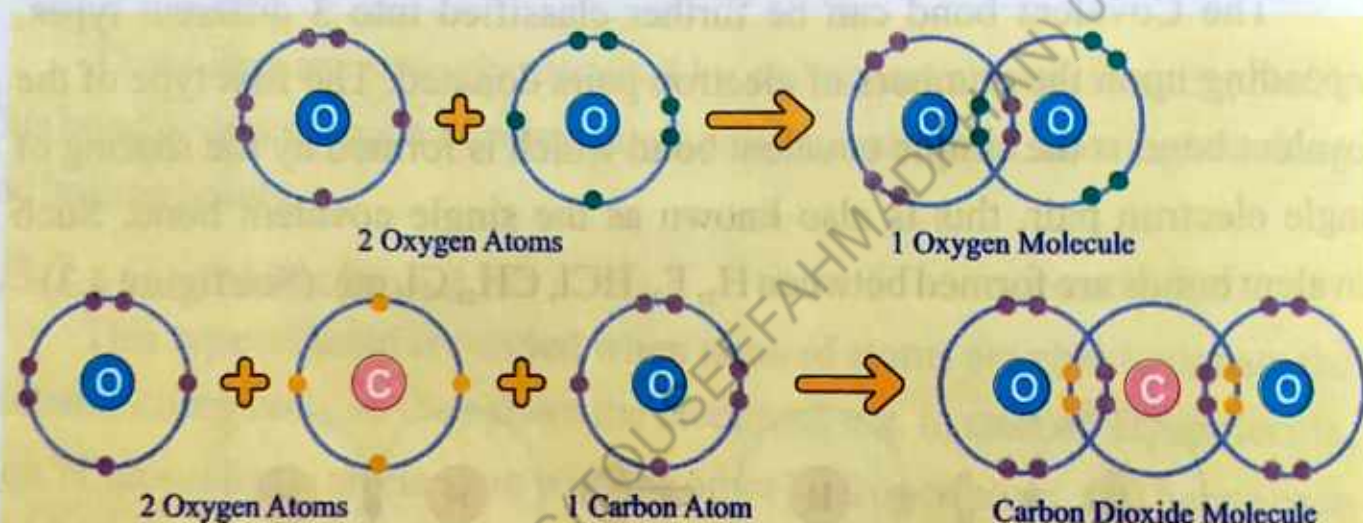
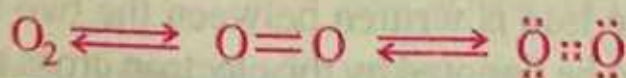
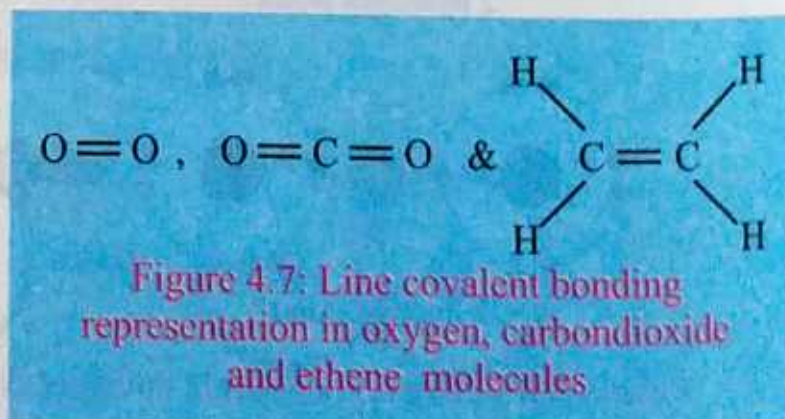


Figure 4.6: Formation of double covalent bonds in oxygen and carbondioxide

These are denoted by the double lines, as shown in the cases in figure 4.7.

The cross and dot structure of O_2 is:



The third type of covalent bond involves 3 pairs of electron sharing, and is known as the Triple covalent bond, e.g. in N_2 and acetylene (C_2H_2).



These are represented by triple lines joining each covalently bonded atoms.

Activity 4.1

Write the electron cross and dot structures for the CO_2 , NH_3 , N_2 and Ethane molecules.

4.3.3 Co-ordinate Covalent/Dative Bond

This is a type of covalent bond in which both electrons of bond (shared electron pair) comes from the same atom, e.g. formation of $\text{BF}_3 - \text{NH}_3$.

Here, 'B' is electron deficient and 'N' has a lone pair of electron, during bond formation this lone pair of electron participates and is shared between 'N' and 'B'.

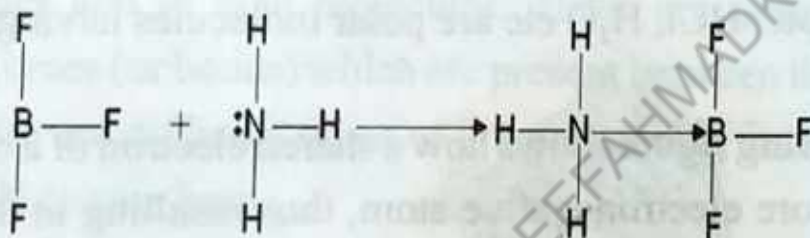


Figure 4.8: Formation of co-ordinate covalent bond in $\text{NH}_3 - \text{BF}_3$ complex

The Co-ordinate covalent bond is usually denoted by an arrow sign which also represents the direction of donation of electrons. Formation of Hydronium ion is also an example of Co-ordinate covalent bond, as seen in figure 4.9.

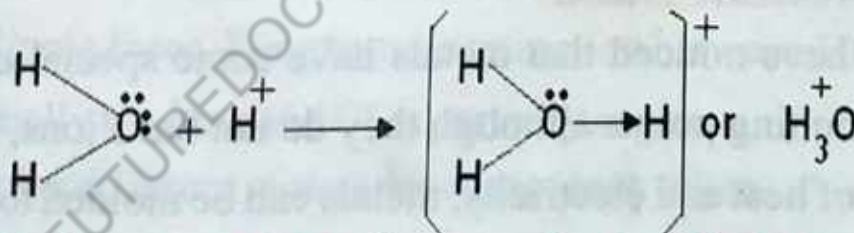


Figure 4.9: Formation of co-ordinate covalent bond in hydronium ion

Another example is the formation of NH_4^+ from NH_3 and H^+ (Figure 4.10)

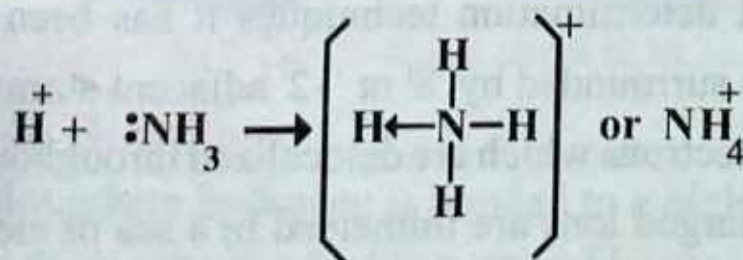


Figure 4.10: Formation of co-ordinate covalent bond in ammonium ion

4.3.4 Polar and Non-polar Bonds

Non-polar Covalent Bond

A covalent bond which is formed between like atoms having same electronegativities is called non-polar covalent bond. In such bond the shared electrons are distributed symmetrically around the bonded atoms.

For example; N_2 , H_2 , O_2 , Cl_2 etc.

Non-polar molecules have non-polar covalent bond.

Polar Covalent Bond

The covalent bond formed between unlike atoms having different electronegativities but the difference in electronegativity would be less than 1.7 but not zero. In such bond the shared electrons are distributed symmetrically around the bond atoms.

For example; HCl , H_2O etc are polar molecules having polar covalent bond.

The following figure shows how a shared electron of a covalent bond is attracted by a more electronegative atom, thus resulting in the formation of polar molecule.



4.3.5 The Metallic Bond

You may have noticed that metals have some special characters e.g. they have high melting points although they do not have ions, the metals are good conductor of heat and electricity, metals can be molded to any shape, all these character show that metals have some special and different type of bonding. Scientists named this bond of metals as metallic bond.

By structural determination techniques it has been revealed that in metals each atom is surrounded by '8' or '12' adjacent atoms. The bonding is due to the valence electrons which are delocalized throughout the entire solid, so the positively charged ions are immersed in a sea of electrons, as can be seen in figure 4.11.

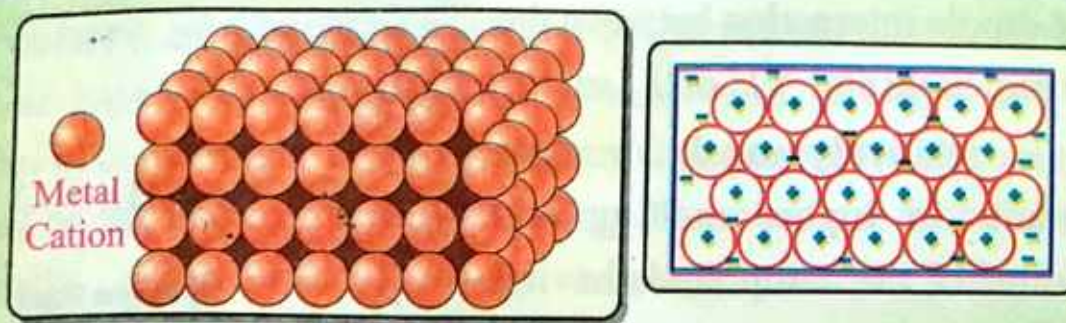


Figure: 4.11: Metallic bonding

Due to these reasons the metals can be drawn into wires, sheets and are very good conductor of heat and electricity. Moreover alloys can be formed easily by them.

4.4 Intermolecular Forces

These are the forces of attraction present between the molecules to bring them closer and to bind molecules. These are quite different from intramolecular forces (or bonds) which are present between the atoms to form a molecule. There are different types of intermolecular forces, of which the important we will discuss here,

1. Dipole-dipole forces
2. Hydrogen bonding

4.4.1 Dipole—dipole Forces

The force of attraction between molecules having permanent dipole is called dipole-dipole force. For example attraction between HCl molecules in which H^+ is partially positive and Cl^- is partially negative.

Due to poles different molecules attract each other.

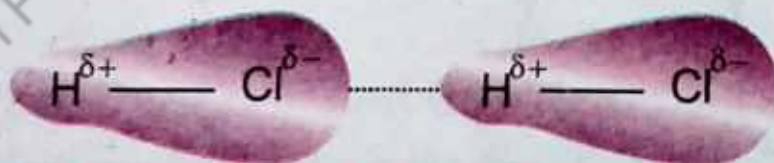


Figure: 4.12: Dipole-dipole forces in HCl

4.4.2 Hydrogen Bonding

The molecules where hydrogen is bonded to a highly electronegative element like 'O' or 'F' results in a highly polar molecule, in such molecules

the dipole-dipole interaction between the 'H' of one molecule and 'O₂' or 'F₂' of 2nd molecule is relatively much stronger, which results in higher melting and boiling points of the compounds having such type of interaction. e.g. water has boiling point '100°C' while H₂S has B.P '-60°C'. Similarly 'HCl' is a gas having B.P '-85°C' as it lack hydrogen bonding while its counterpart 'HF' has B.P='19.5°C'.

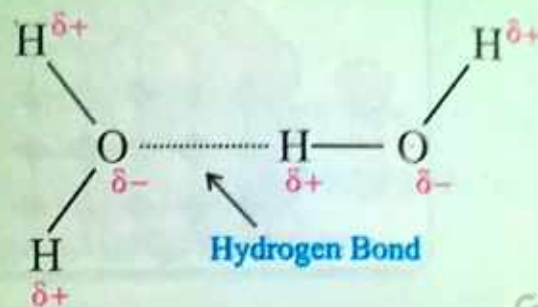
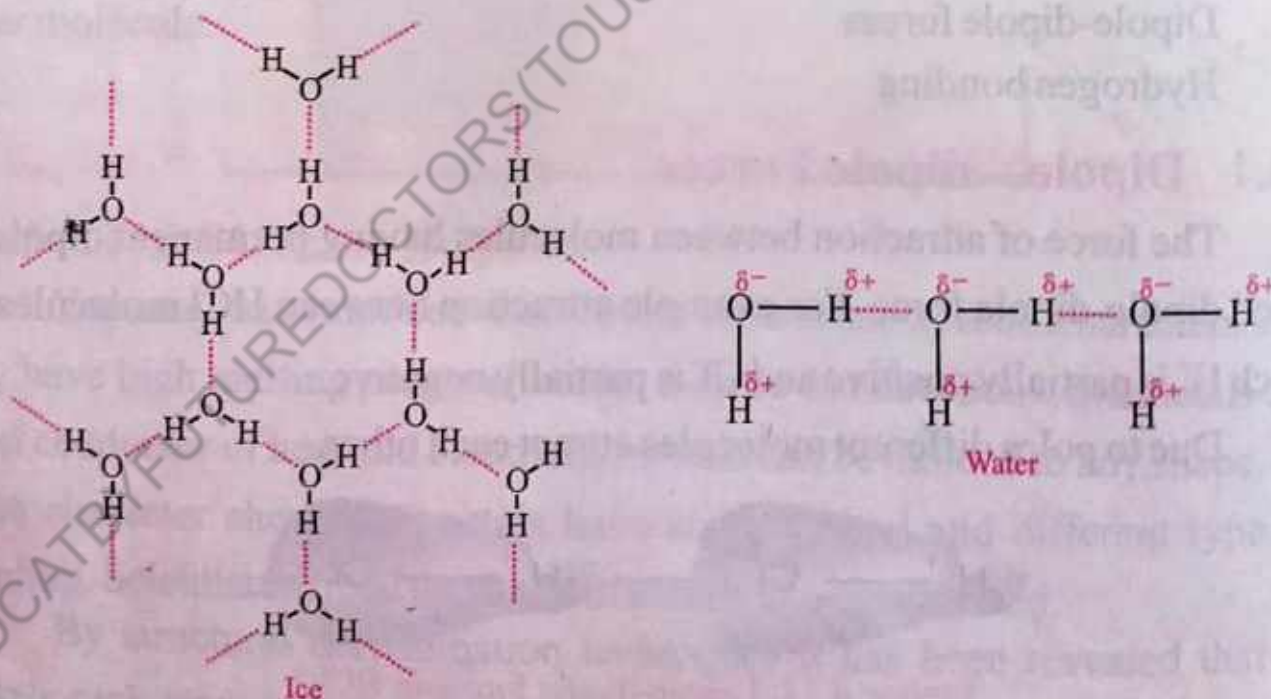


Figure: 4.12: Hydrogen Bonding in Water

The strength of hydrogen bonding changes the physical properties such as boiling point melting point etc.

Interesting Information

This is the hydrogen bonding due to which water expands when freezing, so ice has lower density than water, the picture of arrangement of atoms in ice is shown here.



This property of ice makes the life possible on earth, as ice formed in cold regions of earth floats at surface due to having low density and the life underneath grows without suffering from outer low temperature, (ice is bad conductor of heat too)

4.5 Nature of Bonding and Properties

The type of bonding greatly effects both physical and chemical properties of compounds. It is so important that generally the compounds are classified on the bases of type of bonding. The physical properties e.g M.P, B.P, density , color, surface tension, viscosity, refractive index, solubility, bond energy, vapour pressure, lattice energy etc may be predicted from knowing the type of bonding. Effect of bonding upon various types of compounds is described in following section individually.

4.5.1 Nature of Bonding and Ionic Compounds

The ionic compounds which have a strong type of bonding are hard, solid and have very high melting and boiling points.

The ionic compounds although have ions but they conduct electricity only in molten state, because of the limited mobility in solid state and high mobility in liquid state. The Ionic compounds which are strongly polar are generally soluble in the polar solvents like water, for example NaCl is easily soluble in water to large extent.

As concerned with reactions, bonding also plays an important role here. Generally ionic compounds are more reactive and the rate of reaction is very fast.



4.5.2 Nature of Bonding and Covalent Compounds

The co-valent compounds have sharing of electrons and thus there does not exists strong interactions among the constituting particles like that of ionic compounds, hence they have low melting and boiling points and mostly the covalent compounds are gases (unless other factors do not involve). The covalent compounds do not conduct electricity unless they are ionized by

some factor, so the pure water do not conduct the electricity but when some ionizing material such as an acid or a base or some electrolyte is added to the water, which makes it ionized and thus the flow of charged particles becomes possible.

4.5.3 Nature of Bonding and Polar and Non-polar Compounds

The behavior of polar and non-polar compounds is well understood in terms of the ionic and covalent compounds, where the polarity also counts greatly in determining the properties of these compounds. The non-polar compounds are mostly gases and have low melting and boiling points, and do not conduct electricity. On the other side the polar compounds have relatively high melting and boiling points and conduct electricity.

4.5.4 Nature of Bonding and Metals

The metals have a very special type of bonding and thus their characters also are very interesting. In the metals there exists a positive center around which is fig. 4.14 a sea of negative sphere exists.

The negative sphere which consists of free electrons (the electrons which move freely in all the available space in metal piece), this gives the metals a high conductor character for both the electricity and heat. Moreover the metals have lustrous surface due to transition of electron.

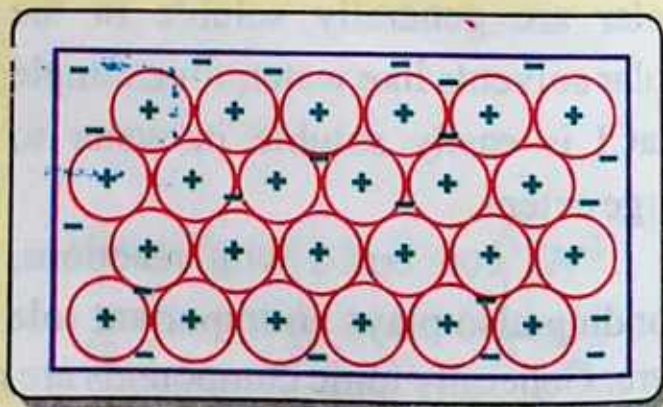


Figure: 4.14: Electron Sea around Cations in Metals

SUMMARY OF THE CHAPTER

- ❖ In order to attain stability the atoms tend to form molecules.
- ❖ The electrostatic force of attraction between atoms in a molecule is termed as the **bond**.
- ❖ There are many types of bonds in the molecules.
- ❖ The bond which is formed by the transfer of electrons between atoms is called the **ionic bond**.
- ❖ The bond which is formed by the sharing of electrons between the atoms is termed as the **Covalent bond**. In a simple covalent bond each atom shares 1 electron.
- ❖ Some times in a covalent bond, the shared electron pair comes from a single atom; such covalent atom is called **Dative covalent bond** or **co-ordinate covalent bond**.
- ❖ When a covalent bond is formed by a single electron pair it is termed as **single covalent bond**.
- ❖ If a covalent bond is formed by two electron pairs it is called **double covalent bond**.
- ❖ When a covalent bond is formed by three electron pairs it is termed as **triple covalent bond**.
- ❖ In a covalent bond when difference of electronegativity between the two atoms is **0.5 or greater** then the bond becomes **polar** and electrons are bent towards more electronegative atoms.
- ❖ Metals have a special type of bonding called the **Metallic bond**, in the metals around the charged positive center an electron sea is present, these electrons are free to move and are called **Free electrons**.
- ❖ The different molecules also show some type of electrostatic attractions, this force between the molecules is called the **intermolecular force**.
- ❖ Different types of intermolecular forces exist, e.g. **dipole-dipole force**,

Hydrogen bonding.

- ❖ The term hydrogen bonding is not like the bond, which joints the atoms in a molecule, but is named such due to its strength. It is present between the hydrogen and some electronegative atom of two different molecules.
- ❖ Both the type of bonding and intermolecular forces affects greatly the properties of different compounds.

EXERCISE

Q1. Fill in the blanks with appropriate words.

- A chemical bond is the force which binds atoms to constitute molecules.
- The bond forms when attractive forces the repulsive forces.
- The water molecule has type of bonding.
- The metals have electrons.
- The water has bonding, which makes it liquid, although it is covalent.
- The ionic compounds always have physical state.
- Difference in physical states among H_2O and H_2S is because of
- The most electronegative element is
- In the type of bond, both shared electrons comes from the same atom.
- Same type of atoms have type of bond.

Q2. Choose the correct answer.

- The KCl has the type of bonding
 - ionic
 - covalent
 - co-ordinate covalent
 - metallic
- A covalent bond forms by:
 - transfer of electrons
 - sharing of electrons

- (c) both by transfer and sharing of electrons
- (d) no transfer and no sharing of electrons
- iii) Generally, the covalent compounds are physically:
 - (a) liquid (b) gas (c) solid (d) plasma
- iv) The metals have characters:
 - (a) solid (b) lustrous (c) conductor (d) all of above
- v) The metals conduct electricity because of:
 - (a) polarity (b) free electrons
 - (c) both by polarity and free electrons
 - (d) Neither polarity nor free electrons are involved

Q3. Answer the following questions in short.

- i) What is a bond? Name different types of bonds formed between atoms.
- ii) How you can differentiate between two compounds having ionic and covalent bonding?
- iii) What type of bond will be formed between following:
 - (a) Na and Br_2 , (b) Ca and Cl_2
 - (c) C and O_2 (d) N_2 and H_2
- iv) What do you know about Lewis structure of a compounds, explain with example.
- v) What different types of covalent bonds are there?
- vi) What is the difference between simple covalent bond and coordinate covalent bond?
- vii) What is meant by polarity of a covalent bond?
- viii) Correlate bonding and special features of chemical compound.
- ix) Heating water would cause breakage of the intermolecular forces or intramolecular forces first.
- x) What types of inter and intra molecular forces are present in H_2O .

Q4. Answer the following questions with reasoning.

- i) Can you explain why similar atoms form covalent bond rather than ionic bond?

- ii) Is hydrogen bonding is a true type of intramolecular attraction? Explain with reasons.
- iii) Explain why water pipes get ruptured during winter in cold regions?
- iv) Why H_2O has boiling point 100°C while H_2S has B.P = -60°C ?
- v) Why NaCl is soluble in cold water but not in boiling oil?

- Q5. What is the difference between the intermolecular force and intramolecular force?
- Q6. Discuss the importance of bonding in establishing the characters of a chemical compound?
- Q7. What is meant by polarity of a covalent bond? Explain with examples.
- Q8. Write a note on types of bonds found in different compounds?.
- Q9. Why the atoms joint together to form a molecule?
- Q10. What are the different types of covalent bonds?
- Q11. Write a note on characteristics of ionic compounds?