

## Chapter - 4

# Chemical Bonding and Molecular Structure

### FAST TRACK : QUICK REVISION

- ◆ **Kossel-Lewis Concept:** Atoms take part in chemical combination to complete octet in their valence shell. This is known as octet rule.
- ◆ **Limitation of Octet Rule:** The octet rule, though useful but has some exceptions e.g.  $\text{BF}_3$ ,  $\text{NO}_2$ ,  $\text{PCl}_5$ ,  $\text{SF}_6$  etc.
- ◆ **Lewis Symbol or Electron Dot Structure:** Representing valence electrons by dots placed around the letter symbol of the element.

### Types of Chemical Bonds:

#### (i) Covalent Bond:

- (a) Formed by sharing of electrons.
- (b) It may be polar or nonpolar.
- (c) It is directional in nature.

#### (ii) Ionic Bond:

- (a) Formed by transfer of electrons.
- (b) Formation of ionic bond is favored by high lattice enthalpy, Low ionization enthalpy of metal atom and more negative electron gain enthalpy of nonmetal atom.
- (c) It is non directional in nature.

#### ◆ Formal Charge (F.C.):

- (i) It is charge appeared on individual atom in covalent molecule.
- (ii)  $\text{F.C.} = (\text{Total No. of valence electrons in free atom}) - (\text{Total No. of unshared electrons}) - \frac{1}{2} (\text{Total No. of shared electrons})$

Greater the F.C on atoms lesser the stability of that Lewis structure.

- ◆ **Lattice Enthalpy:** Energy released when one mole of a crystalline solid is formed from constituent gaseous ions.

**Bond length:**

- (i) It is equilibrium distance between the nuclei of two bonded atoms in a molecule.
- (ii) Greater the size of bonded atoms shorter the bond length.  
**e.g.,**  $\text{H-F} < \text{H-Cl} < \text{H-Br} < \text{H-I}$
- (iii) Greater the s character shorter the bond length.  
**e.g.,**  $\text{C}_{\text{sp}^3}\text{-H} > \text{C}_{\text{sp}^2}\text{-H} > \text{C}_{\text{sp}}\text{-H} >$
- (iv) Bond length decreases with increase in bond order.  
**e.g.,**  $\text{C-C} > \text{C=C} > \text{C}\equiv\text{C}$

**◆ Bond angle:**

- (i) It is angle between the orbitals containing bonding electron pairs around central atom in a molecule or complex ion.
- (ii) Greater the electronegativity of central atom larger the bond angle  
**e.g.,**  $\text{NH}_3 > \text{PH}_3$
- (iii) Greater the number of lone pair around central atom smaller the bond angle. **e.g.,**  $\text{CH}_4 > \text{NH}_3 > \text{H}_2\text{O}$

**◆ Bond Enthalpy:**

- (i) It is defined as amount of energy required to break one mole of bonds of a particular type between two atoms in gaseous state.
- (ii) For diatomic molecules, Bond enthalpy  $\propto$  Bond dissociation enthalpy
- (iii) For polyatomic molecules, Bond enthalpy  $\propto$  Average of all possible bond dissociation enthalpies.
- (iv) Bond enthalpy  $\propto$  Bond order  $\propto$   $1/(\text{Bond length})$

**◆ Resonance:**

- (i) According to the concept of resonance, whenever a single Lewis structure cannot describe a molecule accurately, a number of structures with similar energy, position of nuclei, bonding and non-bonding pairs of electrons are taken as canonical structures of the resonance hybrid which describes the molecule accurately.
- (ii) Resonance averages the bond characteristics as a whole.

**◆ Partial ionic character of covalent bond A–B:**

$$= 16(X_A - X_B) + 3.5(X_A - X_B)^2,$$

where  $X_A$  and  $X_B$  are electro-negativities of A & B.

- ◆ **Partial covalent character in ionic bond (Fajan's rule):**
  - (i) Fajan's rule is used to predict partial covalent character in ionic bond.
  - (ii) Greater the polarizing power of cation and polarisability of anion greater the covalent character in ionic bond.
  - (iii) Polarising power of cation  $\propto$  Charge density [(Charge)/size].
  - (iv) Polarisability of anion  $\propto$  size of anion.
  
- ◆ **Dipole moment:**
  - (i) Dipole moment ( $\mu$ ) = charge (Q)  $\times$  distance of separation (d)
  - (ii) Unit: Debye (D),  $1D = 3.33564 \times 10^{-30}$  Cm
  - (iii) Being vector quantity, dipole moment of polyatomic molecule is taken as the resultant of all the bond moments.
  - (iv) If  $\mu = 0$ , molecule is non polar or symmetric.
  - (v) If  $\mu \neq 0$ , molecule is polar or asymmetric.
  
- ◆ **Hydrogen bond:**
  - (i) It is dipole-dipole interaction between molecules in which 'H' atom is inserted between two highly electronegative elements i. e. F, O or N only.
  - (ii) Hydrogen bond may be intra-molecular (when present within single molecule) and intermolecular (when present b/w two same or different molecules).
  - (iii) Hydrogen bonds are stronger intermolecular forces than van der Waal forces.
  
- ◆ **Sigma ( $\sigma$ ) and pi ( $\pi$ ) bonds:**
  - (i) Sigma bond is formed by axial overlapping and pi bond is formed by sideways overlapping of atomic orbitals.
  - (ii) Sigma bond is stronger than pi bond due to greater extent of overlapping.
  - (iii) Single covalent bond = 1  $\sigma$  bond  
 Double covalent bond = 1  $\sigma$  bond + 1  $\pi$  bond  
 Triple covalent bond = 1  $\sigma$  bond + 2  $\pi$  bond
  
- ◆ **VSEPR Theory:** (VSEPR = Valence Shell Electron Pair Repulsion): The shape of a molecule depends upon the number of valence shell electron pairs (lp and bp) around the central atom and magnitude of repulsive forces between them  
*i.e., lp-lp > lp-bp > bp-bp*

♦ **Hybridisation:**

- (i) It is the phenomena of mixing of atomic orbitals of nearly same energy to form the new orbitals of equal energy and identical shape.
- (ii) The new orbitals are called hybrid orbitals and determine the shape of molecules.

♦ **Molecular Orbital Theory (MOT):**

- (i) The intermixing of atomic orbitals of same symmetry to form bonding and antibonding molecular orbitals by addition and subtraction of their wave functions is known as MO theory.
- (ii) The electrons are filled in molecular orbitals in order of their increasing energy.

*i.e.,*  $\sigma 1s, \sigma^* 1s, \sigma 2s, \sigma^* 2s, \pi 2p_x = \pi 2p_y, \sigma 2p_z, \pi^* 2p_x = \pi^* 2p_y, \sigma^* 2p_z$  (upto 14 electrons)

$\sigma 1s, \sigma^* 1s, \sigma 2s, \sigma^* 2s, \sigma 2p_z, \pi 2p_x = \pi 2p_y, \pi^* 2p_x = \pi^* 2p_y, \sigma^* 2p_z$  (For more than 14 electrons)

- (iii) Bond order =  $1/2 (N_b - N_a)$

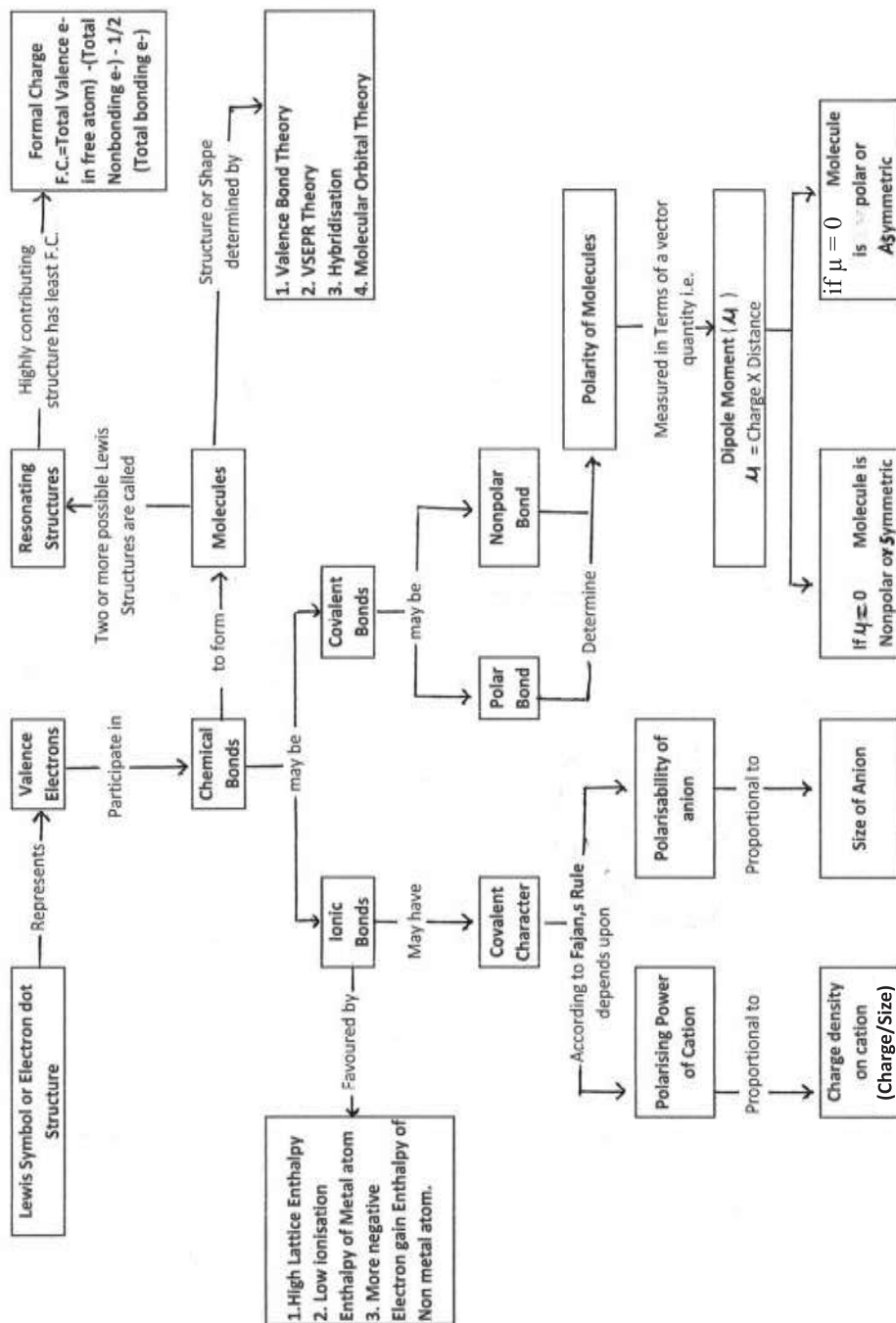
$N_a$  = No of electrons in anti-bonding molecular orbitals

$N_b$  = No of electrons in bonding molecular orbitals

Total electron pairs	Bond pairs	Lone pairs	Type of hybridization	Geometry due to repulsion	Bond angle	Example
2	2	0	sp	Linear	180°	BeCl <sub>2</sub>
3	3	0	sp <sup>2</sup>	Non-polar Planar	120°	BF <sub>3</sub>
3	2	1	sp <sup>2</sup>	Angular	<120°	SO <sub>2</sub>
4	4	0	sp <sup>3</sup>	Tetrahedral	109°28'	CH <sub>4</sub>
4	3	1	sp <sup>3</sup>	Pyramidal	<109°28'	NH <sub>3</sub>
4	2	2	sp <sup>3</sup>	Bent	<109°28'	H <sub>2</sub> O
5	5	0	sp <sup>3</sup> d	Trigonal bipyramidal	120° & 90°	PCl <sub>5</sub>
5	4	1	sp <sup>3</sup> d	See Saw	<120° & <90°	SF <sub>4</sub>
5	3	2	sp <sup>3</sup> d	Bent T-shaped	<90°	ClF <sub>3</sub>
5	2	3	sp <sup>3</sup> d	Linear	180°	I <sub>3</sub> <sup>-</sup>
6	6	0	sp <sup>3</sup> d <sup>2</sup>	Octahedral	90°	SF <sub>6</sub>
6	5	1	sp <sup>3</sup> d <sup>2</sup>	Square pyramidal	<90°	BrF <sub>5</sub>
6	4	2	sp <sup>3</sup> d <sup>2</sup>	Square planar	90°	XeF <sub>4</sub>
7	7	0	sp <sup>3</sup> d <sup>3</sup>	Pentagonal bipyramidal	90° & 72°	IF <sub>7</sub>
7	6	1	sp <sup>3</sup> d <sup>3</sup>	Pentagonal pyramidal	<90° & <72°	
7	5	2	sp <sup>3</sup> d <sup>3</sup>	Pentagonal planar	72°	XeF <sub>5</sub> <sup>-</sup>

# MIND MAP

## CHEMICAL BONDING AND MOLECULAR STRUCTURE



## CASE BASED STUDY-QUESTION

### PASSAGE -1

Pauling introduced the concept of hybridisation. According to him the atomic orbitals combine to form a new set of equivalent orbitals known as hybrid orbitals. Unlike pure orbitals, the hybrid orbitals are used in bond formation. The phenomenon is known as hybridisation which can be defined as the process of intermixing of the orbitals of slightly different energies so as to redistribute their energies, resulting in the formation of a new set of orbitals of equivalent energies and shape.

Source: NCERT

**The following questions are multiple choice questions. Choose the most appropriate answer:**

- I. In  $\text{SF}_6$  molecules, which sets of d-orbitals is involved ?  
(A)  $dx^2-y^2$ ,  $dz^2$  (B)  $dz^2$ ,  $dx^2-y^2$   
(C)  $dxy$ ,  $dyz$  (D)  $dx^2-y^2$ ,  $dxy$
- II. In  $\text{IF}_7$  molecule, which orbitals are involved  
(A)  $dx^2-y^2$ ,  $dz^2$ ,  $dxy$  (B)  $dxy$ ,  $dyz$ ,  $dzx$   
(C)  $dx^2-y^2$ ,  $dxy$ ,  $dxz$  (D)  $dz^2$ ,  $dyz$ ,  $dxz$
- III. In  $\text{PCl}_5$  molecule, d-orbitals involved is  
(A)  $dxy$  (B)  $dyz$   
(C)  $dx^2-y^2$  (D)  $dz^2$
- IV. Which of the following orbitals cannot undergo hybridisation amongst themselves  
(A) 3d, 4s (B) 2s, 2p  
(C) 4s, 4d (D) 3s, 3p, 4s

**ANS. :** I-A, II-A, III-D, IV-D

## PASSAGE -2

It can be said that covalent compound has partial ionic character due to the electronegativity difference of the two elements in a covalent bond. Dipole moment parameter is used to find the % of ionic character in the covalent compound. We can also say that ionic compounds do have some covalent character which can be explained qualitatively on the basis of the Fajan's Rule. According to Fajan rule a cation which has smaller size, high ionic charge must have large polarising power and the anion which has large size and high ionic charge must have large polarisability. Both these factors help to develop covalent character in the molecule.

**In these questions (Q. No V-VIII), a statement of assertion followed by a statement of reason is given. Choose the correct answer out of the following choices.**

- (a) Assertion and reason both are correct statements and reason is correct explanation for assertion.
- (b) Assertion and reason both are correct statements but reason is not correct explanation for assertion.
- (c) Assertion is correct statement but reason is wrong statement.
- (d) Assertion is wrong statement but reason is correct statement

V. ASSERTION:  $\text{CO}_2$  molecule has zero dipole moment despite polar bond.  
REASON:  $\text{CO}_2$  molecule is linear in nature.

VI. ASSERTION: The dipole moment of Dichlorobenzene molecule can be zero.

REASON: The Dichlorobenzene must be 1, 4 Dichlorobenzene.

VII. ASSERTION: LiF has less covalent character than LiI

REASON: Halogen molecule are short of one electron to complete the octet.

VIII. ASSERTION: LiCl is more covalent than KCl

REASON: The polarising power of K is more than Li

**ANS:** V-A, VI-A, VII-B, VIII-C

### MULTIPLE CHOICE QUESTIONS (MCQ)

- Which of the following molecules has both covalent and ionic bond  
(a)  $\text{CH}_3\text{Cl}$       (b)  $\text{NH}_4\text{Cl}$       (c)  $\text{HCl}$       (d)  $\text{BeCl}_2$
- What is the maximum number of water molecules that can attach with one water molecule through intermolecular hydrogen bonds?  
(a) 2      (b) 3      (c) 4      (d) 1
- Which of the following molecules has maximum bond angle  
(a)  $\text{NH}_3$       (b)  $\text{CH}_4$       (c)  $\text{H}_2\text{O}$       (d)  $\text{CO}_2$
- Identify correct statement regarding  $\text{NH}_3$  and  $\text{BF}_3$   
(a) Both are Lewis acid  
(b) Both are iso structural  
(c) Both are Lewis base  
(d) Have different values of dipole moment
- Identify the molecule having sideways overlapping of atomic orbitals  
(a)  $\text{CH}_4$       (b)  $\text{CO}_2$       (c)  $\text{NH}_3$       (d)  $\text{H}_2\text{O}$
- Which of the following chemical species is most stable?  
(a)  $\text{O}_2$       (b)  $\text{O}_2^+$       (c)  $\text{O}_2^-$       (d)  $\text{O}_2^{2-}$
- Which of the following d orbitals involved in  $\text{sp}^3\text{d}$  hybridization?  
(a)  $d_{xy}$       (b)  $d_{xz}$       (c)  $d_{x^2-y^2}$       (d)  $d_{z^2}$
- Which of the following molecule has net dipole moment?  
(a)  $\text{CO}_2$       (b)  $\text{H}_2\text{O}$       (c)  $\text{BF}_3$       (d)  $\text{CH}_4$
- Which of the following compound has highest covalent character  
(a)  $\text{LiCl}$       (b)  $\text{LiBr}$       (c)  $\text{LiF}$       (d)  $\text{LiI}$
- The shape of  $\text{XeF}_4$  molecule according to VSEPR theory is  
(a) Square planar      (b) Square pyramid  
(c) Tetrahedral      (d) Pyramidal

**Ans.** 1.(b) 2.(c) 3.(d) 4.(d) 5.(b) 6.(b) 7.(d) 8.(b) 9.(d) 10.(a)



### FILL IN THE BLANKS

- (i) The energy required to completely separate one mole of solid ionic compound into gaseous constituent ions is called.....
- (ii) Among alkali metal ions .....ion has highest polarizing power.
- (iii) According to molecular orbital theory molecules are said to be stable if the number of electrons in bonding molecular orbitals is ..... than the number of electrons in antibonding molecular orbitals.
- (iv) Isoelectronic molecules and ions have identical.....
- (v) In  $\text{PCl}_5$  molecule the two equivalent axial P – Cl bonds are.....than three equivalent equatorial P – Cl bonds.
- (vi) The state of hybridization of sulphur in  $\text{SF}_6$  is.....
- (vii) The maximum number of Hydrogen bonds formed by a single  $\text{H}_2\text{O}$  molecule is .....
- (viii) A triple covalent bond consists of.....sigma and.....pi bonds.
- (ix) .....bond is directional in nature.
- (x) Atomic orbitals are.....centric and molecular orbitals are.....centric.

**Ans.** (i) Lattice enthalpy (ii)  $\text{Li}^+$  (iii) more (iv) bond order (v) longer  
(vi)  $\text{sp}^3\text{d}^2$  (vii) 4 (viii) 1, 2 (ix) covalent (x) mono, poly

### TRUE AND FALSE TYPE QUESTIONS

**Write true or false for following statements:**

- (i) Energy of resonance hybrid is less as compared to the contributing canonical structures.
- (ii)  $\text{BeF}_2$  has more dipole moment than  $\text{BeCl}_2$ .
- (iii) In water two O–H bond dissociation enthalpies are not identical.
- (iv) Only the half filled orbitals of nearly same energy can participate in hybridization.
- (v) No bond is purely ionic or purely covalent.
- (vi) Chemical species having identical bond order have same bond dissociation enthalpies.

- (vii)  $\text{BF}_3$  is stronger Lewis acid than  $\text{BCl}_3$ .  
 (viii) Among alkali metal halides LiI has highest covalent character.  
 (ix) Resonating structures of a chemical species have no real existence.  
 (x)  $\text{XeF}_2$  and  $\text{ICl}_2^-$  are iso structural.

**Ans.** (i) True (ii) False (iii) True (iv) False (v) True  
 (vi) False (vii) False (viii) True (ix) True (x) True

### MATCH THE COLUMNS

I. Match the species in Column I with the geometry/shape in Column II and Hybridisation in Column III

S.N.	Column I	Column II	Column III
1.	$\text{BF}_3$	(a) Tetrahedral	(p) $\text{sp}^3\text{d}^2$
2.	$\text{ClF}_3$	(b) Trigonal Planer	(q) $\text{sp}^3$
3.	$\text{NH}_4^+$	(c) Octahedral	(r) $\text{sp}^3\text{d}$
4.	$\text{SF}_6$	(d) Bent T-Shape	(s) $\text{sp}^2$

II. Match the species in Column I with the hybridisation in Column II and geometry/shape in Column III

S.N.	Column I	Column II	Column III
1.	$\text{BBr}_3$	(a) $\text{sp}^3$	(p) Square Planer
2.	$\text{H}_2\text{O}$	(b) $\text{sp}^3\text{d}$	(q) Trigonal Planer
3.	$\text{PCl}_5$	(c) $\text{sp}^2$	(r) V-shape
4.	$\text{XeF}_4$	(d) $\text{sp}^3\text{d}^2$	(s) Trigonal Bipyramidal

ANS : MATCH-I

1. b, s    2. d, r    3. a, q    4. c, p

MATCH-II

1. c, q    2. a, r    3. b, s    4. d, p

## ASSERTION AND REASON TYPE QUESTIONS

In the following questions a statement of assertion (A) followed by a statement of Reason (R) is given. Choose the correct option out of the choices given below for each question:

- (i) A and R both are correct, and R is correct explanation of A.
  - (ii) A and R both are correct, but R is not the correct explanation of A.
  - (iii) A is true but R is false.
  - (iv) A and R both are false.
1. Assertion (A): Among the two O–H bonds in  $\text{H}_2\text{O}$  molecule, the energy required to break the first O–H bond and the other O–H bond is the same.  
Reason (R): This is because the electronic environment around the oxygen is same after breakage of one O–H bond.
  2. Assertion (A): Though the central atom of both  $\text{NH}_3$  and  $\text{H}_2\text{O}$  molecules are  $\text{sp}^3$  hybridised, yet H–N–H bond angle is greater than that of H–O–H.  
Reason (R): This is because nitrogen atom has one lone pair and oxygen atom has two lone pairs.
  3. Assertion (A):  $\text{SF}_6$  molecule is unstable.  
Reason (R): A stable molecule must have 8 electrons around the central atom. i.e. octet rule should be satisfied.
  4. Assertion (A): Pi bond is never formed alone. It is formed along with a sigma bond  
Reason (R): Pi bond is formed by sideway overlap of p- orbitals only.
  5. Assertion (A): Ionic compounds tend to be non-volatile.  
Reason (R): Ionic compounds are solid.
  6. ASSERTION : Bonding molecular orbitals are more stable than Antibonding Molecular orbitals.  
REASON : Electrons placed in Bonding molecular orbitals tend to hold the nuclei more together as compared to electrons placed in Antibonding molecular orbitals.

7. ASSERTION : Ortho-Nitrophenol has higher boiling point than Para-Nitrophenol

REASON : Intermolecular Hydrogen bonding occurs in Ortho-Nitrophenol as compared to intramolecular hydrogen bonding in Para-Nitro Phenol.

8. ASSERTION : When  $p_x$  orbital combine with  $p_y$  orbital then a sigma bond is produced.

REASON : Atomic orbitals of similar symmetry can result in positive and negative overlap.

9. ASSERTION :  $BF_3$  molecule has zero dipole moment.

REASON :  $BF_3$  molecule shape is trigonal planer and symmetrical.

10. ASSERTION : O-O bond length in  $O_3$  molecule is identical.

REASON : Ozone molecule is angular in shape

**Ans.** 1. (iv) 2. (i) 3. (iv) 4. (iv) 5. (ii) 6.(i) 7. (iv) 8. (iv) 9. (ii) 10. (ii)

### ONE WORD ANSWER TYPE QUESTIONS

1. Write the formal charge on central oxygen atom in  $O_3$  molecule?
2. Write the shape of  $AB_2E_3$  type molecule.
3. Name the property used to measure the degree of polarity.
4. Name the covalent bond formed by axial overlapping of atomic orbitals.
5. Out of  $p_x$ ,  $p_y$ ,  $p_z$  orbitals which p orbital takes part in  $sp$  hybridization?
6. Name the molecular orbital having energy greater than that of combining atomic orbitals.
7. Name the intermolecular forces responsible for liquid state of water.
8. Name the phenomenon used to describe a molecule whose single Lewis structure cannot describe it.
9. Name the geometry involved in  $sp^3d$  hybridization.
10. Name the molecular theory that can explain magnetic character of molecules.

**Ans.** 1. +1, 2. Linear, 3. Dipole moment, 4. Sigma bond, 5.  $p_z$   
6. Antibonding molecular orbital, 7. Hydrogen bond, 8. Resonance,  
9. Trigonal bipyramid, 10. Molecular orbital theory

### 1-MARK QUESTIONS

1. Why noble gases exist in mono atomic form?
2. Write the Lewis structure of  $\text{NO}_2^-$ .
3. Why  $\text{NH}_3$  and  $\text{BF}_3$  have different shapes?
4. How many sigma and pi bonds are present in HCN molecule?
5. Why sigma bond is stronger than pi bond?
6. Explain why  $\text{BeH}_2$  molecule has zero dipole moment although the Be–H bonds are polar?
7. Which has highest bond angle?  $\text{NO}_2$ ,  $\text{NO}_2^-$ ,  $\text{NO}_2^+$
8. What is magnetic character of anion of  $\text{KO}_2$ ?
9. Why do atoms combine?
10. What is the significance of Lewis Symbols?
11. Why density of water is maximum at 277K?
12. Give structure of  $\text{BrF}_5$  according to VSEPR theory.
13. Why  $\text{NH}_3$  is liquid and  $\text{PH}_3$  is a gas?
14. Why  $\text{KHF}_2$  exist but  $\text{KCl}_2$  and  $\text{KBr}_2$  does not?  
[Ans.  $\text{HF} \dots \text{F}^\ominus$  hydrogen bonding].
15. Boiling point of p-nitrophenol is more than O-nitrophenol why?
16. How paramagnetic character of a compound is related to the no. of unpaired electrons?
17. Define the term bond length.
18.  $\text{He}_2$  molecule does not exist. Give reason.
19. Why  $\text{PCl}_5$  dissociates to give  $\text{PCl}_3$  and  $\text{Cl}_2$ ?
20. Write the state of hybridization of O in  $\text{H}_2\text{O}$ .
21. Predict the shape of  $\text{ClF}_3$  according to VSEPR theory.
22. Why ice has less density than water?
23. Why the H–P–H bond angle in  $\text{PH}_3$  is less than H–N–H bond angle in  $\text{NH}_3$ ?
24. At room temperature  $\text{H}_2\text{O}$  exist as liquid while  $\text{H}_2\text{S}$  exist as gas. Give reason.
25.  $\text{NH}_3$  has higher boiling point than  $\text{PH}_3$ . Give reason.
26. Identify the chemical species having identical bond order:  $\text{O}_2^{2+}$ ,  $\text{N}_2$ ,  $\text{O}_2$ ,  $\text{O}_2^{2-}$ .

## 2-MARKS QUESTIONS

1. What is Octet rule? What are its limitations?
2. The enthalpy needed to break the two O–H bonds in water are as follows:  
$$\text{H}_2\text{O (g)} \rightarrow \text{H (g)} + \text{O–H(g)} \quad \Delta_a\text{H}_1^0 = 493 \text{ kJ mol}^{-1}$$
$$\text{O–H (g)} \rightarrow \text{H (g)} + \text{O(g)} \quad \Delta_a\text{H}_1^0 = 424 \text{ kJ mol}^{-1}$$
What is the average bond enthalpy of  $\text{H}_2\text{O}$ ?
3. Write two points of difference between sigma and pi bond.
4. Define Hydrogen bond. Is it weaker or stronger than van der Waal forces?
5. Define dipole moment. Give its significance.
6. Give applications of dipole moment.
7. Which is more polar and why,  $\text{CO}_2$  or  $\text{N}_2\text{O}$ ?
8. Discuss the partial ionic character of covalent bond by taking an example.
9. Draw the resonating structures of  $\text{O}_3$  and calculate formal charges on each O atom.
10. O-Nitrophenol is steam volatile while p-Nitrophenol is not. Give reason.
11. Define bond enthalpy. Why the bond enthalpy of  $\text{F}_2$  is less than that of  $\text{Cl}_2$ ?
12. Define resonance. Draw resonating structures of  $\text{CO}_2$ .
13. Assign reason for the following;
  - (i)  $\text{NH}_3$  is freely soluble in water while  $\text{PH}_3$  is not.
  - (ii)  $\text{B}_2$  is paramagnetic while  $\text{C}_2$  is not.
14. Out of  $\text{NH}_3$  and  $\text{NF}_3$  which is more polar. Explain with the help of dipole moment.
15.  $\text{N}_2$  is diamagnetic while  $\text{O}_2$  is paramagnetic. Explain on the basis of Molecular orbital theory.
16.  $\text{H}_2^+$  and  $\text{H}_2^-$  have same bond order. Which is more stable?
17. Differentiate between bonding and anti bonding molecular orbitals.
18. Discuss the conditions for the combination of atomic orbitals to form molecular orbitals.

19. Although Chlorine (EN = 3.2) is more electronegative than Nitrogen (EN = 3.0), yet chlorine does not form hydrogen bond while nitrogen does. Give reason. (Ans: larger atomic size of Cl).
20.  $\text{ClF}_3$  is T shaped but  $\text{BF}_3$  is planar. Explain.
21.  $\text{N}(\text{SiH}_3)_3$  and  $\text{N}(\text{CH}_3)_3$  are not isostructural. Give reason.
22. Draw molecular orbital diagram for  $\text{N}_2^+$  molecule.
23.  $\text{HCl}$  is a covalent compound but it ionises in the solution?
24. The molecule of  $\text{CO}_2$  is linear whereas that of  $\text{SnCl}_2$  is angular why?
25. Arrange the following in the order of property indicated for each set:
  - (i)  $\text{O}_2, \text{O}_2^+, \text{O}_2^-, \text{O}_2^{2-}$  (increasing stability)
  - (ii)  $\text{LiCl}, \text{NaCl}, \text{KCl}, \text{RbCl}$  (increasing covalent character)
  - (iii)  $\text{NO}_2, \text{NO}_2^+, \text{NO}_2^-$  (decreasing bond angle)
  - (iv)  $\text{H-F}, \text{H-Cl}, \text{H-Br}, \text{H-I}$  (increasing bond dissociation enthalpy)
26. Arrange the following in the order of property indicated for each set:
  - (i)  $\text{H}_2\text{O}, \text{NH}_3, \text{H}_2\text{S}, \text{HF}$  (increasing polar character)
  - (ii)  $\text{HF}, \text{HCl}, \text{HBr}, \text{HI}$  (decreasing dipole moment)
  - (iii)  $\text{NO}_3^-, \text{NO}_2^-, \text{NO}$  (decreasing 's' character of hybridization)
  - (iv)  $\text{BeCl}_2, \text{BCl}_3, \text{CCl}_4, \text{PCl}_3$  (increasing bond angle)

### 3-MARKS QUESTIONS

1. How is ionic bond formed? On what factors it depends?
2. Calculate the lattice enthalpy of  $\text{KCl}$  from the following data by Born-Haber's Cycle.
 

Enthalpy of sublimation of  $\text{K} = 89 \text{ kJ mol}^{-1}$   
 Enthalpy of dissociation of  $\text{Cl}_2 = 244 \text{ kJ mol}^{-1}$   
 Ionization enthalpy of potassium =  $425 \text{ kJ mol}^{-1}$   
 Electron gain enthalpy of chlorine =  $-355 \text{ kJ mol}^{-1}$   
 Enthalpy of formation of  $\text{KCl} = -438 \text{ kJ mol}^{-1}$
3. What is meant by hybridization? Describe the shape of  $sp$ ,  $sp^2$  and  $sp^3$  hybridised orbitals.

- Define bond order. Calculate the bond order in  $N_2$  and  $O_2$  molecules.
- Give molecular orbital energy level diagram of  $O_2^{2-}$ . Write its electronic configuration, magnetic behaviour and bond order.
- Which of the following in each pair has larger bond angle  
(i)  $CO_2$ ,  $BF_3$       (ii)  $H_2O$ ,  $H_2S$       (iii)  $CH_4$ ,  $C_2H_2$
- What is meant by resonance? Draw the resonating structures of carbonate ion and explain why all the C–O bond lengths are identical in carbonate ion?
- Compare relative stability of following species and predict their magnetic properties:  
 $O_2$ ,  $O_2^+$ ,  $O_2^-$  (superoxide),  $O_2^{2-}$  (peroxide)
- Draw the Lewis structure of the species as mentioned  $BF_3$ ,  $SF_6$ ,  $NO_2$ :  
(i) In which the central atom has incomplete octet.  
(ii) In which the central atom has an expanded octet,  
(iii) An odd electron molecule is formed.
- Explain the structure of  $PCl_5$  according to hybridization. Why all P–Cl bonds lengths are not equivalent in  $PCl_5$ ?

### 5-MARKS QUESTIONS

- Give reasons for the following:  
(a)  $NH_3$  has higher boiling point than  $PH_3$ .  
(b) Ionic compounds do not conduct electricity in solid state.  
(c)  $LiCl$  is more covalent than  $KCl$ .  
(d)  $NH_3$  is more polar than  $NF_3$ .  
(e)  $H_2O$  has bent structure.
- (a) Define the term bond dissociation enthalpy. How is it related to bond order?  
(b) Explain why  $N_2$  has greater bond dissociation enthalpy than  $N_2^+$  while  $O_2$  has lesser bond dissociation enthalpy than  $O_2^+$ ?
- Draw the shape of following molecules according to VSEPR theory;  
 $XeO_3$ ,  $XeF_2$ ,  $XeOF_4$ ,  $SF_4$ ,  $XeF_4$



## HOTS QUESTIONS

1. The bond angle of  $\text{H}_2\text{O}$  is  $104.5^\circ$  while that of  $\text{F}_2\text{O}$  is  $102^\circ$ . Explain why?

**Solution:** The bond pair of electrons are drawn more towards F in  $\text{F}_2\text{O}$ , whereas in  $\text{H}_2\text{O}$  it is drawn towards O. So bp–bp repulsion in  $\text{H}_2\text{O}$  is greater than that in  $\text{F}_2\text{O}$ .

2. Anhydrous  $\text{AlCl}_3$  is covalent. From the data given below, predict whether it would remain covalent or become ionic in aqueous solution.

$$\Delta_f H(\text{AlCl}_3) = 5137 \text{ kJ mol}^{-1}, \quad \Delta_{\text{hyd}} H(\text{Al}^{3+}) = -4665 \text{ kJ mol}^{-1},$$

$$\Delta_{\text{hyd}} H(\text{Cl}^-) = -381 \text{ kJ mol}^{-1}.$$

**Solution:** Total energy released =  $1\Delta_{\text{hyd}} H(\text{Al}^{3+}) + 3\Delta_{\text{hyd}} H(\text{Cl}^-)$

$$= [(-4665) + (3 \times -381)] \text{ kJ mol}^{-1} = -5808 \text{ kJ mol}^{-1}$$

Total energy required =  $\Delta_f H(\text{AlCl}_3) = 5137 \text{ kJ mol}^{-1}$

Since energy released is greater than the energy required, the compound will ionize in aqueous solution.

3. The dipole moment of HCl is 1.03 D, and the bond length is 127 pm. Calculate the percent ionic character of HCl molecule.

**Solution:**  $\mu_{\text{cal}} = Q \times r = (1.6 \times 10^{-19} \text{C}) \times (127 \times 10^{-12} \text{m}) = 2.032 \times 10^{-29} \text{C m}$

$$= (2.032 \times 10^{-29} \text{C m}) \times \frac{1\text{D}}{3.336 \times 10^{-30} \text{Cm}} = 6.09 \text{ D}$$

$$\% \text{ ionic character} = \frac{\mu_{\text{obs.}}}{\mu_{\text{cal}}} \times 100 = \frac{1.03\text{D}}{6.09\text{D}} \times 100 = 16.9\%$$

## UNIT TEST-I

**Time Allowed: 1 hr.**

**Maximum Marks : 20**

*General Instructions:*

- (i) All questions are compulsory.
  - (ii) Maximum marks carried by each question are indicated against it.
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1. Identify the molecule having sideways overlapping of atomic orbitals [1]  
(a) CH<sub>4</sub>                      (b) CO<sub>2</sub>                      (c) NH<sub>3</sub>                      (d) H<sub>2</sub>O
2. The shape of XeF<sub>4</sub> molecule according to VSEPR theory is [1]  
(a) Square planar                      (b) Square pyramid  
(c) Tetrahedral                      (d) Pyramidal
3. Write the Lewis structure of NO<sub>2</sub><sup>-</sup>. [1]
4. Which has highest bond angle? NO<sub>2</sub>, NO<sub>2</sub><sup>-</sup>, NO<sub>2</sub><sup>+</sup> [1]
5. Draw the resonating structures of CO<sub>2</sub>. [1]
6. The enthalpy needed to break the two O–H bonds in water are as follows:  
$$\text{H}_2\text{O}(\text{g}) \longrightarrow \text{H}(\text{g}) + \text{O}-\text{H}(\text{g}) \quad \Delta_a\text{H}_1^0 = 493 \text{ kJ mol}^{-1}$$
$$\text{O}-\text{H}(\text{g}) \longrightarrow \text{H}(\text{g}) + \text{O}(\text{g}) \quad \Delta_a\text{H}_2^0 = 424 \text{ kJ mol}^{-1}$$

What is the average bond enthalpy of H<sub>2</sub>O? [2]
7. Out of NH<sub>3</sub> and NF<sub>3</sub> which is more polar. Explain with the help of dipole moment. [2]
8. Compare relative stability of following species and predict their magnetic properties: O<sub>2</sub>, O<sub>2</sub><sup>+</sup>, O<sub>2</sub><sup>-</sup> (superoxide), O<sub>2</sub><sup>2-</sup> (peroxide) [3]
9. Explain the structure of PCl<sub>5</sub> according to hybridization. Why all P–Cl bonds lengths are not equivalent in PCl<sub>5</sub>? [3]
10. (i) N<sub>2</sub> is diamagnetic while O<sub>2</sub> is paramagnetic. Explain on the basis of Molecular orbital theory. [2]  
(ii) Give reasons for the following: [3]
  - (a) NH<sub>3</sub> has higher boiling point than PH<sub>3</sub>.
  - (b) Ionic compounds do not conduct electricity in solid state.
  - (c) LiCl is more covalent than KCl.

## UNIT TEST-II

**Time Allowed: 1 hr.**

**Maximum Marks : 20**

*General Instructions:*

- (i) All questions are compulsory.
- (ii) Maximum marks carried by each question are indicated against it.

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1. Identify the molecule in which carbon has 'sp' hybridisation. [1]  
(a) CO<sub>2</sub>                      (b) CH<sub>4</sub>                      (c) C<sub>2</sub>H<sub>4</sub>                      (d) C<sub>2</sub>H<sub>2</sub>
  2. The shape of the molecule SF<sub>4</sub> is [1]  
(a) Bent    (b) See-saw  
(c) Tetrahedral                                      (d) Square Planer
  3. Write the Lewis structure of CO<sub>3</sub><sup>2-</sup> [1]

**In following questions a statement of assertion followed by a statement of reason is given. Choose the correct answer out of the following choices:**

- (a) Assertion and Reason both are correct statements and Reason is correct explanation for assertion.
  - (b) Assertion and Reason both are correct statement but Reason is not correct explanation for assertion.
  - (c) Assertion is correct statement but Reason is wrong statement.
  - (d) Assertion is wrong statement but Reason is correct statement.
4. **Assertion :** Pie ( $\pi$ ) bond are directional in nature. [1]  
**Reason :** Sigma bond are formed by axial approach of atomic orbitals.
  5. **Assertion :** Boiling point of water is higher than H<sub>2</sub>S. [1]  
**Reason :** Hydrogen bonding is feasible in Water but in H<sub>2</sub>S there is no Hydrogen bonding.
  6. Why dipole moment of BF<sub>3</sub> is zero but for PCl<sub>3</sub> it is non zero? [2]
  7. Which one LiF or LiI is more ionic and why? [2]
  8. Explain with the help of labeled diagram the Valence Bond Theory for formation of H<sub>2</sub> molecule. [3]
  9. Explain the Octet rule with relevant example. Write two limitation of Octet rule also. [3]
  10. Define Hybridisation. Write the salient features of hybridisation. Explain the hybridisation in SF<sub>6</sub> molecule with relevant diagram. [5]

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