

## Chapter-1

### INNOVATIVE METHOD FOR THE PREDICTION OF THE HYBRIDIZATION STATE OF SIMPLE MOLECULES & IONS

**Arijit Das**

Department of Chemistry, Bir Bikram Memorial College, Agartala, Tripura, India

Email: [arijitas78chem@gmail.com](mailto:arijitas78chem@gmail.com)

In this innovative chapter, formula-based mnemonics by counting total number of  $\sigma$  bonds and lone pair of electrons ( $T_{SLP}$ ) and subtract one (01) from this total value of  $T_{SLP}$  to predict the power of the hybridization state have been highlighted by innovative and time economic way to enhance interest of students' who belong to paranoia zone of chemistry for the prediction of hybridization state of simple molecules or ions by using conventional method. Educators can use these mnemonics in their teaching style in the classroom lectures after discussing conventional methods to make chemistry intriguing. Here, I have tried to focus four (04) time economic mnemonics by including one (01) formula for the prediction of hybridization state of simple molecules or ions. This chapter encourages students to solve multiple choice type questions (MCQs) at different competitive examinations in a time economic ground on the prediction of hybridization state of simple molecules or ions to know their normal and subnormal geometry. This innovative chapter emphasizes chemical education in the light of a variety of mnemonic techniques to make chemistry metabolic, time economic and intriguing for students because the use of mnemonics in classroom lectures is an essential tool to become a distinguished educator.

The conventional formula for determination of hybridization state of simple molecules or ions is time-consuming<sup>1-7</sup>. Keeping this in mind, in this innovative pedagogical chapter, I have introduced some innovative mnemonics to make chemistry metabolic, time economic and interesting<sup>8-10</sup>.

- 
1. L. Pauling, "The Nature Chemical Bond. Application of Results Obtained from the Quantum Mechanics and from a Theory of Paramagnetic Susceptibility to the Structure of Molecules", *J.Am.Chem.Soc.*53(1931):1367-1400, doi:10.1021/ja01355a027, <https://pubs.acs.org/doi/abs/10.1021%2Fja01355a027>.
  2. L. Pauling and P. Pauling, *Chemistry* (Freeman International Ed. : 1975), 148, 163-167.
  3. James S. Wright, "Theoretical Evidence for a Stable form of Cyclic Ozone, and its Chemical Consequences", *Can. J. Chem.* 51 (1973): 139-146, <http://www.nrcresearchpress.com/doi/10.1139/v73-020#.XEsGBtlza1s>.
  4. J. D. Lee, *Concise Inorg.Chem.* (Wiley India and Oxford, 5<sup>th</sup> ed. : 2009), 944, 109-112.
  5. J. E. Huheey, et.al. *Inorganic Chemistry* (Pearson, 4<sup>th</sup> ed., India: 2006), 172-185.
  6. B. Douglas et.al. *Concepts and Models of Inorg. Chem.* (Wiley India, 3<sup>rd</sup> ed. : 2007), 157, 38.
  7. F.A. Cotton et.al. *Basic Inorg.Chem.* (Wiley India, 3<sup>rd</sup> ed. : 2007), 107, 523, 111.
  8. A.Das et.al "Innovative And Time Economic Pedagogical Views In Chemical Education - A Review Article", *World Journal of Chemical Education* 2 (July 2014): 29-38, doi:10.12691/wjce-2-3-1, <http://pubs.sciepub.com/wjce/2/3/1/index.html#>.
  9. A. Das and B. Paul "Time Economic Innovative Pedagogies In Chemical Science - A Review Article", *Education in Chemical Science and Technology, Indian Chemical Society* 3 (Aug 2015): 1-28.
  10. A. Das, "A Review of Time Economic Innovative Mnemonics In Chemical Education", *International Journal of Physics & Chemistry Education* 10(June 2018): 27-40,doi: 10.12973/ijpce/81589, <http://www.ijpce.org/A-Review-of-Time-Economic-Innovative-Mnemonics-in-Chemical-Education,81589,0,2.html>.
-

Here, I have tried to discuss them abruptly along with their limitations, applications, and problems in the different competitive examinations.

## METHODOLOGY

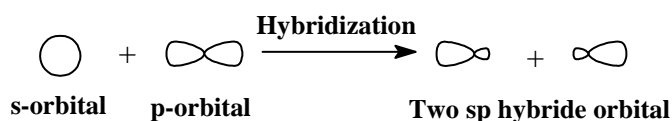
### A. Hybridization state theory

Prof. Linus Pauling (1931), first developed the Hybridization state theory in order to explain the structure of molecules such as methane ( $\text{CH}_4$ ) using atomic orbitals<sup>1,2</sup>. This concept was developed for simple chemical systems but this one applied more widely later on and from today's point of view, it is considered an operative empirical for excusing the structures of organic and inorganic compounds along with their related problems.

In hybridization, intermixing of orbitals of the same atom with slightly different energies takes place, resulting in the formation of the same number of new orbitals called hybrid orbitals with equal energies and shape.

The mixing pattern is as follows:

one s + one p = sp hybrid orbital, one s + two p =  $\text{sp}^2$  hybrid orbital, one s + three p =  $\text{sp}^3$  hybrid orbital, one s + three p + one d ( $d_z^2$ ) =  $\text{sp}^3\text{d}$  hybrid orbital, one s + three p + two d ( $d_{x^2-y^2}$ ,  $d_z^2$ ) =  $\text{sp}^3\text{d}^2$  hybrid orbital and one s + three p + three d ( $d_{xy}$ ,  $d_{yz}$ ,  $d_{xz}$ ) =  $\text{sp}^3\text{d}^3$  hybrid orbital.



The ability of the hybrid orbitals to overlap is in the order  $\text{sp}^3 > \text{sp}^2 > \text{sp}$ , greater the p character, greater is the ability to overlap and stronger will be the bond. Whereas the bond angles formed by different hybrid orbitals are in the order  $\text{sp} (180^\circ) > \text{sp}^2(120^\circ) > \text{sp}^3(109.5^\circ)$ , greater the s-character, greater is the bond angle. Electronegativity of carbon also depends upon the state of hybridization. More the s-character in hybridization more is the electronegativity. Thus the order of electronegativity of C atom is  $\text{C}_{\text{sp}} > \text{C}_{\text{sp}^2} > \text{C}_{\text{sp}^3}$ .

### Some important facts about hybridization

- i) Orbitals of comparable energies belonging to same atom or ion can undergo hybridization.
  - ii) The number of hybrid orbitals is equal to the number of atomic orbitals mixed during hybridization.
  - iii) Half filled, fully filled or even empty atomic orbitals of similar energy can participate in hybridization.
  - iv) All the hybrid orbitals resulting from a particular type of hybridization is similar in all respect (same energy, shape, and size).
-

v)The hybrid orbitals are distributed in space as far apart as possible and hence assign a particular shape and geometry to the molecule.

vi)Hybrid orbitals follow Hund's rule and also Pauli's exclusion principle like atomic orbitals.

vii)The bond formed between hybrid orbitals is known as hybrid bond and is stronger than non-hybrid bonds of comparable length.

Hybrid orbitals are the dumb-bell type with a larger lobe having a (+ve) sign and a smaller lobe having a (-ve) sign.

## **B. The conventional method for prediction of hybridization state**

### **VALANCE SHELL ELECTRON PAIR REPULSION THEORY (VSEPR THEORY):**

VSEPR theory was given by Sidgwick and Powell in 1940 and further improved by Nyholm and Gillespie in 1957. In a molecule, the central atom is surrounded by shared pairs of electrons (bond pairs) as well as nonbonding electrons (lone pairs). The main concept of the theory is that the electron pairs surrounding the central atom repel each other and move away from one another to occupy the most appropriate position in such a way that there are no further repulsions between them, and molecule is in the state of minimum energy and maximum stability. This arrangement gives a particular shape to the molecules. The order of repulsion between electron pairs is lone pair-lone pair (LP-LP) > lone pair – bond-pair (LP-BP) > bond pair – bond-pair (BP-BP).

If the central atom is surrounded by only bond pairs of similar atoms, the repulsive interactions are equivalent and molecule has regular geometry. If the central atom is surrounded by only bond pairs of dissimilar atoms, the repulsive interactions are not equivalent and the molecule will not have the regular geometry. If the central atom is surrounded by both bond pairs and lone pairs, the repulsive interactions are very much different and molecular geometry will be distorted from the regular one.

### **The conventional formula used for the prediction of hybridization state**

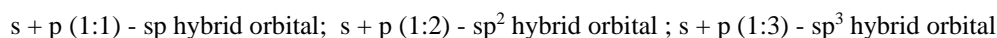
Hybridization state for a molecule calculated by the formula  $\frac{1}{2}(V+MA-C+A)$ , where, V = Number of valance electrons in the central atom, MA = Number of surrounding monovalent atoms, C = Cationic charge, A = Anionic charge.

Eg: Methane  $\text{CH}_4$ ,  $P = \frac{1}{2}(4 + 4 - 0) = 4$  ( $\text{sp}^3$  hybridization state); Ethylene ( $\text{CH}_2 = \text{CH}_2$ ),  $P = \frac{1}{2}(4 + 2 - 0) = 3$  ( $\text{sp}^2$  hybridization state)

## C. Innovative method for predicting hybridization state of simple molecules or ions

### i) Prediction of $sp$ , $sp^2$ , $sp^3$ Hybridization state

Hybridization is nothing but the mixing of orbital's in different ratio and the newly mixed orbitals called hybrid orbitals. The mixing pattern is as follows:



Formula: prediction of  $sp$ ,  $sp^2$ , and  $sp^3$  hybridization state

$$\text{Power on the hybridization state of the central atom } (P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1$$

where,  $P_{\text{Hyb}}$  = Power on the hybridization state of the central atom,  $T_{\text{SLP}}$  = (Total no of  $\sigma$  bonds around each central atom + LP).

From the Lewis structure of a molecule, first of all, predict the number of sigma bonds ( $\sigma$ -bonds), pi bonds ( $\pi$ -bonds) and the lone pair of electrons (LP) if any. All single (-) bonds are the  $\sigma$  bond, in the double bond (=), there is 1 $\sigma$  and 1 $\pi$ , in triple bond ( $\equiv$ ) there is 1 $\sigma$  and 2 $\pi$  (exclude  $\pi$  bond). In addition to these, each Co-ordinate bond ( $\rightarrow$ ) can be treated as 1 $\sigma$  bond. This formula is applicable up to four (04)  $T_{\text{SLP}}$ .

If the power of the hybridization state ( $P_{\text{Hyb}}$ ) will be 03, 02 and 01 then the hybridization state will be  $sp^3$ ,  $sp^2$  and  $sp$  respectively<sup>8, 11, 12</sup>.

### ii) Prediction of $sp^3d$ , $sp^3d^2$ , $sp^3d^3$ Hybridization state

In case of  $sp^3d$ ,  $sp^3d^2$  and  $sp^3d^3$  hybridization state there is a common term  $sp^3$  for which four (04)  $T_{\text{SLP}}$  is responsible. So, with four (04)  $T_{\text{SLP}}$ , for each additional  $T_{\text{SLP}}$  (additional sigma bond or lone pair of electron), added one d orbital gradually as follows:-

$$5 T_{\text{SLP}} = 4 T_{\text{SLP}} + 1 \text{ additional } T_{\text{SLP}} = sp^3d \text{ hybridization}$$

$$6 T_{\text{SLP}} = 4 T_{\text{SLP}} + 2 \text{ additional } T_{\text{SLP}} = sp^3d^2 \text{ hybridization}$$

$$7 T_{\text{SLP}} = 4 T_{\text{SLP}} + 3 \text{ additional } T_{\text{SLP}} = sp^3d^3 \text{ hybridization}$$

In case of cationic species, requisite electron/electrons must be removed from the outermost orbit of the central atom and in case of anionic species, added requisite electron/electrons with the outermost electrons of the central atom<sup>8, 11, 12</sup>.

11. A. Das, "Innovative Mnemonics In Chemical Education: Review Article", *African Journal of Chemical Education* 8, (July 2018): 144-189, <https://www.ajol.info/index.php/ajce/article/view/176086>.

12. A. Das, "Innovative Mnemonics Make Chemical Education Time Economic – A Pedagogical Review Article", *World Journal of Chemical Education*, 6.4 (Sept 2018): 154-174, doi:10.12691/wjce-6-4-2, <http://pubs.sciepub.com/wjce/6/4/2/index.html>.

## RESULTS AND DISCUSSION

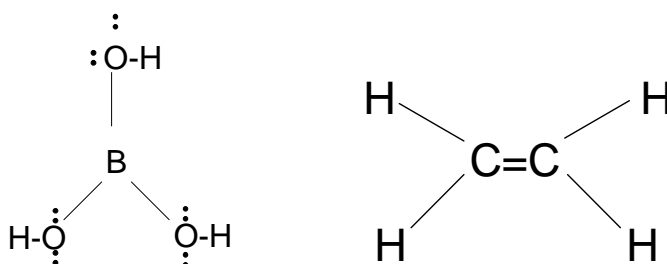
### 1. Innovative mnemonics for predicting hybridization state of simple molecules or ions

i) Prediction of the hybridization state ( $sp$ ,  $sp^2$  &  $sp^3$ ) of simple molecules and ions can be well explained in the following way:

**Ex.a.**  $\text{NH}_3$ : In  $\text{NH}_3$ , central atom N is surrounded by three N-H single bonds i.e. three (03) sigma ( $\sigma$ ) bonds and one (01) lone pair (LP). So,  $T_{\text{SLP}} = 4$ , in  $\text{NH}_3$ , hence, power on the hybridization state of N in  $\text{NH}_3$ ,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = (3+1) - 1 = 3$  i.e. hybridization state =  $sp^3$ .

**Ex.b.**  $\text{H}_2\text{O}$ : In  $\text{H}_2\text{O}$ , central atom O is surrounded by two O-H single bonds i.e. two (02) sigma ( $\sigma$ ) bonds and two (02) lone pairs. So, in this case, power on the hybridization state of O,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = (2+2) - 1 = 3$ , i.e. hybridization state of O in  $\text{H}_2\text{O} = sp^3$ .

**Ex.c.**  $\text{H}_3\text{BO}_3$ : In  $\text{H}_3\text{BO}_3$ , B has (Fig. 1.1), three (03)  $\sigma$  bonds only (LP = 0) and oxygen has two (02)  $\sigma$  bonds and two (02) lone pair of electrons, so, in this case, power on the hybridization state of B,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = (3+0) - 1 = 2$  i.e. B is  $sp^2$  hybridized in  $\text{H}_3\text{BO}_3$ . On the other hand, the power of the hybridization state of O,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = (2+2) - 1 = 3$  i.e. hybridization state of O in  $\text{H}_3\text{BO}_3$  is  $sp^3$ .



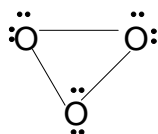
**Fig. 1.1** Structure of  $\text{H}_3\text{BO}_3$  and  $\text{C}_2\text{H}_4$

**Ex.d.**  $\text{CH}_2 = \text{CH}_2$ : In  $\text{C}_2\text{H}_4$ , each carbon (Fig. 1.1), is attached with two (02) C-H single bonds ( $2 \sigma$  bonds) and one C=C bond ( $1 \sigma$  bond), so, altogether there are 3 sigma bonds. So, in this case, the power on the hybridization state of both C,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = (3+0) - 1 = 2$  i.e. hybridization state of both carbons are  $sp^2$ .

**Ex.e.** I-Cl: In I-Cl, I and Cl both have one (01)  $\sigma$  bond and three (03) lone pair of electrons, so, in this case, power on the hybridization state of both I and Cl,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = (1+3) - 1 = 3$  i.e. hybridization state of I and Cl both are  $sp^3$ .

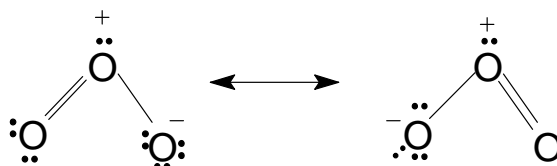
**Ex.f.**  $\text{O}_3$ : Ozone ( $\text{O}_3$ ) exists as a stable form of cyclic ozone (Fig. 1.2) and its structure is equilateral triangle<sup>2,3</sup>. In which each center O atom has two (02) O-O single bonds ( $2 \sigma$  bonds) and two (02) lone pair of electrons. So,

in this case, power on the hybridization state of central O atom ( $P_{\text{Hyb}} = (T_{\text{SLP}}) - 1 = (2+2) - 1 = 3$  i.e. hybridization state of center atom O in cyclic  $\text{O}_3$  is  $sp^3$ .



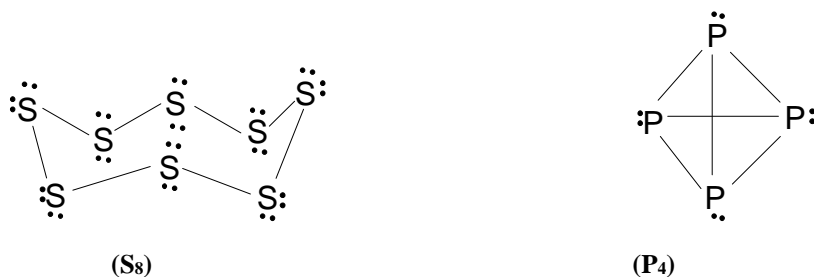
**Fig. 1.2 Equilateral triangle structure of cyclic ozone ( $\text{O}_3$ )**

But the resonance description of ozone involves two structures (**Fig. 1.3**), in which, the central oxygen atom of ozone will have  $sp^2$  hybridization state. In this case, the central O atom has two (02)  $\sigma$  bonds and one (01) lone pair of electron ( $LP = 01$ ), hence, power on the hybridization state of central O atom in resonance hybrid of ozone, ( $P_{\text{Hyb}} = (T_{\text{SLP}}) - 1 = (2+1) - 1 = 2$  ( $sp^2$ )).



**Fig. 1.3 Resonating structures of Ozone ( $\text{O}_3$ )**

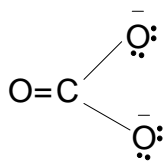
**Ex.g. $\text{S}_8$ :** The ordinary form of sulfur (orthorhombic sulfur, yellow crystals) contains octatomic molecules ( $\text{S}_8$ ), in which, S can form single covalent bonds with two other S atoms in a zigzag fashion (**Fig. 1.4**), into a long chain. In this case, each sulfur atom attached with two (02) adjacent  $\sigma$  bonds and two (02) lone pair of electrons ( $LP = 2$ ). Hence, power on the hybridization state of any S atom ( $P_{\text{Hyb}} = (T_{\text{SLP}}) - 1 = (2+2) - 1 = 3$  i.e. hybridization state of S atoms in  $\text{S}_8$  is  $sp^3$ .



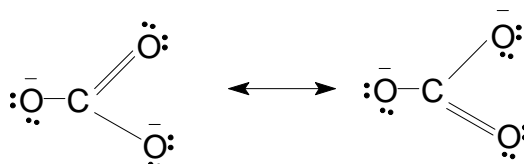
**Fig. 1.4 Zigzag structure of  $\text{S}_8$  and Tetrahedron structure of  $\text{P}_4$**

**Ex.h. $\text{P}_4$ :** In  $\text{P}_4$ , the four P atoms are arranged at the corners of a regular tetrahedron (**Fig. 1.4**). Here, each P atom forms three covalent bonds ( $3\sigma$  bonds) and one lone pair electron ( $LP = 1$ ). Hence, power on the hybridization state of any P atom ( $P_{\text{Hyb}} = (T_{\text{SLP}}) - 1 = (3+1) - 1 = 3$  i.e. hybridization state of P atoms in  $\text{P}_4$  is  $sp^3$ .

**Ex.i.**  $\text{CO}_3^{2-}$ : In the valence bond structure of carbonate ion ( $\text{CO}_3^{2-}$ ), the central carbon atom does not contain any lone pair electron ( $\text{LP} = 0$ ) but it has three (03)  $\sigma$  bonds (**Fig. 1.5**). Hence, power on the hybridization state of central C atom in carbonate ion,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = (3+0) - 1 = 2$  ( $\text{sp}^2$ ). But in resonance hybrid of  $\text{CO}_3^{2-}$  (**Fig. 1.6**), carbon atoms are in  $\text{sp}^2$  hybridization state due to 3  $\sigma$  bonds and no lone pair of electrons ( $\text{LP} = 0$ ).



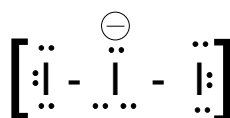
**Fig. 1.5** Valence bond structure of carbonate ion ( $\text{CO}_3^{2-}$ )



**Fig. 1.6** Resonance hybrid of  $\text{CO}_3^{2-}$

ii) Prediction of the hybridization state ( $\text{sp}^3\text{d}$ ,  $\text{sp}^3\text{d}^2$  &  $\text{sp}^3\text{d}^3$ ) of simple molecules and ions can be well explained in the following way

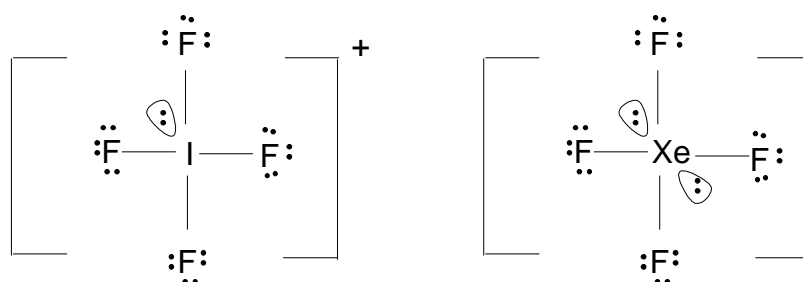
**Ex.a.**  $\text{I}_3^-$ : In Tri iodide ion ( $\text{I}_3^-$ ), central I atom has 2  $\sigma$  bonds and 3 lone pairs of electrons ( $\text{LP} = 3$ ) (**Fig.1.7**). Hence for central I, there is 5  $T_{\text{SLP}}$  So, 5  $T_{\text{SLP}} = 4 T_{\text{SLP}} + 1$  additional  $T_{\text{SLP}} = \text{sp}^3\text{d}$  hybridization.



**Fig. 1.7** Linear structure of triiodide ion ( $\text{I}_3^-$ )

**Ex.b.**  $\text{IF}_4^+$ : In  $\text{IF}_4^+$  (**Fig. 1.8**), I have 7 e's in its outermost shell, so, in this case, subtract one e<sup>-</sup> from 7 i.e.  $7 - 1 = 6$ . So, out of 6 electrons, 4 electrons form four (04) I-F  $\sigma$  bonds and there is one (01) LP. So, altogether there are 5  $T_{\text{SLP}}$ . So, 5  $T_{\text{SLP}} = 4 T_{\text{SLP}} + 1$  additional  $T_{\text{SLP}} = \text{sp}^3\text{d}$  hybridization.

**Ex.c.**  $\text{XeF}_4$ : In  $\text{XeF}_4$  (**Fig. 1.8**), Xe, an inert gas, consider 8 e's in its outermost shell, four (04) of which form four (04) Xe-F sigma bonds and there are two (02) lone pair of electrons, so, altogether there is 06  $T_{\text{SLP}} = 4 T_{\text{SLP}} + 2$  additional  $T_{\text{SLP}} = \text{sp}^3\text{d}^2$  hybridization.

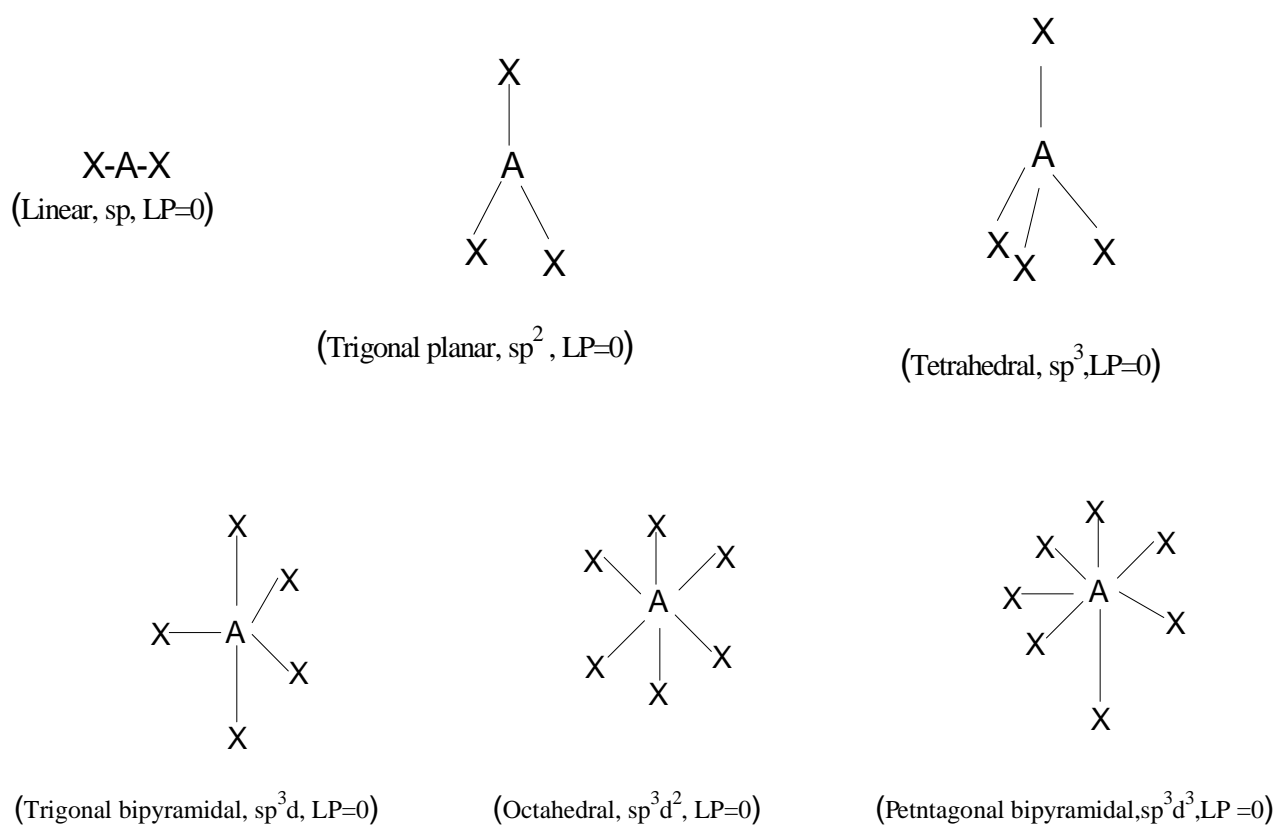


**Fig. 1.8 Structure of  $\text{IF}_4^+$  and  $\text{XeF}_4$**

**Ex.d.**  $\text{IF}_7$ : In  $\text{IF}_7$ , there is seven (07) I-F single bonds i.e. 7 $\sigma$  bonds and no lone pair of electron (LP=0), so, altogether there is 07  $T_{\text{SLP}} = 4 T_{\text{SLP}} + 3$  additional  $T_{\text{SLP}} = \text{sp}^3\text{d}^3$  hybridization.

### THE GEOMETRY OF SIMPLE MOLECULES OR IONS

In absence of lone pair electrons (LPs) a molecule or ion exhibits regular geometry (**Fig. 1.9**). For  $\text{sp}$ ,  $\text{sp}^2$ ,  $\text{sp}^3$ ,  $\text{sp}^3\text{d}$ ,  $\text{sp}^3\text{d}^2$ , and  $\text{sp}^3\text{d}^3$  hybridization state, geometry will be linear, trigonal planar, tetrahedral, trigonal bipyramid, octahedral and pentagonal bipyramid respectively, whereas for the same hybridization state in presence of the lone pair of electrons they exhibit subnormal geometry (**Fig. 1.10**)<sup>8,11,12</sup>.



**Fig.1.9 Regular / Normal Molecular Geometry without Lone pair of electrons**



Adequate examples on prediction of the hybridization state from the corresponding  $T_{SLP}$  value (total number of  $\sigma$  bonds around the central atom + lone pair of electron on central atom) of the central atom have been explored in **Table 1.1** and molecular geometry (normal and sub-normal) and bond angle with respect to the corresponding hybridization state and lone pair of electrons of simple molecules or ions have been displayed in **Table 1.2**.

**Table 1.1  $T_{SLP}$  and corresponding hybridization state**

$T_{SLP}$ (Total number of $\sigma$ bonds + LP)	Nature of Hybridization State	Examples
2	sp	BeCl <sub>2</sub> , HgCl <sub>2</sub> , C <sub>2</sub> H <sub>2</sub> , CO <sub>2</sub> , CO, CdCl <sub>2</sub> , ZnCl <sub>2</sub> etc.
3	sp <sup>2</sup>	BCl <sub>3</sub> , AlCl <sub>3</sub> , C <sub>2</sub> H <sub>4</sub> , C <sub>6</sub> H <sub>6</sub> , SO <sub>2</sub> , SO <sub>3</sub> , HNO <sub>3</sub> , H <sub>2</sub> CO <sub>3</sub> , SnCl <sub>2</sub> , PbCl <sub>2</sub> etc.
4	sp <sup>3</sup>	NH <sub>4</sub> <sup>+</sup> , BF <sub>4</sub> <sup>-</sup> , H <sub>2</sub> SO <sub>4</sub> , HClO <sub>4</sub> , PCl <sub>3</sub> , NCl <sub>3</sub> , AsCl <sub>3</sub> , HClO <sub>3</sub> , ICl <sub>2</sub> <sup>+</sup> , OF <sub>2</sub> , HClO <sub>2</sub> , SCl <sub>2</sub> , HClO, ICl, XeO <sub>3</sub> etc.
5	sp <sup>3</sup> d	PCl <sub>5</sub> , SbCl <sub>5</sub> , SF <sub>4</sub> , ClF <sub>3</sub> , BrF <sub>3</sub> , XeF <sub>2</sub> , ICl <sub>2</sub> <sup>-</sup> etc.
6	sp <sup>3</sup> d <sup>2</sup>	SF <sub>6</sub> , AlF <sub>6</sub> <sup>3-</sup> , SiF <sub>6</sub> <sup>2-</sup> , PF <sub>6</sub> <sup>-</sup> , IF <sub>5</sub> , BrF <sub>5</sub> , XeOF <sub>4</sub> , XeF <sub>4</sub> , BrF <sub>4</sub> <sup>-</sup> , ICl <sub>4</sub> <sup>-</sup> etc.
7	sp <sup>3</sup> d <sup>3</sup>	IF <sub>7</sub> , XeF <sub>6</sub> etc.

**Table 1.2 Hybridization, Molecular Geometry, and Bond Angles**

Hybridization	LP	Molecular Geometry (Regular / Normal)	Approximate Bond Angles (Degree)	Examples	LP	Molecular Geometry (Sub-normal)	Approximate Bond Angles (Degree)	Example
sp	0	Linear	180	CO <sub>2</sub> , CS <sub>2</sub> , BeCl <sub>2</sub> , HgCl <sub>2</sub>	-	-	-	-
sp <sup>2</sup>	0	Trigonal Planar or Triangular Planar	120	BH <sub>3</sub> , AlCl <sub>3</sub> , C <sub>2</sub> H <sub>4</sub> , BCl <sub>3</sub> , BF <sub>3</sub> , NO <sub>3</sub> <sup>-</sup> , CO <sub>3</sub> <sup>2-</sup>	01	Angular or V-shape	<120	SO <sub>2</sub> , NO <sub>2</sub> <sup>-</sup>
sp <sup>3</sup>	0	Tetrahedral	109.5	BH <sub>4</sub> <sup>-</sup> , BF <sub>4</sub> <sup>-</sup> , SnCl <sub>4</sub> , H <sub>2</sub> SO <sub>4</sub> , HClO <sub>4</sub> , SiCl <sub>4</sub>	01	Pyramidal	<109.5	NH <sub>3</sub> , PH <sub>3</sub> , AsH <sub>3</sub>
					02	Bent shape or V- shape	<109.5	H <sub>2</sub> O, H <sub>2</sub> S, H <sub>2</sub> Se
					03	Linear	180	ICl, BrF, ClF

sp <sup>3</sup> d	0	Trigonal bipyramid	120 (equatorial) 90 (axial)	PF <sub>5</sub> , PCl <sub>5</sub>	01	See-Saw	<120(equatorial) <90 (axial)	SF <sub>4</sub>
					02	T-shape	<90	ICl <sub>3</sub> , F <sub>3</sub> Cl
					03	Linear	180	XeF <sub>2</sub> , I <sub>3</sub> <sup>-</sup>
sp <sup>3</sup> d <sup>2</sup>	0	Octahedral	90	SF <sub>6</sub> , TeF <sub>6</sub> , WF <sub>6</sub> , SeF <sub>6</sub> , SnCl <sub>6</sub> <sup>2-</sup>	01	Square pyramidal	<90	IF <sub>5</sub> , BrF <sub>5</sub>
					02	Square planar	90	XeF <sub>4</sub>
sp <sup>3</sup> d <sup>3</sup>	0	Pentagonal bipyramid	72 & 90	IF <sub>7</sub>	01	Pentagonal Pyramidal or Distorted octahedral	72 & 90	XeF <sub>6</sub>

### BOND ANGLE OF SIMPLE MOLECULES OR IONS

The angle between the two covalent bonds of a molecule is called the bond angle. When in covalent bonds, bond pair electron clouds, are adjacent to each other, then, due to excessive repulsive force between two adjacent bond pair electron clouds, the bond angle increases. When bond pair electron clouds move towards the central atom instead of the peripheral atom, then, they are adjacent to each other and exhibit much more repulsive force, which increases the bond angle of the molecule. So, the mainly responsible repulsive force for bond angle prediction is a bond pair – bond-pair (BP-BP) repulsion. If there is any other repulsive force greater than BP-BP repulsions, such as lone pair-lone pair (LP-LP) or lone pair-bond pair (LP-BP) repulsion, in this particular case, BP-BP repulsion not freely act, hence, bond angle diminishes. The order of repulsive force is a lone pair-lone pair (LP-LP) > lone pair – bond-pair (LP-BP) > bond pair – bond-pair (BP-BP).

Factors affecting the bond angle of simple molecules or ions:

i) Different Repulsive force: The order of bond angle depends on different repulsive forces is as follows

bond pair – bond-pair (BP-BP) > lone pair – bond-pair (LP-BP) > lone pair-lone pair (LP-LP).

(LP = 0)

(LP = 1)

(LP=2)

Thus, with increasing number of lone pair electrons, bond angle decreases.

**Ex.** The bond angle of methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>) & water (H<sub>2</sub>O), follows the order: methane (CH<sub>4</sub>) > ammonia (NH<sub>3</sub>) > water (H<sub>2</sub>O). In methane (CH<sub>4</sub>), LP on C = 0 and only BP-BP repulsion is there, in ammonia

( $\text{NH}_3$ ), LP of N = 1 and hence, two repulsive forces (LP-BP & BP-BP) are there, in water ( $\text{H}_2\text{O}$ ), LP on O = 2, hence, three types of repulsive forces (LP-LP, LP-BP & BP-BP) are there.

ii) Electronegativity of the central atom (when repulsive force and peripheral atoms are same): When a pair of molecules, having the same repulsive force, in which, peripheral atoms are the same but central atoms are different, then, bond angle increases with increasing electronegativity values of the central atom due to much more repulsive interactions between two adjacent bond pair electron clouds, shifted towards higher electronegative central atom.

**Ex.** In between  $\text{H}_2\text{O}$  and  $\text{H}_2\text{S}$ , both exhibit the same repulsive forces (LP-LP, LP-BP & BP-BP). Here, peripheral atoms are same 'H' but central atoms are different 'O' & 'S'. In between oxygen and sulfur, since, central atom 'O' in  $\text{H}_2\text{O}$  is much more electronegative (E.N. of O = 3.5) than central atom 'S' in  $\text{H}_2\text{S}$  (E.N. of S = 2.5), therefore, oxygen attracts bond pair electron clouds towards itself more closely than that of sulfur. As a result of it, bond pair-bond pair repulsion between two bond pair electron clouds will be much more in water,  $\text{H}_2\text{O}$  than that of  $\text{H}_2\text{S}$ . Hence, bond angle of  $\text{H}_2\text{O} > \text{H}_2\text{S}$ .

ii) Electronegativity of the peripheral atom (when repulsive force and central atoms are same): When, pair of molecules, having same repulsive force, in which, central atoms are same but peripheral atoms are different, then, bond angle decreases with increasing electronegativity values of the peripheral atom due to much less repulsive interactions between two bond pair electron clouds, shifted towards higher electronegative peripheral atom.

**Ex.** In between  $\text{NH}_3$  and  $\text{NF}_3$ , both have LP = 1 and hence, exhibit same repulsive forces (LP-BP & BP-BP). Here, central atoms are same 'N' but peripheral atoms are different 'H' & 'F'. In between fluorine and hydrogen, since, peripheral atom 'F' in  $\text{NF}_3$  is much more electronegative (E.N. of F = 4.0) than peripheral atom 'H' in  $\text{NH}_3$  (E.N. of H = 2.1), therefore, fluorine attracts bond pair electron clouds towards itself more closely than that of hydrogen. As a result of it, bond pair-bond pair repulsion between two adjacent bond pair electron clouds will be much more in ammonia,  $\text{NH}_3$  than that of  $\text{NF}_3$ . Hence, bond angle of  $\text{NH}_3 > \text{NF}_3$ .

## **APPLICATIONS OF HYBRIDIZATION STATE IN CHEMICAL FIELD:**

**Hybridization state has a variety of applications as follows:**

### **1. Hybridization state used in the prediction of dipole moment ( $\mu$ ) as well as polarity.**

**Ex.a.** Cis-2-butene is polar whereas trans-2-butene is a nonpolar described as follows with the help of hybridization state (**Fig. 1.11**)

% of s character is directly proportional to the electronegativity, hence electronegativity order is  $sp - C$  (s 50%) >  $sp^2 - C$  (s 33.3%) >  $sp^3 - C$  (s 25%)

## 2. Hybridization state used in the prediction of acidic order of hydrocarbons (alkyne, alkene, and alkane).

**Ex.b.** Acidic order of alkyne, alkene, and alkane can be well explained as follows:



Decreasing acidic order is alkyne ( $HC \equiv CH$ ) > alkene ( $H_2C = CH_2$ ) > alkane ( $H_3C - CH_3$ )

Alkyne having  $sp$  hybridized carbon atoms, whereas, alkene having  $sp^2$  hybridized carbon atoms and alkane having  $sp^3$  hybridized carbon atoms. Since, % of s character  $\propto$  electronegativity and electronegativity of carbon in hydrocarbons  $\propto$  proton donation tendency (Acidity), hence, electronegativity order is

$sp - C$  (s 50%) >  $sp^2 - C$  (s 33.3%) >  $sp^3 - C$  (s 25%) and thus, decreasing acidic order is alkyne ( $HC \equiv CH$ ) > alkene ( $H_2C = CH_2$ ) > alkane ( $H_3C - CH_3$ ).

## 3. Hybridization state used in the prediction of basic order.

**Ex.c.** Basic strength between amine ( $-NH_2$ ) and nitrile ( $-CN$ ) can be explained as follows:

Nitrogen atom in methylamine ( $CH_3NH_2$ ) is  $sp^3$  hybridized (% s character = 25%) and in methyl cyanide ( $CH_3C \equiv N$ ) is  $sp$  hybridized (% s character = 50%). With % s character electronegativity increases. Hence,  $sp$  N of methyl cyanide ( $CH_3C \equiv N$ ) is more electronegative than methylamine ( $CH_3NH_2$ ), which ( $sp$  N of methyl cyanide), tightly holds the lone pair of electrons on it and thus less readily available for protonation or donation and thus decreases basic character of methyl cyanide ( $CH_3C \equiv N$ ) with respect to methylamine ( $CH_3NH_2$ ).

## 4. Hybridization state used in the prediction of normal and subnormal geometry.

Simple molecules or ions having  $LP = 0$  ( $LP =$  lone pair of electrons), show normal geometry, whereas, ( $LP \neq 0$ ), show subnormal geometry (Table 1.2).

## 5. Hybridization state is useful for the prediction of bond length and bond strength of any bonds.

Power of the hybridization state ( $P_{Hyb}$ ), is directly proportional to bond length and inversely proportional to the bond strength of bonds. Generally, mixing of hybridization state decreases bond length value and in such cases, with decreasing power of the mixed hybridization state, bond length value decreases.

**Ex.d.**  $C-C: sp^3-sp^3, P_{Hyb} = 3+3 = 6$ , C-C bond length =  $1.54 \text{ \AA}$ ;  $C-C sp^3-sp^2, P_{Hyb} = 3+2 = 5$ , C-C bond length =  $1.50 \text{ \AA}$ ;

$C-C : sp^3-sp$ ,  $P_{Hyb} = 3+1 = 4$ , C-C bond length =  $1.46 \text{ \AA}$

$C=C : sp^2-sp^2, P_{Hyb} = 2+2 = 4$ , C-C bond length =  $1.34 \text{ \AA}$ ;  $C=C sp^2-sp$ ,  $P_{Hyb} = 2+1 = 3$ , C-C bond length =  $1.31 \text{ \AA}$

$C \equiv C : sp-sp, P_{Hyb} = 1+1 = 2$ , C-C bond length =  $1.21 \text{ \AA}$

C-H :  $sp^3$ -H,  $P_{Hyb} = 3$ , C-H bond length =  $1.11 \text{ \AA}$ ;  $sp^2$ -H,  $P_{Hyb} = 2$ , C-H bond length =  $1.10 \text{ \AA}$ ;

$sp$ -H,  $P_{Hyb} = 1$ , C-H bond length =  $1.08 \text{ \AA}$  .

C-O:  $sp^3$ -O ,  $P_{Hyb} = 3$ , bond length =  $1.41 \text{ \AA}$ ; C=O:  $sp^2$ -O ,  $P_{Hyb} = 2$ , bond length =  $1.20 \text{ \AA}$

C-N:  $sp^3$ -N,  $P_{Hyb} = 3$ , bond length =  $1.47 \text{ \AA}$ ; C=N:  $sp^2$ -O ,  $P_{Hyb} = 2$ , bond length =  $1.28 \text{ \AA}$ ;

C≡N:  $sp$ -N ,  $P_{Hyb} = 1$ , bond length =  $1.16 \text{ \AA}$

6. Bond angle can also be evaluated from the hybridization state.

Bond angle is directly proportional to the s character of a hybrid orbital as follows:

Bond angle follows the order

$sp - C$  (50 % s) >  $sp^2 - C$  (33.3 % s) >  $sp^3 - C$  (25% s)

### PROBLEMS ON HYBRIDIZATION & GEOMETRY

**Q1. Which of the following pairs of ions is isoelectronic and isostructural? (NEET II-2016)**

a.  $CO_3^{2-}, NO_3^-$  b.  $ClO_3^-, CO_3^{2-}$  c.  $SO_3^{2-}, NO_3^-$  d.  $ClO_3^-, SO_3^{2-}$

Ans: a & d

( $CO_3^{2-}, NO_3^-$  both have 32 e<sup>-</sup>s,  $sp^2$ , LP=0, trigonal planar geometry) & ( $ClO_3^-, SO_3^{2-}$  both have 42 e<sup>-</sup>s,  $sp^3$ , LP=1, pyramidal geometry)

**Q2. The correct geometry and hybridization for  $XeF_4$  are (NEET II 2016)**

a. octahedral,  $sp^3d^2$  b. trigonal bipyramidal,  $sp^3d$  c. planar triangle,  $sp^3d^3$  d. square planar,  $sp^3d^2$

Ans: d - square planar,  $sp^3d^2$

**Q3.  $XeF_2$  is iso-structural with (NEET 2013)**

a.  $SbCl_3$  b.  $BaCl_2$  c.  $TeF_2$  d.  $ICl_2^-$

Ans: d.  $ICl_2^-$   $sp^3d$  linear

**Q4. The structure of  $IF_7$  is (AIIEE 2011)**

a. Square pyramid b. trigonal bipyramid c. octahedral d. pentagonal bipyramid

Ans: d.  $IF_7$  -  $sp^3d^3$  LP=0, pentagonal bipyramid (Normal Geometry).

**Q5. Consider the state of hybridization of carbon atoms, find out the molecule among the following**

**which is linear ? (CBSE PMT 2011)**

a.  $CH_3 - CH = CH - CH_3$

b.  $CH_3 - C \equiv C - CH_3$

c.  $CH_2 = CH - CH_2 - C \equiv CH$

d.  $CH_3 - CH_2 - CH_2 - CH_3$

Ans: b.  $CH_3 - C \equiv C - CH_3$  ( both -  $C \equiv C$  - will be in  $sp$  hybridization state and LP = 0)

**Q6. Base strength of  $\text{H}_3\text{C}-\text{CH}_2^-$  (i),  $\text{H}_2\text{C} = \text{CH}^-$  (ii) and  $\text{H} - \text{C} \equiv \text{C}^-$  (iii) is in the order of**

- a. (i) > (iii) > (ii)      b. (i) > (ii) > (iii)      c. (ii) > (i) > (iii)      d. (iii) > (ii) > (i)

Ans: b. (i) > (ii) > (iii)

Acidic order is  $\text{H}-\text{C} \equiv \text{C}-\text{H} > \text{H}_2\text{C} = \text{CH}_2 > \text{H}_3\text{C}-\text{CH}_3$

since stronger acid will have weaker conjugate base therefore, order of the conjugate base of the

above acid is  $\text{H}_3\text{CCH}_2^- > \text{H}_2\text{C} = \text{CH}^- > \text{H} - \text{C} \equiv \text{C}^-$ .

**Q7. Methylamine ( $\text{CH}_3\text{NH}_2$ ) is more basic than methyl cyanide ( $\text{CH}_3\text{C}\equiv\text{N}$ ). This is due to the which one of the following reason**

- a. both having different (+I) effect group      b. both having same (+I) effect group  
c. both nitrogens having same s character      d. both nitrogens have different s character

Ans: d. both nitrogens having different s character      [stated in the application]

**Q8. Which of the following species contains 3 bond pairs and one lone pair around the central atom? (NEET 2013)**

- a.  $\text{H}_2\text{O}$    b.  $\text{BF}_3$    c.  $\text{NH}_2^-$    d.  $\text{PCl}_3$

Ans:  $\text{PCl}_3$  (LP = 1 and BPs = 3)

**Q9. The hybridization of atomic orbitals of nitrogen in  $\text{NO}_2^+$ ,  $\text{NO}_3^-$  and  $\text{NH}_4^+$  respectively are (NEET & JEEMAIN 16)**

- a.  $sp$ ,  $sp^3$  and  $sp^2$    b.  $sp^2$ ,  $sp^3$  and  $sp$    c.  $sp$ ,  $sp^2$ , and  $sp^3$    d.  $sp^2$ ,  $sp$ , and  $sp^3$

Ans: c.  $sp$ ,  $sp^2$ , and  $sp^3$

**Q10. Total number of lone pair electrons in  $\text{I}_3^-$  ion is (JEE MAIN 2018)**

- a. 3      b. 6      c. 9      d. 12

Ans: c. 9

**Q11. Which of the following molecules represents the order of hybridization  $sp^2$ ,  $sp^2$ ,  $sp$ ,  $sp$  from Left to Right atoms (NEET 18)**

- a.  $\text{CH}_2=\text{CH}-\text{CH}=\text{CH}_2$    b.  $\text{CH}_2=\text{CH}-\text{C}\equiv\text{CH}$    c.  $\text{CH}\equiv\text{C}-\text{C}\equiv\text{CH}$    d.  $\text{CH}_3-\text{CH}=\text{CH}=\text{CH}_3$

Ans: b.  $\text{CH}_2=\text{CH}-\text{C}\equiv\text{CH}$  (Limitation of Conventional Method)

**Q12. In which of the following pair both have  $sp^3$  hybridization? (Karnataka NEET 2013)**

- a.  $\text{SiF}_4$ ,  $\text{BeH}_2$    b.  $\text{NF}_3$ ,  $\text{H}_2\text{O}$    c.  $\text{NF}_3$ ,  $\text{BF}_3$    d.  $\text{H}_2\text{S}$ ,  $\text{BF}_3$

Ans: b.  $\text{NF}_3$ ,  $\text{H}_2\text{O}$

**Q13. The correct geometry and hybridization for  $\text{XeF}_4$  are (NEET II 2016)**

- a. octahedral,  $sp^3d^2$    b. trigonal bipyramidal,  $sp^3d$    c. planar triangle,  $sp^3d^3$    d. square planar,  $sp^3d^2$

Ans: d - square planar,  $sp^3d^2$

**Q14. Which of the following bonds is strongest?**

- a.  $H_3C-CH_3$    b.  $H_2C=CH_2$    c.  $H_3C-CH=$    d.  $HC\equiv CH$

Ans: d.  $HC\equiv CH$

**Q15. Which of the following is planar in shape?**

- a. Methane   b. Acetylene   c. Benzene   d. Isobutane

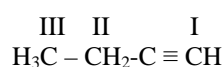
Ans: c. Benzene (all six carbons are in  $sp^2$  hybridized makes it planar)

**Q16. Bond length among C-C in ethane (I), ethene (II) and ethyne (III) follows the order**

- a.  $I > II > III$    b.  $II > I > III$    c.  $III > I > II$    d.  $III > II > I$

Ans: a.  $I > II > III$  [I (ethane,  $sp^3$ ,  $P_{Hyb}=3$ ) > II (ethene,  $sp^2$ ,  $P_{Hyb}=2$ ) > III (ethyne,  $sp$ ,  $P_{Hyb}=1$ )

**Q17. Which of the following carbon atoms is most electronegative?**



- a. I   b. II   c. III   d. all are equally electronegative

Ans: a. (sp C, s 50 %, % of s character  $\propto$  electronegativity)

**Q18. An  $sp^3$  hybrid orbital contains**

- a. 1/4 s-character   b. 1/2 s-character   c. 2/3 s-character   d. 3/2 s-character

Ans: a. 1/4 s-character (s:p = 1:3 in  $sp^3$ )

**Q19. In,  $CCl_4$ , the four valencies of carbon are directed towards the corner of a**

- a. Cube   b. Hexagon   c. Prism   d. Tetrahedron

Ans: d. Tetrahedron (in  $CCl_4$  - C is in  $sp^3$ , BP = 0 & LP of C = 0, regular geometry) (See Table 1.2)

**Q20. In which of the following the angle between the two covalent bonds is largest?**

- a.  $H_2O$    b.  $NH_3$    c.  $CO_2$    d.  $CH_4$

Ans: c.  $CO_2$  (in  $O=C=O$ , hybridization  $sp$  & bond angle  $180^\circ$ ) (See Table 1.2)

**Q21. Which has the minimum bond angle?**

- a.  $H_2O$    b.  $H_2S$    c.  $NH_3$    d.  $CH_4$

Ans: b.  $H_2S$  [Bond angle  $\propto 1 / \text{number of lone pair of electrons (LPs)}$  & (for same repulsive force), Bond angle  $\propto$  electronegativity of the central atom]

**Q.22. Which of the following geometry is associated with the compound in which the central atom assumes  $sp^3d$  hybridization?**

- a. Planar   b. Pyramidal   c. Angular   d. Trigonal bipyramidal

Ans: d. Trigonal bipyramidal (for hybridization  $sp^3d$  - geometry is Trigonal bipyramidal) (See Table 1.2)

**Q.23. The pyramidal geometry is associated with**

- a.  $CH_4$    b.  $NH_3$    c.  $H_2O$    d.  $CO_2$

Ans: b.  $NH_3$  (See Table 1.2)

**Q.24. According to VSEPR theory, which one of the following has ideal tetrahedral shape? (NET 2011)**

- a.  $SO_2$    b.  $SO_3$    c.  $SO_4^{2-}$    d.  $SO_3^{2-}$

Ans: c.  $SO_4^{2-}$  ( $SO_4^{2-}$  is ideal because of the presence of same atoms and it has LP = 0 and BP = 4 around the S atom) (See Table 1.2)

**Q.25. Which of the following molecules is linear?**

- a.  $C_2H_2$    b.  $SiCl_4$    c.  $CH_4$    d.  $H_2Se$

Ans: a.  $C_2H_2$  ( $H-C\equiv C-H$ , sp-C, LP = 0, linear geometry)

**Q.26. Boron in  $BCl_3$  has (NET 2017)**

- a) sp hybridization   b)  $sp^2$  hybridization   c)  $sp^3$  hybridization   d) no hybridization

Ans: b)  $sp^2$  hybridization (See Table 1.1)

**Q.27. A molecule in which  $sp^2$  hybrid orbitals are used by the central atom in forming covalent bonds is**

- a.  $He_2$    b.  $SO_2$    c.  $PCl_5$    d.  $N_2$

Ans: b.  $SO_2$  (See Table 1.2)

**Q.28. The bond angle in  $NH_3$  is close to**

- a.  $90^\circ$    b.  $180^\circ$    c.  $109^\circ$    d.  $120^\circ$

Ans: c.  $109^\circ$

**Q.29. The octahedral shape is associated with**

- a.  $PF_5$    b.  $SF_4$    c.  $TeF_6$    d.  $ClF_3$

Ans: c.  $TeF_6$  (LP of Te = 0,  $sp^3d^2$  - octahedral) (See Table 1.2)

**Q.30. The hybrid states of carbon in diamond, graphite and acetylene are respectively**

- a.  $sp^2$ , sp,  $sp^3$    b. sp,  $sp^2$ ,  $sp^3$    c.  $sp^3$ ,  $sp^2$ , sp   d.  $sp^2$ ,  $sp^3$ , sp

Ans: c.  $sp^3$ ,  $sp^2$ , sp (in diamond C -  $sp^3$ , in graphite C -  $sp^2$  and in acetylene C - sp)



**Q.31. The  $\text{AsF}_5$  molecule is trigonal bipyramidal. The orbitals used by As for hybridization are**

- a.  $d_z^2, s, p_x, p_y, p_z$       b.  $d_{x^2-y^2}, s, p_x, p_y, p_z$       c.  $s, p_x, p_y, p_z, d_{xz}$       d. None of these.

Ans: a.  $d_z^2, s, p_x, p_y, p_z$  (see in the text)

**Q.32. The molecule with highest number of lone pairs and has a linear shape based on VSEPR theory is (NET 2011)**

- a.  $\text{CO}_2$       b.  $\text{I}_3^-$       c.  $\text{NO}_2$       d.  $\text{NO}_2^+$

Ans: b.  $\text{I}_3^-$  (Tri iodide ion  $\text{I}_3^-$  is linear geometry in which central I contain 3 lone pairs – see Fig. 1.7)

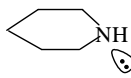
**Q.33. Which of the following molecules/ions has a triangular pyramidal shape?**

- a.  $\text{BF}_3$       b.  $\text{NO}_3^-$       c.  $\text{H}_3\text{O}^+$       d.  $\text{CO}_3^{2-}$

Ans: c.  $\text{H}_3\text{O}^+$  (It is  $sp^3$  hybridized with 01 LP and 3 BPs around the oxygen atom similar to  $\text{NH}_3$  shows triangular pyramidal shape – see Fig. 1.10)

**Q.34. In piperidine, the hybrid state assumed by N is**

- a. sp      b.  $sp^2$       c.  $sp^3$       d.  $dsp^2$



Ans: c.  $sp^3$  (In piperidine, N is surrounded by 01 LP and 3 BPs –  $sp^3$  hybridized)

**Q.35. Which of the following pairs contains isostructural species?**

- a.  $\text{CH}_3^-$  and  $\text{CH}_3^+$       b.  $\text{NH}_4^+$  and  $\text{NH}_3$       c.  $\text{SO}_4^{2-}$  and  $\text{BF}_4^-$       d.  $\text{NH}_2^-$  and  $\text{BeF}_2$

Ans: c.  $\text{SO}_4^{2-}$  and  $\text{BF}_4^-$  (both are in  $sp^3$  hybridized having tetrahedral geometry)

**Q.36. The  $\text{BCl}_3$  molecule is planar while  $\text{NCl}_3$  is pyramidal because**

- a.  $\text{BCl}_3$  does not have the lone pair on B but  $\text{NCl}_3$  has one b. N atom is smaller than B  
c. B-Cl bond is more polar than N-Cl bond d. N-Cl bond is more covalent than B-Cl bond

Ans: a.  $\text{BCl}_3$  does not have the lone pair on B but  $\text{NCl}_3$  has one (See Table 1.2)

**Q.37. Among  $\text{SF}_4$ ,  $\text{BF}_4^-$ ,  $\text{XeF}_4$ , and  $\text{ICl}_4^-$ , the number of species having two lone pairs on the central atom according to VSEPR theory is (NET 2011)**

- a)2      b)3      c)4      d)0

Ans: a)2 ( $\text{XeF}_4$  &  $\text{ICl}_4^-$  both have LP =2; see Table 1.2)

**Q.38. Total number of lone pairs of electrons of Xe in  $\text{XeOF}_4$  is**

- a.0      b.1      c.2      d.3

Ans:  $\text{XeOF}_4$  (LP = 1 & BPs = 6 around Xe in  $\text{XeOF}_4$ )

**Q.39. The angles between covalent bonds is maximum in**

- a. CH<sub>4</sub>      b. BF<sub>3</sub>      c. PF<sub>3</sub>      d. NH<sub>3</sub>

Ans: b. BF<sub>3</sub> (sp<sup>2</sup> hybridized - highest bond angle, where, rest three are sp<sup>3</sup> hybridized lower bond angle)

**Q.40. The bond length between C-C bonds in sp<sup>2</sup> hybridized molecule is**

- a. 1.2Å      b. 1.62Å      c. 1.54Å      d. 1.34Å

Ans: d. 1.34Å (C=C : sp<sup>2</sup>-sp<sup>2</sup>, C-C bond length = 1.34Å)

**Q.41. The hybridization of Xe in XeF<sub>2</sub> is**

- a. sp<sup>3</sup>      b. sp<sup>2</sup>      c. sp<sup>3</sup>d      d. sp<sup>3</sup>d<sup>2</sup>

Ans: c. sp<sup>3</sup>d ( BPs = 2 & LPs = 3 around Xe in XeF<sub>2</sub> - 5 T<sub>SLP</sub> = 4 T<sub>SLP</sub> + 1 additional T<sub>SLP</sub> = sp<sup>3</sup>d hybridization)

**Q.42. Which of the following will be octahedral ?**

- a. SF<sub>6</sub>      b. BF<sub>4</sub><sup>-</sup>      c. PCl<sub>5</sub>      d. H<sub>3</sub>BO<sub>3</sub>

Ans: a. SF<sub>6</sub> (LP = 0, sp<sup>3</sup>d<sup>2</sup> – regular geometry - octahedral)

**Q.43. The structure of CH<sub>2</sub>=C=CH<sub>2</sub> is**

- a. Linear      b. Planar      c. Non-Planar      d. None

Ans: b. Planar (since carbon uses only sp and sp<sup>2</sup> hybrid orbitals)

**Q.44. Carbon atoms in benzene molecule are inclined at an angle of**

- a. 120°      b. 180°      c. 109°      d. 60°

Ans: a. 120° ( in benzene, each carbon atom is sp<sup>2</sup> hybridized)

**Q.45. In BrF<sub>3</sub> molecule, the lone pairs occupy equatorial positions to minimize**

- a. Lone pair – lone pair repulsion only      b. Lone pair – bond pair repulsion only  
c. Bond pair – bond pair repulsion only      d. Lone pair – lone pair repulsion and lone pair – bond pair repulsion.

Ans: d. Lone pair – lone pair repulsion and lone pair – bond pair repulsion

**Q.46. The shape of gaseous SnCl<sub>2</sub> is**

- a. Tetrahedral      b. Linear      c. Angular      d. T-shaped

Ans: c. Angular (Sn is sp<sup>2</sup> hybridized and thus angular shaped)

**Q.47. The shape of the molecule SF<sub>2</sub>Cl<sub>2</sub> is**

- a. Trigonal bipyramidal      b. Cube      c. Octahedral      d. Tetrahedral

Ans: a. Trigonal bipyramidal (in SF<sub>2</sub>Cl<sub>2</sub>, LP=1 & BPs = 4, hence, 5T<sub>SLP</sub> = 4 T<sub>SLP</sub> + 1 additional T<sub>SLP</sub> = sp<sup>3</sup>d hybridization)

**Q.48. Which carbon is more electronegative ?**

- a.  $sp^3$ -hybridized carbon    b.  $sp$ -hybridized carbon    c.  $sp^2$ -hybridized carbon  
d. Irrespective of the hybrid state

Ans: b.  $sp$ -hybridized carbon (% s = 50%)

**Q.49. The shape of  $O_2F_2$  is similar to that of**

- a.  $C_2F_2$     b.  $H_2O_2$     c.  $H_2F_2$     d.  $C_2H_2$

Ans: b.  $H_2O_2$

**Q.50. The most efficient overlapping is**

- a.  $sp^2-sp^2$     b. s-s    c.  $sp^3-sp^3$     d.  $sp-sp$

Ans: c.  $sp^3-sp^3$  (Greater the p-character, greater is the ability to overlap)

**Q.51. In  $NO_3^-$  ion, number of bond pairs and lone pairs of electrons are respectively**

- a. 2,2    b. 3,1    c. 1,3    d. 5,8

Ans: d. 4,8 ( $NO_3^-$  be the conjugate base of  $HNO_3$  in which BPs = 5 and LPs of O = 8)

**Q.52. The shape of  $ClO_3^-$  is**

- a. Triangular pyramidal    b. Tetrahedral    c. Angular    d. Linear

Ans: b. Tetrahedral (In  $ClO_3^-$  LP = 0,  $sp^3$  hybridization state)

**Q.53.  $IF_5$  has the following hybridization**

- a.  $sp^3d^2$     b.  $sp^3d$     c.  $sp^3d^3$     d. None of these

Ans: a.  $sp^3d^2$  [LP = 1 & BPs = 5, hence,  $6 T_{SLP} = 4 T_{SLP} + 2$  additional  $T_{SLP} = sp^3d^2$  hybridization)]

**Q.54. The correct order of bond angle is**

- a.  $H_2O > NH_3 > CH_4 > CO_2$     b.  $H_2O < NH_3 < CO_2 < CH_4$     c.  $H_2O < NH_3 > CO_2 > CH_4$     d.  $CO_2 > CH_4 > NH_3 > H_2O$

Ans: d.  $CO_2 > CH_4 > NH_3 > H_2O$  (In  $CO_2$  LP = 0, linear,  $sp$ ; in  $CH_4$  LP = 0, tetrahedral,  $sp^3$ ; in  $NH_3$ , LP = 1,  $sp^3$  and in  $H_2O$ , LP = 2,  $sp^3$ )

**Q.55. In  $OF_2$ , number of bond pairs and lone pairs of electrons are respectively**

- a. 2,6    b. 2,8    c. 2,10    d. 2,9

Ans: b. 2,8 (In F-O-F, each F has 3 LPs and O has 2 LPs . Here, BPs = 2)

**Q.56. Which of the following bonds requires the largest amount of bond energy to dissociate into corresponding atoms?**

- a. H-H bond in  $H_2$     b. C-H bond in  $CH_4$     c.  $N \equiv N$  bond in  $N_2$     d.  $O=O$  bond in  $O_2$

Ans: c.  $\text{N}\equiv\text{N}$  bond in  $\text{N}_2$  (B.O. is directly proportional to the bond dissociation energy, B.O. of  $\text{N}_2$  is 3.0, greater the multiplicity of the bond, more is the bond strength and hence more will be the bond dissociation energy)

**Q.57. Beryllium atom in  $\text{BeF}_2$  is**

- a.  $\text{sp}^3$  hybridized      b.  $\text{sp}^2$  hybridized      c. sp hybridized      d. Unhybridized

Ans: c. sp hybridized [In  $\text{BeF}_2$ , Be has LP = 0 and  $\sigma$  bonds = 2,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = 2 - 1 = 1$  (sp)]

**Q.58. Amongst the following the molecule that is linear is**

- a. ICl      b.  $\text{NO}_2$       c.  $\text{SO}_2$       d.  $\text{ClO}_2$

Ans: a. ICl [In ICl, LP of each halogen = 3,  $\sigma$  bond = 1,  $(P_{\text{Hyb}}) = (T_{\text{SLP}}) - 1 = 4 - 1 = 3$  ( $\text{sp}^3$ ), linear]

**Q.59. Amongst the following molecules the one with the largest distance between the two adjacent carbon atoms is**

- a. Ethane      b. Ethene      c. Ethyne      d. Benzene

Ans: a. Ethane ( $\text{sp}^3$ , Lower the multiplicity of the bond, higher is the bond length)

**Q.60. The correct sequence of the decrease in the bond angles of the following molecules is**

- a.  $\text{NH}_3 > \text{PH}_3 > \text{AsH}_3 > \text{SbH}_3$       b.  $\text{NH}_3 > \text{AsH}_3 > \text{PH}_3 > \text{SbH}_3$       c.  $\text{SbH}_3 > \text{AsH}_3 > \text{PH}_3 > \text{NH}_3$   
d.  $\text{PH}_3 > \text{NH}_3 > \text{AsH}_3 > \text{SbH}_3$

Ans: a.  $\text{NH}_3 > \text{PH}_3 > \text{AsH}_3 > \text{SbH}_3$  (Under the same repulsive force, bond angle is directly proportional to the electronegativity of the central atom when peripheral atoms are same, electronegativity order is  $\text{N} > \text{P} > \text{As} > \text{Sb}$ )

**Q.61. The compound in which C uses its  $\text{sp}^3$  hybrid orbitals for bond formation is**

- a.  $\text{HCOOH}$       b.  $(\text{H}_2\text{N})_2\text{CO}$       c.  $\text{HCHO}$       d.  $\text{CH}_3\text{CHO}$

Ans: d.  $\text{CH}_3\text{CHO}$  ( $\text{CH}_3$  group in  $\text{CH}_3\text{CHO}$  is in  $\text{sp}^3$  hybridized)

**Q.62. The correct order of increasing C-O bond length of  $\text{CO}$ ,  $\text{CO}_3^{2-}$ ,  $\text{CO}_2$  is**

- a.  $\text{CO}_3^{2-} < \text{CO}_2 < \text{CO}$       b.  $\text{CO}_2 < \text{CO}_3^{2-} < \text{CO}$       c.  $\text{CO} < \text{CO}_3^{2-} < \text{CO}_2$       d.  $\text{CO} < \text{CO}_2 < \text{CO}_3^{2-}$

Ans: d.  $\text{CO} < \text{CO}_2 < \text{CO}_3^{2-}$  [Resonance possible in  $\text{CO}_3^{2-}$ ,  $\text{O} = \text{C} = \text{O}$ ,  $\text{C} \equiv \text{O}$ ]

**Q.63. Among the following, the pair in which the two species are not isostructural is**

- a.  $\text{PF}_6^-$  and  $\text{SF}_6$       b.  $\text{SiF}_4$  and  $\text{SF}_4$       c.  $\text{XeF}_2$  and  $\text{BrCl}$       d.  $\text{BH}_4^-$  and  $\text{NH}_4^+$

Ans: b.  $\text{SiF}_4$  and  $\text{SF}_4$  ( $\text{SiF}_4$ , tetrahedral,  $\text{sp}^3$  and  $\text{SF}_4$ , see-saw,  $\text{sp}^3\text{d}$ ) (see Table 1.2)

**Q.64. The number of  $\sigma$  and  $\pi$  bonds in pent-4-ene-1-yne is**

- a. 3, 10      b. 9, 4      c. 4, 9      d. 10, 3

Ans: d. 10, 3 ( $\text{H}\equiv\text{C}-\text{CH}_2-\text{CH}=\text{CH}_2$ , all single bonds are  $\sigma$  bonds, in double bond 1 $\sigma$  & 1 $\pi$ , in triple bonds 1 $\sigma$  & 2 $\pi$ )

**Q.65. Lone pair of electrons is present in the central atom of** (STGT 2018)

- (a)  $\text{CCl}_4$  (b)  $\text{BF}_3$  (c)  $\text{NH}_3$  (d) None of the above

Ans: (c)  $\text{NH}_3$  (for N, LP = 1, BPs = 3)

**Q.66. C—C bond length in ethane molecule is** (STGT 2018)

- (a) 1.20 Å (b) 1.54 Å (c) 1.34 Å (d) 1.39 Å

Ans: (b) 1.54 Å (in ethane, C-C:  $\text{sp}^3\text{-sp}^3$ ,  $P_{\text{Hyb}} = 3+3 = 6$ , C-C bond length = 1.54 Å)

**Q.67. C—C—C bond angle in diamond crystal is** (STGT 2018)

- (a)  $109^\circ 28'$  (b)  $107^\circ 28'$  (c)  $120^\circ$  (d) None of the above

Ans: (a)  $109^\circ 28'$  (in diamond C -  $\text{sp}^3$  & in graphite C -  $\text{sp}^2$  see Table 1.2)

**Q.68. In crystalline graphite, C—C bond length is** (STGT 2017)

- (a) 1.54 Å (b) 1.34 Å (c) 1.42 Å (d) 1.62 Å

Ans: (b) 1.34 Å (in graphite, C-C :  $\text{sp}^2\text{-sp}^2$ ,  $P_{\text{Hyb}} = 2+2 = 4$ , C-C bond length = 1.34 Å)

**Q.69. What is the C-C bond length (in angstrom) in diamond?** (STGT 2016)

- (a) 5.2 (b) 2.0 (c) 1.54 (d) 3.35

Ans: (c) 1.54 (in diamond, C-C :  $\text{sp}^3\text{-sp}^3$ ,  $P_{\text{Hyb}} = 3+3 = 6$ , C-C bond length = 1.54 Å)

**Q.70. The ratio of  $\sigma$  and  $\pi$  bonds in naphthalene is** (STGT 2016)

- (a) 11:5 (b) 5:11 (c) 8:5 (d) 19:5

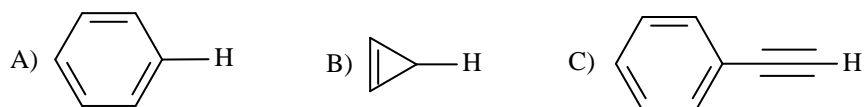
Ans: (d) 19:5 (in naphthalene, there is 19  $\sigma$  and 5  $\pi$  bonds)

**Q.71. Among  $\text{ClO}_3^-$ ,  $\text{XeO}_3$  and  $\text{SO}_3$ , species with pyramidal shape is/are?** (NET 2017)

- a)  $\text{ClO}_3^-$  and  $\text{XeO}_3$  (b)  $\text{XeO}_3$  and  $\text{SO}_3$  (c)  $\text{ClO}_3^-$  and  $\text{SO}_3$  (d)  $\text{SO}_3$

Ans: a)  $\text{ClO}_3^-$  and  $\text{XeO}_3$  (see Table 1.2)

**Q.72. The correct order of the bond dissociation energies for the indicated C-H bond in following compounds is** (NET 2016)



- a)  $\text{C} > \text{B} > \text{A}$  (b)  $\text{A} > \text{B} > \text{C}$  (c)  $\text{A} > \text{C} > \text{B}$  (d)  $\text{C} > \text{A} > \text{B}$

Ans: d)  $\text{C} > \text{A} > \text{B}$  [The power of the hybridization state ( $P_{\text{Hyb}}$ ) of hydrogen bonded carbon atom is directly proportional to the bond length and bond length is inversely proportional to the bond dissociation energies; in A :

$sp^2$ -H,  $P_{Hyb} = 2$ , C-H bond length =  $1.10\text{\AA}$ ; in B :  $sp^3$ -H,  $P_{Hyb} = 3$ , C-H bond length =  $1.11\text{\AA}$ ; and in C :  $sp$ -H,  $P_{Hyb} = 1$ , C-H bond length =  $1.08\text{\AA}$  ].

**Q.73. The correct shape of  $[\text{TeF}_5]^-$  ion on the basis of VSEPR theory is (NET 2016)**

- a) Trigonal bipyramidal    b) Square pyramidal    c) Pentagonal planar    d) See-saw

Ans: b) Square pyramidal (see **Table 1.2**)

### Conclusion

It may be expected **that these four (04) times economic innovative methods would go a long way to help to the students of chemistry at Undergraduate, Senior Undergraduate and Post-Graduate level**, who would choose the chemistry as their career. Experiments, *in vitro*, on 100 students, showed that **by using these mnemonics based teaching methodologies students can save up to 3-5 minutes' time in the examination hall.**

### Contributor:

**Dr. Arijit Das**, Ph.D., MACS, SFICS, MISC, MIAFS (India), Assistant Professor, Department of Chemistry, **Bir Bikram Memorial College, Agartala, Tripura(W)**, Tripura, India, Pin-799004. URL: [www.arijitchemistryworld.com](http://www.arijitchemistryworld.com).