Innovative Mnemonics in Chemical Education

Innovative Mnemonics in Chemical Education:

A Handbook for Classroom Lectures

By

Arijit Das

Cambridge Scholars Publishing

Innovative Mnemonics in Chemical Education:
A Handbook for Classroom Lectures

By Arijit Das

This book first published 2019

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN (10): 1-5275-3922-9
ISBN (13): 978-1-5275-3922-8

TABLE OF CONTENTS

PREFACE

The word ‘mnemonic' is derived from the Ancient Greek language. Here, the first letter 'm', in mnemonic is silent. Mnemonics are a memory device, which helps something to be remembered for a long time in the human memory. We remember different colors of the spectrum by ‘VIBGYOR', so, ‘VIBGYOR' acts as a useful mnemonic to remember the colors of the spectrum.

Here, the book entitled, ‘Innovative Mnemonics in Chemical Education’, provides innovative learning techniques in chemical education, which allow students and educators to keep chemical formula for a long time in their memory.

Simple thinking outside the book transports innovation and builds mnemonics and such innovative mnemonics makes chemical education metabolic and intriguing for students and educators both.

In this book, formulae based innovative mnemonics have been discussed to create interest and solve problems of students in the field of organic and inorganic chemical education. Educators can use these mnemonics in their teaching style in the classroom lectures after discussing conventional methods to make chemistry intriguing. Mnemonics allow you to become a successful educator. Here, I have tried to focus some time economic mnemonics by including invented formulae in the field of chemical education. It will encourage students to solve multiple choice type questions (MCQs) in different competitive examinations (NET, NEET, JEE MAIN, JEE ADVANCE, STGT, STPGT etc.) in a time economic way. This book emphasizes chemical education in the light of a variety of mnemonic techniques to make it metabolic, time economic and intriguing for students because the use of mnemonics in classroom lectures is an essential tool to become a distinguished educator.

These mnemonics based innovative methodologies are also suitable for computer-based learning (CBL) activities or for writing computer programs for solving chemistry problems.

It may be expected that this book and its time economic innovative mnemonics would go a long way to help to the students of chemistry at Undergraduate, Senior Undergraduate and Post-Graduate level who would choose the subject as their career. *In vitro* experiments on 100 students showed that by using these formulae students can save up to 30-40 minutes' time in the examination hall. On the basis of this, I can strongly recommend using this book in the field of chemical education.

I would be grateful to the SERB, DST, New Delhi, Govt. of India, for their financial assistance (Sanction no – SERB/F/5537/2013-14 dated 27/11/2013 and D.O. No. SB/EMEQ-014/2013) to carry out my innovative research in the field of Chemical Education.

I would be grateful to the Ministry of Commerce & Industry, Department of Industrial Policy Promotion, Copyright office, Govt. of India, New Delhi for giving me copyright registration certificate bearing registration number L-77140/2018 dated 07/08/2018.

I would be grateful subsequently to Prof. Delmer Larsen, Dept. of Chemistry, University of California, Davis, USA; Prof. Cao Cu Giac, Head, Dept. of Teaching Methods of Chemistry, Vinh University, Vietnam; Dr. Edel Garcia, Administrator of Minerazzi.com, Bayamon, Puerto Rico, USA; Dr. Satish Nimse, Dept. of Chemistry, Hyllym University, South Korea; V. Jagannadam, Editor-in-Chief, World Journal of Chemical Education, USA; Prof. Temechegn Engida, Editor-in-Chief, African Journal of Chemical Education, Ethiopia, Africa; Prof. G.N. Mukherjee, Sir Rashbehary Ghose Professor of Chemistry, Dept. of Chemistry, Calcutta University; Prof. R. N. Mukherjee, Former Director, IISER, Kolkata; Prof. P. K. Chattaraj, Convenor, centre for Theoretical studies, Dept. of Chemistry, IIT Kharagpur, India; Prof. Samar Kumar Das, School of Chemistry, University of Hyderabad; Prof. Partha Sarathi Mukherjee, Dept. of Chemistry, Indian Institute of Science, Bangalore; Prof. A. T. Khan, Former Head, IIT Patna; Prof. A.K. Das, Ex Vice-Chancellor of Kalyani University; Prof. Nilashis Nandi, Dept. of Chemistry, Kalyani University, W.B., India; Prof. Md. Ali, Dept. of Chemistry, Jadavpur University; Prof. R. A. Lal, Head, Dept. of Chemistry, NEHU, Shillong; Prof. M.K. Singh and Prof. R. K. Nath, Dept. of Chemistry, Tripura Central University for their most valuable guidance in my innovational research journey.

Furthermore, I give my special accolade to Dr. Manoj Kumar Pradhan, Director & Principal, UK Heritage Institute of Management & Technology, India; Mr. Sekhar Datta, Former Senior Journalist 'The Telegraph'; Mr. Sanjib Deb, Editor, 'North East Colors', English daily, Agartala Tripura; Mr. Jayanta Debnath, Managing Director, tripurainfo.com, Agartala, Tripura and Mr. Santanu Chakraborty, Editor, newsupdateoftripura.com, Agartala and Tripura for their constant valuable sustaining mentality to carry out my innovative research work in the field of chemical education.

I want to dedicate this book 'Innovative Mnemonics in Chemical Education (A Handbook for Classroom Lectures)' to my beloved father Late Anil Ranjan Das, who was also a chemistry teacher and was the founder of my chemistry world.

CHAPTER 1

INNOVATIVE MNEMONICS FOR THE PREDICTION OF THE HYBRIDIZATION STATE OF SIMPLE MOLECULES & IONS

In this innovative chapter, formula-based mnemonics count the total number of σ bonds and lone pairs of electrons (T_{SLP}) and then subtract 1 to predict the power of the hybridization state. This method is both innovative and time efficient; it will also enhance the interest of those students who belong to the "paranoia zone of chemistry". Educators can use these mnemonics, after discussing conventional methods, to make chemistry intriguing. This chapter encourages students to solve multiple choice type questions (MCQs) in a time efficient manner to predict the hybridization state of simple molecules and ions; this enables them to find out their normal and sub-normal geometry. This innovative chapter uses a variety of mnemonic techniques to make chemistry fascinating. Also, the use of mnemonics is an essential tool that can be used in classroom lectures.

The conventional formula to determine the hybridization state of simple molecules and ions is time-consuming.[1] Therefore, in this innovative

---

[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; L. Pauling and P. Pauling, *Chemistry* (Freeman International Ed.: 1975), 148, 163–167; 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#.XEsGBtIza1s; J. D. Lee, *Concise Inorg. Chem.* (Wiley India and Oxford, 5th ed.: 2009), 944, 109–112; J. E. Huheey, et al. *Inorganic Chemistry* (Pearson, 4th ed., India: 2006), 172–185; B. Douglas et al. *Concepts and Models of Inorg. Chem.* (*Wiley India,* 3rd ed.: 2007), 157, 38; F A. Cotton et al. *Basic Inorg. Chem.* (Wiley India, 3rd ed.: 2007), 107, 523, 111.

pedagogical chapter, I have introduced some mnemonics to make chemistry interesting.[2] I have discussed them along with their limitations, applications, and problems.

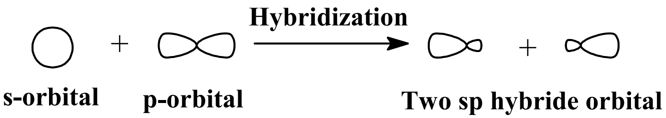
METHODOLOGY

A. Hybridization state theory

Prof. Linus Pauling (1931), first developed hybridization state theory in order to explain the structure of molecules, such as methane (CH_4), using atomic orbitals. This concept was developed for simple chemical systems but it was applied more widely later on. It is an essential part of finding structures from organic and inorganic compounds.

In hybridization, orbitals from the same atom intermix with slightly different energies and this results in the formation of new orbitals. There are called hybrid orbitals and they have the same energy and shape. The mixing pattern is as follows:

one s + one p = sp hybrid orbital, one s + two p = sp^2 hybrid orbital, one s + three p = sp^3 hybrid orbital, one s + three p + one d (d_{z^2}) = sp^3d hybrid orbital, one s + three p + two d (d_{x2-y2}, d_{z^2}) = sp^3d^2 hybrid orbital, and one s + three p + three d (d_{xy}, d_{yz}, d_{xz}) = sp^3d^3 hybrid orbital.



The ability of the hybrid orbitals to overlap follows the order $sp^3 > sp^2 > sp$. As the p character increases, then it will have more ability to overlap; it will also develop a stronger bond. The bond angles formed by different

[2] 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#; 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; A. Das, "A Review of Time Economic Innovative Mnemonics In Chemical Education", *International Journal of Physics and 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.

hybrid orbitals are in the order sp (180^0) > sp^2(120^0) > sp^3(109.5^0). A larger s-character creates a greater bond angle. The carbon electronegativity also depends upon the state of hybridization. A larger s-character in hybridization will increase the electronegativity. The order of electronegativity of a C atom is $C_{sp} > C_{sp2} > C_{sp3}$.

Some important facts about hybridization are as follows:

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 with a similar energy can participate in hybridization.
iv) Al hybrid orbitals resulting from a particular type of hybridization will be similar in all respects (same energy, shape, and size).
v) Hybrid orbitals are distributed in space as far apart as possible; therefore, they assign a particular shape and geometry to the molecule.
vi) Hybrid orbitals follow Hund's rule and also Pauli's exclusion principle, just like atomic orbitals.
vii) The bond formed between hybrid orbitals is known as a hybrid bond and this is stronger than non-hybrid bonds of comparable length.
viii) Hybrid orbitals are the "dumb-bell" type with a larger lobe with a +ve sign and a smaller lobe with a -ve sign.

B. The conventional method to predict the hybridization state: VALANCE SHELL ELECTRON PAIR REPULSION THEORY (VSEPR THEORY)

Sidgwick and Powell created VSEPR theory in 1940 and it was 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 non-bonding electrons (lone pairs). The main concept is that the electron pairs surrounding the central atom repel each other until they no longer react and the molecule is in a state of minimum energy and maximum stability. This arrangement gives a particular shape to the molecules. The order of repulsion between the electron pairs is lone pair–lone pair (LP–LP) > lone pair–bond-pair (LP–BP) > bond pair–bond-pair (BP–BP).

If only bond pairs surround the central atom, the interactions will be equivalent and the molecule will have a regular geometry. If only bond pairs of dissimilar atoms surround the central atom, the interactions will not be equivalent and the molecule will not have a regular geometry. If both bond pairs and lone pairs surround the central atom, the interactions will be very different and the molecular geometry will be distorted.

The conventional formula to predict the hybridization state is 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, and A = anionic charge. For example, methane CH_4, P = 1/2 (4 + 4 - 0) = 4 (sp^3 hybridization state); ethylene ($CH_2 = CH_2$), P = 1/2 (4 + 2 - 0) = 3 (sp^2 hybridization state).

C. Innovative mnemonics to predict the hybridization state of simple molecules and ions

i) To predict the sp, sp^2, or sp^3 hybridization state:

Hybridization means mixing orbitals in various ratios; these are called hybrid orbitals. The mixing pattern is s + p (1:1) - sp hybrid orbital; s + p (1:2) - sp^2 hybrid orbital; s + p (1:3) - sp^3 hybrid orbital.

The formula to predict the sp, sp^2, and sp^3 hybridization state is (P_{Hyb}) = (T_{SLP}) – 1

Where, P_{Hyb} = power of the hybridization state of the central atom, T_{SLP} = (total no. of σ bonds around each central atom + LP).

From the Lewis structure of a molecule, first predict the number of sigma bonds (σ-bonds), pi bonds (π-bonds), and the lone pair of electrons (LP). All single (-) bonds are σ bonds; in a double bond (=), there is 1σ and 1π; in a triple bond (≡), there is 1σ and 2π (exclude the π bond). In addition to this, each co-ordinate bond (→) can be treated as an σ bond. This formula is applicable up to 4 T_{SLP}. If the power of the hybridization state (P_{Hyb}) is 3, 2, or 1, then the hybridization state will be sp^3, sp^2, and sp, respectively.

ii) In an sp^3d, sp^3d^2, and sp^3d^3 hybridization state, there is a common sp^3 and 4 T_{SLP}. So, for each additional T_{SLP} (an additional sigma bond or lone pair of electrons), add one d orbital gradually as follows:

5 T_{SLP} = 4 T_{SLP} + 1 additional T_{SLP} = sp^3d hybridization
6 T_{SLP} = 4 T_{SLP} + 2 additional T_{SLP} = sp^3d^2 hybridization

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

In the case of a cationic species, these electrons should be removed from the outermost orbit of the central atom and, in case of an anionic species, remove the outermost electrons of the central atom.[3]

RESULTS AND DISCUSSION

1. Innovative mnemonics to predict the hybridization state of simple molecules and ions

i) Here are some examples that predict the hybridization state (sp, sp^2, and sp^3) of simple molecules and ions:

Example A: NH_3: The central atom N is surrounded by three N-H single bonds (3 sigma σ bonds and an LP). $T_{SLP} = 4$ and, therefore, the power of the hybridization state of N in NH_3 is $(P_{Hyb}) = (T_{SLP}) – 1= (3+1)-1 = 3$: i.e., the hybridization state = sp^3.

Example B: H_2O: The central atom O is surrounded by two O-H single bonds: i.e., 2 sigma σ bonds and 2 lone pairs. The power of the hybridization state of O is $(P_{Hyb}) = (T_{SLP}) – 1= = (2+2)-1 = 3$: i.e., the hybridization state of O in $H_2O = sp^3$.

Example C: H_3BO_3: B (Fig. 1.1) only has 3 σ bonds (LP = 0) and oxygen has 2 σ bonds and 2 lone pair of electrons, so, in this case, the power of the hybridization state is $(P_{Hyb}) = (T_{SLP}) – 1= (3+0)- 1 = 2$: i.e., B is sp^2 hybridized in H_3BO_3. However, the power of the hybridization state is $(P_{Hyb}) = (T_{SLP}) – 1= = (2+2)-1= 3$: i.e., the hybridization state of O in H_3BO_3 is sp^3.

Example D: I-Cl: I and Cl both have 1 *σ* bond and 3 lone pairs of electrons. The power of the hybridization state of both I and Cl, $(P_{Hyb}) = (T_{SLP}) – 1= (1+3) - 1 = 3$: i.e., the hybridization state of I and Cl is sp^3.

Example E: $CH_2 = CH_2$: Each carbon (Fig. 1.1) is attached with 2 C-H single bonds (2 *σ* bonds) and 1 C=C bond (1*σ* bond) and altogether there

---

[3] 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; 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.

are 3 sigma bonds. The power of the hybridization state of both is C (P_{Hyb}) = (T_{SLP}) – 1= (3+0)-1 = 2: i.e. hybridization state of both carbons is sp^2.

Example F: O_3: Ozone (O_3) exists as a stable form of cyclic ozone (Fig. 1.2) and it is in the shape of an equilateral triangle. Each central O atom has 2 O–O single bonds (2 σ bonds) and 2 LPs. The power of the hybridization state of the central O atom is (P_{Hyb}) = (T_{SLP}) – 1= (2+2) - 1 = 3: i.e., the hybridization state of center atom O in cyclic O_3 is sp^3. However, the resonance description of ozone involves 2 structures (Fig. 1.3), where the central oxygen atom will have an sp^2 hybridization state. In this case, the central O atom has 2 σ bonds and 1 LP. The power of the hybridization state of the central O atom is (P_{Hyb}) = (T_{SLP}) – 1= (2+1) - 1 = 2 (sp^2).

Example G: S_8: The ordinary form of sulfur (orthorhombic sulfur, yellow crystals) contains octatomic molecules (S_8), where S can form single covalent bonds in a long chain with 2 other S atoms in a zigzag fashion (Fig. 1.4). Each sulfur atom is attached with 2 adjacent σ bonds and 2 LPs. The power of the hybridization state of any S atom is (P_{Hyb}) = (T_{SLP}) – 1= (2+2) - 1 = 3: i.e. the hybridization state of S atoms in S_8 is sp^3.

Example H: P_4: The 4 P atoms are arranged at the corners of a regular tetrahedron (Fig. 1.4). Each P atom forms 3 σ bonds and 1 LP. The power of the hybridization state of any P atom is (P_{Hyb}) = (T_{SLP}) – 1= (3+1) - 1 = 3: i.e., the hybridization state of the P atom in P_4 is sp^3.

Example I: CO_3^{2-}: In the valence bond structure of carbonate ion (CO_3^{2-}), the central carbon atom does not contain any lone pair electrons but it does have 3 σ bonds (Fig. 1.5). The power of the hybridization state of the central C atom in carbonate ion is (P_{Hyb}) = (T_{SLP}) – 1= (3+0) - 1 = 2 (sp^2). However, in the resonance hybrid of CO_3^{2-} (Fig. 1.6), the carbon atoms are in a sp^2 hybridization state due to 3 σ bonds and the fact there are no lone pairs of electrons.

ii) Predicting the hybridization state (sp^3d, sp^3d^2, and sp^3d^3) of simple molecules and ions

Example A: I_3^-: The central I atom has 2 σ bonds and 3 lone pairs of electrons (Fig. 1.7). There are 5 T_{SLP}: 5 T_{SLP} = 4 T_{SLP} + 1 additional T_{SLP} = sp^3d hybridization.

Example B: IF_4^+: (Fig. 1.8) There are 7 e^-s in its outermost shell, so subtract one e^- from 7: i.e., 7 – 1 = 6. Out of 6 electrons, 4 electrons form 4

I–F σ bonds and there is 1 LP. Altogether there are 5 T_{SLP}. So, 5 T_{SLP} = 4 T_{SLP} + 1 additional T_{SLP} = sp^3d hybridization.

Example C: XeF_4: (Fig. 1.8) Xe is an inert gas that has 8 e^-s in its outermost shell, 4 form 4 Xe-F sigma bonds and there are 2 lone pair of electrons. Altogether there are 06 T_{SLP} = 4 T_{SLP} + 2 additional T_{SLP} = sp^3d^2 hybridization.

Example D: IF_7: There are 7 I–F single bonds: i.e., 7σ bonds and LP=0. Altogether there are 07 T_{SLP} = 4 T_{SLP} + 3 additional T_{SLP} = sp^3d^3 hybridization.

THE GEOMETRY OF SIMPLE MOLECULES AND IONS

In the absence of lone pair electrons (LPs), a molecule or ion exhibits a regular geometry (Fig. 1.9). For sp, sp^2, sp^3, sp^3d, sp^3d^2, and sp^3d^3 hybridization states, the geometry will be linear, trigonal planar, tetrahedral, trigonal bipyramid, octahedral, and pentagonal bipyramid, respectively. However, for the same hybridization state, and in the presence of the lone pair of electrons, they will exhibit sub-normal geometry (Fig. 1.10). Adequate examples that predict the hybridization state from the corresponding T_{SLP} value (total number of σ bonds around the central atom + lone pair of electrons on the central atom) of the central atom have been explored in Table 1.1. The molecular geometry (normal and sub-normal) and bond angle with respect to the corresponding hybridization state and lone pair of electrons from simple molecules and ions have been displayed in Table 1.2.

THE BOND ANGLE OF SIMPLE MOLECULES AND IONS

The angle between the two covalent bonds of a molecule is called a bond angle. In covalent bonds, the bond pair electron clouds will be adjacent to each other and, due to the excessive force between them, the bond angle will increase. When the bond pair electron clouds move towards the central atom instead of the peripheral atom, then they will be adjacent to each other and exhibit much more repulsive force, which increases the bond angle of the molecule. This is known as a bond pair–bond-pair (BP–BP) repulsion. If there is any other repulsive force greater than this, such as lone pair–lone pair (LP–LP) or lone pair–bond pair (LP–BP) repulsion, the bond angle will decrease. The order of repulsive force is LP–LP > LP–BP > BP–BP.

Factors affecting the bond angle of simple molecules or ions are as follows:

i) Different repulsive force: The order of the bond angle depends on different repulsive forces:

BP–BP > LP–BP > LP–LP.

(LP = 0) (LP = 1) (LP=2)

Therefore, with an increasing number of lone pair electrons, the bond angle will decrease.

Example: The bond angle of methane (CH_4), ammonia (NH_3), and water (H_2O), follows the order: methane (CH_4) > ammonia (NH_3) > water (H_2O). In methane (CH_4), the LP on C = 0 and has a BP–BP repulsion; in ammonia (NH_3), LP of N = 1 and has both LP–BP and BP–BP forces; and in water (H_2O), LP on O = 2 and LP–LP, LP–BP, and BP–BP are all present.

ii) Electronegativity of the central atom (when repulsive force and peripheral atoms are equal): When there are a pair of molecules with an equal repulsive force, the same peripheral atoms but different central atoms, then the bond angle will increase with the electronegativity values due to the greater repulsive interactions between the 2 adjacent bond pair electron clouds.

Example: H_2O and H_2S both exhibit the same repulsive forces (LP–LP, LP–BP, and BP–BP). Here, the peripheral atoms are the same (H) but the central atoms are different (O and S). In oxygen and sulfur, the O central atom in H_2O is more electronegative (E.N. of O = 3.5) than the S central atom in H_2S (E.N. of S = 2.5); therefore, oxygen attracts bond pair electron clouds more closely than sulfur. As a result of this, BP–BP repulsion between two bond pair electron clouds will be greater in H_2O than H_2S.

iii) The electronegativity of the peripheral atom (when the repulsive force and central atoms are the same): When a pair of molecules have the same repulsive force and central atoms but different peripheral atoms the bond angle decreases with the increasing electronegativity values of the peripheral atom. This is due to fewer repulsive interactions between the 2 bond pair electron clouds, which will have been shifted towards the higher electronegative peripheral atom.

Example: NH_3 and NF_3 both have LP =1 and exhibit the same repulsive forces (LP–BP and BP–BP). Here, the central atoms are the same (N) but the peripheral atoms are different (H and F). The peripheral atom (F) in NF_3 is more electronegative (E.N. of F = 4.0) than the peripheral atom (H) in NH_3 (E.N. of H = 2.1). Fluorine attracts bond pair electron clouds more closely than hydrogen. As a result of this, BP–BP repulsion between the 2 adjacent bond pair electron clouds will be greater in NH_3 than NF_3.

APPLICATIONS FOR THE HYBRIDIZATION STATE:

1. The hybridization state used to predict the dipole moment (μ) as well as polarity.

Example A: Cis-2-butene is polar, while trans-2-butene is a non-polar (Fig. 1.11). The % of s character is directly proportional to electronegativity; therefore, the order of electronegativity is sp - C (s 50%) > sp^2 - C (s 33.3%) > sp^3 - C (s 25%)

2. The hybridization state used to predict the acidic order of hydrocarbons (alkyne, alkene, and alkane).

Example B: The acidic order of alkyne, alkene, and alkane is sp sp, sp^2 sp^2, and sp^3 sp^3

The decreasing acidic order is alkyne (HC ≡ CH) > alkene ($H_2C = CH_2$) > alkane ($H_3C – CH_3$)

Alkyne has sp hybridized carbon atoms, alkene has sp^2 hybridized carbon atoms, and alkane has sp^3 hybridized carbon atoms: % of s character α electronegativity and electronegativity of carbon in hydrocarbons α proton donation tendency (acidity). The electronegativity order is sp - C (s 50%) > sp^2 - C (s 33.3%) > sp^3 - C (s 25%) and the decreasing acidic order is alkyne (HC ≡ CH) > alkene ($H_2C = CH_2$) > alkane ($H_3C – CH_3$).

3. The hybridization state used to predict the basic order.

Example 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 ($CH_3C≡N$) is sp hybridized (% s character = 50%). With % s character, the electronegativity increases. Hence, sp N of methyl cyanide ($CH_3C≡N$) is more electronegative than methylamine (CH_3NH_2), which (sp N of methyl cyanide) tightly holds the lone pair of electrons and is less readily available for protonation or donation. This decreases the basic character of methyl cyanide ($CH_3C{\equiv}N$) with respect to methylamine (CH_3NH_2).

4. The hybridization state used to predict normal and sub-normal geometry.

Simple molecules or ions with LP = 0 have a normal geometry, while LP ≠ 0 have sub-normal geometry (Table 1.2).

5. The hybridization state used to predict the bond length and strength.

The power of the hybridization state (P_{Hyb}) is directly proportional to bond length and inversely proportional to the bond strength. Generally, mixing the hybridization state decreases the bond length.

Example D:

C-C: sp^3-sp^3, P_{Hyb} = 3+3 = 6, C-C bond length = 1.54Ǻ

C-C sp^3-sp^2, P_{Hyb} = 3+2 = 5, C-C bond length = 1.50Ǻ

C-C: sp^3-sp, P_{Hyb} = 3+1 = 4, C-C bond length = 1.46Ǻ

C=C: sp^2-sp^2, P_{Hyb} = 2+2 = 4, C-C bond length = 1.34Ǻ

C=C sp^2-sp, P_{Hyb} = 2+1 = 3, C-C bond length = 1.31Ǻ

C≡C: sp-sp, P_{Hyb} = 1+1 = 2, C-C bond length = 1.21Ǻ

C-H: sp^3-H, P_{Hyb} = 3, C-H bond length = 1.11Ǻ

sp^2-H, P_{Hyb} = 2, C-H bond length = 1.10Ǻ

sp-H, P_{Hyb} = 1, C-H bond length = 1.08Ǻ

C-O: sp^3-O, P_{Hyb} = 3, bond length = 1.41Ǻ

C=O: sp^2-O, P_{Hyb} = 2, bond length = 1.20Ǻ

C-N: sp^3-N, P_{Hyb} = 3, bond length = 1.47Ǻ

C=N: sp^2-O, P_{Hyb} = 2, bond length = 1.28Ǻ

C≡N: sp-N, P_{Hyb} = 1, bond length = 1.16Ǻ

6. The bond angle can also be evaluated from the hybridization state.

The bond angle is directly proportional to the s character of a hybrid orbital: sp – C (50 % s) > sp^2 – C (33.3 % s) > sp^3 – C (25% s)

QUESTIONS ON HYBRIDIZATION AND 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: both (a) and (d) (CO_3^{2-}, NO_3^- both have 32 e^-s, sp^2, LP=0, trigonal planar geometry) and (ClO_3^-, SO_3^{2-} both have 42 e^-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 strucure of IF_7 is (AIEEE 2011)

a) square pyramid b) trigonal bipyramid c) octahedral d) petagonal bipyramid

Ans: (d) IF_7 - sp^3d^3 LP=0, petagonal bipyramid (normal geometry).

Q5. Consider the state of hybridization in carbon atoms and find the linear the molecule (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 ≡ C – will be in a sp hybridization state and LP = 0)

Q6. Base strength of $H_3C\text{-}CH_2^-$ (i), $H_2C = CH^-$ (ii) and $H - C \equiv C^-$ (iii) is in which order?

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

Ans: (b) (i) > (ii) > (iii), acidic order is $H\text{-}C \equiv C\text{-}H > H_2C = CH_2 > H_3C\text{-}CH_3$ as a stronger acid will have a weaker conjugate base; therefore, the order is $H_3CCH_2^- > H_2C = CH^- > H - C \equiv C^-$.

Q7. Methylamine (CH_3NH_2) is more basic than methyl cyanide ($CH_3C{\equiv}N$). Why?

a) both have a different (+I) group b) both have the same (+I) group

c) both nitrogens have the same s character d) both nitrogens have a different s character

Ans: (d) both nitrogens have a different s character

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

a) H_2O b) BF_3 c) NH_2^- d) PCl_3

Ans: (d) PCl_3 (LP = 1 and BPs = 3)

Q9. What is the hybridization of atomic orbitals in NO_2^+, NO_3^-, and NH_4^+? (NEET 16) (JEE MAIN 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. The total number of lone pair electrons in 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) from left to right (NEET18)

a) CH_2=CH-CH=CH_2 b) CH_2=CH-C≡CH c) CH≡C-C≡CH d) CH_3-CH=C=CH_2

Ans: (b) CH_2=CH-C≡CH (This demonstrates the limitations of the conventional method)

Q12. Which of the following pair have sp^3 hybridization? (Karnataka NEET 2013)

a) SiF_4, BeH_2 b) NF_3, H_2O c) NF_3, BF_3 d) H_2S, BF_3

Ans: (b) NF_3, H_2O

Q13. 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

Q14. Which of the following bonds is the strongest?

a) H_3C-CH_3 b) H_2C=CH_2 c) H_3C-CH=CH_2 d) HC≡CH

Ans: (d) HC≡CH

Q15. Which of the following is planar?

a) methane b) acetylene c) benzene d) isobutane

Ans: (c) benzene (all six carbons are sp^2 hybridized, which makes it planar)

Q16. The order of bond length of C–C in ethane (I), ethene (II) and ethyne (III) is

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))

Q.17. 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 α electronegativity)

Q.18. 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)

Q.19. In CCl_4, the four valences 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 and LP of C = 0, regular geometry) (See Table 1.2)

Q.20. Which has the largest angle between the two covalent bonds?

a) H_2O b) NH_3 c) CO_2 d) CH_4

Ans: (c) CO_2 (In O=C=O, hybridization sp and bond angle 180^0) (See Table 1.2)

Q.21. Which has the smallest bond angle?

a) H_2O b) H_2S c) NH_3 d) CH_4

Ans: (b) H_2S (Bond angle α 1/number of LPs and the repulsive force; bond angle α and electronegativity of the central atom)

Q.22. Which of the following is associated with the compound where the central atom has sp^3d hybridization?

a) planar b) pyramidal c) angular d) trigonal bipyramidal

Ans: (d) 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 an 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 equal 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≡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. The molecule where sp^2 hybrid orbitals are used by the central atom to form covalent bonds is known as

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° b) 180° c) 109° d)120°

Ans: (c) 109°

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 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_{x2-y2}, s, p_x, p_y, p_z c) s, p_x, p_y, p_z, d_{xz} d) none of the above

Ans: (a) $d_z{}^2$, s, p_x, p_y, p_z (see earlier in this chapter)

Q.32. Using VSEPR theory, the molecule with the highest number of LPs and a linear shape is (NET 2011)

a) CO_2 b) I_3^- c) NO_2 d) NO_2^+

Ans: (b) I_3^- (Tri iodide ion I_3^- has a linear geometry in which the central I contains 3 LPs; see Fig. 1.7)

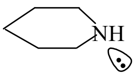
Q.33. Which of the following molecules/ions has a triangular pyramidal shape?

a) BF_3 b) NO_3^- c) H_3O^+ d) CO_3^{2-}

Ans: (c) H_3O^+ (It is sp^3 hybridized with 1 LP and 3 BPs around the oxygen atom. This is similar to NH_3. It also has a 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 the isostructural species?

a) CH_3^- and CH_3^+ b) NH_4^+ and NH_3 c) SO_4^{2-} and BF_4^- d) NH_2^- and BeF_2

Ans: (c) SO_4^{2-} and BF_4^- (both are sp^3 hybridized and have tetrahedral geometry)

Q.36. The BCl_3 molecule is planar, while NCl_3 is pyramidal because

a) BCl_3 does not have the lone pair on B but NCl_3 has one b) the N atom is smaller than B c) the B-Cl bond is more polar than the N-Cl bond d) the N-Cl bond is more covalent than the B-Cl bond

Ans: (a) BCl_3 does not have the lone pair on B but the NCl_3 has one (See Table 1.2)

Q.37. According to VSEPR theory, in SF_4, BF_4^-, XeF_4, and ICl_4^-, the number of species with two LP on the central atom is (NET 2011)

a) 2 b) 3 c) 4 d) 0

Ans: (a) 2 (XeF_4 and ICl_4^- both have LP =2; see Table 1.2)

Q.38. The total number of Xe lone pairs of electrons in $XeOF_4$ is/are

a) 0 b) 1 c) 2 d) 3

Ans: (b) (LP = 1 and BPs = 6 around Xe in $XeOF_4$)

Q.39. The angles between covalent bonds is highest in

a) CH_4 b) BF_3 c) PF_3 d) NH_3

Ans: (b) BF_3 (sp^2 hybridized has the highest bond angle, while the others are sp^3 hybridized with a lower bond angle)

Q.40. The bond length between the C–C bonds in sp^2 hybridized molecule is

a) 1.2Å b) 1.62Å c) 1.54Å d) 1.34Å

Ans: (d) 1.34Å (C=C: sp^2-sp^2, C-C bond length = 1.34Å)

Q.41. The hybridization of Xe in XeF_2 is

a) sp^3 b) sp^2 c) sp^3d d) sp^3d^2

Ans: (c) sp^3d (BPs = 2 and LPs = 3 around Xe in XeF_2 - 5 T_{SLP} = 4 T_{SLP} + 1 additional T_{SLP} = sp^3d hybridization)

Q.42. Which of the following is octahedral?

a) SF_6 b) BF_4^- c)PCl_5 d) H_3BO_3

Ans: (a) SF_6 (LP = 0, sp^3d^2 – regular geometry = octahedral)

Q.43. The structure of CH_2=C=CH_2 is

a) linear b) planar c) non-planar d) none of the above

Ans: (b) Planar (since carbon only uses sp and sp^2 hybrid orbitals)

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

a) 120^0 b) 180^0 c) 109^0 d) 60^0

Ans: (a) 120^0 (in benzene, each carbon atom is sp^2 hybridized)

Q.45. In a BrF_3 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 $SnCl_2$ is

a) tetrahedral b) linear c) angular d) T-shaped

Ans: (c) angular (Sn is sp^2 hybridized and angular shaped)

Q.47. The shape of the molecule SF_2Cl_2 is

a) trigonal bipyramidal b) cube c) octahedral d) tetrahedral

Ans: (a) trigonal bipyramidal (in SF_2Cl_2, LP=1 and BPs = 4, hence, $5T_{SLP}$ = 4 T_{SLP} + 1 additional T_{SLP} = sp^3d 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

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 overlap is

a) sp^2-sp^2 b) s-s c) sp^3-sp^3 d) sp-sp

Ans: (c) sp^3-sp^3 (The larger the p-character, the greater its ability to overlap)

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

a) 2, 2 b) 3, 1 c) 1, 3 d) 5, 8

Ans: (d) 4, 8 (NO_3^- is the conjugate base of HNO_3 where 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 the above

Ans: (a) sp^3d^2 (LP = 1 and BPs = 5, hence, 6 T_{SLP} = 4 T_{SLP} + 2 additional T_{SLP} = sp^3d^2 hybridization)

Q.54. The correct order of the 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, the number of bond pairs and lone pairs of electrons are

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; BPs = 2)

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

a) H-H bond in H_2 b) C-H bond in CH_4 c) N≡N bond in N_2 d) O=O bond in O_2

Ans: (c) N≡N bond in N_2 (BO is directly proportional to the bond dissociation energy; the BO of N_2 is 3.0; the greater the multiplicity of the bond, the greater the bond strength and the bond dissociation energy)

Q.57. A beryllium atom in BeF_2 is

a) sp^3 hybridized b) sp^2 hybridized c) sp hybridized d) unhybridized

Ans: (c) sp hybridized (In BeF_2, Be has LP = 0 and σ bonds = 2, (P_{Hyb}) = (T_{SLP}) – 1= 2 - 1 = 1 (sp))

Q.58. Which molecule is linear?

a) ICl b) NO_2 c) SO_2 d) ClO_2

Ans: (a) ICl (In ICl, the LP of each halogen = 3, σ bond = 1, (P_{Hyb}) = (T_{SLP}) – 1= 4 - 1 = 3 (sp^3), linear)

Q.59. The molecule with the largest distance between the two adjacent carbon atoms is

a) ethane b) ethene c) ethyne d) benzene

Ans: (a) ethane (sp^3; the lower the multiplicity of the bond, the higher the bond length)