

CHAPTER - 04

CHEMICAL BONDING AND MOLECULAR STRUCTURE

SYNOPSIS

Lewis - Kossel electronic theory of valency

Atoms try to become more stable by gaining 8 electrons in their valence shell (Octet rule). Elements near to He try to obtain 2 electrons in their valence shell (duplet rule)

Energy

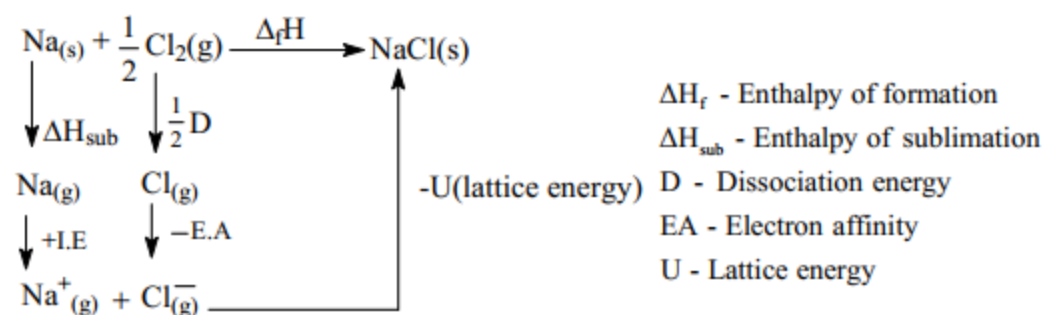
Atoms combine to minimise their energy and become more stable.

Ionic bond

It is formed by the transference of one or more electrons from the electropositive atom to the electronegative atom. The cation and anion are held together by electrostatic forces. Electrovalency is the number of electrons lost or gained by an atom. It is equal to number of charges on the ion.

The ionic bond is nondirectional. The compounds have very high M.Ps. So they are solids. They are soluble in polar solvents like water. They are electrical conductors in solution and molten state. They do not show stereoisomerism.

Energetics of formation of ionic compound-Born Haber cycle



$$\therefore \Delta H_f = \Delta H_{\text{sub}} + \text{I.E.} + \frac{1}{2} D - \text{E.A.} - U$$

Favourable conditions for ionic compound formation

- 1) Low IE
- 2) High EA
- 3) High lattice enthalpy

Lattice energy U

It is energy required to completely separate one mole of an ionic solid compound into gaseous constituent ions. It increases with decrease in size and increase in charge of the ions. As it increases M.P. increases, solubility in water decreases and stability of the compound increases.

Covalent bond

It is formed by the sharing of one or more electron pairs between two electronegative atoms. The shared pairs hold the atoms together. Valency is the number of electrons given by an atom for sharing. Each atom gains one more electron from each bond.

The bond is directional. The compounds have low M.Ps. and B. Ps. So they are gases, liquids or low melting solids. They are insoluble in polar solvents but soluble in nonpolar solvents. They are electrical non conductors. They show stereoisomerism.

Coordinate bond or Dative bond or semi polar bond

It is formed by the sharing of an electron pair between 2 atoms, but the shared pair comes from only one of the atoms. The properties of the compounds are intermediate between those of ionic and covalent compounds. The acceptor gains two more electrons but the donor has no loss or gain of electrons.

Partial covalent character in ionic compounds

The cation attracts (polarises) the electron cloud of the anion and thus ionic compounds get partial covalent character. Higher covalent character decreases M.P. and solubility in water.

Fajan's rules

- 1) Smaller cations and larger anions give more covalent character
- (2) Higher charges on the ions make the compound more covalent

Partial ionic character in covalent compounds

Due to electronegativity difference the more electronegative atom gets partial negative charge and the other atom gets partial positive charge in a heteronuclear molecule like HCl. The molecule becomes polar and it turns into a dipole. The partial charges attract each other and the covalent compound gets partial ionic character.

The % of ionic character depends on the electronegativity difference between the atoms bonded. If the difference is 1.7, the bond is 50% ionic and 50% covalent. If it is greater than 1.7, the bond is ionic and if it is less than 1.7, the bond is covalent. Covalent character is inversely proportional to electronegativity difference between the atoms.

Smith and Hannay equation - % of ionic character = $16 (X_B - X_A) + 3.5 (X_B - X_A)^2$

Pauling equation - % of ionic character = $18 (X_B - X_A)^{1.4}$

X_A and X_B are electronegativities of the atoms in the bond A - B

Violation of Octet Rule

1. Electron deficient or hypovalent molecules in which the central atom has less than eight outermost electrons. Eg: BF_3 , AlCl_3 etc.
2. Super octet or hypervalent or expanded octet molecules in which the central atom has more than eight outermost electrons. Eg : PCl_5 , ClF_3 , SF_6 etc.
3. Odd electron molecules. Eg: NO_2 , NO etc.

Formal charge

Formal charge of an atom is the difference between the number of valence electrons in the free atom and the number of electrons assigned to it in the Lewis structure of a molecule or ion. It can be calculated as

Formal charge = Number of valence electrons in the free atom – Number of nonbonding electrons

$$-\frac{1}{2} \times \text{total number of bonding electrons (OR total number of bonds with the atom)}.$$

Structures minimising formal charges and structures with negative formal charge on the more electronegative atom are more stable.

VBT

A covalent bond is formed by the overlap of half filled atomic orbitals of the combining atoms. The electrons in them should be of opposite spins. During overlap these electrons are paired and energy is released. The strength of a bond is directly proportional to the extent of overlap. A bond is formed along the direction of overlap. The net attractive and repulsive forces balance each other in a bond. The overlapping orbitals should be of similar energy.

σ bond

1. Formed by axial overlap
2. Stronger bond
3. Formed by all types of orbitals
4. Determines the shape of molecules
5. Rotation of the molecule is possible about σ bond
6. σ electrons are less reactive
7. σ electrons are localised

π bond

- formed by lateral overlap
- weaker bond
- cannot be formed by s orbitals
- cannot affect the shape
- not possible
- π electrons are more reactive
- π electrons are delocalised and mobile

Hybridisation

It is the mixing up of different atomic orbitals of an atom forming an equal number of identical orbitals having mixed character. The orbitals formed are called hybridised orbitals. They keep maximum distance among them. This decides the shape of a molecule. Usually they form only σ bonds (π bonds are formed by AO_s) They form stronger bonds than AO_s due to better overlap. They have mixed character of the AO_s involved. The orbitals mixed should be of comparable energy.

Hybridisation	Shape	Bond angles
sp	linear	180°
sp ²	trigonal planar	120°
sp ³	tetrahedral	109° 28'
sp ³ d	trigonal bipyramidal	120° and 90°
sp ³ d ²	Octahedral	90°
sp ³ d ³	Pentagonal bipyramidal	90° and 72°

Determination of hybridisation

$$\text{Number of hybrid orbitals, } H = \frac{1}{2}(V + X + A - C)$$

V = number of valence electrons

X = number of surrounding monovalent atoms

A = number of anion charges

C = number of cation charges

H	2	3	4	5	6	7
Hybridisation	sp	sp ²	sp ³	sp ³ d	sp ³ d ²	sp ³ d ³

H can be calculated also as

H = number of σ bonds + number of coordinate bonds + number of *lps* + number of odd electrons.

VSEPR theory

The electron pairs around the central atom in a polyatomic molecule repel each other. So they try to keep maximum distance among them. This decides the shape of a molecule. There may be bps and *lps*. Their repulsions are in the order.

$$lp - lp > lp - bp > bp - bp$$

If there are lone pairs in addition to bond pairs, shape and bond angles are different.

Shapes of different molecules

Shapes of the molecules depend on bps, *lps* and their sum.

H = total number of hybrid orbitals = number of bps + number of *lps*

Number of bps = number of all surrounding atoms. Number of *lps* = H - number of bps. (only σ bps are considered here). In sp³d *lps* are at equatorial positions. In sp³d², if there is only one *lp*, it is in any position. If there are two *lps*, they are at 180° with each other

A molecule has a regular shape as given by hybridisation if there are only bps around the central atom. If there are *lps* also the shape and bond angle are different.

Dipole moment μ

The polarity of a molecule is measured by dipole moment. μ = charge on any of the atoms \times distance between the charges. μ is a vector quantity. In diatomic molecules it is same as the bond moment. In polyatomic molecules the molecular dipole moment is the vector sum of the bond moments. Unit of dipole moment is debye, D one D = 3.3356×10^{-30} C m or 10^{-18} esu cm. eg. (1) nonpolar molecules H_2 , CO_2 , BF_3 , CH_4 , PCl_5 , SF_6 , IF_7 , etc. Molecules with only bps and identical surrounding atoms are usually non polar.

eg. (2) polar molecules H_2O , HCl , CH_3Cl etc. % of ionic character =
$$\frac{\mu_{\text{observed}} \times 100}{\mu_{\text{theoretical if the bond is 100\% ionic}}}$$

Resonance

If a molecule can be represented by different structures which differ in the position of the electrons, then its properties are due to a hybrid of the different structures. The different structures are called resonating or canonical or contributing forms and the real structure is called resonance hybrid. The resonance hybrid cannot be written.

The canonical forms do not exist. They should have the same atomic positions. The number of unpaired electrons in them should be the same. A form with more bonds is more stable. A neutral form is more stable than a charged form. A form with a negative charge on the more electronegative atom and a positive charge on the less electronegative atom is more stable than the reverse case. A charged form with similar charges on adjacent atoms is less stable. A form that obeys octet rule is more stable. More stable form contribute more to the properties of the hybrid. Stability is proportional to resonance energy. It is the difference in energy between the resonance hybrid and the most stable canonical form. The resonating forms should be of similar energy.

Hydrogen bond

In compounds containing hydrogen covalent bonded to highly electronegative F, O and N, the hydrogen atom forms a partial electrostatic bond with another F, O or N in another or the same molecule. This is called hydrogen bond. Molecules associate by hydrogen bond and their properties change. H bond is stronger type of van der Waal forces. The H bond strength is as $H \cdots F > H \cdots O > H \cdots N$. HF and H_2O are liquids due to H bond. B.P., viscosity and surface tension increase due to this. Covalent compounds like alcohol dissolve in water due to H bond.

MOT

When atoms form covalent bond, all of their atomic orbitals overlap and change into new type of orbitals called molecular orbitals. MO_s are polycentric. They have shapes, energy etc. different from AO_s . Usually half of the MO_s are of energy lower than AO_s . They are called BMO_s . The other half are of energy higher than AO_s . They are called $ABMO_s$. In BMO electrons try to concentrate in the internuclear region and form the bond. In $ABMO$ electrons try to avoid the internuclear region attempting not to form the bond. According to LCAO method, BMO is obtained by the addition of AO_s and $ABMO$ by subtraction of them $\psi_{BMO} = \psi_1 + \psi_2$, $\psi_{ABMO} = \psi_1 - \psi_2$. ψ_1 and ψ_2 are AO wave functions. σ MO_s are symmetric about the internuclear axis and π MO_s are antisymmetric. BMO is obtained by the constructive interference of the AOs and $ABMO$ by destructive interference.

Conditions favouring bond formation

1) The overlapping AO_s should be of comparable energy (2) They should overlap considerably (3) They should be of same symmetry.

Aufbau order of MO_s in diatomic molecules

Upto $N_2 - \sigma_{1s} < \sigma_{1s}^* < \sigma_{2s} < \sigma_{2s}^* < \pi_{2p_x} = \pi_{2p_y} < \sigma_{2p_z} < \pi_{2p_x}^* = \pi_{2p_y}^* < \sigma_{2p_z}^*$

After $N_2 - \sigma_{1s} < \sigma_{1s}^* < \sigma_{2s} < \sigma_{2s}^* < \sigma_{2p_z} < \pi_{2p_x} = \pi_{2p_y} < \pi_{2p_x}^* = \pi_{2p_y}^* < \sigma_{2p_z}^*$

$$\text{Bond order B.O.} = \frac{1}{2} (N_b - N_a)$$

B.O. is same as the number of covalent bonds between 2 atoms. But B.O. can have fractional values. Bond energy, bond strength are stability of the molecule are directly proportional to B.O. Bond length is inversely proportional to B.O. It is positive in stable molecules. Addition of an electrons to BMO increases the BO by 0.5. Removal of an electron from BMO decreases the BO by 0.5. Addition of an electron to ABMO decreases the BO by 0.5. Removal of an electron from ABMO increases BO by 0.5.

Bond Length

It is the average distance between the centres of the nuclei of two atoms. It increases with increase in the size of the atoms in the bond. Multiple bonds are shorter than single bonds. Polar bonds are shorter than nonpolar bonds. When hybrid orbitals are used in the bonds, the bond length decreases with increase in s character.

Bond Energy

It is the average amount of energy required to break one mole of the bond and separate the atoms in the gaseous state. It is same as bond dissociation energy in diatomic molecules. In polyatomic molecules like CH_4 where there are several bonds of the same type, it is the average of the different bond dissociation energy. Greater the bond energy, stronger is the bond. Bond energy increases with decrease in the size of the atoms, increase in the polarity of the bonds, increase in the extent of overlap of the orbitals in the bond formation, increase in bond order etc. Bond energy decreases with increase in the number of lps on the bonded atoms.

Bond Angle

It is the angle between two bonds around the central atom

It depends on

(1) Hybridisation

(2) Difference in electron pair repulsion in the order $lp - lp > lp - bp > bp - bp$

- (3) **Central atom** : If structure and surrounding atoms are same, bond angle is directly proportional to electronegativity of the central atom
- (4) **Surrounding atom** : If structure and central atoms are same, bond angle is inversely proportional to electronegativity of the surrounding atom
- (5) **Steric repulsion** : Bulkier surrounding atoms or groups can repel with each other changing the bond angle
- (6) **Bond multiplicity** : Double bond pairs repel more than single bond pair changing the bond angle

PART-I (JEE MAIN)

SECTION-I- Straight objective type questions

- Which of the following molecules/ions violates the octet rule?

1) CF_4	2) NCl_3	3) PCl_3	4) SF_4
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- The correct order of increasing C – O bond length of CO , CO_3^{2-} and CO_2 is

1) $\text{CO}_3^{2-} < \text{CO}_2 < \text{CO}$	2) $\text{CO}_2 < \text{CO}_3^{2-} < \text{CO}$
3) $\text{CO} < \text{CO}_3^{2-} < \text{CO}_2$	4) $\text{CO} < \text{CO}_2 < \text{CO}_3^{2-}$
- Which of the following is not the correct increasing order of the property indicated?

1) $\text{BaO} < \text{SrO} < \text{CaO} < \text{MgO} < \text{BeO}$	-	Lattice energy
2) $\text{LiF} < \text{LiCl} < \text{LiBr} < \text{LiI}$	-	melting point
3) $\text{AlF}_3 < \text{AlCl}_3 < \text{AlBr}_3 < \text{AlI}_3$	-	Covalent character
4) $\text{NaF} < \text{MgO} < \text{AlN} < \text{SiC}$	-	Lattice energy
- Formal charge on the three atoms in ozone molecule are respectively

1) 0, 0, +1	2) 0, +1, -1	3) -1, +1, -2	4) 0, 0, +2
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- The type of hybrid orbitals present on the chlorine atom in ClO_2^- is

1) sp^3	2) sp^2	3) sp	4) sp^3d
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- The shape / structure of $[\text{XeF}_5]^-$ and XeO_3F_2 are respectively

1) pentagonal planar and trigonal bipyramidal
2) octahedral and square pyramidal
3) pentagonal bipyramidal and pentagonal planar
4) square pyramidal and trigonal bipyramidal

7. In which of the following pairs, both species have the same hybridisation?
 1) SF_4 , XeF_4 2) I_3^- , XeF_2 3) ICl_4^+ , SiCl_4 4) ClO_3^- , ClF_3
8. Assertion : Bond angles in NH_3 , PH_3 , AsH_3 and SbH_3 follow the order $\text{NH}_3 > \text{PH}_3 > \text{AsH}_3 > \text{SbH}_3$
 Reason : The central atom in each molecule has a lone pair of electrons.
 Choose the correct option from the following
 1) Both assertion and reason are true and reason is the correct explanation of assertion
 2) Both assertion and reason are true but reason is not the correct explanation of assertion
 3) Assertion is true but reason is false
 4) Both assertion and reason are false
9. The species having no $p\pi - p\pi$ bond but has bond order equal to that of O_2 is
 1) ClO_3^- 2) PO_4^{3-} 3) SO_4^{2-} 4) XeO_3
10. If z-axis is the internuclear axis, then π bond is formed by the overlap of
 1) s and p_z orbitals 2) p_x and p_y orbitals 3) p_z and p_z orbitals 4) p_x and p_x orbitals
11. Arrange the following compounds in order of increasing dipole moment.
 (I) Toluene (II) m-dichlorobenzene
 (III) o-dichlorobenzene (IV) p-dichlorobenzene
 1) $\text{I} < \text{IV} < \text{II} < \text{III}$ 2) $\text{IV} < \text{I} < \text{II} < \text{III}$ 3) $\text{IV} < \text{I} < \text{III} < \text{II}$ 4) $\text{IV} < \text{II} < \text{I} < \text{III}$
12. Which of the following arrangements of molecules is correct on the basis of their dipole moments?
 1) $\text{BF}_3 > \text{NF}_3 > \text{NH}_3$ 2) $\text{NF}_3 > \text{NH}_3 > \text{BF}_3$ 3) $\text{NH}_3 > \text{BF}_3 > \text{NF}_3$ 4) $\text{NH}_3 > \text{NF}_3 > \text{BF}_3$
13. The dipole moments of CCl_4 , CHCl_3 , CH_2Cl_2 , CH_3Cl and CH_4 are in the order:
 1) $\text{CH}_4 = \text{CCl}_4 < \text{CHCl}_3 < \text{CH}_2\text{Cl}_2 < \text{CH}_3\text{Cl}$ 2) $\text{CH}_4 < \text{CCl}_4 < \text{CH}_3\text{Cl} < \text{CHCl}_3 < \text{CH}_2\text{Cl}_2$
 3) $\text{CCl}_4 = \text{CH}_4 < \text{CHCl}_3 < \text{CH}_3\text{Cl} < \text{CH}_2\text{Cl}_2$ 4) $\text{CH}_3\text{Cl} < \text{CH}_2\text{Cl}_2 < \text{CHCl}_3 < \text{CH}_4 = \text{CCl}_4$
14. **Assertion:** B_2 molecule is paramagnetic.
Reason: The highest occupied molecular orbital of B_2 is of σ type.
 In the light of the above statements choose the correct option
 1) Both assertion and reason are true and the reason is the correct explanation of the assertion.
 2) Both assertion and reason are true but reason is not the correct explanation of the assertion.
 3) Assertion is true but reason is false.
 4) Assertion is false but reason is true.

15. Correct order of O–O bond length in O_2 , H_2O_2 and O_3 is

- 1) $H_2O_2 > O_3 > O_2$ 2) $H_2O_2 > O_2 > O_3$ 3) $O_2 > O_3 > H_2O_2$ 4) $O_3 > O_2 > H_2O_2$

SECTION-II - Numerical Type Questions

16. Total number of lone pair(s) of electrons in I_3^- ion is _____

17. Total number of polar molecule(s) among the following is _____

- i) BF_3 ii) PCl_3F_2 iii) PCl_2F_3 iv) ICl_3
v) CH_4 vi) SF_6 vii) SF_4 viii) PCl_5

18. Among the triatomic molecules/ions $BeCl_2$, N_3^- , N_2O , NO_2^+ , O_3 , SCl_2 , ICl_2^- , I_3^- and XeF_2 , the total number of linear molecules/ions where the hybrid orbital of the central atom does not have contribution from d orbitals is _____

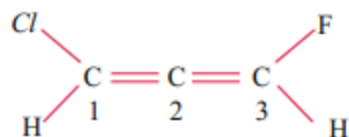
PART-II (JEE ADVANCED)

Section-III - Only one option correct type

19. The correct increasing order of C – C bond length of the following compounds is

- i) $F_3C - CF_3$ ii) $CH_3 - CH_2F$ iii) $H_3C - CH_3$ iv) $FCH_2 - CH_2F$
A) $iv < i < ii < iii$ B) $i < iv < ii < iii$ C) $iv < i < iii < ii$ D) $i < iv < iii < ii$

20. Consider the following substituted allene system



If nodal plane of the π bond formed between C_1 and C_2 is perpendicular to the plane of paper, then select the correct statement

- A) Fluorine is perpendicular to the plane of paper
B) Chlorine is present in the plane of paper
C) σ – bond of $C_2 - C_3$ is perpendicular to the plane of paper
D) Nodal plane of the π bond formed between C_2 and C_3 is the plane of paper itself

21. Back bonding in BF_3 does not affect its

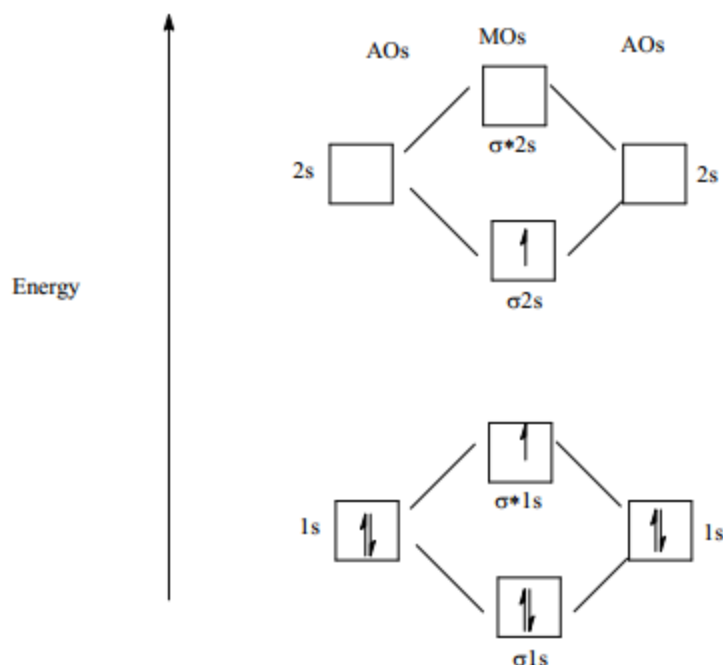
- A) planarity, Lewis acidity and bond angle
B) bond length, hybridisation and bond strength
C) bond angle, planarity and geometry
D) Lewis acidity, bond length and bond order

22. Select the correct order for the strength of hydrogen bond in the following compounds
- A) $(CH_3)_3SiOH > (CH_3)_3COH$
- B) $(CH_3)_3COH > (CH_3)_3SiOH$
- C) $(CH_3)_3COH = (CH_3)_3SiOH$
- D) Hydrogen bonding is not possible in $(CH_3)_3COH$ and $(CH_3)_3SiOH$
23. The total number of planes in CH_4 molecule that contain three atoms and pass through the central atom is
- A) 5 B) 6 C) 7 D) 8
24. The sum of $p\pi-d\pi$ bonds in SO_2 and SO_3 is —
- A) 2 B) 3 C) 4 D) 5
25. Select the incorrectly matched pair
- A) $XeF_2 \rightarrow$ central atom is sp^3d hybridisation; linear molecule/ion
- B) $N_3^- \rightarrow$ central atom has sp hybridisation; linear molecule/ion
- C) $PCl_6^- \rightarrow$ central atom has sp^3d^2 hybridisation; distorted octahedral molecule/ion
- D) $ICl_2^+ \rightarrow$ central atom has sp^3 hybridisation; bent molecule/ion

Section IV - One or more option correct type

26. Select the correct statement(s) regarding the structure of azide ion (N_3^-) and hydrazoic acid (N_3H)
- A) All the N–N bond lengths are same in N_3^- ion
- B) All the N–N bond lengths are not identical in N_3H
- C) In N_3H , the terminal N–N bond is shorter than the central N–N bond
- D) N_3^- ion and N_3H molecule have the same number of electrons
27. Both $N(SiH_3)_3$ and $NH(SiH_3)_2$ have trigonal planar skeleton. The correct statement(s) about the compounds is/are
- A) N–Si bond length in $NH(SiH_3)_2 <$ N–Si bond length in $N(SiH_3)_3$
- B) Si–N–Si bond angle in $NH(SiH_3)_2 >$ Si–N–Si bond angle in $N(SiH_3)_3$
- C) Back bond strength in $NH(SiH_3)_2 >$ back bond strength in $N(SiH_3)_3$
- D) N–Si bond length in $NH(SiH_3)_2 >$ N–Si bond length in $N(SiH_3)_3$

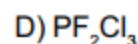
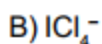
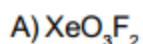
28. The molecular orbital electronic configuration of molecular species X_2 is given below



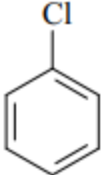
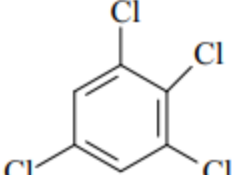
Which of the following conclusions is/are correct?

- A) It is the excited electronic configuration of X_2
 - B) It is more stable than the ground state of X_2
 - C) Bond order of X_2 in the excited state is one
 - D) X_2 is more likely to dissociate into two X atoms in the ground state than in the excited state
29. The correct statement(s) among the following is/are
- A) Diamagnetic C_2 molecules have been detected in vapour phase
 - B) Double bond in C_2 consists of both π - bonds because of the presence of four electrons in π_{2p} molecular orbitals
 - C) Assuming z axis as the internuclear axis, molecular orbitals obtained from $2p_x$ and $2p_y$ orbitals are not symmetrical around the bond axis.
 - D) The energy of bonding and antibonding molecular orbitals, respectively, are lower and higher than that of the original atomic orbitals.
30. Identify the correct statement(s) from the following
- A) $NH_4^+ > NH_3 > NH_2^-$: order of bond angle
 - B) In NH_4NO_3 , both the nitrogen atoms have sp^3 hybridisation
 - C) Bond energy of C_2 molecule is greater than that of O_2 molecule
 - D) Bond length of C_2 molecule is greater than that of O_2 molecule.

31. Which of the following species do(es) not contain 90° bond angle(s)?



Section V - Numerical type questions

32. The dipole moment of  is 1.5 D and that of  is $\frac{x}{2}$ D. Find the value of x

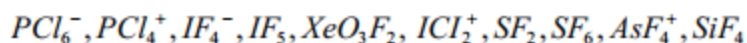
33. Maximum number of atoms that can be accommodated in a plane in the allene molecule ($\text{CH}_2 = \text{C} = \text{CH}_2$) is —

34. Consider the following table regarding electronic structure of molecules

Total number of electron pairs around central atom	Total number of lone pair(s) on central atom	Shape of molecule
5	p	linear
q	1	see saw
4	r	bent shape
s	2	square planar
5	t	T-shape

Find the value of $p + q + r - s - t$

35. Find the number of molecules/ions among the following in which d-orbital(s) is (are) not involved in hybridisation of the central atom



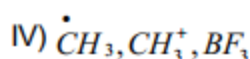
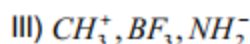
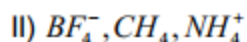
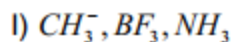
36. The hybridization of central atom in compounds A, B, C and D are sp^3d , sp^3 , sp^2 and sp respectively.

If compounds A and D have the same molecular shape as that of I_3^- and compounds B and C have the same molecular shape as that of H_2O , then calculate the value of $P+Q+R+S$ where P, Q, R and S are the number of lone pair(s) on central atom in compounds A, B, C and D respectively.

Section-VI - Matrix match type

37. Match the items of List I with those of List II.

List - I (Set of species)

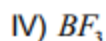
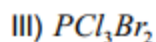
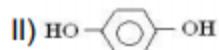
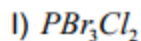


A) I - S, II-PS, III - QR, IV - PR

C) I-S, II-QS, III - QR, IV - QR

38. Match the following List - I with List - II

List - I



A) I - QS; II - PR, III - QR, IV - PS

C) I - QS, II - PS, III - QR, IV - PS

List - II (Features)

P) Same hybridisation

Q) Same bond angle

R) All are planar species

S) All are non planar species

T) Contains both planar and non planar species

B) I-T, II-PQS, III-R, IV - PR

D) I - T, II-PQS, III-R, IV - PQR

List - II

P) Planar structure

Q) Non planar structure

R) Non-zero dipole moment

S) Zero dipole moment

B) I - QR, II - QR, III - QS, IV - PS

D) I - QR, II - QS, III - QS, IV - PS