Unit-3 – Chemical Bonding and Atomic Structure

Chemical bond – attractive forces that hold or bind atoms or ions together in the molecule or compound.

- There are three main type of chemical bond (Ionic, Covalent and Metallic).

2009. The force that hold different atoms or ions together are called

A. Electrical force C. Chemical bond
B. Physical force D. atomic force

2008. (Bon→Q_9). Which of the following is NOT a form of main chemical bonding?

A. Covalent Bonding C. Ionic Bonding
B. Metallic Bonding D. Hydrogen Bonding

3.1. Ionic Bonding (IB) is also called **electrovalent bond**

- Formed between :-
  - i. Metal and non metal
    - ✓ low ionization energy and high electron affinity)
  - ii. Metal (NH_4^+) and non metal (radical)
  - ➢ **Radical (compound ion)** →OH^-, NO_3^-, CO_3^{-2}, NO_2^-, SO_4^{-2}, SO_3^{-2}, PO_4^{-3}, ClO_4^-

❖ Compound of one metal and one non metal contain only ionic bond

Example: - NaCl, $MgBr_2$, $CaCl_2$, KBr, KI,

❖ Compound of one metal and two non metals (radical) contain both ionic bond and covalent bond.

Example: - Na_2CO_3, $MgSO_4$, $CaCO_3$, KNO_3, K_3PO_4,

❖ Compound NH_4^+ and non metal contain ionic, covalent and dative bond

Example: - NH_4Cl, NH_4Br, NH_4I, $(NH_4)_2CO_3$, $(NH_4)_2SO_4$

2010. Which of the following **DOES NOT** contain an ionic bond?

A. HCl B. LiH C. NaOH D. K_2S

2002. Which of the following compounds **UNLIKELY to** contain ionic bond?

A. CO B. LiCl C. NaF D. $MgBr_2$

2002. Four elements A, B, C, and D have atomic number z-1, z, z+1 and z+2 respectively. If z is 9, then the bond between which pair of elements will be ionic?

A. B &D B. A & C C. C & D D. B & C

A. z-1 = 9-1 = 8 (Oxygen → non metal)
B. z = (Fluorine → non metal)
C. z +1 = 9+1 = 10 (Neon →non metal)
D. z+2 = 9+2 = 11 (Sodium → metal)

→ Ionic bond is formed by A & D and B& D

2006. (Ionic Q_{30}). Which compound contains both ionic and covalent bond?

A. Sodium carbonate (Na_2CO_3) C. Ethanoic acid (CH_3COOH)
B. Magnesim bromide ($MgBr_2$) D. Dichloro ethane (CH_2Cl_2)

1999. Which of the following compound contains both ionic and covalent bond?

A. $CaCO_3$ B. PCl_3 C. MgF_2 D. CH_2O

Empirical Formula (EF) –is the simplest chemical or molecular formula.

- ❖ **Step or rule to write empirical formula**

i. Write metal and non metal with their charge respectively

Charge of metal = group of metal = Zeff = valence electron of metal
Charge of non metal = Group of non metal – 8

ii. Use criss – cross method to write empirical formula.

iii. Write radical in brackets.

2009. What is the chemical formula of the compound formed by Al (III) & sulfate (SO_4^{-2})?

A. $AlSO_4$ B. Al_2SO_4 C. $Al_2(SO_4)_3$ D. Al (SO_4

Al^{+3} SO_4^{-2} → $Al_2(SO_4)_3$

2006. (Simp. Q_7**).** The simplest formula for a compound containing Mn^{+4} & O^{2-} is

A. MnO B. Mn_2O_4 C. MnO_2 D. Mn_4O_2

Mn^{+4} O^{-2} → Mn_2O_4 → MnO_2

2007. (Comb). Q_{72}**).** A compound is formed by the combination of V^{+1} & X^{-3} is

A. VX B. V_2X C. V_3X D. V_3X_2

2005. Which of the following ionic compounds is formed from the reaction between magnesium and nitrogen?

A. MgN_2 B. Mg_2N_2 C. Mg_3N_2 D. Mg_2N_3

Lattice energy (U) is :-

- Coulombic attractive force between ions
- Energy required break one molecule of ionic solid into isolated gaseous ions.
- Indicate strength of ionic bond (U increases→ strength of ionic bond increases)
- Plays crucial role in the ionic bond formation
- Determines many properties of ionic compounds.
  - As **lattice energy increases** →
    - ➢ Strength (hardness) of ionic bond increases
    - ➢ Melting point of ionic compound increases
    - ➢ Boiling point of ionic compound increases
    - ➢ Ionic charge increases
    - ➢ Rate of reaction increases
    - ➢ **Ionic size or radius decreases**
    - ➢ Solubility of ionic compounds in water decreases

Identify :- Lattice energy of compounds of the same group by ionic size Lattice energy of compounds of different group by ionic charge.

Activity 3.6

Q_1. In general, how does the lattice energy of an ionic compound depend on the charges and size of ions?

The lattice is directly proportional to charges of ions and inversely proportional to radius of ions.

Q₂.For each pair, choose the compound with the higher lattice energy and explain.

A. LiClor CsCl→ LiCl because Li is by much smaller than Cs in size.
B. NaF or MgO→ MgO the charges on Mg and O are twice that of Na and F.
C. BaS or CSCl→ BaS the charges on Ba and S are twice that of CS and I
D. Arrange the following ionic compounds in increasing order of lattice energy, melting point, boiling point and solubility.
   a. NaCl, LiCl, KCl, RbCl
      Ans→**RbCl < KCl <NaCl < LiCl** (increasing orderof melting point, boiling point and lattice energy) and **LiCl, NaCl, KCl and RbCl** incrasing order of solubility in water.

2007. Which of the ionic compounds has the greatest lattice energy?

A. LiF B. LiCl C. LiBr D.LiI

As size of metal and nonmetal increases → lattice energy, melting and boiling point decreases

1999. Which of the ionic compounds has the smallest lattice energy?

A. LiF B. NaF C. CsI D.LiI

2002. Which of the compounds would be expected to have the highest melting point?

A. BaF_2 B. $BaCl_2$ C. $BaBr_2$ D.$BarI_2$

3.2. Covalent (electron pair sharing) bond

❖ Is formed by sharing pairs of electrons between non-metals (metalloid and non metals). **Example:** - H_2O, HCl, CH_4, PCl_3, NH_3, SiO_2

Bonding pairs (BP)	Lone pairs(LP)
▪ Pair of electrons remain or exist between two atoms ▪ Bonding electrons ▪ electrons involve in bond formation ▪ Shared pair of electrons between two atoms ▪ Written (-) or : between atoms	▪ Pair of electrons remain on one atom/element/ ▪ Non- bonding electrons ▪ Un- shared pair of electrons ▪ Electrons that do not involve in bond formation ▪ Written: on one element.

Types of Covalent bonding

1) **Singe Bond(SB)**
   ❖ Covalent bond formed by sharing one pair (two) electrons
   ❖ One pair bond
   Example: - F_2, Cl_2, Br_2, I_2, H_2, H_2O, HCl, CH_4, NH_3, Alkane
2) **Double Bond (DB)**
   ❖ Covalent bond formed by sharing two pair (four) electrons
   ❖ Two pair bond
   Example: Alkenes, CO_2, C_2H_4, O_2, SO_2, SO_3, O_3
3) **Triple Bond(TB)**
   ❖ Is covalent bond formed by sharing three pair (six) electrons
   ❖ Three pair bond Example: Alkynes, CO, C_2H_2, N_2, HCN

2009. How many electrons are shared between two atoms in a double bond?

A. 2 B. 3 C. 4 D.6

- ✓ **Single bond** contains **two** shared electrons
- ✓ **Double bond** contains **four** shared electrons
- ✓ **Triple bond** contains **six** shared electrons

Rules to write the Lewis structure/ for a covalent compound/molecule/

1. Determine the total number of valence electrons and number of pairs (BP and LP).
   - ✓ The total number of electrons for a molecule is the sum of the valence electrons for each atom.
   - ✓ For a polyatomic anion, which has one or more extra electrons, add one electron for each unit of negative charge.
   - ✓ For a polyatomic cation, which is missing one or more electrons, subtract one electron for each unit of positive charge.

     Number of pair = Bond pair/2 + lone pair/2 = Total valence electrons/2

2. Predict /decide/ central atom or element
   - ➢ **Central atom** is most electropositive atom or fewer atom
   - ➢ **Terminal or surrounding atoms** – most electron negative atoms (F)
   - ➢ Hydrogen and F are always a terminal atom
   - ➢ O and halogen usually surrounding atoms
3. Place electron pairs between central and terminal atoms
4. Assign any remaining/extra/ electrons as lone-pairs around the central atom
5. If octet rule of central atom is not complete.
   - ✓ Make multiple bond (DB and TB) between central atom and surrounding atoms by removing lone pair from surrounding atoms
   - ✓ Terminal oxygen is **not** shares its electron to form single bond with central atom
   - ✓ Terminal oxygen is shares its electron to form multiple bond with central atom

2004. What is the total number of valence electrons in $\mathbf{BrO_3}^{-?}$

A. 20 **B. 26** C. 32 D.36

- Total number of valence electrons in BrO_3^- = (1x7) + (3x6) + 1 = 26

Exercise 3.4

Determine the total number of valence electrons for the following species:

a CO_2 c NH_4^+

b SO_4^{2-} d N_2O_4

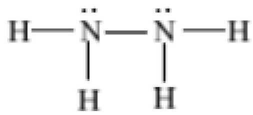
Answers

a. CO_2 has $(1 \times 4) + (2 \times 6) = 16$ b. SO_4^{2-} has $(1 \times 6) + (4 \times 6) + 2 = 32$

c. NH_4^+ has $(1 \times 5) + (4 \times 1) - 1 = 8$ d. N_2O_4 has $(2 \times 5) + (4 \times 6) = 34$

2010. When a student draws a plausible Lewis Structure for **hydrazine (N_2H_4)** molecules, how many lone pair of electrons are available? **Review Q_{31}**

A. 1   **B. 2**   C. 3   D.0



2009. Which of the following Lewis structure for oxygen atom?

A. Three lone pairs of valence electrons
B. One lone pair of valence electrons and one bonding sites
C. Two lone pairs of valence electrons and one bonding site
D. Two lone pairs of valence electrons and two bonding site

- ✓ O atom has two lone pairs and two bonding sites

Number of bonding sites = number of single electrons

2008. Which of the following statements is **NOT** true about covalent bonding?

A. Covalent bonds are least likely to be formed between atoms of the same element.
Example: H_2, Cl_2, F_2, Br_2, I_2, O_2, N_2

B. Covalent bonds are least likely to be formed between atoms of different elements on the right side of the periodic table.
Example: CO_2, SO_2, F_2O

C. Covalent bonds are least likely to be formed between an element in Group I and an element in Group VII.
Form ionic bond

D. Covalent bonds are least likely to be formed by head o the group elements with high ionization energies.
Covalent bond is formed by nitrogen, oxygen, halogen …

2008. How many bonding pairs and lone pairs, respectively does the ion ICl_4^- have?

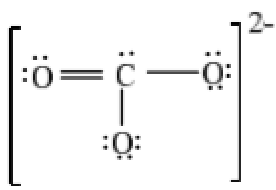
A. 3, 2   B. 4, 2   C. 5, 1   D. 4, 1

2007. How many unpaired electrons are there in the Lewis structure of N^{-3}?

- ✓ All electrons are paired

2005. The total number of electrons participating in the bond formation of carbonate anion CO_3^{2-} in the molecule of carbonic acid is:

A. 16   B. 10   C. 8   D. 5



- Total valence electrons= 1x4 + 3x6 + 2 = 24 electrons

- Total pair of electrons = 24/2 = 12
- Central atom is C
- Bond pairs = 4, shared electrons = 8, lone pairs = 8 and unshared electrons = 16

2004. Which term describes the unit make up to compounds with covalent bond?
A. Ions B. Acids C. Salts D. Molecule

2003. Which set contains set contains only covalently bonded molecules?
A BCl_3, $SiCl_4$, PCl_3 C. I_2, H_2S, NaI
B. NH_4Br, N_2H_4, HBr D. Al, O_3, AS_4

Home work. 2001. Which of the following Lewis structure is correct for tri iodide (I_3^-)?

2001. A covalent bond is **unlikely e**xist in which of the following substance?
A. H_2 B. SeH_2 C. SiF_4 D. CaO

2000. What does the correct Lewis structure for the molecule CCl_4 molecule?
A. 5- bonds C. 24 – unshared electrons
B. no unshared electrons D. 10 –electrons

- ✓ Lewis structure of CCl_4 has 4BP (8 shared electrons) and 12 LP (24unshared electrons)

1995. How many pairs of unshared (non-bonding) valence electrons are on the central atom of SF_4 molecule?
A. 0 B. 2 C. 1 D. 3

Coordinate Covalent Bond

- Also called dative or donor- acceptor bond
- Formed by sharing of electrons pair donated by one atom
- Formed between Lewis acid(acceptor) and Lewis base (donar)
- Formed by Oxygen and Ammonia
- One atom can "donate" two of its electrons to provide the shared pair between itself and an "acceptor" atom.
- Donor Atom – provide both electrons
  - ✓ Must contain at least one lone pair on the central atom (example: NH_3)
- Acceptor atom- must contain vacant orbital to accommodate donated electron pairs

  Example: Oxygen atom

  Example: O_3, H_3O^+, NH_4^+, HNO_3, NH_3BF_3, $POCl_3$, SO_2, SO_3, NO_2^-, NO_3^-, CO_3^{-2} and CO contains Coordinate Covalent Bond.

2012. Given the reaction: $NH_3 + H^+ \longrightarrow NH_4^+$. The bond formed between **NH_3 and H^+** is
A. Ionic bond B. Covalent Bond C. Hydrogen bonding D. Coordinate covalent bond

2000. Which of the following molecules does **not** have coordinate covalent bond?
A. H_3O^+ B. NH_4^+ C. NH_3BF_3 D. CO_2

1999. What type of bond formed when a **Lewis acid reacts with Lewis base**?
A. Ionic bond B. Covalent Bond C. Hydrogen bonding D. Coordinate covalent bond

Resonance Structure is:

- ❖ Also called contributing structures
- ❖ Different Lewis structures used to represent the single molecule, compound or ion
- ❖ Cannot be described by single Lewis structure.
- ❖ Differ only in the distribution/position/ or arrangement of electrons
- ❖ Exist in the compound that contain multiple bond
- ❖ Does not exist in the molecule /compound/ that contains only single bond.
- ❖ Linked each other by double-headed arrows ($\longleftrightarrow$)
- ❖ Resonance is the appearance of delocalized electrons within certain molecules or polyatomic ions
- ❖ Delocalized' refers to an electron which is not 'attached' to a particular atom.

2010 .Number of resonance structure for $\mathbf{CO_3^{-2}}$ is:

A. 9 B. 6 C. 3 D.2

Number of resonance structure = Number of identical surrounding atoms = 3

2006. (DeliQ68). Which of the following molecules or ions will exhibit delocalized bonding?

NO_2^-, NH_4^+, N_3^-

A. NO_2^- and N_3^- B. NH_4^+ and N_3^- C. NO_2^- D. NO_2^- and NH_4^+

- ✓ NO_2^- and N_3^- are contain multiple bond (exhibit delocalized bond)
- ✓ NH_4^+ is contains single bond (does not exhibit delocalized bond)

11. Which of the following species cannot be adequately described by a single Lewis structure?

a OH^- c NH_4^+

b C_2H_2 d HCO_3^-

Answer: D

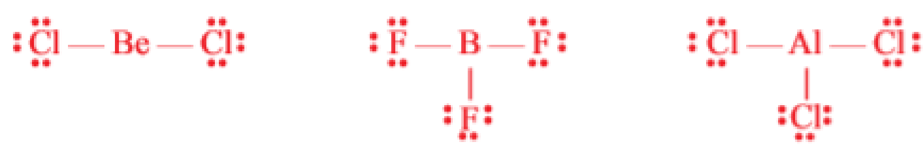
Exceptions to the Octet rule in Covalent Bonding

- Molecules or compounds that do not obey octet(violate) octet rule
- There are three groups of molecules that are exceptions to the octet rule

A. Less than octet (central atom is deficient of electrons):

- Molecules whose central atoms have fewer than eight electrons (Below octet).
- Incomplete octet rule.
- Molecules containing central atoms of Group IIA and IIIA.
- Compounds of Be, B, Al

Example: $BeCl_2$, BF_3 and $AlCl_3$

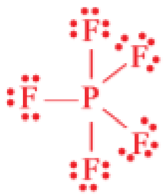


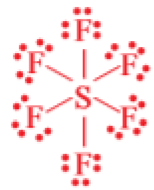
4 electrons around Be 6 electrons around B 6 electrons aroud Al

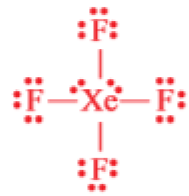
B. More than octet (central atom has excess of electrons):

- Molecules whose central atoms have more than eight electrons (Expanded octet).
- Molecules containing central atoms from periods 3, 4, 5, and 6.

Example: PF_5, SF_6, XeF_4, SF_4, BrF_5, I_3^-, XeF_2, PF_6^- are obey expanded octet rule


10 electrons around P


12 electrons around S


12 electrons aroud Xe

C. Molecules containing an odd number of electrons:

- Molecule or compound that contains odd or unpaired electrons.

Examples are ClO_2, NO and NO_2 having19, 11 and 17 valence electrons respectively.


ClO_2

2007. Which of the following does **NOT** obey octet rule?

A. CS_2 B. PBr_3 C. IBr D. BrF_5

2004. Which of the following molecules has Lewis structure that does not obey the octet rule?

A. NO B. CS_2 C. PF_3 D. HCN

Dipole Moment (μ) is defined as the product of the magnitude of the charge (δ) at either end of the dipole multiplied by the distance (d) that separates the charge. $\mu = \delta \times d$

- ❖ Measure of polarity of a polar covalent bond.
- ❖ For a diatomic molecule
  - ✓ The bond moment is the dipole moment.
  - ✓ Dipole moment is a vector sum of the bond moments in a molecule.

Example HCl

Polarity of bond & molecule

I. Polarity of Bond

Covalent bond	
Non-Polar bond	**Polar Bond**
✓ Covalent bond formed between like/identical / atoms or elements **Example**: Homo/pure/ molecule (O_2,N_2,H_2,F_2,Cl_2, Br_2,I_2, O_3, P_4, S_8)	✓ Covalent bond formed between different atoms or elements **Example:** hetero molecule (CO_2,CS_2,$CCl_{\$}$, H_2O, NH_3, AB, XY)

2005. Which of the following molecules represents a non polar covalent bond?

A. B-Cl B. C-Cl C. Cl-Cl D. Mg-Br

2003. Which bond between the following molecules is most polar?

A. .S-F B. S-Cl C. S-Cl D. S-I

1995. Which set is arranged in order of increasing polarity?

HI<HBr <HCl <HF

✓ **As electro negativity difference increase = bond polarity increase**

II. Polarity of molecule or compound

❖ Polar bonds do not necessarily lead to polar molecules

Molecule or compound	
Non-Polar molecule or compound	**Polar molecule or compound**
i. Opposite bond are identical bond ii. Central atom surrounded by identical atom without lone on it iii. Form trans geometry iv. $\mu = 0$	i. Opposite bond are different bond ii. Central atom surrounded by different atom and central atom contain lone pair iii. Form Cis-geometry iv. $\mu > 0$

✓ **Polarity of molecule or compound depends on the:**

i. Polarity of bond

ii. Geometry or shape of molecule (Tans and cis geometry)

iii. Electro negativity difference

2007/2005 Which of the following molecules has a **dipole** moment?

A. XeF_4 B. H_2S C. SO_3 D. CH_4

✓ A. Opposite bonds are identical and cancel each other (non-polar molecule)

✓ B. has lone pair on the central atom(polar molecule)

✓ C and D haven't lone pair on the central atom (non polar molecule)

1996/1998. Which of the following molecule is no-polar?

A. SO_2 B. CS_2 C. $CHCl_3$ D. SF_4

✓ A and D have lone pair on the central atom(polar molecule)

✓ C. opposite bonds are different (polar molecule)

✓ B hasn't lone pair on the central atom (non polar molecule)

Properties of Covalent Compounds or molecules

❖ They are found in gaseous state at room temperature.

❖ They are liquids or gases at room temperature.

Liquid — H_2O, Br_2, Gas — CO_2, H_2, Cl_2, NH_3.

❖ Some covalent molecules like iodine are solids at room temperature.

❖ Covalent have low melting and boiling points.

❖ They are volatile.

❖ Generally they have low melting points and boiling points. •

❖ They are insoluble in water.

❖ Most covalent compounds are soluble in non- polar solvents.

❖ Non-polar covalent compounds are non-electrolytes because **they do not conduct electricity.**

2012. Which of the following properties is true about covalent molecules?

A. High melting but low boiling point C. Low melting but high boiling point

B. High melting and low boiling point D. High electrical and thermal conductivity

Valence Shell Electron Pair Repulsion (VSEPR) Theory or model

- Model or procedure used to predict the shape/geometry/ of molecule or ions
- Used to convert two-dimensional Lewis structure (2D) into three-dimensional (3D) geometry.

A. Set of electrons or electron sets

- Defined as any number of electron pairs around a central atom.
- Consists of bond pair [single bond (–), double bond (=), triple bond (≡)], lone-pair(s) or a lone (single) electron.
- Ranges from 2 to 6.
- One set of electrons = one (single bond, double bond, triple bond, lone pair or single electron = one area of electron density.

B. **Electron pair arrangement or geometry is:**

- Defined by the sets of electrons (both bonding and nonbonding) around the central atom.
- Arrangement of electron pairs around central atom
- Determined from electron sets or pairs (bond pair and lone pair)= steric number

Pair or set of electrons	Electron pair arrangement
2 ⟶ (20)	Linear
3 ⟶ (21,30)	Trigonal Planar(TP)
4 ⟶ (22, 31,40)	Tetrahedral or tetrahedron (Td)
5 ⟶ (31,41,50)	Trigonal bi-pyramid (TBP)
6 ⟶ (42,51, 60)	Octahedral or octahedron (Oh)

C. **Molecular shape or geometry is:**

- Defined by the relative positions of the atomic nuclei.
- Arrangement of atoms in a molecule or compounds around central atom
- Determined from :
  - ✓ AX_mE_n (electron pairs), where A is the central atom, X is the terminal atom, E is lone-pair (nonbonding) electron sets, m is bond pair and n is non bonding pair
  - ✓ Number of bonding and non bonding pairs
- If there is no lone pair on the central atom electron pair arrangement and molecular shape are the same.

What is a steric number and what is the use of it?

- Streric number is:
  - Sum of bonded and unbounded electron pairs in the molecule(BP + LP)
  - Can be used to predict shape of molecule
  - Range from 2-6

1. Linear (20/23)
2. Bent or V-shape (21/22)
3. Trigonal planar (30)

4. Trigonal pyramid (31)
5. T-shape (32)
6. Tetrahedral (40)
7. Seesaw or distorted tetrahedral (41)
8. Square planar (42)
9. Trigonal bi-pyramid (50)
10. Square pyramid(51) and
11. Octahedral (60).

✓ The 1st number is bond pair and the 2nd number is lone pair

Decreasing/minimizing/diminishing order of Repulsion/distortion/ of valence shell electron pairs:

Lone pair vs lone pair > lone pair vs bonding pair > bonding pair vs bonding pair.

Triple bond > double bond > single bond.

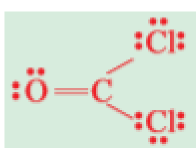
❖ Electron negativity difference increase = Repulsion increase or distortion increase = Bond angle decrease

D. Bond Angle is:

- Formed by two surrounding atoms at vertex of central atom

Molecular shape	Bond Angle
Linear	180^0
Trigonal planar	120^0
Tetrahedral	109.5^0
Trigonal pyramidal	107.5^0
Vent or angular or V-shaped	104.5^0
Trigonal bi-pyramid	$90^0, 180^0$
Oh, T-shape and square pyramidal	90^0

2012. For the molecule phosgene shown below, why do the lone pairs and double bonds effects the bond angles?



E. Lone pairs repel more due a greater charge density than bonding pairs.
F. Lone pairs repel smaller than bonded pairs and multiple bonds have a higher charge density around the central atom.
G. Both multiple bond and lone pairs occupy less space.
H. Lone pairs occupy less space, but multiple bonds occupy more space than single bonds

2012. Based on the VSEPR model, what shape would you expect for the molecule **$[I_3^-]$?**

2012. Which of the following is **NOT** the correct geometric configuration for the given molecule?

A. CH_4, tetrahedral
B. NF_3, trigonal planar
C. SF_6, Octahedral
D. BF_3, trigonal Planar

2010. From **CO_2, H_2O, $BeCl_2$ and N_2O** which have the same molecular geometry?
A. CO_2, H_2O and N_2O
B. CO_2 and $BeCl_2$
C. CO_2, $BeCl_2$ and N_2O
D. H_2O and N_2O

2009. Which of the following molecule is in correctly matched with the **electronic geometry** of central atom?
A. CF_4- Tetrahedral
B. H_2O- Tetrahedral
C. PCl_3 - Pyramidal
D. $BeBr_2$ – lenear

- CF_4, H_2O and PCl_3 are surrounded by four set of electrons (40, 22 and 31) ⟶ have tetrahedral electronic geometry
- **$BeBr_2$** is surrounded by **two sets of electrons** (20) ⟶ has **linear electronic geometry**

2008. Which of the following molecule is **NOT** probable shape of molecule?
A. $GeCl_4$- Tetrahedral
B. HCN- Bent
C. PCl_5 – Trigonal Bi-Pyramidal
D. BrF_3 – T-shape

- $GeCl_4$ is surrounded by four set of electrons (40) ⟶ have tetrahedral electronic geometry and molecular geometry.
- HCN is surrounded by two set of electrons (20) ⟶ have linear electronic geometry and molecular geometry.
- PCl_5 is surrounded by five set of electrons (50) ⟶ have trigonal Bi-pyramidal electronic geometry and molecular geometry.
- BrF_3 is surrounded by five set of electrons (32) ⟶ have trigonal bi-pyramidal electronic geometry and T- shape geometry.

2008. Which of the following molecules does **NOT** have a **trigonal bi-pyramidal electron geometry?**
A. SF_4 B. ClF_3 C. XeF_2 D. BrF_5

- **SF_4, ClF_3 and XeF_2** are surrounded by **five se**t of **electrons (41, 32 and 23)** ⟶ have **trigonal bi-pyramidal electronic geometry**
- BrF_5 is surrounded by six sets of electrons (51) ⟶ has octahedron electronic geometry

2005. Which of the following molecule has a **trigonal bi-pyramidal structure?**
A. SF_4 B. IF_5 C. ICl_4^- D. BrF_5

Molecule	Electron set	Molecular shape	Electron pair arrangement
SF_4	5 ⟶ 41	Seesaw	Trigonal bi-piramid

IF_5/ BrF_5	6 ⟶ 51	Trigonal bi-pyramidal	Octahedral
ICl_4^-	6 ⟶ 42	Square planar	

2008. Which of the following molecules **does not have a tetrahedral** central atom?

A. XeF_4 B. $SiCl_4$ C. BF_4^- D. NH_4^+

2007. The molecular shape of the $\mathbf{H_3O^+}$?

A. Linear B. Tetrahedral C. Bent D. trigonal pyramidal

- H_3O^+ is surrounded by four set of electrons(31) ⟶ have tetrahedral electronic geometry and trigonal bi-pyramidal

2006. Which molecule or ion **does not have a tetrahedral** shape?

A. SF_4 B. AlH_4^- C. BF_4^- D. $SiCl_4$

- $\mathbf{SiCl_4}$, $\mathbf{BF_4^-}$, $\mathbf{NH_4^+}$, $\mathbf{AlH_4^-}$ are surrounded by four **set** of **electrons(40)**

  ⟶ Have tetrahedral molecular and **electronic geometry**

- XeF_4 is surrounded by six sets of electrons(42) ⟶ has octahedron electronic geometry and square planar molecular geometry

- SF_4 is surrounded by five sets of electrons(41) ⟶ has trigonal bi-poramidal electronic geometry and seesaw molecular geometry

2003. What is the molecular geometry of O_3?

A. Trigonal Planar B. Tetrahedral C. Bent D. Trigonal pyramidal

- O_3 is surrounded by three set of electrons (21) ⟶ have trigonal planar electronic geometry and bent molecular geometry.

2003. $\mathbf{NF_3}$, $\mathbf{BF_3}$, $\mathbf{ClF_3}$ all have formula of $\mathbf{XF_3}$.Which molecule(s) has (have) trigonal pyramid molecular geometry?

A. NF_3 & BF_3 B. BF_3 & ClF_3 C. NF_3 & ClF_3 D. NF_3

- $\mathbf{NF_3}$ is surrounded by four **set** of **electrons(31)** ⟶ Has trignal molecular geometry and tetrahedral **electronic geometry**

- BF_3 is surrounded by three sets of electrons(30) ⟶ has trigonal planr electronic and molecular geometry

- ClF_3 is surrounded by five sets of electrons(32) ⟶ has trigonal bi-poramidal electronic geometry and T- shape molecular geometry

1999. What is the shape of the $\mathbf{TeF_5^-}$ anion?

A. Seesaw B. Square pyramid C. Trigonal pyramid D. Trigonal bi-pyramid

- $\mathbf{TeF_5^-}$ **is** surrounded by six **set** of **electrons(51)** ⟶ Has square pyramid molecular geometry and octahedral **electronic geometry**

1999. In a molecule of ICl_3, the arrangement of electron pair would be described as:

A. Square planar B. Trigonal Bi-pyramid

C. Trigonal pyramid D. Octahedral

- ICl_3 is surrounded by five sets of electrons(32) ⟶ has trigonal bi-poramidal electronic geometry and T- shape molecular geometry

Questions related to Bond Angle

2010. Given the following **AF_n** species **BF_3, BeF_2, CF_4, NF_3, and OF_2**.
What is the correct order of **F-A-F** bond angles?
Answer: - OF_2 (104.5 ^{o}) < NF_3 (107.5 ^{o}) < CF_4 (109.5^o) < BF_3 (120^o) < BeF_2 (180^o)

2009/2010. What is (are) the **F-S-F** bond angle (s) in **SF_6?**
A. 109.5^o B.120^o C. 90^o/120^o D. 90^o and 180^o

2008. Which molecule has the **largest** bond angle?
A. H_2O B. CO_2 C. NH_3 D. CH_4

2004. Which of the following species has the smallest **H-X-H** bond angle where X is central atom? A. OH_2 B. NH_3 C. BH_3 D. CH_4

1998. Which molecule has the **largest** bond angle?
A. H_2O B. CO_2 C. NH_3 D. CH_4

Molecule	Electron sets	Molecular Geometry	Bond Angle
OH_2, H_2O, OF_2, NH_2^-	22→2+2 = 4	Bent/V-shape/angular	104.5 ^{o}
NF_3, NH_3	31→ 3+1 = 4	Trigonal Pyramid	107.5 ^{o}
CF_4, CH_4, NH_4^+	40→4+0 =4	Tetrahedral	109.5 ^{o}
BF_3, BH_3	30 →3+0=3	Trigonal Planar	120 ^{o}
BeF_2, CO_2,	20→2+0= 2	Linear	180^o
SF_6	60→6+0= 0	Octahedral	90 ^{o} or 180^o

1998. What is the **H-N-H** bond angle in the **three** species NH_2^-, NH_3 and NH_4^+ respectively?
As lone pair increase = Bond angle decrease (**NH_2^- (104.5 ^{o}) < NH_3 (107.5 ^{o}) < NH_4^+ (109.5^o)**)

Home work (1996/1995)

Intermolecular Force (IMF)

- There are two types of electrostatic forces. These are: intramolecular and intermolecular forces.

Electrostatic force	
Intramolecular force:	Intermolecular forces
❖ **Chemical bond (ionic, covalent or metallic)** ❖ **Force that exists within a particle (molecule or polyatomic ion) and** ❖ **Affects the chemical properties** ❖ **Stronger than IMF**	❖ **Attraction between ions and molecules** ❖ **Exist between particles** ❖ **Forces that holds molecules together (forces inside of molecule)** ❖ **Influence physical properties (mpt, Bpt)** ❖ **Responsible for condensation and sublimation of molecule** ❖ **Weaker than intramolecular force**

- There are Three Types of Intermolecular Force

1. London(Dispersion) Force

- Exists in all atoms and non-polar molecules

- Weakest IMF

  Example: Mono atomic molecule (Rn, Xe, Kr, Ar, Ne and He), homo molecule (H_2, O_2, N_2, F_2, Cl_2, Br_2, I_2, P_4, S_8) and CO_2, SO_3, CCl_4

2. Dipole-dipole force

- Found in polar molecule
- Stronger than London force.

  Example: Hetro diatomic molecule (HCl, HBr,HF, NO), H_2S, SO_2, PH_3, NH_3, H_2O, CH_3OH

3. Hydrogen bonding

  - Special type of DDF
  - Formed between hydrogen and FON
  - Strongest IMF

  Example: HF, NH_3, H_2O, Carboxylic acid (CH_3COOH, CH_3CH_2COOH), lower alcohol (CH_3OH, CH_3CH_2OH) and Protein (DNA, RNA)

Intermolecular force	Strength	Polarity
Hydrogen Bonding	The Strongest	Polar
Dipole-dipole Forces	Moderate	Polar
London Dispersion Forces	The Weakest	Non-polar

LF < DDF <HB < CB < IB

- As molecular size (weight) = (Number of electrons, number of atoms, IMF, boiling point, melting point) increase

  2012. Which of the following substances has London dispersion forces as its only intermolecular force? (No hydrogen bonding, no dipole- dipole forces).

  A. CH_3OH B. NH_3 C. H_2S D. CH_4

  HB HB DDF LF

  2004. Which of the following explains, why at room temperature I_2 is a solid, Br_2 is a liquid and Cl_2 is a gas?

  A. Ionic bonding B. Hybridization

  C. Hydrogen bonding D. London- dispersion force

- Molecular mass increase = Strength of IMF = State of substance change from gas to liquid and liquid to solid.
- I_2 , Br_2 and Cl_2 are non polar molecule and contain London force

2003. Of Br_2, Ne, HCl and N_2, which is likely to have the largest intermolecular dispersion forces?

A. Br_2 B. Ne C. HCl D. N_2

- HCl is polar molecule and contains dipole –dipole force
- Br_2, Ne and N_2 are non polar molecule and contain London force
- Largest molecular mass = Largest IMF (LF)

- Br_2 (160), N_2(28) and Ne(20)
- Br_2 has largest London force because Br_2 has largest molecular mass or size

2001. Which of the hydrogen halide has the highest enthalpy of vaporization?

A. HCl B. HBr C. HI D. HF

- ✓ IMF increase = heat of vaporation, Bpt and Mpt increase
- ✓ HF has hydrogen bonding(highest IMF)
- ✓ HCl<HBr<HI<HF

2000. Which type of bonding explains best high boiling point of water?

A. Vander Waals forces B. Covalent Bonding

C. Polar ionic Bonding D. Hydrogen Bonding

1999. Which type of molecular attraction accounts for high boiling point of water ?

Compound	H_2O	H_2S	H_2Se	H_2Te
BPt	$100^o{}_C$	$-60.7\ ^o{}_C$	$-4.5\ ^o{}_C$	$-2.2^o{}_C$

A. Vander Waals forces B. Molecular

C. Ion-ion D. Hydrogen Bonding

- ✓ Hydrogen bond is responsible for high boiling point of water.

1999. Which type of IMF exists in non polar molecule?

A. Dipole- Dipole forces B. Ion –dipole force

C. London force D. Hydrogen Bonding

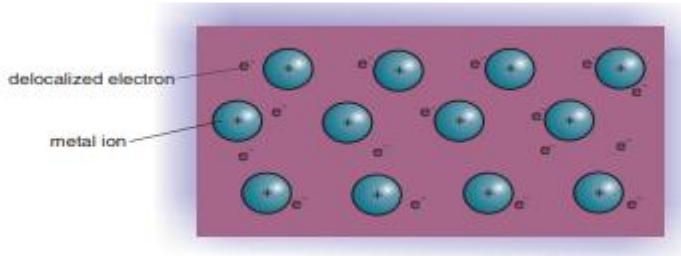
Metallic Bonding is:

- Bonding in metal atoms(Ni, Mg, Pt, Pd, Cu, K, Fe, Al)
- Electrostatic force between metal cations and delocalized electrons.
- Interaction between metal nuclei (positive metal ions) and delocalized (conduction or mobile)electrons
- Force of attraction which binds together the positive metal ions or Kernels with the electrons
- Imagined as sea of electrons in which positive metal ions are embedded..
- The strength of the metallic bond depends on the:
  1. Number of valence electrons in the delocalised 'sea' of electrons.
  2. Packing arrangement of the metal atoms.
  3. Size of cations
- More delocalised electrons, more closely packed the atoms and smaller size of cations are results in a stronger bond and a higher melting point.
- Strength of metallic bonding decrease down a group and increase across a period.
- Metallic character increase down a group and decrease across a period.

Electron-Sea Model is:

- Model which represents the electronic structures of metals
- All metal atoms contribute their valence electrons to from "sea" of electrons

❖ The metal ions (the nuclei with their core electrons) are submerged in the electron sea



Properties of Metals

Metals are:

✓ Malleable (hammered into thin sheets)
✓ Ductile (drawn into tubes or wires)
✓ Durable, hard, Strong and opaque
✓ Good conductors of heat and electricity because of their mobile electrons.
✓ Sonorous (have deep sound when hit)
✓ Shiny, Lustrous and very cool
✓ Solids with high melting and much higher boiling points; because the atoms of metals have strong attractive forces between them and much energy is required to overcome this force.
✓ Metals have a wide range of melting points, (from - 39°C (mercury) to 3410°C (tungsten).
✓ Metals have high MPt, Bpt, density and conductivity of heat and electricity

2006. Why are metals soft and malleable ?

A. Because they are very shiny.
B. Because they experince electrstatic repulsion
C. Because of the presence of mobilde electrons.
D. Because the metals cations can slip over each other.

✓ Metals are malleable and ductile because atoms of metallic lattice are capable of slipping with respect to one other.

2004. Which of the following elements has the highest Melting point ?

A. Iodine B. Tungsten C. Mercury D. Bromine

✓ Metals have high melting point, boiling point and density.

2002. Which of the folowing is **not true** of metallic bonding ?

A. It gives rise to excellent electrical conducitivity
B. Electrons are free to move throughout the structructure.
C. The strength of metallic bonding increase down agroup
D. The strength of metallic bonding affects the melting and boiling point of metals.

Atomic size increase = metallic character increase =metallic bonding decrease(down agroup).

CHEMICAL BONDING THEORIES

❖ The two modern chemical bonding theories are the Valence Bond Theory (VBT) and the Molecular Orbital Theory (MOT).

2012. Which of the following is a basic chemical bonding theory ?

A. Molecular borbital theory

B. Covalent bonding theory

C. Ionic bonding theory

D. Valence Shell Electron Repulsion (VSEPR) Theory

- Valence Bond Theory (VBT)

- Also called localized electron model
- Explains formation of covalent bonds in terms of overlap of half-filled atomic orbitals.
- Covalent bond is formed by overlapping of orbitals.
- Covalent bond is formed when a half –filled orbital of one atom overlaps with a half –filled of another.
- Treats electrons as localized between two atoms
- Each bond only involves two atoms
- Leads to concept of hybridization.

2012. Which statements is **NOT** correct about the **Valence Bond Theory** ?

A. According to the valence bond theory , hybrid orbitals are formed by overlapping of atomic orbitals.

A. Acording to valence bond theory, molecular orbitals are formed by ccombing atomic orbitals.

B. Valence bond theory treats electrons as localized between two atoms

C. According to valence bond theory, each bond only involves two atoms.

- **Overlapping :-**
  - ✓ Sharing a common region in the space
- Types of overlap : Head to head and side to side overlap

Overlap	
Head to head overlap	**Side to side overlap**
❖ Also Head on, end-to-end, end on or linear overlap and ❖ Include s – s, s – p and p-p overlap along the nuclear axis ❖ Results only in sigma bonds.	❖ Also Side-on, side-way, lateral or parallel overlap and ❖ Include only p-p overlap ❖ Form Pi- overlap

Sigma(σ)bond:	Pi(π) – bond
❖ Formed by head to head overlap ❖ Presents in the molecule that contains single and multiple bond **Example:** F_2, Cl_2, Br_2, I_2, HBr, HI, HF, HCl, H_2O, CH_4, CCl_4, NH_4^+	❖ Formed by side-side overlap ❖ Exists in the molecule that contains multiple bond(double bond and multiple bond) **Example:** O_2, N_2, CO_2, COS, HI, SO_2, C_2H_4, C_2H_2

Note:

i. A single-bond always consists of one σ bond.

ii. A double-bond always consists of one σ and one π bond.

iii. A triple bond consists of one σ and two π bonds.

iv. Sigma bond is formed by s-s, s-p and p-p overlap

A. s-s orbital overlap: -H_2, BeH_2

B. s-p orbital overlap: -CH_4, $AlH^-_{4,}$ BH_3, H_2O, NH_3, PH_3, AsH_3, HF, HBr, HCl, HI, C_2H_4

C. p-p orbital overlap: F_2, $Cl_{2,}$ Br_2, I_2, $AlCl^-_4$, BCl^-_4, CI_4, IBr_3, XeF_4

v. Pi bond formed by p-p overlap

- ❖ p-p orbital overlap: O_2, $CO_{2,}$ N_2, C_2H_4, $_3$, HF, HBr, HCl, HI

2008. Which of the following is **NOT** true about Carbonyl Compounds?

A. The carbonyl compounds contain three sigma bonds and one pi-bond

B. The carbon oxygen bond is both longer and weaker.

C. The bond angle of carbonyl is about 120^o

D. carbonyl group may be hydrolyzed

- Carbonyl Group is hydrolyzed(react with water)
- C and O double bond is shorter and stronger than single bond
- Carbonyl group has **trigonal molecular shape** with bond angle $\mathbf{120^o}$

2007. According to the valence bond theory, which orbital's on bromine atom overlap in the formation of bond in Br_2?

A. 3s B. 3p C. 4s D. 4p

- Electron configuration of Br is: - $1s^22s^22p^63s^23p^64s^23d^{10}4p^5$
- Half filled 4p orbital involves in overlap.

2007. How many **sigma and pi-**bond are present in the following molecule $H_3CCHCHCH_3$?

A. 8 sigma bonds and one pi-bond

B. 10 sigma bonds and two pi-bonds

C. 8 sigma bonds and two pi-bonds

D. 11 sigma bonds and one pi-bond

- $H_3CCHCHCH_3$ – contains 10 single or sigma bond and one double bond(one sigma and pi- bond)

2006. How many **pi-**bonds are present in the following molecule $CO_{2?}$

A. 1 B. 2 C. 3 D. 4

- CO_2 contains two double bond(two sigma and two pi- bonds)

2004. Which molecule listed below has two sigma and two pi bonds?

A. N2 B. N_2F_2 C. C_2H_4 D. HCN

- N_2 contains one triple bond (one sigma and two pi- bonds)
- N_2F_2 contains two single bonds and one double bond(three sigma and one pi - bonds)
- C_2H_2 contains four single bonds and one double bond(five sigma and one pi - bonds)
- HCN contains one single bonds and one triple bond(two sigma and two pi - bonds)

Home work.

Determine number of sigma bond in:-

A. Phenol………...3and 3 pi- bonds

B. Benzene……….12 and 3 pi- bonds

C. Toluene…………15 and 3 pi- bonds
D. Naphthalene…….19and 5 pi- bonds

❖ **Hybridization is:-**

- Mixing or blending of s and p orbitals or s, p and d orbitals.
- Hybridized orbital is combination of s, p and d orbital's, such as sp, sp^2, sp^3, sp^3d and sp^3d^2
- Hybrid orbital's overlap in the usual way (end-to-end) and form σ bonds.
- Unhybridized p orbitals overlap in a side-by-side manner and give rise to π bonds
- Determined from pair of electrons:-

Number of pairs/orbitals	hybridization	Shape of molecule
2	Sp	Linear (20)
3	Sp^2	Trigonal planar(30), bent(21)
4	Sp^3	Tetrahedral(40) trigonal pyramid(31), bent(22)
5	Sp^3d	Linear (23), T-shape(32), trigonal bi-pyramid (50), seesaw(41)
6	Sp^3d^2	Octahedral (60), square pyramid(51) and square planar (42)

❖ Hybridization is also determined by the following formula :-

✓ Hybridization(X) = SA + ½ (G – V)
✓ X is number of orbitals/pairs of central atom, SA is number of surrounding atoms, VE or G is group of central atom, V is oxidation number of surrounding atoms (8 - group of element)

2010. In the following equation, What type of the hybridization if any occurs at the **Xe** atom?

$$XeF_2\,(s) + F_2(s) \longrightarrow XeF_4\,(s)$$

A. Sp^3d and sp^3
B. dsp^2 and sp^3
C. Sp^3 and sp^3d
D. Sp^3d and sp^3d^2

➢ Hybridization in XeF_2 is sp^3d and hybridization in the XeF_4 is sp^3d^2

2009. What kind of hybrid orbitals is utilized by the carbon atom in CF_4?

A. sp B. sp^2 C. sp^3 D. sp^3d

➢ Number of orbital's or pairs (40) = 4+0 = 4 (sp^3)
➢ SA = 4, Group of central atom(G) = 4, V is oxidation number of F (8-7 = 1) = 1 x 4 = 4
✓ Hybridization(X) = SA + ½ (G – V)
✓ Hybridization(X) = 4 + ½ (4 -4) = 4

2008. Formic acid, which released by ants, has a molecular formula of HCOOH.
What is the possible hybridization that exists in the molecule?

A. Sp^2 and sp^3
B. Sp and sp^3
C. Sp, sp^2 and Sp^3
D. Sp and sp^2

➢ Number of pairs or orbitals around C (30) = 3+0 = 3) and hybridization around the C is sp^2
➢ Number of pairs or orbitals around O bonded to H (40) = 4+0 = 4) and hybridization around O is sp^3

2008. How many atomic orbital's are required for an sp^3 hybridized atom?

A.2 B. 4 C. 6 D. 8

- ✓ Number of pairs or orbital's around central atom (31)= 3+1 = 4

2007. What is hybridization change does the carbon atom under go in the combustion of methane? $CH_4 (g) + 2O_2 (g) \longrightarrow CO_2 (s) + 2H_2O (g)$

A. Sp to sp^2 C. Sp^3 to sp

B. sp^2 to sp^3 D. Sp^2nd sp^3

- CH_4 (number of pairs or orbitals (40) = 4 + 0 = 4, hybridization of C in the CH_4 Sp^3)
- CO_2 (number of pairs or orbitals (20) = 2 + 0 = 2, hybridization of C in the Co_2 Sp)

2007. The hybridization of central atom in the XeF_4 molecule is:-

A . sp^3d^2 B. sp^2 C. sp^3 D. sp^3d

Method 1:-

- ➢ Number of pairs or orbitals in the XeF_4 is 4+2 = 6
- ➢ Hybridization of central atom (Xe) is sp^3d^2

Method 2:- **SA = 4**, G = VE of Xe = 8 and V is oxidation number of F = 1x4 = 4

- ✓ Hybridization(**CA**) = SA + ½ (G –V)
- ✓ Hybridization(CA) = 4 + ½ (8 -4) = 4 +2 = 6 orbital's = 6 pairs
- ✓ Hybridization of central atom (Xe) is sp^3d^2

2005. Which of the following hybrid orbitals is favoring the formation of trigonal bi-pyramid?

A . sp^3d B. sp^2 C. sp^3 D. sp^3d^2

2004. What is the hybridization of P in the PCl_5?

A . sp^3d B. sp^2 C. sp^3 D. sp^3d^2

SA = 5, G = VE of P = 5 and V is oxidation number of Cl = 1x5 = 5

- ✓ Hybridization(P) = SA + ½ (G –V)
- ✓ Hybridization(P) = 5+ ½ (5 -5) = 5 + 0= 5 orbitals = 5 pairs
- ✓ Hybridization of P in the PCl_5 is sp^3d^2

2003. What is the orbital hybridization of oxygen in the water?

A . sp^3 B. sp^2 C. sp D. sp^3d

SA = 2, G = VE of O = 6 and V is oxidation number of H = 1x2 = 2

- ✓ Hybridization(O) = SA + ½ (G –V) for simple molecule
- ✓ Hybridization(O) = 2+ ½ (6 -2) = 2+ 2= 4 orbitals = 4 pairs
- ✓ Hybridization of O in the H_2O is sp^3

2003. What is the hybridization of C in the C_2H_2? Ans (sp)

2003. What is the hybridization of S in the SF_6? Ans (sp^3d^2)

1997. What is the hybridization of P in the PCl_3? Ans (sp^3)

- Molecular orbital theory (MOT)

- The two main types of MOs are bonding molecular obitals and antibonding molecular orbital.

- Bonding molecular obitals(BMO)- concentrate electron charge density between atoms or just above and below the imaginary line joining the two nuclei and
- Antibonding molecular orbitals (ABO) - concentrate electron charge densities away from the intermolecular bonding region

A. Electron Configuration of Diatomic Molecules

- Apply Afubau principle and Pauli exclusion principle

Rule to write electron configuration for hetero or homo molecule or molecular ion:-

a. For diatomic molecules with total electrons = 14 or less) the order is:

$$\sigma_{1s}\sigma^*_{1s}\sigma_{2s}\sigma^*_{2s}\left(\pi_{2p_y}=\pi_{2p_z}\right)\sigma_{2p_x}\left(\pi^*_{2p_y}=\pi^*_{2p_z}\right)\sigma^*_{2p_x}$$

b. For diatomic molecules (total electrons greater than 14) the

the $\left(\pi_{2p_y}=\pi_{2p_z}\right)$ comes after σ_{2p_x} and the order is:

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

✓ The π_{2py} and π_{2pz} orbitals are said to be double degenerate and π^*_{2py} and π^*_{2pz} orbitals are double degenerate

2010. Which of the following molecular diagrams is correct for the carbide ion (C_2^{2-})?

A. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\pi_{2p}^4 = \pi_{2pz}^2$ C. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2p}^4\sigma_{2p}^2\pi^*_{2p}{}^2$

B. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2py}^4\sigma_{2p}^2$ D. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2p}^4\sigma_{2p}^2\pi^*_{2p}{}^4$

✓ Electron configuration of $C_2^{2-} = \sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2py}^2\pi_{2pz}^2\ \sigma_{2px}^2$

2010. How many electrons are present in the molecular orbital of N_2^+?

A. 1 B. 2 C. 3 D. 4

✓ Electron configuration of $N_2^+ = \sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2py}^2\pi_{2pz}^2\ \sigma_{2px}^1$

2006. What the is correct molecular elevtronic configuration for the molecular ion, B_2^+?

A. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\sigma_{2p}^2$ C. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2px}^1\pi_{2py}^1$

B. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2py}^2$ D. $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2p}^1$

✓ Electron configuration of $B_2^+ = \sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\ \sigma^*_{2s}{}^2\ \pi_{2py}^1$

B. Bond Order is:-

- Number of bond in the molecule or compound.
  - ✓ Bond order = 0 (molecule does not exist or unstable (reactive).
  - ✓ Bond order > 0 (molecule does exist or stable (un reactive).
  - ✓ Bond order = 1 (molecule does exist and contains single bond)
  - ✓ Bond order = 2 (molecule does exist and contains double bond)
  - ✓ Bond order = 3 (molecule does exist and contains triple bond)

- Used to determine :-
  - ✓ Stability of molecule
  - ✓ Existence of molecule

- ✓ Number of bond
- ✓ Bond length and
- ✓ Bond energy of molecule.

➢ As bond order increase = (Number of bond, stability of molecule, bond energy of molecule, existence of molecule) increase and bond length decrease.

➢ B.O = ½ (nb-na)

- ✓ nb = number of bonding (σ and π) electrons and
- ✓ na = number of anti-bonding (σ^* and π^*) electrons

$$\text{Bond order} = \frac{1}{2}\left[\begin{pmatrix}\text{Number of } e^- \text{ in}\\ \text{bonding MOs}\end{pmatrix} - \begin{pmatrix}\text{Number of } e^- \text{ in}\\ \text{antibonding MOs}\end{pmatrix}\right]$$

2009. What is the bond order of a superoxide anion, with the chemical formula O_2^-?

A. 3 B. 2.5 C. 2 D. 1.5

- Total electron of O_2^- = 8x2 + 1 = 17 electrons
- Electron configuration of O_2^- = $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\,\sigma^*_{2s}{}^2\,\sigma_{2px}^2(\pi_{2py}^2 = \pi_{2pz}^2)\,(\pi^*_{2py}{}^2 = \pi^*_{2pZ}{}^1)$
  - ✓ nb = 10 and na = 6
- Bond order (B.O) = ½ (nb-na) = ½(10-7) = ½(3) = 1.5
- O_2^- is paramagnetic molecule
- O_2^- does exist or stable molecule.

2002. What is the bond order of O_2^+?

A. 3 B. 2.5 C. 2 D. 1.5

- Total electron of O_2^+ = 8x2 -1 = 15 electrons
- Electron configuration of O_2^+ = $\sigma_{1s}^2\sigma^*_{1s}{}^2\sigma_{2s}^2\,\sigma^*_{2s}{}^2\,\sigma_{2px}^2(\pi_{2py}^2 = \pi_{2pz}^2)\,(\pi^*_{2py}{}^1 = \pi^*_{2pZ})$
  - ✓ nb = 10 and na = 5
- Bond order (B.O) = ½ (nb-na) = ½(10-5) = ½(5) = 2.5
- O_2^+ is paramagnetic molecule
- O_2^+ does exist or stable molecule.

2006. Based on the molecular orbital theory, the bond order of H_2, H_2^+, H_2^- are__respectively ?

A. 1, 0 and 0 B. 1, ½ and 0

C. 1, 0 and ½ D. 1, 1/2 and ½

- Total electron of H_2 = 1x2 = 2 electrons
- Electron configuration of H_2 = σ_{1s}^2 , nb =2 and na = 0
- Bond order (B.O) = ½ (nb-na) = ½(2-0) = ½(2) = 1
- H_2 is diamagnetic molecule
- H_2 does exist or stable molecule.
  - ➢ Total electron of H_2^+ = 1x2 -1 = 1 electron
  - ➢ Electron configuration of H_2^+= σ_{1s}^1 , nb =1 and na = 0
  - ➢ Bond order (B.O) = ½ (nb-na) = ½(1-0) = ½(1) = 0.5 = ½
  - ➢ H_2^+ is diamagnetic molecule
  - ➢ H_2^+ does exist or stable molecule.

- Total electron of H_2^- = 1x2 +1 = 3electrons
- Electron configuration of H_2^-= $\sigma_{1s}^2\sigma^*{}_{1s}^1$, nb =2 and na = 1
- Bond order (B.O) = ½ (nb-na) = ½(2-1) = ½(1) = 0.5 = ½
- H_2^- is diamagnetic molecule
- H_2^- does exist or stable molecule.
- The bond order of three molecule are : - 1, ½ and ½

2008. What would happen to the O_2 molecule upon ionization to O_2^+?

A. The bond length will increase and bond energy will increase.
B. The bond length will increase and bond energy will decrease.
C. The bond length will decrease and bond energy will increase.
D. The bond length will decrease and bond energy will decrease

- ✓ Bond order of O_2 = ½ (10-6) = ½ (4) = 2
- ✓ Bond order of O_2^+ = ½ (10-5) = ½ (5) = 2.5

- Bond energy increase = (bond energy, stability or existence of molecule) increase = bond length decrease.
- O_2^+ is shorter bond length than O_2
- O_2^+ has higher bond energy and bond order than O_2.

1998. Why does the peroxide ion (O_2^{-2}) have larger bond than does superoxide (O_2^-)?

A. O_2^- has a greater bond order than O_2^{-2}
B. O_2^- has a smaller bond order than O_2^{-2}
C. O_2^{-2} has a greater bond order than O_2^-
D. O_2^{-2} has a smaller bond order than O_2^-

- Bond order of O_2^{-2} = ½ (10-8) = ½ (2) = 1
- Bond order of O_2^- = ½ (10-7) = ½ (3) = 1.5
- Bond energy increase = (bond energy, stability or existence of molecule) increase = bond length decrease.
- O_2^- is smaller bond length than O_2^{-2}
- O_2^- has higher bond energy and bond order than O_2^{-2}

Q_1. Which of the following molecule does exist?

A. Be_2/Ne_2 B. He_2/B_2^{+2} C. B_2 D. O_2/F_2

Q_2. Which of the following molecule is most stable?

A. O_2	B. O_2^-	C. O_2^+	D. O_2^{-2}
B.O = 2	B.O = 1.5	B.O = 2.5	B.O = 1

Q_3. Which of the following molecule has the highest bond energy?

A. F_2	B. F_2^-	C. F_2^+	D. F_2^{-2}
B.O = 1	B.O = 0.5	B.O = 1.5	B.O = 0

Q_4. Which of the following molecule has the largest bond length?

A. N_2	B. N_2^-	C. N_2^+	D. N_2^{-2}
B.O = 3	B.O = 2.5	B.O = 2.5	B.O = 2

Magnetic Properties	
Paramagnetic property :- - Species with unpaired/odd/electrons - Species attracted/affected/ by an external magnetic field - 1- 19 odd electron, 10/16 and even electron	Diamagnetism property :- - Species with all paired or even electrons - Species repelled by magnetic field - 2-20 even electron except 10/16

2005. Which one of the following molecules or molecule ion is paramagnetic?

A. O_2^{-2} B. O_2 C. F_2 D. O_2^{+2}

Total electron 18 16 18 16

2003. Which one of the following molecules or molecule ion is paramagnetic?

A. F_2 B. H_2 C. NO D. NO^+

Total electron 18 2 15 14

1997. Which one of the following molecules or molecule ion is **NOT** paramagnetic?

A. O_2^{-2} B. O_2 C. O_2^- D. O_2^+

Total electron 18 16 17 15

Crystals is:-

- A piece of a solid substance that has plane surface, sharp edges, and a regular geometric shape.
- The fundamental units of crystal are atoms, ions or molecules

Types of solids	
1. Amorphous solids	2. Crystalline Solids
- Amorphous without shape (non-crystalline) - Have no well defined shape - Break to give curved or irregular faces - Melts over range of temperature **Example**:- Paraffine, asphalt, rubber , plastic, glass, amorphous sulfur	- Have regular/well defined/ shapes - Clave to give flat or well defined faces - Melts at definite temperature

Types of crystalline	
1. Ionic Crystals	2. Molecular crystals
- Consists of positive and negative ions	- Consists of molecules

❖ Attraction force – ionic bond Properties of ionic crystals :- ✓ Hard and brittle ✓ Have high(melting point, heat of fusion and vaporization) ✓ Conductors in liquid states ✓ Non- conductors in the solid states **Example**: Table salt (NaCl), Salt peter(KNO_3), Washing soda ($Na_2CO_3.10H_2O$), $CaCO_3$, MgO	❖ Attraction force – London force, dipole-dipole force and hydrogen bonding Properties of ionic crystals :- ✓ Soft to hard and brittle ✓ Have low (melting point, heat of fusion and vaporization) ✓ Have high volatility ✓ Non- conductors **Example**: sugar ($C_{12}H_{22}O_{11}$), H_2O, Dry ice(solid CO_2), ice(solid water) Iodine(I_2), glucose, S_8, P_4, Aspirin,
3. Covalent Network crystals	4. Metallic crystals
❖ Consists of atoms ❖ Attraction force – covalent bonding Properties of ionic crystals :- ✓ Very hard, strong and brittle ✓ Have extremely high (melting point, heat of fusion and vaporization) ✓ Have low volatility ✓ Non- conductors (insulator) **Example**: quartize or silica (SiO_2), carbonrundum (silicon carbide (SiC)), diamond (C), boron nitride(BN), oxides of transition metals	❖ Consists of metal atoms or ions ❖ Attraction force – metallic bonding Properties of ionic crystals :- ✓ Very soft to hard, brittle, shiny, ductile and malleable ✓ Have high (melting point, boiling point) ✓ Have variable heat of fusion ✓ Have high thermal and electrical conductivities ✓ Good conductors(✓ Have wide range of melting point (-30^o-3410^o) ✓ **Example**: Hg, Cu, Fe, Ag, Au, Al, Mg, Na, W

2012. Which types of intermolecular forces are present in molecular crystalline solids?

A. Ionic, dispersion, dipole-dipole, hydrogen bonding

B. Dispersion, dipole-dipole, hydrogen bonding

C. Covalent, dispersion, dipole-dipole, hydrogen bonding

D. Metallic, dispersion, dipole-dipole, hydrogen bonding

2005. Which of the following crystals process high electrical and thermal conductivities?

A. Ionic crystals B. Metallic crystals

C. Molecular crystals D. Covalent network crystals

1999. SiO_2 and Diamonds are best described as ___________________________________

A. Molecular substances with coordinate covalent bonding

B. Molecular substance with ionic bonding

C. Network solids with covalent bonding

D. network solids with ionic bonding