

XI

CBSE

CHEMISTRY

CHEMICAL
BONDING



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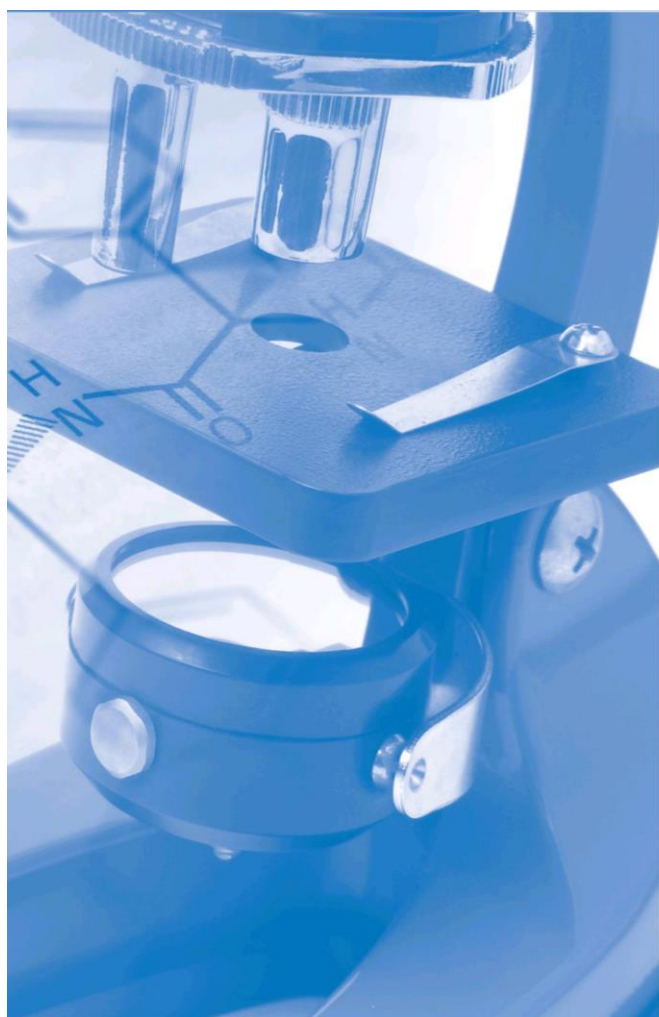


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CHEMICAL bonding



Remember

Before beginning this chapter, you should be able to:

- understand the relation between electronic configuration and bond formation.
- represent bonds by Lewis dot structures

Key Ideas

After completing this chapter, you should be able to:

- understand the concept of ionic character in covalent bond and covalent character in ionic bond
- study the properties of ionic and covalent compounds in correlation with the type of bond present in them
- explain Lewis theory of covalent bond formation on the basis of octet rule and exceptions to octet rule
- introduce the concept of orbital overlapping to overcome the drawbacks of Lewis theory
- illustrate the theory of hybridization
- correlate the shapes of molecules with the concept of VSEPR theory
- compare various types of non-bonded forces of attraction and their relative strengths
- understand the concept of metallic bond and its effect on properties of metals
- describe the electronic concept of oxidation and reduction

Nature is invariably associated with numerous chemical reactions. It is an established fact that an atom is the smallest particle which takes part in a chemical reaction. Nevertheless, most of the elements exist in combined state in the form of molecules. Only in case of very few elements namely noble gases, the atom has an independent existence. The existence of these elements in atomic state is attributed to the high stability associated with the completely filled octet or duplet configuration in their valence shells. Obviously, the atoms of other elements have an inherent tendency to attain the above configuration by means of bond formation. This is known as an octet rule envisaged by Lewis theory. The process of bond formation is associated with the decrease in the energy of the system. This lowest energy state corresponds to the most stable state of the system. Different types of bond formation takes place depending on the nature of participant atoms.

IONIC BOND

An ionic bond is formed between two atoms, which differ much in electronegativities. One atom loses one or more electrons and the other atom gains these electrons to attain the noble gas configuration. The atom losing the electrons forms a positively charged ion (cation) and the atom gaining electrons forms a negatively charged ion (anion). The cation and anion are held together by the electrostatic force of attraction. The electrostatic force of attraction existing between the oppositely charged ions is called an ionic bond.

Energy Changes Involved in the Formation of Ionic Compounds

Ionic compounds are formed due to the transfer of one or more electrons from one atom to the other. Hence two oppositely charged ions are formed in this process and an electrostatic force of attraction is developed between them.

In addition to the force of attraction between the individual pair, forces of attraction also exist among the oppositely charged ions of different pairs which bring them close to each other. As a result of this, repulsive forces are also generated between similar ions of different pairs.

But the cation–cation distance and the anion–anion distance (measured from their centre) of different pairs is greater than the cation–anion distance of different pairs. Hence the force of attraction is greater than the repulsive forces and the ions arrange themselves in such a way that their potential energy becomes minimum. The arrangement of ions associated with minimum potential energy gives the crystalline structure of the ionic compound.

The potential energy of the ions is assumed to be zero when they are separated by an infinite distance. When the ions approach each other, each releases a certain amount of energy.

The amount of energy released when the oppositely charged gaseous ions are brought closer from an infinite distance to form one mole of ionic crystal is called lattice energy.

COVALENT BOND

When the elements do not differ much in their electronegativities, transfer of electrons is not possible between the atoms. Then, sharing of electrons takes place.

A covalent bond is formed, when two atoms attain their nearest noble gas configuration by sharing one or more electron pairs. Each of the atoms contributes equal number of electrons towards the bond formation.

Energy Changes During Covalent Bond Formation

Example: Formation of hydrogen molecule

When two hydrogen atoms are brought close together, two types of forces start acting as listed hereunder:

- (i) Proton–proton and electron–electron repulsion and
- (ii) proton–electron attraction.

Bond formation between two H-atoms takes place at a distance where the proton–electron attraction just balances the electron–electron repulsion and proton–proton repulsion.

At this stage the system becomes stable because it possesses the lowest possible energy, and H₂ molecule is formed. The distance between the nuclei of the hydrogen atoms, after the formation of the bond, is called the bond length.

The total energy of this system is a function of the distance between hydrogen nuclei as shown in Fig. 5.1.

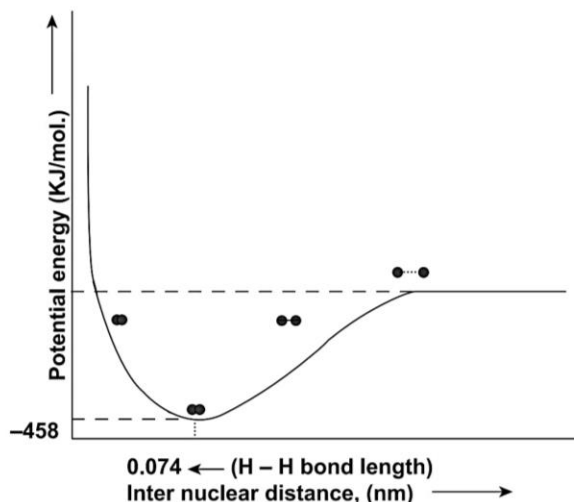


Figure 5.1 Potential energy curve representing the formation of covalent bond in hydrogen molecule

This is the way covalent bond formation takes place between two atoms.

A covalent bond can be formed between two identical atoms (atoms of same element) as well as between the atoms of two different elements.

Nonpolar Covalent Bond

In a bond between two identical atoms, the electrons are shared equally between the atoms. No separation of charge takes place in the molecule. This type of bond is called nonpolar covalent bond.

Polar Covalent Bond

A polar covalent bond is formed between non-identical atoms, which differ in electronegativities. Since the two atoms differ in their capacity to attract the shared electron pair, unequal sharing of electron density results. As a result, polarity is developed in the bond and the bond is said to have dipole moment. **Dipole moment** is the quantitative measure of the polarity of the molecule. A slight ionic character is imparted to this type of bond due to the difference in electronegativity between the bonded atoms and such type of bond is called polar covalent bond.

The relative tendency of non-identical atoms to form ionic bond or polar covalent bond depends upon the ease of the formation of cation and anion by the respective elements.

The easier is the formation of cation and anion, the more is the tendency of the formation of ionic bond. Larger size of the atom favours cation formation, whereas smaller atoms have greater tendency of attracting electrons towards it which leads to the formation of anion.

Ionic bonds are associated with some covalent character due to the attractive forces acting between the cation and the electron cloud of the anion.

The relative proportions of ionic character and covalent character of an ionic compound can be explained on the basis of the concept of polarization and Fajan's rules.

Concept of Polarization and Fajan's Rules

During the formation of an ionic compound, when a cation and anion approach each other, the nucleus of cation exerts some attractive force on the electron cloud. As a result of this, the symmetry of the electron cloud gets distorted and it shifts slightly towards the cation. This phenomenon is called *polarization*. This results in the partial sharing of electron cloud between the bonded atoms which is considered as a covalent character. This ability of a cation to distort the electron cloud of the anion is called *polarizing power* of the cation and the tendency of the anion to get distorted by the influence of the cation is called the *polarizability* of anion.

The relative proportions of ionic and covalent characters of an ionic compound depend upon the polarizing power and polarizability of the respective cation and anion which can be explained on the basis of **Fajan's rules**.

(i) Size of cation and anion

- (a) A large cation and a small anion result in maximum ionic character for the bond.
Example: Cs^+ and F^-
- (b) A small cation and a large anion result in maximum covalent character for the bond.
Example: Li^+ and I^-

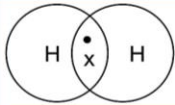
(ii) Charge of cation and anion

- (a) Low charge on cation and anion results in maximum ionic character for the bond.
Example: Na^+ Cl^-
- (b) High charge on cation and anion results in greater proportion of covalent character for the bond.
Example: Al^{+3} O^{-2}

Theories of Covalent Bond Formation

Many theories have been proposed in order to explain covalent bond formation and the stability of the resultant molecules. **Octet rule** states that the atoms of the elements have a tendency to attain the nearest inert gas configuration either by the transfer of electrons or by the sharing of electrons.

Some examples of covalent molecules, the stability of which can be satisfactorily explained with the help of the octet rule are provided in the following:

| Molecules | No. of valence electrons | Structure |
|---------------------------|--------------------------|--|
| Hydrogen (H_2) | 1 |  1 shared pair |

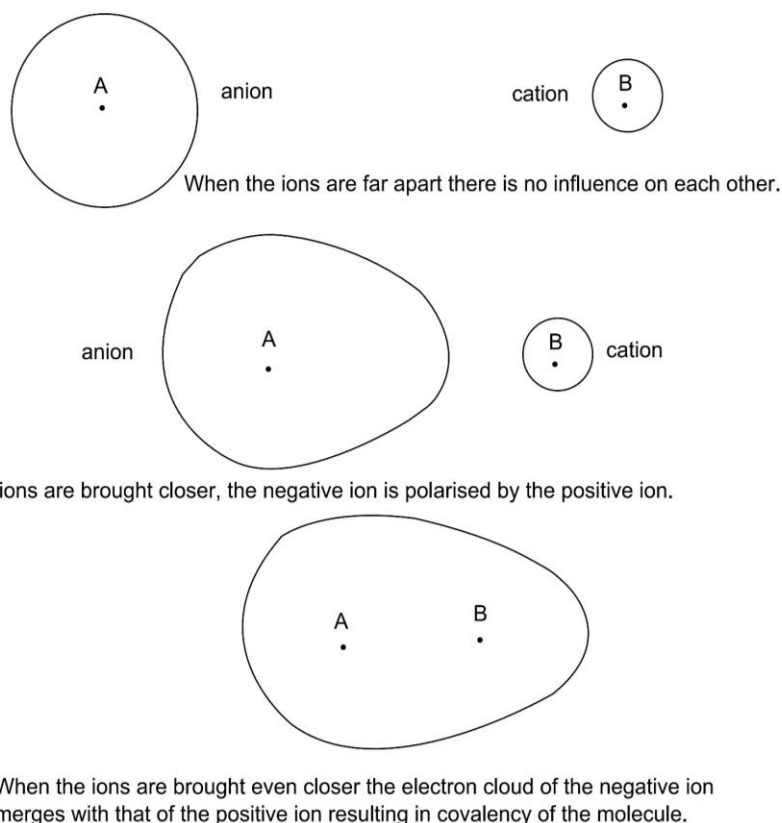


Figure 5.2 Covalant Bond Formation

| Molecules | No. of valence electrons | Structure |
|---------------------|--------------------------------------|----------------|
| Oxygen (O_2) | 6 | 2 shared pairs |
| Nitrogen (N_2) | 5 | 3 shared pairs |
| Chlorine (Cl_2) | 7 | 1 shared pair |
| Water (H_2O) | H \rightarrow 1, O \rightarrow 6 | 2 shared pairs |
| Methane (CH_4) | C \rightarrow 4, H \rightarrow 1 | 4 shared pairs |

All the above molecules are found to obey the octet rule which is visualized by writing their Lewis dot structures. Therefore, it is justified that the atoms acquire stability by gaining the octet

configuration. However, some molecules are also found in which the central atom does not acquire the octet configuration. But the fact that their stability is comparable with the stability of molecules which obey the octet rule indicates that the octet rule itself cannot completely justify formation and stability of covalent molecules.

Exceptions to the Octet Rule

The molecules may contain less than eight or more than eight electrons around the central atom. These are considered as deviations from the octet rule.

Incomplete Octet or Contracted Octet

Molecules in which the central atom possesses less than eight electrons in its valence shell.

Examples: BF_3 , BeCl_2

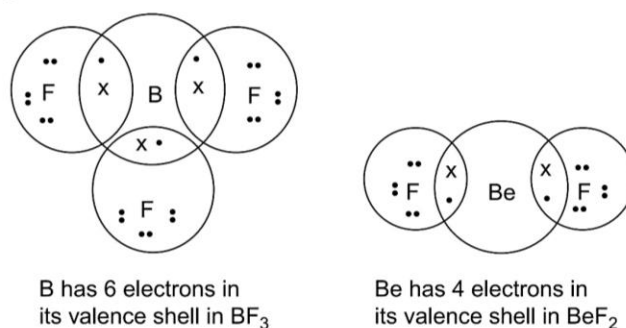


Figure 5.3 Incomplete Octet or Contracted Octet

Expanded octet

Molecules in which the central atom possesses more than eight electrons in its valence shell.

Examples: PCl_5 , SF_6 , IF_7

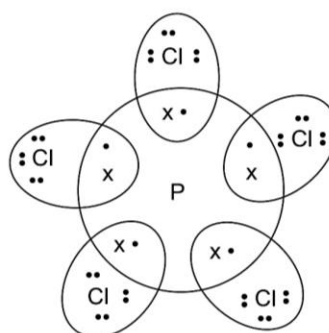


Figure 5.4 Expanded octet

P has 10 electrons in its valence shell in PCl_5 .

Lewis theory explains the formation of covalent bond through sharing of electrons, but this theory does not explain the mechanism of sharing of electrons that leads to the stability of molecules. The mechanism of sharing of electrons was interpreted with the help of the concept of orbital overlapping after the quantum mechanical model of atom was proposed.

EXAMPLE

Between CaCl_2 and KCl , which has a stronger ionic bond? Why?

SOLUTION

Ca^{+2} ion is smaller than K^{+} ion. Greater the charge on cation, the greater is the effective nuclear charge and thus smaller is the size of the cation. Hence, due to the smaller size of Ca^{+2} than K^{+} , CaCl_2 has a stronger ionic bond than KCl .

EXAMPLE

Between CuO and CuS which is more covalent and why?

SOLUTION

Between CuO and CuS , CuS is the more covalent. Since cation is same in both, the anion determines the extent of polarization. Larger anions have greater polarizability. Between O^{-2} and S^{-2} ions, S^{-2} ion is the more polarisable. Greater polarizability imparts greater covalent character to the compound.

EXAMPLE

Distinguish between polar covalent bond and nonpolar covalent bond with respect to

- (a) mode of formation
- (b) charge separation
- (c) type of atoms involved in bond formation.

SOLUTION

- (a) Polar covalent bond is a bond formed by unequal sharing of electrons between the bonded atoms. Nonpolar covalent bond is a bond formed by equal sharing of electrons between the bonded atoms.
- (b) Polar covalent bond results in the formation of opposite partial charges on the bonded atoms which is called dipole. Nonpolar covalent bond does not result in charge separation between bonded atoms.
- (c) Polar covalent bond is formed between atoms of different elements. Nonpolar covalent bond is formed between atoms of same element.

EXAMPLE

Ionic bond formation takes place between sodium and chlorine. But between hydrogen and chlorine, covalent bond formation takes place. Give reason.

SOLUTION

Sodium belongs to IA group and is highly electropositive. Chlorine belongs to VII A group and is highly electronegative. Sodium has very low IP value and can form Na^{+} ion easily. Chlorine has very high IP value and high EA value and can form Cl^{-} ion easily. Thus ionic bond results between sodium and chlorine. IP value of hydrogen is not as low as alkali metals that is Na. Hence its tendency to form H^{+} ion is very less. Sharing of electrons takes place between hydrogen and chlorine resulting in the formation of polar covalent bond.

Concept of Orbital Overlapping

According to this concept, covalent bond is formed when an overlap takes place between the orbital of one atom with the orbital of another atom.

Conditions required for orbital overlapping:

- (i) The orbitals belonging to the valence shell only take part in overlapping.
- (ii) Each of the overlapping orbitals should contain an unpaired electron.
- (iii) The electrons in the overlapping orbitals should have an opposite spin.

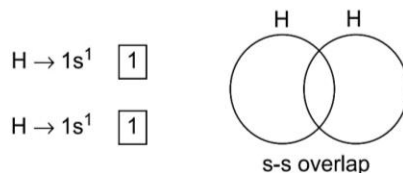
Different Types of Overlapping

(i) s-s overlapping

Example: H₂ molecule

Each hydrogen atom has only one electron (1s¹) which is available for bonding.

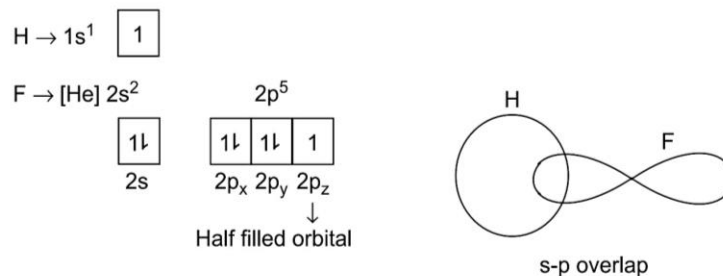
In the formation of H₂ molecules, 1s orbital of one atom overlaps with that of the other forming a single covalent bond.



(ii) s-p overlapping

Example: HF molecule

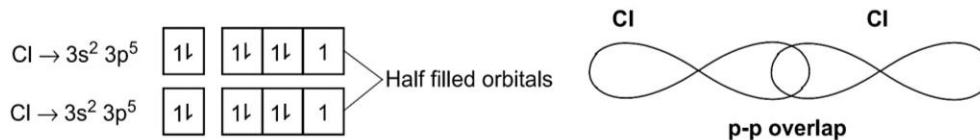
It is formed by the overlapping of 1s orbital of hydrogen atom and 2p_z orbital of fluorine atom, i.e., by s-p overlapping.



(iii) p-p overlapping

Examples: Cl₂, F₂, Br₂ molecules, etc.

Cl₂ molecule is formed by the overlapping of 3p_z orbitals of two chlorine atoms.



In the above examples (H₂, HF and Cl₂), orbitals of two atoms, each having one unpaired electron overlap to form a single covalent bond.

If the atom possesses more than one atomic orbital having unpaired electrons, then more than one covalent bond can be formed.

Strength of a Covalent Bond

The strength of a covalent bond is related to the extent to which the two combining atomic orbitals can overlap. The greater the extent of overlap between the atomic orbitals, the greater is the strength of the resulting covalent bond.

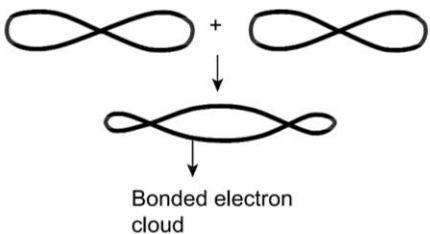
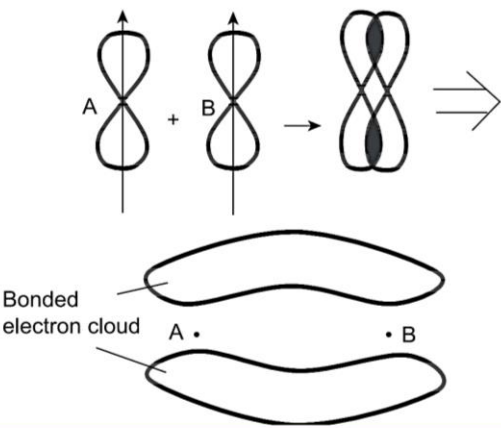
The covalent bond formed by the end to end or head on overlapping of atomic orbitals is called sigma bond. The covalent bond formed by the sidewise or lateral overlapping of atomic orbitals is called pie bond.

Sigma (σ) Bond

Sigma bond is a covalent bond formed as a result of maximum overlapping (end-to-end overlapping) of s-s, s-p and p-p orbitals along the internuclear axes. Due to the greater extent of overlapping, this type of overlapping results in a strong bond.

Pi (π) bond: A covalent bond which is formed between two atoms by lateral overlapping of orbitals perpendicular to the internuclear axis is called a *pi bond*. Due to the less extent of overlapping, this type of overlapping results in a weak bond.

Comparative Study of Sigma and pi Bonds

| Sigma Bond | Pi bond |
|--|--|
| It is a strong covalent bond formed due to end-to-end overlapping of orbitals. | It is a weak covalent bond formed by lateral overlapping of orbitals. |
| It is denoted by σ . | It is denoted by π . |
| It has an independent existence. | It does not have any independent existence as it can be formed only after the formation of a σ bond. |
| Bond dissociation energy is high. | Bond dissociation energy is low. |
| Orbitals s, p and d are capable of forming bond. | Orbitals other than "s" are capable of forming a π bond. |
| The bonded electron cloud is distributed in a cylindrically symmetrical way around the internuclear axis.  | The bonded electron cloud is distributed in two banana-shaped regions above and below the internuclear axis.  |

Explanation of sigma and pi bond with the help of formation of O₂ and N₂ molecules

O₂ molecule: The electronic configuration of an oxygen atom is $1s^2 2s^2 2p_x^2 2p_y^1 2p_z^1$. Hence, the oxygen atom has two unpaired electrons. Singly occupied $2p_z$ orbital of one oxygen atom overlaps (end to end) with the same orbital of another oxygen atom to give rise to a sigma bond. Singly occupied $2p_y$ orbitals of both the oxygen atoms overlap (sidewise) along a line perpendicular to z-axis (molecular axis) to give pi bond. Thus, a double bond is formed.

Thus an O_2 molecule has a double bond between the atoms: one is a p_z-p_z sigma bond and the other p_x-p_x pi bond called double bond.

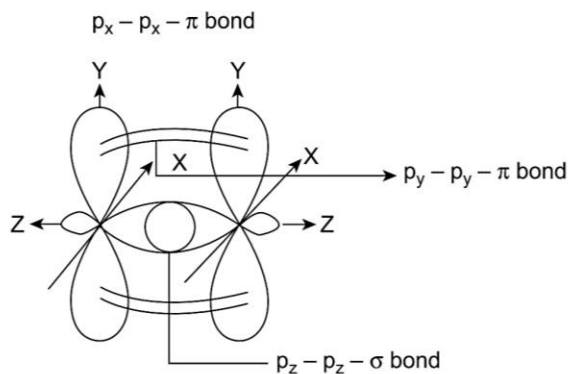


Figure 5.5 O_2 molecule (one bond and one π bond)

N_2 molecule: The electronic configuration of a nitrogen atom: $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$. Hence, a nitrogen atom has three singly occupied orbitals. One $2p_z-2p_z$ sigma bond is formed. The other two pi bonds are $2p_x-2p_x$ and $2p_y-2p_y$. Thus N_2 molecule has three bonds—one (p_z-p_z) sigma bond and other two (p_x-p_x and p_y-p_y) pi bonds which are perpendicular to each other and perpendicular to the z -axis, i.e., the axis of the sigma bond (molecular axis). Hence, a triple bond is formed.

The concept of orbital overlapping gives satisfactory explanation for the formation of covalent bond and the stability of the molecule. But the bond formation in certain molecules like $BeCl_2$, BF_3 , CH_4 , etc., cannot be explained only on the basis of this concept.

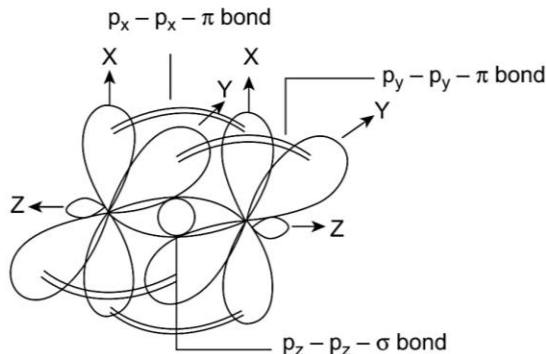


Figure 5.6 N_2 molecule (two π bonds and one σ bond)

However, the bond formation in $BeCl_2$, BF_3 , CH_4 , etc., can be explained by using the concept of excitation of electrons. Beryllium has no unpaired electron in its valence shell, boron has only one unpaired electron and carbon has two unpaired electrons. But the bicovalency of beryllium in $BeCl_2$, tricovalency of boron in BF_3 and tetravalency of carbon in CH_4 is possible due to the promotion of electron from the “s” orbital to “p” orbital. The state of atom before the promotion of electron is called ground state and that after the promotion of electron is called excited state.

However, in the excited state of beryllium, one of the two unpaired electrons is present in “2s” orbital and the other one is in “2p” orbital. Hence, during the formation of $BeCl_2$ the overlapping of orbitals should take place between s-p and p-p orbitals which are nonidentical.

But the bonds in $BeCl_2$ are found to be identical in all respects. Similarly in BF_3 , the three B-F bonds and in CH_4 , the four C-H bonds are identical.

In order to explain this identical nature of the bonds, concept of hybridization and hybrid orbitals has come into existence.

Hybridization is a process of intermixing of two or more atomic orbitals of almost equal energies (belonging to the valence shell) of an atom and their redistribution into an equal number of identical orbitals. The resultant orbitals are called hybrid orbitals.

Structure of BeCl_2

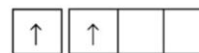
Electronic configuration of beryllium is $1s^2 2s^2 2p^0$.

Valence shell configuration of Be is $2s^2 2p^0$.

Ground state configuration of Be is



Excited State Configuration of Be is



Mixing up of one s-orbital and one p-orbital to give two new identical orbitals is called sp hybridization and the two orbitals formed are called “sp” hybrid orbitals.

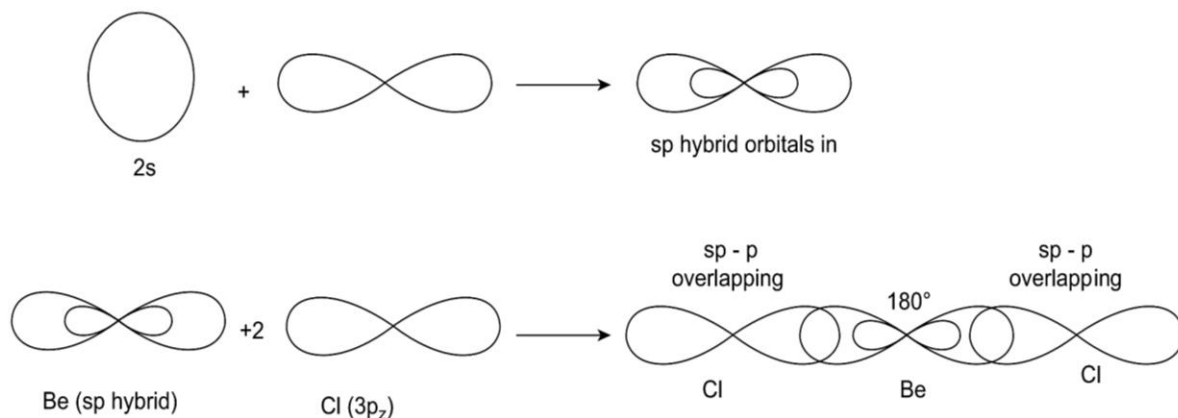
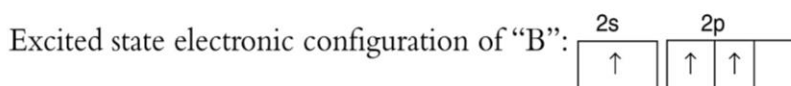
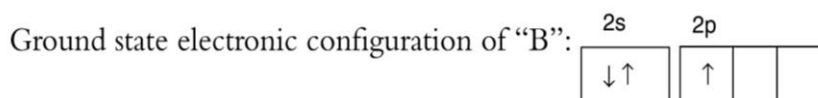


Figure 5.7 Formation of BeCl_2 molecule

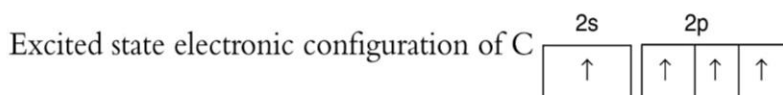
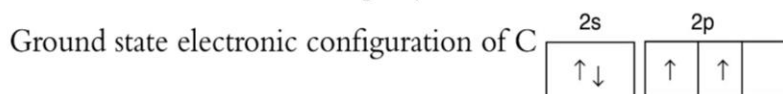
Structure of BCl_3

Mixing up of one s-orbital and two p-orbitals to form three new identical orbitals is called sp^2 hybridization. The orbitals so formed are called sp^2 hybrid orbitals.



Structure of Methane

Mixing up of one s- and three p-orbitals to form four identical orbitals is called sp^3 hybridization. These three orbitals are called sp^3 hybrid orbitals.



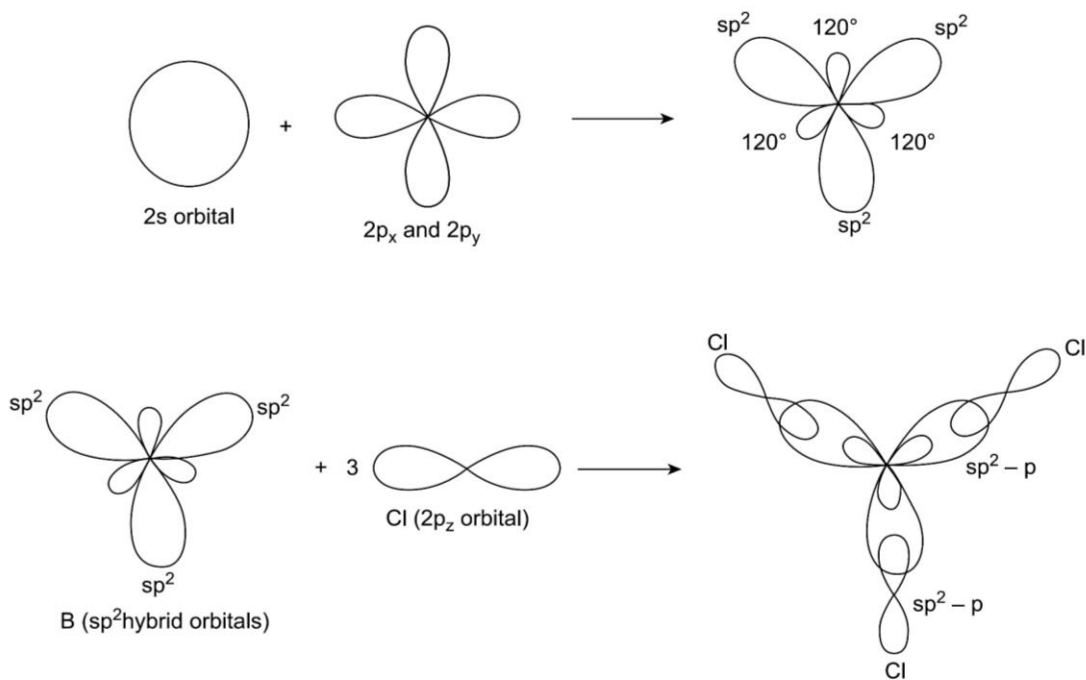


Figure 5.8 Formation of BCl_3 molecule

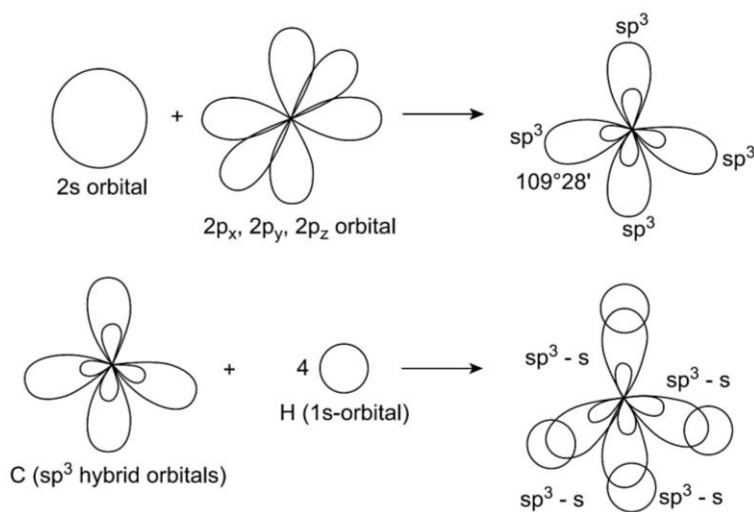


Figure 5.9 Formation of methane molecule

Shapes of the Covalent Molecules

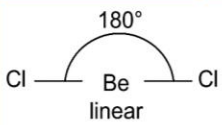
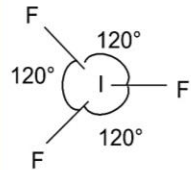
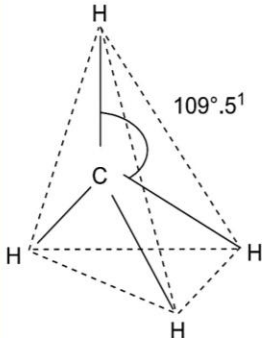
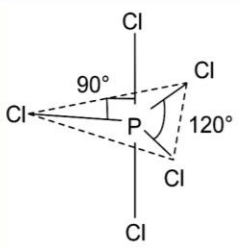
On the basis of valence shell electron pair repulsion (VSEPR) theory, the geometry and the shapes of the covalent molecules can be explained.

Postulates of the VSEPR Theory

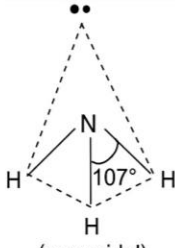
- Different geometrical shapes of the covalent molecules are generated due to the repulsion between the electron pairs present in the valence shell of the central atom of the molecules.
- These electron pairs arrange themselves in such a way that the repulsion among them becomes minimum.
- The electron pairs involved in bond formation are called bonded electron pairs. The electron pairs which are present in the valence shell of central atom but not involved in bond formation are called lone electron pairs.

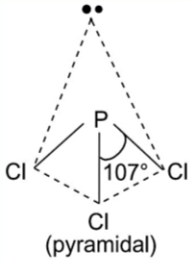
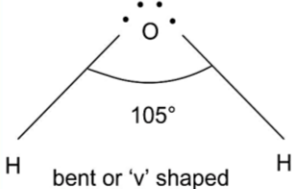
- Repulsion between two lone pairs is greater than the repulsion between a lone pair and a bond pair which is in turn greater than the repulsion between two bond pairs. Therefore, the shape of the molecule does not depend only on the number of electron pairs but also depends upon the number of bonded electron pairs and lone electron pairs on the central atom in that molecule.

Shapes of the Molecules Without Lone Pair of Electrons

| Molecules | Number of bond pairs | Shapes |
|-----------------|----------------------|---|
| BeCl_2 | 2 |  <p>linear</p> |
| BF_3 | 3 |  <p>trigonal planar</p> |
| CH_4 | 4 |  |
| PCl_5 | 5 |  <p>trigonal bipyramidal</p> |

Shapes of Molecules Having Lone Pair(s) of Electrons

| Molecules | Number of bond pairs | Number of lone pairs | Shapes |
|---------------|----------------------|----------------------|--|
| NH_3 | 3 | 1 |  <p>(pyramidal)</p> |

| Molecules | Number of bond pairs | Number of lone pairs | Shapes |
|------------------|----------------------|----------------------|---|
| PCl ₃ | 3 | 1 |  (pyramidal) |
| H ₂ O | 2 | 2 |  bent or 'v' shaped |

EXAMPLE

Explain how chlorine exhibits a maximum covalency of 7.

SOLUTION

Electronic configuration of Cl is [Ne] 3s²3p⁵. In 3rd shell, there are vacant d orbitals.

The paired electrons of 3s and 3p orbitals can be excited to 3d orbitals. Therefore the number of unpaired electrons increases. As a result, covalency corresponding to the number of unpaired electrons is exhibited. In the fully excited state of Cl atom, there are 7 half filled orbitals giving covalency of 7. As there is no scope for further excitation, it is the maximum covalency that chlorine can show.

Ground state : $\uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow \square \square \square \square \square \square \square \square \square \square \square$ ⇒ Covalency of 1

1st excited state : $\uparrow\downarrow \uparrow\downarrow \uparrow \uparrow \uparrow \uparrow \square \square \square \square \square \square \square \square \square \square \square$ ⇒ Covalency of 3

2nd excited state : $\uparrow\downarrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \square \square \square \square \square \square \square \square \square \square \square$ ⇒ Covalency of 5

3rd excited state : $\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \square \square \square \square \square \square \square \square \square \square \square$ ⇒ Covalency of 7

EXAMPLE

Both helium and beryllium have ns² valence electronic configuration. But, beryllium forms compounds and helium cannot form compounds. Explain.

SOLUTION

Both helium and beryllium have ns² valence electronic configuration. Beryllium has an electron pair in 2s orbital and all three 2p orbitals are vacant. The paired electron of 2s orbital can be excited to 2p orbital thereby giving a covalency of 2. Helium has an electron pair in '1s' orbital and there is no scope for excitation of electrons in 1st shell. Hence Helium can not form any compounds.

EXAMPLE

Why is the repulsion between two lone pairs of electrons more than that between a lone pair and a bond pair or a bond pair and a bond pair of electrons?

SOLUTION

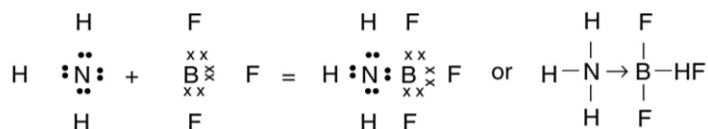
Lone pair of electrons is under the sole influence of the nucleus of one atom, but the bond pair of electrons is under the influence of the nuclei of the two atoms. Hence spreading of the electron cloud of the lone pair of electrons which is much closer to the central atom. Hence they occupy a broader orbital with greater electron density and exert greater repulsion on the adjacent electrons.

Special types of bonds and non bonded forces of attraction

Coordinate Covalent Bond

It is a special type of covalent bond in which only one of the participating atoms contributes the electron pair for sharing. The atom which gives the electron pair for sharing is called the donor and the other atom which accommodates the shared pair of electrons is called an acceptor. In this mechanism, the contribution of electron pair is one-sided, and slight polarity develops in the molecule. A coordinate bond is represented by “→,” pointing from the donor atom to the acceptor atom. It is also called a *dative bond*. A coordinate bond is explained below with the help of an example.

(i) Formation of $\text{NH}_3 \rightarrow \text{BF}_3$



Nitrogen atom of ammonia has a lone pair of electrons and these are accepted by the vacant p-orbital of the boron atom of BF_3 . Hence nitrogen atom is the donor and boron atom is the acceptor.

Other examples with coordinate covalent bond formation are H_3O^+ , $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$, etc.

Metallic Bond

Each atom in a metal crystal loses all its valence electrons. The electrons thus obtained form an electron pool. The resulting positively charged metal ions are believed to be held together by the electron pool. The positively charged metal ions have a definite position in the crystal lattice of the metal. The valence electrons are not attached to any individual ions, they belong to the crystal as a whole and are free to move throughout the metal crystal.

The electrostatic force of attraction that binds metal ions to the mobile electrons within its sphere of influence is known as a *metallic bond*.

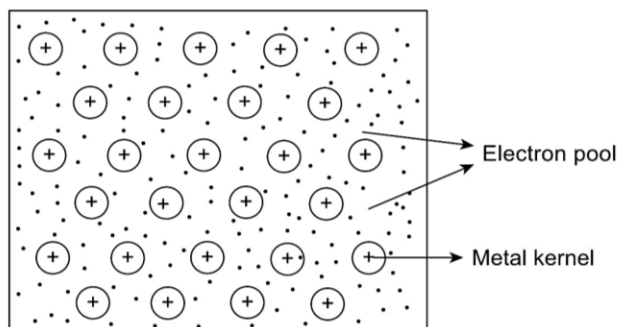


Figure 5.10 Schematic illustration of metallic bond in “electron sea model”

EXAMPLE

Hydrogen bond is nothing but strong dipole-dipole attraction. Justify.

SOLUTION

When a covalent bond is formed between atoms of different elements, partial charges are developed on the bonded atoms. This molecule is called dipole. Due to the presence of opposite

partial charges on the atoms, dipole – dipole attractions exist between the molecules. In case of polar covalent bond between hydrogen and highly electronegative atom, the magnitude of partial charges will be much greater. As a result the dipole-dipole attractions become stronger and this is called hydrogen bond.

EXAMPLE

Why do NH_3 and H_2O act as electron pair donors?

SOLUTION

Ammonia molecule possesses one lone pair on nitrogen atom. Water molecule possesses two lone pairs on oxygen atom. They can therefore donate the excess electron pair to any ion or atom or molecule which has electron deficiency.

EXAMPLE

Between vanderwaal's forces and dipole- dipole attractions, which are stronger? Why?

SOLUTION

Dipole-dipole attractions are stronger as they exist between opposite partial charges. Vanderwaal's forces are weaker as they exist between the nucleus of one atom and the electrons of the other atom.

EXAMPLE

Some metals like sodium can be cut with a knife. How do you explain with respect to metallic bond?

SOLUTION

Sodium has one electron in its valence shell. Being the first element of that period, it has large size. The force of attraction binding the metal ions with electrons that means metallic bond is weaker when compared to the other metals. Therefore, sodium is soft metal and can be cut with a knife.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

- Why do atoms have a tendency to form molecules?
- Which force opposes the interionic forces of attraction between the oppositely charged ions during the formation of an ionic crystal?
- Sharing of three electron pairs between two atoms results in the formation of a _____ bond.
- What type of forces acts between the ions during the formation of a crystal of ionic compound?
- What types of overlapping take place in a sigma and a pi bond?
- Why is more energy required to break a sigma bond than a pi bond?
- The number of non-bonded electrons present on the central atom in the molecule of ammonia is _____.
- How is the strength of the covalent bond related to overlapping of the orbitals?
- Why do polar covalent compounds dissolve in water?
- If the electron pair is unequally shared between the bonded atoms, it results in _____ bond.
- What would be the shape of XY_3 molecule if there is no lone pair on the central atom?
- Why is the H–O–H bond angle in H_2O smaller than H–N–H bond angle in NH_3 ?
- In the formation of a Br_2 molecule, the overlapping of _____ orbitals takes place.
- How many lone pair of electrons are present on the central atom of CH_4 , H_2O , NH_3 , PCl_3 and PCl_5 molecules?
- What type of bond formation takes place between the atoms of Group IA and Group VIIA?
- Although the number of bond pair of electrons in the valence shell of phosphorus in a PCl_3 molecule is 3, its shape is not trigonal planar. Why?
- What are the donors in a hydronium ion and ammonium ion?
- Why do metals conduct electricity?
- The number of σ bonds and π bonds in CO_2 molecule are _____ respectively.
- Why does the presence of a lone pair change the shape of the molecule?
- Why are the participating atoms of a coordinate bond called the donor and the acceptor?
- The electrostatic forces of attraction between the metallic ions and free electrons is called _____.
- How many electrons are present in the valence shells of the central atoms in the molecules of $BeCl_2$, BF_3 and PCl_5 ?
- In PCl_5 molecule, the bond angles are _____ and _____.
- The shape of $BeCl_2$ is _____.
- Write the order of repulsions among the electron pairs.
- How are the hybrid orbitals arranged in the molecules?
- The forces of attraction between the elemental gaseous molecules are called _____.
- How many new hybrid orbitals are formed in sp , sp^2 and sp^3 hybridizations?
- The shape of BF_3 molecule is _____.

Short Answer Type Questions

- “Molecules are stable only when the constituent atoms attain octet configuration.” State whether the given statement is true or false and justify your answer.
- Define an ionic bond and a covalent bond.
- How many sigma bonds and pi bonds are there in a chlorine molecule? Justify your answer.
- Why is a nitrogen molecule less reactive than an oxygen molecule?
- Explain the role of electron affinity and ionization potential during the ionic and covalent bond formation?

36. How is the metallic or non-metallic character of an atom related to bond formation?
37. Explain the structure of BeCl_2 with the help of hybridization.
38. Why is BeCl_2 molecule linear, but BF_3 is trigonal planar?
39. Write a note on the energy changes during the formation of a hydrogen molecule.
40. Write about the partial covalent nature of ionic bond and explain it on the basis of Fajan's rules.
41. "The orbitals of two different shells of an atom combine and form one hybrid orbital." State whether the statement is true or false and justify your answer.
42. Explain the structure of CH_4 with the help of hybridization.
43. Explain the formation of hydrogen, oxygen and nitrogen molecules.
44. Mention two main striking differences between sigma and pi bonds.
45. Explain different types of bond formation in $\text{H}_3\text{N} \rightarrow \text{BF}_3$.

Essay Type Questions

46. Explain the formation of an ionic compound with respect to lattice energy.
47. (a) The strength of a covalent bond depends on which factor/factors?
(b) Classify covalent bonds depending on the strength. Compare those bonds.
48. What are the factors on which the geometrical shapes of covalent molecules depend?
Explain with suitable examples.
49. (a) What are the conditions required for the overlapping of the orbitals during covalent bond formation?
(b) Describe the different types of orbital overlapping with suitable examples.
50. (a) What is hybridization?
(b) What are the conditions for an atom to undergo hybridization?
(c) How can we explain the shapes and bond angles of BeCl_2 , BCl_3 and CH_4 with hybridization?

CONCEPT APPLICATION

Level 1

Direction for questions from 1 to 7: State whether the following statements are true or false.

1. Ionic compounds are soluble in organic solvents.
2. All covalent compounds possess coordinate covalent bonds.
3. BF_3 does not obey the octet rule.
4. The bond angle in ammonia is $109^\circ 28'$.
5. A sigma (σ) bond is stronger than a pi (π) bond.
6. The hydrogen bond is always formed between the molecules of the same substance.
7. Covalent bonds are non-directional bonds.

Direction for questions from 8 to 14: Fill in the blanks.

8. In CaF_2 , the number of electron(s) transferred from calcium to fluorine atoms is _____.
9. The bond formed by end on overlap is _____ than the bond formed by side on overlap.
10. Linear overlapping of any two pure atomic p-orbitals lead to _____ bond formation.
11. Cl-C-Cl bond angle in CCl_4 is _____.
12. Among the hydrogen halides _____ has maximum ionic character.
13. The shape of BeCl_2 molecule is _____.
14. In ammonia-boron trifluoride complex, the donor molecule is _____.



Direction for question 15: Match the entries given in column A with appropriate ones from column B.

| Column A | Column B |
|-------------------------|------------------------------------|
| A. Nitrogen | () a. Polar covalent bond |
| B. Xenon | () b. 107° |
| C. Ammonia | () c. Octahedral |
| D. Sulphur hexafluoride | () d. $109^\circ 28'$ |
| E. Hydrogen chloride | () e. Triple bond |
| F. Methane | () f. Two lone pairs of electrons |
| G. Water molecule | () g. Octet configuration |

Direction for questions from 16 to 45: For each of the questions, four choices have been provided. Select the correct alternative.

16. Expanded octet occurs in
(a) NH_3 (b) PF_5
(c) H_2O (d) O_2
17. The lesser covalency of FeCl_2 over FeCl_3 is due to
(a) lower polarizing power of Fe^{+2} than that of Fe^{+3} ion
(b) lower polarizing power of Fe^{+3} than that of Fe^{+2}
(c) higher polarizability of Fe^{+3} than Fe^{+2}
(d) higher polarizability of Fe^{+2} than Fe^{+3}
18. An element X has low ionization energy and another element Y has high electron affinity. The bond formed between them could be
(a) ionic (b) polar covalent
(c) coordinate covalent (d) non-polar covalent
19. Which of the following statements regarding pi bond is not true?
(a) It may be formed by the overlapping of p-atomic orbitals.
(b) It has no independent existence.
(c) It is weaker bond compared to σ bond.
(d) It can be formed by hybrid orbitals.
20. Arrange the following in increasing order of their bond lengths.
 $\text{C}-\text{C}, \text{C}=\text{C}, \text{C}\equiv\text{C}$
(a) $\text{C}\equiv\text{C} < \text{C}=\text{C} < \text{C}-\text{C}$
(b) $\text{C}=\text{C} < \text{C}-\text{C} < \text{C}\equiv\text{C}$
(c) $\text{C}\equiv\text{C} < \text{C}-\text{C} < \text{C}=\text{C}$
(d) $\text{C}-\text{C} < \text{C}=\text{C} < \text{C}\equiv\text{C}$
21. Which of the following statements is wrong?
(a) KCl is soluble in water.
(b) HCl conducts electricity in its aqueous solution.
(c) Acetic acid is soluble in water.
(d) The bond formed between aluminum and fluorine is covalent.
22. NH_4^+ is isostructural with
(a) PCl_3 (b) CH_4
(c) BF_3 (d) NO_3^-
23. In water molecule, the bond angle of 104.5° around oxygen is accounted due to
(a) high electron affinity of oxygen
(b) very high repulsions between lone pair and bond pair of electrons
(c) very high repulsion between lone pair and lone pair electrons
(d) small size of hydrogen
24. Which of the following bonds is more polar when compared to others?
(a) O-H (b) N-H
(c) C-H (d) H-H
25. The number of sigma and pi bonds in benzene are
(a) 6σ and 3π bonds (b) 12σ and 3π bonds
(c) 9σ and 3π bonds (d) 6σ and 6π bonds
26. Which among the following pairs of molecules possess same geometry?
(a) $\text{BeCl}_2, \text{SiO}_2$ (b) $\text{CO}_2, \text{SiO}_2$
(c) $\text{BF}_3, \text{PCl}_3$ (d) $\text{F}_2\text{O}, \text{H}_2\text{S}$
27. The number of σ and π bonds in C_2H_2 is _____.
(a) 0 and 4 (b) 2 and 2
(c) 3 and 2 (d) 4 and 2
28. A species H_3O^+ pyramidal in shape. The number of lone pairs of electrons is
(a) 0 (b) 1
(c) 2 (d) 3
29. The shape of H_2O molecule is _____.
(a) linear (b) tetrahedral
(c) v-shaped (d) trigonal planar





30. The covalency of "N" in NH_4^+ ion is equal to number of
- covalent bonds
 - coordinate bonds
 - covalent bonds and coordinate bonds
 - valence electrons

31. Two substances X and Y are dissolved in water under suitable conditions. X is a gas while Y is a solid under normal conditions. Solution of Y is found to conduct electricity but not "X." Based on the conclusion identify the nature of bond present in X and Y with appropriate reasons as given below.

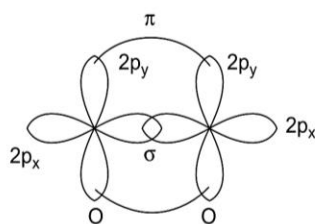
Arrange the steps given below in a sequence.

- Y is a solid at room temperature and its aqueous solution conducts electricity. This shows that it is an ionic compound.
- X on dissolution in water doesn't conduct electricity and is a gas at room temperature. Hence it should be a nonpolar covalent molecule.
- Aqueous solutions of both ionic compounds and polar covalent compounds conduct electricity because of the presence of free ions.
- All ionic compounds are solids and most of the nonpolar covalent molecules are gases or solids at room temperature. Polar covalent compounds are liquids or gases.

- 3 4 2 1
- 1 4 3 2
- 1 3 2 4
- 3 1 2 4

32. The formation of double bond in an oxygen molecule is explained below. Arrange the given points in a sequential order.

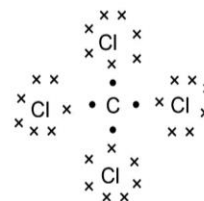
- $2p_y$ orbitals of each oxygen atom overlap laterally/sidewise to form a pi bond.
- Thus, double bond between two oxygen atoms in which one p_z-p_z sigma bond and p_y-p_y pi bond is formed.



- All the three $2p$ orbitals are perpendicular to each other. Hence $2p_z$ orbitals of each oxygen atom overlap end to end to form a sigma bond.

- The electronic configuration of oxygen is O: $1s^2 2s^2 2p_x^1 2p_y^2 2p_z^1$.
- 3 1 4 2
 - 4 3 1 2
 - 3 4 2 1
 - 3 4 1 2

33. The necessary steps required to show the formation of CCl_4 by Lewis electron dot diagram have been jumbled. Arrange them in a sequence.



- Thus, an electron pair is shared between C and Cl. This is the Lewis electron dot diagram for CCl_4 .

- Write the symbol of chlorine and represent its valence electrons with the help of crosses, i.e.,



- Write the symbol of carbon and represent its valence electrons with the help of dots, i.e.,



- When carbon combines with four chlorine atoms, the carbon atom contributes four electrons for sharing, whereas each chlorine atom contributes only one electron for sharing. Thus, both the atoms in CCl_4 attain an octet.

- 1 3 2 4
- 2 1 3 4
- 4 3 2 1
- 3 2 4 1

34. Which among the following substances does not conduct electricity in its aqueous solution state?

- glucose
- alcohol
- hydrochloric acid
- common salt

35. The ease of formation of which of following chlorides is maximum?

- NaCl
- KCl
- RbCl
- CsCl

36. During the formation of sodium chloride from its constituents,

- Na undergoes oxidation and acts as an oxidizing agent.
- Na undergoes reduction and Cl undergoes oxidation.

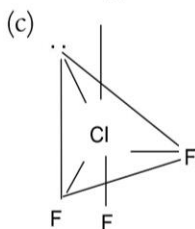
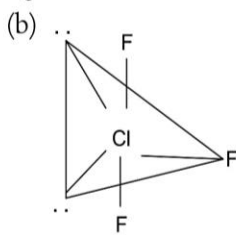
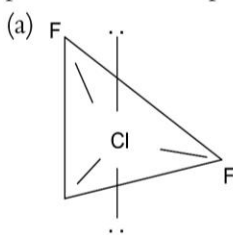
- (c) Cl undergoes reduction and acts as a reducing agent.
(d) Na acts as a reducing agent and Cl acts as an oxidizing agent.
37. The valence electronic configurations of two elements are $4s^1$ and $3s^2 3p^5$, respectively. The type of bond expected to be present between them is
(a) polar covalent bond
(b) nonpolar covalent bond
(c) metallic bond
(d) ionic bond
38. The angular shape of water molecule is due to
(a) high electron affinity of oxygen
(b) very high repulsions between lone pair and bond pair of electrons
(c) very high repulsion between lone pair and lone pair electrons
(d) small size of hydrogen
39. The element which has the strongest metallic bond among $_{11}A^{23}$, $_{12}B^{24}$, $_{13}C^{27}$ and $_{19}D^{39}$ is _____.
(a) A (b) B
(c) C (d) D
40. Identify the compound that exhibits maximum ionic character among the following:
(a) $MgCl_2$ (b) $BaCl_2$
(c) $NaCl$ (d) $CsCl$
41. Identify the favourable conditions for the formation of ionic bond:
(a) low IP value of metal, low EA value of nonmetal
(b) high IP value of metal, high EA value of nonmetal
(c) low IP value of metal, high EA value of nonmetal
(d) high IP value of metal, low IP value of nonmetal
42. Among the following molecules, p-p overlap takes place in
(a) H_2 (b) $BeCl_2$
(c) F_2 (d) HF
43. Among the following molecules H-bond is present in
(a) NH_3 (b) PH_3
(c) H_2S (d) CH_4
44. The covalency of oxygen in hydronium ion is equal to number of
(a) covalent bonds
(b) coordinate bonds
(c) covalent bonds and coordinate bonds
(d) valence electrons
45. A solid compound "A" consists of simple ions. Choose corresponding answers from the choices given below.
Nature of the bond present in A will be
(a) ionic (b) covalent
(c) molecular (d) hydrogen bond

Level 2

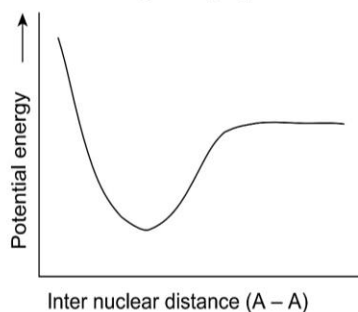
- Both CH_4 and CCl_4 are non-polar molecules, but $CHCl_3$ is a polar molecule. Discuss.
- Copper (I) and silver (I) halides are more covalent in nature compared to sodium and potassium halides although the charges on the ions are same. How do you account for this?
- The orbitals p and d can form π bonds, but the s-orbital cannot form a π bond. Give reasons.
- Compare the shapes of the meniscus of water in a glass tube and in wax coated glass tube. Give an appropriate reason.
- Between CuO and CuS which is more covalent and why?
- Why is the repulsion between two lone pairs of electrons more than that between a lone pair and a bonded pair or a bonded pair and a bonded pair of electrons?
- Between NF_3 and BF_3 , which is the more polar molecule? Why?
- Noble gases do not usually form chemical bonds. But xenon forms a number of stable compounds. Account for this.
- Just like H_2O , there are two lone pairs in Cl_2O molecule. But bond angle in Cl_2O is 111° . Explain.
- Though sulphur has only two unpaired electrons it exhibits covalency of 2, 4, 6. Explain.



- Phosphorous can form PCl_5 molecule in the excited state of phosphorous atom. But the formation of PH_5 is not possible in the same state. Account for this.
- Between LiF and LiI , which has the higher lattice energy and why?
- Which among the following geometries is most preferred with respect to ClF_3 molecule and why?



- Explain and give reasons for the changes in potential energy after the bond formation in a diatomic molecule from the given graph.



- In comparison with sodium salts, ammonium salts are more soluble in water. Explain.

Level 3

- CO_2 exists in the gaseous state, whereas SiO_2 is a hard solid though both carbon and silicon belong to the same group. Give reasons.
- A molecule has 3 bonded pairs and 2 lone pairs on the central atom. Explain the shape of the molecule with an example.
- XeF_2 is also a linear molecule like BeCl_2 . But they differ in their formation and structural aspects. How can you justify this?
- A molecule has an octahedral geometry. So how many number of valence electrons should the

Directions for questions from 16 to 25: Application-Based Questions

- Compare NaCl and CsCl with respect to ease of formation and also strength of ionic bond.
- Comment on the intensity of charge of an electric field when HF and dry air are placed between two charged parallel plates.
- Phosphorous can form PCl_5 molecule in the excited state of phosphorous atom. But the formation of PH_5 is not possible in the same state. How do you account for this?
- Predict hybridization and shape of SF_4 molecule.
- All halides of sodium are ionic. Fluorides and chlorides of magnesium are ionic. But among halides of aluminum, only AlF_3 is ionic. How do you account for this variation?
- The nitrogen atom of NH_3 acts as a donor during the formation of a coordinate covalent bond while the central nitrogen atom in NO_2 cannot act as a donor. Explain.
- Increase in temperature decreases the conductivity of metallic conductors. Give a reason.
- Why are metals malleable and ductile?
- Explain how chlorine exhibits a maximum covalency of 7.
- Both helium and beryllium have ns^2 valence electronic configuration. But beryllium forms compounds and helium cannot form compounds. Explain.

central atom possess and are the number of valence electrons is the same if one, two bond pairs are successively replaced by lone pairs? What are the geometries of the molecules with one and two lone pairs? Explain with the help of hybridization.

- Thallos compounds are more common and stable than thallic compounds. Justify this statement.

Directions for questions from 6 to 10: Application-Based Questions

- Lattice energies of fluoride, chloride, bromide and iodide compounds are 766.5, 597.5, 537.5 and



437.03 kJ/mole, respectively. Compare the oxidizing capacities of the halogens on the basis of the lattice energies of these compounds with an appropriate reason.

7. A molecule "AB₅" has five bond pairs around the central atom "A." If the bond pair of electrons are successively replaced by one, two and three lone pair of electrons, then what would be the preferred shapes of the molecules and how do they differ from actual geometry of AB₅?
8. Though covalent character increases from lithium fluoride to lithium iodide, lithium fluoride is insoluble in water while lithium iodide is soluble. Justify the above statement.
9. Between NF₃ and BF₃, which is the more polar molecule? Why?
10. The atomic number of tin is 50 and chlorine is 17. What should be the shape of SnCl₂ molecule in its vapour state?



CONCEPT APPLICATION

Level 1

True or false

- | | | | |
|----------|----------|----------|----------|
| 1. False | 2. False | 3. True | 4. False |
| 5. True | 6. False | 7. False | |

Fill in the blanks

- | | | | |
|--------|-------------|-------------|----------------------|
| 8. two | 9. stronger | 10. sigma | 11. $109^{\circ}28'$ |
| 12. HF | 13. linear | 14. ammonia | |

Match the following

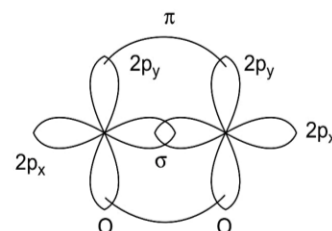
- | | | | |
|-----------|-------|-------|-------|
| 15. A : e | C : b | E : a | G : f |
| B : g | D : c | F : d | |

Multiple choice questions

- | | | | | |
|-------|-------|-------|-------|-------|
| 16. b | 17. a | 18. a | 19. d | 20. a |
| 21. d | 22. b | 23. c | 24. a | 25. b |
| 26. d | 27. c | 28. b | 29. c | 30. c |

Solutions for questions from 31 to 45:

31. (i) Aqueous solutions of both ionic compounds and polar covalent compounds conduct electricity because of the presence of free ions.
- (ii) All the ionic compounds are solids and most of the nonpolar covalent molecules are gases or solids at room temperature. Polar covalent compounds are liquids or gases.
- (iii) As aqueous solution of X doesn't conduct electricity and moreover it is a gas at room temperature. It should be a non-polar molecule. Hence, it is a covalent molecule.
- (iv) Y is a solid at room temperature in which its aqueous solution conducts electricity shows that it is an ionic compound.
32. (i) The electronic configuration of oxygen is O: $1s^2 2s^2 2p_x^2 2p_y^1 2p_z^1$.



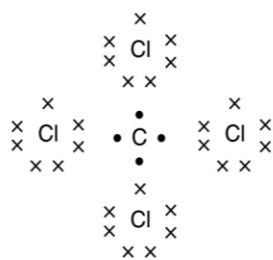
- (ii) All the three 2p orbitals are perpendicular to each other.

Hence 2p_z orbitals of each oxygen atom overlap end to end to form a strong sigma bond.

- (iii) 2p_y orbitals of each oxygen atom overlap laterally/sidewise to form a weak pi bond.
- (iv) Thus double bond between two oxygen atoms in which one p_y-p_y pi bond is formed.

33. (i) Write the symbol of carbon and represent its valence electrons with the help of dots, i.e.,





(ii) Write the symbol of chlorine and represent its valence electrons with the help of crosses, i.e.,



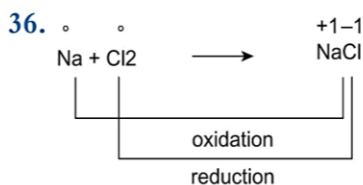
(iii) When carbon combines with four chlorine atoms, the carbon atom contributes four electrons for sharing, whereas each chlorine atom contributes only one electron. Thus, both the atoms in CCl_4 attain an octet.



(iv) Lewis electron dot diagram for CCl_4 . Thus, an electron pair is shared between C and Cl.

34. Since glucose does not ionize in water, it does not conduct electricity in its aqueous solution state.

35. The ease of formation of ionic bond is directly proportional to the size of metal atom and inversely proportional to the size of non-metallic atom. Hence the ease of formation of ionic bond is maximum in CaCl .



During the formation of NaCl , Na undergoes oxidation and Cl undergoes reduction. Hence Na is the reducing agent and Cl is the oxidizing agent.

37. The two elements are potassium and chlorine, respectively. Hence the bond formed between them is an ionic bond.

Level 2

- (i) bonds present in the molecule of CH_4 , CCl_4 and CHCl_3 and their polarity
(ii) bond moments of C-H and C-Cl bonds
(iii) shapes of the respective molecules
(iv) influence of the shape on the molecule of the net dipole moment

38. In a water molecule, oxygen has sp^3 hybridization. Two of these hybrid orbitals have lone pair of electrons, and the other two overlap with s-orbital of hydrogen to form sigma bonds. The expected shape is tetrahedral. But due to lone pair-lone pair repulsions, the shape becomes angular.

39.

| Elements | Atomic numbers | Electronic configurations |
|----------|----------------|---------------------------|
| A | 11 | 2, 8, 1 |
| B | 12 | 2, 8, 2 |
| C | 13 | 2, 8, 3 |
| D | 19 | 2, 8, 8, 1 |

A and D can lose one electron and become stable, B loses two electrons and C loses 3. Strength of metallic bond depends on the charges on metal kernels and radii. As C has the maximum charge and is the smallest in size among the given elements, the metallic bond is the strongest in C.

40. CsCl is a compound in which the bond shows maximum ionic character. According to Fajan's rule, caesium has large size and lesser charge and hence shows maximum ionic character.

41. Ionic bond formation is favourable between metals having low IP values and nonmetals having high EA values.

42. Electronic configuration of fluorine is $1s^2 2s^2 2p^5$ and has a half-filled p-orbital for overlapping.

43. Since the electronegativity of N is greater than P, S and C, H-bond is present in NH_3 gas.

44. In hydronium ion both coordinate and covalent bonds are present. Hence the covalency of oxygen in hydronium ion is equal to number of covalent bonds and coordinate bonds.

45. As the solid compound A consists of simple ions, A is ionic in nature.



3. (i) shape of orbitals
(ii) shapes of p- and d-orbitals in contrast to the shape of "s-" orbitals
(iii) type of overlapping in π bond
4. (i) composition and nature of glass and wax
(ii) comparison of types of forces existing between the molecules of water, glass and water and wax
(iii) relation between type of force and meniscus
5. (i) comparison of size of the anions
(ii) comparison between anionic sizes of O^{-2} and S^{-2} ions
(iii) effect of anionic size on the polarizing power of Cu^{+2} ion
6. (i) difference between lone pair and bond pair
(ii) comparative study of nuclear force of attraction on the lone pairs and bond pairs
(iii) comparison of spreading of electron clouds of lone pairs and bond pairs
7. (i) comparison of shape of BF_3 and NF_3
(ii) number of lone pairs and bond pairs present in the valence shell of the central atom of respective molecules
(iii) shapes of the respective molecules
(iv) influence of shape on the polarity of the molecule
8. (i) comparison of atomic size of xenon with other noble gases
(ii) electronic configuration of xenon and atomic size of xenon
(iii) scope for excited state configurations
(iv) types of hybridizations possible
9. (i) comparison of electrons present in the valence shell in Cl in Cl_2O and H in H_2O
(ii) comparison of size between chlorine and hydrogen
(iii) comparison of the valence electronic configuration between hydrogen and chlorine
10. (i) valence shell of "S."
(ii) number and type of orbitals present in the valence shell
(iii) number of unpaired and paired electrons present in valence shell in ground state
(iv) number of unpaired electrons possible in different excited states
- (v) relation between number of unpaired electrons and covalency
11. (i) valence electronic configuration of hydrogen and chlorine
(ii) type of hybridization in PCl_5
(iii) comparison of electronegativities between hydrogen and chlorine
(iv) the difference between the energies of overlapping orbitals
12. (i) comparison of the size of the anions
(ii) factors affecting the lattice energy
13. (i) order or intensity of repulsions between different electron pairs
(ii) preferred positions of an electron pair which causes more repulsion
(iii) geometry based on arrangement of different electron pairs
14. (i) relation between the energy of the system and its stability
(ii) kind of force exerted on the atoms when they approach each other after bond formation
(iii) interrelation among work, force and energy
(iv) effect of the amount of force on the rate of change of energy
15. (i) requisite of a substance to be soluble in water
(ii) type of forces of attraction in between the compounds of $NaCl$ and NH_4Cl
(iii) effect of this on solubility

Solutions for questions from 16 to 25: Application-Based Questions

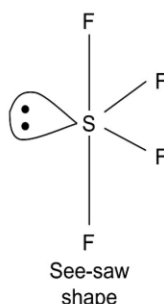
16. Ionic compounds are formed easily between larger cation and smaller anion. This is because an atom whose atomic radius is large can form a cation easily and an atom which has a small atomic radius can form an anion easily. Cs^+ ion can be formed more easily than Na^+ ion. Formation of $CsCl$ is easier than the formation of $NaCl$. Between $NaCl$ and $CsCl$, as the anion is the same, i.e., Cl^- , the sizes of the cations are compared. Cs^+ has a larger ionic radius than Na^+ . Thus the strength of ionic bond is more in $NaCl$ than $CsCl$.
17. When a polar molecule like HF is placed between charged parallel plates, the molecule orients in such a way that the positive end of the molecule is

directed towards the negatively charged plate and the negative end of the molecule is directed towards the positively charged plate. As a result of this, the intensity of the charge on each plate is diminished. However, when dry air (nitrogen, oxygen) which is nonpolar in nature is placed, there would be no change in the intensity of the charge.

18. The valence electronic configurations of phosphorous is $3s^23p^3$. Though there are only 3 half-filled orbitals for bonding, in the excited state five half-filled orbitals are available for bond formation. Among these five orbitals, three are “p-” orbitals and two are “d-“ orbitals. These orbitals overlap with the half-filled “3p” orbitals of five chlorine atoms forming PCl_5 molecule. Such a situation is not possible with hydrogen atoms since there is wide variation in energies between “3d” orbitals of phosphorous and “1s” orbitals of hydrogen.

19. electronic configuration of sulphur is $[Ne]3s^23p^43d^0$
electronic configuration of excited state of sulphur is $[Ne]3s^23p^33d^1$

SF_4 is formed when four half-filled sp^3 hybrid orbitals of sulphur atom overlap with half-filled “p” orbitals of fluorine atoms. Hence there exist four bond pairs and one lone pair in SF_4 molecule. According to the VSEPR theory expected structure of SF_4 is trigonal bipyramidal but as the lone pair and two bond pairs of the molecule lie on the plane and other two bond pairs present above and below the plane and the structure of SF_4 is “seesaw” structure. This deviation is due to the lone pair of electrons.



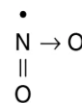
20. Polarizing power of the cation depends on its size and the charge present on it. The smaller the size and the higher the charge of the cation, the greater the polarizing power. Among Na^+ , Mg^{+2} and Al^{+3} , Al^{+3} has least ionic size and the charge present on it is maximum. Hence, polarizing power of Al^{+3} is maximum. Among the halides AlF_3 is ionic, but

other halides of aluminium are covalent. Polarizing power of magnesium is less than aluminium. Hence, chloride and fluoride of magnesium are ionic. But Na^+ has the least polarizing power. Hence, all the halides of sodium are ionic.

21. The central nitrogen atom of ammonia has lone pair of electrons on it which can be donated to form coordinate covalent bond, which is obvious from the nature of bonding present in NH_3 . Thus, the central N atom of NH_3 acts as a donor.



The central “N” atom of NO_2 doesn’t participate in coordinate covalent bond formation due to the lack of lone electron pair on nitrogen. The central “N” participates in coordinate covalent bond formation with oxygen during the formation of NO_2 and thus it cannot further act as donor and forms coordinate covalent bond with other species which is obvious from the nature of bonding present in NO_2 .



22. Being more electropositive in nature, metals have a tendency to lose their valence electrons. Due to the presence of these free electrons metals act as good conductors. But increase in temperature increases the vibrations of metal kernels in the metal lattice. Increase in the vibrations obstructs the path of the electrons which in turn increases the resistance of the metal. Therefore, the conductivity decreases.
23. When a large amount of shearing force is applied to a metal, the metal kernels of one layer slide over the other. After getting displaced, the metal kernels again get stabilized there due to the uniform distribution of free electrons throughout the metal. Hence metals can be permanently deformed without breaking and exhibit malleability and ductility.
24. Electronic configuration of Cl is $[Ne] 3s^23p^5$. In the 3rd shell, there are vacant d-orbitals. The paired electrons of 3s and 3p orbitals can be excited to 3d orbitals. Therefore, the number of unpaired electrons increases. As a result, covalency corresponding to the number of unpaired electrons is exhibited. In the fully excited state of Cl atom, there are 7 half-filled orbitals giving covalency of 7. As there is



no scope for further excitation, it is the maximum covalency that chlorine can show.

Ground state : $\uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \square\square\square\square\square\square$ \Rightarrow Covalency of 1

1st excited state : $\uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\square\square\square\square\square$ \Rightarrow Covalency of 3

2nd excited state : $\uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow\square\square\square$ \Rightarrow Covalency of 5

3rd excited state : $\uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow\square$ \Rightarrow Covalency of 7

Level 3

- comparison of size of carbon and silicon
 - effect of size of carbon and silicon on the nature of bond present in CO₂ and SiO₂
 - influence of nature of bonds on the structure of the molecules
 - relation between the structure of the substance and physical state of matter
- expected shape with 5 bond pairs
 - determination of number of hybrid orbitals
 - the expected shape of the molecule
 - distortion due to lone pairs and resultant shape of the molecule
- comparison of electronic configuration of beryllium and xenon
 - type of hybridization in XeF₂ and BeCl₂
 - the number of lone pairs and bond pairs present in the valence shell of the central atom
- relation between number of valence electron pairs (bond pairs and lone pairs) and geometry
 - number of valence electrons around central atom for octahedral geometry
- valence electronic configuration of thallium
 - difference in the electronic configuration of thallos and thallic ions
 - comparison of the ease of formation of thallos and thallic ions
 - relation between the ease of formation of ion and availability of the compound in nature containing that ion

Solutions for questions from 6 to 10: Application-Based Questions

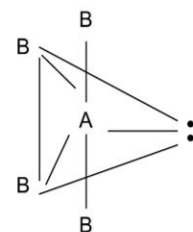
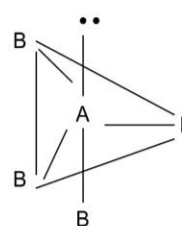
- The more the lattice energy, the stronger the ionic bond which in turn depends on the ease of formation

- Both helium and beryllium have ns² valence electronic configuration. Beryllium has an electron pair in 2s orbital and all three 2p orbitals are vacant. The paired electron of 2s orbital can be excited to 2p orbital thereby giving a covalency of 2. Helium has an electron pair in “1s” orbital and there is no scope for excitation of electrons in the 1st shell. Hence, helium cannot form any compounds.

of anion if the cation is the same. The easier the formation of the anion, the more the oxidizing capacity. Hence, from the given lattice energies it can be concluded that the increasing order of the oxidizing capacities of halogens is

$$I_2 < Br_2 < Cl_2 < F_2$$

- In AB₅ molecule, central atom A is surrounded by five electron pairs and no lone pairs. Hence the structure is a trigonal bipyramid and as there are no lone pairs, so the structure is not distorted. Here in this structure three bonded atoms occupy equatorial positions of the triangle and other two axial positions (top and bottom) of the equilateral triangle. When one of the bond pairs is replaced by a lone pair, the preferred position of the lone pair is equatorial and the geometry is distorted trigonal bipyramid because in this structure it experiences less number of repulsions and hence stable.



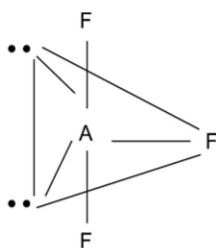
- (i) Wrong structure (ii) Right structure

When two bond pairs are replaced by lone pair of electrons, then the preferred geometry will be the one of lowest energy with minimum repulsions.

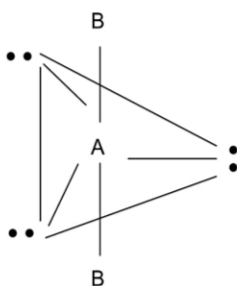
When two lone pairs are present among five electron pairs allowed the central atom then the molecule experiences three types of repulsions and their order is

- $p - l, p > l, p - b, p > b, p - b, p$. The structure which has lesser repulsions is





The two lone pairs are separated by maximum bond angle of 120° and hence the above structure is most preferred geometry which is T-shape with minimum repulsions. When three bond pairs are replaced by a lone pair, then the preferred geometry is the one where three lone pairs occupy equatorial positions with maximum separation of bond angle and hence shape is linear.



8. Since the size of halide ion increases down the group, the ease of getting polarized by a cation also increases. Thus Li^+ ion can polarize I^- ion to a greater extent and thus from LiF to LiI covalent character increases. Hence we expect that LiF is more soluble in water and LiI is less soluble or not

soluble in water. The solubility of an ionic compound in water depends on the relative values of lattice energy and hydration energy. The substance becomes soluble in water if hydration energy exceeds lattice energy. From LiF to LiI , lattice energy decreases while hydration energy increases. Since lattice energy of LiF is much greater than hydration energy, it is insoluble in water and thus solubility in water increases from LiF to LiI .

9. Between NF_3 and BF_3 , NF_3 is polar but BF_3 is non-polar. In the BF_3 molecule there is no lone pair of electrons on the central atom. The shape of this molecule is trigonal planar which is symmetrical. NF_3 has three bond pairs and one lone pair. But due to the presence of a lone pair on nitrogen the polarities are not cancelled. Hence, the NF_3 molecule is polar.
10. The electronic configuration of Sn is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2$ and chlorine is $1s^2 2s^2 2p^6 3s^2 3p^5$. Hence in SnCl_2 molecule in vapour state, there is one lone pair of electrons and two bond pairs of electrons in the valence shell of tin. Therefore, the expected shape is trigonal planar. But due to presence of the lone pair, its shape is bent and bond angle is 88° .

