CHEMICAL BONDING

FLOWCHART TO CHEMICAL BONDING

Why a chemical bond is formed ?

- Lewis-Kossel approach (Octet)
  - Lewis Structure
  - Formal Charge
  - Resonance
- Decrease in Potential energy
  - Ionic attraction
  - Attraction between Nucleus & electron cloud

Type of Bond

- Forces of attraction
  - (1) Hydrogen Bonding
    - (a) Inter molecular H-bonding
    - (b) Intra molecular H-bonding
  - (2) Vander Waals Force
  - (3) Ion-dipole
  - (4) Ion induced dipole
- Typical Bonds
  - (1) Odd Electron bond
  - (2) Back Bonding
  - (3) Multicentre bond
    - (a). Banana bond ($3c–2e^-$)
    - (b). ($3c–4e^-$) bond

Chemical bond

- Ionic Bond
  - (1) Electrovalency: or Loss & Gain of electrons
  - (2) Favourable Conditions
    - (a) Low I.E.
    - (b) High E.A.
    - (c) High Lattice Energy
  - (3) General Characteristics
    - (a) Good electrolytes
    - (b) Hard, Crystalline , Brittle
    - (c) High M.P./B.P.
    - (d) Fast reactions in polar solvent
  - (4) Inert Pair Effect
  - (5) Covalent character in ionic compounds: Fajan's rule
- Covalent Bond
  - (1) Sharing of electrons or Covalency
  - (2) Favourable Conditions
    3, 4, 5, 6 ,7 valence electrons at central atom
  - (3) General Characteristics
    - (a) Low M.P. & B.P.
    - (b) Generally poor/ bad conductor of electricity except graphite
  - (4) Theories
    - (a) Electronic theory of valency
    - (b) VBT(hybridisation)
    - (c) MOT
  - (5) Due to E.N. difference 'Dipole Moment'
- Co-ordinate Bond
  - (1) Lewis acid
  - (2) Lewis base
- Metallic Bond

Note : Hydrogen bond is an extreme manifestation of dipole dipole interaction.

CHEMICAL BOND

(a) The attractive force which holds various constituents (atoms, ions, etc.) together in different chemical species is called a chemical bond.
(b) It is the combination of two or more chemical species involving redistribution of e^- among them.
(c) This process is accompanied with decrease in energy.
(d) Decrease in energy strengthens the bond.
(e) Therefore, molecules are more stable than atoms.

CAUSE OF CHEMICAL COMBINATION

1. Tendency to acquire minimum energy :

2. Tendency to acquire noble gas configuration (Octet rule) :

Atoms combine to complete an octet of electrons in their outer most shell. Hence all atoms have a tendency to acquire octet (ns^2np^6) configuration or to attain nearest noble gas configuration in their outermost orbit. This can be achieved by combining with other atom or ion.

LIMITIATION OF OCTET RULE

1. Contraction of octet (incomplete octet)

$\underline{Be}F_2$	$\underline{B}F_3$	$\underline{Al}Cl_3$	$\underline{B}Cl_3$
($4e^-$)	($6e^-$)	($6e^-$)	($6e^-$)

These compounds are hypovalent.

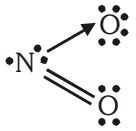
2. Expansion of Octet (due to empty d-orbitals)

PCl_5	SF_6	ClF_3	IF_5	IF_7
↓	↓	↓	↓	↓
($10e^-$)	($12e^-$)	($10e^-$)	($12e^-$)	($14e^-$)

These compounds are hypervalent.

3. Odd electron species

Ex. NO, NO_2, ClO_2 etc.



OTHER EXCEPTIONS OF OCTET RULE

1. Compounds of Noble gases

Noble gases which have already completed their octets (or duplet in case of He.) should not form compounds. However, their compounds like XeF_2, XeF_6 & KrF_2 etc., have been actually prepared.

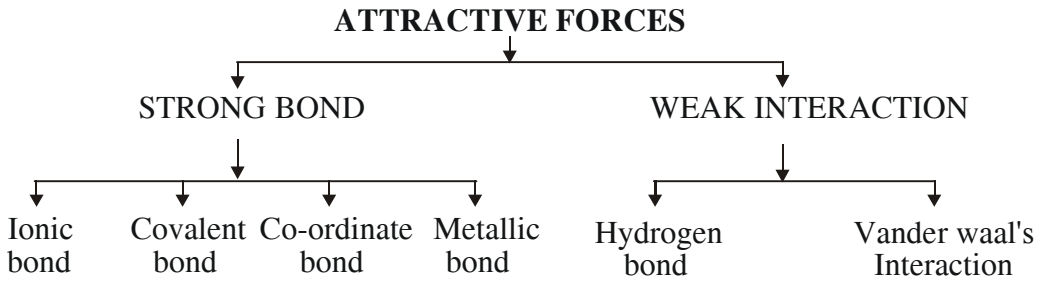
2. Transition metal ions

Cr^{3+}	Mn^{2+}	Fe^{2+}
$[Ar]3d^3$	$[Ar]3d^5$	$[Ar]3d^6$
[2, 8, 11]	[2, 8, 13]	[2, 8, 14]

3. Pseudo inert gas configuration [$(n-1)s^2p^6d^{10}$]

Zn^{2+}	Cd^{2+}
$[Ar]3d^{10}$	$[Kr]4d^{10}$

CLASSIFICATION OF BONDS



ELECTROVALENT OR IONIC BOND

(a) The chemical bond formed between two or more atoms as a result of the complete transfer of one or more electons from one atom to another is called as ionic or electrovalent bond.

Ex.

(i) $Mg + O \longrightarrow Mg^{+2} + O^{-2} = MgO$

Mg (2, 8, 2) + O (2, 6)

$2e^-$

electrovalency of Mg = 2

electrovalency of O = 2

Note : Ionic bond is non-directional.

FACTORS FAVOURING IONIC BOND FORMATION

(a) Less ionization energy of atom forming cation

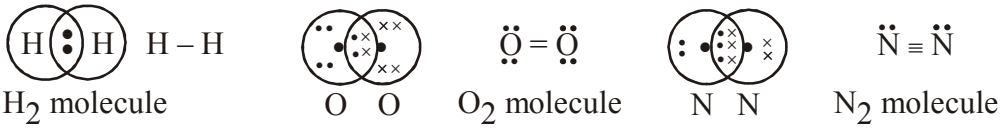
(b) Higher electron affinity of atom forming anion

(c) Greater lattice energy of formed product.

(d) Greater electronegativity difference between atoms forming cation & anion.

COVALENT BOND

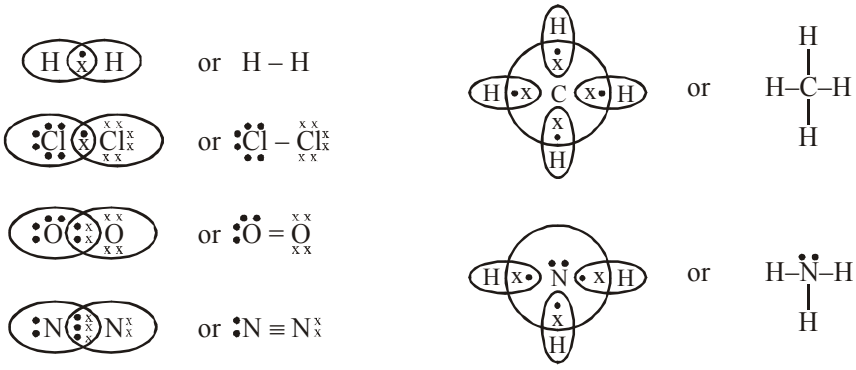
(a) A covalent bond is formed by the mutual sharing of electrons between two atoms.



(b) The shared pair of electrons must have opposite spins, and are localised between two atoms concerned.

(c) On the basis of electrons being shared between two atoms the bonds are of three types –
(i) Single bond, (ii) Double bond, (iii) Triple bond

It is represented by (–) small line. – means single bond ; = means double bond ; ≡ means triple bond.

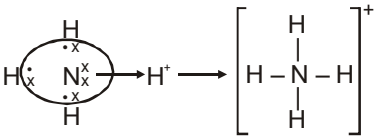


Covalency : Capacity to form covalent bond is known as covalency

COORDINATE BOND (DATIVE BOND)

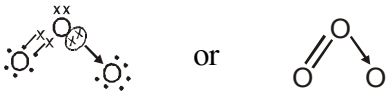
The bond formed between two atom in which contribution of an electron pair is made by one of them while the sharing is done by both.

(i) NH_4^+ (ammonium ion)



Donor Acceptor

(ii) O_3 (ozone)



VALENCE BOND THEORY

Valence bond theory was introduced by Heitler and London (1927) and developed further by Pauling and others. A discussion of the valence bond theory is based on the knowledge of atomic orbitals, electronic configurations of elements, the overlap criteria of atomic orbitals and the hybridization of atomic orbitals.

Formation of H_2 molecule :

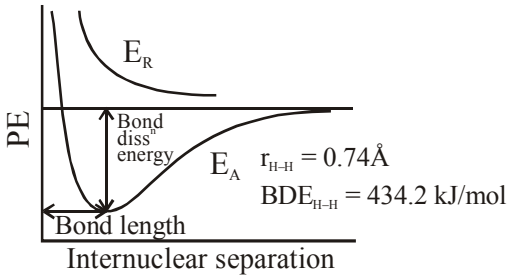
When two 'H'-atoms approaches towards each other for the formation of H_2 molecule. The following interactions takes place.

(i) e-e repulsion

(ii) e-p attraction

(iii) p-p repulsion

Experimentally, it has been found that the magnitude of attractive forces is more than the repulsive forces. As a result, when two atoms approach each other then potential energy decreases. Ultimately a stage is reached where the net force of attraction balances the force of repulsion and system acquires minimum energy.



The potential energy curve for the formation of H_2 molecule as a function of internuclear distance of the H atoms. The minimum in the curve corresponds to the most stable state of H_2.

At this stage two hydrogen atoms are said to be bonded together to form a stable molecule having the bond length of 74 pm. Since the energy gets released when the bond is formed between two hydrogen atoms, the hydrogen molecule is more stable than that of isolated hydrogen atoms.

Bond Length : Internuclear distance at minimum potential energy is called bond length.

Bond Dissociation Energy : The amount of energy released when one mole of same type of bonds are formed is called B.D.E.

434.2 kJ/mol of energy is required to dissociate one mole of H_2 molecule.

$H_2(g) + 434.2\ kJ\ mol^- \rightarrow H(g) + H(g)$

ORBITAL OVERLAP CONCEPT

In the formation of hydrogen molecule, there is a minimum energy state when two hydrogen atoms are so near that their atomic orbitals undergo partial interpenetration. This partial merging of atomic orbitals is called overlapping of atomic orbitals which results in the pairing or merging of electrons. The extent of overlap decides the strength of a covalent bond. In general, greater the overlap the stronger is the bond formed between two atoms. Therefore, according to orbital overlap concept, the formation of a covalent bond between two atoms results by pairing of electrons, present in the valence shell having opposite spins.

Directional Properties of Bonds :

The valence bond theory explains the formation and directional properties of bonds in polyatomic molecules like CH_4, NH_3 and H_2O, etc. in terms of overlap and hybridisation of atomic orbitals.

Types of Overlapping and Nature of Covalent Bonds

The covalent bond may be classified into following types depending upon the types of overlapping :- (i) sigma(σ) bond (ii) pi (π) bond (iii) delta(δ) bond

(i) Sigma (σ) bond : This type of covalent bond is formed by the end to end (head on or axial) overlap of bonding orbitals along the internuclear axis. This can be formed by any one of the following types of combinations of atomic orbitals.

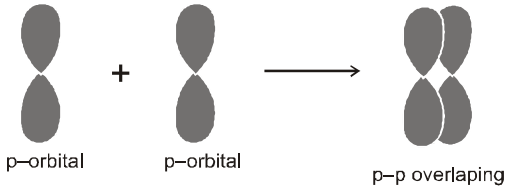
- s-s overlapping : In this case, there is overlap of two half filled s-orbitals along the internuclear axis as shown below :

- s-p overlapping: This type of overlap occurs between half filled s-orbital of one atom and half filled p-orbital of another atom.

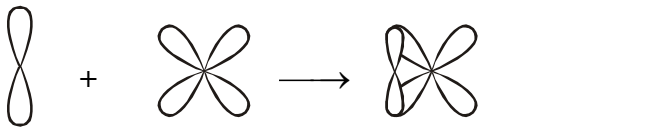
- p-p overlapping : This type of overlap takes place between half filled similar p-orbitals of the two approaching atoms.

(ii) Pi(π) bond : In the formation of π bond the atomic orbitals overlap in such a way that their axis remain parallel to each other and perpendicular to the internuclear axis. The orbitals formed due to sidewise overlapping consists of two saucer type charged clouds above and below the plane of the participating atoms.

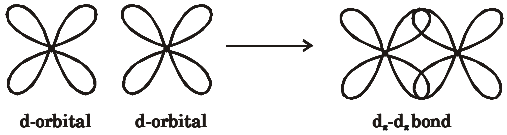
(a) p_π–p_π



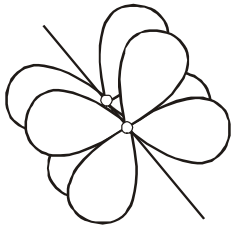
(b) p_π–d_π



(c) d_π–d_π



(iii) Delta (δ) bond : are the covalent bonds where four lobes of d-orbital of one atom overlap with four lobes of the similar d-orbital of other atom. Except d_{z^2} all d orbitals form δ bond.



Strength of sigma and pi bonds :

Basically the strength of a bond depends upon the extent of overlapping- In case of sigma bond, the overlapping of orbitals takes place to a larger extent. Hence, it is stronger as compared to the pi bond where the extent of overlapping occurs to a smaller extent. Further, it is important to note that pi bond between two atoms is formed in addition to a sigma bond. It is always present in the molecules containing multiple bond (double or triple bonds)

Advantages of VBT :

- ❖ It explain various bond characteristics e.g., bond length, bond strength.
- ❖ It explains the quantitative relationship between the extent of overlapping and bond dissociation energy.
- ❖ This theory accounts for shape and nature of bonding of the molecule whose covalency is not according to the number of half-filled orbitals present in the ground state.
- ❖ This theory redefined the stability of molecules e.g. BF_3, $AlCl_3$, PCl_5, SF_6 etc which are exception to octet rule.

Disadvantages of VBT :

- ❖ According to this theory three bond angle in CH_4 should be 90°, as these are formed by p–p overlapping, but actually it has four 109°28 angles. In NH_3 & H_2O, angle should be 90°. This is in disagreement with the actual bond angles of 107° & 104.5° in NH_3 & H_2O molecules respectively.
- ❖ In order to explain the characteristic geometrical shapes of polyatomic molecules like CH_4, NH_3, H_2O etc. Pauling introduced the concept of hybridisation.

HYBRIDISATION

The phenomenon of intermixing of the orbitals of slightly different energies so as to redistribute their energies, resulting in the formation of new set of orbitals of equivalent energies and shape. For example when one 2s and three 2p-orbitals of carbon hybridise, there is the formation of four new sp^3 hybrid orbitals.

Salient features of hybridisation: The main features of hybridisation are as under :

1. The number of hybrid orbitals is equal to the number of the atomic orbitals that get hybridised.

2. The hybridised orbitals are always equivalent in energy and shape.

3. The hybrid orbitals are more effective in forming stable bonds than the pure atomic orbitals.

4. These hybrid orbitals are directed in space in some preferred direction to have minimum repulsion between electron pairs and thus a stable arrangement. Therefore, the type of hybridisation indicates the geometry of the molecules.

Important conditions for hybridisation

(i) The orbitals present in the valence shell of the atom are hybridised.

(ii) The orbitals undergoing hybri disation should have almost equal energy.

(iii) Promotion of electron is not essential condition prior to hybridisation.

(iv) It is not necessary that only half filled orbitals participate in hybridisation. In some cases, even filled orbitals of valence shell take part in hybridisation.

Types of Hybridisation

There are various types of hybridisation involving s, p and d orbitals. The different types of hybridisation are as under :

(i) *sp hybridisation* (ii) *sp^2 hybridisation* (iii) *sp^3 hybridisation*

(iv) *sp^3d hybridisation:* (v) *sp^3d^2 hybridisation:* (vi) *sp^3d^3 hybridisation:*

Determination of hybridisation state :

To predict the hybridisation following formula may be used :

Number of hybrid orbital = Steric Number (S.N.) = Number of σ-bond arround that atom + Number of lone pair on that atom.

Molecule	Method	Hybridisation
NH_4^+	S.N. = 4 + 0 = 4	sp^3 hybridisation.

Number of hybrid orbitals	Hybridisation
two	sp
three	sp^2
four	sp^3
five	sp^3d
six	sp^3d^2
seven	sp^3d^3

Hybridisation of following species in their specified state

Species	Cationic part	Anionic part
PCl_5 (solid)	PCl_4^+ (sp^3)	PCl_6^- (sp^3d^2)
PBr_5 (solid)	PBr_4^+ (sp^3)	Br^-
XeF_6 (solid)	XeF_5^+ (sp^3d^2)	F^-
N_2O_5 (solid)	NO_2^+ (sp)	NO_3^- (sp^2)
I_2Cl_6 (liquid)	ICl_2^+ (sp^3)	ICl_4^- (sp^3d^2)
Cl_2O_6 (solid)	ClO_2^+ (sp^2)	ClO_4^- (sp^3)
I_2 (molten state)	I_3^+ (sp^3)	I_3^- (sp^3d)

VALENCE SHELL ELECTRON PAIR REPULSION THEORY (VSEPR)

(a) Molecules having covalent bond have definite geometry as covalent bonding has directional characteristics. A simple theory was given for the molecular shape of the covalent molecules by Gillespie and Nyholm in 1957.

(b) This theory predicts the shape of the molecule by considering the most stable configuration of the bond angles in the molecule. This theory states

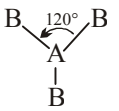
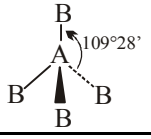
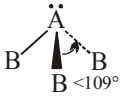
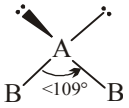
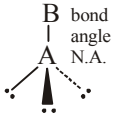
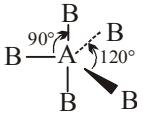
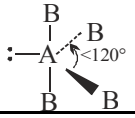
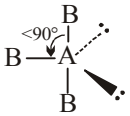
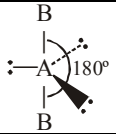
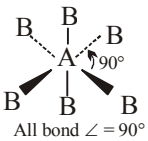
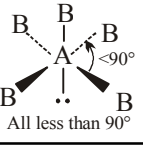
(i) Electron pairs in the valence shell of the central atom of a molecule, whether bonding or lone pairs are regarded as occupying localised orbitals. These orbitals arange themselves in so as to minimize the mutual electronic repulsions.

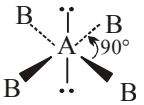
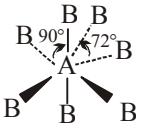
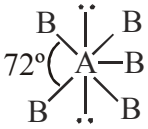
(ii) The magnitude of the different types of electronic repulsions follows the order given below:
lone pair-lone pair > lone pair - bonded pair > bonded pair - bonded pair

(iii) The electronic repulsion between two pairs of electrons will be minimum if they are as far apart as possible.

(iv) The actual shape of the molecules containing lone pairs is a little distorted from the basic shape as in the NH_3 and H_2O molecules, the bond angles are not 109°28' but 107° and 104.5° respectively due to presence of one lone pair in NH_3 and two lone pairs in H_2O.

SHAPES OF MOLECULES BASED ON VSEPR THEORY

Total no. of hybrid orbitals	No. of b.p. (bond pairs)	No. of unshared pair i.e. l_p	General formula	Type of hybridisation	Stereo chemical formula/str.	Shape	Exam.
2	2	0	AB_2	sp		linear	$BeCl_2$
3	3	0	AB_3	sp^2		Trigonal planar	BCl_3, NO_3^- GaF_3, CO_3^{--}
3	2	1	AB_2	sp^2		V or Bent or angular	$SnCl_2$, O_3,SO_2
4	4	0	AB_4	sp^3		Tetrahedron	CH_4, SiF_4, NH_4^+
4	3	1	AB_3	sp^3		Trigonal pyramidal	NH_3, CH_3^-
4	2	2	AB_2	sp^3		V or Bent or angular	H_2O, SF_2
4	1	3	AB	sp^3		linear	ClO^-
5	5	0	AB_5	sp^3d		Trigonal bipyramidal	PF_5, SF_5^+, $SbBr_5$, XeO_3F_2
5	4	1	AB_4	sp^3d		Seesaw	SF_4
5	3	2	AB_3	sp^3d		T-shaped	ClF_3, BrF_3
5	2	3	AB_2	sp^3d		Linear	ICl_2^-, XeF_2, I_3^-
6	6	0	AB_6	sp^3d^2	 All bond $\angle = 90°$	Octahedral or Square bipyramidal	SF_6, IF_6^+
6	5	1	AB_5	sp^3d^2	 All less than 90°	Square pyramidal	IF_5, $XeOF_4$, BrF_5

6	4	2	AB_4	sp^3d^2		Square planar	IF_4^-, XeF_4, ICl_4^-
7	7	0	AB_7	sp^3d^3		Pentagonal bipyramidal	IF_7
7	5	2	AB_5	sp^3d^3		Pentagonal Planar	XeF_5^-

BOND PARAMETERS

(I) Bond Length (Bond distance) (II) Bond Angle (III) Bond Enthalpy (IV) Bond order

(I) Bond Length :- Bond length is defined as the equilibrium distance between the nuclei of two bonded atoms in a molecule.

Factors affecting bond length

(a) Size of atoms

(b) Effect of bond order or number of bonds

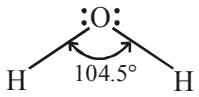
(c) Effect of Resonance

(d) Effect of Electronegativity difference

(f) Effect of Hybridisation

(II) Bond angle :

It is defined as the angle between the orbitals containing bonding electron pairs around the central atom in a molecule/complex ion. Bond angle is expressed in degree which can be experimentally determined by spectroscopic methods. For example H–$\hat{O}$–H bond angle in water can be represented as under :



Factors affecting bond angle

(a) State of Hybridisation

(b) Presence of lone pair

(c) Electronegativity of central atom

(d) Electronegativity of surrounding atom

(e) Size of surrounding atom

(f) Lone pairs may sometimes be transferred from a filled shell of one atom to an unfilled shell of another bonded atom, causing less repulsion.

(g) Multiple bond orbital repel other orbitals more strongly than single bond orbitals.

(III) Bond Enthalpy

It is defined as the amount of energy required to break one mole of bonds of a particular type between two atoms in a gaseous state. The unit of bond enthalpy is kJ mol^{-1}. For example, the H–H bond enthalpy in hydrogen molecule is 435.8 kJ mol^{-1}.

$H_2(g) \longrightarrow H(g) + H(g)$; $\Delta_a H^\ominus = 435.8$ kJ mol^{-1}

⇒ In polyatomic molecules the **term mean or average bond enthalpy** is used. It is obtained by dividing total bond dissociation enthalpy by the number of bonds broken as explained below in case of water molecule,

$H_2O(g) \longrightarrow H(g) + OH(g)$; $\Delta_a H_1^{\ominus} = 502$ kJ mol^{-1}

$OH(g) \longrightarrow H(g) + O(g)$; $\Delta_a H_2^{\ominus} = 427$ kJ mol^{-1}

$$\text{Average bond enthalpy} = \frac{502 + 427}{2} = 464.5 \text{ kJ mol}^{-1}$$

(IV) Bond Order

The Bond Order is given by the number of bonds between the two atoms in a molecule.

The bond order, for example in H_2 (with a single shared electron pair), in O_2 (with two shared electron pairs) and in N_2 (with three shared electron pairs) is 1,2,3 respectively.

Note : Isoelectronic molecules and ions have identical bond orders ; for example, F_2 and O_2^{2-} have bond order 1. N_2, CO and NO^+ have bond order 3.

Note : A general correlation useful for understanding the stablities of molecules is that: with increase in bond order, bond enthalpy increases and bond length decreases.

RESONANCE

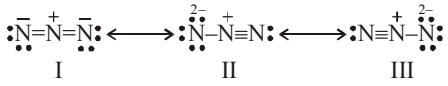
When a molecule cannot be completely represented by a single Lewis structure but it's characteristic properties can be described by two or more different structures, with similar energy position of nuclei, bonding and non-bonding pairs of electrons, then the true structure is said to be resonance hybrid of these structures. The phenomenon is called resonance and different contributing structures are called resonating structures or canonical structures.

- ❖ Resonance stabilizes the molecule as the energy of the resonance hybrid is less than the energy of any single canonical structure.
- ❖ Resonance averages the bond characteristics as a whole.
- ❖ The canonical forms have no real existence.

Resonance Structure of Some Molecules/Ions :

(i) Azide ion, N_3^- :

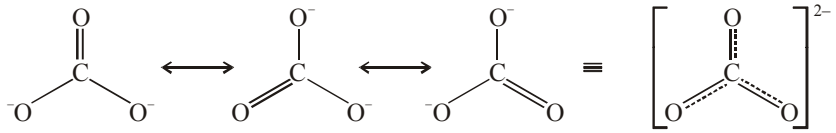
The azide ion may be represented as -



I II III

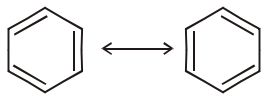
The structures II and III contribute equally and the molecule has almost double bond character in each N–N bond.

(ii)



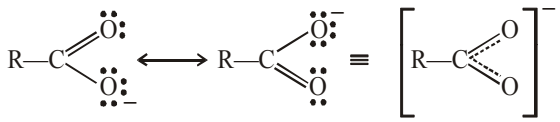
B.O. = 1.33

(iii)



BO = 1.5

(iv)



Bond order = $\frac{2+1}{2} = \frac{3}{2} = 1.5$

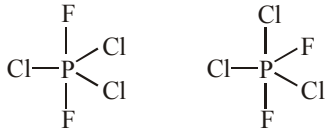
BENT'S RULE

(i) A lone pair of electron prefers to occupy that hybrid orbitals which has greater percentage of s-character.

(ii) A more electronegative atom/group prefers to occupy that hybrid orbital which has smaller percentage of s-character.

Ex. Draw the geometry of PCl_3F_2

Sol.



Correct Structure | Wrong Structure

Because highly electronegative atom occupy axial position (axial position has smaller percentage of s-character).

DRAGO'S RULE

On the basis of experimental bond angles of certain molecules fulfilling the following three conditions,

(i) Central atom belongs to third or lower period in periodic table

(ii) Central atom must contain atleast one lone pair of electron, and

(iii) Electronegativity of surrounding atom is $\leqslant 2.5$

Drago generalised that in such molecules justification of experimental bond angle can be made satisfactorily if one considers no hybridisation, i.e., overlapping of almost pure atomic orbitals from central atom.

In such molecules bond angle is approximately 90°.

Group 15	**Bond angle**	**Group 16**	**Bond angle**
NH_3	107°48'	H_2O	104°28'
PH_3	93°36'	H_2S	92°
AsH_3	91°48'	H_2Se	91°
SbH_3	91°18'	H_2Te	90.5°

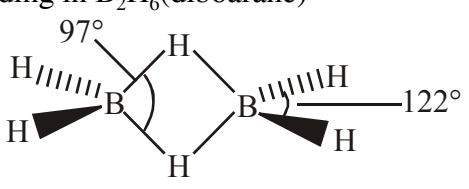
- Right order of bond angle.
  (a) $H_2O > H_2S > H_2Se > H_2Te$ (b) $NH_3 > PH_3 > AsH_3 > SbH_3$

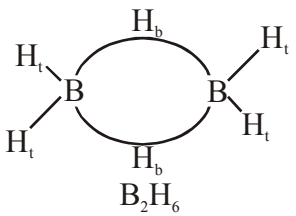
ELECTRON DEFICIENT BONDING

(a) Bridge Bonding

There are many compounds in which some electron deficient bonds are present apart from normal covalent bonds or coordinate bonds which are 2c-2e$^-$ bonds(two centre two electron bonds). These electron deficient bonds have less number of electrons than the expected such as three centre-two electron bonds (3c-2e) which are present in diborane B_2H_6, $Al_2(CH_3)_6$, BeH_2(s) etc.

bonding in B_2H_6(diboarane)



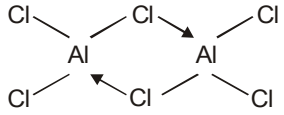


B_2H_6

The structure of diborane containing four terminal(t) and two bridging(b) hydrogen atoms. The model determined by molecular orbital theory indicates that the bonds between boron and the terminal hydrogen atoms are conventional 2c-2e$^-$ covalent bonds.

The bonding between the boron atoms and the bridging hydrogen atoms is, however different from that in molecules such as hydrocarbons. Having used two electrons in bonding to the terminal hydrogen atoms, each boron has one valence electron remaining for additional bonding. The bridging hydrogen atoms provide one electron each. Thus the B_2H_2 ring is held together by four electrons, an example of 3c-2e$^-$bonding. This type of bond is sometimes called as **'banana bond'**. Group 13, gallium is known to form a similar compound, digallane, Ga_2H_6.

But Al_2Cl_6 have covalent bond only and there is no electron deficient bonding as depicted in the given structure.



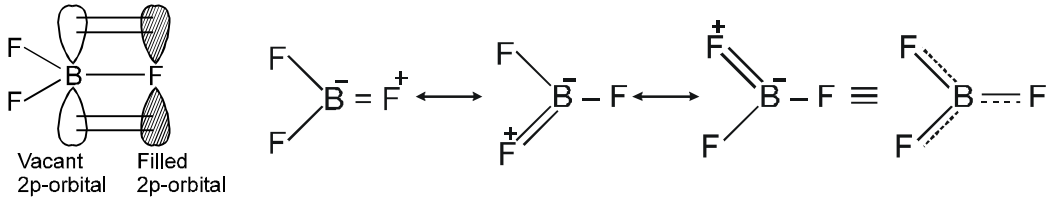
(Al – Cl – Al is 3c – 4e bond)

Examples of 3c-4e$^-$bonding are:- dimer and polymer of $BeCl_2$, Al_2Cl_6, I_2Cl_6 etc

(b) Back Bonding

Back bonding generally takes place when out of two bonded atoms one of the atom has vacant orbitals(generally this atom is from second or third period) and the other bonded atom is having some non-bonded electron pair(generally this atom is from the second period). Back bonding increases the bond strength and decreases the bond length.

For example, in BF_3 the boron atom completes its octet by accepting 2p-electrons of fluorine into 2p empty orbital.



❍ Decrease in B – F bond length is due to delocalised pπ–pπ back bonding between filled p-orbital of F atom and vacant p-orbital of B atom.

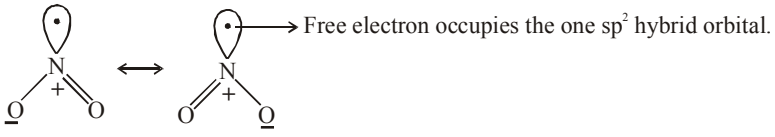
The extent of back bonding is much larger if the orbitals involved in the back bonding are of same size, for example the extent of back bonding in boron trihalides is as follows :

$BF_3 > BCl_3 > BBr_3$

There is pπ-pπ back bonding in boron trihalide. The extent of back bonding decreases from BF_3 to BI_3 because of increasing size of p-orbitals participating in back bonding that is from 2p(in F) to 5p(in I).

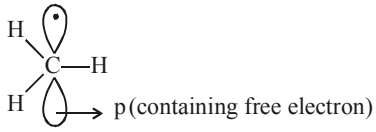
STRUCTURE OF ODD ELECTRONIC SPECIES

(1) NO_2 :



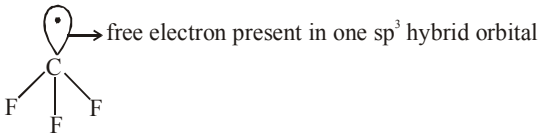
(2) $\dot{C}H_3$:

Structure :



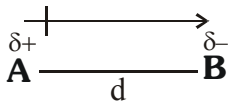
(3) $\dot{C}F_3$:

Structure :



DIPOLE MOMENT

- The degree of polarity of covalent bond is given by the dipole moment (μ)
- It is the product of the either charge and the distance between them.



Electronegativity of A < Electronegativity of B

$$\mu = \delta \times d$$

- Dipole moment is a vector quantity.
  The direction of dipole moment is represented by $\overset{+}{\longrightarrow}$
- Units = Cm (S.I.) or esu cm(cgs) or Debye (common unit)
- 1 D = 10^{-18} esu cm = 3.33×10^{-30} coulomb m

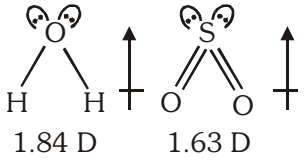
Dipole moment depends on

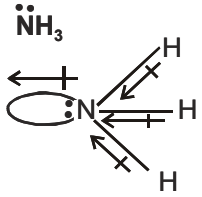
- ✦ Electronegativity difference between bonded atoms
- ✦ Direction of bond dipole moment
- ✦ Angle between various bonds
- ✦ Influence of unshared e^- pairs
- ✦ Magnitude of polarity of the molecule
- ✦ Symmetrical / Unsymmetrical shape.

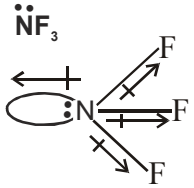
Application of dipole moment

- To determine the polarity and geometry of molecules

Example :







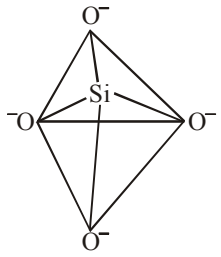
Note : To the calculate the percentage of ionic character

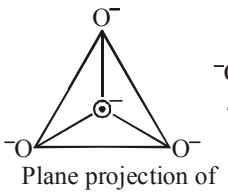
$$\% \text{ ionic character} = \frac{\text{observed } \mu}{\text{calculated } \mu \text{ (for 100 \% ionic)}} \times 100$$

SILICATES

Silicates are metal derivatives of silicic acid, H_4SiO_4 or $Si(OH)_4$. Silicates are formed by heating metal oxide or metal carbonates with sand, e.g.,

$$Na_2CO_3 \xrightarrow[SiO_2]{\text{Fused with sand}} Na_4SiO_4,\ Na_2(SiO_3)_n, \text{ etc.}$$





Plane projection of silicate ion

⁻O ⟶ Oxygen
• ⟶ Silicon

Silicates have basic unit of SiO_4^{4-}, each silicon atom is bonded with four oxide ions tetrahedrally. There are following types of silicates

Silicates	Sharing of O-atom / Basic Tetrahedral unit	Contribution of O-atom/Basic Tetrahedral unit	General formula
Ortho	0	4	SiO_4^{4-}
Pyro	1	3.5	$Si_2O_7^{-6}$
Cyclic	2	3	$(SiO_3)_n^{2n-}$
Simple chain (pyroxene)	2	3	$(SiO_3)_n^{2n-}$
Double chain (Amphibole)	(3, 2) av = 2.5	$\frac{11}{4} = \left(\frac{5.5}{2}\right)$	$(Si_4O_{11})_n^{6n-}$
2D or (Sheet)	3	2.5	$(Si_2O_5)_n^{2n-}$
3D	4	2	$(SiO_2)_n$

INERT PAIR EFFECT

In p-block elements the stability of the lower oxidation state increases on descending the group. Because increased effective nuclear charge holds ns electrons tightly due to poor shielding effect of inner d & f orbitals and thereby, restrict their (ns electrons) participation in bonding only np electrons take part in bond formation. As a result of this, +1 oxidation state of Tl is more stable than it's +3 oxidation state. Pb shows +2 stable oxidation state and Bi shows +3 stable oxidation state.

For example :

Group 13	Group 14
B (+3)	C (+4)
Al (+3)	Si (+4)
Ga (+3), (+1)	Ge (+4), (+2)
In (+3), (+1)	Sn (+4), (+2)
Tl (+3), (+1)	Pb (+4), (+2)

Order of stability : $Tl^{+1} > In^{+1} > Ga^{+1}$ (due to inert pair effect)

Order of stability : $Pb^{+2} > Sn^{+2} > Ge^{+2}$ (due to inert pair effect)

Ex. $PbCl_4$ is stable at room temperature whereas PbI_4 doesn't exist.

Sol. Due to inert pair effect Pb(4) is less stable than Pb(2). Hence it is very good oxidant.

$Pb(4) + 2e^- \longrightarrow Pb(2)$

Reducing abilities of halides follows the sequence

$I^- > Br^- > Cl^-$

MOLECULES THAT DO NOT EXIST

(1) SF_4, SF_6 & PF_5 exist while. OF_4, OF_6, NF_5 do not exist

(2) (a) PI_5(vap) & SCl_6 do not exist

(b) SCl_6 does not exist while $TeCl_6$ exist

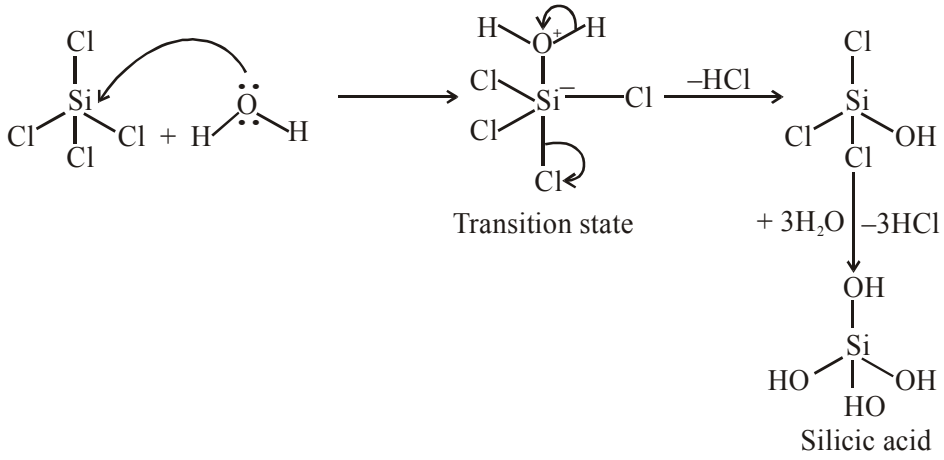
(c) PI_5 (Solid) exist

(3) SF_6, PF_5, XeF_6, XeF_4 & XeF_2 exist while SH_6, PH_5, XeH_6, XeH_4, XeH_2 do not exist

HYDROLYSIS :

In hydrolysis of covalent molecules the nucleophilic centre of molecule is replaced by OH^- group of water generally through nucleophilic substitution reaction.

Ex. Hydrolysis of $SiCl_4$



Note : CCl_4, NF_3, is inert towards hydrolysis due to the absence of d orbital, but under drastic condition these molecules under goes hydrolysis.

$$CCl_4 + H_2O \xrightarrow{\text{superheated}} COCl_2 + 2HCl$$

Note : Hydrolysis of XeF_2 & XeF_4 takes place through with redox reaction.

$$XeF_2 + H_2O \longrightarrow Xe + 2HF + \frac{1}{2}O_2$$

$$3XeF_4 + 6H_2O \longrightarrow 2Xe + XeO_3 + 12HF + \frac{3}{2}O_2$$

$$XeF_6 + 3H_2O \longrightarrow XeO_3 + 6HF$$

MOLECULAR ORBITAL THEORY (MOT)

Given by Hunds & Mulliken

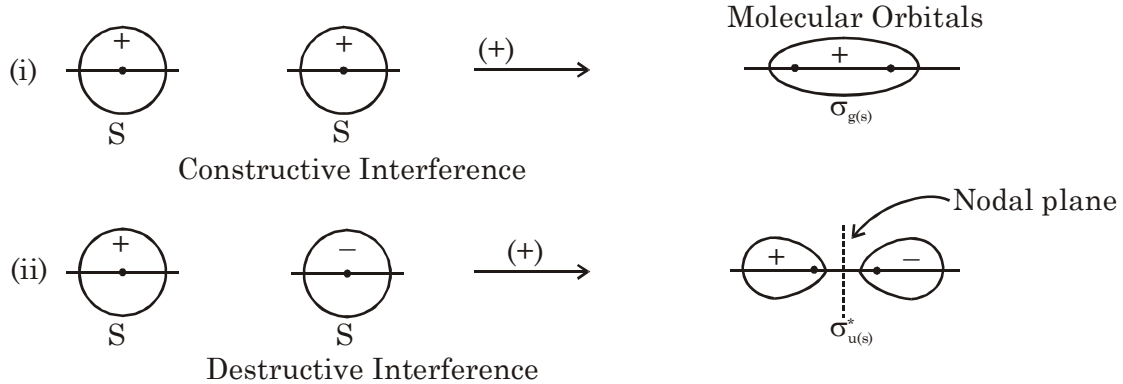
(a) Two atomic orbital come nearer & then overlap each other to form two molecular orbitals (MO)

(b) Combination of atomic orbital (AO) forms molecular orbital (MO)

LINEAR COMBINATION OF ATOMIC ORBITALS (L.C.A.O.)

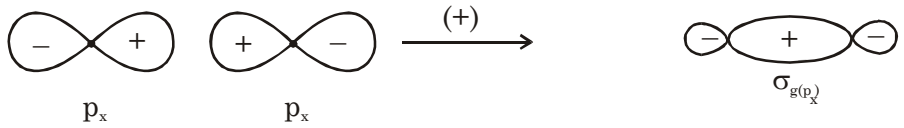
σ-bond

s-s overlapping



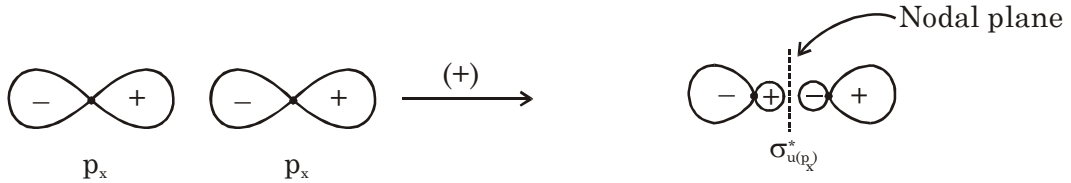
p-p overlapping

(i)



Constructive Interference

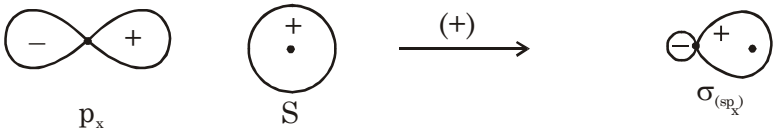
(ii)



Destructive Interference

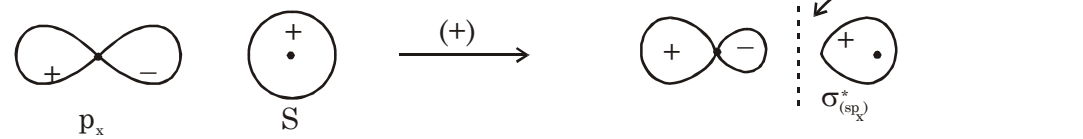
s-p overlapping

(i)



Constructive Interference

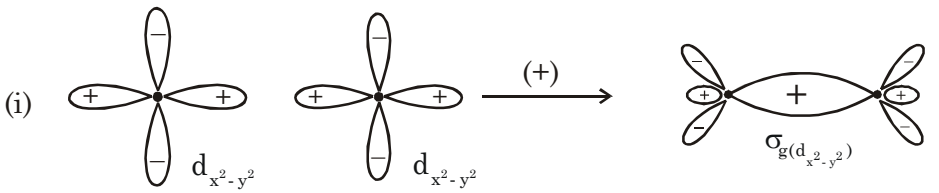
(ii)



Destructive Interference

d-d overlapping

(i)



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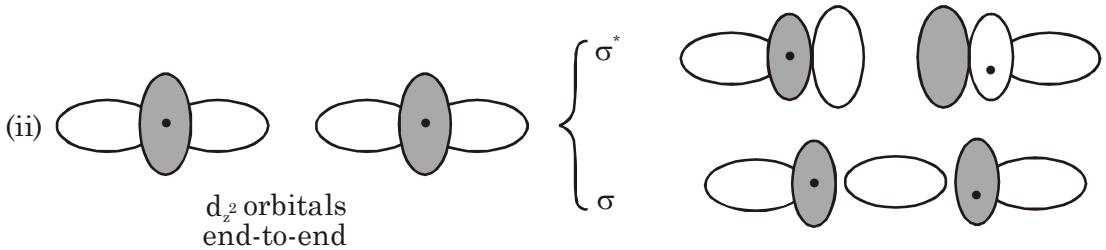
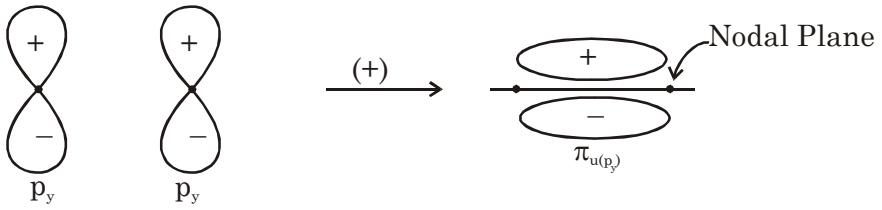


d_{z^2} orbitals
end-to-end

π-bond

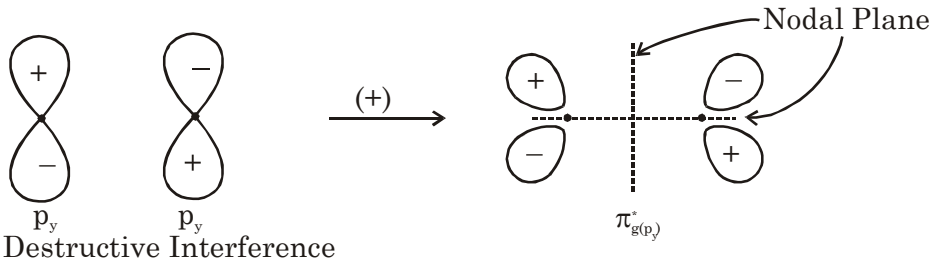
p-p overlapping

(i)



Constructive Interference

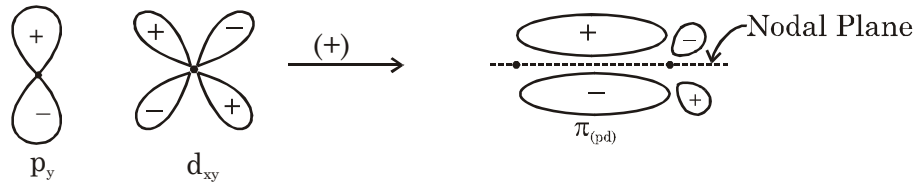
(ii)



Destructive Interference

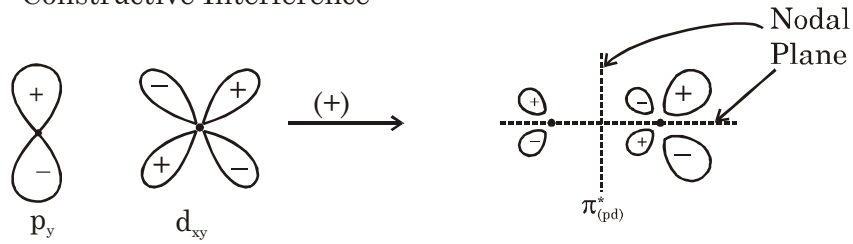
p-d overlapping

(i)



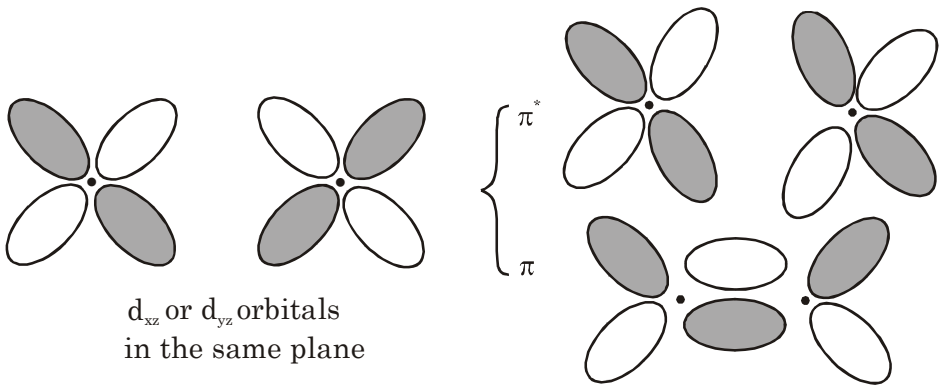
Constructive Interference

(ii)



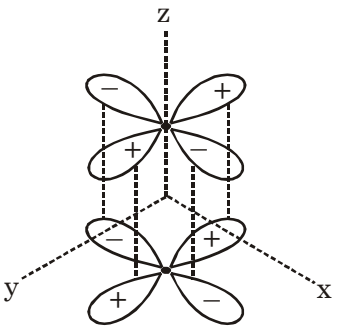
Destructive Interference

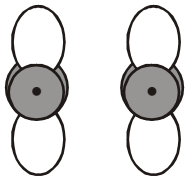
d-d overlapping



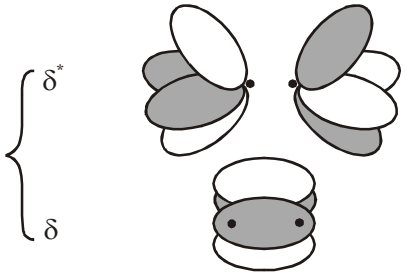
d_{xz} or d_{yz} orbitals
in the same plane

δ-bond



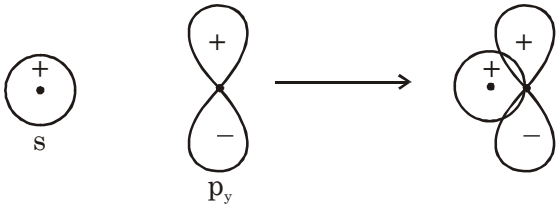


$d_{x^2-y^2}$ or d_{xz} orbitals
in parallel planes

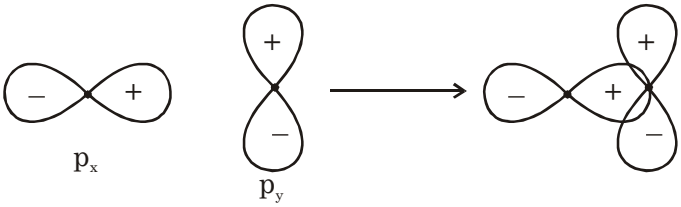


non bonding molecular orbitals

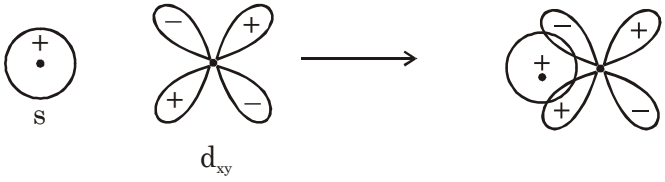
(i)



(ii)



(iii)

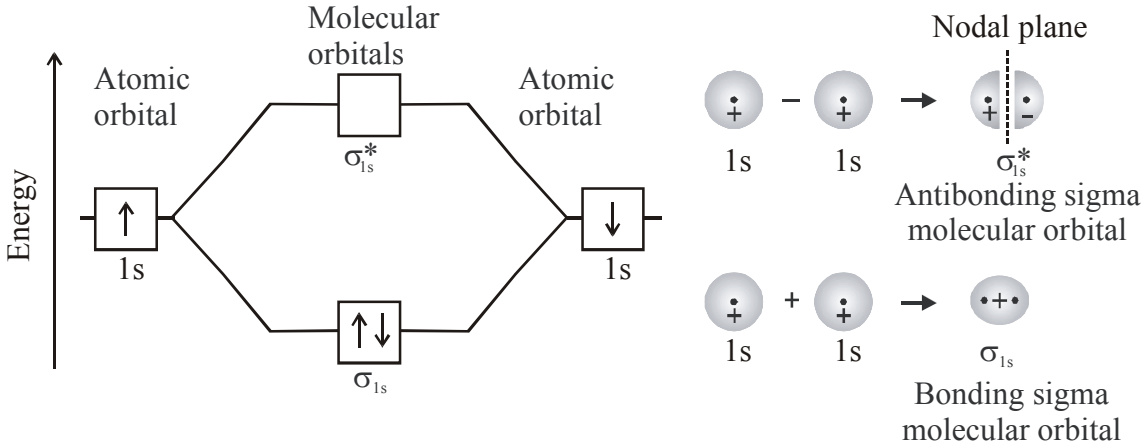


Types of molecular orbitals

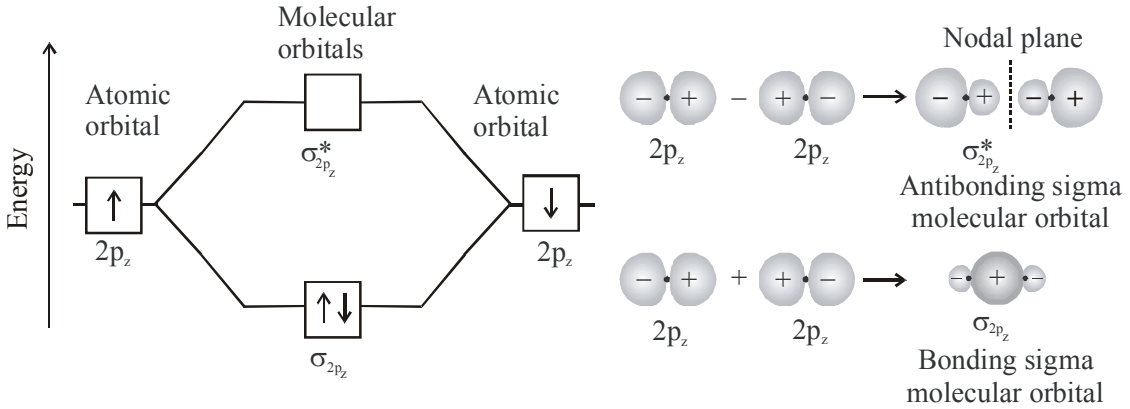
Molecular orbitals of diatomic molecules are designated as σ(sigma), π(pie), δ(delta) etc.

In this nomenclature, the **sigma (σ) molecular orbitals are symmetrical around the inter molecular axis (assumed to be z-axis) while pi (π) molecular orbitals are not symmetrical.**

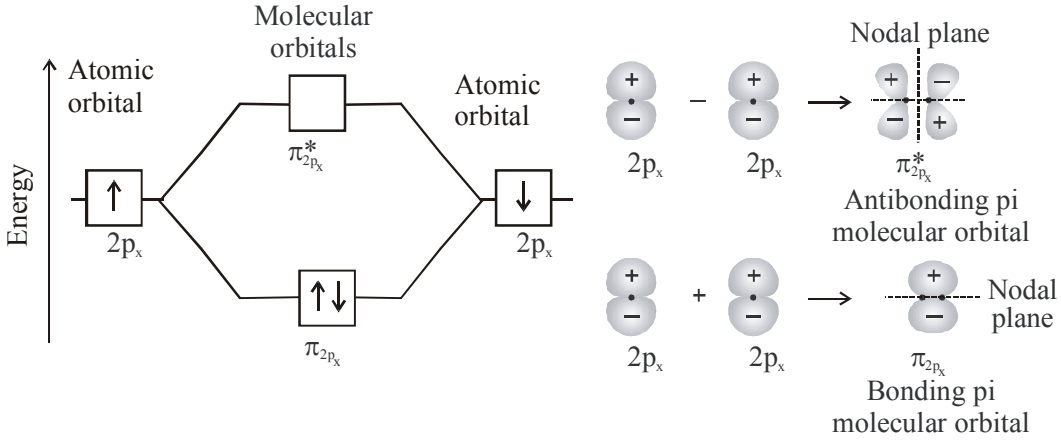
(1) s-s combination of orbitals



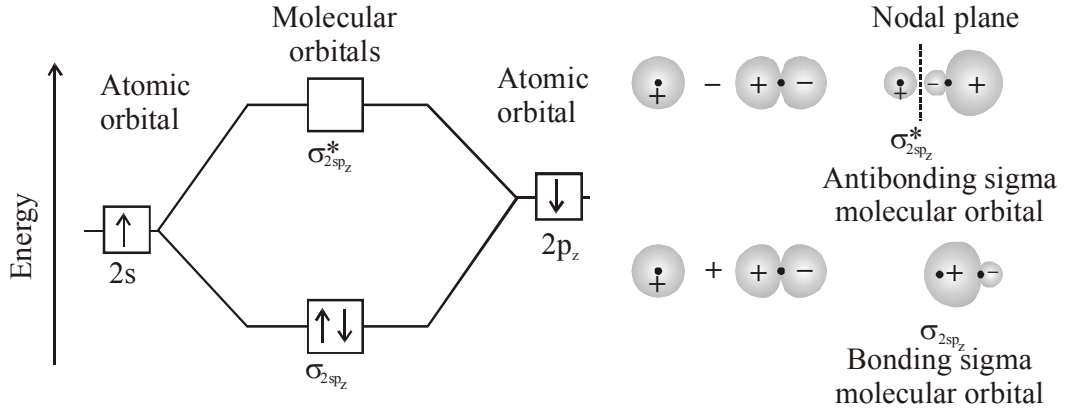
(2) p-p combination of orbitals(end to end overlap)



(3) p-p combination of orbitals (side by side overlap)



(4) s-p combination of orbitals



(c) Energy of BMO < Energy of ABMO.

(d) Molecular orbitals can be filled by electrons according to Aufbau, Hund's, Pauli's principle.

(e) Energy order of the molecular orbitals of homonuclear di-atomic molecules.

Note : Molecular orbital energy diagram for up to N_2 (molecule having ≤ 14 electrons)

$$\sigma_{1s} < \sigma^*_{1s} < \sigma_{2s} < \sigma^*_{2s} < \pi_{2p_x} = \pi_{2p_y} < \sigma_{2p_z} < \pi^*_{2p_x} = \pi^*_{2p_y} < \sigma^*_{2p_z}$$

Note : Molecular orbital energy diagram for O_2 and F_2 (molecule having > 14 electrons)

$$\sigma_{1s} < \sigma^*_{1s} ; < \sigma_{2s} < \sigma^*_{2s} < \sigma_{2p_z} < \pi_{2p_x} = \pi_{2p_y} < \pi^*_{2p_x} = \pi^*_{2p_y} < \sigma^*_{2p_z}$$

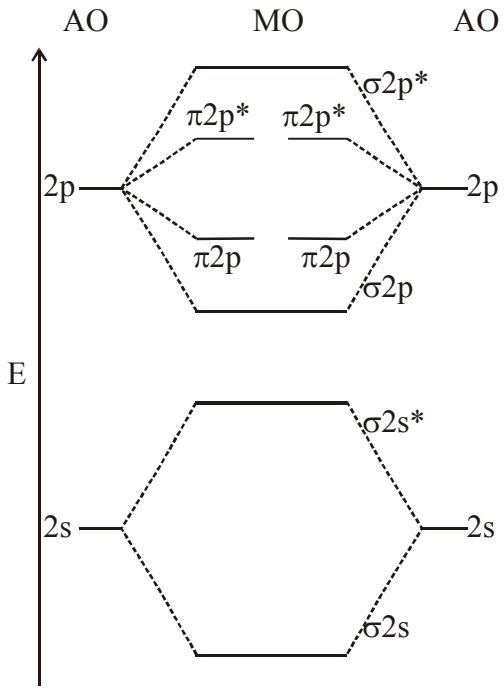
σ *, π * = antibonding molecular orbital

σ, π = bonding molecular orbital

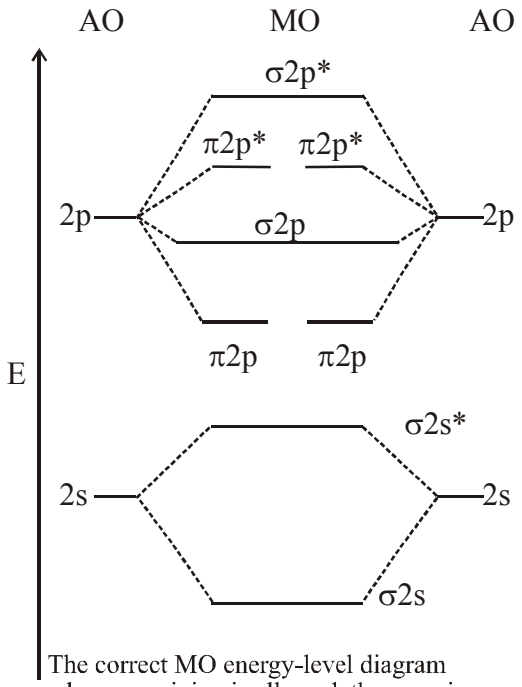
Ex. Why molecular orbital have different order of energy in N_2 & O_2 ?

Sol. s-p mixing

Hint



The correct MO energy-level diagram when s-p mixing is not allowed.



The correct MO energy-level diagram when s-p mixing is allowed, the energies of the σ_{2p} and π_{2p} orbitals are reversed.

Bond Order

Bond order can be defined as :

$$\textbf{Bond order} = \frac{N_b - N_a}{2}$$

N_b = No. of electron in bonding MO's

N_a = No. of electron in antibonding MO's

- If bond order = 0, it means species does not exist.
- Bond order of 1, 2 & 3 corresponds to a single bond, double & triple bond respectively.
- Bond order ↑ stability of molecule ↑ bond length ↓

Magnetic behaviour

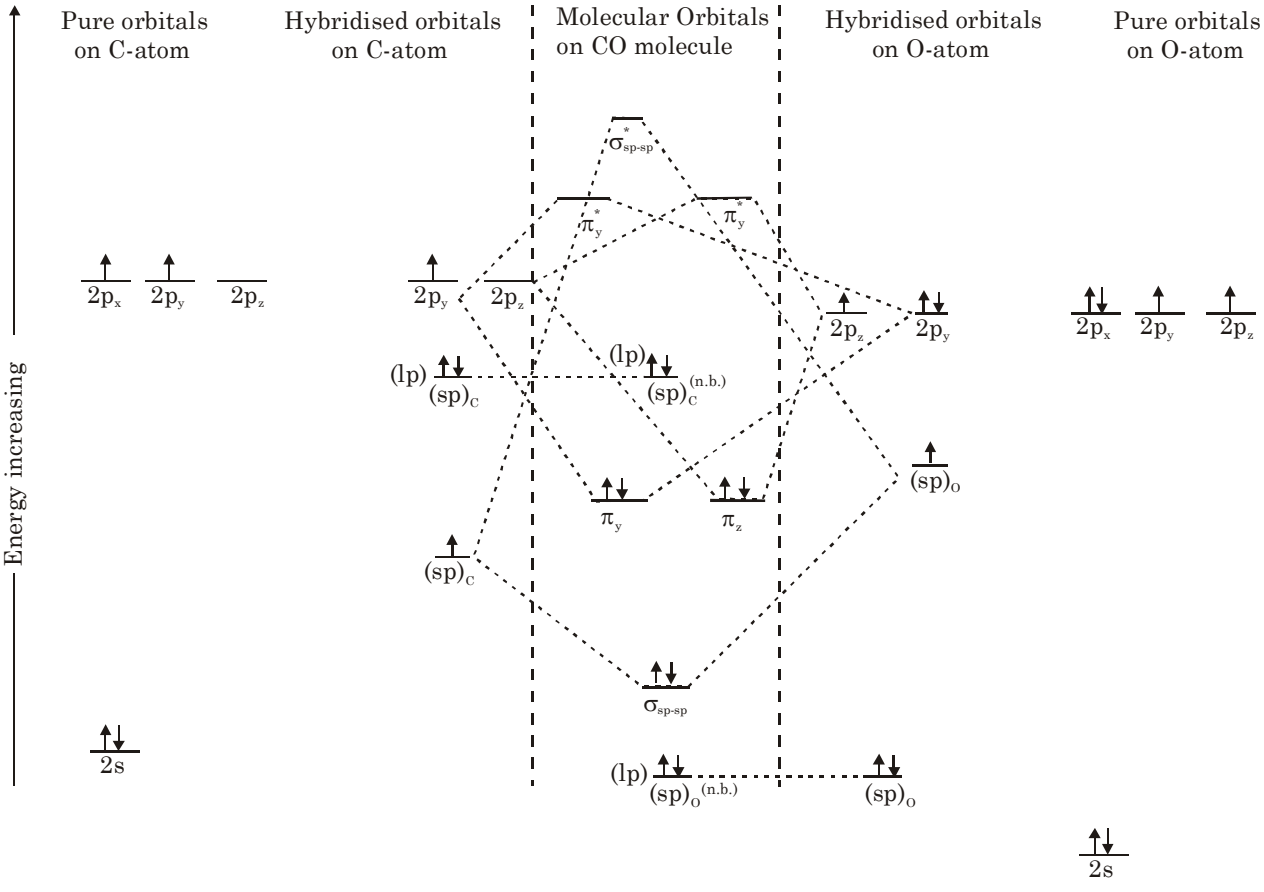
- If the molecule has one or more unpaired electron, it will be paramagnetic,
- If all the electrons are paired it will be diamagnetic.
- Magnetic strength can be calculated by using spin only formula of magnetic moment (μ).
- $\mu = \sqrt{n(n+2)}$ B.M. (where n = number of unpaired electron)

Ex. H_2 = Configuration : $\sigma^2_{(1s)}$, $\sigma^{*0}_{(1s)}$

Bond order = $\frac{N_b - N_a}{2} = \frac{2-0}{2} = 1$, Hence H – H (dimagnetic)

Hetero Nuclear Species

- NO
- **CO**

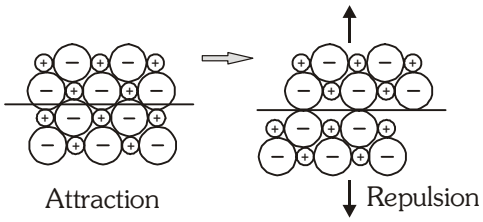


Molecular orbital energy level diagram of CO molecule

IONIC COMPOUNDS

Properties of ionic compound

(a) Physical state : Ionic compounds are hard, crystalline and brittle due to strong electrostatic force of attraction. Brittleness → {Same charged ions comes nearer. So they repell each other}



(b) Isomorphism : The phenomenon of different ionic compounds, having same crystal arrangement of ions is termed as isomorphism

Condition of Isomorphism :

(i) Same charge on cation & anion between isomorphs

(ii) Same radius ratio range of cation & anion between isomorphs

(iii) Same number of water of crystalization between isomorphs

Ex. (i) $ZnSO_4 \cdot 7H_2O$, $FeSO_4 \cdot 7H_2O$ are isomorphous

(ii) All alums are isomorphous

(c) Boiling point and melting point : Ionic compounds have high boiling point and melting point due to strong electrostatic force of attraction among oppositely charged ions.

(d) Conductivity : It depends on ionic mobility.

(i) In solid state - No free ions - Bad conductor of electricity.

(ii) In fused state or aqueous solution Due to free ions - Good conductor of electricity.

Conductivity order : Solid state < fused state < Aqueous solution

(e) Solubility :

Ionic compounds are more soluble in polar solvalents and less soluble in non polar solvents. Solubility of ionic compounds in water mainly depends upon hydration energy & lattice energy.

Q.1 Why does the solubility of alkaline earth metal hydroxides in water increase down the group?

Ans. Among alkaline earth metal hydroxides, the anion being common the cationic radius will influence the lattice enthalpy. Since lattice enthalpy decreases much more than the hydration enthalpy with increasing ionic size, the solubility increases as we go down the group.

Q.2 Why does the solubility of alkaline earth metal carbonates and sulphates in water decrease down the group?

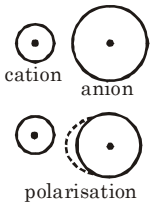
Ans. The size of anions being much larger compared to cations, the lattice enthalpy will remain almost constant within a particular group. Since the hydration enthalpies decrease down the group, solubility will decrease as found for alkaline earth metal carbonates and sulphates.

FAJANS RULE

Just as all the covalent bonds have some partial ionic character, the ionic bonds also have partial covalent character. The partial covalent character of ionic bonds was discussed by Fajans in terms of the following rules :

- The smaller the size of the cation and the larger the size of the anion, the greater the covalent character of an ionic bond.
- The greater the charge on the cation, the greater the covalent character of the ionic bond.
- For cations of the same size and charge, the one, with electronic configuration $(n-1)d^x ns^0$, typical of transition metals, is more polarising than the one with a noble gas configuration, $ns^2 np^6$, typical of alkali and alkaline earth metal cations.

- The cation polarises the anion, pulling the electronic charge toward itself and thereby increasing the electronic charge between the two. This is precisely what happens in a covalent bond, i.e., buildup of electron charge density between the nuclei. The polarising power of the cation, the polarisability of the anion and the extent of distortion (polarisation) of anion are the factors, which determine the per cent covalent character of the ionic bond.



⇒ Polarisation power of a cation is usually called ionic potential or charge density.

$$\text{Ionic potential } \phi \text{ (phi)} = \frac{\text{Charge on cation}}{\text{Size of cation}}$$

APPLICATION OF THE CONCEPT OF POLARISATION :

(a) To compare the covalent and ionic character of molecule
(b) To compare the nature of oxide
(c) To compare the electrical conductivity of ionic comopounds
(d) Tendency of the formation of complex compounds
(e) To compare the thermal stability of metal salts
(f) To compare the intensity of colour of compounds
(g) To compare the solubility of heavier metal halide in water.
(h) To compare melting point of some ionic solids

ORDER OF MELTING POINT

1. $LiF > LiCl > LiBr > LiI$
2. $AlF_3 > MgF_2 > NaF$
3. $NaCl > MgCl_2 > AlCl_3$
4. $NaCl > KCl > RbCl > CsCl > LiCl$
5. $NaBr > KBr > RbBr > CsBr > LiBr$
6. $BeCl_2 < MgCl_2 < CaCl_2 < SrCl_2 < BaCl_2$
7. $A\ell F_3 > A\ell Cl_3 > A\ell I_3 > A\ell Br_3$
8. $MgO > SrO > CaO > BeO > BaO$
9. $NaF > KF > LiF > RbF > CsF$
10. $SrF_2 > CaF_2 > BaF_2 > MgF_2 > BeF_2$
11. $KI > NaI > RbI > CsI > LiI$

VANDER WAAL'S FORCES

⇒ These are the weakest type of inter molecular forces that exist among the chemical species which being significant change in physical properties.

⇒ These are non-directional, non-valence cohesive forces. These attractive forces being played between the two molecules are independent of the presence of other molecules.

⇒ Solid, liquid or gaseous states of many molecules are explained on the basis of inter molecular forces other than covalent, ionic or metallic bonds. Although inert gases do not form any type of bond but may exist in liquid and solid states. This shows that the atoms of inert gases are attracted by each other through some type of inter molecular forces. These intermolecular forces are called Vander Waals forces.

Types of Vander Waal's Forces

(1) ***Dipole-dipole interaction (Keesom forces) :*** The force of attraction between the oppositely charged poles of two polar molecules (for example : H_2S, HCl, PH_3 etc.) is called dipole-dipole attraction.

(2) ***Dipole-induced dipole interaction (Debye forces) :*** This type of cohesive forces occurs in a mixture of polar and non polar molecules. The former induce polarity in non polar molecules by disturbing their electron system. for example force of attraction between Cl_2 and H_2O.

(3) ***Instantaneous dipole-Induced dipole interaction (Dispersion forces/London forces) :*** The weak intermolecular forces operating in similar non polar gaseous molecules are called London forces. These forces are very weak in nature and exists only at low temperature. For example weak intermolecular forces in F_2, Cl_2, N_2, molecules and in noble gasses.
(Note :- London forces present in both polar and non polar species)

Other Weak Interactions

(1) ***Ion-dipole interaction :*** Polar molecules are attracted by ions. The negative pole is attracted by cation and positive pole attracted by the anion. This type of attraction is called ion dipole attraction, ion-dipole attraction is observed generally in the process of solvation when sodium chloride ($Na^+ Cl^-$) is dissolved in water because negative poles of water aggregate around Na^+ ions and positive poles around Cl^- ions.

(2) ***Ion-induced dipole interaction :*** When non polar molecules come in contact with ions, its electron cloud gets polarised and the oppositely charged end of it is attracted by the ion. For example attraction between I^- and I_2 molecule.

ORDER OF BOILING POINT

1. $F_2 < Cl_2 < Br_2 < I_2$

2. $He < Ne < Ar < Kr < Xe$

3. $CH_4 < SiH_4 < GeH_4 < SnH_4$

4. $CO_2 < CS_2$

5. $PF_5 < PCl_5$

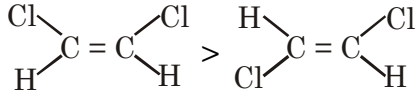
6. $CH_4 < CF_4 < CCl_4$

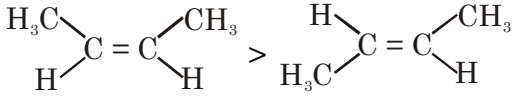
7. $CH_3F < CH_3Cl$

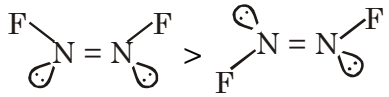
8. $BF_3 < BCl_3 < BBr_3 < BI_3$

9. $H_2 < D_2 < T_2$

10. $H_2O < D_2O$

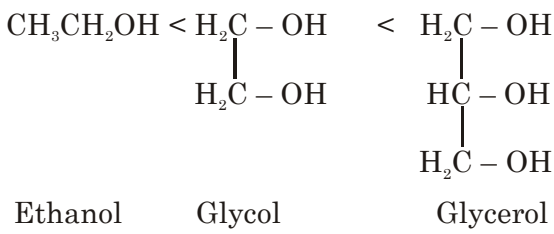
11. 

12. 

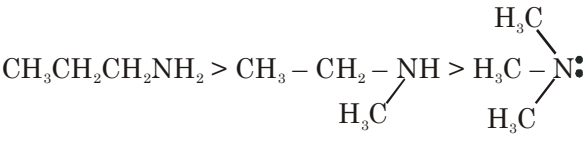
13. 

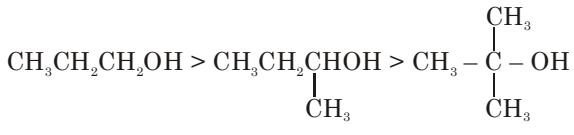
14. n-pentane > isopentane > neopentane

15. $H_2O_2 > H_2O$

16. 

17. $CH_3OCH_3 < CH_3OH < H_2O$

18. 

19. 

20. o-nitrophenol < p-nitrophenol

21. $H_2S < H_2Se < H_2Te < H_2O$ **22.** $PH_3 < AsH_3 < NH_3 < SbH_3$
23. $HCl < HBr < HI < HF$ **24.** Pyrol > Pyridine > Benzene
25. o-dichlorobenzene > p-dichlorobenzene > m-dichlorobenzene
26. $CCl_4 > SiCl_4$ **27.** $CH_4 < CF_4$
28. $C_2H_6 < C_2F_6$ **29.** $C_3H_8 < C_3F_8$
30. $n\text{-}C_5H_{12} > n\text{-}C_5F_{12}$ **31.** $H_2 > He$

ORDER OF MELTING POINT

1. $PH_3 < AsH_3 < SbH_3 < NH_3$ **2.** $H_2S < H_2Se < H_2Te < H_2O$
3. $HCl < HBr < HF < HI$

HYDROGEN BONDING

✦ **Hydrogen bonding:** When a hydrogen atom is bonded to a highly electronegative atom (like F, O or N) comes under the influence of another strongly electronegative atom, then a weak electrostatic force of attraction is developed between them, which is called as hydrogen bond.

Cause of Formation of Hydrogen Bond

When hydrogen is bonded to strongly electronegative element ëXí, the electron pair shared between the two atoms moves far away from hydrogen atom. As a result the hydrogen atom becomes highly electropositive with respect to the other atom eXi. Since there is displacement of electrons towards X, the hydrogen acquires fractional positive charge (δ^+) while ëXí attain fractional negative charge ($\delta^\ominus$). This results in the formation of a polar molecule having electrostatic force of attraction which can be represented as :

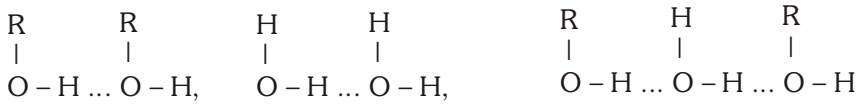
$H^{\delta+} - X^{\delta-} - - - H^{\delta+} - X^{\delta-} - - - H^{\delta+} - X^{\delta-}$

The magnitude of H-bonding depends on the physical state of the compound. It is maximum in the solid state and minimum in the gaseous state. Thus, the hydrogen bonds have strong influence on the structure and properties of the compounds.

Types of H-bonding :

✦ Intermolecular H-bond

(i) This type of H-bonding takes place between two moleules. **Ex.** ROH, H_2O, R - OH & H_2O



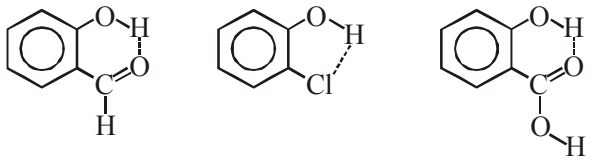
(ii) In such compounds molecular wt., M.P, & B.P. are high.

(iii) Extent of H-bonding ↑ viscosity & density ↑.

✦ Intramolecular H-bond

This type of hydrogen bond takes place with in a molecule.

Normally when 2 hydroxyl groups are present on the same carbon atom i.e. gem diols are unstable, but "chloralhydrate" is a stable molecule due to formation of H-bond.



Applications :

(a) Abnormal behaviour of water.

(b) Association of molecules eg. dimersiation of CH_3COOH, HCOOH

(c) Dissociation of a polar species.

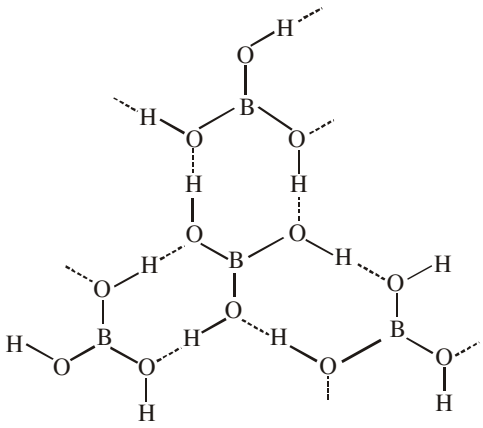
(d) Abnormal melting point & boiling point.

(e) Enhanced solubility in water.

SOME EXAMPLES & APPLICATIONS OF H-BONDING

1. Explain the structure of Boric acid in solid state.

Sol.



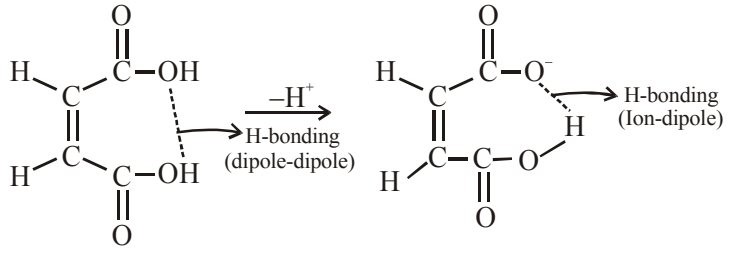
Structure of boric acid ; The dotted lines represent hydrogen bonds

2. Boiling point of o-Nitrophenol is less than meta and para nitrophenol. Why?

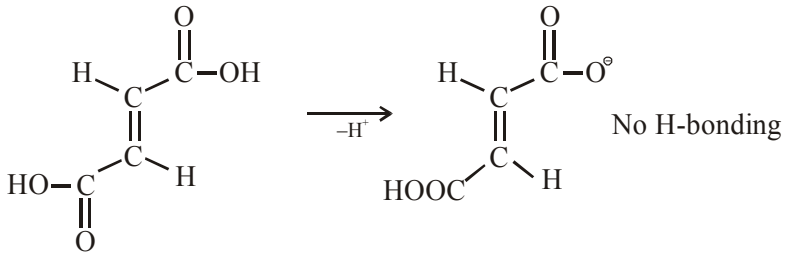
Sol. Inter molecular H-Bonding in case of para nitro phenol is strong enough to increase boiling point which is not favoured in o-Nitro phenol.

3. Maleic acid is more acidic than fumaric acid. Why?

Sol. Maleic acid anion gets stabilize due to intra molecular H-bonding which is not possible in anion of Fumaric acid. So H^+ releasing tendency is more in case of maleic acid



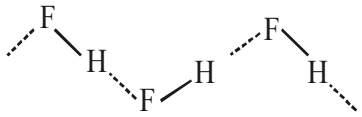
Maleic acid



Fumaric acid

4. H – F is only liquid among halogen acid. Why?

Sol. Due to strong H-Bonding in H–F



5. Ammonia is more easily liquefied than HCl, explain.

Sol. Due to H-Bonding in NH_3.

6. Why ice floats on water?

Sol. Density of ice is higher than that of water due to cage like structure of ice volume of ice increases and density decreases.

7. Water shows maximum density at 4°C. Why?

Sol. On heating ice in temperature range 0–4°C H-bonds of ice break down, which decreases volume, hence density of H_2O increases. On heating ice after 4°C thermal vibrations of H_2O molecules increases which increases effective volume of ice, so density of ice again decreases.

8. HI is the strongest halogen acid, whereas H–F is the weakest. Why?

Sol. H-I bond is weak as compare to H-F so it can be dissociated easily and can give H^+ easily.

9. Wood pieces are used to hold ice-cream. Why?

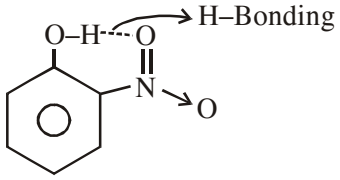
Sol. The organic matter in wood participate in H-bonding with water molecules in ice-cream.

10. KHF_2 is possible but not $KHBr_2$ or KHI_2. Why?

Sol. $K^+[F–H\cdots F^-]$ (H-bonding) But $KHBr_2$ & KHI_2 can't form H-Bond.

11. O – Nitrophenol is less soluble in H_2O than p – Nitrophenol. Why?

Sol. In o-Nitrophenol intra molecular H-bond is present which decreases it's solubility in water.



Ortho Nitro-phenol

12. o-Hydroxy benzaldehyde is a liquid at room temperature while p-hydroxy benzaldehyde is a high melting solid.

Sol. In o-hydroxy benzeldehyde intramolecular H-bond is present which is less stronger than intermolecular H-bond in p-hydroxy benzeldehyde.

13. Glycerol is more viscous than ethanol. Explain.

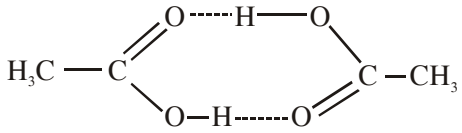
Sol. Extent of H-bonding in glycerol is more as compare to ethanol so it is more viscous.

14. CH_4 and H_2O have nearly same molecular weight. Yet CH_4 has a boiling point 112 K and water 373 K. Explain.

Sol. Due to H-bonding in H_2O

15. The experimental molecular weight of acetic acid is just double than theoretical molecular weight of acetic acid. Why?

Sol. Due to H-bonding in acetic acid it forms dimer so overall molecular weight is just double of original



Dimer of CH_3COOH

16. Although chlorine has same electronegativity as nitrogen but the former does not form effective H-bonding. Explain.

Sol. Due to bigger size of 'Cl' atom it's interaction is not enough to evolve the aomount of energy which lies in the range of H-bond.

17. Molar entropy change of vapourization of acetic acid is less than that of water. Explain

Sol. $\underset{\text{liquid}}{(AcOH)_n} \xrightarrow{\text{on vapour}} \frac{n}{2}(AcOH)_2$ } Not completely converted

But in $\underset{\text{liquid}}{(H_2O)_n} \xrightarrow{\text{on vapour}} n(H_2O)$

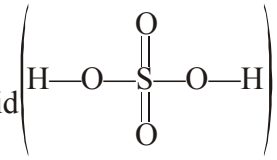
Here all H_2O molecule gets vapourised. So entropy change is more

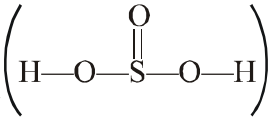
18. Heat of vapourization of water is higher than HF, however strength of H-bond in HF is higher than water. Explain

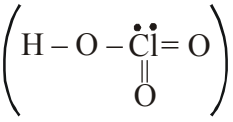
Sol. As extent of H-bond is more in H_2O as compare to HF, heat of vaporisation of water is higher than HF.

INORGANIC OXY-ACIDS

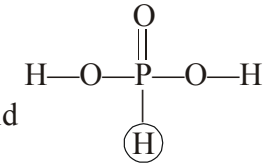
Those compounds which contain X–O–H bond are called oxy-acids. Where X is usually a non-metal. But sometimes X may also be a metal.

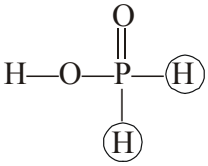
H_2SO_4 Sulphuric acid 

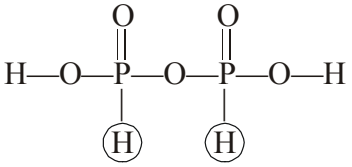
H_2SO_3 Sulphurous acid 

$HClO_3$ Chloric acid 

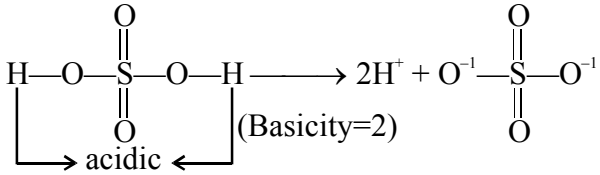
In oxy acids, all the hydrogens are attached with oxygen. Although there are a very few exceptions (as given below), in which all hydrogens are not attached with oxygen.

H_3PO_3 Phosphorus acid 

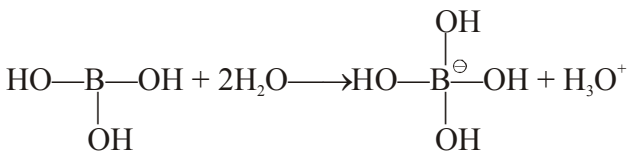
H_3PO_2 Hypophosphorus acid 

$H_4P_2O_5$ Pyrophosphorus acid 

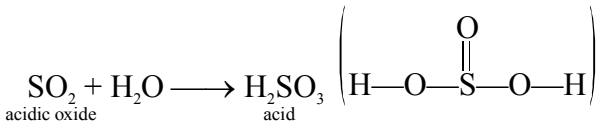
In these three oxyacids circled hydrogens are not attached with oxygen.
In oxyacids, those hydrogens which are attached with oxygen are acidic in nature, i.e., they ionise in solution.

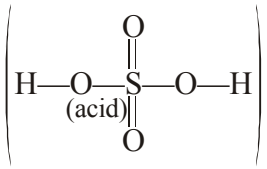


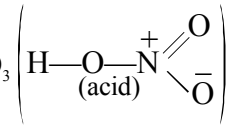
No. of hydrogens attached with oxygen is known as basicity of the acid. *One notable exception is H_3BO_3 in which all the three hydrogens are attached with oxygen yet, they do not ionise in soluion. In fact, H_3BO_3 when dissolved in water, it behaves as a monobasic acid.*



Oxyacids are actually aqueous solutions of acidic oxides.



$\underset{\text{acidic oxide}}{SO_3} + H_2O \longrightarrow H_2SO_4$ 

$\underset{\text{acidic oxide}}{N_2O_5} + H_2O \longrightarrow 2HNO_3$ 

- Some acids have suffix-ic acid and some has-ous acid. Usually, when the central atom in oxy acid is in higher oxidation state the name of the acid ends with –ic acid and when the central atom is in lower oxidation state, it's name ends with –ous acid.

Oxyacids can be classified as

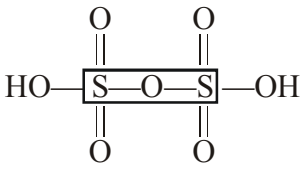
❑ **PYRO ACIDS :**

When one mole of water is removed from two moles of an oxyacid, the resultant oxy acid is known as pyro acid. In general pyro acids contain X—O—X bonds.

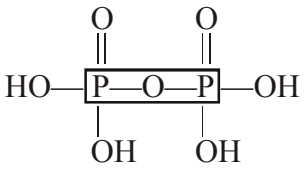
Oxy acid (2 moles) $\xrightarrow{-H_2O}$ Oxy acid [Pyro acid]

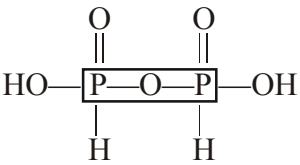
- H_2SO_4 (2 moles) = $H_4S_2O_8 \xrightarrow{-H_2O} H_2S_2O_7$ [Pyrosulphuric acid]
[Sulphuric acid]

In general Pyro acids contain X–O–X bond.

$H_2S_2O_7$  (S—O—S bond)

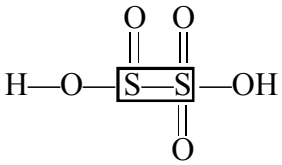
- H_3PO_4 (2 moles) = $H_6P_2O_8 \xrightarrow{-H_2O} H_4P_2O_7$ [Pyrophosphoric acid]
[Orthophosphoric acid]

 (P—O—P bond)

- $2H_3PO_3$ (phosphorus acid) $\xrightarrow{-H_2O}$ $H_4P_2O_5$ (pyrophosphorus acid) 

- $2H_2SO_3 \xrightarrow{-H_2O} H_2S_2O_5$(Pyrosulfurous acid)

Exception : $H_2S_2O_5$ [Pyrosulfurous acid] does not contain S–O–S linkage.



Pyrosulfurous acid

❑ HYPO ACID :

Hypo prefix is added to those oxy acids which is obtained when one oxygen atom is removed from ous form of (usually) acids.

Oxy acid(-ous form) $\xrightarrow{-O}$ Oxy acid (Hypo -ous acid)

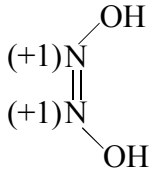
- H_3PO_3 [Phosphorous acid] $- O \longrightarrow H_3PO_2$ [Hypophosphorous acid] monobasic acid

- $\underset{\text{Halousacid (x=Cl,Br,I)}}{\overset{+3}{HXO_2}} - [O] \longrightarrow \underset{\text{Hypohalous acid}}{\overset{+1}{HOX}}$

HOCl - Hypochlorous acid
HOBr - Hypobromous acid
HOI - Hypoiodous acid

- $\underset{\text{Nitrous acid}}{\overset{+3}{HNO_2}} - [O] \longrightarrow \overset{+1}{HNO}$

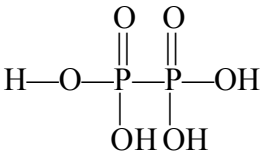
HNO exist in dimeric from i.e. as $(HNO)_2 = H_2N_2O_2$

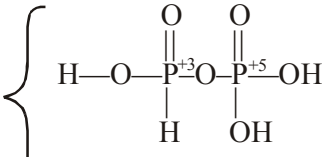


Hyponitrous acid

If one O is removed from pyro 'ic' acid it produce hypo 'ic' acid

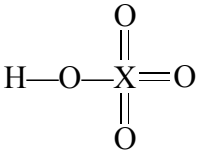
$\underset{\text{Pyrosulphuric acid}}{H_2S_2O_7} \xrightarrow{-"O"} \underset{\text{Hyposulphuric acid}}{H_2S_2O_6}$

$\underset{\text{Pyrophosphoricacid}}{\overset{(+5)}{H_4P_2O_7}} \xrightarrow{"-O"} \underset{\text{Hypophosphoricacid}}{\overset{(+4)}{H_4P_2O_6}}$ 

Exception : ***(It may be exist as isohypophosphoric acid)*** 
Isohypophosphoric acid

❑ PER ACID AND PEROXY ACID :

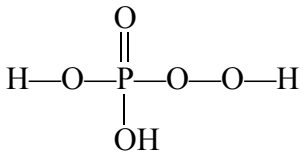
When one oxygen in added to –ic form of acid and if the oxidation number of central atom in resulting oxy acid is more than the –ic form of acid, then it is per acid.

- $\underset{\text{(X=Cl,Br,I) Halic acid}}{\overset{(+5)}{HXO_3}} + O \longrightarrow \underset{\text{Perhalic acid}}{\overset{(+7)}{HXO_4}}$ 

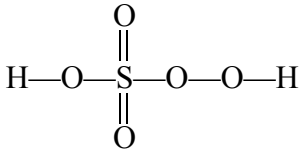
$HClO_4$ perchloric acid $HBrO_4$ - Perbromic acid.

Peroxy prefix is added to those oxy acids which are obtained when one oxygen is added to –ic from of acid and the oxidation number of central atom remains the same. Peroxy acids contain peroxy linkage (—O—O—).

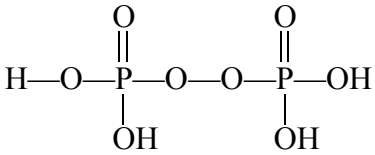
- $\overset{+5}{H_3PO_4} + O \longrightarrow \overset{+5}{H_3PO_5}$
  Orthophosphoric acid → Peroxyphosphoric acid



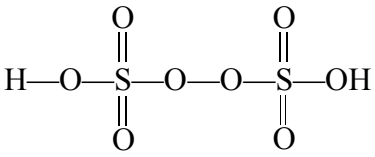
- $\overset{+6}{H_2SO_4} + O \longrightarrow \overset{+6}{H_2SO_5}$
  Peroxysulfuric acid (caro's acid)



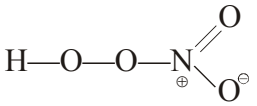
- $\overset{+5}{H_4P_2O_7} + O \longrightarrow \overset{+5}{H_4P_2O_8}$
  diphosphoric acid pyrophosphoric acid → Peroxy diphosphoric acid



- $\overset{+6}{H_2S_2O_7} + O \longrightarrow \overset{+6}{H_2S_2O_8}$
  Pyrosulphuric acid disulphuric acid → Peroxydisulphuric acid (Marshall acid)



- $\overset{+5}{HNO_3} + O \longrightarrow \overset{+5}{HNO_4}$
  (nitric acid) → (peroxy nitric acid)

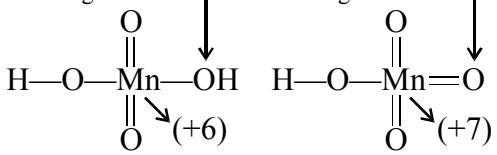


Note : Peroxynitric acid does not contain N—O—H bond, yet it is considered to be oxy acid.

Exception : $H_2\overset{+6}{Mn}O_4$ is manganic acid when one hydrogen is removed from H_2MnO_4, $HMnO_4$ is formed which is named as permanganic acid.

$\overset{(+6)}{H_2MnO_4}—H \longrightarrow \overset{(+7)}{HMnO_4}$

Manganic acid → Permanganic acid



❑ ORTHO ACIDS AND META ACIDS :-

When one mole of H_2O is removed from one mole of an oxy acid, the resulting compound, if an oxy acid (i.e. it contains at least one X–OH bond) then the oxy acid from which H_2O is removed is named as ortho acid and the product oxyacid is known as META ACID.

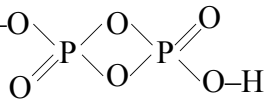
$$\underset{\text{(ortho)}}{\text{Oxy acid (1 mol)}} \xrightarrow{-H_2O} \underset{\text{meta}}{\text{Oxy acid}}$$

- $H_3PO_4 \xrightarrow{-H_2O} HPO_3$ Meta phosphoric acid *(It forms Cyclic polymetaphosphoric acids)*

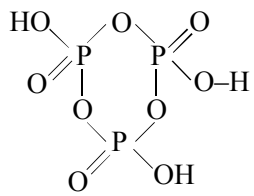
  (ortho – phosphoric acid)

◆ Cyclic polymetaphosphoric acids :

$(HPO_3)_2$ - Dimetaphosphorsphoric acid

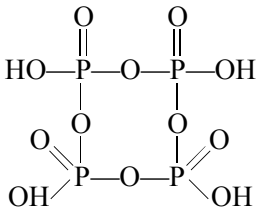
$(H_2P_2O_6)$  (expected)

$(HPO_3)_3$

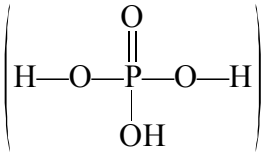


Trimetaphosphoric acid

$(HPO_3)_4$



Tetrametaphosphoric acid



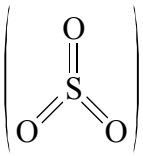
Orthophosphoric acid

An ortho acid must contain at least three hydrogens.

- $H_3BO_3 \xrightarrow[-H_2O]{} HBO_2$

  Ortho-boric acid — Meta boric acid

- H_2SO_4(~~ortho~~ -sulphuric acid) $\xrightarrow{-H_2O}$ SO_3 sulfur trioxide(anhydride of H_2SO_4)

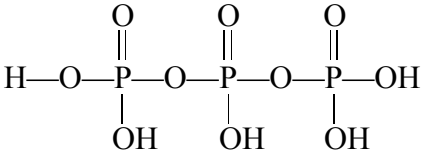


As SO_3 does not contain any hydrogen (i.e., X–OH/S–OH bond), so SO_3 is not an oxy acid rather it is anhydride of sulphuric acid (H_2SO_4) so, H_2SO_4 can't be prefixed with ortho, and its name does not contain any prefix and it is named as sulphuric acid.

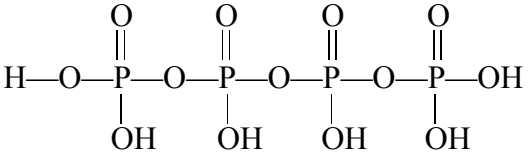
❑ POLYPHOSPHORIC ACID :

Oxy acids having general formula $H_{(n+2)}P_nO_{(3n+1)}$ are known as polyphosphoric acids. These contain (n–1) P–O–P bonds.

$H_5P_3O_{10}$ - Tripolyphosphoric acid

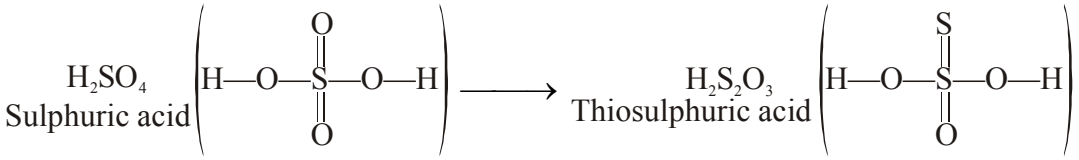


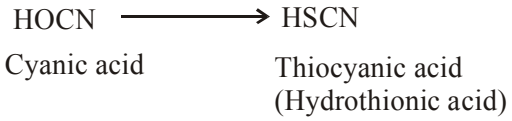
$H_6P_4O_{13}$ - Tetrapolyphosphoric acid



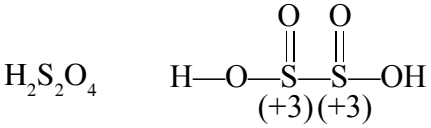
❑ THIO ACID :

◆ **1.** Oxy acids in which one oxygen atom are replaced by sulphur are considered as thio acid.
For example :-



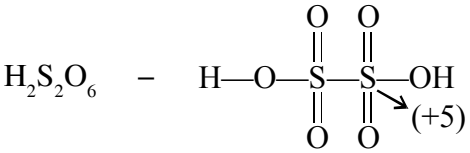


◆ **2.** Oxy acids of sulphur containing S—S bonds are known as thio acids.

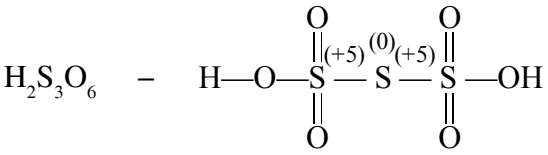


dithionous acid.

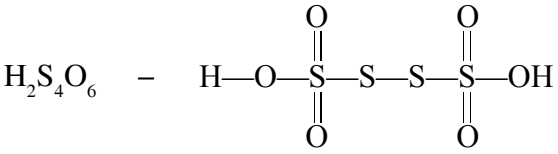
Thionic acids : Oxy acids of sulphur containing S—S bond and having general formula $H_2S_{(n+2)}O_6$ are known as thionic acids



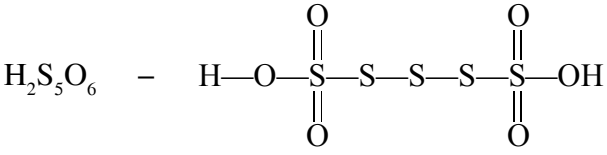
Dithionic acid (hyposulphuric acid)



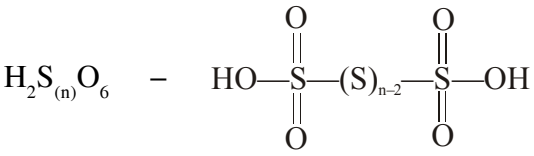
Trithionic acid



Tetrathionic acid

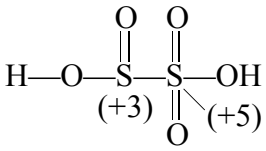
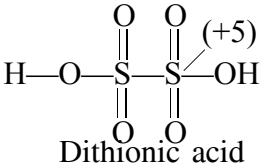
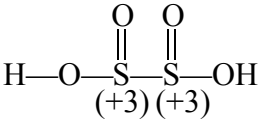
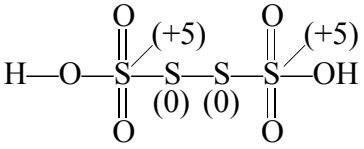
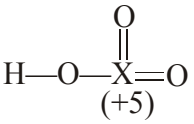
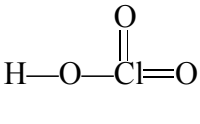
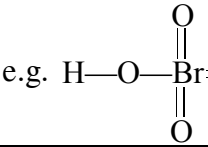


Pentathionic acid



Polythionic acid

❑ TABLE OF OXIDATION STATE OF OXY-ACIDS :

Element	–Ous acid	–ic acid
P	**(+3,** H_3PO_3, $H_4P_2O_5$) **(+2,** H_3PO_2)	**(+4)** $H_4P_2O_6$ (Hypophosphoric acid) +5 → $H_{n+2}P_nO_{3n+1}$ - polyphosphoric acid; H_3PO_4, $H_4P_2O_7$, $H_4P_2O_8$; H_3PO_5 - peroxymonophosphoric acid
S	**(+4)** H_2SO_3 Sulfurous acid  Pyrosulfurous acid	**(+6)** Sulphuric acid (H_2SO_4) $H_2S_2O_7$ - Pyrosulphuric acid $H_2S_{(n+2)}O_6$- Thionic acids e.g :  Dithionic acid
	$H_2S_2O_4$  dithionous acid	 Tetrathionic acid $H_2\overset{(+6)}{S}O_5$- Peroxymonosulfuric acid $H_2\overset{(+6)}{S_2}O_8$- Peroxydisulfuric acid
X (X=Cl,Br,I)	**(+1)** H–O–X Hypohalous acid e.g. H–O–Cl - Hypochlorous acid H–O–I - Hypoiodous acid **(+3)** HXO_2 ; H–O–X=O Halous acid H–O–I=O - Iodous acid	**(+5)** Halic acid (HXO_3)   [Chloric acid] **(+7)** Perhalic acid (HXO_4)  [Perbromic acid]
Others		(+3) H_3BO_3 Orthoboric acid (+3) HBO_2 - Metaboric acid (+5) H_3BiO_4 Orthobismuthic acid (+5) $HBiO_3$ metabismuthic acid (+4) Orthosilicic acid H_4SiO_4 H_2SiO_3 - Metasilicic acid $H_6Si_2O_7$ - Pyrosilicic acid

- **Naming of salts of oxy acids : The name of salt ends with – "ate" if the name of the oxy acid ends with - ic acid and all prefix remain same eg. :-**

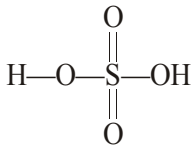
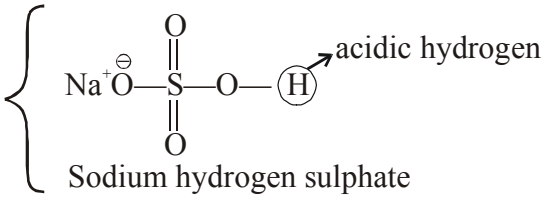
H_2SO_4	Na_2SO_4 - Sodium sulfate
Sulphuric acid	K_2SO_4 - Potassium sulfate
	$BaSO_4$ - Barium sulfate
	$FeSO_4$ - Ferrous sulfate
	$Al_2(SO_4)_3$ - Aluminium sulfate
H_3PO_4	Na_3PO_4 - Sodium orthophosphate
Orthophosphoric acid	K_3PO_4 - Potassium orthophosphate
	$Ca_3(PO_4)_2$ - Calcium Orthophosphate
	$AlPO_4$ - Aluminium orthophosphate
HPO_3	$NaPO_3$ - Sodium metaphosphate
meta phosphoric acid	KPO_3 - Potassium metaphosphate
	$Ca(PO_3)_2$ - Calcium metaphosphate
	$Al(PO_3)_3$ - Aluminium metaphosphate
$HClO_3$	$KClO_3$ - Potassium chlorate
chloric acid	$NaClO_3$ - Sodium chlorate
	$Ca(ClO_3)_2$ - Calcium chlorate
$HClO_4$	$NaClO_4$ - Sodium perchlorate
Perchloric acid	$KClO_4$ - Potassium perchorate
	NH_4ClO_4 - Ammonium perchlorate
	$Ca(ClO_4)_2$ - Calcium perchlorate
H_3PO_4	KH_2PO_4 potassium dihydrogen orthophosphate
Orthophosphoric acid	$Ca(H_2PO_4)_2$ calcium dihydrogen orthophosphate
$(HPO_3)_6 = H_6P_6O_{18}$	$Na_6P_6O_{18}$
Hexametaphosphoric acid	Sodium hexametaphosphate
$HBiO_3$	$NaBiO_3$. Sodium metabimuthate
Metabismuthic acid	$KBiO_3$. Potassium melabismuthate
HBO_2	$NaBO_2$ sodium metaborate
metaboric acid	
H_2SO_5	Na_2SO_5. Sodium peroxysulfate
Peroxysulphuric acid	
$H_4P_2O_7$	$Na_4P_2O_7$ - Sodium pyrophosphate
Pyrophosphoric acid	

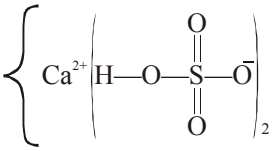
If the name of the oxy acid ends with ous acid then the name of the salt ends with "ite"

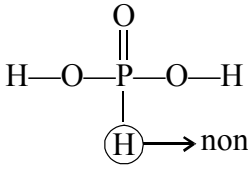
$HClO_2$	$NaC1O_2$ sodium chlorite
chlorous acid	$KClO_2$ potassium chlorite
	$Ca(ClO_2)_2$ calcium chlorite
H_3PO_3	Na_2HPO_3 sodium phosphite
Phosphorous acid	K_2HPO_3 Potassium phosphite
(dibasic acid)	$Ca(HPO_3)_2$ calcium phosphite
H_2SO_3	Na_2SO_3 sodium sulfite
sulfurous acid	K_2SO_3 potassium sulfite
HNO_2	$NaNO_2$ sodium nitrite
Nitrous acid	KNO_2 potassium nitrite

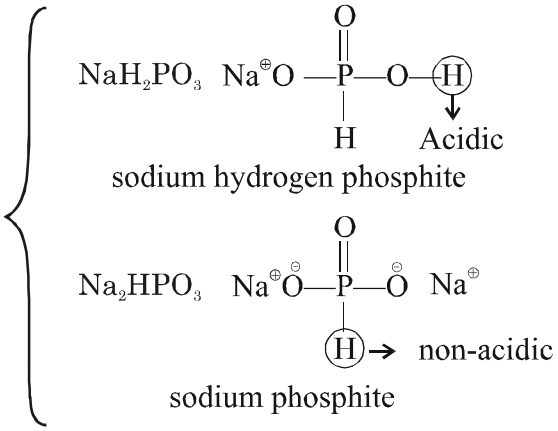
HOCl	NaOCl sodium hypochlorite
Hypochlorous acid	KOBr potassium hypobromite
	NaOI sodium hypoiodite
H_3PO_2	NaH_2PO_2 sodium hypophosphite
Hypophosphorous acid	$Ba(H_2PO_2)_2$ Barium hypophosphite
(monobasic acid)	

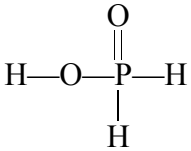
If all the ionisable hydrogens are not removed from the acid to form salt, then the hydrogen word is added to the name of the salt containing acidic hydrogens (H attached with oxygen)

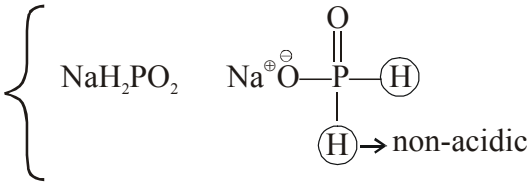
Ex.1  Sulphuric acid $NaHSO_4$  acidic hydrogen Sodium hydrogen sulphate

Ex.2 $Ca(HSO_4)_2$ calcium hydrogensulphate 

Ex.3 H_3PO_3 Phosphorous acid  nonacidic



Ex.4 H_3PO_2  Hypophosphorous acid (monobasic)



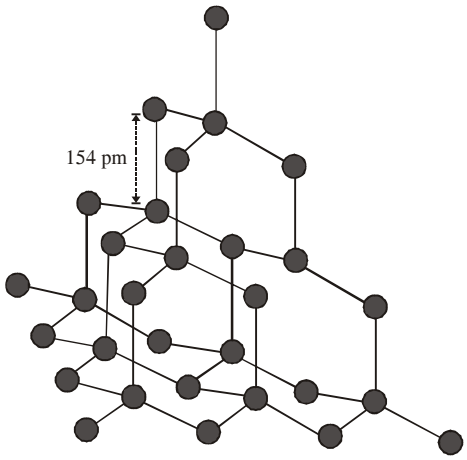
sodium hypophosphite but not sodium dihydrogen phosphite as H is not acidic.

ALLOTROPES OF CARBON FAMILY

Diamond ***(kinetically most stable allotrope of carbon, meta stable phase of carbon)***

It has a crystalline lattice. In diamond each carbon atom undergoes sp^3 hybridisation and linked to four other carbon atoms by using hybridised orbitals in tetrahedral fashion.

The C–C bond length is 154 pm. The structure extends in space and produces a rigid three dimensional network of carbon atoms.



The structure of diamond

In this structure, directional covalent bonds are present throughout the lattice. It is very difficult to break extended covalent bonding and, therefore, diamond is a very hard substance.

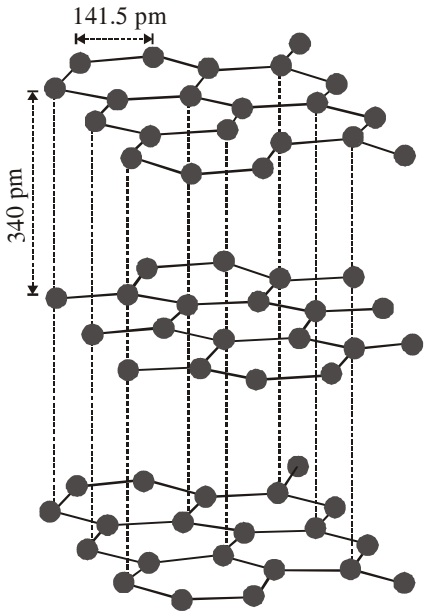
It is used as an abrasive for sharpening hard tools, in making dyes and in the manufacture of tungsten filaments for electric light bulbs.

Graphite ***(Thermodynamically most stable allotrope of carbon)***

Graphite has layered structure. Layers are held by van der Waals forces and distance between two layers is 340 pm.

Each layer is composed of planar hexagonal rings of carbon atoms. C—C bond length within the layer is 141.5 pm.

Each carbon atom in hexagonal ring undergoes sp^2 hybridisation and makes three sigma bonds with three neighbouring carbon atoms. Fourth electron forms a π bond. The electrons are delocalised over the whole sheet. Thus, graphite is lusturous. Electrons are mobile and, therefore, graphite conducts electricity along the sheet.



The structure of graphite

Graphite cleaves easily between the layers and, therefore, it is very soft and slippery. For this reason graphite is used as a dry lubricant in machines running at high temperature, where oil cannot be used as a lubricant.

Fullerenes

Fullerenes are made by the heating of graphite in an electric arc in the presence of inert gases such as helium or argon.

The sooty material formed by condensation of vapourised C_n small molecules consists of mainly C_{60} with smaller quantity of C_{70} and traces of fullerenes consisting of even number of carbon atoms up to 350 or above.

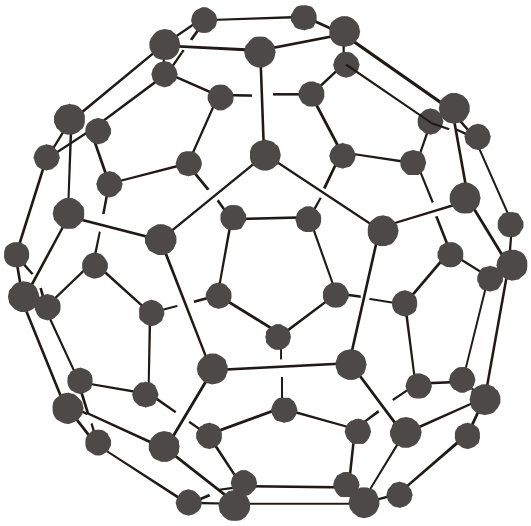
Fullerenes are the only pure form of carbon because they have smooth structure without having 'dangling' bonds. Fullerenes are cage like molecules. C_{60} molecule has a shape like soccer ball and called Buckminsterfullerene.

It contains twenty, six- membered rings and twelve, five membered rings.

A six membered ring is fused with six or five membered rings but a five membered ring can only fuse with six membered rings.

All the carbon atoms are equal and they undergo sp^2 hybridisation. Each carbon atom forms three sigma bonds with other three carbon atoms. The remaining electron at each carbon is delocalised in molecular orbitals, which in turn give aromatic character to molecule. However, because of non-planar nature of fullerenes, their aromatic character gets diminished and reactivity increases.

This ball shaped molecule has 60 vertices and each one is occupied by one carbon atom and it also contains both single and double bonds with C–C distances of 143.5 pm and 138.3 pm respectively. Spherical fullerenes are also called *bucky balls* in short.



[The structure of C_{60}, Buckminsterfullerene : Note that molecule has the shape of a soccer ball (football)]

* **It is very important to know that graphite is thermodynamically most stable allotrope of carbon and, therefore, ΔH_f of graphite is taken as zero. ΔH_f values of diamond and fullerene, C_{60} are 1.90 and 38.1 kJ mol^{-1}, respectively**.

Other forms of elemental carbon like carbon black, coke, and charcoal are all impure forms of graphite or fullerenes. Carbon black is obtained by burning hydrocarbons in a limited supply of air. Charcoal and coke are obtained by heating wood or coal respectively at high temperatures in the absence of air.

Uses of Carbon

Graphite fibres embedded in plastic material form high strength, lightweight composites. The composites are used in products such as tennis rackets, fishing rods, aircrafts and canoes. **Being good conductor, graphite is used for electrodes in batteries and industrial electrolysis.** Crucibles made from graphite are inert to dilute acids and alkalies. Being highly porous, activated charcoal is used in adsorbing poisonous gases; also used in water filters to remove organic contaminators and in airconditioning system to control odour. Carbon black is used as black pigment in black ink and as filler in automobile tyres. Coke is used as a fuel and largely as a reducing agent in metallurgy. Diamond is a precious stone and used in jewellery. It is measured in carats (1 carat = 200 mg).

ALLOTROPES OF OXYGEN FAMILY

Oxygen occurs as two non-metallic forms, dioxygen O_2 and ozone O_3. Dioxygen O_2 is stable as a diatomic molecule. O_3 molecule is diamagnetic while O_2 is paramagnetic.

Six allotropes of selenium are known.

Tellurium has only one crystalline form, which is silvery white and semimetallic.

This is similar to grey Se, but has stronger metallic interaction.

Sulphur Allotropic forms :

Sulphur forms numerous allotropes of which the yellow rhombic (α-sulphur) and monoclinic (β -sulphur) forms are the most important. The stable form at room temperature is rhombic sulphur, which transforms to monoclinic sulphur when heated above 369 K.

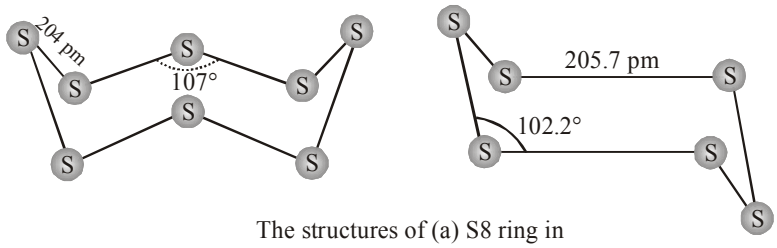
Rhombic sulphur (α-sulphur) (*Most stable sulphur allotrope at room temperature***)**

This allotrope is yellow in colour, m.p. 385.8 K and specific gravity 2.06. Rhombic sulphur crystals are formed on evaporating the solution of roll sulphur in CS_2. It is insoluble in water but dissolves to some extent in benzene, alcohol and ether. It is readily soluble in CS_2.

Monoclinic sulphur (β-sulphur)

Its m.p. is 393 K and specific gravity 1.98. It is soluble in CS_2 while water insoluble. This form of sulphur is prepared by melting rhombic sulphur in a dish and cooling, till crust is formed. Two holes are made in the crust and the remaining liquid poured out. On removing the crust, colourless needle shaped crystals of β-sulphur are formed. It is stable above 369 K and transforms into α-sulphur below it. Conversely, α-sulphur is stable below 369 K and transforms into β-sulphur above this. At 369 K, both the forms are stable. This temperature is called transition temperature.

Both rhombic and monoclinic sulphur have S_8 molecules. These S_8 molecules are packed to give different crystal structures. The S_8 ring in both the forms is puckered and has a crown shape. The molecular dimensions are given in the figure.



The structures of (a) S8 ring in rhombic sulphur and (b) S_6 form

Several other modifications of sulphur containing 6-20 sulphur atoms per ring have been synthesised in the last two decades. In cyclo-S_6, the ring adopts the chair form and the molecular dimensions are as shown in figure. At elevated temperatures (~1000 K), S_2 is the dominant species and is paramagnetic just like O_2.

Note : Engel's sulphur (ε-sulphur) is unstable and contains S_6 rings arranged in the chair conformation. It is made by pouring $Na_2S_2O_3$ solution into concentrated HCl and extracting the S with toluene. Plastic sulphur-(χ) is obtained by pouring liquid sulphur into water.

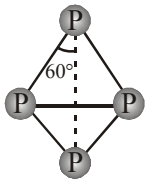
Allotropes of Nitrogen Family :

Solid As, Sb and Bi each exist in several allotropic forms. Arsenic vapour contains tetrahedral As_4 molecules. A reactive yellow form of the solid resembles white phosphorus and is thought to contain tetrahedral As_4 units. Sb also has a yellow form. All three elements have much less reactive metallic or α-forms.

PHOSPHORUS ALLOTROPIC FORMS

Phosphorus is found in many allotropic forms, the important ones being white, red and black. White phosphorus is a translucent, white, waxy solid. It is poisonous, insoluble in water but soluble in carbon disulphide and glows in dark (chemiluminescence). It dissolves in boiling NaOH solution in an inert atmosphere giving PH_3.

$$P_4 + 3NaOH + 3H_2O \longrightarrow PH_3 + \underset{\text{(Sodium hypophosphite)}}{3NaH_2PO_2}$$



White Phosphorus

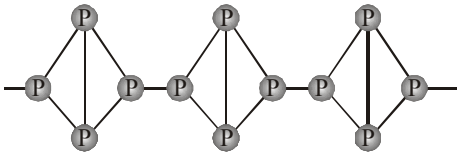
White phosphorus is less stable and therefore, more reactive than the other solid phases under normal conditions because of angular strain in the P_4 molecule where the angles are only 60°. It readily catches fire in air to give dense white fumes of P_4O_{10}.

$$P_4 + 5O_2 \rightarrow P_4O_{10}$$

It consists of discrete tetrahedral P_4 molecule as shown in Fig.

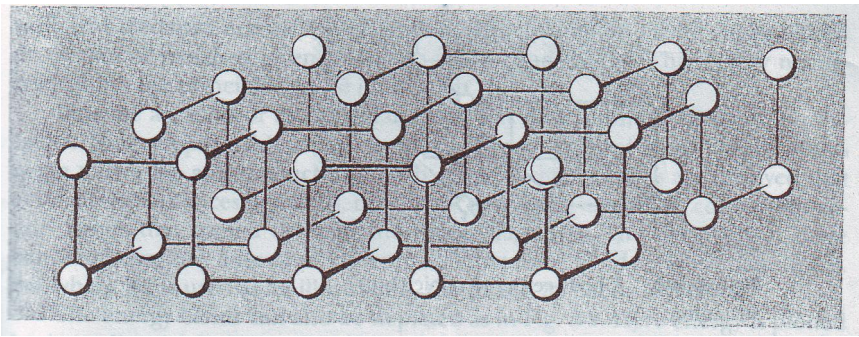
Red phosphorus is obtained by heating white phosphorus at 573K in an inert atmosphere for several days. When red phosphorus is heated under high pressure, a series of phases of black phosphorus is formed. Red phosphorus possesses iron grey lustre. It is odourless, nonpoisonous and insoluble in water as well as in carbon disulphide. Chemically, red phosphorus is much less reactive than white phosphorus. It does not glow in the dark.

It is polymeric, consisting of chains of P_4 tetrahedra linked together in the manner as shown in Fig.



Red Phosphorus

Black phosphorus has two forms α-black phosphorus and β-black phosphorus. α-Black phosphorus is formed when red phosphorus is heated in a sealed tube at 803K. It can be sublimed in air and has opaque monoclinic or rhombohedral crystals. It does not oxidise in air. β-Black phosphorus is prepared by heating white phosphorus at 473 K under high pressure. It does not burn in air upto 673 K.



Thermodynamic stability order : Black phosphorus > Red phosphorus > White phosphorus

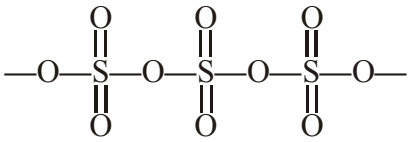
Reactivity order : Black phosphorus < Red phosphorus < White phosphorus

ALLOTROPIC FORM OF SO_3

SO_3 have three allotropic forms α-SO_3 , β-SO_3 and γ-SO_3

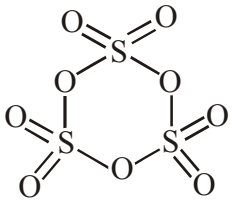
α-SO_3
Cross linked solid

,



Polymeric chain structure
β-SO_3

,



γ-SO_3
(S_3O_9)
cylic trimer

NOTE:- Si, Ge and Sn have a diamond type of structure, though Sn exists as a metallic form. Pb exists only in the metallic form. Ge is unusual because the liquid expands when it forms the solid. This property is unique to Ga, Ge and Bi.

$$\underset{\substack{\text{grey tin}\\(\text{Diamond structure})}}{\alpha - Sn} \underset{}{\overset{13.2^\circ C}{\rightleftharpoons}} \underset{\substack{\text{white tin}\\(\text{metallic})}}{\beta - Sn}$$

EXERCISE # O-1

VALENCY & OCTET RULE

1. The maximum covalency is equal to
(A) the number of unpaired p-electrons
(B) the number of paired d-electrons
(C) the number of unpaired s and p-electrons
(D) total number of unpaired electron in ground state or in excited state **CBO0198**

2. **Statement-1 :** POF_3 exist but NOF_3 does not exist.
Statement-2 : 'P' can form five bonds by expanding its octet while 'N' cannot expand its octet to form five bonds.
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CBO0199**

3. The types of bond present in N_2O_5 are
(A) only covalent (B) only ionic
(C) ionic and covalent (D) covalent & coordinate **CBO0005**

4. NH_3 and BF_3 combine readily because of the formation of :
(A) a covalent bond (B) a hydrogen bond
(C) a co-ordinate bond (D) an ionic bond **CBO0200**

5. Which of the following molecule does not have co-ordinate bonds?
(A) CH_3–NC (B) CO (C) O_3 (D) CO_3^{2-} **CBO0006**

6. Which of the following species are hypervalent ?
1. AsF_5 2. BF_3 3. SF_6 4.CO_3^{2-}
(A) 1, 2, ,3 (B) 1, 3 (C) 3,4 (D) 1, 2 **CBO0201**

VBT / HYBRIDISATION / VSEPR THEORY

7. What is the state of hybridisation of Xe in cationic part of solid XeF_6 ?
(A) sp^3d^3 (B) sp^3d^2 (C) sp^3d (D) sp^3 **CBO0202**

8. Which of the following diagram / statement is **CORRECT** for the hybrid orbitals ?
(A) $s + p_y \longrightarrow z'$  z
(B) $s + p_y + p_Z \longrightarrow sp^2$ orbitals lie in the xy plane
(C) $ns + np^3 +$ any $d^2 \longrightarrow$ results octahedral geometry of sp^3d^2 hybrid orbitals.
(D) None of these **CBO0203**

9. When 2s - 2s, 2p - 2p and 2p - 2s orbitals overlap, the bond strength decreases in the order :
(A) p–p > s–s > p–s (B) p–p > p–s > s–s (C) s–s > p–p > p–s (D) s–s > p–s > p–p **CBO0015**

10. Which of the following has been arranged in increasing order of size of the hybrid orbitals ?
(A) $sp < sp^2 < sp^3$ (B) $sp^3 < sp^2 < sp$ (C) $sp^2 < sp^3 < sp$ (D) $sp^2 < sp < sp^3$
CBO0013

11. In the context of carbon, which of the following is arranged in the **CORRECT** order of electronegativity:
(A) $sp > sp^2 > sp^3$ (B) $sp^3 > sp^2 > sp$ (C) $sp^2 > sp > sp^3$ (D) $sp^3 > sp > sp^2$
CBO0014

12. The **CORRECT** order of increasing s-character (in percentage) in the hybrid orbitals of following molecules/ ions is :
(I) CO_3^{2-} (II) XeF_4 (III) I_3^- (IV) NCl_3 (V) $BeCl_2$
(A) II < III < IV < I < V (B) II < IV < III < V < I
(C) III < II < I < V < IV (D) II < IV < III < I < V **CBO0204**

13. **Statement-1 :** The species $[I(CN)_2]^-$ is overall linear.
Statement-2 : I-atom and C-atoms are 'sp' hybridised
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CBO0205**

14. **Statement-1 :** C_3O_2 has linear structure.
Statement-2 : Each C atom in C_3O_2 is sp-hybridised.
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CBO026**

BOND ANGLE & BOND LENGTH

15. The **CORRECT** order of increasing X–O–X bond angle is (X = H, F or Cl) :
(A) $H_2O > C1_2O > OF_2$ (B) $C1_2O > H_2O > OF_2$
(C) $OF_2 > C1_2O > H_2O$ (D) $OF_2 > H_2O > Cl_2O$ **CBO0207**

16. Arrange the following in order of decreasing N–O bond length : NO_2^+, NO_2^- , NO_3^- :-
(A) $NO_3^- > NO_2^+ > NO_2^-$ (B) $NO_3^- > NO_2^- > NO_2^+$
(C) $NO_2^+ > NO_3^- > NO_2^-$ (D) $NO_2^- > NO_3^- > NO_2^+$ **CBO0208**

17. Which has higher bond energy ?
(A) F_2 (B) Cl_2 (C) Br_2 (D) I_2 **CBO0209**

18. Which of the following species is / are linear ?
(A) H_2S (B) NH_3 (C) CO_2 (D) SO_2 **CBO0210**

19. Which one of the following molecules is planar ?
(A) NF_3 (B) NCl_3 (C) BF_3 (D) PH_3 **CBO0211**

20. The **CORRECT** order of increasing C—O bond length of CO, CO_3^{2-}, CO_2 is :
(A) $CO_3^{2-} < CO_2 < CO$ (B) $CO_2 < CO_3^{2-} < CO$
(C) $CO < CO_3^{2-} < CO_2$ (D) $CO < CO_2 < CO_3^{2-}$ **CBO0212**

BENT'S RULE AND DRAGO'S RULE

21. C–H bond distance is the longest in:
(A) C_2H_2 (B) C_2H_4 (C) C_2H_6 (D) $C_2H_2Br_2$ **CBO0018**

22. The bond angle and hybridization in ether (CH_3OCH_3) is :
(A) 106°51', sp^3 (B) 104°31', sp^3 (C) 110°, sp^3 (D) 109°28', sp^3
CBO0019

23. Which of the following has been arranged in order of decreasing bond length ?
(A) P–O > Cl–O > S–O (B) P–O > S–O > Cl–O
(C) S–O > Cl–O > P–O (D) Cl–O > S–O > P–O **CBO0020**

24. Among the following, the **CORRECT** statement is :
(A) Between NH_3 and PH_3, NH_3 is a better electron donor because the lone pair of electrons occupies spherical 's' orbital and is less directional
(B) Between NH_3 and PH_3, PH_3 is a better electron donor because the lone pair of electrons occupies sp^3orbital and is more directional
(C) Between NH_3 and PH_3, NH_3 is a better electron donor because the lone pair of electrons occupies sp^3 orbital and is more directional
(D) Between NH_3 and PH_3, PH_3 is a better electron donor because the lone pair of electrons occupies spherical 's' orbital and is less directional **CBO0022**

25. Which of the following order is **CORRECT** for increasing p-character in orbital used for bonding by central atom
(A) $SiH_4 > CH_4$ (B) $H_2S > H_2O$ (C) $PH_4^+ > PH_3$ (D) $NH_3 > PH_3$
CBO0025

BACK BONDING

26. Boron forms BX_3 type of halides. The **CORRECT** increasing order of Lewis-acid strength of these halides is
(A) $BF_3 > BCl_3 > BBr_3 > BI_3$ (B) $BI_3 > BBr_3 > BCl_3 > BF_3$
(C) $BF_3 > BI_3 > BCl_3 > BBr_3$ (D) $BF_3 > BCl_3 > BI_3 > BBr_3$ **CBO0213**

27. Select species which is planar at nitrogen :
(A) $(CH_3)_3N$ (B) $(SiH_3)_3N$ (C) NF_3 (D) NH_3 **CBO0214**

28. Type of back bonding in $(SiH_3)_2O$ is :
(A) $p\pi - d\pi$ (B) $p\pi - p\pi$ (C) $d\pi - d\pi$ (D) None of these
CBO0215

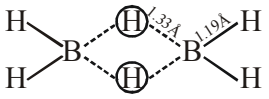
MULTICENTERED BOND

29. The type of overlap in the bridge bond existing in $Al_2(CH_3)_6$ is :-
(A) sp^3–sp^3d–sp^3 (B) sp^3–sp^2–sp^3 (C) sp^3–s–sp^3 (D) sp^3–sp^3–sp^3
CB0006

30. Which one of the following statements is **NOT** true regarding diborane?
(A) It has two bridging hydrogens and four perpendicular to the rest.
(B) When methylated, the product is $Me_4B_2H_2$
(C) The bridging hydrogens are in a plane perpendicular to the rest.
(D) All the B–H bond distances are equal. **CB0007**

31. The molecular shapes of diborane, is shown:

Consider the following statements for diborane :



(1) Boron is approximately sp^3 hybridised

(2) B–H–B angle is 180°

(3) There are two terminal B–H bonds for each boron atom

(4) There are only 12 bonding electrons available

Of these statements:

(A) 1, 3 and 4 are **CORRECT** (B) 1, 2 and 3 are **CORRECT**

(C) 2, 3 and 4 are **CORRECT** (D) 1, 2 and 4 are **CORRECT** **CB0008**

SILICATE

32. The number of corners or O-atoms shared per tetrahedron for pyroxene chain silicate is -

(A) 3 (B) 2 (C) 2.5 (D) 1 **CBO0044**

33. The mineral $Na_2Fe_3^{II}Fe_2^{III}[Si_8O_{22}](OH)_2$ (chrocidolite) is a :

(A) Pyroxene chain silicate (B) Sheet silicate

(C) Amphiboles chain silicate (D) 3D-silicate **CBO0045**

34. The silicate anion in the mineral kinoite is a chain of three SiO_4 tetrahedra that share corners with adjacent tetrahedra. The mineral also contains Ca^{2+} ions, Cu^{2+} ions, and water molecules in a 1:1:1 ratio mineral is represented as :

(A) $CaCuSi_3O_{10}.H_2O$ (B) $CaCuSi_3O_{10}.2H_2O$

(C) $Ca_2Cu_2Si_3O_{10}.2H_2O$ (D) none of these **CBO0046**

ODD ELECTRON SPECIES

35. Hybridisation related to NO_2 molecule is -

(A) sp^3 (B) sp (C) sp^3d (D) sp^2 **CB0009**

36. In which of the following processes, the magnetic behaviour of the species is changed ?

(A) $2\dot{C}H_3 \longrightarrow C_2H_6$ (B) $2NO_2 \longrightarrow N_2O_4$ (C) $2ClO_3 \longrightarrow Cl_2O_6$ (D) All of these

CB0010

HYDROLYSIS

37. Which of the following statement is **CORRECT** ?

(A) BCl_3 is not hydrolysed while $SiCl_4$ can be hydrolysed

(B) CCl_4 is hydrolysed under ordinary condition

(C) XeF_2 produces on hydrolysis $Xe(OH)_2$ as the final product

(D) Hydrolysis of XeF_2 is a redox reaction **CB0011**

38. **Statement-1 :** Between $SiCl_4$ and CCl_4 only $SiCl_4$ reacts with water at room temperature.

Statement-2 : $SiCl_4$ is ionic and CCl_4 is covalent.

(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **CB0012**

MOLECULE DOES NOT EXIST

39. Which of the following molecules do not exist.

(A) BF_6^{3-} (B) NCl_3 (C) NOF_3 (D) XeF_5^- **CBO0027**

40. Select non existing species

(A) PH_3 (B) PH_4^+ (C) $[PF_6]^-$ (D) None of these **CBO0028**

INERT PAIR EFFECT

41. **Statement-1 :** Boron does not show univalent nature but unipositive nature of thallium is quite stable.

Statement-2 : Inert pair effect predominates in thallium.

(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **CB0014**

42. **Statement-1 :** PbI_4 doesn't exist and converts into PbI_2 and I_2 spontaneously at room temperature but $PbCl_4$ needs heating to convert into $PbCl_2$ and Cl_2.

Statement-2 : Pb^{2+} is more stable than Pb^{4+} due to inert pair effect.

(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **CB0015**

IONIC COMPOUND

43. The dissolution of ionic compounds involves :

(A) Evolution of heat (B) Weakening of attractive forces

(C) Dissociation into ions (D) All of these **CB0016**

44. Select **CORRECT** order out of given options :

(A) $BeCO_3 < BaCO_3$: Covelant character (B) BeO > SrO : lattice energy

(C) $Be^{2+} < Li^+$: Hydration energy (D) $Be^{2+}(aq.) > Li^+(aq.)$: Ionic mobility **CB0017**

45. The polarizibility of the following compounds is/are

(A) $I^- > Br^- > Cl^- > F^-$ (B) $I^- > Br^- > F^- > C1^-$

(C) $I^- < Br^- < Cl^- < F^-$ (D) $I^- < Br^- < F^- < Cl^-$ **CB0018**

46. Which of the following equilibria would have the highest value of K_p at a common temperature?

(A) $MgCO_3 \Leftrightarrow MgO + CO_2$ (B) $CaCO_3 \Leftrightarrow CaO + CO_2$

(C) $SrCO_3 \Leftrightarrow SrO + CO_2$ (D) $BaCO_3 \Leftrightarrow BaO + CO_2$ **CB0019**

47. The solubility of anhydrous $AlCl_3$ and hydrated $AlCl_3$ in diethyl ether are S_1 and S_2 respectively. Then

(A) $S_1 = S_2$ (B) $S_1 > S_2$ (C) $S_1 < S_2$ (D) $S_1 < S_2$ but not $S_1 = S_2$ **CB0021**

48. **Statement-1 :** Among alkali metal cations, Li^+(aq.) has highest electrical conductance.
Statement-2 : Li^+(aq.) is largest alkali metal cation because of greater degree of hydration.
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CB0022**

MOLECULAR ORBITAL THEORY

49. The bond energy order of He_2^+ and HeH^+ is
(A) $He_2^+ > HeH^+$ (B) $HeH^+ = He_2^+$ (C) $HeH^+ > He_2^+$ (D) Can't be predicted
CB0024

50. Which of the following species have more number of electrons in bonding MO's as compared to antibonding MO's :-
(A) O_2^- (B) N_2^+ (C) C_2 (D) All of these
CB0153

51. During the formation of a molecular orbital from atomic orbitals, probability of electron density is
(A) minimum in the nodal plane
(B) maximum in the nodal plane
(C) zero in the nodal plane
(D) zero on the surface of the lobe **CB0026**

52. Pick out the **INCORRECT** statement ?
(A) N_2 has greater dissociation energy than N_2^+
(B) O_2 has lower dissociation energy than O_2^+
(C) Bond length in N_2^+ is less than N_2
(D) Bond length in NO^+ is less than in NO **CB0027**

53. A simplified application of MO theory to the hypothetical molecule 'OF' would give its bond order as :
(A) 2 (B) 1.5 (C) 1.0 (D) 0.5 **CB0028**

54. Which of the following is **TRUE** ?
(A) With increasing Bond order , Bond length decreases & Bond energy increases
(B) With increasing Bond order , Bond length increases & Bond energy decreases
(C) With increasing Bond order , Bond length decreases & Bond energy decreases
(D) With increasing Bond order , Bond length increases & Bond energy increases **CB0029**

55. Which of the following has fractional bond order ?
(A) O_2^{2+} (B) O_2^{2-} (C) F_2^{2-} (D) H_2^- **CB0030**

56. **Statement-1:** H_2 molecule is more stable than He–H molecule.
Statement-2 : The antibonding electron in He–H molecule decreases the bond order and there by the stability.
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CB0031**

57. **Statement-1 :** Super oxide ion is paramagnetic whereas peroxide ion is diamagnetic.
Statement-2 : Super oxide ion has one unpaired electron whereas peroxide ion has no unpaired electron.
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CB0032**

58. **Statement-1:** π_b and π^* orbitals obtained from 2p orbital are lying in the same plane.
Statement-2 : Bonding M.O's are formed by constructive interference while antibonding M.O's are formed by destructive interference.
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CB0033**

WEAK FORCES

59. **Statement-1 :** The melting point of noble gases increases as its atomic mass increases.
Statement-2 : Instantaneous dipole induced dipole attraction increases with increase in atomic mass of noble gases.
(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.
(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1
(C) Statement-1 is true, statement-2 is false.
(D) Statement-1 is false, statement-2 is true. **CB0001**

60. Which of the following boiling point order is **CORRECT** :-
(A) $He > T_2 > D_2$ (B) $He < T_2 < D_2$
(C) $T_2 > He > D_2$ (D) $He < D_2 < T_2$ **CB0003**

61. Which is the **INCORRECT** match for the energy distance function for following interaction -
(A) Debye force : r^{-6} (B) Ion-induced dipole interaction : r^{-2}
(C) London force : r^{-6} (D) Keesom force : r^{-3} **CB0004**

62. Identify the **INCORRECT** order of boilng point in the following pair.
(A) $B(OH)_3 < B(OCH_3)_3$ (B) $NF_3 < N(CH_3)_3$
(C) $BF_3 < B(CH_3)_3$ (D) $C_2H_6 < C_2F_6$ **CB0005**

HYDROGEN BONDING

63. Two ice cubes are pressed over each other and unite to form one cube. Which force is responsible for holding them together :
(A) Van der Waal's forces (B) Covalent attraction
(C) Hydrogen bond formation (D) Dipole-dipole attraction **CBO0216**

64. **Statement-1 :** H_2SO_4 in more viscous than water.

Statement-2 : In H_2SO_4, S has highest oxidation state.

(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **CBO0217**

65. The volatility of HF is low because of :

(A) its low polarizability

(B) the weak dispersion interaction between the molecules

(C) its small molecular mass

(D) Its strong hydrogen bonding **CBO0218**

66. Which of the following compounds would have significant intermolecular hydrogen bonding ?

HF, CH_3OH, N_2O_4, CH_4

(A) HF, N_2O_4 (B) HF, CH_4, CH_3OH (C) HF, CH_3OH (D) CH_3OH, CH_4

CBO0034

67. The pairs of bases in DNA are held together by :

(A) Hydrogen bonds (B) ionic bonds (C) Phosphate groups (D) Deoxyribose groups

CBO0219

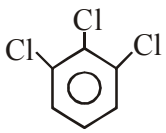
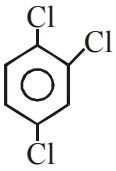
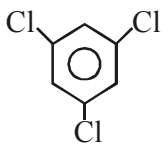
DIPOLE MOMENT

68. Which of the set of isomers of $C_6H_4Cl_2$ is having equal dipole moment with C_6H_5Cl and C_6H_6 respectively?

(A) ortho and meta (B) meta and para

(C) ortho and para (D) para and ortho **CBO0220**

69. Which has maximum dipole moment?

(A)  (B)  (C)  (D)  **CBO0221**

70. Which of the following has been arranged in order of decreasing dipole moment ?

(A) $CH_3Cl > CH_3F > CH_3Br > CH_3I$

(B) $CH_3F > CH_3Cl > CH_3Br > CH_3I$

(C) $CH_3Cl > CH_3Br > CH_3I > CH_3F$

(D) $CH_3F > CH_3Cl > CH_3I > CH_3Br$ **CBO0031**

71. **Statement-1 :** The direction of dipole moment in CO is from'O' to 'C'.

Statement-2 : The contribution of co-ordinated π-bond is more compared to electronegativity factor in the overall polarity of the molecule.

(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **CBO0222**

MISCELLANEOUS

72. In a molecule of phosphorus(V)oxide, there are

(A) 4P–P, 10P–O and 4P=O bonds (B) 12P–O and 4P=O bonds

(C) 2P–O and 4P=P bonds (D) 6P–P, 12P–O and 4P=P bonds **CBO0223**

73. There is no S–S bond in:

(A) $S_2O_4^{2-}$ (B) $S_2O_5^{2-}$ (C) $S_2O_3^{2-}$ (D) $S_2O_7^{2-}$ **CBO0224**

74. The cationic part of solid Cl_2O_6 is having the " _____ " shape.

(A) Linear (B) Angular (C) Tetrahedron (D) Undefined

CBO0225

75. The **CORRECT** order of acidic strength of oxy-acids of chlorine is

(A) $HClO < HClO_2 < HClO_3 < HClO_4$ (B) $HClO_4 < HClO_3 < HClO_2 < HClO$

(C) $HClO > HClO_4 > HClO_3 > HClO_2$ (D) $HClO_4 < HClO_2 > HClO_3 > HClO$

CBO0226

76. **Statement-1 :** H_3BO_3 in water behaves as monobasic acid

Statement-2 : The ionisation reaction is: $H_3BO_3 + H_2O \rightleftharpoons B(OH)_4^- + H^+$

(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **CBO0227**

77. **Statement-1:** White phosphorus is less stable whereas red phosphorus is more stable.

Statement-2 : White phosphorus exist as individual P_4 having more strained geometery while red phosphorus has P_4 tetrahedron structure linked together.

(A) Statement-1 is true, statement-2 is true and statement-2 is **CORRECT** explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the **CORRECT** explanation for statement-1

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **CBO0228**

78. Among the species NF_3, NO_3^-, BF_3, H_3O^+ and HN_3, identify the isostructural species :

(A) (NF_3 , NO_3^-) and (BF_3 , H_3O^+)

(B) (NF_3 , HN_3) and (NO_3^- , BF_3)

(C) (NF_3 , H_3O^+) and (NO_3^- , BF_3)

(D) (NF_3 , H_3O^+) and (HN_3 , BF_3) **CBO0229**

EXERCISE # O-2

(CHOOSE THE CORRECT OPTION. ONE OR MORE THAN ONE ARE CORRECT)

VALENCY & OCTET

1. Which of the following compounds contain both ionic and covalent bonds ?
(A) NH_4Cl (B) KCN (C) $CuSO_4.5H_2O$ (D) NaOH **CBO0053**

2. The octet rule is **NOT** obeyed in :
(A) CO_2 (B) BCl_3 (C) PCl_5 (D) SiF_4 **CBO0230**

3. To which of the following species octet rule is **NOT** applicable ?
(A) BrF_5 (B) SF_6 (C) IF_7 (D) CO **CBO0055**

4. Which of the following species contain coordinate bond ?
(A) $AlCl_3$ (B) CO (C) NOF_3 (D) N_3^- **CBO0231**

VBT / HYBRIDISATION / VSEPR THEORY

5. The linear structure is assumed by :
(A) $SnCl_2$ (B) NCO^- (C) CS_2 (D) NO_2^+ **CBO0232**

6. Shape of NH_3 is very similar to
(A) SeO_3^{2-} (B) CH_3^- (C) BH_3 (D) CH_3^+ **CBO0233**

7. Pick out among the following species isoelectronic with CO_2 :
(A) N_3^- (B) $(CNO)^-$ (C) $(NCN)^{2-}$ (D) NO_2^- **CBO0234**

8. The structure of XeF_6 is :
(A) pentagonal bipyramidal (B) distorted octahedral
(C) capped octahedral (D) square pyramidal **CBO0235**

9. A π-bond may between two p_x, orbitals containing one unpaired electron each when they approach each other appropriately along :
(A) x-axis (B) y-axis (C) z-axis (D) any direction **CBO0236**

BOND ANGLE / BOND LENGTH

10. Which of the following statements are **not CORRECT** ?
(A) All C–O bonds in CO_3^{2-} are equal but not in H_2CO_3
(B) All C–O bonds in HCO_2^- are equal but not in HCO_2H
(C) C–O bond length in HCO_2^- is longer than C–O bond length in CO_3^{2-}
(D) C–O bond length in HCO_2^- and C–O bond length in CO_3^{2-} are equal. **CBO0237**

BENT'S AND DRAGO RULE

11. The decreasing values of bond angles from NH_3 (106°) to SbH_3 (91°) down group-15 of the periodic table is due to
(1) decreasing lp – bp repulsion (2) increasing electronegativity
(3) increasing bp – bp repulsion (4) increasing p-orbital character in sp^3 **CBO0238**

BACK BONDING

12. Molecules in which bond angle is changed due to back bonding w.r.t B/O/N.
(A) H_3BO_3 (B) $B(OMe)_3$ (C) BF_3 (D) $N(SiH_3)_3$ **CBO0239**

13. $3d\pi$-$2p\pi$ type back bonding is observed in :
(A) $N(SiH_3)_3$ (B) $\bar{C}Cl_3$ (C) $S(CH_3)_2$ (D) BCl_3 **CBO0240**

MULTICENTERED BOND

14. No X–X bond exists in which of the following compounds having general form of X_2H_6 ?
(A) B_2H_6 (B) C_2H_6 (C) Al_2H_6 (D) Si_2H_6 **CB0036**

15. Three centre - two electron bonds exist in :
(A) B_2H_6 (B) $Al_2(CH_3)_6$ (C) $BeH_2(s)$ (D) $BeCl_2(s)$ **CB0037**

16. Select **CORRECT** statement about B_2H_6
(A) Bridging groups are electron-deficient with 12 valence electrons
(B) It has 2c – 2e B–H bonds
(C) It has 3c – 2e B–H–B bonds
(D) All of above are **CORRECT** statements **CB0038**

SILICATE

17. In which of the following cases the number of corner shared per tetrahedron is '2' -
(A) Pyroxene chain silicate (B) Amphibole chain silicate
(C) 5-membered cyclic silicate (D) None of these **CBO0080**

ODD ELECTRON SPECIES

18. Select **CORRECT** about NO_2 :
(A) It is an odd electron species (B) N–O bond order = 1.5
(C) Paramagnetic species (D) Isoelectronic with CO_2 **CB0039**

19. Which of the following statement is **CORRECT** :-
(A) The free electron of ClO_3 molecule is present in d-orbital of Cl-atom
(B) The free electron of $\dot{C}F_3$ is present in sp^3 hybrid orbital
(C) NO is polar
(D) The free electron of ClO_2 molecule is present in d-orbital of Cl-atom **CB0041**

HYDROLYSIS

20. Which of the following halides **cannot** be hydrolysed ?
(A) SeF_6 (B) SF_6 (C) CCl_4 (D) NF_3 **CB0043**

MOLECULE DOES NOT EXIST

21. Which of the following molecules do not exist ?
(A) Br_2O (B) SF_6 (C) NCl_5 (D) OF_4 **CBO0067**

22. Which of the following do not exists ?
(A) SH_6 (B) HFO_4 (C) $SiCl_6^{-2}$ (D) $HClO_3$ **CBO0068**

23. Which of the following molecule exist-
(A) SF_6 (B) IH_3 (C) SH_2 (D) PCl_5 **CBO0069**

INERT PAIR EFFECT

24. Which of the following have an (18 + 2) electron configuration ?
(A) Pb^{2+} (B) Cd^{2+} (C) Bi^{3+} (D) SO_4^{2-} **CB0045**

25. Which of following stability order is/are **CORRECT** due to inert pair effect ?
(A) $Hg > Hg^{2+}$ (B) $Bi^{3+} < Bi^{5+}$ (C) $Pb^{2+} > Pb^{4+}$ (D) $Fe^{2+} < Fe^{3+}$
CB0046

IONIC COMPOUND

26. Choose the **CORRECT** order for the given properties.

(A) $MgSO_4 < SrSO_4 < BaSO_4$: Thermal stability order

(B) $BeC_2O_4 < CaC_2O_4 < BaC_2O_4$: Solubility in water

(C) $LiCl > NaCl > KCl$: Melting point order

(D) $BeF_2 > CaF_2 > SrF_2$: Covalent character order

CB0047

27. Which of the following order is/are **CORRECT** :-

(A) $MgCO_3 < BaCO_3$ (Thermal stability)

(B) $LiF < CsF$ (Solubility)

(C) $Li_3N < K_3N$ (Thermal stability)

(D) $MgSO_3 > BaSO_3$ (Solubility) **CB0154**

28. Most ionic compounds have :

(A) high melting points and low boiling points

(B) high melting points and nondirectional bonds

(C) high solubilities in polar solvents and low solubilities in nonpolar solvents

(D) three-dimentional network structures, and are good conductors of electricity in the molten state

CB0049

29. Choose the **CORRECT** order for the given properties.

(A) $NaF < MgF_2 < AlF_3$: covalent character order.

(B) $NaF < MgF_2 < AlF_3$: melting point order

(C) $NaF < MgF_2 < AlF_3$: lattice energy order

(D) $NaF > MgF_2 > AlF_3$: order of polarising power of cation. **CB0050**

MOLECULAR ORBITAL THEORY

30. Which of the following have identical bond order ?

(A) O_2^{2+} (B) NO^+ (C) CN^- (D) CN^+ **CB0051**

31. Which of the following statement is/are **CORRECT ?**

(A) The peroxide ion has a bond order of 1 while the oxygen molecule has a bond order of 2

(B) The peroxide ion has a weaker bond than the dioxygen molecule has.

(C) The peroxide ion as well as the dioxygen molecules are paramagnetic

(D) The bond length of the peroxide ion is greater than that of the dioxygen molecule

CB0052

32. Given the species : N_2, CO, CN^- and NO^+. Which of the following statements are true for these

(A) All species are paramagnetic (B) The species are isoelectronic

(C) All the species have dipole moment (D) All the species are linear **CB0053**

33. Which of the following have unpaired electron(s) ?

(A) O_2^+ (B) O_2^- (C) NO (D) H_2^+ **CB0054**

34. Which of the following are paramagnetic ?

(A) B_2 (B) O_2 (C) N_2 (D) He_2 **CB0055**

35. Which of the following species have a bond order of 3 ?

(A) CO (B) CN^- (C) NO^+ (D) O_2^+ **CB0056**

36. Which of the following is **CORRECT** ?

(A) During N_2^+ formation, one electron is removed from the bonding molecular orbitals

(B) During O_2^+ formation, one electron is removed from the antibonding molecular orbitals

(C) During O_2^- formation, one electron is added to the bonding molecular orbitals

(D) During CN^- formation, one electron is added to the bonding molecular orbitals **CB0057**

WEAK FORCES AND HYDROGEN BONDING

37. Which of the following factors are responsible for origination of vander Waals forces ?

(A) Instantaneous dipole-induced dipole interaction

(B) Dipole-induced dipole interaction

(C) Dipole-dipole interaction

(D) Size of molecule **CB0034**

38. Which of the following are **TRUE** ?

(A) Vander Waals forces are responsible for the formation of molecular crystals

(B) Branching lowers the boiling points of isomeric organic compounds due to decrease in Vander Waals forces of attraction

(C) In graphite, vander Waals forces act between the carbon layers

(D) In diamond, vander Waals forces act between the carbon layers **CB0035**

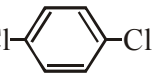
39. Which of the following molecules are expected to exhibit intermolecular H-bonding

(A) Acetic acid (B) o-nitrophenol (C) m-nitrophenol (D) o-boric acid

CBO0241

DIPOLE MOMENT

40. Which has (have) zero value of dipole moment?

(A) XeF_4 (B) $CHCl_3$ (C) CO_2 (D) 

CBO0242

41. Which of the following have dipole moment ?

(A) nitrobenzene (B) p-chloronitrobenzene

(C) m-dichlorobenzene (D) o-dichlorobenzene **CBO0243**

MISCELLANEOUS

42. Borax is actually made of two tetrahedra and two triangular units joined together and should be written as: $Na_2[B_4O_5(OH)_4].8H_2O$

Consider the **CORRECT** statements about borax:

(A) Each boron atom has four B-O bonds

(B) Each boron atom has three B-O bonds

(C) Two boron atoms have four B-O bonds while other two have three B-O bonds

(D) Each boron atom has one –OH groups **CBO0244**

43. Rotation around the bond (between the underlined atoms) is restricted in :

(A) $\underline{C}_2H_4$ (B) $H_2\underline{O}_2$ (C) $\underline{C}_2H_2$ (D) $\underline{C}_2H_6$ **CB0058**

44. Which of the following have a three dimentional network structure ?

(A) SiO_2 (B) $(BN)_x$ (C) P_4(white) (D) CCl_4 **CBO0245**

45. Specify the coordination geometry around and hybridisation of N and B atoms in a 1 : 1 complex of BF_3 and NH_3 –

(A) N : tetrahedral sp^3 ; B : tetrahedral sp^3

(B) N : pyramidal sp^3 ; B : pyramidal sp^3

(C) N : pyramidal sp^3 ; B : planar sp^2

(D) N : pyramidal sp^3 ; B : tetrahedral sp^3 d **CBO0246**

46. Which of the following molecular species has unpaired electron(s) ?

(A) N_2 (B) F_2 (C) O_2^- (D) O_2^{2-} **CBO0247**

47. Among the following, the paramagnetic compound is

(A) Na_2O_2 (B) O_3 (C) N_2O (D) KO_2 **CBO0248**

48. **Statement-1 :** In water, orthoboric acid behaves as a weak monobasic acid.

Statement-2 : In water, orthoboric, acid acts as a proton donor.

(A) Statement-1 is True, Statement-2 is True; Statement-2 is a **CORRECT** explanation for Statement-1.

(B) Statement-1 is True, Statement-2 is True; Statement-2 is NOT a **CORRECT** explanation for Statement-1.

(C) Statement-1 is True, Statement-2 is False.

(D) Statement-1 is False, Statement-2 is True. **CBO0249**

49. **Statement-1 :** Pb^{+4} compounds are stronger oxidizing agents than Sn^{4+} compounds

Statement-2 : The higher oxidation states for the group 14 elements are more stable for the heavier members of the group due to 'inert pair effect' .

(A) Statement-1 is True, Statement-2 is True; Statement-2 is a **CORRECT** explanation for Statement-1.

(B) Statement-1 is True, Statement-2 is True; Statement-2 is NOT a **CORRECT** explanation for Statement-1.

(C) Statement-1 is True, Statement-2 is False.

(D) Statement-1 is False, Statement-2 is True. **CBO0250**

50. The nitrogen oxide(s) that contain(s) N–N bond(s) is (are)

(A) N_2O (B) N_2O_3 (C) N_2O_4 (D) N_2O_5 **CBO0251**

EXERCISE # S-1

1. The number of corner of O-atom shared per tetrahedron in 2D-silicate is .....
CB0155

2. Find the number of angles less than 120° in PH_2F_3. **CB0060**

3. Among N_2O, SO_2, I_3^+ & I_3^-, the number of linear species are : **CBO0252**

4. Find the ratio of π-electrons in the C_2-molecule with that of B_2 molecule according to M.O.T.
CB0062

5. In which of the following silicates structure, the number of corner/oxygen atoms shared per tetrahedron is '2'.

Pyrosilicate , pyroxene chain silicate ,

2D-silicate , 3D-silicate , 4-membered cyclic silicate **CBO0102**

6. The total number of bonding and antibonding electrons in O_2^+ are "....." and "....." respectively.

[If the answer is 14 and 7, then represent as 147] **CB0063**

7. Find the total number of following molecule(s) which have all bond lengths are same.

XeF_4, SF_4, SH_2, NO_3^-, SiF_4, ClF_3, PF_2Cl_3, XeO_3F_2 **CB0064**

8. Among the following total number of planar molecules is / are

Cl_2O , $P(CH_3)_3$, $N(CH_3)_3$, ClO_2 , $^{\bullet}CH_3$, NCl_3 **CB0065**

9. Calculate the value of "n" in $Zn_nCa_2(Si_3O_{10}).2H_2O$ **CBO0101**

10. How many compounds give diprotic acid on hydrolysis ?

SO_2Cl_2, $SOCl_2$, $POCl_3$, XeF_2, N_2O_5, P_4O_6, SF_4, BCl_3 **CB0066**

EXERCISE # S-2

Comprehension # 1 (1 to 3 Questions)

Boron is the first element of III[rd] group. It forms a number of electron deficient halides and hydrides. Among the hydrides diborane is an important compound.

1. Which of the following halide is the strongest Lewis acid?

(A) BF_3 (B) BCl_3 (C) BBr_3 (D) BI_3 **CB0067**

2. Which of the following compounds has $2p\pi$ - $2p\pi$ bond ?

(A) BF_3 (B) BCl_3 (C) BBr_3 (D) BI_3 **CB0067**

3. In B_2H_6 number of 3c – 2e bonds is/are

(A) 1 (B) 2 (C) 3 (D) None **CB0067**

Comprehension # 2 (4 to 6 Questions)

Molecular orbital theory is based on linear combination of atomic orbitals (LCAO). According to LCAO when respective atomic orbitals of the atoms interact, they undergoes constructive and destructive interference giving two types of molecular orbital i.e. bonding and antibonding molecular orbitals respectively.

4. Which of the following species is paramagnetic ?

(A) NO^- (B) O_2^{2-} (C) CN^- (D) CO **CB0068**

5. Bond order of Be_2 is :

(A) 1 (B) 2 (C) 3 (D) 0 **CB0068**

6. Number of anti bonding electrons in N_2 is :

(A) 4 (B) 10 (C) 12 (D) 14 **CB0068**

Comprehension # 3 (7 to 8 Questions)

Polarisation of anion in ionic compounds play an important role to influnce the various physical and chemical properties of ionic compound.

7. Which of the following has highest covalent character.

(A) $CaCl_2$ (B) $ZnCl_2$ (C) KCl (D) $CuCl$ **CB0069**

8. Compound with maximum ionic character is formed from :

(A) Na and Cl (B) Cs and F (C) Cs and I (D) Na and F **CB0069**

MATCHING LIST

9. Match list I with list II and select the **CORRECT** answer:

List I (species)	**List II (O-N-O angle)**
(P) NO_2^+	(1) 180°
(Q) NO_2	(2) 134°
(R) NO_2^-	(3) 120°
(S) NO_3^-	(4) 115°
	(5) 109°

	P	Q	R	S
(A)	5	4	3	2
(C)	1	2	4	3

	P	Q	R	S
(B)	5	2	4	3
(D)	1	4	3	2

CB0071

10. Match list I with list II and select the **CORRECT** answer:

List–I (Molecule / Species)	**List–II (Unpaired electron resides in)**
(P) NO_2	(1) d-orbital
(Q) ClO_2	(2) sp^2-orbital
(R) ClO_3	(3) sp^3-orbital
(S) $^{\bullet}CH_3$	(4) p-orbital

Code :

	P	**Q**	**R**	**S**		**P**	**Q**	**R**	**S**	
(A)	2	4	1	3	(B)	2	1	3	4	
(C)	1	4	2	3	(D)	3	1	2	4	**CB0072**

11. Match list I with list II and select the **CORRECT** answer:

List–I (Process)	**List–II (Operating interaction involved)**
(P) Clathrate compound of Xe in ice	(1) Ion - Dipole
(Q) Liquation of Xe gas	(2) Dipole - Dipole
(R) Liquation of HCl gas	(3) Dipole - Induced dipole
(S) Hydration of Na^+	(4) London forces

Code :

	P	**Q**	**R**	**S**		**P**	**Q**	**R**	**S**	
(A)	1	3	4	2	(B)	3	4	1	2	
(C)	3	4	2	1	(D)	1	3	2	4	**CB0073**

MATRIX MATCH

12. Match the column

Column-I (Process)	**Column-II (Characteristics)**
(A) $N_2^+ \longrightarrow N_2$	(P) Magnetic moment gets changed
(B) $Zn^{2+} \longrightarrow Zn$	(Q) The process is associated with two electronic change
(C) $O_2^{2-} \longrightarrow 2O^{2-}$	(R) Magnetic behaviour gets changed
(D) $C_2^{2-} \longrightarrow C_2$	(S) Electron(s) associated in the process enter(s) into π^*_{2p} orbital
	(T) Electron(s) associated in the process involve(s) σ_{2p} orbital

CB0076

Answer Q.13 to Q.15 by appropriately matching the information given in the three columns of the following table

Molecular Orbital	Number of nodal plane	Symmetry of Molecular Orbital
(1) σ_s	(P) 3	(I) BMO, gerade
(2) π_p	(Q) 2	(II) ABMO, ungerade
(3) $\sigma^*_{p_z}$	(R) 1	(III) BMO, ungerade
(4) δ^*	(S) 0	(IV) ABMO, gerade

13. Which of the following matching is **INCORRECT.**

(A) (1), S, I (B) (2), R, I (C) (3), P, II (D) (4), P, II

CB0077

14. How many orbitals are occupied with set (1)(S)(I) in F_2

(A) 0 (B) 1 (C) 2 (D) 3 **CB0077**

15. If z axis is the molecular axis then **CORRECT** matching for $d_{xy} + d_{xy}$ orbital is 4, P, II for the substraction of wave function.

Which of the following matching is **CORRECT** for the addition of wave function for same combination of orbitals.

(A) P, IV (B) P, III (C) Q, II (D) Q, I **CB0077**

EXERCISE # J-MAIN

1. The hybridisation of orbitals of N atom in NO_3^-, NO_2^+ and NH_4^+ are respectively:- **[AIEEE-2011]**
(1) sp, sp^3, sp^2 (2) sp^2, sp^3, sp (3) sp, sp^2, sp^3 (4) sp^2, sp, sp^3 **CBO0115**

2. Among the following the maximum covalent character is shown by the compound :- **[AIEEE-2011]**
(1) $AlCl_3$ (2) $MgCl_2$ (3) $FeCl_2$ (4) $SnCl_2$ **CB0091**

3. Which of the following has maximum number of lone pairs associated with Xe **[AIEEE-2011]**
(1) XeO_3 (2) XeF_4 (3) XeF_6 (4) XeF_2 **CBO0117**

4. The number of types of bonds between two carbon atoms in calcium carbide is :- **[AIEEE-2011]**
(1) One sigma, two pi (2) One sigma, one pi
(3) Two sigma, one pi (4) Two sigma, two pi **CBO0253**

5. The molecule having smallest bond angle is :- **[AIEEE-2012]**
(1) PCl_3 (2) NCl_3 (3) $AsCl_3$ (4) $SbCl_3$ **CBO0118**

6. In which of the following pairs the two species are not isostructural ? **[AIEEE-2012]**
(1) AlF_6^{3-} and SF_6 (2) CO_3^{2-} and NO_3^- (3) PCl_4^+ and $SiCl_4$ (4) PF_5 and BrF_5 **CBO0119**

7. The number of S–S bonds in SO_3, $S_2O_3^{2-}$, $S_2O_6^{2-}$ and $S_2O_8^{2-}$ respectively are :- **[JEE-MAINS-2012]**
(1) 1, 0, 1, 0 (2) 0, 1, 1, 0 (3) 1, 0, 0, 1 (4) 0, 1, 0, 1 **(On-line)** **CBO0120**

8. Dipole moment is shown by :- **[JEE-MAINS-2012]**
(1) trans-2, 3-dichloro- 2-butene (2) 1, 2-dichlorobenzene **(On-line)**
(3) 1, 4-dichlorobenzene (4) trans-1, 2-dinitroethene **CBO0254**

9. Among the following species which two have trigonal bipyramidal shape ? **[JEE-MAINS-2012]**
(I) NI_3 (II) I_3^- (III) SO_3^{2-} (IV) NO_3^- **(On-line)**
(1) II and III (2) III and IV (3) I and IV (4) I and III **CBO0121**

10. Among the following, the species having the smallest bond is :- **[JEE-MAINS-2012]**
(1) NO (2) NO^+ (3) O_2 (4) NO^- **(On-line)** **CBO0255**

11. Based on lattice energy and other considerations, which one of the following alkali metal chloride is expected to have the highest melting point ? **[JEE-MAINS-2012]**
(1) RbCl (2) LiCl (3) KCl (4) NaCl **(On-line)** **CB0157**

12. The compound of Xenon with zero dipole moment is :- **[JEE-MAINS-2012]**
(1) XeO_3 (2) XeO_2 (3) XeF_4 (4) $XeOF_4$ **(On-line)** **CBO0123**

13. Among the following the molecule with the lowest dipole moment is :- **[JEE-MAINS-2012]**
(1) $CHCl_3$ (2) CH_2Cl_2 (3) CCl_4 (4) CH_3Cl **(On-line)** **CBO0124**

14. The formation of molecular complex $BF_3 - NH_3$ results in a change in hybridisation of boron :-
(1) from sp^3 to sp^3d (2) from sp^2 to dsp^2 **[JEE-MAINS-2012]**
(3) from sp^3 to sp^2 (4) from sp^2 to sp^3 **(On-line)**
CBO0125

15. Which one of the following molecules is expected to exhibit diamagnetic behaviour ?
(1) C_2 (2) N_2 (3) O_2 (4) S_2 **[AIEEE-2013]**
CB0092

16. Which of the following is the wrong statement? **[JEE-M-2013]**
(1) ONCl and ONO^- are not isoelectronic (2) O_3 molecule is bent
(3) Ozone is violet-black in solid state (4) Ozone is diamagnetic gas **CBO0256**

17. In which of the following pairs of molecules/ions, both the species are not likely to exist ?
(1) H_2^+, He_2^{2-} (2) H_2^-, He_2^{2-} (3) H_2^{2+}, He_2 (4) H_2^-, He_2^{2+}
[JEE-M-2013]
CB0093

18. Which of the following exists as covalent crystals in the solid state ? **[JEE-M-2013]**
(1) Iodine (2) Silicon (3) Sulphur (4) Phosphorus **CBO0257**

19. Stability of the species Li_2, Li_2^- and Li_2^+ increases in the order of :- **[JEE-M-2013]**
(1) $Li_2 < Li_2^+ < Li_2^-$ (2) $Li_2^- < Li_2^+ < Li_2$ (3) $Li_2 < Li_2^- < Li_2^+$ (4) $Li_2^- < Li_2 < Li_2^+$
CB0094

20. Trigonal bipyramidal geometry is shown by: **[JEE-MAINS-2013]**
(1) XeO_3F_2 (2) $XeOF_2$ (3) XeO_3 (4) $FXeOSO_2F$ **(On-line)**
CBO0126

21. In which of the following ionization processes the bond energy has increased and also the magnetic behaviour has changed from paramagnetic to diamagnetic ? **[JEE-MAINS-2013]**
(1) $NO \rightarrow NO^+$ (2) $O_2 \rightarrow O_2^+$ (3) $N_2 \rightarrow N_2^+$ (4) $C_2 \rightarrow C_2^+$ **(On-line)**
CB0158

22. Which one of the following molecules is polar? **[JEE-MAINS-2013]**
(1) CF_4 (2) SbF_5 (3) IF_5 (4) XeF_4 **(On-line)**
CBO0127

23. Oxidation state of sulphur in anions SO_3^{2-} $S_2O_4^{2-}$ and $S_2O_6^{2-}$ increases in the orders :
(1) $S_2O_6^{2-} < S_2O_4^{2-} < SO_3^{2-}$ (2) $SO_3^{2-} < S_2O_4^{2-} < S_2O_6^{2-}$ **[JEE-MAINS-2013]**
(3) $S_2O_4^{2-} < SO_3^{2-} < S_2O_6^{2-}$ (4) $S_2O_4^{2-} < S_2O_6^{2-} < SO_3^{2-}$ **(On-line)**
CBO0128

24. Bond order normally gives idea of stability of a molecular species. All the molecules viz. H_2, Li_2 and B_2 have the same bond order yet they are not equally stable. Their stability order is:
(1) $Li_2 > H_2 > B_2$ (2) $H_2 > B_2 > Li_2$ **[JEE-MAINS-2013]**
(3) $B_2 > H_2 > Li_2$ (4) $Li_2 > B_2 > H_2$ **(On-line)**
CB0159

25. The solubility order for alkali metal fluoride in water is : **[JEE-MAINS-2013]**
(1) LiF < NaF < KF < RbF (2) LiF > NaF > KF > RbF **(On-line)**
(3) RbF < KF < NaF < LiF (4) LiF < RbF < KF < NaF **CB0160**

26. XeO_4 molecule is tetrahedral having : **[JEE-MAINS-2013]**

(1) Two pπ-dπ bonds (2) Four pπ-dπ bonds **(On-line)**

(3) One pπ-dπ bond (4) Three pπ-dπ bonds **CBO0129**

27. Bond distance in HF is 9.17×10^{-11} m. Dipole moment of HF is 6.104×10^{-30} Cm. The percent ionic character in HF will be : (electron charge = 1.60×10^{-19} C) **[JEE-MAINS-2013]**

(1) 61.0% (2) 38.0% (3) 35.5% (4) 41.5% **(On-line)**

CBO0130

28. The shape of IF_6^- is : **[JEE-MAINS-2013]**

(1) Trigonally distorted octahedron (2) Pyramidal **(On-line)**

(3) Octahedral (4) Square antiprism **CBO0131**

29. Which has trigonal bipyramidal shape ? **[JEE-MAINS-2013]**

(1) $XeOF_4$ (2) XeO_3 (3) XeO_3F_2 (4) $XeOF_2$ **(On-line)**

CBO0132

30. The catenation tendency of C, Si and Ge is in the order Ge < Si < C. The bond energies (in kJ mol^{-1}) of C — C, Si —Si and Ge—Ge bonds are respectively : **[JEE-MAINS-2013]**

(1) 348, 260, 297 (2) 348, 297, 260 (3) 297, 348, 260 (4) 260, 297, 348

(On-line)

CBO0133

31. In which of the following sets, all the given species are isostructural ?

[JEE-MAINS-2013, (On-line)]

(1) BF_3, NF_3, PF_3, AlF_3 (2) PCl_3, $AlCl_3$, BCl_3, $SbCl_3$

(3) BF_4^-, CCl_4, NH_4^+, PCl_4^+ (4) CO_2, NO_2, ClO_2, SiO_2 **CBO0134**

32. The internuclear distances in O —O bonds for O_2^+, O_2, O_2^- and O_2^{2-} respectively are :

[JEE-MAINS-2013, (On-line)]

(1) 1.49 Å, 1.21 Å, 1.12 Å, 1.30 Å (2) 1.30 Å, 1.49 Å, 1.12 Å, 1.21 Å

(3) 1.12 Å, 1.21 Å, 1.30 Å, 1.49 Å (4) 1.21 Å, 1.12 Å, 1.49 Å, 1.30 Å **CB0161**

33. Which one of the following properties is **not** shown by NO ? **[JEE-M-2014]**

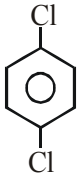
(1) It combines with oxygen to form nitrogen dioxide

(2) It's bond order is 2.5

(3) It is diamagnetic in gaseous state

(4) It is a neutral oxide **CB0095**

34. For which of the following molecule significant $\mu \neq 0$ **[JEE-M-2014]**

(1) 

(2) 

(3) 

(4) 

(1) Only (3) (2) (3) and (4) (3) Only (1) (4) (1) and (2)

CBO0135

35. Among the following oxoacids, the **CORRECT** decreasing order of acid strength is :-

(1) $HClO_4 > HClO_3 > HClO_2 > HOCl$ **[JEE-M-2014]**

(2) $HClO_2 > HClO_4 > HClO_3 > HOCl$

(3) $HOCl > HClO_2 > HClO_3 > HClO_4$

(4) $HClO_4 > HOCl > HClO_2 > HClO_3$ **CBO0136**

36. For the compounds **[JEE-MAINS-2014]**

CH_3Cl, CH_3Br, CH_3I and CH_3F, **(On-line)**

the **CORRECT** order of increasing C-halogen bond length is :

(1) $CH_3F < CH_3Br < CH_3Cl < CH_3I$ (2) $CH_3F < CH_3Cl < CH_3Br < CH_3I$

(3) $CH_3Cl < CH_3Br < CH_3F < CH_3I$ (4) $CH_3F < CH_3I < CH_3Br < CH_3Cl$ **CBO0138**

37. Which of the following has unpaired electron(s) ? **[JEE-MAINS-2014]**

(1) O_2^- (2) N_2^{2+} (3) O_2^{2-} (4) N_2 **(On-line)**

CB0162

38. Shapes of certain interhalogen compounds are stated below. Which one of them is not **CORRECT**ly stated? **[JEE-MAINS-2014]**

(1) IF_7 : Pentagonal bipyramid (2) BrF_5 : Trigonal bipyramid **(On-line)**

(3) ICl_3 : Planar dimeric (4) BrF_3 : Planar T-shaped **CBO0139**

39. The **CORRECT** order of bond dissociation energy among N_2, O_2, $O_2^-$is shown in which of the following arrangements? **[JEE-MAINS-2014 (On-line)]**

(1) $N_2 > O_2 > O_2^-$ (2) $O_2 > O_2^- > N_2$ (3) $N_2 > O_2^- > O_2$ (4) $O_2^- > O_2 > N_2$

CB0163

40. Which of the following molecules has two sigma(σ) and two pi(π) bonds :-**[JEE-MAINS-2014]**

(1) HCN (2) $C_2H_2Cl_2$ (3) N_2F_2 (4) C_2H_4 **(On-line)**

CBO0140

41. Which of the following xenon-OXO compounds may not be obtained by hydrolysis of xenon fluorides? **[JEE-MAINS-2014]**

(1) XeO_2F_2 (2) XeO_3 (3) XeO_4 (4) $XeOF_4$ **(On-line)**

CB0164

42. Which one of the following molecules is paramagnetic? **[JEE-MAINS-2014]**

(1) NO (2) O_3 (3) N_2 (4) CO **(On-line)**

CB0165

43. Amongst LiCl, RbCl, $BeCl_2$ and $MgCl_2$ the compounds with the greatest and the least ionic character, respectively are : **[JEE-MAINS-2014]**

(1) RbCl and $MgCl_2$ (2) LiCl and RbCl **(On-line)**

(3) $MgCl_2$ and $BeCl_2$ (4) RbCl and $BeCl_2$ **CB0166**

44. Which one of the following alkaline earth metal sulphates has its hydration enthalpy greater than its lattice enthalpy ? **[JEE-MAINS-2015]**
(1) $BaSO_4$ (2) $SrSO_4$ (3) $CaSO_4$ (4) $BeSO_4$ **CB0098**

45. The intermolecular interaction that is dependent on the inverse cube of distance between the molecules is :- **[JEE-MAINS-2015]**
(1) London force (2) Hydrogen bond (3) ion-ion interaction (4) ion-dipole interaction **CB0099**

46. Which one has the highest boiling point ? **[JEE-MAINS-2015]**
(1) Kr (2) Xe (3) He (4) Ne **CB0100**

47. Which one of the following statements about water is **FALSE** ? **[JEE-MAINS-2016]**
(1) Ice formed by heavy water sinks in normal water.
(2) Water is oxidized to oxygen during photosynthesis.
(3) Water can act both as an acid and as a base. **CBO0258**
(4) There is extensive intramolecular hydrogen bonding in the condensed phase.

48. The species in which the N atom is in a state of sp hybridization is :- **[JEE-MAINS-2016]**
(1) NO_2 (2) NO_2^+ (3) NO_2^- (4) NO_3^- **CBO0259**

49. The pair in which phosphorous atoms have a formal oxidation state of + 3 is :-
(1) Pyrophosphorous and pyrophosphoric acids **[JEE-MAINS-2016]**
(2) Orthophosphorous and pyrophosphorous acids
(3) Pyrophosphorous and hypophosphoric acids
(4) Orthophosphorous and hypophosphoric acids **CBO0145**

50. Which intermolecular force is most responsible in allowing xenon gas to liquefy?
(1) Ionic (2) Instantaneous dipole- induced dipole
(3) Dipole - dipole (4) Ion - dipole **[JEE-MAINS-2016 (On-line)]** **CBO0144**

51. The non-metal that does not exhibit positive oxidation state is : **[JEE-MAINS-2016 (On-line)]**
(1) Oxygen (2) Fluorine
(3) Iodine (4) Chlorine **CBO0260**

52. The group of molecules having identical shape is : **[JEE-MAINS-2016 (On-line)]**
(1) SF_4, XeF_4, CCl_4 (2) ClF_3, $XeOF_2$, XeF_3^+
(3) PCl_5, IF_5, XeO_2F_2 (4) BF_3, PCl_3, XeO_3 **CBO0146**

53. The bond angle H–X–H is the greatest in the compound : **[JEE-MAINS-2016 (On-line)]**
(1) NH_3 (2) H_2O (3) PH_3 (4) CH_4 **CB0102**

54. Which of the following species is not paramagnetic :- **[JEE-MAINS-2017]**
(1) NO (2) CO (3) O_2 (4) B_2 **CB0103**

55. Which of the following is paramagnetic ? **[JEE-MAINS-2017 (On-line)]**
(1) CO (2) O_2^{2-} (3) NO^+ (4) B_2 **CB0104**

56. The number of S=O and S–OH bonds present in peroxodisulphuric acid and pyrosulphuric acid respectively are : **[JEE-MAINS-2017 (On-line)]**
(1) (2 and 4) and (2 and 4) (2) (4 and 2) and (2 and 4)
(3) (2 and 2) and (2 and 2) (4) (4 and 2) and (4 and 2) **CB0106**

57. The correct sequence of decreasing number of π-bonds in the structures of H_2SO_3, H_2SO_4 and $H_2S_2O_7$ is :- **[JEE-MAINS-2017 (On-line)]**
(1) $H_2S_2O_7 > H_2SO_4 > H_2SO_3$ (2) $H_2SO_3 > H_2SO_4 > H_2S_2O_7$
(3) $H_2S_2O_7 > H_2SO_3 > H_2SO_4$ (4) $H_2SO_4 > H_2S_2O_7 > H_2SO_3$ **CB0107**

58. The increasing order of the boiling points for the following compounds is:- **[JEE-MAINS-2017 (On-line)]**

(I) C_2H_5OH (II) C_2H_5Cl (III) $C_2H_5CH_3$ (IV) $C_2H_5OCH_3$

(1) (III) < (II) < (I) < (IV) (2) (II) < (III) < (IV) < (I)

(3) (IV) < (III) < (I) < (II) (4) (III) < (IV) < (II) < (I) **CB0108**

59. The number of P–OH bonds and the oxidation state of phosphorus atom in pyrophosphoric acid ($H_4P_2O_7$) respectively are :- **[JEE-MAINS-2017 (On-line)]**

(1) five and four (2) five and five (3) four and five (4) four and four **CB0109**

60. The group having triangular planar structures is :- **[JEE-MAINS-2017 (On-line)]**

(1) CO_3^{2-}, NO_3^-, SO_3 (2) NCl_3, BCl_3, SO_3 (3) NH_3, SO_3, CO_3^{2-} (4) BF_3, NF_3, CO_3^{2-} **CB0110**

61. Which of the following are Lewis acids ? **[JEE-MAINS-2018]**

(1) $AlCl_3$ and $SiCl_4$ (2) PH_3 and $SiCl_4$ (3) BCl_3 and $AlCl_3$ (4) PH_3 and BCl_3 **CB0111**

62. According to molecular orbital theory, which of the following will not be a viable molecule ? **[JEE-MAINS-2018]**

(1) He_2^+ (2) H_2^- (3) H_2^{2-} (4) He_2^{2+} **CB0112**

63. Which of the following compounds contain(s) no covalent bond(s) ? **[JEE-MAINS-2018]**

KCl, PH_3, O_2, B_2H_6, H_2SO_4

(1) KCl, H_2SO_4 (2) KCl (3) KCl, B_2H_6 (4) KCl, B_2H_6, PH_3 **CB0113**

64. The number of P–O bonds in P_4O_6 is :- **[JEE-MAINS-2018 (Online)]**

(1) 18 (2) 12 (3) 9 (4) 6 **CBO0154**

65. In XeO_3F_2, the number of bond pair(s), π-bond(s) are lone pair(s) on Xe atom respectively are :- **[JEE-MAINS-2018 (Online)]**

(1) 4, 2, 2 (2) 4, 4, 0 (3) 5, 2, 0 (4) 5, 3, 0 **CBO0155**

66. In KO_2, the nature of oxygen species and the oxidation state of oxygen atom are, respectively **[JEE-MAINS-2018 (Online)]**

(1) Superoxide and –1/2 (2) Oxide and –2

(3) Peroxide and –1/2 (4) Superoxide and –1 **CB0114**

67. Which of the following best describes the diagram below of a moleuclar orbital ? **[JEE-MAINS-2018 (Online)]**

(1) An antibonding π orbital (2) An antibonding σ orbital

(3) A non-bonding orbital (4) A bonding π orbital **CB0115**

68. In the molecular orbital diagram for the molecular ion, N_2^+, the number of electrons in the σ_{2p} molecular orbital is :- **[JEE-MAINS-2018 (Online)]**

(1) 3 (2) 1 (3) 0 (4) 2 **CB0116**

69. The decreasing order of bond angles in BF_3, NH_3, PF_3 and I_3^- is :- **[JEE-MAINS-2018 (Online)]**

(1) $I_3^- > BF_3 > NH_3 > PF_3$ (2) $BF_3 > NH_3 > PF_3 > I_3^-$

(3) $I_3^- > NH_3 > PF_3 > BF_3$ (4) $BF_3 > I_3^- > PF_3 > NH_3$ **CBO0156**

70. $H—\overset{(I)}{N}\text{----}\overset{(II)}{N}\text{----}N$

In hydrogen azide (above) the bond orders of bonds (I) and (II) are :- **[JEE-MAINS-2018 (Online)]**

	(I)	(II)
(1)	>2	<2
(2)	<2	<2
(3)	<2	>2
(4)	>2	>2

CBO0261

71. Xenon hexafluoride on partial hydrolysis produces compounds 'X' and 'Y' Compounds 'X' and 'Y' and the oxidation state of Xe are respectively : **[JEE-MAINS-2018 (Online)]**

(1) XeO_2F_2(+6) and XeO_2(+4) (2) $XeOF_4$(+6) and XeO_2F_2(+6)

(3) $XeOF_4$(+6) and XeO_3(+6) (4) XeO_2(+4) and XeO_3(+6) **CB0117**

72. Which of the following is a lewis acid ? **[JEE-MAINS-2018 (Online)]**

(1) NaH (2) NF_3 (3) PH_3 (4) $B(CH_3)_3$ **CB0118**

73. Among the oxides of nitrogen : N_2O_3, N_2O_4 and N_2O_5; the molecule(s) having nitrogen-nitrogen bond is/are :- **[JEE-MAINS-2018 (Online)]**

(1) N_2O_3 and N_2O_5 (2) N_2O_4 and N_2O_5 (3) N_2O_3 and N_2O_4 (4) Only N_2O_5

CBO0159

74. A group 13 element 'X' reacts with chlorine gas to produce a compound XCl_3. XCl_3 is electron deficient and easily reacts with NH_3 to form $Cl_3X \leftarrow NH_3$ adduct; however, XCl_3 does not dimerize. X is :- **[JEE-MAINS-2018 (Online)]**

(1) Ga (2) Al (3) In (4) B **CB0119**

75. Which of the following conversions involves change in both shape and hybridisation ? **[JEE-MAINS-2018 (Online)]**

(1) $BF_3 \rightarrow BF_4^-$ (2) $H_2O \rightarrow H_3O^+$ (3) $CH_4 \rightarrow C_2H_6$ (4) $NH_3 \rightarrow NH_4^+$

CB0120

76. Two pi and half sigma bonds are present in: **[JEE-MAINS-2019 (Online)]**

(1) N_2^+ (2) N_2 (3) O_2^+ (4) O_2 **CB0167**

EXERCISE # J-ADVANCED

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

Column I	Column II
(A) B_2	(P) Paramagnetic
(B) N_2	(Q) undergoes oxidation
(C) O_2^-	(R) Undergoes reduction
(D) O_2	(S) Bond order ≥ 2
	(T) Mixing of 's' and `p' orbitals

CB0133

2. In the reaction **[JEE 2009]**

$$2X + B_2H_6 \longrightarrow [BH_2(X)_2]^+ [BH_4]^-$$

the amine(s) X is (are)

(A) NH_3 (B) CH_3NH_2 (C) $(CH_3)_2NH$ (D) $(CH_3)_3N$ **CB0134**

3. The species having pyramidal shape is **[JEE 2010]**

(A) SO_3 (B) BrF_3 (C) SiO_3^{2-} (D) OSF_2 **CB0135**

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

(A) 1 and diamagnetic (B) 0 and diamagnetic

(C) 1 and paramagnetic (D) 0 and paramagnetic **CB0136**

5. Which ordering of compounds is according to the decreasing order of the oxidation state of nitrogen-

(A) HNO_3, NO, NH_4Cl, N_2 (B) HNO_3, NO, N_2, NH_4Cl **[JEE 2012]**

(C) HNO_3, NH_4Cl, NO, N_2 (D) NO, HNO_3, NH_4Cl, N_2 **CBO0262**

6. The shape of XeO_2F_2 molecule is : **[JEE 2012]**

(A) Trigonal bipyramidal (B) Square planar

(C) tetrahedral (D) see-saw **CBO0263**

SUBJECTIVE :

7. The number of water molecule(s) directly bonded to the metal centre in $CuSO_4.5H_2O$ is **[JEE 2009]**

CBO0178

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

CBO0179

9. The value of n in the molecular formula $Be_nAl_2Si_6O_{18}$ is **[JEE 2010]**

CB0137

10. The total number of diprotic acids among the following is **[JEE 2010]**

H_3PO_4 H_2SO_4 H_3PO_3 H_2CO_3 $H_2S_2O_7$

H_3BO_3 H_3PO_2 H_2CrO_4 H_2SO_3

CB0138

11. Among the following, the number of elements showing only one non-zero oxidation state is

O, Cl, F, N, P, Sn, Tl, Na, Ti **[JEE 2010]**

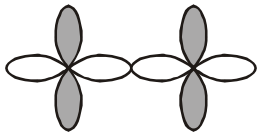
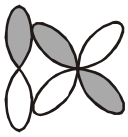
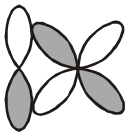
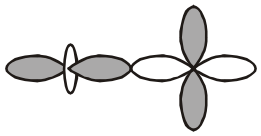
CB0139

12. The difference in the oxidation numbers of the two types of sulphur atoms in $Na_2S_4O_6$ is.
[JEE 2011]
CBO0180

13. The total number of lone-pairs of electrons in melamine is **[JEE Adv. 2013]**
CBO0181

14. Assuming 2s-2p mixing is NOT operative, the paramagnetic species among the following is :
[JEE Adv. 2014]
(A) Be_2 (B) B_2 (C) C_2 (D) N_2 **CB0140**

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

List-I	**List-II**
(P) 	(1) p – d π antibonding
(Q) 	(2) d – d σ bonding
(R) 	(3) p – d π bonding
(S) 	(4) d – d σ antibonding

Code :

	P	**Q**	**R**	**S**		**P**	**Q**	**R**	**S**
(A)	2	1	3	4	(B)	4	3	1	2
(C)	2	3	1	4	(D)	4	1	3	2

CB0141

16. Among the triatomic molecules / ions, $BeCl_2$, N_3^-, N_2O, NO_2^+, O_3, SCl_2 , ICl_2^- , I_3^- and XeF_2 the total number of linear molecules(s) / ion(s) where the hybridization of the central atoms does not have contribution from the d-orbital(s) is : **[JEE Adv. 2015]**

(Atomic number : S = 16, Cl = 17, I = 53 and Xe = 54) **CBO0264**

17. The total number of lone pairs of electrons in N_2O_3 is : **[JEE Adv. 2015]**
CBO0265

18. The **CORRECT** statement(s) regarding, (i) $HClO$, (ii) $HClO_2$, (iii) $HClO_3$ and (iv) $HClO_4$, is(are)

(A) The number of Cl=O bonds in (ii) and (iii) together is two **[JEE Adv. 2015]**

(B) The number of lone pairs of electrons on Cl in (ii) and (iii) together is three

(C) The hybridization of Cl in (iv) is sp^3

(D) Amongst (i) to (iv), the strongest acid is (i) **CBO0266**

19. When O_2 is adsorbed on a metallic surface, electron transfer occurs from the metal to O_2. The **TRUE**, statement (s) regarding this adsorption is (are) **[JEE Adv. 2015]**

(A) O_2 is physisorbed

(B) heat is released

(C) occupancy of π^*_{2p} of O_2 is increased

(D) bond length of O_2 is increased **CB0143**

20. According to Molecular Orbital Theory, **[JEE Adv. 2016]**

(A) C_2^{2-} is expected to be diamagnetic

(B) O_2^{2+} is expected to have a longer bond length than O_2

(C) N_2^+ and N_2^- have the same bond order

(D) He_2^+ has the same energy as two isolated He atoms **CB0144**

21. The colour of the X_2 molecules of group 17 elements changes gradually from yellow to violet down the group. This is due to - **[JEE Adv. 2017]**

(A) the physical state of X_2 at room temperature changes from gas to solid down the group

(B) decrease in HOMO-LUMO gap down the group

(C) decrease in π^*-σ^* down the group

(D) decrease in ionization energy down the group **CB0145**

22. Among H_2, He_2^+, Li_2, Be_2, B_2 ,C_2, N_2, O_2^-, and F_2 , the number of diamagnetic species is -
(Atomic number) : H = 1, He = 2, Li = 3, Be = 4, B = 5, C = 6, N = 7, O = 8 , f = 9)
[JEE Adv. 2017]
CB0146

23. The sum of the number of lone pairs of electrons on each central atom in the following species is. **[JEE Adv. 2017]**

$[TeBr_6]^{2-}$, $[BrF_2]^+$, SNF_3 and $[XeF_3]^-$

[Atomic number : N = 7, F = 9, S = 16, Br = 35, Te = 52, Xe = 54] **CB0147**

24. The option(s) with only amphoteric oxides is (are): **[JEE Adv. 2017]**

(A) Cr_2O_3, CrO, SnO, PbO (B) NO, B_2O_3, PbO, SnO_2

(C) Cr_2O_3, BeO, SnO, SnO_2 (D) ZnO, Al_2O_3, PbO, PbO_2 **CB0148**

25. Among the following, the correct statement(s) is are **[JEE Adv. 2017]**

(A) $Al(CH_3)_3$ has the three-centre two-electron bonds in its dimeric structure

(B) $AlCl_3$ has the three-centre two-electron bonds in its dimeric structure

(C) BH_3 has the three-centre two-electron bonds in its dimeric structure

(D) The Lewis acidity of BCl_3 is greater than that of $AlCl_3$ **CB0149**

26. The order of the oxidation state of the phosphorus atom in H_3PO_2 , H_3PO_4 , H_3PO_3 and $H_4P_2O_6$ is **[JEE Adv. 2017]**

(A) $H_3PO_4 > H_4P_2O_6 > H_3PO_3 > H_3PO_2$ (B) $H_3PO_3 > H_3PO_2 > H_3PO_4 > H_4P_2O_6$

(C) $H_3PO_2 > H_3PO_3 > H_4P_2O_6 > H_3PO_4$ (D) $H_3PO_4 > H_3PO_2 > H_3PO_3 > H_4P_2O_6$

CBO0195

27. Based on the compounds of group 15 elements , the correct statement(s) is (are) **[JEE Adv. 2018]**

(A) Bi_2O_5 is more basic than N_2O_5

(B) NF_3 is more covalent than BiF_3

(C) PH_3 boils at lower temperature than NH_3

(D) The N–N single bond is stronger than the P–P single bond **CB0150**

28. The total number of compounds having at least one bridging oxo group among the molecules given below is_____. **[JEE Adv. 2018]**

N_2O_3 , N_2O_5 , P_4O_6 , P_4O_7 , $H_4P_2O_5$, $H_5P_3O_{10}$, $H_2S_2O_3$, $H_2S_2O_5$ **CBO0197**

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

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

(2) SO_2, C_6H_5Cl, H_2Se, BrF_5

(3) BF_3, O_3, SF_6, XeF_6

(4) NO_2, NH_3, $POCl_3$, CH_3Cl **CB0151**

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

CB0152

ANSWER KEY

EXERCISE # O-1

Que.	1	2	3	4	5	6	7	8	9	10
Ans.	D	D	D	C	D	B	B	D	B	A
Que.	11	12	13	14	15	16	17	18	19	20
Ans.	A	A	C	A	B	B	B	C	C	D
Que.	21	22	23	24	25	26	27	28	29	30
Ans.	C	C	B	C	B	B	B	A	D	D
Que.	31	32	33	34	35	36	37	38	39	40
Ans.	A	B	C	C	D	D	D	C	A	D
Que.	41	42	43	44	45	46	47	48	49	50
Ans.	A	B	D	B	A	A	B	D	C	D
Que.	51	52	53	54	55	56	57	58	59	60
Ans.	C	C	B	A	D	A	A	B	A	D
Que.	61	62	63	64	65	66	67	68	69	70
Ans.	B	A	C	B	D	C	A	B	A	A
Que.	71	72	73	74	75	76	77	78		
Ans.	A	B	D	B	A	A	A	C		

EXERCISE # O-2

Que.	1	2	3	4	5	6	7	8	9	10
Ans.	A,B,C,D	B,C	A,B,C	B,C,D	B,C,D	A, B	A, B, C	B, C	B, C	C, D
Que.	11	12	13	14	15	16	17	18	19	20
Ans.	D	A, B, D	A, B	A, C	A, B, C	B, C	A, C	A,B,C	B,C,D	B, C, D
Que.	21	22	23	24	25	26	27	28	29	30
Ans.	C, D	A, B, C	A, C, D	A, C	A, C	A, D	A, B, D	B, C, D	A, B, C	A, B, C
Que.	31	32	33	34	35	36	37	38	39	40
Ans.	A, B, D	B, D	A,B,C,D	A, B	A, B, C	A, B, D	A, B, C	A, B, C	A, C, D	A, C, D
Que.	41	42	43	44	45	46	47	48	49	50
Ans.	A,B,C,D	C, D	A, B, C	A, B	A	C	D	C	C	A,B,C

EXERCISE # S-1

Que.	1	2	3	4	5	6	7	8	9	10
Ans.	3	8	2	2	2	105	4	3	2	4

EXERCISE # S-2

Que.	1	2	3	4	5	6	7	8	9	10
Ans.	D	A	B	A	D	A	B	B	C	B
Que.	11	12				13	14	15		
Ans.	C	(A) – P,R,T (B) – Q (C) – Q (D) – Q,T				B	C	D		

EXERCISE # J-MAINS

Que.	1	2	3	4	5	6	7	8	9	10
Ans.	4	1	4	1	4	4	2	2	BONUS	2
Que.	11	12	13	14	15	16	17	18	19	20
Ans.	4	3	3	4	2	1	3	2	2	1
Que.	21	22	23	24	25	26	27	28	29	30
Ans.	1	3	3	2	1	2	4	1	3	2
Que.	31	32	33	34	35	36	37	38	39	40
Ans.	3	3	3	2	1	2	1	2	1	1
Que.	41	42	43	44	45	46	47	48	49	50
Ans.	3	1	4	4	2	2	4	2	2	2
Que.	51	52	53	54	55	56	57	58	59	60
Ans.	2	2	4	2	4	4	1	4	3	1
Que.	61	62	63	64	65	66	67	68	69	70
Ans.	3	3	2	2	4	1	1	2	1	3
Que.	71	72	73	74	75	76				
Ans.	2	4	3	4	1	1				

EXERCISE # J-ADVANCED

1. $A \rightarrow P,Q,R,T$; $(B) \rightarrow Q,R,S,T$; $(C) \rightarrow P,Q,R$; $(D) \rightarrow P,Q,R,S$

2. B,C **3.** D **4.** A **5.** B

6. D **7.** 4 **8.** 0 **9.** 3

10. 6

Sol. H_2SO_4 H_3PO_3 H_2CO_3 $H_2S_2O_7$ H_2CrO_4 H_2SO_3

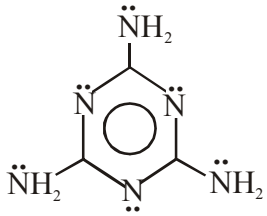
11. 2

Sol. F, Na

12. 5

13. 6

Sol.



14. C

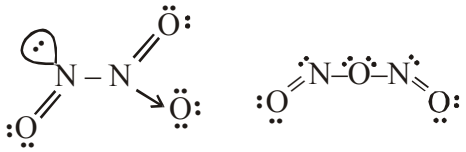
15. C

16. D

$BeCl_2$, N_3^-, N_2O, NO_2^+

17. 8

Sol.



18. B,C **19.** B,C,D **20.** A,C **21.** B,C

22. 5 or 6 **23.** 6 **24.** C,D **25.** A,C,D

26. A **27.** A,B,C **28.** 5 or 6 **29.** 2,4

30. 4.00