16

THE CHEMICAL BOND-I

16.1 INTRODUCTION

Why do atoms combine and make bonds ? We consider this natural question as the backbone of the basic issue. Like any individual who is standing, will like to sit. Sitting for a long time may lead to preference for lying down or perhaps sleeping. Here we see that each of the subsequent step : standing, sitting, lying lead to more stable position, where lesser energy is spent per unit time.

Something very similar can be identified when atoms combine to form molecules. They are found to do so if the resultant molecules are more stable and have lower energy than the combing atoms. In this lesson we shall study different types of bonds, their energy and structure. All through we shall see that electronic configuration of the combining atoms play a crucial role in the determination of the nature of the bond expected to form.

16.2 OBJECTIVES

After reading this lesson you will be able to

- explain why atoms combine with the help of potentials energy diagram
- define ion bond
- list the characteristics of ionic compounds
- explain the energetics of ionic bond formation
- define lattice energy and dissociations energy
- explain Born Haber cycle
- define covalent bond
- explain octet rule

- give examples of compounds which violate octet rule
- list the characteristics of covalent compounds
- explain to partial ionic character of covalent bonds
- give example of polar and non-polar compunds.
- define dipole moment
- explain coordinate covalent bond
- explain bond length, bond energy and bond angle.

16.3 WHY DO ATOMS COMBINE?

The simplest answer to this question is that the atoms tend to acquire more stability than their prior position as individual atoms.

This can also discussed with the help of an energy level diagram:

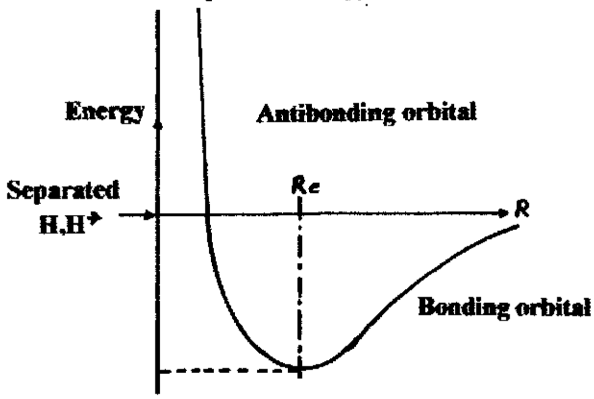


Fig. 16.1 Potential Energy Curve

When two atoms come closer there are a variety of interactions such as those between electron - electron, nucleus–nucleus and electrons of one atom with nucleus of another atom.

As a result or this, there is a certain interatomic distance where the resultant energy of the molecule is minimum. The '0' level (zero level) shows the energy of individual atoms (which is arbitrarily taken as zero) in fig 16.1 above. Thus we see that the atoms which combine to form a molecule acquire stability, are lowered in energy and thus release energy in the process. We may then conclude that the energy possessed by a molecule is lesser then the combined energy of the individual atoms. This difference is called the bond energy of the molecule(for definition see section 16.9)

16.4 IONIC BOND

Two scientists, Kossel and Lewis worked independently in earlier part of the twentieth century and put forward their views that the elements tend to react together to attain stable electronic configurations of the noble gases.

It is well known that noble gases show very little reactivity because of the fact that they possess very stable electronic configuration. From this observation it is clear that the atoms tend to stabilise their electronic configuration by acquiring the nearest noble gas structure.

Let us consider the case of sodium which is a alkali metal. We see that the loss of only one electron from this atom will leave the rest of the configuration as a very stable configuration as it is that of a noble gas. But in doing so, the atom has acquired a positive charge by virtue of loss of one electron, leaving one excess proton in the nucleus. In this consideration it is essential that there should be an atom which is ready to receive the electron released by sodium. Let us suppose that the receiving atom is that of chlorine, which becomes chlorin ion (Cl^-) and it also acquires a noble gas configuration.

$$\underset{2,8,1}{Na} + \underset{2,8,7}{Cl} \longrightarrow \underset{2,8,}{Na^+} \quad \underset{2,8,8}{Cl^-}$$

Both Sodium ion (Na^+) and the chloride ion (Cl^-) are oppositely charged and each one of them acquires the noble gas configuration. Since these ions are oppositely charged, they exert electrostatic attraction and an ion pair Na^+Cl^- is formed. The ion pair is held together by electrostatic attraction. This type of bonding is termed as electrovalent or ionic bond. The ion pair should not be called a molecule. example :

$$\underset{2,1}{Li} + \underset{2,7}{F} \longrightarrow \underset{2}{Li^+} \quad \underset{2,8}{F^-}$$

OR

$$\underset{1s^2 2s^1}{Li} + \underset{1s^2 2s^2 2p^5}{F} \longrightarrow \underset{\substack{1s^2 \\ \text{Stable}}}{Li^+} \quad \underset{\substack{1s^2 2s^2 2p^6 \\ \text{Stable}}}{F^-}$$

Electrovalent compounds are formed between the alkali or alkaline earth metals and non-metals from 16 or 17 groups.

Electrovalent compounds exist as hard crystals possessing some specific lattice structure. They have high melting points. The ions having opposite charges are arranged in a symmetrical array.

The spectroscopic study of the parameters of NaCl shows that sodium ion is surrounded by six chloride ions and each chloride ion in turn is surrounded by six sodium ions. The exact positions taken up by these ions in a crystal lattice is always definite therefore the shape of the crystal is always specific. The whole crystal is also termed as a gaint molecule or macromolecule.

> An electrovalent bond is formed when one or more electrons from one atom gets completely transferred to another atom or atoms and each atom acquires a nearest noble gas configuration.

16.4.1 CHARACTERISTICS OF IONIC COMPOUNDS

1. They exist as hard crystalline substance.
2. They have high melting and boiling points.
3. They are soluble in water and less soluble in non-polar solvents.
4. Their aqueous solutions conduct electricity.
5. Their colour depends on the colour of the ions.

16.4.2 ENERGETICS OF IONIC BOND

An ionic compound is a cluster of ions. The attractive forces will be maximum when each ion is surrounded by the highest possible member of oppositely charged ions. The number of ions surrounding any particular ion is called the co-ordination number.

The limiting factor in deciding the co-ordination number of any ion is the radius/charge ratio, which also decides the geometry and hence shape of the molecule or crystal.

The number of ions surrounding any particular ion is called the co-ordination number of the ion.
When a crystal is formed from its ions in gaseous state, certain amount of energy is released. This energy is termed as lattice energy, it is measured in kJ mol^{-1}.

When a crystal is subjected to heat or any other source of energy, the ions dissociate and the crystal collapses. The amount of energy thus absorbed is termed as **dissociation energy**. It is measured in kJ mol^{-1}.

The lattice energy is equal to dissociation energy but opposite in sign. Lattice energy cannot be measured directly but in direct measurements using Born - Haber cycle are able to provide the thermodynamical data from which relevant experimental values can be obtained.

Lattice energy is the amount of energy released when one mole of the substance is formed from its ions. eg.

$$Na^+ (g) + Cl^- (g) \longrightarrow Na^+Cl^-(s) - \Delta H$$

$$\Delta H = -788.5 \text{ kJ mol}^{-1}$$

16.5 BORN-HABER CYCLE

It is a theoretical device that includes hypothetical steps in the formation of one mole of (Crystalline) substance form its elements in the *native* state at STP. An example is given in Fig 16.2

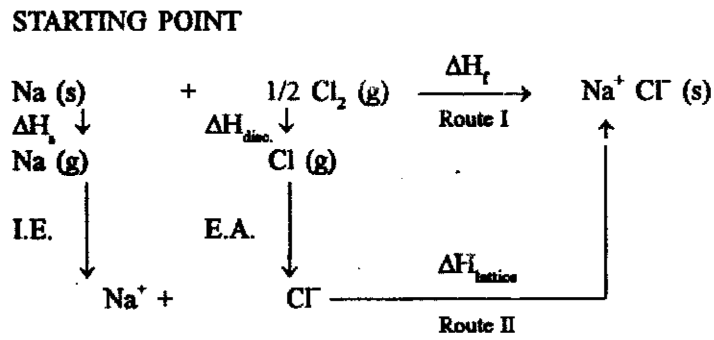


Fig. 16.2: Born Haber Cycle.

The meaning of the ymbols used in fig. 16.2 are given below:

Enthalpy sublimation	= ΔHs
Ionization Energy	= I.E.
Dissociation energy	= ΔH_{diss}
Electron affinity	= E.A.
Lattice Energy	= $\Delta H_{lattice}$
Enthalpy of formations of the compounds	= ΔH_f

Since ΔH_f connot be calculated directly route-I and route-II energies are summed up separately and equated to get the compound from elements. Enthalpy of formation can then be calculated since all other energies can b e experimentally determined.

∴ We get $\Delta Hs + IE + \Delta H_{diss} - EA + \Delta H_{latti} = \Delta H_f$

INTEXT QUESTIONS 16.1

1. Define electrovalent bond.

   ....

2. List briefly characteristics of ionic compounds.

   ....

3. Explain the term lattice energy as applied to ionic crystal.

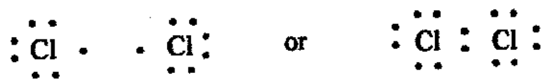
   ....

16.6 CO-VALENT BOND

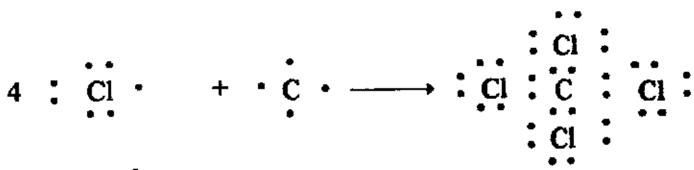
Sometimes it is not possible for an atom to loose an electron completely or gain an electron from the other atom due to considerations of energy. However, the tendency to acquire the nearest noble gas configuration is present in every atom.

An alternative to this problem comes from the fact that atoms tend to share electrons with other atoms in such a way that all the atoms involved in bond formation acquire nearest noble gas configuration. e.g., Hydrogen molecule : (H_2).

In a hydrogen molecule one electron is contributed for sharing by each atom and the net result is that each atom experiences two electrons around its nucleus i.e. one of its own and the one from the other atom, thus achieving the structure of Helium. Now consider a chlorine molecule. A chlorine atom has seven electrons in its outer most shell. So by sharing an electron with an other chlorine atom, both atoms attain eight electron or an octet in their outermost orbit. For example:



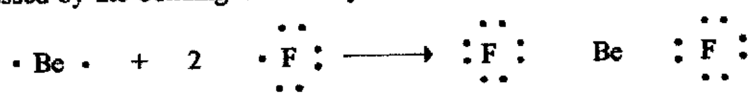
A stable arrangement is attained when an atom is surrounded by eight electrons. This is known as octet rule. Similarly, carbon tetra chlorined can be shown to possess four co-valent bonds.



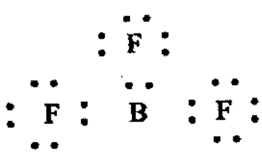
Some other examples are:

Water Ammonia

However, all the molecules may not follow the octet rule and the number of electrons possessed by the bonding atoms may be lesser or more than eight. i.e.



Thus we see that Berylium in Beryllium difluoride does not possess eight electrons. Thus this is an electron deficient compound and behaves as an acid. This is termed as a Lewis acid. Another example is BF_3.



Boron triflouride

On the other hands substances rich electrons (that possess more than eight electrons which can donate electron pairs to other atoms (capable of accepting) are known as Lewis base e.g.

$$NH_3 + BF_3 \longrightarrow H_3NBF_3$$

16.6.1 CHARACTERISTICS OF COVALENT COMPOUNDS

1. Covalent compounds are soluble in non-polar solvents and are generally insoluble in water.
2. They have low melting and boiling points.
3. Their solutions do not conduct electricity.
4. Some of them (organic) burn with a smoky flame.
5. Some of the covalent compounds (organic) have smell associated with them.

INTEXT QUESTIONS : 16.2

1. Is Lewis acid an electron donor or an acceptor.

   ....

2. Draw the electron—dot structure of $CHCl_3$.

   ....

3. Why is Boron trifluoride a Lewis acid?

   ....

4. Classify ammonia as Lewis acid or Lewis base.

   ....

16.7 PARTIAL-IONIC CHARACTER

Ionic bonding or covalent bonding are extreme cases of bonding. In general some percentage of ionic character is found in most of the covalent molecules. In all such cases where the bonding is between two similar atoms (homo atoms) the bonds are purely covalent. They two atoms have exactly the same electronegativity and so the bonding electron pair is shared equally between two atoms and the bond is said to be non-polar covalent bond. When the bonding atoms are dissimilar (Hetroatoms) the covalent bond possess some ionic character. All atoms have been assigned certain value of electronegativity. It is a relative value of an atom in relation to other atoms. Fluorine is considered to be the most electronegetive atom. Other highly electronegative atoms are Oxygen, Chlorine, etc.

When two atoms having different electronegativities form a bond, the more electronegative atom attracts the electron cloud of the other atom to itself. Thus there is charge shift which polarises the molecule into positive and negative charge. These charges are of equal but opposite sign. This type of bond is called a polar covalent bond. Such molecules show dipole moment and possess partial ionic character. In addition dipole possess direction (from positively charged to negatively charged) as well as magnitude. The dipole moment is equal to the product of charge (q) and direction R. Dipole moment = qR (in debye).

Homonuclear molecules are non-polar, because the difference in the electronegativities of the two atoms is zero. The more the polarity the more the percentage ionic character of the molecule. Few examples of polar and non-polar compounds are as follows polar HCl, H_2O, HF, CO etc.

Non-Polar H_2, Cl_2, F_2, O_2, N_2 etc.

16.8 CO-ORDINATE COVALENT BOND

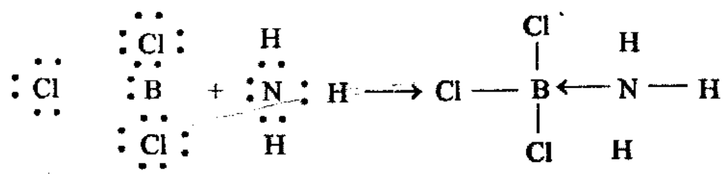
The formation of a co-ordinate covalent bond is possible between an atom or ion having an unshared pair of electrons in its valence shell on one side, and an atom or ion that is ready to accept a pair of electrons on the other hand. The donor atom donates a pair of electrons and the acceptor atom accepts that pair of electrons to acquire a more stable configuration. In Lewis statement the donated pair is initially shown by an arrow.

We realise that the bonding atoms share a pair of electrons and once the bond is formed the shared pair becomes a bond pair. This bond pair is in no way different from the bond pair of any other covalent bond. Thus we see that in case of a co-ordinate bond the mode of formation is different but once the bond is formed it cannot be differentiated from any other covalent bond.

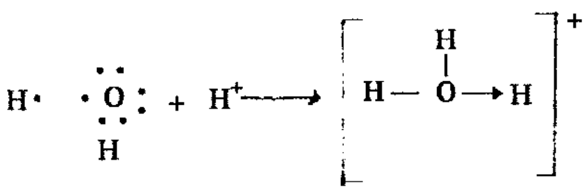
A bond in which both the bonding electrons are contributed by one atom only is called a Co-ordinate Covalent bond.

Examples:

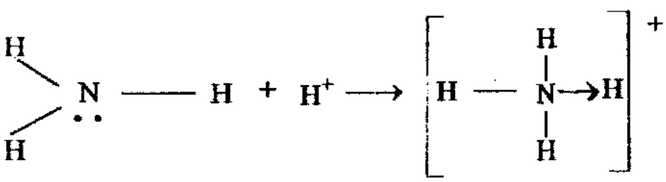
1.



2.



3.



16.9 PARAMETERS OF THE BOND

Bond length, bond energy and bond angle are the parameters of a bond. Through this data large information about a bond can be obtained.

i) BOND LENGTH (BOND DISTANCE)

Bond length is also termed as bond distance. It is the distance between the centres of the two nuclei of the atoms forming the bond along a straight line joining the nuclei. It is measured in picometers (1 pm = 10^{-12} m). The bond distance in the molecules on an average is approximately between 100 pm to 200 pm for a single bond.

> Bond length is the distance between the centres of two nuclei of the atoms forming the bond. It is generally measured in picometers.

ii) BOND ENERGY

A long bond is a weak bond. On the other hand a short bond is a stronger bond. Two atoms form a bond because of the interaction of the components of one atom with that of the other. Thus two atoms are always held together by certain firmness. This firmness is termed as bond strength or bond energy. It is expressed in kJ mol^{-1}. Like bond length, bond strength varies from atom to atom and within the same molecule, stronger bonds release more energy when they are formed and they need more energy when they are broken.

> The energy required to break chemical bond between two atom into two neutral fragments is known as bond energy. The energy required per bond is very small. To overcome the inconvenience of working with very small numbers, bond energies are usually reported in kilojoules per mole

iii) BOND ANGLE

Bond angle is the angle between any two bonds emerging form the same atom. The bond angle in a molecule is measured in degrees. e.g., the bond angle between the N–H bonds of ammonia is 106.8°. The B–Cl bonds in BCl_3 form a bond angle of 120°. You will read more about bond length, bond strength and bond angle in the second part of chemical bond.

> A bond angle is the angle between any two bonds energy from the same atom in a molecule. It is measured in degrees (°)

INTEXT QUESTIONS 16.3

1. Define bond angle, bond length and bond energy

   ....

2. How is a coordinate covalent bond different from covalent bond?

   ....

16.10 WHAT YOU HAVE LEARNT

- Atoms combine to form bonds to attain stability.
- When an electron is completely transferred from one atom to another atom and results in the formation of an ion pair, an electrovalent bond is said to have formed.
- The number of ions surrounding any particular ion is called the co-ordination number of the ion.
- Ionic compounds are hard crystallins solids have high melting and boiling points. They are soluble in water and their aqueous solutions conduct electricity.
- When an ionic crystal is formed from its ions in a gaseous state, certain amount of energy is released. This energy is termed as lattice energy.
- Born-Haber cycle is a theoretical device that includes hypothetical steps in the formation of one mole of (crystalline) substance.
- When electrons are shared by the atoms in the course of forming a bond and acquire noble gas configuration, the bond is said to be covalent.
- Stable arrangement is attained when the atom is surrounded by eight electrons. This is called "Octal rule".
- Certain compounds like BeF_2 violate octet rule.
- Covalent compounds have low melting and low boiling points. They are soluble in non-polar solvents.
- A bond may not be purely ionic or covalent. It may have a partial ionic character.
- Dipole moment is the product of the charge (q) and separation (R)
- A bond in which both the bonding electrons are contributed by one atom and shared by the other is called a co-ordinate covalent bond.
- Bond length is the distance between the centres of two nuclei of the atoms forming the bond. It is measured in picometer.
- Bond energy is the firmness with which the two atoms are held together. It is measured in kJ mol^{-1}.
- Bond angle is the angle between any two bonds emerging from the same atom in a molecule. It is measured in degrees.

ACTIVITY

1. Collect compounds which may be available at home or in areas around and try to classify them as electrovalent or co-valent.

16.12 TERMINAL EXERCISE

1. Some molecules containing polar bonds have zero dipole moment Comment.

....

2. a) Give examples of ionic and covalent compounds.

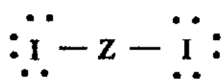
   b) Give two examples of compounds that contain co-ordinate covalent bond.

....

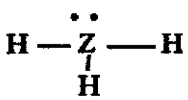
3. Describe the relationship between electronegativity of an atom and polarity of a covalent bond.

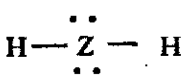
....

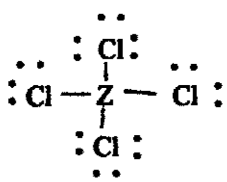
4. Z may be taken as a symbol (different for each structure) of some representative element in the following Lewis structures. Identify the group to which Z may belong in each of the following. Redraw the structure with proper element.

i) 

ii) 

iii) 

iv) 

(v) 

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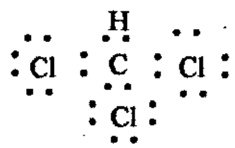
CHECK YOUR ANSWERS

INTEXT QUESTIONS : 16.1

1. **Refer to section 16.4**
2. **Refer to section 16.4.1**
3. **Refer to section 16.4.2**

INTEXT QUESTIONS : 16.2

1. Accepter

2. 

3. Because it is electron deficient.

4. Lewis base.

INTEXT QUESTIONS : 16.3

1. Refer to section 16.9

2. Refer to section 16.8

ANSWERS TO TERMINAL EXCERCISE

1. The polarities are neutralised in certain cases (highly symmetrical structures) resulting in a non-polar compound.

2. a) $Na^+ Cl^-$, $Na^+ F^-$, $K^+ Cl^-$, $Rb^+ F^-$, $Cs_2^+ O^{--}$, $C Cl_4$, CH_4, $CHCl_3$, H_2O, CO_2.

   b) CO and H_2SO_4

3. Atoms possessing high electronegativity in molecule makes the bond polar to a great extent.

4. (i) II (ii) VII

   (iii) V (iv) VI

   (v) IV