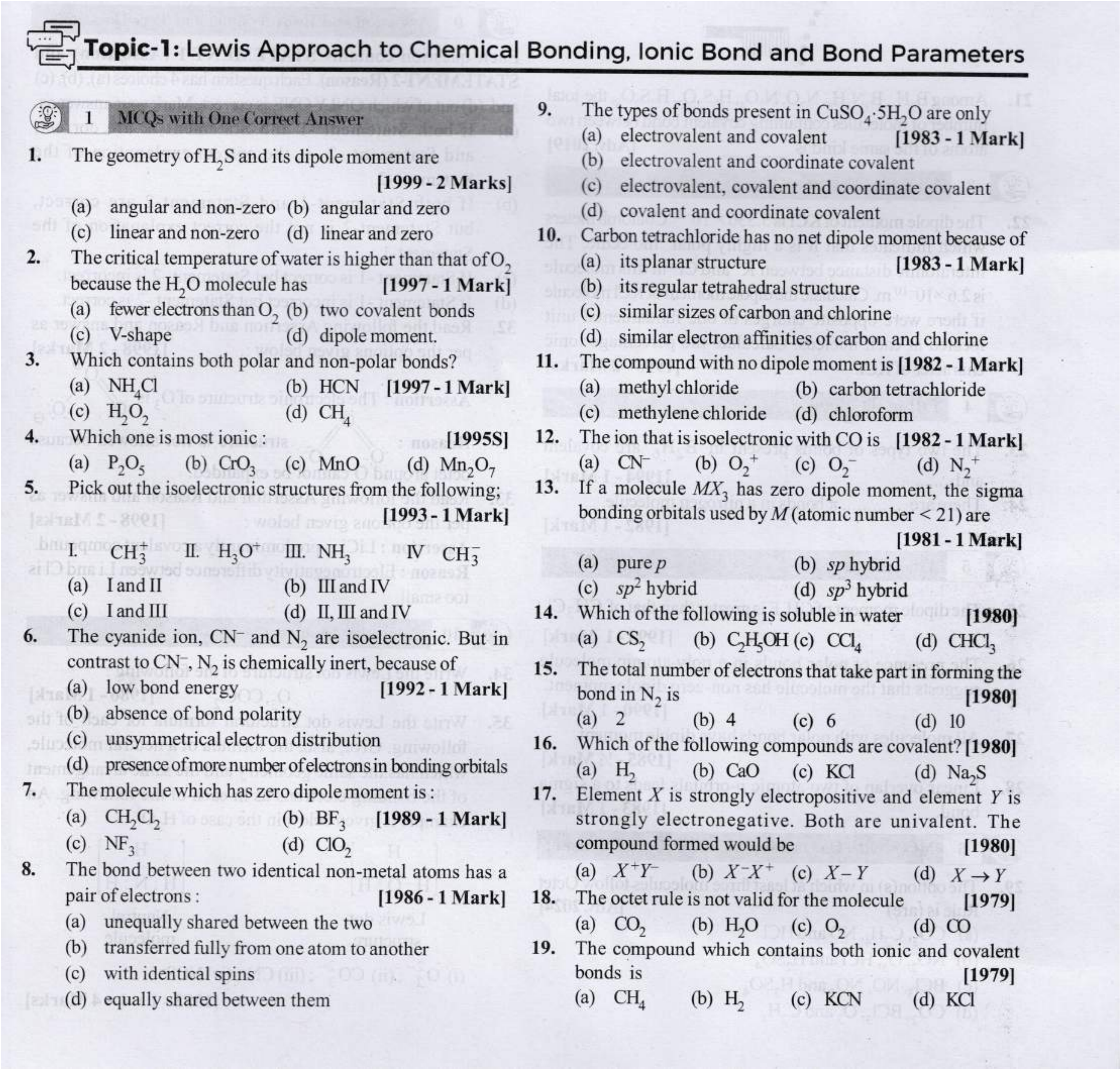
Chapter
Chemical Bonding and Molecular Structure



Topic-1: Lewis Approach to Chemical Bonding, Ionic Bond and Bond Parameters

1 MCQs with One Correct Answer

1. The geometry of H_2S and its dipole moment are **[1999 - 2 Marks]**
   (a) angular and non-zero (b) angular and zero
   (c) linear and non-zero (d) linear and zero

2. The critical temperature of water is higher than that of O_2 because the H_2O molecule has **[1997 - 1 Mark]**
   (a) fewer electrons than O_2 (b) two covalent bonds
   (c) V-shape (d) dipole moment.

3. Which contains both polar and non-polar bonds?
   (a) NH_4Cl (b) HCN **[1997 - 1 Mark]**
   (c) H_2O_2 (d) CH_4

4. Which one is most ionic : **[1995S]**
   (a) P_2O_5 (b) CrO_3 (c) MnO (d) Mn_2O_7

5. Pick out the isoelectronic structures from the following; **[1993 - 1 Mark]**
   I. CH_3^+ II. H_3O^+ III. NH_3 IV CH_3^-
   (a) I and II (b) III and IV
   (c) I and III (d) II, III and IV

6. The cyanide ion, CN^- and N_2 are isoelectronic. But in contrast to CN^-, N_2 is chemically inert, because of
   (a) low bond energy **[1992 - 1 Mark]**
   (b) absence of bond polarity
   (c) unsymmetrical electron distribution
   (d) presence of more number of electrons in bonding orbitals

7. The molecule which has zero dipole moment is :
   (a) CH_2Cl_2 (b) BF_3 **[1989 - 1 Mark]**
   (c) NF_3 (d) ClO_2

8. The bond between two identical non-metal atoms has a pair of electrons : **[1986 - 1 Mark]**
   (a) unequally shared between the two
   (b) transferred fully from one atom to another
   (c) with identical spins
   (d) equally shared between them

9. The types of bonds present in $CuSO_4 \cdot 5H_2O$ are only
   (a) electrovalent and covalent **[1983 - 1 Mark]**
   (b) electrovalent and coordinate covalent
   (c) electrovalent, covalent and coordinate covalent
   (d) covalent and coordinate covalent

10. Carbon tetrachloride has no net dipole moment because of
    (a) its planar structure **[1983 - 1 Mark]**
    (b) its regular tetrahedral structure
    (c) similar sizes of carbon and chlorine
    (d) similar electron affinities of carbon and chlorine

11. The compound with no dipole moment is **[1982 - 1 Mark]**
    (a) methyl chloride (b) carbon tetrachloride
    (c) methylene chloride (d) chloroform

12. The ion that is isoelectronic with CO is **[1982 - 1 Mark]**
    (a) CN^- (b) O_2^+ (c) O_2^- (d) N_2^+

13. If a molecule MX_3 has zero dipole moment, the sigma bonding orbitals used by M (atomic number < 21) are **[1981 - 1 Mark]**
    (a) pure p (b) sp hybrid
    (c) sp^2 hybrid (d) sp^3 hybrid

14. Which of the following is soluble in water **[1980]**
    (a) CS_2 (b) C_2H_5OH (c) CCl_4 (d) $CHCl_3$

15. The total number of electrons that take part in forming the bond in N_2 is **[1980]**
    (a) 2 (b) 4 (c) 6 (d) 10

16. Which of the following compounds are covalent? **[1980]**
    (a) H_2 (b) CaO (c) KCl (d) Na_2S

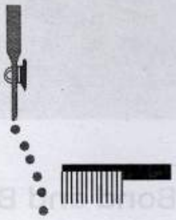
17. Element X is strongly electropositive and element Y is strongly electronegative. Both are univalent. The compound formed would be **[1980]**
    (a) X^+Y^- (b) X^-X^+ (c) $X-Y$ (d) $X \rightarrow Y$

18. The octet rule is not valid for the molecule **[1979]**
    (a) CO_2 (b) H_2O (c) O_2 (d) CO

19. The compound which contains both ionic and covalent bonds is **[1979]**
    (a) CH_4 (b) H_2 (c) KCN (d) KCl

2 Integer Value Answer

20. Consider the following compounds in the liquid form: O_2, HF, H_2O, NH_3, H_2O_2, CCl_4, $CHCl_3$, C_6H_6, C_6H_5Cl. When a charged comb is brought near their flowing stream, how many of them show deflection as per the following figure? **[Adv. 2020]**



21. Among B_2H_6, $B_3N_3H_6$, N_2O, N_2O_4, $H_2S_2O_3$, $H_2S_2O_8$, the total number of molecules containing covalent bond between two atoms of the same kind is _______ **[Adv. 2019]**

3 Numeric / New Stem Based Questions

22. The dipole moment of KCl is 3.336×10^{-29} Coulomb meters which indicates that it is a highly polar molecule. The interatomic distance between K^+ and Cl^- in this molecule is 2.6×10^{-10} m. Calculate the dipole moment of KCl molecule if there were opposite charges of one fundamental unit located at each nucleus. Calculate the percentage ionic character of KCl. **[1993 - 2 Marks]**

4 Fill in the Blanks

23. The two types of bonds present in B_2H_6 are covalent and .... **[1994 - 1 Mark]**

24. There are .... π bonds in a nitrogen molecule. **[1982 - 1 Mark]**

5 True / False

25. The dipole moment of CH_3F is greater than that of CH_3Cl. **[1993 - 1 Mark]**

26. The presence of polar bonds in a poly-atomic molecule suggests that the molecule has non-zero dipole moment. **[1990 - 1 Mark]**

27. All molecules with polar bonds have dipole moment. **[1985 - ½ Mark]**

28. Linear overlap of two atomic *p*-orbitals leads to a sigma bond. **[1983 - 1 Mark]**

6 MCQs with One or More than One Correct Answer

29. The option(s) in which at least three molecules follow Octet Rule is (are) **[Adv. 2024]**

(a) CO_2, C_2H_4, NO and HCl

(b) NO_2, O_3, HCl and H_2SO_4

(c) BCl_3, NO, NO_2 and H_2SO_4

(d) CO_2, BCl_3, O_3 and C_2H_4

30. Each of the following options contains a set of four molecules. Identify the option(s) were all four molecules posses permanent dipole moment at room temperature. **[Adv. 2019]**

(a) BF_3, O_3, SF_6, XeF_6

(b) NO_2, NH_3, $POCl_3$, CH_3Cl

(c) SO_2, C_6H_5Cl, H_2Se, BrF_5

(d) $BeCl_2$, CO_2, BCl_3, $CHCl_3$

31. The molecules that will have dipole moment are **[1992 - 1 Mark]**

(a) 2, 2-dimethylpropane

(b) *trans*-2-pentene

(c) *cis*-3-hexene

(d) 2,2,3,3-tetramethylbutane

9 Assertion and Reason /Statement Type Questions

Each question contains **STATEMENT-1 (Assertion)** and **STATEMENT-2 (Reason)**. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct. Mark your answer as

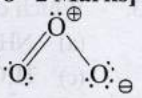
(a) If both Statement -1 and Statement -2 are correct, and Statement -2 is the correct explanation of the Statement -2.

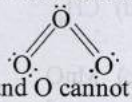
(b) If both Statement-1 and Statement-2 are correct, but Statement-2 is not the correct explanation of the Statement-1.

(c) If Statement -1 is correct but Statement -2 is incorrect.

(d) If Statement -1 is incorrect but Statement -2 is correct.

32. Read the following Assertion and Reason and answer as per the options given below : **[1998 - 2 Marks]**

Assertion : The electronic structure of O_3 is 

Reason :  structure is not allowed because octet around O cannot be expanded.

33. Read the following Assertion and Reason and answer as per the options given below : **[1998 - 2 Marks]**

Assertion : LiCl is predominantly a covalent compound.

Reason : Electronegativity difference between Li and Cl is too small.

10 Subjective Problems

34. Write the Lewis dot structure of the following :

O_3, $COCl_2$ **[1986 - 1 Mark]**

35. Write the Lewis dot structural formula for each of the following. Give, also, the formula of a neutral molecule, which has the same geometry and the same arrangement of the bonding electrons as in each of the following. An example is given below in the case of H_3O^+ :

$$\left[\begin{array}{c} \mathrm{H} \\ \mathrm{H}:\ddot{\mathrm{O}}:\mathrm{H} \end{array}\right]^{+} \qquad\qquad \left[\begin{array}{c} \mathrm{H} \\ \mathrm{H}:\ddot{\mathrm{N}}:\mathrm{H} \end{array}\right]$$

Lewis dot structure — Neutral molecule

(i) O_2^{2-} ; (ii) CO_3^{2-} ; (iii) CN^-; (iv) NCS^-

[1983 - 1 × 4 = 4 Marks]

Topic-2: VSEPR Theory and Hybridisation

1 MCQs with One Correct Answer

1. The species having pyramidal shape is : **[2010]**
(a) SO_3 (b) BrF_3 (c) SiO_3^{2-} (d) OSF_2

2. Which species has the maximum number of lone pair of electrons on the central atom? **[2005S]**
(a) $[ClO_3]^-$ (b) XeF_4 (c) SF_4 (d) $[I_3]^-$

3. Which of the following are isoelectronic and isostructural? NO_3^-, CO_3^{2-}, ClO_3^-, SO_3 **[2003S]**
(a) NO_3^-, CO_3^{2-} (b) SO_3, NO_3^-
(c) ClO_3^-, CO_3^{2-} (d) CO_3^{2-}, SO_3

4. Specify the coordination geometry around and hybridisation of N and B atoms in a 1 : 1 complex of BF_3 and NH_3 **[2002S]**
(a) N : tetrahedral, sp^3; B : tetrahedral, sp^3
(b) N : pyramidal, sp^3; B : pyramidal, sp^3
(c) N : pyramidal, sp^3; B : planar, sp^2
(d) N : pyramidal, sp^3; B : tetrahedral, sp^3

5. The correct order of hybridization of the central atom in the following species NH_3, $[PtCl_4]^{2-}$, PCl_5 and BCl_3 is **[2001S]**
(a) dsp^2, dsp^3, sp^2, sp^3 (b) sp^3, dsp^2, sp^3d, sp^2
(c) dsp^2, sp^2, sp^3, dsp^3 (d) dsp^2, sp^3, sp^2, dsp^3

6. The hybridisation of atomic orbitals of nitrogen in NO_2^+, NO_3^- and NH_4^+ are **[2000S]**
(a) sp, sp^3 and sp^2 respectively
(b) sp, sp^2 and sp^3 respectively
(c) sp^2, sp and sp^3 respectively
(d) sp^2, sp^3 and sp respectively

7. Molecular shapes of SF_4, CF_4 and XeF_4 are **[2000S]**
(a) the same, with 2, 0 and 1 lone pairs of electrons respectively
(b) the same, with 1, 1 and 1 lone pairs of electrons respectively
(c) different, with 0, 1 and 2 lone pairs of electrons respectively
(d) different, with 1, 0 and 2 lone pairs of electrons respectively

8. The geometry and the type of hybrid orbital present about the central atom in BF_3 is **[1998 - 2 Marks]**
(a) linear, sp (b) trigonal planar, sp^2
(c) tetrahedral, sp^3 (d) pyramidal, sp^3.

9. Which one of the following compounds has sp^2 hybridization? **[1997 - 1 Mark]**
(a) CO_2 (b) SO_2 (c) N_2O (d) CO

10. Among the following species, identify the isostructural pairs. NF_3, NO_3^-, BF_3, H_3O^+, HN_3 **[1996 - 1 Mark]**
(a) $[NF_3, NO_3^-]$ and $[BF_3, H_3O^+]$
(b) $[NF_3, HN_3]$ and $[NO_3^-, BF_3]$
(c) $[NF_3, H_3O^+]$ and $[NO_3^-, BF_3]$
(d) $[NF_3, H_3O^+]$ and $[HN_3, BF_3]$

11. The type of hybrid orbitals used by the chlorine atom in ClO_2^- is **[1992 - 1 Mark]**
(a) sp^3 (b) sp^2
(c) sp (d) none of these

12. The compound in which $\overset{*}{C}$ uses its sp^3 hybrid orbitals for bond formation is : **[1989 - 1 Mark]**
(a) $H\overset{*}{C}OOH$ (b) $(H_2N)_2\overset{*}{C}O$
(c) $(CH_3)_3\overset{*}{C}OH$ (d) $CH_3\overset{*}{C}HO$

13. The species in which the central atom uses sp^2 hybrid orbitals in its bonding is **[1988 - 1 Mark]**
(a) PH_3 (b) NH_3 (c) CH_3^+ (d) SbH_3

14. The hybridisation of sulphur in sulphur dioxide is : **[1986 - 1 Mark]**
(a) sp (b) sp^3 (c) sp^2 (d) dsp^2

2 Integer Value Answer

15. Among $[I_3]^+$, $[SiO_4]^{4-}$, SO_2Cl_2, XeF_2, SF_4, ClF_3, $Ni(CO)_4$, XeO_2F_2, $[PtCl_4]^{2-}$, XeF_4, and $SOCl_2$, the total number of species having sp^3 hybridised central atom is ______. **[Adv. 2023]**

16. The sum of the number of lone pairs of electrons on each central atom in the following species is
$[TeBr_6]^{2-}$, $[BrF_2]^+$, SNF_3 and $[XeF_3]^-$
(Atomic numbers: N = 7, F = 9, S = 16, Br = 35, Te = 52, Xe = 54) **[Adv. 2017]**

17. 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 molecule(s)/ion(s) where the hybridization of the central atom does not have contribution from the *d*-orbital(s) is [Atomic number : S = 16, Cl = 17, I = 53 and Xe = 54] **[Adv. 2015]**

18. A list of species having the formula XZ_4 is given below.
XeF_4, SF_4, SiF_4, BF_4^-, BrF_4^-, $[Cu(NH_3)_4]^{2+}$, $[FeCl_4]^{2-}$, $[CoCl_4]^{2-}$ and $[PtCl_4]^{2-}$.
Defining shape on the basis of the location of *X* and *Z* atoms, the total number of species having a square planar shape is **[Adv. 2014]**

19. Based on VSEPR theory, the number of 90 degree F–Br–F angles in BrF_5 is **[2010]**

4 Fill in the Blanks

20. The shape of $[CH_3]^+$ is .... **[1990 - 1 Mark]**

21. The angle between two covalent bonds is maximum in .... (CH_4, H_2O, CO_2) **[1981 - 1 Mark]**

5 True / False

22. sp^2 hybrid orbitals have equal *s* and *p* character. **[1987 - 1 Mark]**

23. In benzene, carbon uses all the three p-orbitals for hybridisation. **[1987 - 1 Mark]**

24. $SnCl_2$ is a non-linear molecule. **[1985 - ½ Mark]**

6 MCQs with One or More than One Correct Answer

25. The compound(s) with TWO lone pairs of electrons on the central atom is(are **[Adv. 2016]**
(a) BrF_5 (b) ClF_3 (c) XeF_4 (d) SF_4

26. The linear structure is assumed by : **[1991 - 1 Mark]**

(a) $SnCl_2$ (b) NCO^- (c) CS_2 (d) NO_2^+

27. CO_2 is isostructural with : **[1986 - 1 Mark]**

(a) $HgCl_2$ (b) $SnCl_2$ (c) C_2H_2 (d) NO_2

7 Match the Following

28. Based on **VSEPR** model, match the xenon compounds given in **List-I** with the corresponding geometries and the number of lone pairs on xenon given in **List-II** and choose the correct option. **[Adv. 2024)]**

List-I	List-II
(P) XeF_2	(1) Trigonal bipyramidal and two lone pair of electrons
(Q) XeF_4	(2) Tetrahedral and one lone pair of electrons
(R) XeO_3	(3) Octahedral and two lone pair of electrons
(S) XeO_3F_2	(4) Trigonal bipyramidal and no lone pair of electrons
	(5) Trigonal bipyramidal and three lone pair of electrons

(a) P-5, Q-2, R-3, S-1 (b) P-5, Q-3, R-2, S-4

(c) P-4, Q-3, R-2, S-1 (d) P-4, Q-2, R-5, S-3

10 Subjective Problems

29. Draw the structure of XeF_4 and OSF_4 according to VSEPR theory, clearly indicating the state of hybridisation of the central atom and lone pair of electrons (if any) on the central atom. **[2004 - 2 Marks]**

30. Using VSEPR theory, draw the shape of PCl_5 and BrF_5. **[2003 - 2 Marks]**

31. Interpret the non-linear shape of H_2S molecule and non-planar shape of PCl_3 using valence shell electron pair repulsion (VSEPR) theory. (Atomic numbers : H = 1, P = 15, S = 16, Cl = 17.) **[1998 - 4 Marks]**

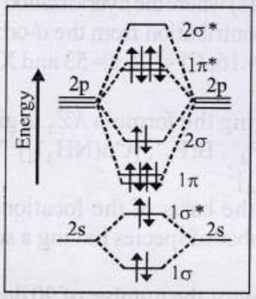
32. Using the VSEPR theory, identify the type of hybridization and draw the structure of OF_2. What are the oxidation states of O and F ? **[1994 - 3 Marks]**

Topic-3: VBT, MOT and Hydrogen Bonding

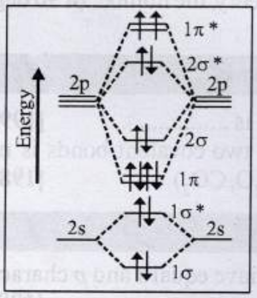
1 MCQs with One Correct Answer

1. The correct molecular orbital diagram for F_2 molecule in the ground state is **[Adv. 2023]**

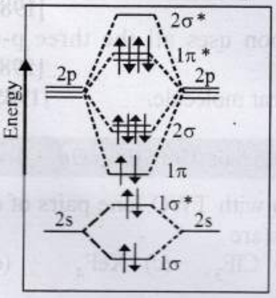
(a)



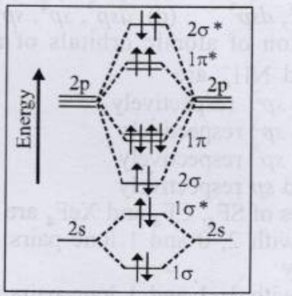
(b)



(c)



(d)



2. Assuming 2*s*-2*p* mixing is **NOT** operative, the paramagnetic species among the following is **[Adv. 2014]**

(a) Be_2 (b) B_2 (c) C_2 (d) N_2

3. Assuming that Hund's rule is violated, the bond order and magnetic nature of the diatomic molecule B_2 is **[2010]**

(a) 1 and diamagnetic (b) 0 and dimagnetic

(c) 1 and paramagnetic (d) 0 and paramagnetic

4. The species having bond order different from that in CO is **[2007]**

(a) NO^- (b) NO^+ (c) CN^- (d) N_2

5. Among the following, the paramagnetic compound is **[2007]**

(a) Na_2O_2 (b) O_3 (c) N_2O (d) KO_2

6. According to molecular orbital theory, which of the following statement about the magnetic character and bond order is correct regarding O_2^+ ? **[2004S]**

(a) Paramagnetic and Bond order < O_2

(b) Paramagnetic and Bond order > O_2

(c) Diamagnetic and Bond order < O_2

(d) Diamagnetic and Bond order > O_2

7. Which of the following molecular species has unpaired electron(s) ? **[2002S]**

(a) N_2 (b) F_2 (c) O_2^- (d) O_2^{2-}

8. Identify the least stable ion amongst the following : **[2002S]**
(a) Li^- (b) Be^- (c) B^- (d) C^-

9. The common features among the species CN^-, CO and NO^+ are **[2001S]**
(a) bond order three and isoelectronic
(b) bond order three and weak field ligands
(c) bond order two and π–acceptors
(d) isoelectronic and weak field ligands

10. The correct order of increasing C — O bond length of CO, CO_3^{2-}, CO_2, is **[1999 - 2 Marks]**
(a) $CO_3^{2-} < CO_2 < CO$ (b) $CO_2 < CO_3^{2-} < CO$
(c) $CO < CO_3^{2-} < CO_2$ (d) $CO < CO_2 < CO_3^{2-}$

11. The number and type of bonds between two carbon atoms in CaC_2 are : **[1996 - 1 Mark]**
(a) one sigma (σ) and one pi (π) bonds
(b) one sigma (σ) and two pi (π) bonds
(c) one sigma (σ) and one and a half pi (π) bonds
(d) one sigma (σ) bond.

12. Number of paired electrons in O_2 molecule is : **[1995S]**
(a) 7 (b) 8 (c) 16 (d) 14

13. The maximum possible number of hydrogen bonds a water molecule can form is **[1992 - 1 Mark]**
(a) 2 (b) 4 (c) 3 (d) 1

14. Which of the following is paramagnetic? **[1989 - 1 Mark]**
(a) O_2^- (b) CN^- (c) CO (d) NO^+

15. The molecule which has pyramidal shape is : **[1989 - 1 Mark]**
(a) PCl_3 (b) SO_3
(c) CO_3^{2-} (d) NO_3^-

16. The molecule that has linear structure is **[1988 - 1 Mark]**
(a) CO_2 (b) NO_2 (c) SO_2 (d) SiO_2

17. Hydrogen bonding is maximum in **[1987 - 1 Mark]**
(a) Ethanol (b) Diethyl ether
(c) Ethyl chloride (d) Triethylamine

18. The hydrogen bond is strongest in : **[1986 - 1 Mark]**
(a) O–H...........S (b) S–H...........O
(c) F–H...........F (d) F–H...........O

19. The molecule having one unpaired electron is: **[1985 - 1 Mark]**
(a) NO (b) CO (c) CN^- (d) O_2

20. On hybridization of one *s* and one *p* orbitals we get : **[1984 - 1 Mark]**
(a) two mutually perpendicular orbitals
(b) two orbitals at 180°
(c) four orbitals directed tetrahedrally
(d) three orbitals in a plane

21. Which one among the following does not have the hydrogen bond? **[1983 - 1 Mark]**
(a) phenol (b) liquid NH_3
(c) water (d) liquid HCl

2 Integer Value Answer

22. Thermal decomposition of $AgNO_3$ produces two paramagnetic gases. The total number of electrons present in the antibonding molecular orbitals of the gas that has the higher number of unpaired electrons is _____. **[Adv. 2022]**

3 Numeric / New Stem Based Questions

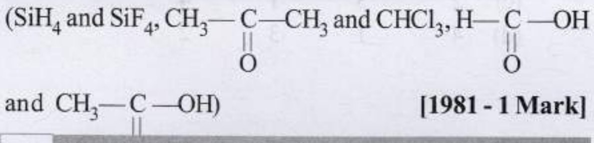
23. Among H_2, He_2^+, Li_2, Be_2, B_2, C_2, N_2, O_2^- and F_2, the number of diamagnetic species is
(Atomic numbers: H = 1, He = 2, Li = 3, Be = 4, B = 5, C = 6, N = 7, O = 8, F = 9) **[Adv. 2017]**

4 Fill in the Blanks

24. When N_2 goes to N_2^+, the N–N bond distance ..., and when O_2 goes to O_2^+ the O–O bond distance.... **[1996 - 1 Mark]**

25. .... hybrid orbitals of nitrogen atom are involved in the formation of ammonium ion. **[1982 - 1 Mark]**

26. Pair of molecules which forms strongest intermolecular hydrogen bond is ....



(SiH_4 and SiF_4, $CH_3—\underset{\underset{O}{\|}}{C}—CH_3$ and $CHCl_3$, $H—\underset{\underset{O}{\|}}{C}—OH$ and $CH_3—\underset{\underset{O}{\|}}{C}—OH$) **[1981 - 1 Mark]**

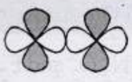
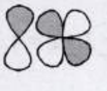
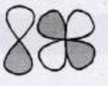
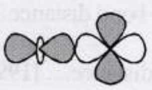
6 MCQs with One or More than One Correct Answer

27. For diatomic molecules, the correct statement(s) about the molecular orbitals formed by the overlap of two $2p_z$ orbitals is (are) **[Adv. 2022]**
(a) σ orbital has a total of two nodal planes.
(b) σ^* orbital has one node in the *xz*-plane containing the molecular axis.
(c) π orbital has one node in the plane which is perpendicular to the molecular axis and goes through the center of the molecule.
(d) π^* orbital has one node in the *xy*-plane containing the molecular axis.

28. According to Molecular Orbital Theory, **[Adv. 2016]**
(a) C_2^{2-} is expected to be diamagnetic
(b) O_2^{2+} is expected to have a longer bond length than O_2
(c) N_2^+ and N_2^- have the same bond order
(d) He_2^+ has the same energy as two isolated He atoms

7 Match the Following

29. Match the orbital overlap figures shown in List-I with the description given in List-II and select the correct answer using the code given below the lists. **[Adv. 2014]**

List-I		List-II
P.		1. $p-d\,\pi$ antibonding
Q.		2. $d-d\,\sigma$ bonding
R.		3. $p-d\,\pi$ bonding
S.		4. $d-d\,\sigma$ antibonding

Code:

	P	**Q**	**R**	**S**
(a)	2	1	3	4
(b)	4	3	1	2
(c)	2	3	1	4
(d)	4	1	3	2

30. Match each of the diatomic molecules in **Column I** with its property/properties in **Column II.** **[2009]**

Column I	**Column II**
(A) B_2	(p) Paramagnetic
(B) N_2	(q) Undergoes oxidation
(C) O_2^-	(r) Undergoes reduction
(D) O_2	(s) Bond order ≥ 2
	(t) Mixing of '*s*' and '*p*' orbital

10 Subjective Problems

31. Arrange the following :

(i) N_2, O_2, F_2, Cl_2 in increasing order of bond dissociation energy. **[1988 - 1 Mark]**

(ii) Increasing strength of hydrogen bonding (X–H–X) : O, S, F, Cl, N **[1991 - 1 Mark]**

(iii) In the decreasing order of the O – O bond length present in them **[2004 - 4 Marks]**

O_2, KO_2 and $O_2[AsF_4]$

32. How many sigma bonds and how many pi-bonds are present in a benzene molecule? **[1985 - 1 Mark]**

33. Water is liquid while H_2S is a gas at room temperature. Why? **[1978]**

Answer Key

Topic-1 : Lewis Approach to Chemical Bonding, Ionic Bond and Bond Parameters

1. (a) **2.** (d) **3.** (c) **4.** (c) **5.** (d) **6.** (b) **7.** (b) **8.** (d) **9.** (c) **10.** (b)
11. (b) **12.** (a) **13.** (c) **14.** (b) **15.** (c) **16.** (a) **17.** (a) **18.** (d) **19.** (c) **20.** (6)
21. (4) **22.** (80.09) **23.** (banana bond) **24.** (2) **25.** (False) **26.** (False) **27.** (False) **28.** (True) **29.** (a, d)
30. (b,c) **31.** (b,c) **32.** (a) **33.** (c)

Topic-2 : VSEPR Theory and Hybridisation

1. (d) **2.** (d) **3.** (a) **4.** (a) **5.** (b) **6.** (b) **7.** (d) **8.** (b) **9.** (b) **10.** (c)
11. (a) **12.** (c) **13.** (c) **14.** (c) **15.** (5) **16.** (6) **17.** (4) **18.** (4) **19.** (4)
20. (Planar) **21.** (CO_2) **22.** (False) **23.** (False) **24.** (True) **25.** (b,c) **26.** (b,c,d) **27.** (a,c) **28.** (b)

Topic-3 : VBT, MOT and Hydrogen Bonding

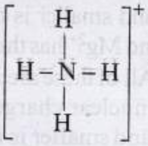
1. (c) **2.** (c) **3.** (a) **4.** (a) **5.** (d) **6.** (b) **7.** (c) **8.** (b) **9.** (a) **10.** (d)
11. (b) **12.** (d) **13.** (b) **14.** (a) **15.** (a) **16.** (a) **17.** (a) **18.** (c) **19.** (a) **20.** (b)
21. (d) **22.** (6) **23.** (6) **24.** (Increases, decreases) **25.** (sp^3) **27.** (a, d) **28.** (a, c) **29.** (c)
30. ((A) – p, r, t ; (B) – s,t ; (C) – p, q ; (D) – p, q, s)

Hints & Solutions

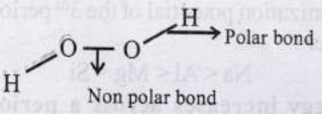
Topic-1: Lewis Approach to Chemical Bonding, Ionic Bond and Bond Parameters

1. **(a)** Hybridisation of S in $H_2S = \frac{1}{2}(6+2+0-0) = 4$
$\therefore$ S has sp^3 hybridisation and 2 lone pair of electrons in H_2S.
$\therefore$ It has angular geometry and so it has non-zero value of dipole moment.

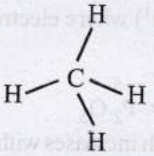
2. **(d)** Critical temperature of water is higher than O_2 because H_2O molecule has dipole moment which is due to its V-shape.

3. **(c)** (a) 
$\left[\begin{array}{c} H \\ | \\ H-N-H \\ | \\ H \end{array}\right]^+ [Cl]^-$ – It has ionic and non-polar covalent bond

(b) $H-C\equiv N$ - It has ionic and polar covalent bonds.

(c) 

It has polar and non polar both type of covalent bonds.

(d) 

It has non polar covalent bonds only.

4. **(c)**
(i) P_2O_5 will be more covalent than other metallic oxides.
(ii) Oxidation state of Mn is + 7 in Mn_2O_7, oxidation state of Cr in CrO_3 is + 6 and oxidation state of Mn is + 2 in MnO.
$\therefore$ MnO is most ionic.
P_2O_5, being a non-metallic oxide will definitely be more covalent than the other metallic oxides. Further, we know that higher the polarising power of the cation (higher for higher oxidation state of the similar size cations) more will be the covalent character. Here Mn is in +7 O.S in Mn_2O_7, Cr in +6 in CrO_3 and Mn in +2 in MnO. So, MnO is the most ionic and Mn_2O_7 is the most covalent.

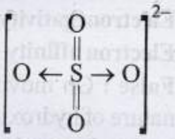
5. **(d)** No. of e^- in $CH_3^+ = 6+3-1 = 8$
No. of e^- in $H_3O^+ = 3+8-1 = 10$
No. of e^- in $NH_3 = 7+3 = 10$
No. of e^- in $CH_3^- = 6+3+1 = 10$
$\therefore$ H_3O^+, NH_3 and CH_3^- are isoelectronic.

6. **(b)** In N_2, similar atoms are linked to each other and thus, there is no polarity.

7. **(b)** The zero dipole moment of BF_3 is due to its symmetrical (triangular planar) structure. The three fluorine atoms lie at the corners of an equilateral triangle with boron at the centre.
The vectorial addition of the dipole moments of the three bonds gives a net sum of zero because the resultant of any two dipole moments is equal and opposite to the third.

8. **(d)** In covalent bonds, between two identical non-metal, atoms share the pair of electrons equally between them, *e.g.* : F_2, O_2, N_2.

9. **(c)** Ionic bond or electrovalent between Cu^{2+} and SO_4^{2-},

covalent and coordinate in SO_4^{2-} ;  ion.
$\left[\begin{array}{c} O \\ \| \\ O\leftarrow S\rightarrow O \\ \| \\ O \end{array}\right]^{2-}$

10. **(b)** In regular tetrahedral structure, dipole moment of one bond is cancelled by opposite dipole moment of the other bonds.

11. **(b)** $\because$ Carbon tetrachloride having regular geometry and identical atoms attached to bonds has zero dipole moment.

12. **(a)** Isoelectronic species have same number of electrons.
Electrons in $CO = 6+8 = 14$
Electrons in $CN^- = 6+7+1 = 14$

13. **(c)** In trigonal planar geometry (for sp^2 hybridisation), the vector sum of two bond moments is equal and opposite to the dipole moment of third bond.

14. **(b)** $\because$ It forms hydrogen bonds with water.

15. **(c)** $N\equiv N$ $\quad$:N⁝⁝N:

16. **(a)** H_2 $\quad$ $H-H$

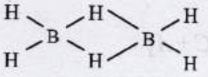
17. **(a)** X^+Y^-
$\because$ Electropositive elements forms cation and electronegative elements forms anion.

18. **(d)** $\because$ after forming the bonds, C has only 6 e^- in its valence shell.

19. **(c)** In KCN, ionic bond is present between K^+ and CN^- and covalent bonds are present between carbon and nitrogen $C\equiv N$.

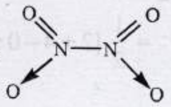
20. **(6)** Polar molecules will be attracted/deflected near charged comb.
Polar molecules : HF, H_2O, NH_3, H_2O_2, $CHCl_3$, C_6H_5Cl (6-polar molecules)
Nonpolar molecules : O_2, CCl_4, C_6H_6

21. **(4)** B_2H_6

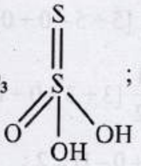


N_2O $\overset{-}{N}=\overset{+}{N}=O \longleftrightarrow N\equiv\overset{+}{N}-\overset{-}{O} \longleftrightarrow \overset{-}{N}-\overset{+}{N}\equiv\overset{+}{O}$

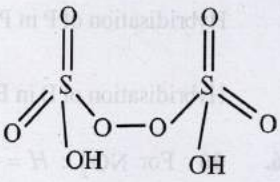
N_2O_4



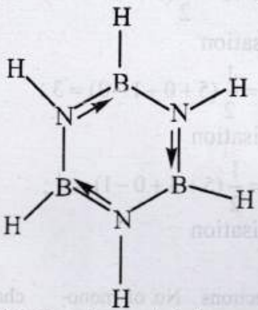
$H_2S_2O_3$



; **$H_2S_2O_8$**



$B_3N_3H_6$



Total No. of molecules containing covalent bond between two atoms of the same kind are 4.

22. **(80.09)** Dipole moment, $\mu = e \times d$ coulombs metre

For KCl $d = 2.6 \times 10^{-10}$ m

For complete separation of unit charge (electronic charge) $(e) = 1.602 \times 10^{-19}$ C

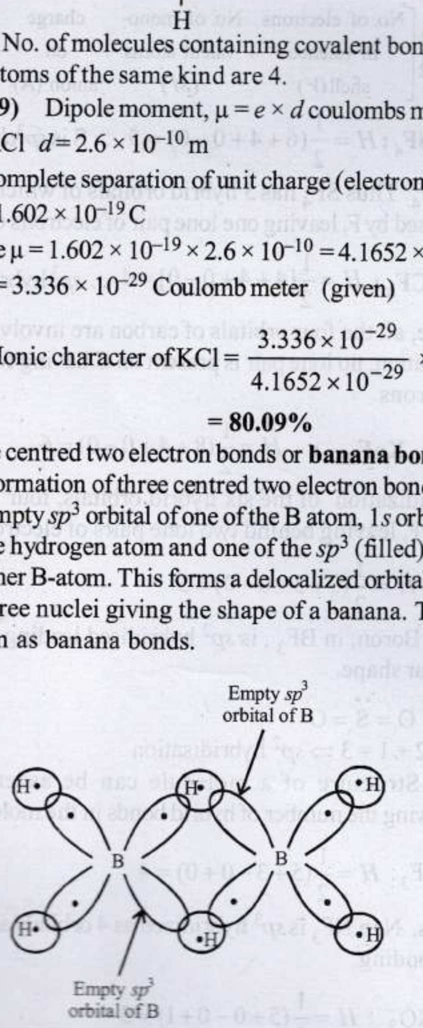
Hence $\mu = 1.602 \times 10^{-19} \times 2.6 \times 10^{-10} = 4.1652 \times 10^{-29}$ Cm

$\mu_{KCl} = 3.336 \times 10^{-29}$ Coulomb meter (given)

$$\therefore \text{ \% Ionic character of KCl} = \frac{3.336 \times 10^{-29}}{4.1652 \times 10^{-29}} \times 100$$

$$= \mathbf{80.09\%}$$

23. Three centred two electron bonds or **banana bond;** The formation of three centred two electron bond is due to one empty sp^3 orbital of one of the B atom, 1*s* orbital of the bridge hydrogen atom and one of the sp^3 (filled) orbital of the other B-atom. This forms a delocalized orbital covering the three nuclei giving the shape of a banana. Thus, also known as banana bonds.



24. **2;** $N\equiv N$ (N_2) has 1σ and 2π bonds. (A triple bond consists of 1σ and 2π bonds)

25. **False :** The C – F distance is less than the C – Cl, although the former involves more charge separation. However, here bond distance has more dominating effect causing dipole moment of CH_3Cl to be more than that of CH_3F.

26. **False :** The presence of polar bonds in a polyatomic molecule does not always lead to a definite dipole moment. This is because the dipole moment is a vector quantity and when the bond moment of one bond is cancelled by the equal but opposite bond moment due to other bond(s), the molecule has zero dipole moment, *e.g.* CO_2, CH_4, CCl_4 *etc.*

27. **False :** Symmetrical molecules with polar bonds have zero dipole moment.

28. **True :** Sigma bond is formed by the overlapping of two *s*-orbitals or one *s* and one *p* or the two *p* orbitals of the two different atoms. Thus, linear overlap of two *p*-orbitals results in formation of a σ– bond.

Axial p-p overlapping

29. **(a, d)** (a) CO_2, C_2H_4 and HCl follow octet rule.

(b) O_3 and HCl and follow octet rule.

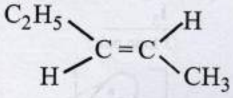
(c) None of them follow octet rule.

(d) CO_2, O_3 and C_2H_4 follow octet rule.

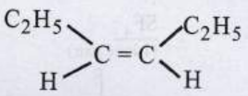
Correct answer is (a) and (d).

30. **(b, c)** Dipole moment (μ) value of BF_3, SF_6, $BeCl_2$, CO_2, BCl_3 is zero.

31. **(b, c)** Alkanes (a) and (d) don't have dipole moment because of symmetry in them.



trans 2-pentene



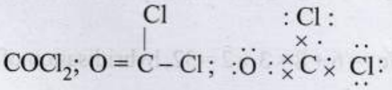
cis 3-hexene

These alkenes are not symmetrical and so, they have dipole moment.

32. **(a)** Both assertion and reason are correct. The reason explains the assertion as the central O-atom cannot have more than 8 electrons (octet).

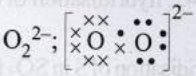
33. **(c)** LiCl is a covalent compound due to the large size of the anion (Cl^-) and small size of Li^+ cation. This generates large amount of polarisation in bond.

34. O_3; $O=O \rightarrow O$; $:\ddot{O}::\ddot{O}:\ddot{O}:$



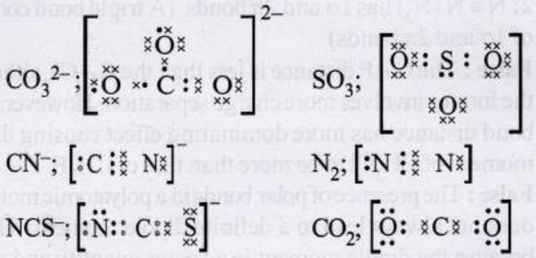
$COCl_2$; $O=\overset{\displaystyle Cl}{\overset{|}{C}}-Cl$; $:\ddot{O}:\overset{\times}{\underset{\times}{C}}\,\ddot{Cl}:$

35. **Lewis dot structure** **Neutral molecule**



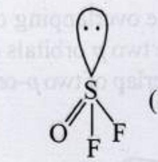
O_2^{2-}; $[:\ddot{O}:\ddot{O}:]^{2-}$

F_2; $[:\ddot{F}:\ddot{F}:]$



Topic-2: VSEPR Theory and Hybridisation

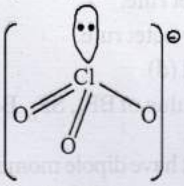
1. **(d)** OSF_2 : $H=\frac{6+2}{2}=4$. It has 1 lone pair.



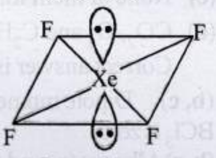
(Shape is trigonal pyramidal)

The shapes of SO_3, BrF_3 and SiO_3^{2-} are triangular planar, see-saw and triangular planar respectively.

2. **(d)** ClO_3^- (1 lone pair) XeF_4^- (2 lone pair)

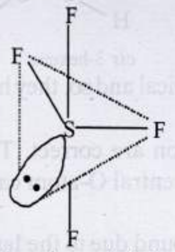


Pyramidal



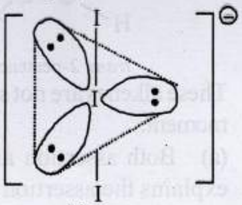
Square planar

SF_4 (1 lone pair)



Irregular tetrahedral

I_3^- (3 lone pair)



Linear

3. **(a)** Isoelectronic species have same number of electrons and isostructural species have same type of hybridisation at central atom.

NO_3^-; No. of $e^- = 7+8\times3+1=32$, hybridisation of N in NO_3^- is sp^3

CO_3^{2-}; No. of $e^- = 6+8\times3+2=32$, hybridisation of C in CO_3^{2-} is sp^3

ClO_3^-; No. of $e^- = 17+8\times3+1=42$, hybridisation of Cl in ClO_3^- is sp^3

SO_3; No. of $e^- = 16+8\times3=40$, hybridisation of S in SO_3 is sp^2

$\therefore$ NO_3^- and CO_3^{2-} are isostructural and isoelectronic.

4. **(a)** $H_3N \rightarrow BF_3$ where both N, B are attaining tetrahedral geomerty.

5. **(b)** $H=\frac{1}{2}[V+M-C+A]$

Hybridisation of N in $NH_3=\frac{1}{2}[5+3-0+0]=4$ $\therefore$ sp^3

Hybridisation of Pt in $[PtCl_4]^{2-}=\frac{1}{2}[2+4-0+2]=4$ $\therefore$ dsp^2

Hybridisation of P in $PCl_5=\frac{1}{2}[5+5-0+0]=5$ $\therefore$ sp^3d

Hybridisation of B in $BCl_3=\frac{1}{2}[3+3-0+0]=3$ $\therefore$ sp^2

6. **(b)** For NO_2^+ : $H=\frac{1}{2}(5+0+0-1)=2$;

$\therefore$ sp hybridisation

For NO_3^- : $H=\frac{1}{2}(5+0+1-0)=3$;

$\therefore$ sp^2 hybridisation

For NH_4^+ : $H=\frac{1}{2}(5+4+0-1)=4$;

$\therefore$ sp^3 hybridisation

7. **(d)**

$$H=\frac{1}{2}\begin{bmatrix}\text{No. of electrons} & \text{No. of mono-} & \text{charge} & \text{charge}\\ \text{in valence} & +\ \text{valent atoms}\ + & \text{on} & -\quad \text{on}\\ \text{shell}\,(V) & (M) & \text{anion (A)} & \text{cation (C)}\end{bmatrix}$$

For SF_4 : $H=\frac{1}{2}(6+4+0-0)=5$, $\therefore$ S is sp^3d hybridised in SF_4. Thus SF_4 has 5 hybrid orbitals of which only four are used by F, leaving one lone pair of electrons on sulphur.

For CF_4 : $H=\frac{1}{2}[4+4+0-0]=4$ $\therefore$ sp^3 hybridisaion

Since, all the four orbitals of carbon are involved in bond formation, no lone pair is present on C having four valence electrons

For XeF_4 : $H=\frac{1}{2}(8+4+0-0)=6$, $\therefore$ sp^3d^2

hybridization of the six hybrid orbitals, four form bond with F, leaving behind two lone pairs of electrons on Xe.

8. **(b)** $H=\frac{1}{2}(3+3+0-0)=3$

$\therefore$ Boron, in BF_3, is sp^2 hybridised leading to trigonal planar shape.

9. **(b)** $O=\ddot{S}=O$

$H=2+1=3 \Rightarrow sp^2$ hybridisation

10. **(c)** Structure of a molecule can be ascertained by knowing the number of hybrid bonds in the molecule. Thus

In NF_3 : $H=\frac{1}{2}(5+3-0+0)=4$

Thus, N in NF_3 is sp^3 hybridized as 4 orbitals are involved in bonding.

In NO_3^- : $H=\frac{1}{2}(5+0-0+1)=3$

Thus, N in NO_3^- is sp^2 hybridized as 3 orbitals are involved in bonding

In BF_3 : $H = \frac{1}{2}(3+3-0+0) = 3$

Thus, B in BF_3 is sp^2 hybridized and 3 orbitals are involved in bonding

In H_3O^+ : $H = \frac{1}{2}(6+3-1+0) = 4$

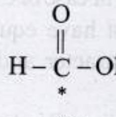
Thus, O in H_3O^+ is sp^3 hybridized as 4 orbitals are involved in bonding.

Thus, isostructural pairs are $[NF_3, H_3O^+]$ and $[NO_3^-, BF_3]$.

11. **(a)** For ClO_2^-, we have, $H = \frac{1}{2}(7+0-0+1)$

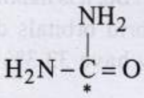
$\Rightarrow H = 4$ or sp^3 hybridisation as 4 orbitals are involved.

12. **(c)** 4σ bonds – sp^3 hybridisation
3σ and 1π bonds – sp^2 hybridisation
2σ and 2π bonds – sp hybridisation
[For hybridization only σ-bonds are considered]



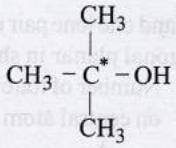
$H-\overset{\overset{O}{\|}}{\underset{*}{C}}-OH$

(a)



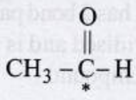
$H_2N-\overset{\overset{NH_2}{|}}{\underset{*}{C}}=O$

(b)



$CH_3-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C^*}}-OH$

(c)



$CH_3-\overset{\overset{O}{\|}}{\underset{*}{C}}-H$

(d)

(a) $3\sigma, 1\pi$ (b) $3\sigma, 1\pi$ (c) 4σ (d) $3\sigma, 1\pi$

$\therefore$ $(CH_3)_3COH$ has 4σ bonds and thus it has sp^3 hybridisation.

13. **(c)** From amongst given species PH_3, NH_3 and SbH_3 are all sp^3 hybridised. Their central atom has both bond pair as well as lone pair of electrons. The lone pair occupy the fourth orbital. CH_3^+ has only three pairs of electrons so it is sp^2 hybridised.

14. **(c)** $H = \frac{1}{2}(V + M - C + A)$

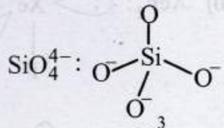
For SO_2, $H = \frac{1}{2}(6+0+0-0) = 3$

$\therefore$ sp^2 hybridisation.

15. **(5)** I_3^+ :

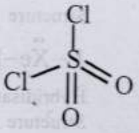
sp^3

; SiO_4^{4-} :



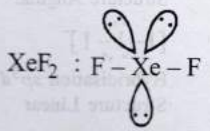
sp^3

SO_2Cl_2 :



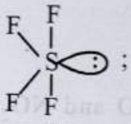
sp^3

; XeF_2 :



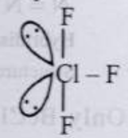
sp^3d

SF_4 :



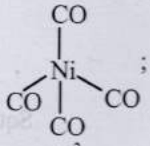
sp^3d

; ClF_3 :



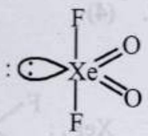
sp^3d

$[Ni(CO)_4]$:



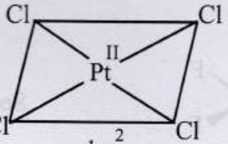
sp^3

; XeO_2F_2 :



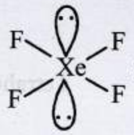
sp^3d

$[PtCl_4]^{2-}$:



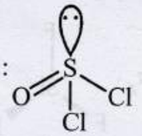
dsp^2

XeF_4 :



sp^3d

; $SOCl_2$:



sp^3

16. **(6)**

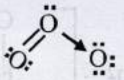
Species	No. of valence e^- with central atom	No. of σ-bonds	No. of lone pairs
$[TeBr_6]^{2-}$	6	6	1
$[BrF_2]^+$	6	2	2
SNF_3	5	4	0
$[XeF_3]^-$	8+1	3	3

Sum of number of lone pairs = 1 + 2 + 0 + 3 = 6

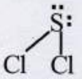
17. **(4)** $Cl-Be-Cl$
Hybridization sp
Structure linear

$N\equiv N-\ddot{\underset{..}{N}}:^-$
Hybridisation sp
Structure linear

$O=\overset{+}{N}\rightarrow O$
Hybridisation sp
Structure Linear



Hybridisation sp^2
Structure Trigonal planar



Hybridisation sp^3

$[Cl-\ddot{I}-Cl]^-$
Hybridisation sp^3d

Structure Angular

$[I-\ddot{I}-I]^-$

Hybridisation sp^3d

Structure Linear

Structure linear

$F-\ddot{Xe}-F$

Hybridisation sp^3d

Structure Linear

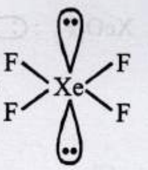
$\overset{-}{N}=\overset{+}{N}=O$

Hybridisation sp

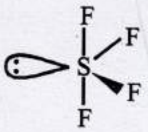
Structure Linear

Only $BeCl_2$, N_3^-, N_2O and NO_2 are linear with sp-hybridisation.

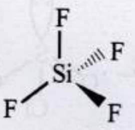
18. **(4)**

XeF_4 :


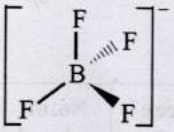
Square planar (sp^3d^2)

SF_4 :


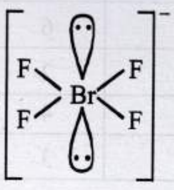
See-saw (sp^3d)

SiF_4 :


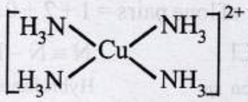
Tetrahedral (sp^3)

BF_4^- :


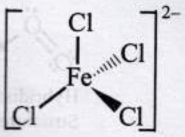
Tetrahedral (sp^3)

BrF_4^- :


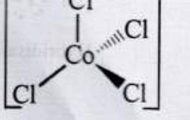
Square planar (sp^3d^2)

$[Cu(NH_3)_4]^{2+}$:


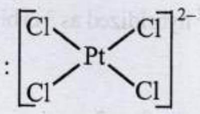
Square planar (dsp^2)

$[FeCl_4]^{2-}$:


Tetrahedral (sp^3)

$[CoCl_4]^{2-}$:


Tetrahedral (sp^3)

$[PtCl_4]^{2-}$:


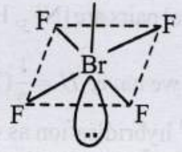
Square planar (dsp^2)

19. **(4)** According to VSEPR theory, number of electron pairs around central atom (Br) are 6.

Five are bond pairs and one is lone pair.

Its geometry is octahedral but due to lone pair –bond pair repulsion, the four fluorine atoms at equatorial positions are forced towards the axial fluorine atom, thus reducing F–Br–F angle from 90° to 84.8°.

The $F_{eq}-Br-F_{eq}$ angle will remain 90°



20. **Planar;** $\overset{+}{C}H_3$ is a carbocation and such a species has a planar shape due to sp^2 hybridisation.

21. **CO_2;** Bond angle in CH_4 is 109°28', in H_2O it is 104.5° and in CO_2 it is 180°. So, it is maximum in case of CO_2.

22. **False :** sp^2 hybrid orbitals do not have equal s and p character. They have 33.3% s-character and 66.7% p-character.

23. **False :** Only two orbitals are used since C in benzene is in sp^2 hybridised state.

24. **True :** $SnCl_2$ has 2 bond pairs and one lone pair of electrons. It is sp^2 hybridised and is trigonal planar in shape.

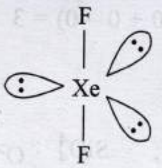
25. **(b, c)**

Compound		Number of lone pairs on central atom
BrF_5	→	1
ClF_3	→	2
XeF_4	→	2
SF_4	→	1

26. **(b, c, d)** $[O=N=O]^+$; $[N\equiv C-O]^-$; $S=C=S$

It can be seen from the structure shown above that CS_2 being sp hybridized has a linear shape and other two molecules are isoelectronic to CS_2, so they are also linear. $SnCl_2$ and SO_2 are sp^2 hybridised and are not linear.

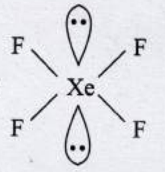
27. **(a, c)** CO_2, $HgCl_2$ and C_2H_2 have linear structure (sp hybridization), while $SnCl_2$ is trigonal planar (sp^2 hybridisation). NO_2 has angular structure (V-shape).

28. **(b)** XeF_2 :


Hybridisation – sp^3d

Geometry – Trigonal bipyramidal

L.P. = 3

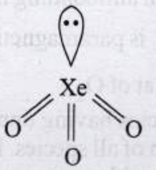
XeF_4 :


Hybridisation – sp^3d^2

Geometry – Octahedral

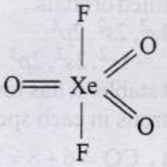
L.P. = 2

XeO_3:



Hybridisation – sp^3
Geometry – Tetrahedral
L.P. = 1

XeO_3F_2:



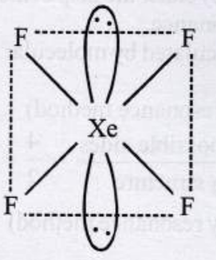
Hybridisation – sp^3d
Geometry – Trigonal bipyramidal
L.P. = 0

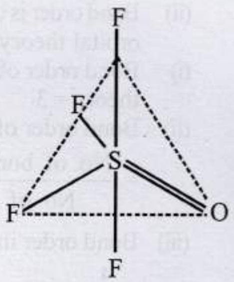
Hence, correct match is:
$P \rightarrow 5; Q \rightarrow 3; R \rightarrow 2; S \rightarrow 4$

29. First determine the total number of electron pairs around the central atom.

$$XeF_4 = \frac{N}{2} = \frac{8+4}{2} = 6$$

Thus, in XeF_4, Xe is sp^3d^2 hybridised. The structure of the molecule is octahedral and shape is square planer with two lone pair of electrons.

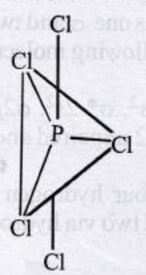


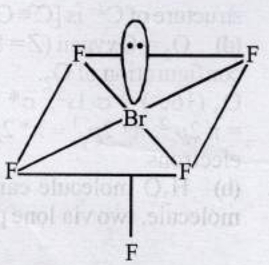


For OSF_4: $\frac{N}{2} = \frac{6+4}{2} = 5$

Thus, the central atom (S) is sp^3d hybridised leading to trigonal bipyramidal structure with no lone pair of electrons.

30.





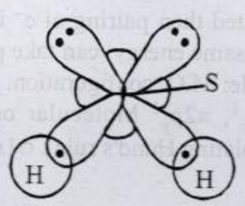
PCl_5 : sp^3d Trigonal bipyramidal BrF_5 : sp^3d^2
Square pyramidal

To decrease lp - bp repulsions, lone pair takes the axial position in BrF_5.

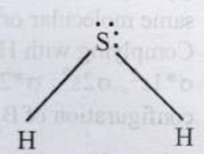
31. In H_2S, no. of hybrid orbitals $= \frac{1}{2}(6+2-0+0) = 4$

Hence, here sulphur is sp^3 hybridised, so

$${}_{16}S = 1s^2, 2s^2 2p^6, \underbrace{3s^2 3p_x^2 3p_y^1 3p_z^1}_{sp^3 \text{ hybridisation}}$$



or

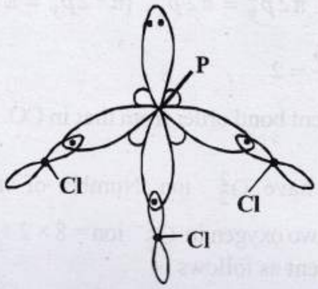


Due to repulsion betwen lp - lp; the geometry of H_2S is distorted from tetrahedral to V-shape.

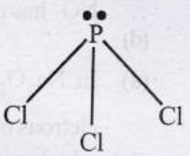
In PCl_3, no. of hybrid orbitals $= \frac{1}{2}[5+3-0+0] = 4$

Hence, here P shows sp^3 - hybridisation

$${}_{15}P = 1s^2, 2s^2 2p^6, \underbrace{3s^2 3p_x^1 3p_y^1 3p_z^1}_{sp^3 \text{ hybridisation}}$$

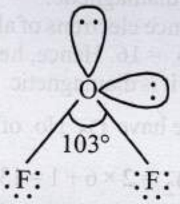


or



Thus, due to repulsion between lp - bp, geometry is distorted from tetrahedral to pyramidal.

32. The structure of OF_2 is similar to H_2O and involves sp^3 hybridization on O atom. The bond angle in F – O – F is not exactly 109°28′, but distorted (103°) due to presence of lone pair of electrons on O as well as F leading to V shape or tetrahedral positions with two positions occupied by lone pair of electrons of the molecule.



Oxidation number of F = –1

∴ Oxidation number of O = +2

Topic-3: VBT, MOT and Hydrogen Bonding

1. (c) $F_2(18e^-)$; $\sigma 1s^2 \sigma^* 1s^2 \sigma 2s^2 \sigma^* 2s^2$

$\sigma 2p_z^2 \pi 2p_x^2 \pi 2p_y^2 \pi^* 2p_x^2 \pi^* 2p_y^2 \sigma^* 2p_z$

2. (c) $C_2 = \sigma 1s^2 \sigma^* 1s^2 \sigma 2s^2 \sigma^* 2s^2 \sigma 2p_z^2 \pi 2p_x^1 \pi 2p_y^1$
When there is no mixing of 2*s* and 2*p* atomic orbitals, the energy of $\sigma 2p_z$ molecular orbital will be low.
Thus, only C_2 will be paramagnetic.

3. **(a)** If Hund's rule is violated then pairing of e^- in the same molecular orbital (of same energy) can take place. Complying with Hund's rule: M.O. configuration: $\sigma 1s^2$, $\sigma^* 1s^2$, $\sigma 2s^2$, $\sigma^* 2s^2$, $\pi 2p_x{}^1$, $\pi 2p_y{}^1$ Molecular orbital configuration of $B_2(10)$ violating Hund's rule : $\sigma 1s^2$, $\sigma^* 1s^2$, $\sigma 2s^2$, $\sigma^* 2s^2$, $\pi 2p_y^2$

Bond order of $B_2 = \frac{6-4}{2} = 1$, B_2 will be diamagnetic.

4. **(a)** Molecular electronic configuration of

$CO : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \pi 2p_y{}^2 = \pi 2p_z{}^2, \sigma 2p_x{}^2$

Therefore, bond order $= \frac{N_b - N_a}{2} = \frac{10-4}{2} = 3$

$$NO^- : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \sigma 2p_z^2,$$
$$\pi 2p_y^2 = \pi 2p_x^2, \{\pi^* 2p_y^1 = \pi^* 2p_x^1$$

Bond order $= \frac{10-6}{2} = 2$

$\therefore$ NO^- has different bond order from that in CO.

5. **(d)**

(a) In Na_2O_2, we have O_2^{2-} ion. Number of valence elctrons of the two oxygen in O_2^{2-} ion $= 8 \times 2 + 2 = 18$ which are present as follows :

$\sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \sigma 2p_z^2, \pi 2p_y^2 = \pi 2p_x^2,$

$\pi^* 2p_y^2 = \pi^* 2p_x^2$

$\therefore$ Number of unpaired electrons = 0, hence, O_2^{2-} is diamagnetic.

(b) No. of valence electrons of all atoms in $O_3 = 6 \times 3 = 18$.
Thus, it also does not have any unpaired electron, hence, it is diamagnetic.

(c) No. of valence electrons of all atom in N_2O $= 2 \times 5 + 6 = 16$. Hence, here also all electrons are paired. So, it is diamagnetic.

(d) In KO_2, we have O_2^- No. of valence electrons of all atoms in $O_2^- = 2 \times 6 + 1 = 13$,
It has one unpaired electron, hence it is paramagnetic.

6. **(b)** $O_2 : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \sigma 2p_x^2, \begin{cases} \pi 2p_y^2 \\ \pi 2p_z^2 \end{cases} \begin{cases} \pi^* 2p_y^1 \\ \pi^* 2p_z^1 \end{cases}$

Bond order $= \frac{10-6}{2} = 2$

(two unpaired electrons in antibonding molecular orbital)

$O_2^+ : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \sigma 2p_x^2, \begin{cases} \pi 2p_y^2, \\ \pi 2p_z^2, \end{cases} \begin{cases} \pi^* 2p_y^1 \\ \pi^* 2p_z^0 \end{cases}$

Bond order $= \frac{10-5}{2} = 2.5$

(One unpaired electron in antibonding molecular orbital)

Hence, O_2 as well as O_2^+ is paramagnetic, and bond order of O_2^+ is greater than that of O_2.

7. **(c)** O_2^- is the only species having unpaired electron.

8. **(b)** Write configuration of all species. Half filled and full filled orbitals are more stable as compared to nearly half filled and nearly full filled orbitals.
$Li^- = 1s^2, 2s^2$; $Be^- = 1s^2, 2s^2, 2p^1$
$B^- = 1s^2, 2s^2, 2p^2$; $C^- = 1s^2, 2s^2, 2p^3$
$\therefore$ Be^- will be least stable. It has lowest I.E.

9. **(a)** Number of electrons in each species are

$CN^- = 6 + 7 + 1 = 14$, $CO = 6 + 8 = 14$

$NO^+ = 7 + 8 - 1 = 14$

Each of the species has 14 electrons which are distributed in MOs as below

$\sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \pi 2p_y^2 = \pi 2p_z^2, \sigma 2p_x^2$

Bond order $= \frac{10-4}{2} = 3$

10. **(d)**

(i) Bond length $\propto \frac{1}{\text{Bond order}}$

(ii) Bond order is calculated by either the help of molecular orbital theory or by resonance.

(i) Bond order of CO as calculated by molecular orbital theory = 3

(ii) Bond order of CO_2 (by resonance method)

$= \frac{\text{No. of bonds in all possible sides}}{\text{No. of resonating structure}} = \frac{4}{2} = 2$

(iii) Bond order in $CO_3{}^{2-}$ (by resonance method)

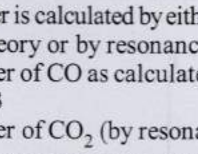
$= \frac{4}{3} = 1.33$

$\therefore$ Order of bond length of C – O is $CO < CO_2 < CO_3{}^{2-}$

11. **(b)** Calcium carbide is an ionic compound ($Ca^{2+} C^{2-}$) which produces acetylene on reacting with water. Thus, the structure of C^{2-} is $[C \equiv C]^{2-}$. It has one σ and two π bonds.

12. **(d)** O_2 = Oxygen (Z = 8) has following molecular orbital configuration of O_2.
$O_2\ (16e^-) = \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \sigma 2p_x{}^2, \pi 2p_y{}^2 = \pi 2p_z{}^2, \pi^* 2p_y{}^1 = \pi^* 2p_z{}^1$ i.e., 2 unpaired and 14 paired electrons.

13. **(b)** H_2O molecule can form four hydrogen bonds per molecule, two via lone pairs and two via hydrogen atoms.



14. **(a)** $O_2^-\ (17e^-) - KK\sigma 2s^2 \sigma^* 2s^2 \sigma 2p_x{}^2,$
$\pi 2p_y{}^2 = \pi 2p_z{}^2, \pi^* 2p_y{}^2 = \pi^* 2p_z{}^1$
Thus, O_2^- has one unpaired electron; hence it is paramagnetic. Other species have no unpaired electron. All of them have 14 electrons.

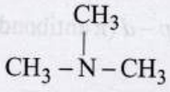
15. **(a)** In PCl_3, P is sp^3 hybridised and has one lone pair of electrons, hence it is pyramidal in shape.

16. **(a)** Compound having *sp* hybridisation will have linear shape.

$\therefore$ CO_2 or (O=C=O) which has C in *sp* hybrid state has linear shape.

17. **(a)** Compounds having F or O or N attached to H form hydrogen bond.

CH_3CH_2OH	$C_2H_5-O-C_2H_5$	CH_3CH_2Cl
ethanol	diethyl ether	ethyl chloride



$CH_3-\overset{\overset{CH_3}{|}}{N}-CH_3$

Trimethyl amine

18. **(c)** $\therefore$ F – H ....F bond is strongest due to largest difference in electronegativity of atoms and smallest size of F atom.

19. **(a)** Write the electronic configuration of each species according to molecular orbital theory.

$$NO\,(15e^-)-\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,\sigma2p_x^2,$$
$$\pi2p_y^2=\pi2p_z^2,\pi^*2p_y^1=\pi^*2p_z^0$$

1 unpaired electron.

$$CO\,(14e^-)-\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,$$
$$\pi2p_y^2=\pi2p_z^2,\sigma2p_x^2$$

no unpaired electron

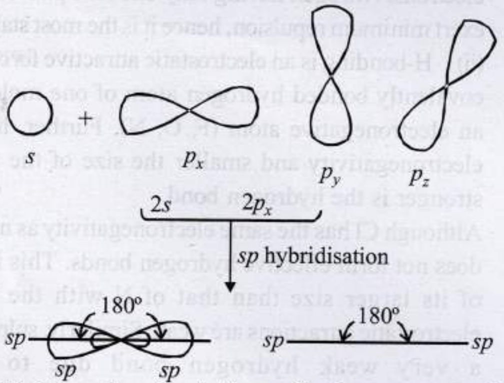
$$CN^-\,(14e^-)-\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,$$
$$\pi2p_y^2=\pi2p_z^2,\sigma2p_x^2$$

$O_2\,(16e^-)-\sigma\,1s^2,\ \sigma^*\,1s^2,\ \sigma\,2s^2,\ \sigma^*\,2s^2,\ \sigma2p_x{}^2,$ $\pi\,2p_y{}^2=\pi\,2p_z{}^2,\pi^*\,2p_y{}^1=\pi^*\,2p_z{}^1;$

Two unpaired electrons.

20. **(b)** *sp* type of hybridization involves the intermixing of one *s* and one *p* (say p_x) orbitals to give two equivalent hybrid orbitals, known as *sp* hybrid orbitals.

The two *sp* hybrid orbitals are directed in a straight line with an angle of 180° **(collinear orbitals)**. The other two *p* orbitals (say p_y and p_z) remain pure.



21. **(d)** Hydrogen bonding is formed in those compounds in which F or O or N atoms are attached to hydrogen atom.

$\because$ HCl does not have F or N or O

$\therefore$ It does not form hydrogen bond.

22. **(6)**

$$2AgNO_3(s)\xrightarrow{\Delta}2Ag(s)+2NO_2(g)+O_2(g)$$

NO_2 has one unpaired e^- and O_2 has two unpaired e^-.

Molecular orbital configuration of O_2 :

$$\sigma1s^2\,\sigma^*1s^2\,\sigma2s^2\,\sigma^*2s^2\,\sigma2p_z^2\,\pi2p_x^2\,\pi2p_y^2\,\pi2^*p_x^1\,\pi^*2p_y^1$$

Total number of e^- present in antibonding molecular orbitals = 6.

23. **(6)** ($H_2, Li_2, Be_2, C_2, N_2, F_2$)

H_2 : $\sigma1s^2$ (Diamagnetic)

He_2^+ : $\sigma1s^2,\sigma^*1s^1$ (Paramagnetic)

Li_2 : $\sigma1s^2,\sigma^*1s^2,\sigma2s^2$ (Diamagnetic)

Be_2 : $\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2$ (Diamagnetic)

B_2 : $\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,\ \pi2p_x^1=\pi2p_y^1$ (Paramagnetic)

C_2 : $\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,\ \pi2p_x^2=\pi2p_y^2$ (Diamagnetic)

N_2 : $\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,\ \pi2p_x^2=\pi2p_y^2,\sigma2p_z^2$ (Diamagnetic)

O_2^- : $\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,\ \sigma2p_z^2,\pi2p_x^2$ $=\pi2p_y^2,\pi^*2p_x^2=\pi^*2p_y^1$ (Paramagnetic)

F_2 : $\sigma1s^2,\sigma^*1s^2,\sigma2s^2,\sigma^*2s^2,\ \sigma2p_z^2,\pi2p_x^2$ $=\pi2p_y^2,\pi^*2p_x^2=\pi^*2p_y^2$ (Diamagnetic)

24. **Increases, decreases;**

$\therefore$ Bond order in $N_2=3$ and Bond order in $N_2^+=2.5$

Thus, conversion of N_2 to N_2^+ decreases bond order (from 3 to 2.5) and hence, increases the N – N bond distance.

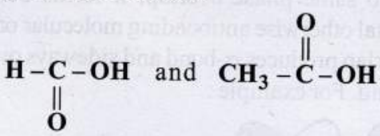
Bond order in $O_2=2$ and Bond order in $O_2^+=2.5$

Thus, conversion of O_2 to O_2^+ increases bond order (from 2 to 2.5) hence, decrease in O – O bond distance.

25. sp^3; Hybridisation (H)= $\frac{1}{2}$ [No. of valence electron in central atom + No. of monovalent atoms – Charge on cation + Charge on anion]

For N in $NH_4{}^+$, hybridisation $(H)=\frac{1}{2}(5+4-1+0)=4$

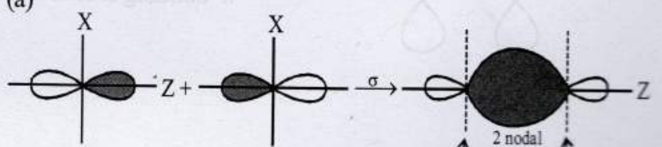
$\therefore$ sp^3 hybridisation.

26. 

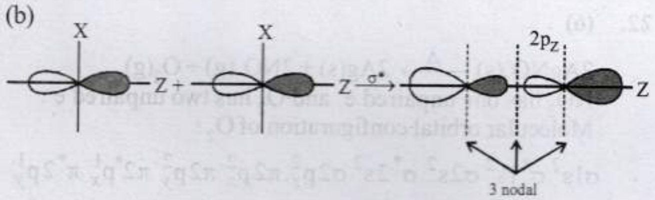
$H-\underset{\underset{O}{\|}}{C}-OH$ and $CH_3-\overset{\overset{O}{\|}}{C}-OH$ form strongest hydrogen bonds because of largest difference in electronegativities of bonded atoms.

27. **(a, d)** Overlap of two $2p_z$ orbitals.

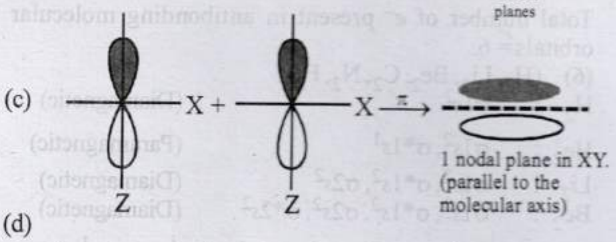
(a)



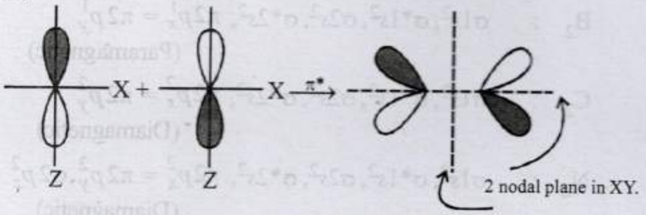
(b)



(c)



(d)



one plane is perpendicular to the molecular axis and another is parallel to molecular axis

28. **(a, c)**

(a) The molecular orbital energy configuration of C_2^{2-} is

$$\sigma_{1s}^2, \sigma_{1s}^{*2}, \sigma_{2s}^2, \sigma_{2s}^{*2}, \pi_{2p_x}^2 = \pi_{2p_y}^2, \sigma_{2p_z}^2$$

In the MO of C_2^{2-}, there is no unpaired electron hence, it is diamagnetic.

(b) Bond order of O_2^{2+} is 3 and O_2 is 2 therefore bond length of O_2 is greater than O_2^{2+}.

(c) The molecular orbital energy configuration of N_2^+ is

$$\sigma_{1s}^2, \sigma_{1s}^{*2}, \sigma_{2s}^2, \sigma_{2s}^{*2}, \pi_{2p_x}^2 = \pi_{2p_y}^2, \sigma_{2p_z}^1$$

Bond order of $N_2^+ = \frac{1}{2}(9-4) = 2.5$

The molecular orbital energy configuration of N_2^- is

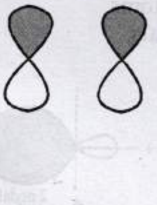
$$\sigma_{1s}^2, \sigma_{1s}^{*2}, \sigma_{2s}^2, \sigma_{2s}^{*2}, \pi_{2p_x}^2 = \pi_{2p_y}^2, \sigma_{2p_z}^2, \pi_{2p_x}^{*1}$$

Bond order of $N_2^- = \frac{1}{2}(10-5) = 2.5$

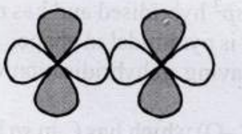
(d) He_2^+ has less energy in comparison to two isolated He atoms because some energy is released during the formation of He_2^+ from 2 He atoms.

29. **(c)** When two same phase overlap, it forms bonding molecular orbital otherwise antibonding molecular orbital. Also axial overlap produces σ-bond and sideways overlap produces π-bond. For example :

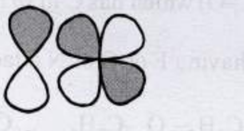

σ-antibonding orbital


π-bonding orbital

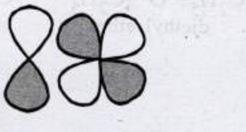
P.


$d-d$ (σ bonding)

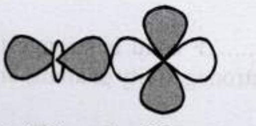
Q.


$p-d$ (π bonding)

R.


$p-d$ (π antibonding)

S.


$d-d$ (σ antibonding)

30. **(A) – p, r, t ; (B) – s, t ; (C) – p, q ; (D) – p, q, s**

(A) $B_2 : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \pi 2p_x^1, \pi 2p_y^1$

Addition of e^- will increase the B.O., hence it will undergo reduction.

(B) $N_2 : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \pi 2p_x^2, \pi 2p_y^2, \pi 2p_z^2,$
$\pi^* 2p_x^{\circ}, \pi^* 2p_y^{\circ}$

Addition or removal of e^- will decrease the B.O., hence it will not undergo oxidation or reduction.

(D) $O_2 : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \pi 2p_z^2, \pi 2p_x^2, \pi 2p_y^2,$
$\pi^* 2p_x^1, \pi^* 2p_y^1$

Removal of e^- will increase the B.O., hence it will undergo oxidation easily.

(C) Similarly, removal of e^- will increase the B.O. for O_2^- also. Hence it will undergo oxidation easily.

31. (i) Increasing order of bond dissociation energy.

$F_2 < Cl_2 < O_2 < N_2$

Fluorine-fluorine bond energy is less than the Cl–Cl because of larger repulsion between the non-bonded electrons of the two smaller fluorine atoms. Oxygen having two lone pairs of electrons on each atom exert less repulsion than that of chlorine or fluorine each having three lone pairs of electrons. Nitrogen having only one lone pair of electrons exert minimum repulsion, hence it is the most stable.

(ii) H-bonding is an electrostatic attractive force between covalently bonded hydrogen atom of one molecule and an electronegative atom (F, O, N). Further, higher the electronegativity and smaller the size of the atom, the stronger is the hydrogen bond.

Although Cl has the same electronegativity as nitrogen, it does not form effective hydrogen bonds. This is because of its larger size than that of N with the result its electrostatic attractions are weak. Similarly, sulphur forms a very weak hydrogen bond due to its low electronegativity, although oxygen present in the same

group forms a strong hydrogen bond.
Hence, the order is $S < Cl < N < O < F$

(iii) In KO_2, O_2 is present as O_2^-, while in $\overset{+1}{O_2}(\overset{+3}{As}\,\overset{-4}{F_4})$, O_2 is present as O_2^+. Write down the MO configuration of O_2, O_2^- and O_2^+.

$O_2 : \sigma 1s^2, \sigma^* 1s^2, \sigma 2s^2, \sigma^* 2s^2, \sigma 2p_x^2, \pi 2p_y^2 = \pi 2p_z^2,$
$\pi^* 2p_y^1 = \pi^* 2p_z^1.$

Thus, the bond order = 2

O_2^- : Same as above except $\pi^* 2p_y^2, \pi^* 2p_z^1$ in place of $\pi^* 2p_y^1, \pi^* 2p_z^1$.

Thus, the bond order in $O_2^- = 1.5$

O_2^+ : Same as in O_2 except $\pi^* 2p_y^1 = \pi^* 2p_z^0$ in place of $\pi^* 2p_y^1, \pi^* 2p_z^1$.

$\therefore$ Bond order in $O_2^+ = 2.5$

$\therefore$ Bond order in the three species is $O_2^+ > O_2 > O_2^-$
or $O_2[AsF_4] > O_2 > KO_2$
Bond length order : $KO_2 > O_2 > O_2[AsF_4]$

32. Benzene has 12σ and 3π bonds.

33. H_2O molecules are held together by hydrogen bonding which is stronger force of attraction but H_2S molecules are held together by van der Waals forces of attraction, which are weaker forces. As a result, water molecules come closer and exist in liquid state.