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CHEMISTRY

CLASS IX
FOUNDATION

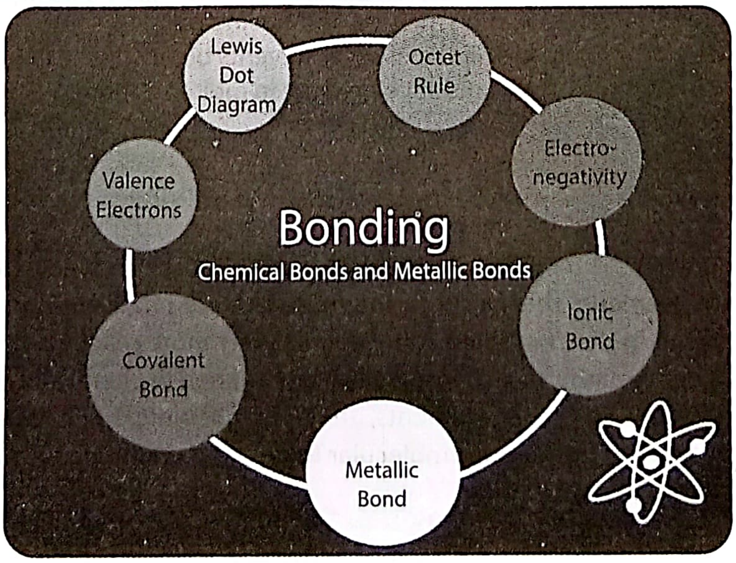
4 | CHEMICAL BONDING

Chapter Outline

Linus Pauling
(Feb. 1901–Aug. 1994)

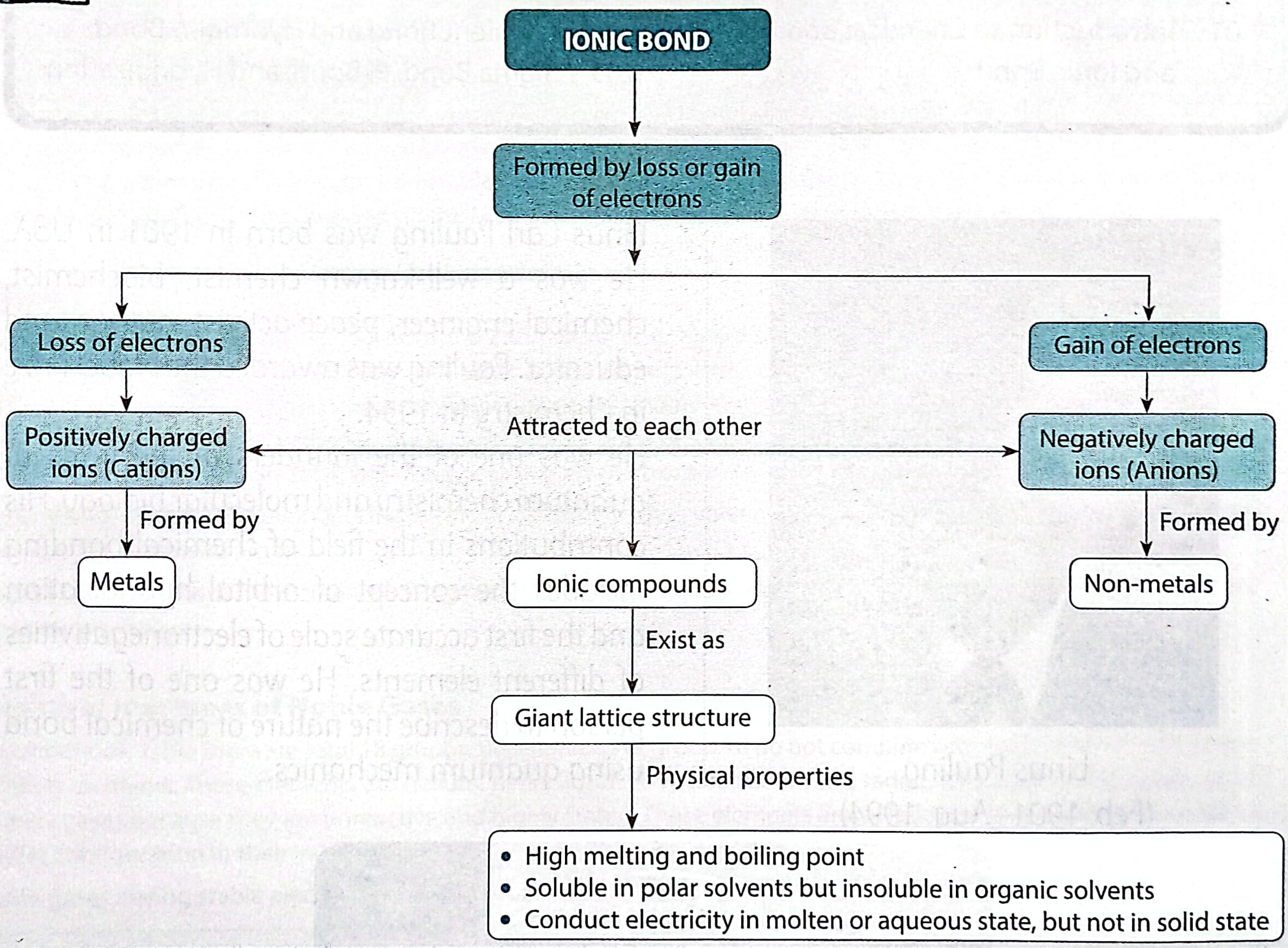
Linus Carl Pauling was born in 1901 in USA. He was a well-known chemist, biochemist, chemical engineer, peace activist, author, and educator. Pauling was awarded the Nobel Prize in Chemistry in 1954.

He was one of the founders of the fields of quantum chemistry and molecular biology. His contributions in the field of chemical bonding includes the concept of orbital hybridization and the first accurate scale of electronegativities of different elements. He was one of the first person to describe the nature of chemical bond using quantum mechanics.



4.01 Introduction to Chemical Bonding and Ionic Bond

MIND MAP



INTRODUCTION

Elements in nature exist not only in the free state, but they also exist in the combined state. Most of the elements exist as compounds in nature. Elements that occur in the free state are relatively non-reactive. They are highly stable atoms. Elements that occur in the combined state are relatively more reactive. They react easily with other elements and hence, occur as compounds. In a chemical reaction, change in chemical composition of a substance takes place. When elements react with other elements, they form chemical bonds and are held together by attractive forces. The study of types of bonds, intermolecular forces, and conditions for bond formation are some of the features of chemical bonding.

Historical Aspects

In 1704, Newton, proposed that atoms get attached to each other by some force. Later in 1819, Berzelius proposed that elements combine due to their electronegative and electropositive character. By the mid-nineteenth century, the theory of valency was well accepted. According to this theory, compounds are formed due to the forces of attraction between the oppositely charged ions.

When the atoms of the same elements or those of different elements combine to form a molecule, a force of attraction develops between the participating atoms which holds them together.

CHEMICAL BONDING

The attractive force, which holds together the various atoms and ions in different chemical species, is called a chemical force. The association between atoms in a molecule by chemical forces is called chemical bond and chemical bonding refers to the formation of these chemical bonds. During a chemical bond formation, there are changes in energy of the participating atoms and the resultant molecules become stable by losing energy. Apart from that, there are different types of bonds formed which depend on the type of atom and the conditions in which it forms.

Valency

The term valency has been derived from the Latin word *Valentia* which means capacity. Valency of an element is the measure of its combining capacity with other atoms when it forms chemical compounds or molecules. Since the valency depends upon the electronic configuration of the atoms, the development of various theories of chemical bonding have closely been related to the understanding of the electronic arrangement of an atom. Valence shell refers to the outermost shell of an atom which can lose or gain electrons to form a chemical bond.

Octet configuration: The elements having eight electrons in their valence shell are said to have an octet configuration. For example, neon and argon

Duplet configuration: The elements having two electrons in their valence shell are said to have a duplet configuration. For example, helium

Chemical Inertness of Noble Gases

In our periodic table there are total 18 groups, the elements of group 18 do not combine with each other or with atoms of other elements. These elements are helium, neon, argon, krypton, xenon, and radon, which are called noble gases or inert gases because they are unreactive and highly stable. These elements are called so as they have either octet or duplet configuration in their valence shell.

Noble gases having stable electronic configurations are shown in the table below.

Noble Gas	Symbol	Atomic Number	Electronic Configuration	Number of Valence Electrons
Helium	He	2	2	2
Neon	Ne	10	2, 8	8
Argon	Ar	18	2, 8, 8	8
Krypton	Kr	36	2, 8, 18, 8	8
Xenon	Xe	54	2, 8, 18, 18, 8	8
Radon	Rn	86	2, 8, 18, 32, 18, 8	8

Atoms of all other elements, except noble gases have 1–7 electrons in their valence shell.

Kossel–Lewis Approach to Chemical Bonding

In 1916, Kossel–Lewis made certain observation about inert gases which are as follows:

(i) Helium is the only noble gas which has two electrons in its valence shell (first energy shell) because the first energy shell (n = 1) cannot have more than two electrons.

(ii) All other noble gases have eight electrons in their valence shell. To have eight electrons in the outermost shell of an atom is known as octet of electrons.

Noble gases are very stable because of their electron configuration with two or eight electrons in their valence shells. In other words, noble gas atoms have completely filled outermost shells. It is not possible to remove or to add electrons to the outermost shell of a noble gas atom. Due to this, the outermost electrons of a noble gas atom cannot take part in chemical reactions.

Key points

- A duplet or octet configuration of electrons is most stable. Any atom or ion having this configuration will be in the minimum state of energy.
- According to Kossel and Lewis, every atom tries to attain stability by attaining their nearest inert gas electronic configuration.

Electronic configurations of some common metals and non-metals

Name of the Metal Atom	Symbol	Atomic Number	Electronic Configuration			
			K	L	M	N
Lithium	Li	3	2	1	-	-
Sodium	Na	11	2	8	1	-
Magnesium	Mg	12	2	8	2	-
Aluminium	Al	13	2	8	3	-
Potassium	K	19	2	8	8	1
Calcium	Ca	20	2	8	8	2
Nitrogen	N	7	2	5	-	-
Oxygen	O	8	2	6	-	-
Fluorine	F	9	2	7	-	-
Phosphorus	P	15	2	8	5	-
Sulphur	S	16	2	8	6	-
Chlorine	Cl	17	2	8	7	-

The elements given above show that they do not have stable electronic configurations. Hence, they combine with each other or with other atoms to achieve stable noble gas electronic configurations. This is the cause for chemical combination, that is, to acquire maximum stability. The principle of attaining a maximum of eight electrons in the valence shell of atoms, is called **octet rule**.

Key point

Since the concept of Kossel and Lewis was based on electronic configuration of atom, it is referred to as "Electronic Theory of Valency."

Bond Formation

Atoms combine with each other to complete their respective octet or duplet so as to acquire a stable inert gas configuration. This can occur in two ways:

1. By transfer of electrons from one atom to another atom, that is, one atom may lose electrons and the other may gain electrons. The bond thus formed between the two atoms is called **ionic bond** (or **electrovalent bond**).
2. By sharing of electrons which can occur in two ways as follows:
   - **(i)** When the shared electrons are contributed by the two combining atoms equally, the bond formed is called **covalent bond.**
   - **(ii)** When electrons are contributed entirely by one of the atoms but shared by both, the bond formed is called **coordinate bond.**

Lewis Symbols (Electron Dot Representation)

G.N Lewis, an American chemist, introduced simple notations to represent the valence electrons in an atom. These notations are called Lewis symbols or electron dot symbols. According to Lewis notations, the symbol of the element represents the whole of the atom except the valence electrons. So, the valence shell electrons are shown as dots or crosses around the symbol of the atom.

A few examples are given below:

Electron dot representation (Lewis symbols) of some common elements

Element	Symbol	Atomic Number	Electronic Configuration				Valence Electrons	Lewis Symbol
			K	L	M	N		
Hydrogen	H	1	1	-	-	-	1	$\overset{\times}{\text{H}}$
Helium	He	2	2	-	-	-	2	$\text{He}^{\times}_{\times}$
Lithium	Li	3	2	1	-	-	1	$\overset{\times}{\text{Li}}$
Beryllium	Be	4	2	2	-	-	2	$\text{Be}^{\times}_{\times}$
Boron	B	5	2	3	-	-	3	$\times\overset{\times}{\text{B}}\times$
Carbon	C	6	2	4	-	-	4	$\times\overset{\times}{\underset{\times}{\text{C}}}\times$
Nitrogen	N	7	2	5	-	-	5	$^{\times}_{\times}\overset{\times}{\underset{\times}{\text{N}}}\times$
Oxygen	O	8	2	6	-	-	6	$^{\times}_{\times}\overset{\times\times}{\text{O}}^{\times}_{\times}$
Fluorine	F	9	2	7	-	-	7	$^{\times}_{\times}\overset{\times\times}{\underset{\times\times}{\text{F}}}\times$
Neon	Ne	10	2	8	-	-	8	$^{\times}_{\times}\overset{\times\times}{\underset{\times\times}{\text{Ne}}}^{\times}_{\times}$

Significance of Lewis Symbols

(i) The Lewis symbols indicate the number of electrons present in the outermost or valence shell.

(ii) These number of electrons help to predict the common valency of the element. The common valency of the element is either equal to the number of dots in Lewis symbol (if these are ≤ 4) or 8 minus the number of dots (if these are ≥ 4).

For example, Li, Be, B, and C have valencies 1, 2, 3, and 4 respectively, that is, equal to the number of dots. Whereas, the valencies of N, O, and F are 3, 2, and 1 respectively, that is, 8 minus the number of dots.

Electropositive and Electronegative Elements

Electropositive elements

The elements which have the tendency to donate electrons from their valence shells and become positively charged ions (cation) are called electropositive elements. For example,

All metals are electropositive elements.

$$\underset{\text{Metal}}{A} \rightarrow \underset{\text{Cation}}{A^+} + e^-$$

Hydrogen is the only non-metal, which is electropositive in nature.

$$H \rightarrow H^+ + e^-$$

Electronegative elements

The elements which have the tendency to accept electrons in their valence shell and become negatively charged ions (anions) are called electronegative elements. For example, all non-metals are electronegative elements except hydrogen.

$$\underset{\text{Non-metal}}{A} + e^- \rightarrow \underset{\text{Anion}}{A^-}$$

IONIC BOND

An ionic bond is a chemical bond formed between two atoms (usually a metal and a non-metal) by complete transfer of electrons from the valence shell of one atom to the valence shell of another atom.

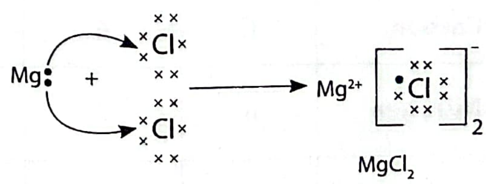
The transfer of electrons takes place in such a way that both the atoms attain an inert gas configuration. The actual bond is formed due to the electrostatic force of attraction between the two resulting oppositely charged ions.

Examples of Ionic Bond

Formation of $MgCl_2$

Electronic configuration of magnesium (12): 2, 8, 2; Mg (with 2 dots)

Electronic configuration of chlorine (17): 2, 8, 7; Cl (with 7 crosses)



Magnesium loses its two electrons from the valence shell and chlorine gains one of these electrons to attain their nearest inert gas configuration.

Formation of NaCl

Consider a sodium and a chlorine atom.

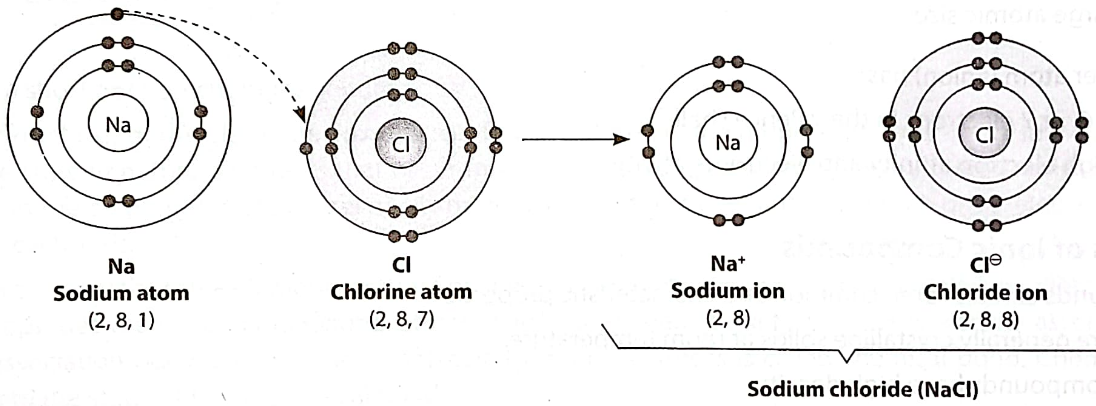
Sodium atom: Electronic configuration of sodium (Na) is 2, 8, 1. So, it tends to lose one electron (oxidation) to form Na^+ ion, which has the stable configuration of neon – an inert gas. Hence, the ion of sodium is more stable than the atom of sodium. Due to this, sodium does not occur in the free state but occurs as compounds of sodium only.

The formation of sodium ion involves ionization.

Chlorine atom: Electronic configuration of chlorine (Cl) is 2, 8, 7. So, it tends to accept one electron (reduction) to form Cl^- ion. On gaining one electron, Cl^- ion is formed which has the stable configuration of argon – an inert gas. Hence, chloride ion is more stable than the atom of chlorine. Due to this, chlorine does not occur in the free state but occurs as compounds of chorine only.

The formation of chlorine ion involves the addition of electron to chlorine atom.

The actual bond in NaCl is formed by attraction of the oppositely charged Na^+ ion and Cl^- ion. The transfer of an electron from valence shell of sodium atom to valence shell of chlorine atom is shown (before transfer and after transfer) below.



Key points

- Oxidation is a chemical process in which an atom(s) or ion loses an electron(s).
- Reduction is a chemical process in which an atom(s) or ion gains an electron(s).

Other examples of ionic bond

S. No.	Compound	Cation Formation and Configuration Changes	Anion Formation and Configuration Changes	Ionic Bond Formation
1.	KCl	$K \rightarrow K^+ + 1e^-$ (2, 8, 8, 1) → (2, 8, 8) K^+ ion attains argon configuration	$Cl + 1e^- \rightarrow Cl^-$ (2, 8, 7) → (2, 8, 8) Cl^- ion gets argon configuration	$K^+ + Cl^- \rightarrow KCl$
2.	MgO	$Mg \rightarrow Mg^{2+} + 2e^-$ (2, 8, 2) → (2, 8) Mg^{2+} ion attains neon configuration	$O + 2e^- \rightarrow O^{2-}$ (2, 6) → (2, 8) O^{2-} ion gets neon configuration	$Mg^{2+} + O^{2-} \rightarrow MgO$
3.	Al_2O_3	$Al \rightarrow Al^{3+} + 3e^-$ (2, 8, 3) → (2, 8) Al^{3+} ion attains neon configuration	$3O + 6e^- \rightarrow 3O^{2-}$ (2, 6) → (2, 8) O^{2-} ion gets neon configuration	$2Al^{3+} + 3O^{2-} \rightarrow Al_2O_3$

4.	$CaCl_2$	$Ca \rightarrow Ca^{2+} + 2e^-$ (2, 8, 8, 2) → (2, 8, 8) Ca^{2+} ion gets argon configuration	$2Cl + 2e^- \rightarrow 2Cl^-$ (2, 8, 7) → (2, 8, 8) $2Cl^-$ ion gets argon configuration	$Ca^{2+} + 2Cl^- \rightarrow CaCl_2$

Factors Favouring Ionic Bond Formation

Two atoms form an ionic bond if:

1. One of the atoms (cation) has

(i) 1, 2, or 3 electrons in the valence shell

(ii) Low ionization potential

(iii) Low electronegativity and electron affinity

(iv) Large atomic size

2. The other atom (anion) has

(i) 5, 6, or 7 electrons in the valence shell

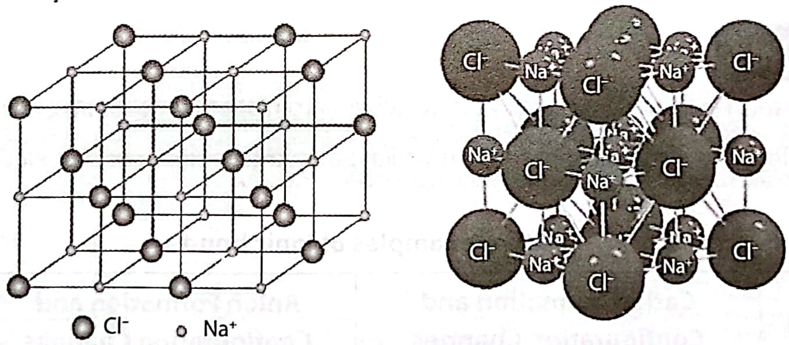
(ii) High electron affinity and electronegativity

Properties of Ionic Compounds

Ionic compounds exhibit some common and characteristic properties:

(i) These are generally crystalline solids at room temperature.

(ii) These compounds have high density.



A large mass is concentrated in a small volume in the ionic crystal. This results in ionic compounds having high densities.

(iii) They are generally hard and brittle.

(iv) Reactions of ionic compounds are very fast in aqueous solutions and fused state. Ionic reactions are fast as the transfer of electrons has already taken place in the ions.

(v) They are poor conductors of electricity (insulators) in the solid state.

(vi) Ionic compounds are soluble in solvents like water, and insoluble in organic solvents like benzene.

(vii) In molten (fused) state or in aqueous solution, the ions conduct electricity.

Reasons for Conductivity in Ionic Compounds

Electricity can flow through the electrolyte only when free charged ions are available. In the solid state of an ionic crystal, the ions are held rigidly and cannot move about. Hence, in solid state, ionic compounds cannot conduct electricity.

In fused state: As the temperature increases, kinetic energy of the ions increases, and the electrostatic forces of attraction are slowly overcome. The rigid network of ions is broken. The ions can now move and hence, conduct electricity.

In aqueous solution: The rigid network of ions is broken as the ionic compound dissociates in aqueous solution, setting the ions free which are available for conducting electricity.

Key point

Ions which do not possess inert gas configuration (i.e., 8 electrons in the valence shell) yet are stable with 18 electrons in their outermost main energy level, are said to possess pseudo inert gas configuration.

EXAMPLES

1. Write a short note on chemical bonding.

Solution: Most of the elements do not occur free in nature but as compounds. Only a very few elements occur in free state in nature. Elements that occur free are relatively unreactive. They are quite stable. Elements that occur in the combined state are relatively more reactive. When elements react with other elements, they form chemical bonds.

When atoms of the same elements or those of different elements combine to form a molecule, a force of attraction develops between the participating atoms which hold them together which is known as chemical force. The association between atoms in a molecule by chemical forces is called chemical bond. Chemical bonding refers to the study of these chemical bonds.

2. Write the electronic configurations of different noble gases.

Solution:

Noble Gas	Symbol	Atomic Number	Electronic Configuration	Number of Valence Electrons
Helium	He	2	2	2
Neon	Ne	10	2, 8	8
Argon	Ar	18	2, 8, 8	8
Krypton	Kr	36	2, 8, 18, 8	8
Xenon	Xe	54	2, 8, 18, 18, 8	8
Radon	Rn	86	2, 8, 18, 32, 18, 8	8

3. What are the modes of chemical combination?

Solution: Atoms combine together in order to complete their respective octet or duplet, so as to acquire a stable inert gas configuration. The different modes of chemical combination are:

(i) By transfer of electrons from one atom to another atom, that is, one atom may lose electrons and the other may gain electrons. The bond thus formed between the two atoms is called ionic bond (or electrovalent bond).

(ii) By sharing of electrons which can occur in two ways as follows:

(a) When the shared electrons are contributed by the two combining atoms equally, the bond formed is called covalent bond.

(b) When electrons are contributed entirely by one of the atoms but shared by both, the bond formed is called as coordinate bond.

4. Define oxidation and reduction.

Solution: Oxidation is a chemical process in which an atom(s) or ion loses electron(s).

Reduction is a chemical process in which an atom(s) or ion gains electron(s).

5. Write a few examples for ionic bond formation.

Solution:

	Compound	Cation Formation and Configuration Changes	Anion Formation and Configuration Changes	Ionic Bond Formation
1.	KCl	$K \rightarrow K^+ + 1e^-$ (2, 8, 8, 1) → (2, 8, 8) K^+ ion attains argon configuration	$Cl + 1e^- \rightarrow Cl^-$ (2, 8, 7) → (2, 8, 8) Cl^- ion gets argon configuration	$K^+ + Cl^- \rightarrow KCl$
2.	$CaCl_2$	$Ca \rightarrow Ca^{2+} + 2e^-$ (2, 8, 8, 2) → (2, 8, 8) Ca^{2+} ion attains argon configuration	$2Cl + 2e^- \rightarrow 2Cl^-$ (2, 8, 7) → (2, 8, 8) $2Cl^-$ ions get argon configuration	$Ca^{2+} + 2Cl^- \rightarrow CaCl_2$

6. Write the factors favourable for the formation of a cation.

Solution:

Factors favourable for the cation formation:

(i) Low electronegativity and electron affinity

(ii) Large atomic sizes

(iii) Low charge on the ion

(iv) Low ionization enthalpy

RECALL

1. The attractive force which holds the constituent particles of atoms or ions together and stabilizes them by the overall loss of energy is known as **chemical bonds.**
2. Valency is the ability or tendency of elements to combine with one another.
3. The elements having eight electrons in their valency shell are said to have an octet configuration.
4. The elements having two electrons in their valency shell are said to have duplet configuration.
5. The elements helium, neon, argon, krypton, xenon and radon are called **noble gases** or **inert gases** because they do not react with each other or with other elements.
6. **Lewis dot symbols (Electron dot representation):** According to **Lewis notations,** a symbol of an element represents the whole of the atom except the valence electrons. The valence shell electrons are shown as dots or crosses around the symbol of the atom.
7. **Electropositive elements** have the tendency to donate electrons from their valence shell and become positively charged ions (cations) are called electropositive elements.

8. **Electronegative elements** have the tendency to accept electrons in their valence shell and become negatively charged ions (anions) are called electronegative elements.
9. Ionic bond is a chemical bond formed by complete transfer of electrons.
10. Ionic compounds exhibit some common and characteristic properties.
    (i) Ionic compounds are generally crystalline solids at room temperature.
    (ii) They have high density.
    (iii) They are generally poor conductors of electricity in the solid state.
    (iv) In molten (fused) state or in aqueous solution the ions conduct electricity.
    (v) They are hard and brittle.
    (vi) They have high melting and boiling point.
11. **Factors favourable for the formation of ionic bond**
    (i) Two atoms must be different, that is, one atom should be metal and other non-metal.
    (ii) Ionization potential of one atom (metal) must be small.
    (iii) Electron affinity of one of the atoms (non-metal) must be high.
    (iv) Electronegativity of the one of the atoms (non-metal) must be high.
    (v) Difference of electronegativity between two atoms should be greater than 1.7.
    (vi) Formation of cations and anions with inert gas configuration.

DESCRIPTIVE QUESTIONS

I. VERY SHORT ANSWER QUESTIONS

1. What is meant by chemical bond?
2. Write the significance of Lewis dot symbols.
3. According to Kossel–Lewis approach, what tendency does atoms of various elements have?
4. What is octet rule?
5. What forces are responsible for ionic bond formation?
6. What is ionic bond?
7. Give the Lewis dot symbols for helium and neon.
8. Why ionic compounds have high density?
9. What is the valency of sodium?
10. Give two examples of inert gas.
11. What is the valency of nitrogen?
12. Can an ionic bond form between two non-metals?

II. SHORT ANSWER QUESTIONS

13. Why element fluorine does not occur in the free state but occurs in the combined state?
14. Explain the formation of ionic bond with example.
15. Write the electronic configurations of given metals: lithium, sodium, magnesium, and aluminium.
16. Explain about Lewis dot representation.
17. Define electropositive and electronegative elements.
18. What are the factors favouring the formation of ionic bond?
19. What happens if the temperature increases of an ionic bond in a fused state?
20. How do ionic compounds conduct electricity?
21. Give the factors favourable for the anion formation.

III. LONG ANSWER QUESTIONS

22. Draw the Lewis dot structure for calcium oxide (CaO).
23. Explain the bond formation of NaCl using neat diagram.
24. What are the properties of ionic bond?
25. How are valence electrons related to ionic bond?

IV. FILL IN THE BLANKS

26. In molten (fused) state or in aqueous solution, the ions conduct ___________.

27. The elements which have the tendency to accept electrons in their valence shell and become negatively charged ions (anions) are called ___________.

28. Ionic compounds are insoluble in other solvents like ___________.

29. Ionic compounds are formed by ___________ of electrons.

30. The difference in electronegativity between two atoms to form an ionic bond should greater than ___________.

V. TRUE OR FALSE

31. The Lewis symbols indicate the number of electrons in the outermost or valence shell.

32. Ionic compounds are generally poor conductors of electricity in the solid state.

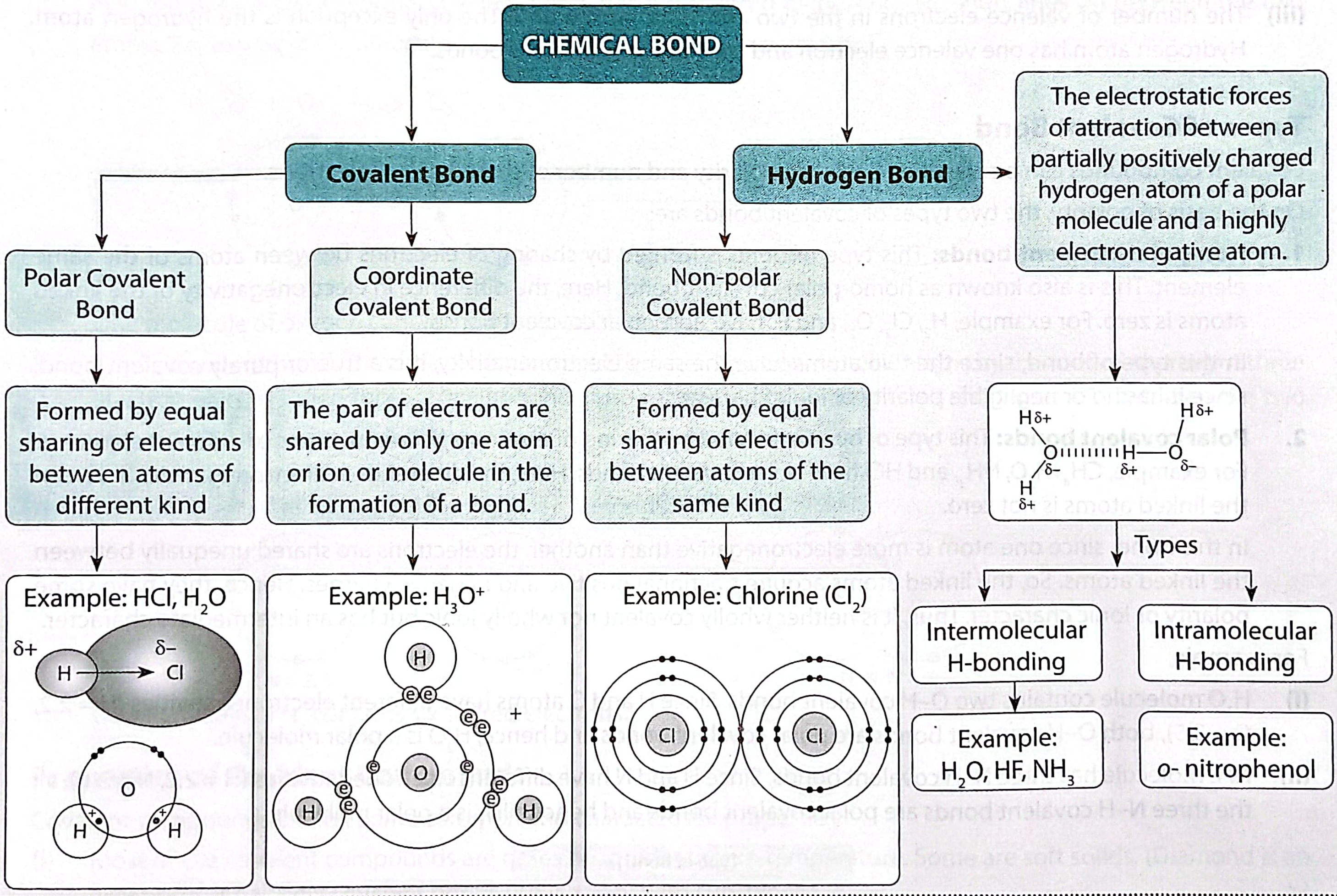
33. Ionic compounds are hard with low melting point and boiling point.

34. Hydrogen is the only non-metal which is an electropositive element.

35. Fluorine (F) has atomic number 7 and electronic configuration (2, 5).

4.02 Covalent Bond and Hydrogen Bond

MIND MAP



INTRODUCTION

The process of chemical bonding can be done by another mode of chemical combination, which is by sharing of one or more electrons. In this bond, the atoms do not acquire any charge as the electron or electrons are not lost completely. The bond is therefore, termed as non-polar bond. A covalent bond is a chemical bond formed between two atoms (usually non-metals) by sharing of valence electrons. These are also known as molecular bonds. The sharing of electrons takes place in such a way that both the atoms attain inert gas configuration. The actual bond is formed due to the force of attraction between the nuclei of two atoms and the shared pair of electrons.

COVALENT BOND

The type of chemical bond formed by sharing of electrons with the atoms of other elements or same element is called a covalent bond. In this bond, both the atoms obtain nearest inert gas configuration in their respective valence shell and thereby, attain stability. The electrons shared between the atoms are known as shared pair or bonding pair.

A covalent bond is formed between elements having:

(i) Very high ionization energies which are incapable of transferring electrons.

(ii) Very low electron affinity and hence, cannot take up electrons in their valence shell.

Factors Favouring Covalent Bond Formation

Two atoms will form a covalent bond if

(i) Both the atoms have less difference in electronegativity.

(ii) Either of the atoms does not attract the shared electron pair with more than optimum force.

(iii) The number of valence electrons in the two atoms are 4, 5, 6 or 7. The only exception is the hydrogen atom. Hydrogen atom has one valence electron and can still form covalent bonds.

Types of Covalent Bond

Covalent compounds can be classified based on polarity and number of shared pair of electrons.

On the basis of polarity, the two types of covalent bonds are:

1. **Non-polar covalent bonds:** This type of bond is formed by sharing of electrons between atoms of the same element. This is also known as homo-polar covalent bond. Here, the difference in electronegativity of the linked atoms is zero. For example, H_2, Cl_2, O_2, and F_2 have non-polar covalent bonds.

   In this type of bond, since the two atoms have the same electronegativity, it is a true or purely covalent bond, since it has no or negligible polarity or ionic character.

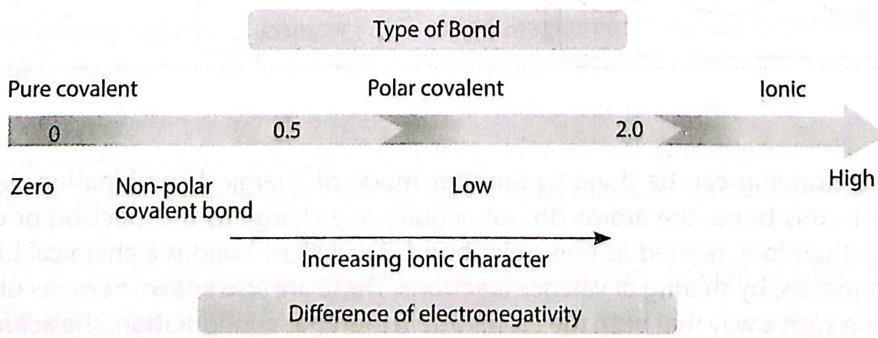
2. **Polar covalent bonds:** This type of bond is formed by sharing of electrons between atoms of different elements. For example, CH_4, H_2O, NH_3, and HCl have polar covalent bonds. Here, the difference in electronegativity between the linked atoms is not zero.

   In this bond, since one atom is more electronegative than another, the electrons are shared unequally between the linked atoms. So, the linked atoms acquire fractional positive and negative charges. Hence, they have some polarity or ionic character. Thus, it is neither wholly covalent nor wholly ionic but has an intermediate character.

For example,

(i) H_2O molecule contains two O–H covalent bonds. Since H and O atoms have different electronegativities (H = 2.2, O = 3.5), both O–H covalent bonds are polar covalent bonds and hence, H_2O is a polar molecule.

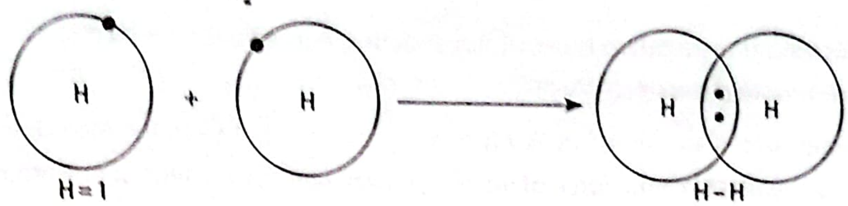
(ii) NH_3 molecule has three N–H covalent bonds. Since H and N have different electronegativities (H = 2.2, N = 3.0), all the three N–H covalent bonds are polar covalent bonds and hence, NH_3 is a polar molecule.



On the basis of number of shared pair of electrons, the three types of covalent bonds are:

1. **Single covalent bond:** A chemical bond formed between two non-metallic atoms by the mutual sharing of one electron pair only is called single covalent bond. It is represented by putting a short line (–) between the two atoms. For example, H_2 molecule

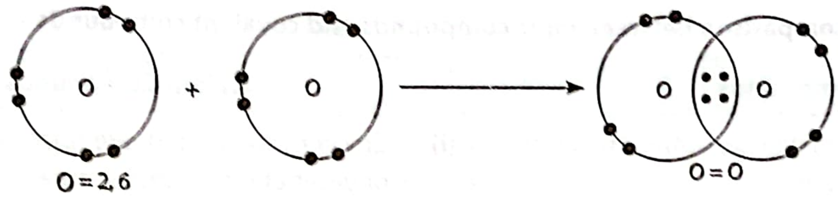
$H + H \longrightarrow H_2$



One molecule of hydrogen contains one shared pair of electrons.

2. **Double covalent bond:** A chemical bond formed between two non-metallic atoms by the mutual sharing of two electron pairs is called double covalent bond. It is represented by putting two short lines (=) between the two atoms. For example, O_2 molecule

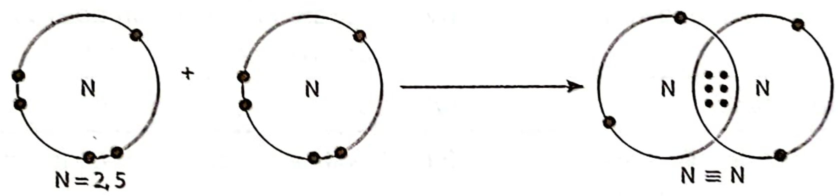
$O + O \longrightarrow O_2$



One molecule of oxygen contains four shared electrons.

3. **Triple covalent bond:** A chemical bond formed between two non-metallic atoms by the mutual sharing of three electron pairs, is called triple covalent bond. It is represented by putting three short lines (≡) between the two atoms. For example, N_2 molecule

$N + N \longrightarrow N_2$



One molecule of N_2 contains six shared electrons.

Properties of Covalent Compounds

Covalent compounds exhibit some common and characteristic properties.

(i) Most of the covalent compounds are gases or liquids at room temperature. Some are soft solids. (Diamond is an exception. It has only covalent bonds but is a very hard substance.)

(ii) They have low melting and boiling points (Diamond is an exception. Its melting point is very high.).

(iii) Covalent compounds are poor conductors of electricity as ions are not available to conduct electricity. (Graphite is an exception. It has mostly polar-covalent bonds like HCl that ionize in aqueous solution and are hence, good conductors.)

(iv) These compounds are insoluble in some solvents like water, and are soluble in other solvents like benzene, carbon disulphide, and carbon tetrachloride.

(v) They are neither hard nor brittle.

(vi) Reaction of covalent compounds are slow as existing bonds have to be broken and new bonds have to form by redistribution of valence electrons again.

(vii) They are directional in nature.

Key points

In covalent molecules, there are two types of forces acting between the molecules, i.e., Van der Waals' forces and dipole-dipole attraction.

(i) **Van der Waals' forces** are weak forces which are present in between the molecules. This force is largely due to the electrostatic force of attraction between the nucleus of one atom and electrons of other atom.

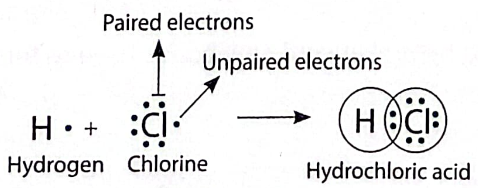
(ii) **Dipole-dipole interactions** are much stronger than Van der Waals' forces and mainly exist in polar covalent molecules. Molecules with partial positive and partial negative charges form a dipole, and these dipoles align with each other. The force of attraction between the oppositely charged ends of two different dipoles is called dipole-dipole interaction.

General comparison between ionic compounds and covalent compounds

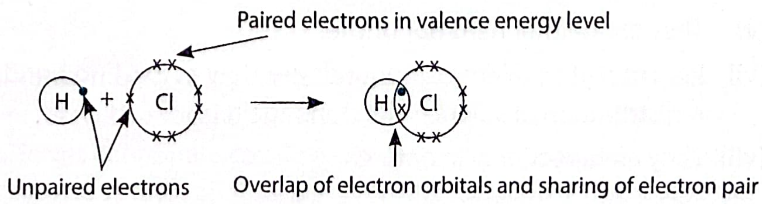
Ionic Compounds	Covalent Compounds
(i) Ionic compounds are crystalline, brittle, and hard solid at room temperature.	(i) Covalent compounds are soft solids or liquids or gases at room temperature. They are neither hard nor brittle.
(ii) These compounds are generally poor conductors of electricity in the solid state. In molten (fused) state or in aqueous solution, the ions conduct electricity	(ii) Most covalent compounds are poor conductors of electricity.
(iii) They have high melting and boiling points.	(iii) They have low melting and boiling points.
(iv) They are soluble in polar solvents and insoluble in non-polar solvents.	(iv) They are soluble in non-polar solvents and insoluble in polar solvents.
(v) Ionic compounds, are very stable.	(v) Covalent compounds are less stable.
(vi) These compounds have high density due to a high mass being concentrated in small volumes.	(vi) Covalent compounds have low density.
(vii) Reaction of ionic compounds are very fast in aqueous solution and fused states. For example, NaCl, $CaCl_2$, MgO, and Al_2O_3	(vii) Reaction of covalent compounds are slow. For example, Cl_2, O_2, NH_3, and CH_4

Formation of Covalent Compounds

(i) **Formation of hydrogen chloride molecule (HCl):** The hydrogen atom has one electron in *K*-shell and hence needs one more electron to have a stable configuration. Chlorine atom has seven electrons in its valence shell, that is, *M*-shell and hence, needs one more electron to have a stable configuration. Thus, when a chlorine atom and a hydrogen atom come closer to each other, they share a single electron pair, by contributing one electron each. In doing so, chlorine atom acquires a stable configuration of argon (2, 8, 8) and hydrogen atom of helium (2). The formation of hydrogen chloride molecule is illustrated below by dot diagram and structural diagram.



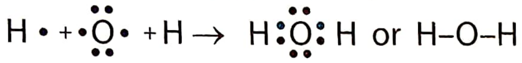
Dot Diagram



Structural Diagram

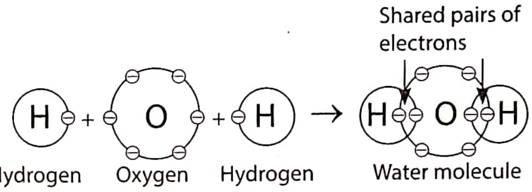
(ii) Formation of water molecule (H_2O): The hydrogen atom has one electron in *K*-shell and hence, needs one more electron to attain a stable configuration. The oxygen atom has six electrons in its valence shell, that is, *L*-shell and hence, needs two more electrons to have stable inert gas configuration. Thus, one atom of oxygen shares one electron each with two hydrogen atoms, such that oxygen atom acquires electronic configuration of neon (2, 8) and each hydrogen atom acquires electronic configuration of helium (2). It can be observed that each atom is bound with other atom by a single covalent bond

Shared electron pair



Hydrogen atom Oxygen atom Hydrogen atom

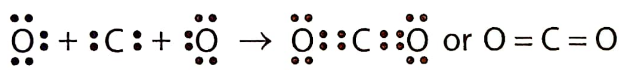
Dot Diagram



Hydrogen atom Oxygen atom Hydrogen atom

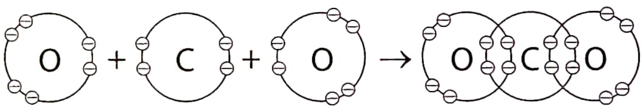
Structural Diagram

(iii) Formation of carbon dioxide molecule (CO_2): The carbon atom has four electrons in its valence shell, that is, *L*-shell and needs four more electrons to have a stable configuration. The oxygen atom has six electrons in its valence shell, i.e., *L*-shell and needs two electrons to have stable inert gas configuration. Thus carbon, share two electron pairs with two oxygen atoms to form molecule of carbon dioxide. The atoms of oxygen are bound to atom of carbon by double covalent bond and each of the participating has an octet configuration like that of neon (2, 8). The formation of carbon dioxide molecule is represented by dot diagram and structural diagram as illustrated below:



One atom of carbon and two atom of oxygen Molecule of carbon dioxide

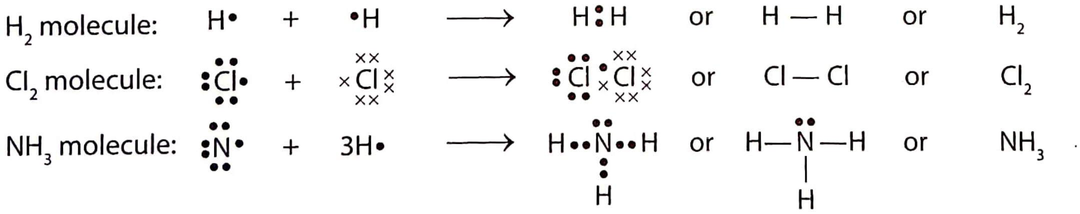
Dot Diagram



One atom of carbon and two atom of oxygen Molecule of carbon dioxide

Structural Diagram

Lewis Dot Representation of Other Covalent Molecules



Coordinate Covalent Bond

Coordinate covalent bond is a specific type of covalent bond. In this type of bond, the pair of electrons are derived from a single atom and are shared between both the bonded atoms. This is an extended Lewis concept to the mechanism of the formation of type of bonds.

During the bond formation, the atom contributing the pair of electrons is known as donor, while the atom which does not contribute but only shares the given pair of electrons is referred to as acceptor. Coordinate bond is represented by "→" (an arrow) starting from the donor atom and directed towards the acceptor atom.

For example,

(i) Formation of ammonia-boron trifluoride: Ammonia molecule contains nitrogen atom with a lone pair of electrons. BF_3 has boron atom with an incomplete octet (with a vacant p_z orbital). Therefore, nitrogen of ammonia donates its lone pair of electron to boron and thus, forms coordinate covalent bond. During this bond formation, the filled orbital of nitrogen having a lone pair, overlaps with the vacant *p*-orbital of boron. The equation corresponding to the reaction is written as follows:

$$H_3N\colon \; + \; BF_3 \; \rightarrow \; [H_3N \rightarrow BF_3]$$

Donor Acceptor Ammonia-Boron trifluoride

(ii) Formation of ammonium ion: Ammonia combines with hydrogen ion and forms ammonium ion $[NH_4]^+$. The reaction is written as follows:

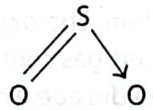
$$H_3N\colon \; + \; H^+ \; \rightarrow \; \left[H_3N \rightarrow H^+\right] \rightarrow [NH_4]^+$$

Donor Acceptor Ammonium ion

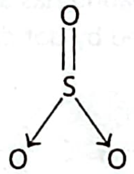
In the formation of ammonium ion, the filled orbital of nitrogen with a lone pair overlaps with the vacant 1*s*-orbital of hydrogen ion and forms a coordinate covalent bond. Once the coordinate bond is formed, the four hydrogen atoms become identical. That is why ammonium ion is generally written as $\left[NH_4\right]^+$.

Some Important Compounds Containing Coordinate Covalent Bond

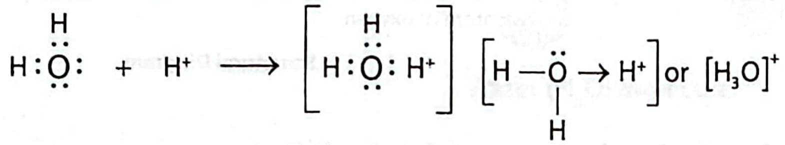
(i) Sulphur dioxide structure: (According to octet rule)



(ii) Sulphur trioxide structure: (According to octet rule)



(iii) Hydronium ion formation:



Hydronium ion

Properties of Coordinate Covalent Bond

The properties of coordinate covalent bond are:

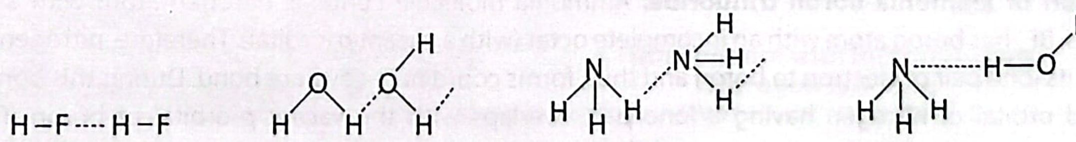
(i) A coordinate covalent bond is a strong bond with a specific directional characteristic similar to covalent bond.

(ii) The melting and boiling points are intermediate to those of the ionic and the covalent compounds. The melting and boiling points of coordinate covalent compounds are neither very high as in ionic compounds nor low as in covalent compounds.

HYDROGEN BOND

The electrostatic forces of attraction between a partially positively charged hydrogen atom of a polar molecule and a highly electronegative atom of the same molecule or of a different molecule is known as a hydrogen bond. This weak electrostatic bond has a strength of about 10–50 kJ mol^{-1}. Hydrogen bonds are formed only with the most electronegative atoms and these are F, O, and N.

The compounds with hydrogen bonding between two atoms are generally indicated by a dotted line as shown below:



Hydrogen fluoride Water Ammonia Ammonia in H_2O

Key point

Hydrogen bond elements have low bond energies and are of great significance in biochemical processes and in chemistry. It is not a true chemical bond.

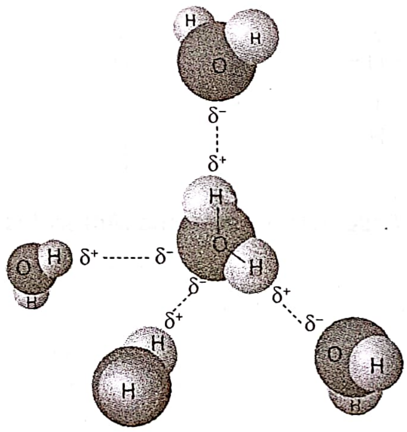
Types of Hydrogen Bonding

In molecules, two types of hydrogen bonding are observed and they are:

1. Intermolecular hydrogen bonding
2. Intramolecular hydrogen bonding

Intermolecular Hydrogen Bond

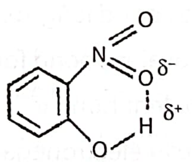
Hydrogen bond formed between two different polar molecules (of the same substance or of different substances) is known as intermolecular hydrogen bond. This type of bonding takes place in water, hydrogen fluoride, or ammonia.



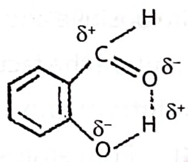
Water (H_2O) Molecule

Intramolecular Hydrogen Bond

Hydrogen bond formed between the atoms of the same molecule is known as intramolecular hydrogen bond. In this type of hydrogen bonding, only one molecule of a substance is involved and a ring formation takes place.



o - nitrophenol

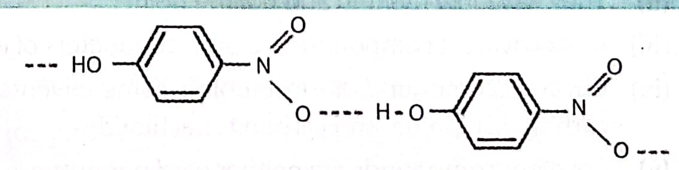


o - hydroxybenzaldehyde

Other examples of compounds having intramolecular hydrogen bonding include *ortho*-fluorophenol ($F.C_6H_4OH$); *ortho*-nitroaniline $[O_2N.C_6H_4(NH_2)]$.

Key points

- Hydrogen bonding is a special kind of dipole-dipole interaction.
- Strength of hydrogen bond depends upon the electronegativity of the highly electronegative atom to which the hydrogen is bonded.
- *p*-nitrophenol shows intermolecular hydrogen bonding.



***p* - Nitrophenol with Intermolecular Hydrogen Bonding**

Effects of Hydrogen Bond on the Properties of a Substance

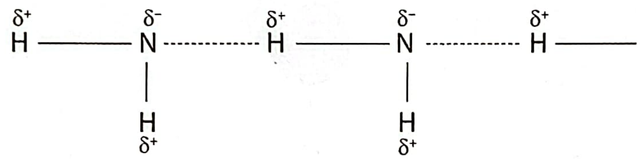
(i) Hydrogen bonds affects the ring formation or chelation through intramolecular hydrogen bonding. This results in greater volatility, higher boiling points, and higher solubility in water.

(ii) The solubility of lower alcohols in water (e.g., CH_3OH, C_2H_5OH, etc.) is due to the hydrogen bonding between molecules of alcohols and the molecules of water.

(iii) H_2O is a liquid whereas H_2S, H_2Te are all gases at room temperature. This is because of intermolecular hydrogen bonding in water molecules.

Comparison of Boiling Points of NH_3 and HCl

NH_3 has a higher boiling point than HCl even though nitrogen and chlorine have nearly the same electronegativity values. NH_3 forms hydrogen bonds while HCl does not. This is because of the smaller size of the nitrogen atom compared to the chlorine atom. The abnormal melting and boiling points of H_2O or HF or NH_3 are due to hydrogen bonding between molecules.



Associated Ammonia Molecules

EXAMPLES

1. Define dipole moment.

Solution: The degree of polarity of polar covalent bond or of a polar molecule is expressed in terms of its dipole moment (μ). It is equal to the products of the magnitude of electric charge (e) in esu and distance (d) in Å between the positive and negative centres (i.e., bond length).

2. Mention the factors favourable for covalent bond formation.

Solution: Two atoms will form a covalent bond if

(i) Both atoms have less difference in electronegativity.

(ii) Either of the atom does not attract the shared electron pair with more than optimum force.

(iii) The number of valence electrons in the two atoms are 4, 5, 6 or 7. The only exception is the hydrogen atom. Hydrogen atom has one valence electron and can still form covalent bonds.

3. Write the properties of covalent bond.

Solution: Covalent compounds exhibit some common and characteristic properties:

(i) These compounds are gases or liquids at room temperature. Some are soft solids.

(ii) They have low melting and boiling points.

(iii) Most covalent compounds are poor conductors of electricity as ions are not available to conduct electricity.

(iv) Covalent compounds are insoluble in some solvents like water and are soluble in other solvents like benzene, carbon disulphide, and carbon tetrachloride.

(v) Covalent compounds are neither hard nor brittle.

(vi) Reaction of covalent compounds are slow as existing bonds have to be broken and new bonds have to form by redistribution of valence electrons again.

4. Define non-polar covalent bond.

Solution: A covalent bond between two similar atoms having same electronegativity or zero electronegativity difference is called a non-polar or homo-polar covalent bond.

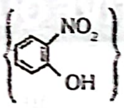
5. Define polar covalent bond.

Solution: A covalent bond between two dissimilar atoms which have different electronegativity values is called a polar covalent bond.

6. Write the two examples of intermolecular hydrogen bonding.

Solution: *m*-nitrophenol or *p*-nitrophenol and *m*-hydroxylbenzaldehyde or *p*-hydroxybenzaldehyde molecules show intermolecular hydrogen bonding

7. Write the two examples of intramolecular hydrogen bonding.

Solution: In compounds like *ortho*-nitrophenol 

intermolecular hydrogen bonding takes place. In this type of hydrogen bonding, only one molecule of a substance is involved.

RECALL

1. **Covalent bonds** are formed by sharing of electrons in such a way that both the atoms attain inert gas configuration. The actual bond is formed due to the nuclei of the two atoms attracting the shared pair.
2. **Non-polar covalent** bond is a type of covalent bond which is formed by sharing electrons between atoms of the same element. For example, H_2, Cl_2, and O_2
3. **Polar covalent bond** is a type of covalent bond which is formed by sharing of electrons between atoms of different elements. For example, CH_4, H_2O, and NH_3
4. **Properties of covalent compounds:**
   (i) Most covalent compounds are gases or liquids at room temperature and have low melting and boiling points.
   (ii) They are poor conductors of electricity as ions are not available to conduct electricity.
   (iii) They are insoluble in some solvents like water and are soluble in solvents like benzene.
   (iv) They are neither hard nor brittle.
5. Based on number of shared pair of electrons, covalent bonds are of three types:
   (i) **Single covalent bond:** $H + H \longrightarrow H_2$ or H–H
   (ii) **Double covalent bond:** $O + O \longrightarrow O_2$ or O=O
   (iii) **Triple covalent bond:** $N + N \longrightarrow N_2$ or N≡N
6. **Coordinate covalent bond** is a specific type of covalent bond. In this type of bond, the pair of electrons are shared by only one atom or ion or molecule.
7. **Properties of coordinate covalent bond:**
   (i) These are not electrical conductors because they do not ionize in water.
   (ii) They form a strong bond with a specific directional characteristic similar to covalent bond.
   (iii) They have intermediate melting points and boiling points.

8. The electrostatic forces of attractions between a partially positively charged hydrogen atom of a polar molecule and a highly electronegative atom (of the same molecule or of a different molecule) is known as a **hydrogen bond**.

9. In the molecules, two types of hydrogen bonding are observed and these are:
   (i) Intramolecular hydrogen bonding
   (ii) Intermolecular hydrogen bonding

DESCRIPTIVE QUESTIONS

I. VERY SHORT ANSWER QUESTIONS

1. Define covalent bond.
2. Give few examples of compounds containing covalent bond.
3. What are the different types of covalent bonds?
4. Give an example of a compound containing coordinate covalent bond.
5. Draw the dot structure of aluminium chloride.
6. Name the type of covalent bond in which the atoms acquire partial positive and partial negative charges.
7. Define hydrogen bonding.
8. Name the different types of hydrogen bonding.
9. Draw the Lewis dot representation of Cl_2 and HCl.
10. Name the factor which should be less for the formation of covalent bond.

II. SHORT ANSWER QUESTIONS

11. Ammonia has higher boiling point than hydrochloric acid. Comment on this statement.
12. Write a short note on the effects of hydrogen bonding in different molecules.
13. Why is covalent bond directional in nature, whereas ionic bond is not?
14. Mention a few properties of coordinate covalent bond.
15. What are the different types of covalent bonds based on the number of shared pair of electrons?
16. In a coordinate covalent bond, one atom is called donor and other is called acceptor. Comment on this statement.

III. LONG ANSWER QUESTIONS

17. Write about the different forces acting between the covalent molecules.
18. Compare the properties of ionic compounds and covalent compounds.
19. Draw the Lewis dot structure of CO_2, CH_4, and NH_3.
20. Explain the formation of hydrogen chloride and water molecules.
21. Name the type of hydrogen bonding present in:
   (i) HF
   (ii) NH_3
   (iii) *o*-nitrophenol
   (iv) *o*-fluorophenol
   (v) *p*-nitrophenol

IV. FILL IN THE BLANKS

22. When electrons are contributed entirely by one of the atoms but shared by both, the bond formed is known as ___________.
23. Any atom or ion having noble inert gas configuration will be in the ___________ state of energy.
24. The valence shell electrons are shown as ___________ around the symbol of the atom.
25. Most ___________ compounds are gases or liquids. Some are soft solids.
26. Covalent compounds are neither ___________ nor ___________.

V. TRUE OR FALSE

27. A covalent bond is a chemical bond formed between two atoms (usually non-metal atoms) by sharing of valence electrons.

28. Covalent compounds are soluble in water.

29. Hydrogen atom has one electron in *K*-shell and hence, needs one more electron to have a stable configuration like that of neon gas.

30. A covalent bond in which electrons are shared equally between the linked atoms is called a non-polar covalent bond.

31. NH_3 has lower boiling point than HCl even though nitrogen and chlorine have nearly the same electronegativity value.

4.03 Sigma Bond, Pi Bond, and Hybridization

MIND MAP

TYPES OF COVALENT BOND AND HYBRIDIZATION

Types of Covalent Bond (Based on overlapping)

Sigma bond

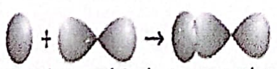
Formed by

s-s overlap

The overlap in which s-orbital of one atom overlaps with s-orbital of another atom to form a covalent bond.

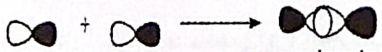
s-p overlap

The overlap in which s-orbital of one atom overlaps with p-orbital of another atom to form a covalent bond.



p-p overlap (Head on)

The overlap in which p-orbital of one atom overlaps with p-orbital of another atom to form a covalent bond.

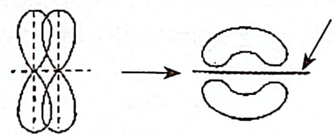


Pi bond

Formed by

p-p overlap (Sideways)

Two p-orbitals can overlap sidewise. Such overlap is called lateral overlap and the bond formed is called pi-bond.

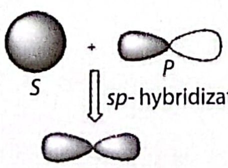


Hybridization

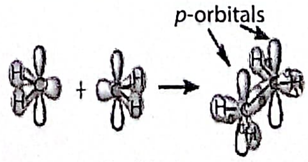
It is the process of mixing up of two or more pure atomic orbitals of an atom of nearly equal energy, to produce a set of entirely new orbitals.

Types of hybridization

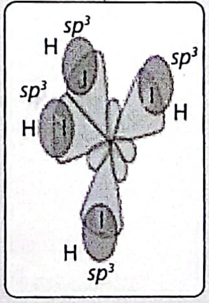
sp



sp²



sp³



INTRODUCTION

Bond formation in various compounds takes place by different ways like transfer of electrons, by mutual sharing of electrons by two atoms or by partial sharing of electrons by only one atom among the two. However, the bond formation can take place even by overlapping of orbitals. The overlapping of atomic orbitals results in pairing of electrons. The degree of overlap decides the strength of a covalent bond. The overlapping of orbitals is an important concept explained by Linus Pauling in understanding molecular bond angles which is the basis for orbital hybridization.

ORBITAL OVERLAP

Orbital overlap refers to the process in which the two atoms come close to each other such that penetration of their atomic orbitals take place. This partial merging of atomic orbitals is called overlapping.

Types of Orbital Overlaps

The different types of orbital overlaps are:

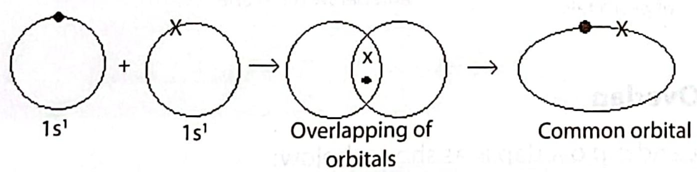
1. *s-s* overlap
2. *s-p* overlap
3. *p-p* overlap

s-s Overlap

The overlap in which *s*-orbital of one atom overlaps with *s*-orbital of another atom to form a covalent bond is known as *s-s* overlap.

For example, the formation of H_2 molecule.

Electronic configuration of hydrogen is $1s^1$. Each hydrogen has one unpaired electron in 1*s* orbital ([↑]). As the two atoms approach each other, the 1*s* orbital overlaps with the other and a single covalent bond is formed.



In the bond formation, both hydrogen atoms share one electron each and attain inert gas configuration of helium. Thus, the molecule becomes stable.

s-p Overlap

The overlap in which *s*-orbital of one atom overlaps with *p*-orbital of another atom to form a covalent bond is known as *s-p* overlap.

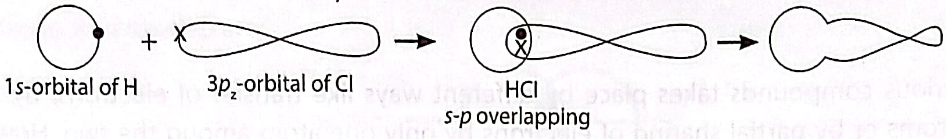
For example, the formation of HCl molecule.

Electron configuration of hydrogen is $1s^1$.

Electronic configuration of chlorine is $1s^2 2s^2 2p^6 3s^2 3p^5$.

$\Rightarrow$ Valence shell electron configuration of chlorine is 3*s* [↑↓] $3p_x\,3p_y\,3p_z$ [↑↓|↑↓|↑].

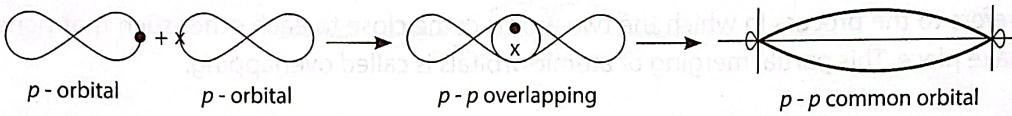
Hydrogen atom has one unpaired electron in 1*s*-orbital and chlorine atom has one unpaired electron in $3p_z$-orbital. As the two atoms approach each other, 1*s*-orbital of hydrogen overlaps with the $3p_z$-orbital of chlorine and covalent bond is formed between them.



p-p Overlap

The overlap in which *p*-orbital of one atom overlaps with *p*-orbital of another atom to form a covalent bond is known as *p-p* overlap. The two *p*-orbitals can overlap in two different ways as follows:

Case I: Two *p*-orbitals can overlap head-on, and the bond formed is called sigma bond.



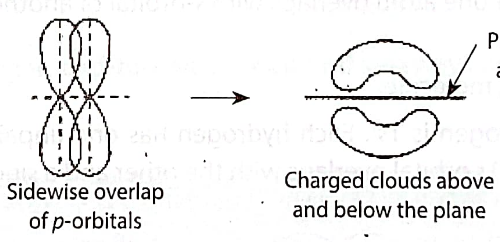
For example, the formation of F_2 molecule.

Electronic configuration of fluorine is $1s^2\ 2s^2\ 2p^5$.

$\Rightarrow$ Valence shell electron configuration is [⇅] [⇅][⇅][↑] (2s, $2p_x$, $2p_y$, $2p_z$).

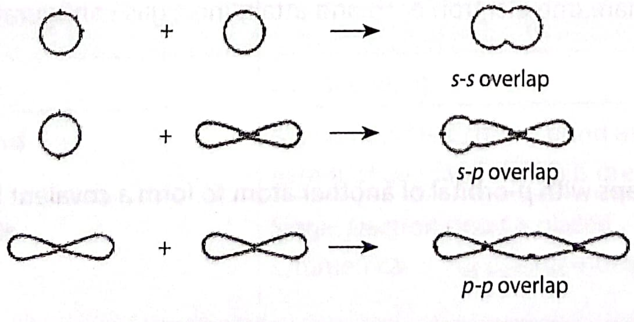
Fluorine (F) has one unpaired electron in the $2p_z$ orbital of valence shell. As the two fluorine atoms approach each other, the $2p_z$ orbitals of each fluorine overlap and a covalent bond is formed.

Case II: Two *p*-orbitals can overlap sidewise. Such overlap is called lateral overlap and the bond formed is called pi bond.



Relative Strength of *s-s*, *s-p*, and *p-p* Overlap

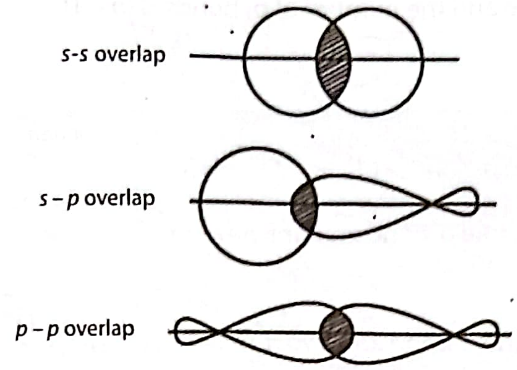
The diagrammatic representation of *s-s*, *s-p*, and *p-p* overlap is as shown below:



It is seen that the extent of overlap is maximum for *p-p* overlap and minimum for *s-s* overlap. On the basis of orbital overlap, the order of strength of covalent bond is *p-p* > *s-p* > *s-s*. On the basis of overlapping, covalent bonds can be classified into two types: (i) sigma bond and (ii) pi bond.

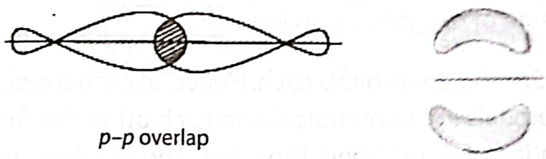
Sigma bond: The covalent bond which is formed by linear overlap or head-on overlap or overlap along the internuclear axis is called sigma bond. It is denoted by the symbol σ.

- Few examples of end-to-end overlap are:



pi bond: The covalent bond which is formed by sidewise overlap or lateral overlap along a line perpendicular to internuclear axis is called pi bond. It is denoted by π.

The extent of overlap is more for end-to-end overlap than for sideways overlap. Hence, sigma bond is stronger than pi bond.



Extent of overlapping in end-to-end overlap and sideways overlap

Key points

- Sigma bonds have high dissociation enthalpies than covalent bonds and can exist independently.
- pi (π) bond cannot be formed by *s*-orbital.

Comparison of sigma and pi bonds

	Sigma Bond (σ)	pi Bond (π)
Type of overlap	Linear overlap	Sideways overlap
Strength of bond	Sigma bond is a strong bond as the extent of overlap orbitals is greater.	pi bond is a weak bond as the extent of overlap of orbitals is less.
Electrons clouds	Single electron cloud is placed symmetrical along the internuclear axis.	Two equal electron clouds in the shape of a banana are placed above and below the internuclear axis.
Rotation of atoms	Rotation of atoms is free.	Rotation of atoms is not free.
Participation of the types of orbitals	Formed by both *s*- and *p*-orbitals.	Formed by *p*-orbitals only.
Nature of hybrid and pure orbitals	Formed by pure and hybrid orbitals.	Formed by only pure orbitals as hybrid orbitals cannot form π-bonds.

Finding the number of sigma and pi bonds: If n is the number of bonds present between two atoms, then the number of sigma bonds is always one and the number of pi bonds is $(n - 1)$.

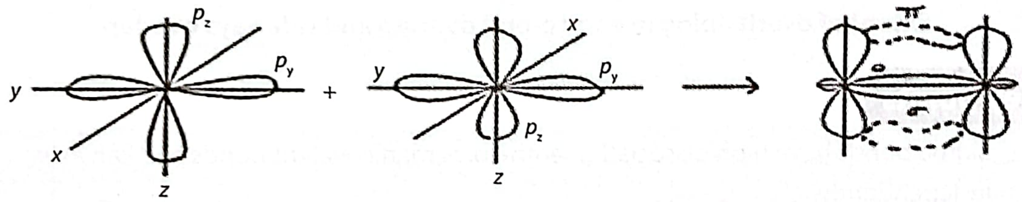
Key points

- All single bonds are σ-bonds. $Cl_2 \Rightarrow Cl - Cl$ (1σ-bond)
- A double bond has one σ-bond and one π-bond. $O_2 \Rightarrow O = O$ (1σ-bond, 1π-bond)
- A triple bond has one σ-bond and two π-bonds. $N_2 \Rightarrow N \equiv N$ (1σ-bond, 1π-bond, 1π-bond)
- To find out the number of sigma bonds, the structure of molecule should be known.

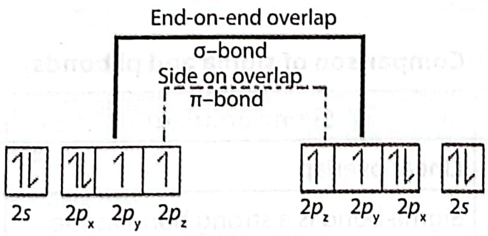
Formation of O_2 molecule by Orbital Overlap

The outermost electronic configuration of oxygen is as follows: $2s^2$ [⇅] $2p^4$ [⇅|↑|↑] (p_x p_y p_z)

There are two unpaired electrons in $2p_y$ and $2p_z$-orbitals each. Hence, in each oxygen, there are two orbitals eligible for overlapping. Since the $2p_y$ and $2p_z$-orbitals are perpendicular to each other, the first bond is formed by linear overlap of $2p_y$-orbitals, resulting in the formation of sigma bond. The second bond is formed by sidewise overlap of $2p_z$-orbitals resulting in the formation of a pi bond.



Oxygen atom | Oxygen atom | Oxygen molecule (σ and π-bonds are involved)



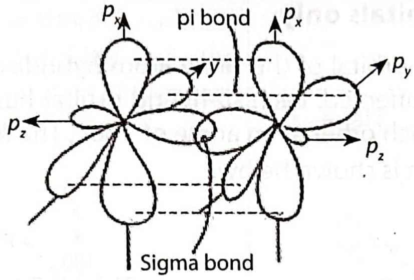
Thus, oxygen molecule has a double bond out of which one is sigma bond and other is pi bond.

Formation of N_2 molecule by Orbital Overlap

The electronic configuration of nitrogen is as follows: $1s^2$ $2s^2$ $2p^3$. The block diagram of outermost electronic configuration is $2s^2$ [⇅] $2p_x 2p_y 2p_z$ [↑|↑|↑].

There are three unpaired electrons in $2p_x$, $2p_y$, and $2p_z$-orbitals each. Thus, in nitrogen, three orbitals are eligible for overlapping.

The first bond which is the sigma bond, is formed by the end-to-end overlap of $2p_z$-orbitals. Now, the remaining orbitals cannot overlap end-to-end, so they overlap sideways resulting in the formation of two pi bond. Thus, nitrogen molecule has triple bond, out of which one is σ-bond and the other two are π-bonds. The overall process of bonding in N_2 is as follows:



N_2 Molecule

Key point

Nitrogen molecule is less reactive in nature due to the presence of triple bond.

HYBRIDIZATION

The process of mixing up of two or more pure atomic orbitals of an atom of nearly equal energy, to produce a set of entirely new orbitals is known as hybridization. The new orbital thus formed have the same energy, identical shapes, and are symmetrically disposed in space. Hybridization helps in understanding the identical nature of bonds in a molecule.

Key point

Hybridization is a hypothetical process. The new orbitals produced are called hybrid orbitals.

Conditions for Hybridization

The hybridization of orbitals take place only if the following conditions are satisfied.

(i) Only the orbitals of the same atom participate in hybridization.

(ii) The orbitals taking part in hybridization belong to the valence shell of atom.

(iii) The orbitals taking part in hybridization should have nearly the same energy.

Characteristics of Hybrid Orbitals

The hybrid orbitals have the following characteristics:

(i) It is the orbital that undergo hybridization, not the electrons.

(ii) The number of hybrid orbitals formed is equal to the number of hybridizing orbitals.

(iii) All the hybrid orbitals are identical in energy and shape.

(iv) All the hybrid orbitals are symmetrically oriented in space.

(v) Only the half-filled orbitals take part in bonding.

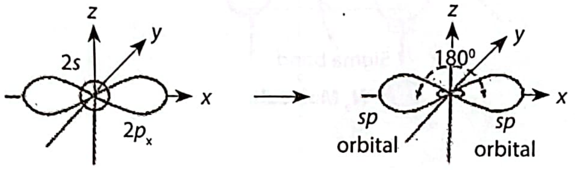
(vi) Due to the repulsion between the electrons, the hybrid orbitals tend to be the farthest apart in a molecule.

Types of Hybridization

Since hybridization lends entirely new shape and orientation to the valence orbitals of an atom, it plays a significant role in determining the shape and geometry of molecules formed from such orbitals. There are various types of hybrid orbitals, depending upon the number and nature of the orbitals undergoing hybridization.

Hybridization Involving *s*- and *p*-orbitals only

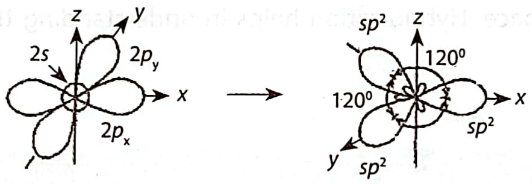
(i) ***sp*-hybridization:** One *s*- and one *p*-orbital of the same atom hybridize to give a set of two *sp*-hybrid orbitals. The other two *p*-orbitals remain unaffected. Each *sp*-hybrid orbital has 50% *s*-character and 50% *p*-character. The two *sp*-orbitals are inclined to each other at an angle of 180°. The formation of *sp*-hybrid orbitals from, one *s*- and one *p*-orbital of the same atom is shown below:



Formation of two *sp*-hybrid orbitals due to mixing of one *s*- and one *p*-orbital

For example, C_2H_2, BeF_2, and $BeCl_2$

(ii) ***sp*²-hybridization:** When one *s*- and two *p*-orbitals hybridize, then three new sp^2-hybrid orbitals are formed. Each sp^2-hybrid orbital has 33.33% *s*-character and 66.66% *p*-character. The three sp^2-hybrid orbitals are oriented in a plane along the three corners of an equilateral triangle inclined to each other at an angle of 120°. It is for this reason that sp^2-hybrid orbitals are also called trigonal hybrids, the process being referred to as trigonal hybridization. The formation of three sp^2-hybrid orbitals from one *s*- and two *p*-orbitals is shown below:

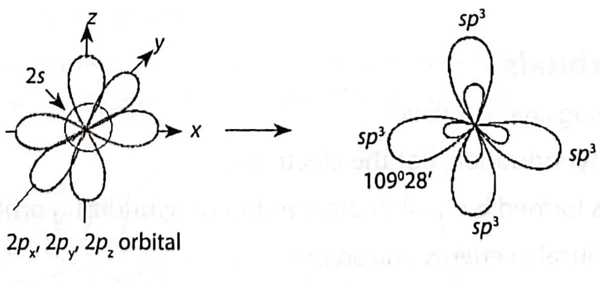


Formation of three sp^2-hybrid orbitals from one *s* and two *p* orbital

For example, BCl_3 and BH_3

(iii) ***sp*³-hybridization:** The four new orbitals formed by intermixing of one *s*-and three *p*-orbitals of an atom are known as sp^3-hybrid orbitals. Each sp^3-hybrid orbital has 25% *s*-character and 75% *p*-character. These four hybrid sp^3-orbitals are directed along the four corners of a tetrahedron and are inclined to each other at an angle of 109.5°.

Therefore, this type of hybridization is also called tetrahedral hybridization. The formation of four sp^3-hybrid orbitals from one *s*-and three *p*-orbitals is shown below:

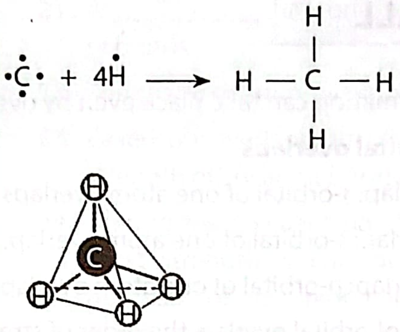
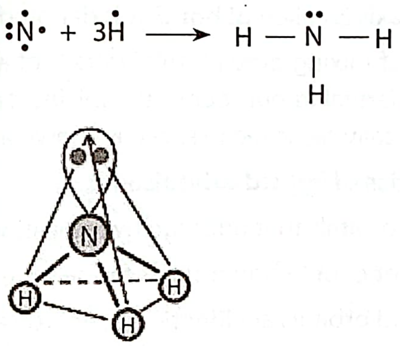


For example, CH_4 and C_2H_6

Hybridization of Atomic Orbitals and the Shape of Molecules

The hybridization of various atomic orbitals and the shape of molecules are:

Molecule	Formation of Bond	Details
Methane (CH_4)	If the four hydrogen atoms in a methane molecule (CH_4) were	Bond angle: 109.5°

	bound to the three 2*p*-orbitals and the 2*s*-orbital of the carbon atom, it results in *sp*³-hybridization.	Shape: Tetrahedron 
Ammonia (NH_3)	During the formation of ammonia, one 2*s*-orbital and three 2*p*-orbitals of nitrogen combine to produce four hybrid orbitals with equivalent energy, which is therefore considered a *sp*³-type of hybridization.	Bond angle: 107° Shape: Exists as a distorted tetrahedron (trigonal pyramidal). 

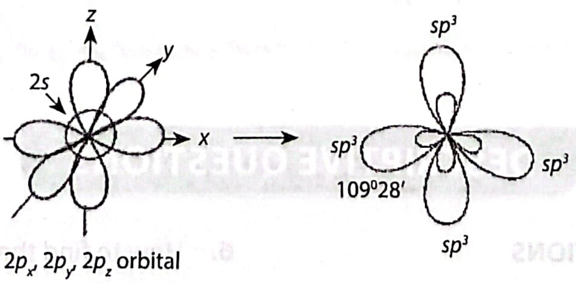
EXAMPLES

1. Define sigma bond.

Solution: The covalent bond formed by linear overlap or end-to-end overlap or overlap along internuclear axis is called sigma bond. It is denoted by the symbol σ. Sigma bonds are the strongest type of covalent bonds.

2. Using a neat diagram represent *sp*³-hybridization.

Solution: The four new orbitals formed by mixing one *s*- and three *p*-orbitals of an atom are known as *sp*³-hybrid orbitals. Each *sp*³-hybrid orbital has 25% *s*-character and 75% *p*-character.



3. Define hybridization.

Solution: The process of mixing pure atomic orbitals of an atom of nearly equal energy to produce a set of entirely new orbitals (equal in number to the mixing orbitals) is called hybridization. The new orbitals formed have same energy, identical shapes and are symmetrically disposed in space. It is a hypothetical process. The new orbitals produced are called hybrid orbitals.

RECALL

1. The bond formation can take place even by overlapping of orbitals.
2. **Types of orbital overlaps**
   (i) *s-s* overlap: *s*-orbital of one atom overlaps with *s*-orbital of another atom.
   (ii) *s-p* overlap: *s*-orbital of one atom overlaps with *p*-orbital of another atom.
   (iii) *p-p* overlap: *p*-orbital of one atom overlaps with *p*-orbital of another atom.
3. On the basis of orbital overlap, the order of strength of covalent bond is *p-p* > *s-p* > *s-s*.
4. The covalent bond which is formed by linear overlap or end-to-end overlap or overlap along internuclear axis is called **sigma bond**. It is denoted by the symbol σ.
5. The covalent bond which is formed by sideways overlap or lateral overlap along a line perpendicular to internuclear axis is called **pi bond**. It is denoted by π.
6. The process of mixing pure atomic orbitals of an atom of nearly equal energy to produce a set of entirely new orbitals (equal in number to the mixing orbitals) which have the same energy, identical shapes, and are symmetrically disposed in space is known as **hybridization**.
7. **Characteristics of hybrid orbitals:**
   (i) It is the orbitals that undergo hybridization, not the electrons.
   (ii) The number of hybrid orbitals formed is equal to the number of hybridizing orbitals.
   (iii) All hybrid orbitals are identical in energy and shape.
   (iv) All hybrid orbitals are symmetrically oriented in space.
   (v) Only the half-filled orbitals take part in bonding.
   (vi) Due to the repulsion between electrons, the hybrid orbitals tend to be the farthest apart in a molecule.
8. ***sp*-hybridization:** One *s*-and one *p*-orbital of the same atom hybridize to give a set of two *sp*-hybrid orbitals. The two *sp*-orbitals are inclined to each other at an angle of 180°. Each *sp*–hybrid orbital has 50% *s*-character and 50% *p*-character.
9. **sp^2-hybridization:** When one *s*- and two *p*-orbitals hybridize, then three new sp^2-hybrid orbitals are formed. The three sp^2-hybrid orbitals are inclined to each other at an angle of 120°.
   Each sp^3-hybrid orbital has 33.33% *s*-character and 66.66% *p*-character.
10. **sp^3-hybridization:** When one *s*- and three *p*-orbitals of the same atom hybridize, then a set of three new sp^3-hybrid orbitals are formed. Each sp^3-hybrid orbital has 25% s-character and 75% *p*-character.

DESCRIPTIVE QUESTIONS

I VERY SHORT ANSWER QUESTIONS

1. Define *s-s* overlap.
2. What is the electronic configuration of hydrogen?
3. Give an example of a molecule with *s-p* overlap.
4. Name the different types of *s-p* hybridization.
5. What kind of overlapping takes place in HCl?
6. How to find the number of sigma and pi bonds?
7. How do hybrid orbitals arrange themselves to form a molecule?
8. Explain why a sigma bond is stronger than a pi bond.
9. Name the bond which is formed by the sideways overlap of two *p*-orbitals.

10. In each sp^3 hybrid orbital, what is the percentage of *s*-character and *p*-character?

II. SHORT ANSWER QUESTIONS

11. What are the conditions required for hybridization?
12. Write a short note on overlapping of hydrogen orbitals to form hydrogen molecule.
13. Why is nitrogen molecule less reactive than oxygen molecule?
14. What is the relation between overlapping of orbitals and the strength of covalent bond?
15. Write about sigma and pi bonds.
16. How is oxygen molecule formed by orbital overlap?

III. LONG ANSWER QUESTIONS

17. Write the difference between sigma and pi bonds.
18. Why is BeF_2 molecule linear in shape, but BF_3 is trigonal planar?
19. Explain *sp*- and sp^2-hybridization with diagram.
20. Explain the nitrogen molecule formation by orbital overlap.

IV. FILL IN THE BLANKS

21. A __________ has one sigma bond and two pi bonds.
22. The shape of ammonia molecule is __________.
23. Based on overlapping of orbitals the order of strength of covalent bond is __________.
24. Among the covalent bonds, the bond with the most strength is considered the __________ because of its high stabilization between bonding orbitals.
25. The number of sigma and pi bond in CO_2 molecule are __________ and __________, respectively.

V. TRUE OR FALSE

26. When end-to-end overlapping takes place, a sigma bond is formed.
27. pi bond is a strong bond as the extent of overlap of orbitals is less.
28. In sp^3 hybridization, the hybrid orbitals are incline to each other at an angle of 120°.
29. Electronic configuration of oxygen is $1s^2\ 2s^2\ 2p^3$.
30. During the overlapping of orbitals, pairing of electrons takes place.

4 | CHEMICAL BONDING

PRACTICE SHEET

SINGLE CORRECT QUESTIONS

1. Which of the following pair of ions are isoelectronic to each other as well as have attained inert gas configuration?
   (A) Na^+, Mg^{2+} **(B)** F^-, Cl^- **(C)** Na^+, Cl^- **(D)** N^{3-}, Cl^-
2. In the formation of an ionic bond, which of the following takes place?
   (A) Electrons are transferred between metals.
   (B) Electrons are transferred from metal to non-metal.
   (C) Electrons are shared between metal and non-metal.
   (D) Electron pair is donated by one atom.
3. Identify the ionic compound from the following.
   (A) HCl **(B)** Na_2O **(C)** CO_2 **(D)** SO_2
4. Why many ionic crystals dissolve in water?
   (A) Water is a universal solvent.
   (B) Water has high boiling point.
   (C) The process is accompanied by a positive heat of solution.
   (D) Water decreases the interionic attraction in the crystal lattice due to the solvation.
5. An element *X* comes next to argon, identify the electronic configuration of that element from the following.
   (A) [Ar] $4s^1$ **(B)** [Ar] $4s^2$ **(C)** [Ar] $4s^2 3d^1$ **(D)** [Ar] $4s^1 3d^2$
6. The element oxygen has six valence electrons and is diatomic. What type of covalent bond is present in an O_2 molecule?
   (A) Single covalent bond **(B)** Double covalent bond **(C)** Triple covalent bond **(D)** Polar covalent bond
7. Coordinate covalent bond is not present in
   (A) NH_4^+ **(B)** HNO_3 **(C)** H_2O **(D)** CO
8. The molecules NH_3 and BF_3 form adduct readily because of formation of
   (A) Ionic bond **(B)** Coordinate bond **(C)** Covalent bond **(D)** All of these
9. In which of the following, the hydrogen bond is the strongest?
   (A) H–F **(B)** H_2O **(C)** NH_3 **(D)** CH_4
10. What is the nature of bond if the shared pair of electrons are present nearer to one of the bonded atoms?
   (A) Ionic bond **(B)** Polar covalent bond **(C)** Non-polar covalent bond **(D)** Coordinate bond

11. The shape of a molecule is decided by

(A) σ-bond **(B)** π-bond **(C)** Both (A) and (B) **(D)** Neither σ–bond nor π–bond

12. The bond between two nitrogen atoms in N_2 molecules consists of

(A) Three π-bonds **(B)** Two π and one σ-bonds

(C) Three σ-bonds **(D)** One π and two σ-bonds

13. How many σ-bonds and π-bonds are present in oxygen molecule?

(A) 1σ, 0π **(B)** 0σ and 1π **(C)** 1σ, 1π **(D)** 2σ, 2π

14. Which of the following is not true for sp^2 hybridization?

(A) Formed by one *s*- and two *p*-orbitals.

(B) The angle between the hybrid molecules is 120°.

(C) BF_2 molecules has sp^2-hybridization.

(D) It is also called trigonal hybridization.

15. Which of the following is formed by hybrid orbitals?

(A) Ionic bonds **(B)** Metallic bonds **(C)** σ-bonds **(D)** π-bonds

SINGLE CORRECT QUESTIONS

16. The charge on a cation *M* is +2 and on anion *A* is –3. The compound has the formula

(A) MA_2 **(B)** M_3A_2 **(C)** M_2A_3 **(D)** M_2A

17. The donor molecule in ammonia-boron trifluoride complex is

(A) Nitrogen **(B)** Hydrogen **(C)** Boron **(D)** Phosphorous

18. Ionic compounds in general don't possess

(A) Low melting point and directional bonds.

(B) High melting and boiling points.

(C) Non-directional bonds and high density.

(D) Solubility in polar and non-polar solvents.

19. The electrons present in an incomplete outermost shell are known as

(A) Kernel electrons **(B)** Valence electrons **(C)** Core electrons **(D)** Shell electrons

20. Identify the compound which contains both ionic and covalent compound?

(A) CH_4 **(B)** H_2 **(C)** KCN **(D)** KCl

21. Identify the correct statement from the following.

(i) H_2O has a higher boiling point than HF.

(ii) HF exists as $(HF)_6$ in both liquid and vapour state.

(iii) The strength of hydrogen bond in HF is greater than H_2O.

(A) (i) and (ii) only **(B)** (ii) and (iii) only **(C)** (iii) and (i) only **(D)** (i), (ii), and (iii)

22. In boron trifluoride which bonds are present?

(A) π-bonds only **(B)** σ-bonds only **(C)** Both (A) and (B) **(D)** neither σ-bond nor π-bond

23. The number of σ- and π-electrons in benzene are

(A) $12\sigma + 3\pi$ **(B)** $12\sigma + 6\pi$ **(C)** $24\sigma + 3\pi$ **(D)** $24\sigma + 6\pi$

24. Nitrogen forms N_2 molecule, but P_2 molecule converts to P_4 because

(A) Triple bond is present between phosphorus atoms

(B) $P_\pi - P_\pi$ bonding is weak

(C) $P_\pi - P_\pi$ bonding is strong

(D) Multiple bonds are formed easily

25. The hybridization of in CH_4 is

(A) *sp* **(B)** sp^2 **(C)** sp^3 **(D)** dsp^2

SINGLE CORRECT QUESTIONS

26. The electronic configuration of four elements *L*, *P*, *Q*, *R* are given below:

$L = 1s^2 2s^2 2p^4$; $P = 1s^2 2s^2 2p^6 3s^1$

$Q = 1s^2 2s^2 2p^6 3s^2, 3p^5$; $R = 1s^2 2s^2 2p^6 3s^2$

The formula of the ionic compounds formed by all of them are

(A) L_2P, RL, PQ, R_2Q **(B)** P_2L, RL, PQ, RQ_2 **(C)** Both (A) and (B) **(D)** L_2P, P_2L, RL, PQ

27. In the given molecules, the octet rule is not valid for which molecule?

(A) CO_2 **(B)** H_2O **(C)** O_2 **(D)** CO

28. Electronic dot diagram of an elements *X* and *Z* are as follows:

:Z̤·· Ẋ·

If two atoms *X* and *Z* were to form covalent bond with each other, what molecule would result?

(A) *XZ* **(B)** X_2Z_3 **(C)** X_3Z **(D)** XZ_3

29. The maximum number of hydrogen bonds that a water molecule can form is

(A) 4 **(B)** 3 **(C)** 2 **(D)** 1

30. In which of the following molecules, the central atom does not use sp^3-hybrid orbitals?

(A) NH_3 **(B)** CH_4 **(C)** BCl_3 **(D)** H_2O

Read the two statements carefully to choose the correct option out of the options given below.

(A) Both Statements are true. **(B)** Both Statements are false.

(C) Statement I is true. Statement II is false. **(D)** Statement I is false. Statement II is true.

STATEMENT BASED QUESTIONS

31. Statement I: In an ionic bond, it is the electrostatic force of attraction which holds the two oppositely charged ions together.

Statement II: A chemical bond is always formed by transfer of electrons from one atom to the other.

32. Statement I: An atom with a low electronegativity loses electrons and forms a positive ion.

Statement II: An atom with a high electronegativity gains electrons and forms a negative ion.

STATEMENT BASED QUESTIONS

33. Statement I: Generally, covalent compounds are gases, liquids, or soft solids at room temperature.

Statement II: Between covalent compounds weak force of attractions exits.

34. Statement I: Sigma bond (σ) determines the shape of the molecules.

Statement II: Molecules having double bonds have only σ-bonds.

STATEMENT BASED QUESTION

35. Statement I: For π-overlap, the lobes of the atomic orbitals are perpendicular to the internuclear axis.

Statement II: Sigma bond be formed by head-on overlapping as well as sidewise overlapping.

MULTI CORRECT QUESTIONS

36. Which of the following is/are generally the properties of ionic compounds?

(A) High melting point and high boiling point.

(B) High density and non-directional bonds.

(C) High solubility in polar solvents and low solubility in non-polar solvents.

(D) Good conductors of electricity in the molten state.

37. Which of the following compounds are examples for ionic compounds?

(A) KCl **(B)** MgO **(C)** Al_2O_3 **(D)** $CaCl_2$

MULTI CORRECT QUESTIONS

38. Which of the following order of boiling points is/are true?

(A) $NH_3>PH_3>ASH_3$ **(B)** $H_2O>H_2S>H_2Se$

(C) HF>HCl>HBr **(D)** $CH_4>SiH_4>GeH_4$

39. Which of the following is/are example for sp^2-hybridization?

(A) BF_3 **(B)** C_2H_4 **(C)** C_2H_2 **(D)** $BeCl_2$

MULTI CORRECT QUESTION

40. In which of the following molecules, the number of sigma (σ) and pi (π) bonds are same?

(A) Nitrogen **(B)** Hydrogen cyanide **(C)** Carbon dioxide **(D)** Methane

INTEGER TYPE QUESTION

41. Number of σ-bonds present in H_2 molecule is ______________.

INTEGER TYPE QUESTION

42. For the formation of non-polar covalent compounds, the electronegativity difference between the two atoms is ______________.

COMPREHENSION TYPE QUESTIONS

Ionic compounds are formed due to the transfer of one or more electrons from one atom to the other. Hence, two oppositely charged ions are formed in this process and an electrostatic force of attraction is developed between them.

In addition to the strong force of attraction between the individual pair, force of attraction also exists among the oppositely charged ions of different pairs which brings them close to each other. As a result of this, repulsive force is also generated between similar ions of different pairs. But the cation-cation distance and the anion-anion distance (measured from their centre) of different pair is greater than the cation-anion distance of same pairs. Hence, the force of attraction is greater than the repulsive force and the ions arrange themselves in such a way that their potential energy becomes minimum. The arrangement of ions associated with minimum potential energy gives the ionic compounds their crystalline structure.

43. When an ionic compound is dissolved in water, then what happens?

(A) New compounds are formed

(B) It splits into its component ions which then get hydrated.

(C) It splits into its component ions.

(D) It decomposes into new product.

44. An element, X has low ionization energy, and another element, Y has high electron affinity. The bond formed between them could be

(A) Ionic **(B)** Polar covalent **(C)** Coordinate covalent **(D)** Non-polar covalent

45. The arrangement of ions associated with minimum potential energy gives that

(A) Crystalline structure of ionic compound **(B)** Zig-zag structure of ionic compound

(C) Lattice structure of ionic compound **(D)** Both (A) and (C)

COMPREHENSION TYPE QUESTIONS

Hydrogen bonding has many effects on the properties of molecules. The molecules having hydrogen bonding have abnormally high melting and boiling point. For example, the boiling points of NH_3, H_2O, HF are more than those of PH_3, H_2S and HCl respectively because intermolecular hydrogen bonds are present in NH_3, H_2O, and HF. Hydrogen bonds are not present in PH_3, H_2S, and HCl.

46. Among the given compounds, which compound has the lowest boiling point?

(A) NH_3 **(B)** H_2O **(C)** HF **(D)** PH_3

47. Hydrogen bonds are present in

(A) PH_3 **(B)** H_2O **(C)** Liquid HCl **(D)** All of these

48. Why the boiling points of NH_3, H_2O, and HF are high?

(A) Due to intermolecular hydrogen bonding **(B)** Due to intramolecular hydrogen bonding

(C) Both (A) & (B) **(D)** Neither (A) nor (B)

MATRIX MATCH QUESTION

49. Match the columns.

Column I	Column II
(p) Strong ionic compound is	**(i)** Solid state
(q) Ionic compounds are bad conductor of electricity in	**(ii)** Transfer of valence electrons
(r) Ionic compounds are good conductor of electricity in	**(iii)** Fused state
(s) Kossel proposed the theory based on	**(iv)** Molten state
	(v) CsCl

(A) p-(i); q-(ii); r-(iii); s-(iv); **(B)** p-(v); q-(i); r-(iii),(iv); s-(ii) **(C)** p-(i); q-(iii), (iv); r-(ii); s-(v) **(D)** p-(i); q-(v); r-(iii), (iv); s-(i).

MATRIX MATCH QUESTION

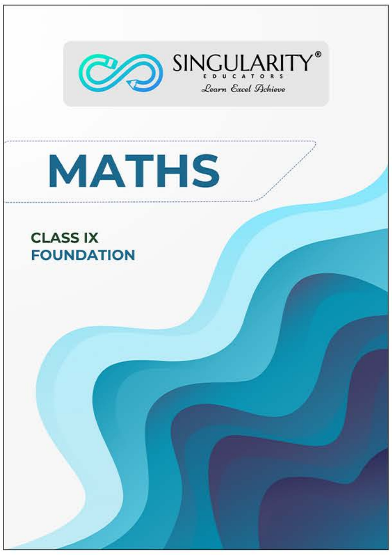
50. Match the columns.

Column I	Column II
(p) CH_4	**(i)** 7σ- and 0π-bonds
(q) C_2H_6	**(ii)** 3σ- and 2π-bonds
(r) C_2H_4	**(iii)** 4σ- and 0π-bonds
(s) C_2H_2	**(iv)** 5σ- and 1π-bonds
	(v) 4σ and 4 π-bonds

(A) p-(iii); q-(i); r-(iv); s-(ii) **(B)** p-(i); q-(ii); r-(iii); s-(iv) **(C)** p-(ii); q-(i); r-(iii); s-(iv) **(D)** p-(iii); q-(v); r-(iv); s-(iii)

KEY BOX

4. CHEMICAL BONDING									
Single Correct Questions									
1	2	3	4	5	6	7	8	9	10
A	B	B	D	A	B	C	B	A	B
11	12	13	14	15	16	17	18	19	20
A	B	C	C	C	B	A	A	B	C
21	22	23	24	25	26	27	28	29	30
D	B	D	B	C	B	D	D	A	C
Statement Based Questions									
31	32	33	34	35					
C	A	A	C	B					
Multi Correct Questions									
36	37	38	39	40					
A, B, C, D	A, B, C, D	A, B, C	A, B	B, C					
Integer Type Questions									
41	42								
1	0								
Comprehension Type Questions									
43	44	45	46	47	48				
B	A	A	D	B	A				
Matrix Match Questions									
49					50				
B					A				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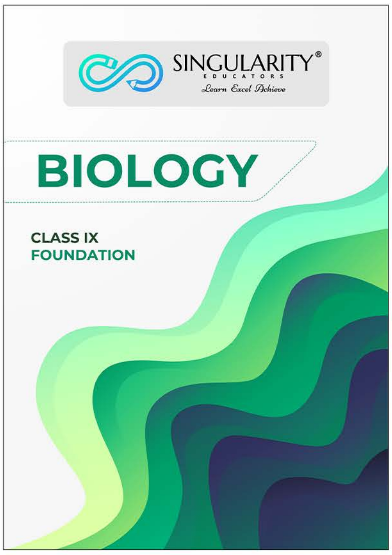
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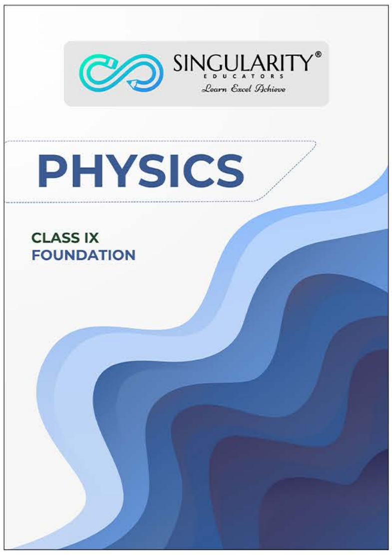
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