2 Chemical Bonding

SYLLABUS

Electrovalent, covalent and co-ordinate bonding, structures of various compounds – orbit structure and electron dot structure.

Definition of Electrovalent Bond.

Structure of Electrovalent compounds NaCl, $MgCl_2$, CaO;

Characteristic properties of electrovalent compounds – state of existence, melting and boiling points, conductivity (heat and electricity), ionisation in solution, dissociation in solution and in molten state to be linked with electrolysis.

Covalent Bond – definition and examples, structure of Covalent molecules on the basis of duplet and octet of electrons (example : hydrogen, chlorine, nitrogen, water, ammonia, carbon tetrachloride, methane.)

Characteristic properties of Covalent compounds – state of existence, melting and boiling points, conductivity (heat and electricity), ionisation in solution.

Comparison of Electrovalent and Covalent compounds.

Definition of Coordinate Bond : The lone pair effect of the oxygen atom of the water molecule and the nitrogen atom of the ammonia molecule to explain the formation of H_3O^+ and OH^- ions in water and NH_4^+ ion. The meaning of lone pair; the formation of hydronium ion and ammonium ion must be explained with the help of electron dot diagrams.

2.1 INTRODUCTION

Everything in this world wants stability so is the case with atoms. For atoms, stability means having the electron arrangement of an inert gas, *i.e.*, octet in its outermost shell. Helium has two electrons (DUPLET) while all other inert gases, *i.e.*, Neon, Argon, Krypton, Xenon and Radon have eight electrons (OCTET) in their outermost shell, as given in Table 2.1 below.

Table 2.1 Electronic configurations of the inert gases.

Inert gas	*Atomic No.*	*Electronic configuration*						*No. of valence electrons*
		K	L	M	N	O	P	
He	2	2						2
Ne	10	2	8					8
Ar	18	2	8	8				8
Kr	36	2	8	18	8			8
Xe	54	2	8	18	18	8		8
Rn	86	2	8	18	32	18	8	8

It is found that the elements with their complete outermost shell do not react or are least reactive. We, therefore, conclude that the atoms having 8 electrons (or 2 electrons, Helium configuration) in their outermost shells are very stable and unreactive. Therefore, *to attain stability, atoms tend to combine chemically by redistribution of electrons in the outermost shell or valence electrons so that each is left with a* ***stable electronic configuration*** **(duplet** or **octet).**

Cause of chemical combination is the tendency of elements to acquire the nearest noble gas configuration in their outermost orbit and become stable.

During redistribution of electrons, a bond (force) of attraction develops between atoms, which binds them together to form molecules. This bond is known as the **chemical bond.**

A ***chemical bond*** *may be defined as the force of attraction between any two atoms, in a molecule, to maintain stability.*

There are *three* methods in which atoms can achieve a stable configuration.

(1) The ***transfer*** of one or more electrons from one atom to the other to form an ***electrovalent*** (or an ***ionic***) ***bond.***

(2) ***Sharing*** of one, two or three pairs of electrons between two atoms to form *a* ***covalent*** (or a ***molecular***) ***bond.***

by only one of the combining atoms, the bond formed is known as **coordinate** (or **dative**) bond.

2.2 ELECTROVALENT (OR IONIC) BOND

Atoms of metallic elements that have 1, 2 or 3 valence electrons can lose electron(s) to atoms of non-metallic elements, which have 7, 6 or 5 electrons respectively in their outermost shell and thereby forming an electrovalent compound.

After the transfer of electron(s), both the combining atoms acquire the electronic configuration of the nearest inert gas.

A metallic atom, which loses electron(s), becomes a positively charged ion and is known as a **cation** and a non-metallic atom, which gains electron(s), becomes a negatively charged ion and is known as an **anion.**

An **ion** is a charged particle which is formed due to the gain or the loss of one or more electrons by an atom.

A metallic element, whose one atom readily loses electron(s) to form a positively charged ion, is an ***electropositive element***.

$$Na - e^- \rightarrow Na^+ \text{ (cation)}$$

A non-metallic element, whose atom readily accepts electron(s) to form a negatively charged ion, is an ***electronegative element.***

$$Cl + e^- \rightarrow Cl^- \text{ (anion)}$$

The **cation** and the **anion** being oppositely charged attract each other and form a chemical bond. Since this chemical bond formation is due to the electrostatic force of attraction between a cation and an anion, it is called an ***electrovalent*** (or an ***ionic***) ***bond.***

Electrovalent (or ionic) compounds : *The chemical compounds formed as a result of the transfer of electrons from one atom of an element to one atom of another element are called* ***ionic*** *(or electrovalent)* ***compounds.***

Electrovalency : *The number of electrons that an atom of an element loses or gains to form a electrovalent bond is called its* ***electrovalency.***

electrovalent (or ionic) bond

When an ionic compound is formed, the neutral atom is changed to a cation or an anion. The formation of cations and anions depends on the following factors :

1. **Low ionisation potential :** If the ionisation potential of a particular atom is **low,** it will lose electron(s) easily, *i.e., a cation is formed easily.*
2. **High electron affinity :** If the electron affinity value is **high,** anion will be formed easily, *i.e., a higher electron affinity value favours ionic bonding.*
3. **Large electronegativity difference :** If the difference in the electronegativities of two elements is **higher,** then the transfer of electrons will be easier. Therefore, *more the difference in electronegativity, more will be the ionic nature of the resulting compound.*

The **metals** of groups 1, 2 and 13 have a tendency to lose their valence electrons. So they combine with the **non-metals** of Groups 15, 16 and 17, which have a tendency to gain electron(s) and form ionic bonds.

Note : Group 1 elements are most electropositive, *i.e.,* they are metallic in nature. Their metallic nature increases down the group.

Group 17 elements are most electronegative. Fluorine is the most electronegative element. Thus, *caesium fluoride CsF is the most ionic compound.*

Bonds formed between metals and non-metals are ionic or electrovalent.

Why are Ionic Compounds Stable ?

Ionic compounds are formed by ions but there also exists a repulsive force between ions for like charges. Since the electrostatic force of attraction between opposite charges is much higher, it makes the ionic compounds stable.

Examples of electrovalent (ionic) compounds.

$NaCl$	(Sodium chloride)
$MgCl_2$	(Magnesium chloride)
CaO	(Calcium oxide)
KBr	(Potassium Bromide)
$CaCl_2$	(Calcium chloride)

2.2.2 Structures of some electrovalent compounds

1. Sodium chloride (NaCl)

The electronic configuration of a **sodium atom is 2, 8, 1.** It has one electron in excess of the stable electronic configuration of the nearest noble gas, neon, (2, 8). Therefore, an atom of sodium shows a tendency to give up the electron from its outermost shell, so as to acquire a stable electronic configuration of neon.

$$\underset{\substack{(2,\,8,\,1)\\ \text{atom}}}{Na} - 1e^- \rightarrow \underset{\substack{(2,\,8)\\ \text{cation}}}{Na^+}$$

However, *after giving up one electron, the sodium atom is no more electrically neutral. It has eleven protons in its nucleus but only ten electrons revolving around it. Therefore, it has a net positive charge of* +1. *This positively charged atom is called sodium ion and is written as* Na^+ and its electronic configuration resembles that of the noble gas neon.

Table 2.2 Comparison of the properties of sodium atom and sodium ion

Property	***Sodium atom*** **(Na)**	***Sodium cation*** **(Na^+)**
Colour	Silvery white	Colourless
Toxicity	Poisonous	Non-poisonous
Chemical action	Very active	Inactive
Valence shell	Incomplete outermost shell	Complete outermost shell
Electrical state	Neutral	Positively charged
Existence	Combined state	Independent existence

The electronic configuration of **chlorine is 2, 8, 7.** It has an electronic configuration with one electron less than that of the nearest noble gas, argon (2, 8, 8). Therefore, the chlorine atom shows a tendency to acquire an electron to attain octet in its outermost shell.

$$\underset{\substack{(2,\,8,\,7)\\ \text{atom}}}{Cl} + 1e^- \rightarrow \underset{\substack{(2,\,8,\,8)\\ \text{anion}}}{Cl^-}$$

An atom of chlorine is electrically neutral, as it contains 17 protons in its nucleus and 17 electrons revolving around it. But, *after acquiring an electron from the sodium atom, the chlorine atom does not remain electrically neutral. It has one electron more than the number of protons in its nucleus and therefore has charge of –1 represented as* Cl^- *i.e.* **chloride ion.**

Table 2.3 Comparison of the properties of chlorine atom and chlorine ion

Property	***Chlorine atom*** **(Cl)**	***Chloride anion*** **(Cl^-)**
Colour	Yellowish green (as Cl_2 gas)	Colourless
Toxicity	Poisonous	Non-poisonous
Odour	Suffocating	Odourless
Chemical action	Very active	Inactive
Valence shell	Incomplete outermost shell	Complete outermost shell
Electrical state	Neutral	Negatively charged
Existence	Not independent	Independent

Chloride ion has an octet of electrons in its outermost shell, and its electronic configuration resembles that of the noble gas argon (Fig. 2.1).

Thus, when an atom of sodium combines with an atom of chlorine (electronic configuration 2, 8, 7), one electron is transferred from the sodium atom to the chlorine atom, resulting in the formation of a sodium chloride molecule.

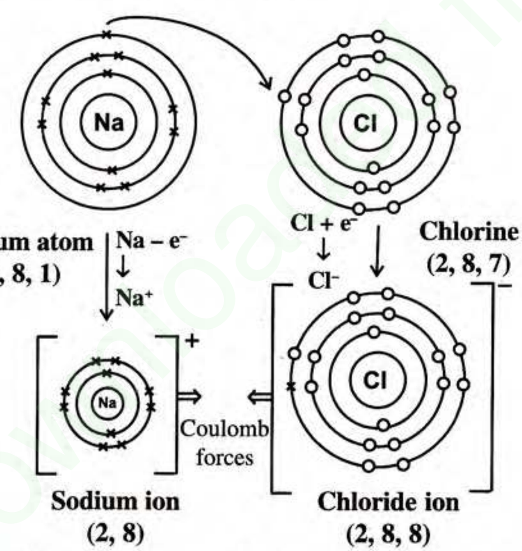


Fig. 2.1 Orbit structure of electrovalent bonding in sodium chloride.

The cation Na^+ and anion Cl^- are attracted towards each other, due to electrical charge or ionic compound.

Electron dot symbol (Lewis symbol)

The electron dot symbol for an atom consists of the symbol of the element surrounded by dots representing the outermost shell electrons. The paired electrons are represented by a pair of dots, whereas the unpaired electron in the outermost orbit is represented by a single dot.

Example : Electron dot symbol of Hydrogen is H•

and of Oxygen is :Ö:

Symbols other than dots, such as circles and crosses can be used to distinguish between the electrons of different atoms in a molecule, *for example* :

Ammonia (NH_3) can be represented as

```
     ••
H  ×:N:×  H
     •×
     H
```

Electron dot structure of NaCl

$$Na^{\bullet} + {}^{\bullet}\ddot{\underset{\bullet\bullet}{Cl}}: \rightarrow Na^{+} + Cl^{-} \text{ or } NaCl$$

2. Magnesium chloride ($MgCl_2$)

The number of valence electrons of magnesium (atomic number 12) is 2 and that of chlorine (atomic number 17) is 7. Magnesium atom acquires a stable configuration of 8 electrons by losing two electrons from its outermost shell (one each to each atom of chlorine) and thus becomes a positive magnesium ion, Mg^{2+}.

Mg	–	$2e^-$	$\rightarrow$	Mg^{2+}
(2, 8, 2)				(2, 8)
atom				cation

However, each chlorine atom, which contains 7 electrons in its outermost shell, can accept only 1 of the 2 electrons donated by a magnesium atom. Therefore, for each magnesium atom forming a magnesium ion, there must be two chlorine atoms to form two chloride ions.

2Cl	+	$2e^-$	$\rightarrow$	$2Cl^-$
(2, 8, 7)				(2, 8, 8)
2 Cl atoms				2 chloride anions

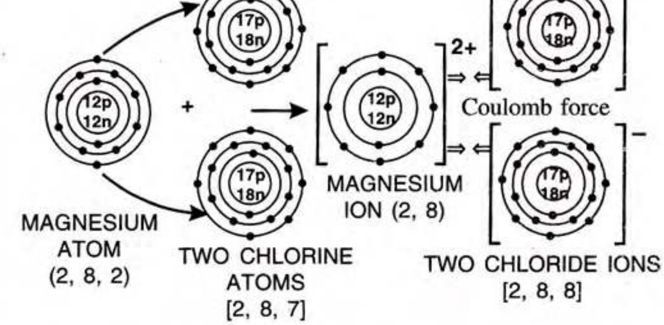
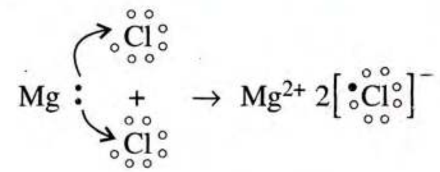


Fig. 2.2 Orbit structure of formation of magnesium chloride ($MgCl_2$) molecules.

Thus, the ratio of magnesium to chloride ions in magnesium chloride must be 1 : 2, so the molecular formula of the compound magnesium chloride is $MgCl_2$ (Fig. 2.2).

Electron dot structure of magnesium chloride



3. Calcium oxide (CaO)

The number of valence electrons of a calcium atom (atomic number 20) is 2, and that of an oxygen atom is 6, *i.e.*, oxygen requires 2 electrons to attain octet. In the presence of oxygen, each calcium atom loses its 2 valence electrons to one oxygen atom (Fig. 2.3). As a result, the calcium atom forms a calcium ion with charge +2 (Ca^{2+}), and the oxygen atom forms an oxide ion with charge –2 (O^{2-}). Since only one oxygen atom is needed to accept the 2 valence electrons donated by a calcium atom, the formula of calcium oxide is CaO and not Ca_2O_2.

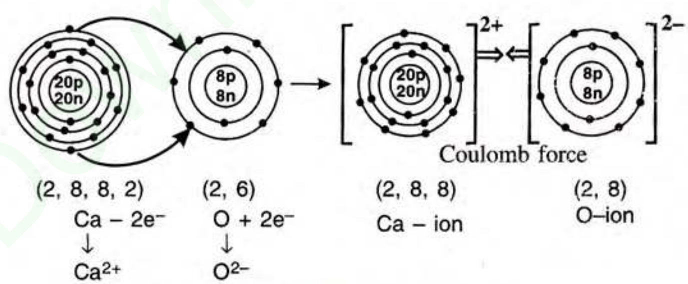


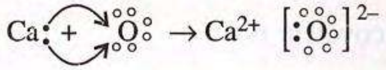
Fig. 2.3 Orbit structure of formation of calcium oxide (CaO).

(2, 8, 8, 2)			(2, 8, 8)
atom			cation

$$O + 2e^- \rightarrow O^{2-}$$

(2, 6)	(2, 8)
atom	anion

Electron dot structure of calcium oxide



In the formation of an electrovalent bond, the transfer of electron(s) is involved. The **electropositive atom** undergoes **oxidation**, while the ***electronegative atom*** undergoes ***reduction***. This is known as REDOX PROCESS.

For example :

Formation of sodium chloride : Sodium chloride is formed by the combination of sodium and chlorine.

$$2Na + Cl_2 \rightarrow 2Na^+ + 2Cl^- \text{ (or 2 NaCl)}$$

The reaction can be written as two half reaction:

$$2Na \rightarrow 2Na^+ + \cancel{2e^-} \text{ (Oxidation)}$$

$$Cl_2 + \cancel{2e^-} \rightarrow 2Cl^- \text{ (Reduction)}$$

Oxidation

$$2Na + Cl_2 \rightarrow 2Na^+ + 2Cl^- \text{ (Redox Reaction)}$$

Reduction

Oxidation and reduction always occur simultaneously because the electron(s) lost by the reducing agent must be gained by the oxidising agent.

For example :

Oxidised

$$\underset{\text{Oxidising agent}}{CuO} + \underset{\text{Reducing agent}}{H_2} \rightarrow Cu + H_2O$$

Reduced

In this reaction, hydrogen acting as a reducing agent reduces Cu(II) oxide to copper. This is a reduction reaction.

$$Cu^{2+} + 2e^- \rightarrow Cu \text{ (Reduction)}$$

At the same time, hydrogen is oxidised to water by the oxidising agent Cu(II) oxide, and this is an oxidation reaction.

$$2H - 2e^- \rightarrow 2H^+ \text{ (Oxidation)}$$

Thus, the net reaction is a redox reaction.

It can be inferred from the above example that an oxidising agent is an acceptor of electron(s) and a reducing agent is a donor of electron(s).

[Also refer chapter 6, article 6.2 (viii) & (ix)]

Intext Questions

1. How do atoms attain noble gas configuration ?
2. Define :
   (a) a chemical bond, (b) an electrovalent bond,
   (c) a covalent bond.
3. What are the conditions for the formation of an electrovalent bond ?
4. An atom X has three electrons more than the noble gas configuration. What type of ion will it form ? Write the formula of its (i) sulphate (ii) nitrate (iii) phosphate (iv) carbonate (v) hydroxide.
5. Mention the basic tendency of an atom which makes it to combine with other atoms.
6. A solid is crystalline, has a high melting point and is water soluble. Describe the nature of the solid.
7. In the formation of the compound XY_2, an atom X gives one electron to each Y atom. What is the nature of bond in XY_2 ? Draw the electron dot structure of this compound.
8. An atom X has 2,8,7 electrons in its shell. It combines with Y having 1 electron in its outermost shell.
   (a) What type of bond will be formed between X and Y ?
   (b) Write the formula of the compound formed.
9. Draw orbit structure and electron dot diagrams of
   (i) NaCl (ii) $MgCl_2$ (iii) CaO
10. Compare :
    (a) sodium atom and sodium ion
    (b) chlorine atom and chloride ion, with respect to
    (i) atomic structure, (ii) electrical state,
    (iii) chemical action, (iv) toxicity.
11. The electronic configuration of Fluoride ion is the same as that of a neon atom. What is the difference between the two ?

12. (a) What do you understand by redox reactions? Explain oxidation and reduction in terms of loss or gain of electrons.

(b) Divide the following redox reactions into oxidation and reduction half reactions.

(i) $Zn + Pb^{2+} \rightarrow Zn^{2+} + Pb$

(ii) $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

(iii) $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$

(iv) $Sn^{2+} + 2Hg^{2+} \rightarrow Sn^{4+} + Hg_2^{2+}$

(v) $2Cu^+ \rightarrow Cu + Cu^{2+}$

(c) Potassium (at No. 19) and chlorine (at No. 17) react to form a compound. Explain on the basis of electronic concept :

(i) oxidation (ii) reduction

(iii) oxidising agent (iv) reducing agent.

2.3 COVALENT (MOLECULAR) BOND

The chemical bond that is formed between two combining atoms by mutual sharing of one or more pairs of electrons is called a ***covalent*** *(or a molecular)* ***bond*** *and the compound formed due to this bond is called a* ***covalent compound.***

The molecule formed due to the sharing of electrons (covalent bond) is called a **covalent molecule.**

The atoms of non-metals usually have 5, 6 or 7 electrons in their outermost shell (except carbon which has 4 and hydrogen which has just 1 electron in the outermost shell). *The atoms of such elements do not favour the loss of its electrons due to energy considerations and thus the transfer of electrons is not possible*. Therefore, this atom can complete its octet only by mutually sharing one or more pairs of electrons. **Each atom contributes equal number of electron(s).** So, whenever a non-metal combines with another non-metal (to attain stable configuration), the sharing of electrons takes place between their atoms and a covalent bond is formed.

For example, hydrogen is a non-metal and chlorine is also a non-metal. When hydrogen combines with chlorine to form hydrogen chloride (HCl), the sharing of electrons takes place between hydrogen and chlorine atoms and a covalent bond is formed. It should be noted that a covalent bond can also be formed between two atoms of the same

combine together by the sharing of electrons to form a chlorine molecule (Cl_2) and a covalent bond is formed between the two chlorine atoms.

Covalent bonds are of following three types:

1. Single covalent bond
2. Double covalent bond
3. Triple covalent bond

A **single covalent** bond is formed by the sharing of one pair of electrons between the atoms, each atom contributing one electron.

A single covalent bond is denoted by putting a short line (—) between the two atoms. So, a hydrogen molecule can be written as H—H.

Likewise, molecules of chlorine, hydrogen chloride, water, ammonia, methane and carbon tetrachloride are examples of single covalent bonds.

```
 Cl—Cl           H—Cl              H—O—H
Chlorine   Hydrogen chloride       Water

                   H                 Cl
                   |                 |
 H—N—H           H—C—H            Cl—C—Cl
   |               |                 |
   H               H                 Cl
Ammonia         Methane     Carbon tetrachloride
```

Similarly, a **double bond** is formed by the sharing of two pairs of electrons between two atoms.

A double bond is actually a combination of two single bonds, so it is represented by putting two short lines (=) between the two atoms. *For example*, oxygen molecule, O_2, contains a double bond between two atoms and it can be written as O=O.

A **triple bond** is a combination of three single bonds, so it is represented by putting three short lines (°) between the two atoms. Nitrogen molecule, N_2, contains a triple bond, so it is written as N ≡ N.

Some molecules have a combination of single bond as well as a double or a triple bond. *For example*, ethene (C_2H_4) molecule has one double covalent bond and four single covalent bonds.

Ethene (C_2H_4)

Similarly, ethyne (C_2H_2) molecule has one triple covalent bond and two single covalent bonds.

Ethyne (C_2H_2) $H-C\equiv C-H$

> ***The covalency*** *of an atom is the number of its electrons taking part in the formation of shared pairs.* Thus, the covalency of hydrogen is 1, oxygen 2, nitrogen 3 and carbon 4.

Non-polar and polar covalent compounds

Covalent compounds are non polar when shared pair of electron(s) are equally distributed between the two atoms. No charge separation takes place. The molecule is symmetrical and electrically neutral.

If the two covalently bonded atoms are identical the shared electron pair(s) is at equal distance from the combining atoms *i.e.*, the shared electron pair(s) is equally attracted by the nuclei of the two type of charge, such molecules are non-polar. For example hydrogen (H_2), chlorine (Cl_2), oxygen (O_2), *etc*., are perfectly non-polar compounds.

The bond formed between dissimilar atoms can be non-polar if their electronegativity difference is little and their structure permits the shared pair of electrons to attract equally the linked atoms and thus the molecule becomes symmetrical. For example methane (see structure 7, article 2.4.2), carbon tetrachloride, etc.

The shared electron pairs in methane are at equal distance from the carbon and the hydrogen atoms, because the two have nearly equal electronegativities (carbon = 2·5, hydrogen = 2·1).

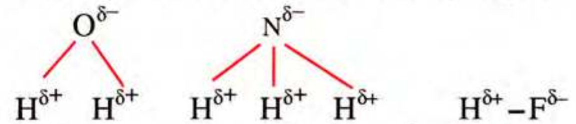
These compounds do not ionise in water due to lack of charge separation.

The covalent compounds are said to be polar when the shared pair of electrons are not at equal distance between the two atoms. *This results in the development of fractional positive and negative charges on them. They ionise in water. For example, hydrogen chloride.*

In hydrogen chloride, the strong nuclear charge of the chlorine atom (the electro-negativity of chlorine is 3) attracts the shared electron pair towards itself, *i.e.*, negative charge shifts towards the chlorine atom thereby developing a slight negative charge ($\delta-$) on it. The hydrogen atom (electronegativity 2.1) develops a slight positive charge ($\delta+$). *Therefore, a polar covalent bond is formed.* This is shown below.

$$\underset{\text{H-atom}}{H^{\times}} + \underset{\text{Cl-atom}}{\cdot\ddot{\underset{..}{Cl}}:} \rightarrow H\overset{\times}{\cdot}\ddot{\underset{..}{Cl}}: \rightarrow H^{\delta+} \rightarrow\!\!- Cl^{\delta-}$$

Other examples of polar covalent compounds that ionise are water, ammonia and hydrogen fluoride.



Water molecule | Ammonia molecule | Hydrogen fluoride molecule

> The process by which covalent compounds are converted into ions is called **ionisation.**

Note :

(i) The more the electronegativity difference between two atoms forming a bond, the more is the polar nature of the molecule.

The bond formed between two atoms (1) with **same** electronegativity is **non-polar** (2) with **slightly different** electronegativity is **polar** and (3) with **much electronegativity** difference is **ionic**.

(ii) Since a polar covalent molecule has both positive and negative poles, it is also known as a ***'dipole molecule'***.

(A molecule that has both, slight positive and slight negative charge is called a **Dipole molecule**)

2.3.1 Conditions for the formation of a covalent bond

1. Both atoms should have four or more electrons in their outermost shells, *i.e.,* non-metals (exceptions are H, Be, B, Al, *etc.*).
2. Both the atoms should have high electronegativity.
3. Both the atoms should have high electron affinity.
4. Both the atoms should have high ionization energy.
5. The electronegativity difference between the combining atoms should either be zero or negligible.

Group →	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII
Chloride →	**NaCl**	**$MgCl_2$**	**$AlCl_3$**	**$SiCl_4$**	**PCl_3/PCl_5**	**S_2Cl_2**	
Bonding →	Ionic solid	Ionic solid	Partially ionic-partially covalent solid	Covalent liquid	Covalent liquid/solid	Covalent liquid	

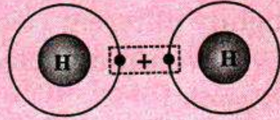
Oxide →	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_2/SO_3	Cl_2O_7
Bonding →	Ionic Solid	Ionic Solid	Ionic Solid	Covalent Solid	Covalent Solid	Covalent Gas/Solid	Covalent Gas

Hydrogen can combine with all non-metals of Group IVA to VIIA with the help of covalent bonds.

Note : As we move across a period, the electrovalent character of chlorides, oxides, etc., decreases. An example of the decreasing electrovalent character of chlorides of the elements of 3rd period is shown below.

Formation of a hydrogen molecule

Before combination



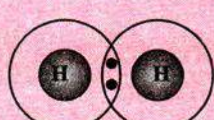
H atom H atom

Electron dot structure

H· + ·H

H-atom H-atom

After combination



Hydrogen molecule

H:H or H—H → H_2

One shared pair of electrons **Single covalent bond**

[A hydrogen molecule contains two atoms of hydrogen]

2. Chlorine molecule (Non-polar compound)

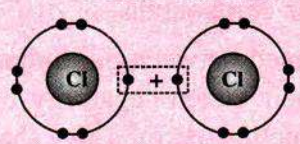
Electronic configuration	*Nearest noble gas*
$_{17}Cl$ [2, 8, 7]	Argon ($_{18}Ar$) [2, 8, 8]

To attain the stable electronic configuration of the nearest noble gas, chlorine needs one electron.

When two chlorine atoms come closer, each contributes one electron and form ***one shared pair of electrons*** between them. Both the atoms of chlorine thus attain an octet. A single covalent bond [Cl — Cl] is formed between them.

Formation of a chlorine molecule

Before combination



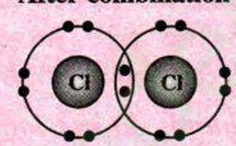
Cl-atom Cl-atom

Electron dot structure

:Cl· + ·Cl:

Cl-atom Cl-atom

After combination



Chlorine molecule

:Cl : Cl: or [Cl—Cl] → Cl_2

One shared pair of electrons **Single covalent bond**

[A chlorine molecule contains two atoms of chlorine]

3. Nitrogen molecule (Non-polar compound)

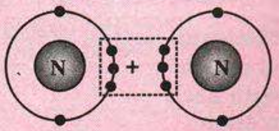
Electronic configuration	*Nearest noble gas*
Nitrogen ($_7N$) [2, 5]	Neon ($_{10}Ne$) [2, 8]

To attain the stable electronic configuration of the nearest noble gas, nitrogen needs three electrons.

When two nitrogen atoms come closer, each contributes three electrons and so they have ***three shared pairs of electrons*** between them. Both atoms attain an octet, resulting in the formation of a triple covalent bond [N ≡ N] between them.

Formation of a nitrogen molecule

Before combination



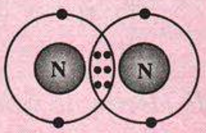
N-atom N-atom

Electron dot structure

:N: + :N:
N-atom N-atom

After combination

Mutual sharing of three pairs of elements



Nitrogen molecule

:N⋮⋮N: or [N≡N] → N_2

Three shared pairs of electrons — **Triple covalent bond**

[A nitrogen molecule contains two atoms of nitrogen]

4. Water molecule (Polar compound)

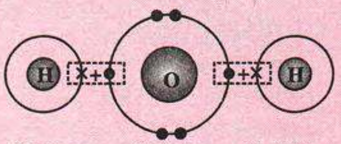
Atoms involved	*Electronic configuration*	*Nearest noble gas*
Hydrogen Oxygen	$_1H$ [1] $_8O$ [2, 6]	Helium [2] Neon [2, 8]

To attain the stable electronic configuration of the nearest noble gas, hydrogen needs one electron and oxygen needs two electrons.

In the case of a water molecule, *each of the two hydrogen atoms share an electron pair with the oxygen atom* such that hydrogen acquires a duplet configuration and oxygen an octet, resulting in the formation of two single covalent bonds.

Formation of a water molecule

Before combination

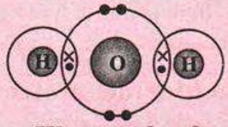


H-atom O-atom H-atom

Electron dot structure

H× + :Ö: + ×H
H-atom O-atom H-atom

After combination



Water molecule

H ×Ö× H or H—O—H → H_2O

One shared pair of electrons — **Two single covalent bond**

[One molecule of water contains a total of three atoms, *i.e.* one atom of oxygen and two atoms of hydrogen]

5. Ammonia molecule (Polar compound)

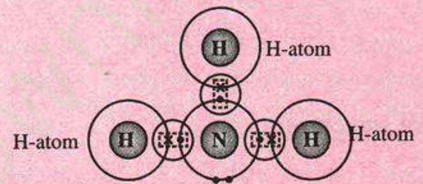
Atoms involved	*Electronic configuration*	*Nearest noble gas*
Nitrogen Hydrogen	$_7N$ [2, 5] $_1H$ [1]	Neon [2, 8] Helium [2]

To attain the electronic configuration of the nearest noble gas, nitrogen needs three electrons and hydrogen needs one electron.

When a molecule of ammonia is to be formed, one atom of nitrogen *shares three electron pairs, one with each of the three atoms of hydrogen.*

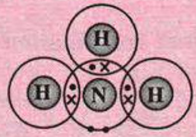
Formation of an ammonia molecule

Before combination

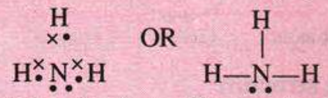


Electron dot structure

H
•
+
H• + •N̈• + •H



Ammonia molecule



One shared pair of electrons with each hydrogen atom

Three single covalent bonds

[The ammonia molecule contain a total of four atoms, *i.e.*, one atom of nitrogen and three atoms of hydrogen]

6. Carbon tetrachloride molecule (Non-polar compound)

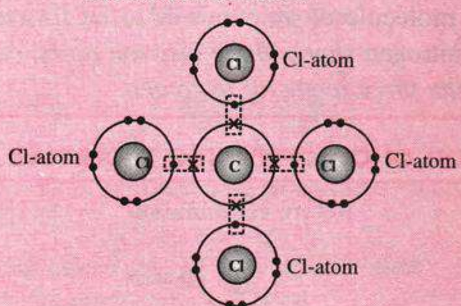
Atoms involved	*Electronic configuration*	*Nearest noble gas*
Carbon	$_{6}C$ [2, 4]	Neon [2, 8]
Chlorine	$_{17}Cl$ [2, 8, 7]	Argon [2, 8, 8]

To attain the stable electronic configuration of the nearest noble gas, carbon needs four electrons and chlorine needs one electron.

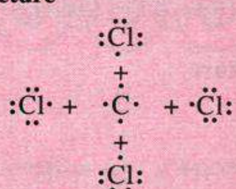
When a molecule of carbon tetrachloride is to be formed, one atom of carbon *shares four electron pairs, one with each of the four atoms of chlorine.*

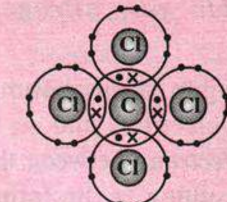
Formation of a carbon tetrachloride molecule

Before combination

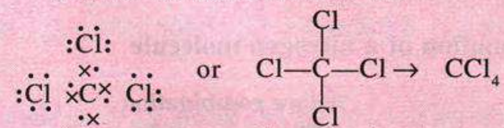


Electron dot structure





Carbon tetrachloride molecule



One shared pair of electrons with each chlorine atom

Four single covalent bonds

[One molecule of carbon tetrachloride contains five atoms in all, *i.e.* one atom of carbon and four atoms of chlorine]

7. Methane molecule (Non-polar compound)

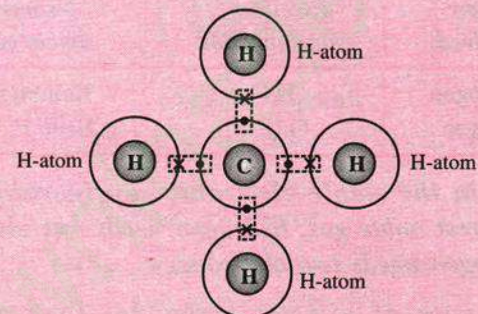
Atoms involved	*Electronic configuration*	*Nearest noble gas*
Carbon	$_{6}C$ [2, 4]	Neon [2, 8]
Hydrogen	$_{1}H$[1]	Helium [2]

To attain the stable electronic configuration of the nearest noble gas, carbon needs four electrons and hydrogen needs one electron.

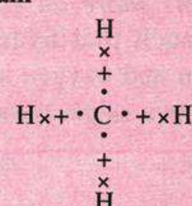
When a molecule of methane is to be formed, one atom of carbon *shares four electron pairs, one with each of the four atoms of hydrogen.*

Formation of a methane molecule

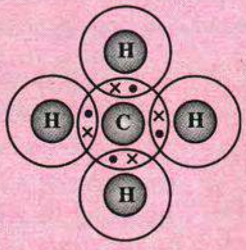
Before combination



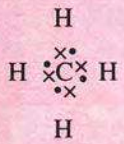
Electron dot diagram



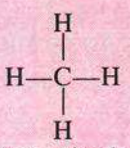
After combination



Methane molecule



or



Four single covalent bonds

[A methane molecule contains a total of five atoms, *i.e.* one atom of carbon and four atoms of hydrogen]

2.4 PROPERTIES AND COMPARISON OF ELECTROVALENT AND COVALENT COMPOUNDS

Electrovalent compounds		Covalent compounds	
Property	***Reason***	***Property***	***Reason***
1. Nature (i) Their constituent particles are ions. (ii) They are hard solids consisting of **ions**.	These have strong electrostatic forces of attraction between their ions, which cannot be separated easily.	**1. Nature** (i) Their constituent particles are molecules. (ii) These are gases or liquids or soft solids.	They have weak forces of attraction between their molecules.
2. Boiling point and melting point These are non-volatile, with high boiling and high melting points.	There exists a strong force of attraction between the oppositely charged ions, so a large amount of energy is required to break the strong bonding force between ions.	**2. Boiling point and melting point** These are volatile, with low boiling and low melting points.	They have weak forces of attraction between the binding molecules, thus less energy is required to break the force of bonding.
3. Electricity conducting nature (i) They do not conduct electricity in the solid state. (ii) They are good conductors of electricity in the fused or in aqueous state.	Electrostatic forces of attraction between ions in the solid state are very strong. These forces weaken in fused state or in solution state. Hence, ions become mobile.	**3. Electricity conducting nature** They are non-conductors of electricity in solid, molten or aqueous state.	Due to the absence of free ions.
4. Ionisation in solution Electrovalent compounds are composed of ions. In solution, these ions become mobile. They are electrolytes.	Water being a polar covalent compound decreases the electrostatic forces of attraction, resulting in free ions in aqueous solution. $NaCl \rightleftharpoons Na^{+}(aq) + Cl^{-}(aq)$	**4. Ionisation in solution** On passing electric current, non-polar covalent compounds do not ionise. ***Some of the covalent compounds are polar in nature.*** *They ionize in their solutions and can act as an electrolyte.* e.g. $HCl + H_2O \rightleftharpoons H_3O^{+} + Cl^{-}$	Covalent compounds do not have ions. Polar covalent molecules form ions in their solutions.
5. Dissociation Their **ions dissociate and migrate** when an electric current passes through them in their molten or aqueous solution state. *e.g.* $NaCl \rightleftharpoons Na^{+} + Cl^{-}$	Ions dissociate in water or in molten state.	**5. Dissociation** The dissociation of molecules into ions does not take place.	Covalent compounds do not have ions, so they do not dissociate.
6. Solubility These are soluble in water but insoluble in organic solvents.	As water is a polar compound, it decreases the electrostatic forces of attraction, resulting in free ions in aqueous solution. Hence they dissolve.	**6. Solubility** These are insoluble in water but dissolve in organic solvents.	As organic solvents are non-polar, hence, these dissolve in non-polar covalent compounds.

7. Rate of reaction They show **rapid speed** of chemical reactions in aqueous solutions.	Since free ions are easily formed in different solutions, they unite very fast forming compounds.	7. Rate of reaction They show **slow speed** of chemical reactions in aqueous solutions.	In covalent molecules, old bonds are broken and new bonds are formed, thus the reaction is slow between covalent compounds.

2.3.2 Some covalent molecules and their structures

1. Hydrogen molecule (Non-polar compound)

A hydrogen atom has one electron in its only shell. It needs one more electron to attain **duplet**. To meet this need, hydrogen atom shares its electron with another hydrogen atom. Thus, one electron each is contributed by the two atoms of hydrogen, and the resulting pair of electrons is mutually shared by both the atoms to form a hydrogen molecule.

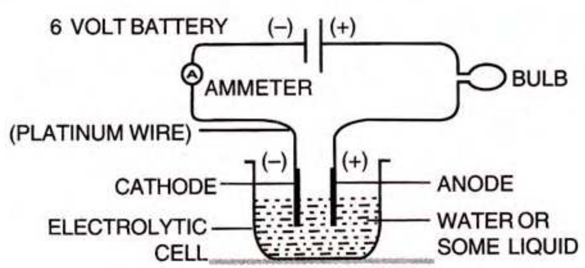


Fig. 2.4 Effects of electric current in different solutions.

2.5 EFFECT OF ELECTRICITY ON ELECTROVALENT AND COVALENT COMPOUNDS

Experiment : Arrange an electrolytic cell as shown in Fig. 2.4. The electric circuit contains a 6-volt battery, an ammeter bulb and platinum electrodes connected in series.

Take the following electrovalent and covalent compounds in solution in separate beakers and dip the platinum electrodes in them for a moment, one by one, and note the change in ammeter reading.

Observations :

Electrovalent compounds : When the current is passed in the solutions of electrovalent compounds, *i.e.*, magnesium chloride, sodium chloride, sodium hydr-oxide and copper sulphate the bulb glows. This shows that they *allow electric current to pass through them.*

Thus, ***ionic compounds are good conductors of electricity in molten or aqueous states due to free mobile ions.***

Covalent compounds : When the current is passed through the solutions of covalent compounds, *i.e.* distilled water, sugar solution, alcohol, chloroform, benzene and petrol the bulb does not glow. This shows that they *do not conduct electricity.* This happens because solutions of covalent compounds contain only molecules and no ions.

Intext Questions

1. What are the conditions necessary for the formation of covalent molecules ?
2. Elements A, B and C have atomic numbers 17,19 and 10 respectively.
   (a) State which one is : (i) a non-metal (ii) a metal, (iii) chemically inert ?
   (b) Write down the formula of the compound formed by two of the above elements.
3. Draw electron dot diagram and structure of :
   (a) nitrogen molecule (b) magnesium chloride
   (c) methane
4. What is the difference between :
   (a) ionic compounds and polar covalent compounds,
   (b) ionic compounds and covalent compounds,
   (c) a polar covalent compound and a non-polar covalent compound ?
5. The element X has the electronic configuration 2, 8, 18, 8, 1. Without identifying X,
   (a) predict the sign and charge on a simple ion of X.
   (b) write if X will be an oxidising agent or reducing agent and why.
6. What do you understand by dipole molecule ? Explain it by taking hydrogen chloride as an example.
7. (a) Explain the bonding in methane molecule using electron dot structure.
   (b) Methane molecule is non-polar molecule. Explain.

8. Give the characteristic properties of :
   (a) electrovalent compounds,
   (b) covalent compounds.
9. (a) Which type of bond is formed when the combining atoms have :
   (i) zero E.N. difference
   (ii) small E.N. difference
   (iii) large E.N. difference
10. Explain the following :
   (a) Electrovalent compounds conduct electricity.
   (b) Electrovalent compounds have a high melting point and boiling point while covalent compounds have low melting and boiling points.
   (c) Electrovalent compounds dissolve in water whereas covalent compounds do not.
   (d) Electrovalent compounds are usually hard crystals yet brittle.
   (e) Polar covalent compounds conduct electricity.
11. Elements X, Y and Z have atomic numbers 6, 9 and 12 respectively. Which one :
   (a) forms an anion ,
   (b) forms a cation,
   (c) state type of bond between Y and Z and give its molecular formula.
12. Taking $MgCl_2$ as an electrovalent compound, CCl_4 as a covalent compound, give four differences between electrovalent and covalent compounds.
13. Potassium chloride is an electrovalent compound, while hydrogen chloride is a covalent compound. But, both conducts electricity in their aqueous solutions. Explain.
14. (a) Name two compounds that are covalent when taken pure but produce ions when dissolved in water.
   (b) For each compound mentioned above give the formulae of ions formed in aqueous solution.
15. An element M burns in oxygen to form an ionic bond MO. Write the formula of the compounds formed if this element is made to combine with chlorine and sulphur separately.

2.6 COORDINATE BOND

The bond formed between two atoms by sharing a pair of electrons, provided entirely by one of the combining atoms but shared by both is called a ***coordinate bond*** or ***dative bond***, e.g., Ammonium ion (NH_4^+), Hydronium ion (H_3O^+).

2.6.1 Conditions for the formation of coordinate bond

(i) One of the two atoms must have at least one lone pair of electrons, *e.g.*, ammonia (NH_3), water (H_2O).

A pair of electrons which is not shared with any other atom is known as the **lone pair** of electrons but it is provided to the other atom for the formation of coordinate bond.

(ii) Another atom should be short of at least a lone pair of electrons, *e.g.*, Hydrogen ion (H^+).

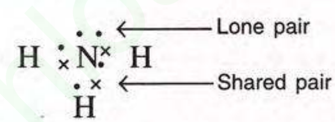
A coordinate bond can also be defined as a bond formed between an ion and an atom of a polar covalent molecule with one or more lone pair of electrons.

A coordinate bond has properties of both covalent and ionic bonds. Therefore, it is also called **co-ionic bond**.

The atom which provides the electron pair for the formation of a coordinate bond is known as the **DONOR** and the atom or ion sharing the donated electron pair is known as the **ACCEPTOR**.

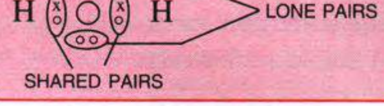
2.6.2 Formation of Ammonium ion (NH_4^+)

Nitrogen atom has five valence electrons and hydrogen atom has one valence electron. In ammonia, each of the three hydrogen atoms are bonded to the nitrogen atom by a pair of shared electrons. (One electron from the hydrogen atom and one from the nitrogen).



Thus, the nitrogen atom in ammonia is left with a **lone pair** of electrons.

This *ammonia molecule* combines with a hydrogen ion H^+, which has no electrons in its outermost orbit in such a way that the lone pair of electrons on the nitrogen atom is shared by the hydrogen ion. The latter thus acquires the helium *the nitrogen atom in ammonia and the hydrogen ion is a coordinate bond and is represented by "→" whereas a covalent bond is represented by "—".*



Dot diagram of water molecule

2.6.3 Formation of H_3O^+ ion and lone pair effect of oxygen atom

Water contains two hydrogen atoms and one oxygen atom. The hydrogen atom has one electron in its valence shell while the oxygen atom has six electrons in its valence shell.

Lewis structure of Hydrogen — Lewis structure of Oxygen

Two hydrogen atoms share one electron each with oxygen atom to form a water molecule.

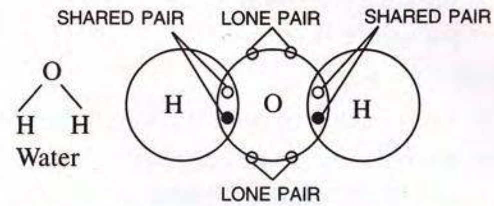
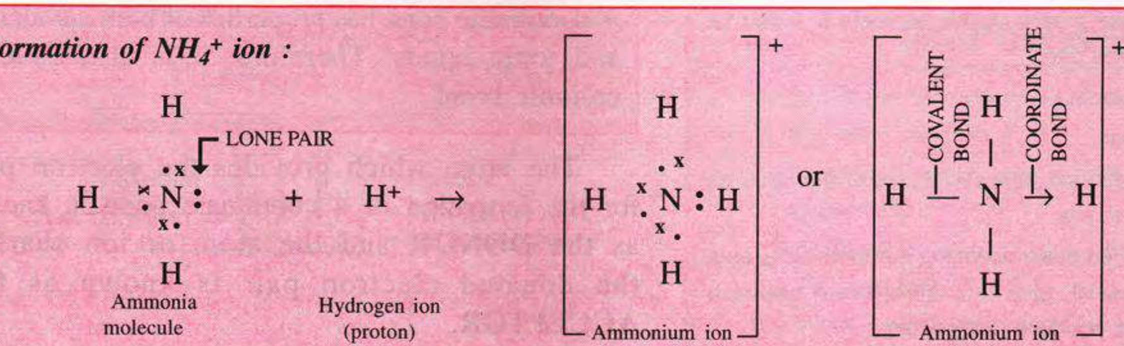


Fig. 2.5 Covalent bonding in water

The two unshared pairs of electrons known as **lone pairs** of electrons, do not participate in the bond formation in water molecule.

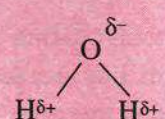
Formation of NH_4^+ ion :



The nitrogen atom in an ammonia molecule contains a ***lone pair of electrons.*** It is a DONOR. The hydrogen ion (H^+) ***accepts that lone pair of electrons*** (ACCEPTOR) and forms a coordinate bond. Once this bond is formed, all four N – H bonds become identical. The linkage forms an ***ammonium ion*** having a ***single positive charge.***

When ammonium chloride NH_4Cl is formed cation NH_4^+ (having 3 covalent and one coordinate bond) and anion Cl^- are attracted towards each other, due to electrical charge existing between them ionic bond is formed. Thus ammonium chloride is a good example of compound having all the three types of bonds *i.e.*, covalent, coordinate and ionic bond.

The O–H bonds in a water molecule are polarised *due to the large difference in the electronegativity values of the oxygen and the hydrogen atoms*. (The oxygen atom has an electronegativity value of 3·5, while that of the hydrogen atom is 2·1). Oxygen has higher electroneg-ativity so it attains slight negative (δ^-) charge while hydrogen atoms attain slight positive charge (δ^+). Therefore, a molecule of water due to these charges is a polar molecule and is represented as shown alongside.

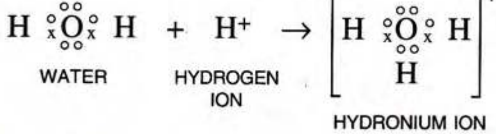


When an acid is added to water, strong dipole interaction (attraction between slight positive and slight negative charge) occurs between the polar water molecules and the polar acid molecules.

As a result of such a dipole interaction, the hydrogen ion gets released from the polar bonds of the acid molecules.

$$HCl \xrightarrow{H_2O} H^+ + Cl^-$$

The hydrogen ion spontaneously adds on to one of the two lone pairs of electrons of the oxygen atom of the water molecule.

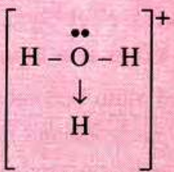


Addition of released H^+ ion to a **lone pair of electrons** of the oxygen atom of the polar water molecule leads to the formation of a *hydronium ion*

Hydronium ion is hydrated proton

$$H^+ + H_2O \rightarrow H_3O^+$$

Proton Water Hydronium ion



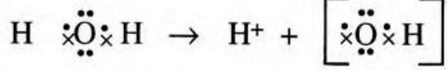
Structure of hydronium ion

2.6.4 Formation of hydroxyl ion (OH^-) :

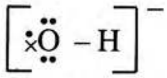
The hydroxyl ion or hydroxide ion is OH^-. It is formed when one hydrogen ion (H^+) is removed from the water molecule.

$$H_2O \rightarrow H^+ + OH^-$$

When H^+ is removed from water molecule, the shared pair of electron remains with oxygen as oxygen is more electronegative and thus hydroxyl ion has negative charge.



Dot diagram



Structure of hydroxyl ion

Self-ionisation of water

Water molecule contains two hydrogen atoms and one oxygen atom. A positive hydrogen ion (H^+) is formed when water ionises.

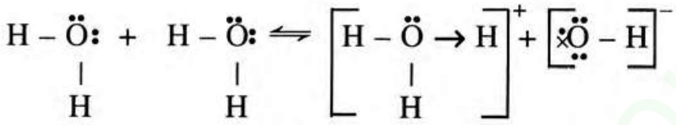
$$H_2O \rightleftharpoons H^+ + OH^-$$

This H^+ ion is transferred from one water molecule to the oxygen atom of another water molecule, forming hydronium ion (H_3O^+).

$$H^+ + H_2O \rightleftharpoons H_3O^+$$

Thus, H_3O^+ and OH^- ions are formed by water molecule.

$$\underset{}{H_2O} + H_2O \rightleftharpoons \underset{\text{hydronium ion}}{H_3O^+} + \underset{\text{hydroxide ion}}{OH^-}$$



EXERCISE

1. Define a coordinate bond and give the conditions for its formation.
2. What do you understand by lone pair and shared pair ?
3. State the type of bonding in the following molecules.
   (a) water, (b) calcium oxide,
   (c) hydroxyl ion, (d) methane,
   (e) ammonium ion, (f) ammonium chloride
4. (a) Draw an electron dot diagram to show the structure of each of the following :
   (i) Hydronium ion, (ii) Ammonium ion,
   (iii) Hydroxyl ion.

   State the type of bonding present in them.

   (b) Give two examples in each case :
   (i) Co-ordinate bonds compounds,
   (ii) Solid covalent compounds,
   (iii) Gaseous polar compounds,
   (iv) Gaseous non polar compounds,
   (v) Liquid non polar compounds.
5. Element M forms a chloride with the formula MCl_2 which is a solid with high melting point. M would most likely be in the group in which .... is placed.
   [(a) Na (b) Mg (c) Al (d) Si.]
6. Complete the following

	Sodium	Phosphorus	Carbon
Formula of chloride			
Nature of bonding			
Physical state of chloride			

atomic number 7.

(a) Write equations to show how A and B form ions.

(b) If B is a diatomic gas, write the equation for the direct combination of A and B to form a compound.

(c) If the compound formed between A and B is melted and an electric current is passed through the molten compound, the element A will be obtained at the .... and B at the .... of the electrolytic cell.

8. (a) How many atoms of each kind are present in the following molecules : calcium oxide, chlorine, water, carbon tetrachloride ?

(b) How many electrons are required by each atom mentioned in (a) to attain the nearest noble gas configuration?

9. Complete the following :

(a) When the nuclei of two different reacting atoms are of .... mass, then a bond so formed is called .... covalent bond (equal, unequal, polar, non-polar).

(b) In case of non-polar covalent bond, the covalent bond is formed in the .... of atoms and shared electrons are .... distributed (corner, middle, equally, unequally).

(c) The ions in .... compounds are held very strongly due to strong .... forces (electrovalent, covalent, electromagnetic, electrostatic).

10. (a) Compound X consists of molecules.

Choose the letter corresponding to the correct answer from the options A, B, C and D given below :

(i) The type of bonding in X will be :

A. ionic B. electrovalent

C. covalent D. molecular

(ii) X is likely to have a :

A. low melting point and high boiling point,

B. high melting point and low boiling point,

C. low melting point and low boiling point,

D. high melting point and high boiling point.

(iii) In the liquid state, X will :

A. become ionic,

B. be an electrolyte,

C. conduct electricity,

D. not conduct electricity.

(b) Electrons are getting added to an element Y :

(i) is Y getting oxidized or reduced ?

(ii) what charge will Y migrate to during the process of electrolysis ?

charged ions. Draw the structure of these positive ions.

(b) Explain why Carbon tetrachloride does not dissolve in water.

(c) Elements Q and S react together to form an ionic compound. Under normal conditions, which physical state will the compound QS exist in ?

(d) Can Q and S, both be metals? Justify your answer.

(e) The property which is characteristic of an electrovalent compound is that :

A. it is easily vaporized,

B. it has a high melting point,

C. it is a weak electrolyte,

D. it often exists as a liquid.

(f) When a metal atom becomes an ion :

A. it loses electrons and is oxidized,

B. it gains electrons and is reduced,

C. it gains electrons and is oxidized,

D. it loses electrons and is reduced.

2007

(a) (i) Name the charged particles which attract one another to form electrovalent compounds.

(ii) In the formation of electrovalent compounds, electrons are transferred from one element to another. How are electrons involved in the formation of a covalent compound ?

(iii) The electronic configuration of nitrogen is (2, 5). How many electrons in the outer shell of a nitrogen atom are not involved in the formation of a nitrogen molecule ?

(iv) In the formation of magnesium chloride (by direct combination between magnesium and chlorine), name the substance that is oxidized and the substance that is reduced.

2008

(a) Which of the following is **not** a common characteristic of an electrovalent compound ?

A. High melting point.

B. Conducts electricity when molten.

C. Consists of oppositely charged ions.

D. Ionizes when dissolved in water.

(b) What are the terms defined below ?

(i) A bond formed by a shared pair of electrons, each bonding atom contributing one electron to the pair.

(ii) A bond formed by a shared pair of electrons with both electrons coming from the same atom.

(a) The one which is composed of all the three kinds of bond [ionic, convalent and coordinate bond]

A. Sodium chloride B. Ammonia

C. Carbon tetrachloride D. Ammonium chloride

(b) Draw the structural formula of carbon tetrachloride and state the type of bond present in it.

2010

(a) Select the correct answer from A, B, C and D — Metals lose electrons during ionization — this change is called

A. Oxidation B. Reduction

C. Redox D. Displacement

(b) Select the right answer —

(i) *Sodium chloride* — convlent bond / ionic bond / convalent and coordinate bond.

(ii) *Ammonium ion* — covalent bond / ionic bond / covalent and coordinate bond.

(iii) *Carbon tetrachloride* — covalent bond / ionic bond / covalent and coordinate bond.

2011

(a) (i) In covalent compounds, the bond is formed due to .... [sharing/transfer] of electrons.

(ii) Electrovalent compounds have a .... [low/high] boiling point.

(iii) A molecule of .... contains a triple bond. [hydrogen, ammonia, nitrogen].

(b) By drawing an electron dot diagram, show the lone pair effect leading to the formation of — ammonium ion from ammonia gas and hydrogen ion.

(c) Give reasons — Hydrogen chloride can be termed as a polar covalent compound.

2012

(a) Draw an electron dot diagram of the structure of — hydronium ion. State the type of bonding present in it.

(b) There are three elements E, F, G with atomic number 19, 8 and 17 respectively. Give the molecular formula of the compound formed between E and G and state the type of chemical bond in this compound.

2013

(a) *A chemical term for.* A bond formed by a shared pair of electrons with both electrons coming from the same atom.

(b) Among the compounds identify the compound that has all three bonds [ionic, covalent and coordinate bond].

A. Ammonia B. Ammonium chloride

C. Sodium hydroxide D. Calcium chloride

(c) State which is not a typical property of an ionic compound.

A. High m.p.

B. Conducts electricity in molten and the aqueous state

C. Are insoluble in water

D. Exist as oppositely charged ions even in the solid state.

(d) Compare carbon tetrachloride and sodium chloride with regard to solubility in water and electrical conductivity.

2014

(a) Compound 'X' consists of only molecules. 'X' will have —

A. Crystalline hard structure

B. A low m.p. and low b.p

C. An ionic bond

D. A strong force of attraction between its molecules

(b) The molecule which contains a triple covalent bond is :

A. ammonia B. methane

C. water D. nitrogen

(c) Give one word or phrase for the following : Formation of ions from molecules.

(d) Give a reason why covalent compounds exist as gases, liquids or soft solids.