CHEMICAL BOND

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CHEMICAL BOND

Aim :

To introduce and familiarize the formation, properties of different types of chemical bond

Goals :

1. Describe the nature of a chemical bond and its relationship to valence electrons
2. Compare ionic and covalent bonding
3. Use Lewis dot diagrams to represent ionic and covalent compounds
4. Explain the nature and effects of metallic bonding

Learning outcomes:

1. Understand the common themes running through ionic, covalent , Coordinate and metallic descriptions of chemical bonding
2. Appreciate how chemical substances can be described (and classified) in terms of structure and bond type

Prerequisites:

1. Concepts of electronic configuration
2. Periodic properties

Chemical Bond

A chemical bond is defined as the attractive force that holds two or more atoms together in a molecule or an ion.

Causes of chemical bond:

By a close study of atoms and molecules it has been found that atoms combine chemically for the following reasons:

1. Net attractive force between atom
2. Octet rule
3. Lowering of energy of combining atoms

Net attractive force between atoms

Atoms consist of strongly positive nucleus and negative electrons. When two atoms come closer to combine with each other to form a bond between them, the attractive and repulsive forces begin to operate between them. The attractive forces are between the electrons of one atom and the nucleus of other atom while the repulsive forces are between the electrons or the nuclei of the two atoms.

When the two atoms approach each other these forces counteract each other. The net result of these forces may be either attraction or repulsion between the atoms.

NET ATTRACTIVE FORCE BETWEEN ATOM–Contd.

If the attractive forces become dominant over the repulsive forces the net result is the attraction between the atoms and hence they combine together to form a chemical bond between them.

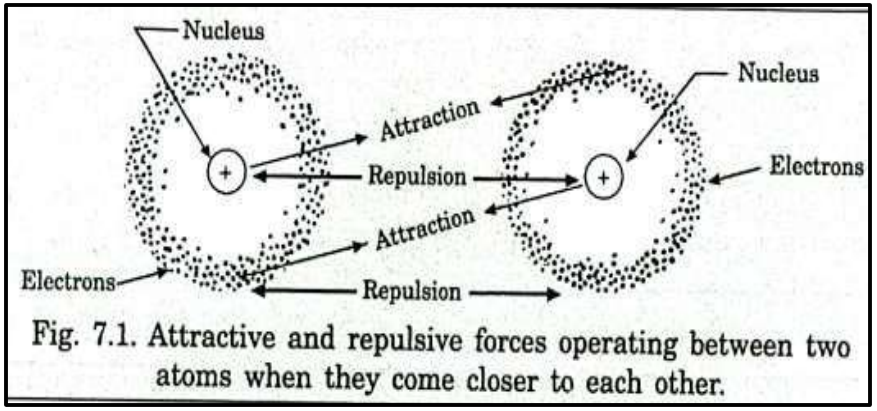


Fig. 7.1. Attractive and repulsive forces operating between two atoms when they come closer to each other.

On the other hand if the repulsive forces become dominant over the attractive forces, the atoms do not combine and hence no chemical bond is established between them.

Attractive force > repulsive force → formation of bond

For example in case of hydrogen atoms the net result is attraction and two hydrogen atoms combine together to form H_2 molecule. On the other hand in case of He atom the net result is repulsion and hence two He atoms do not combine together to form He_2 molecule.

Octet rule or rule of eight

The atoms of noble gases do not normally react with other atoms to form compounds. It is assumed that the outermost shell configuration of the atoms of noble gases is a stable configuration of 8 electrons which is known as **octet**. The two electrons in case of He is also stable as octet which is known as **doublet**.

Noble gas	Atomic No	Electronic configuration
He	2	2
Ne	10	2,8
Ar	18	2,8,8
Kr	36	2,8,18,8
Xe	54	2,8,18,18,8
Rn	86	2,8,18,32,18,8

Octet Rule

The tendency of the atoms to have 8 electrons in their outermost shell is known as **octet rule** or **rule of eight.** Since **helium atom** has **two** electrons, this rule is called **doublet rule or rule of two.**

The atoms possessing less than 4 electrons generally tends to lose them while those having more than 4 electrons in the outer most shell tends to gain the electrons during the chemical combination or bond formation to attain stable configuration of the nearest inert gas

Lowering of energy of combining atoms

When two atoms combine together to form a bond there is an over all decrease in the potential energy of the combining atoms, which has greater stability.

Potential energy curve:

The curve shown below represents the variation of potential energy between the nuclei of the two atoms A and B which are approaching closer to each other form a bond between them. The trend of the curve from right to left should be observed.

When two atoms A and B are far away, say at an infinite distance from each other the attraction between them is zero. Hence there is no possibility of formation of bond between them. This situation has been represented by X.

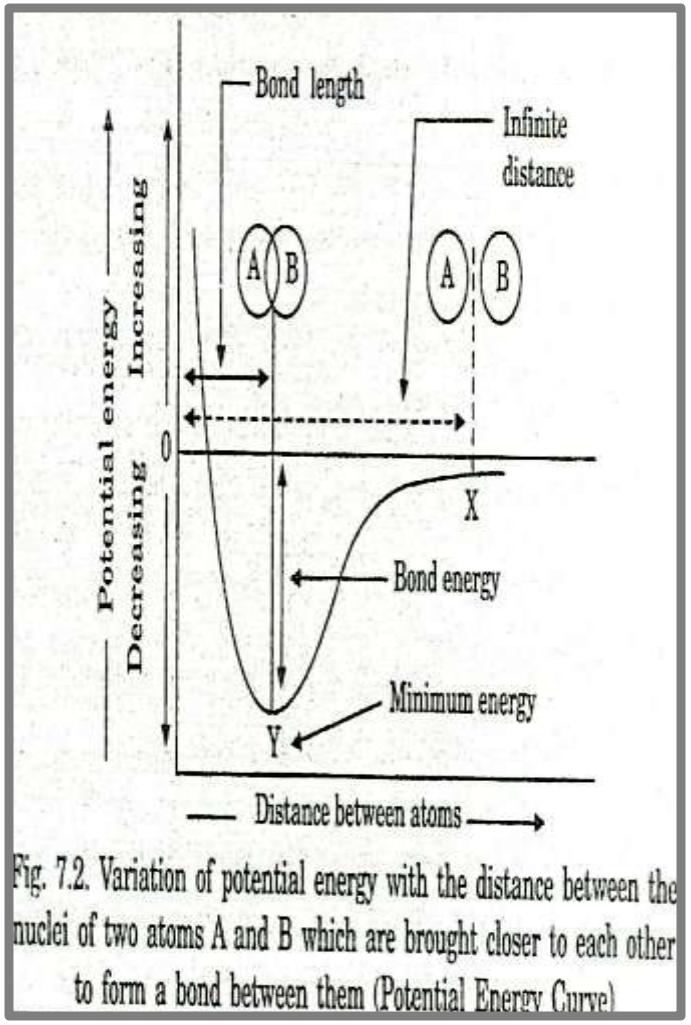


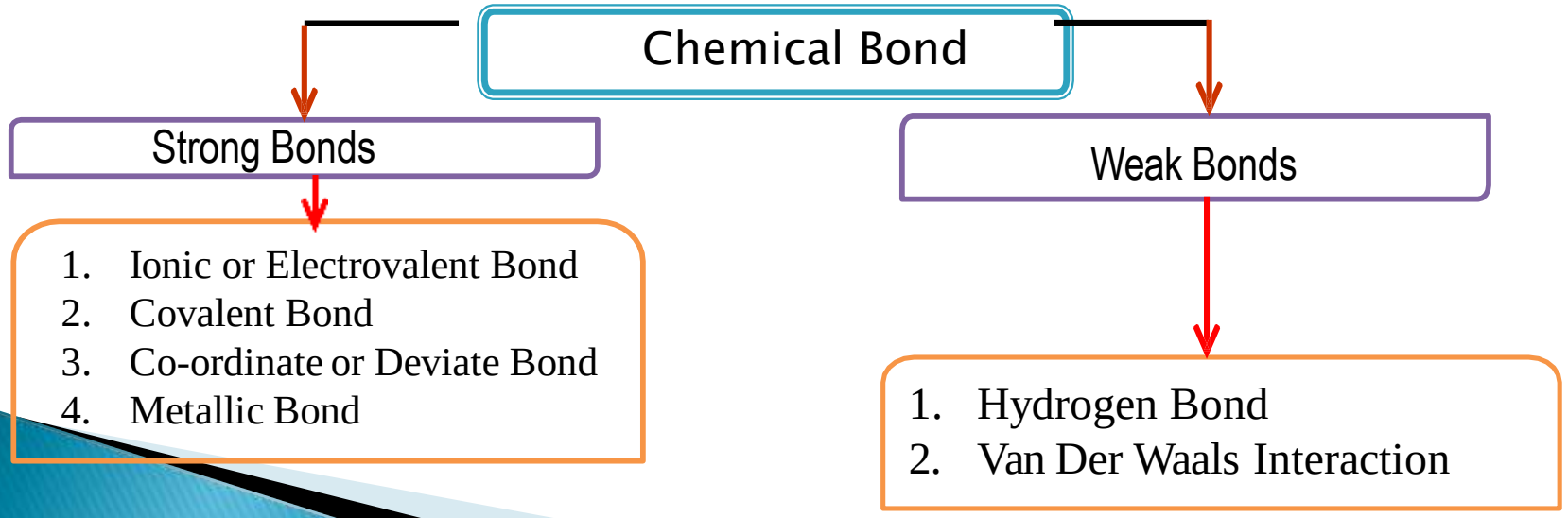
Fig. 7.2. Variation of potential energy with the distance between the nuclei of two atoms A and B which are brought closer to each other to form a bond between them (Potential Energy Curve)

- As the two atoms brought closer to each other i.e. as the distance between the atoms is decreased, the attractive forces between the nucleus and the electrons become more dominant than the repulsive forces operating between the electrons of the two atoms and hence energy of the system goes on decreasing as shown by the downward trend of the curve. This decrease of energy continues till a certain minimum value shown by Y in the curve is obtained.
- Now if the atoms are brought still closer the repulsive forces between the two nuclei at such small internuclear distance becomes dominant and hence the energy of the system starts increasing as shown by the upward trend of the curve.

How Do Atoms Combine ?

- The process by which the atoms of the elements rearrange their outer-most shell electrons to get eight-electron outer most shell configuration which is a stable configuration takes place by the formation of chemical bond.
- In general there are two main classes of bonds (or linkages) which hold the atoms together in a molecule. These two main classes are subdivided into small groups.

Classification of Chemical Bond



Ionic or Electrovalent Bond (Bonding by Transference of Electrons)

- The chemical bond formed between two atoms by transfer of one or more valence electrons from one atom to the other is called ionic bond.
- This bond is also called electrovalent or polar bond.

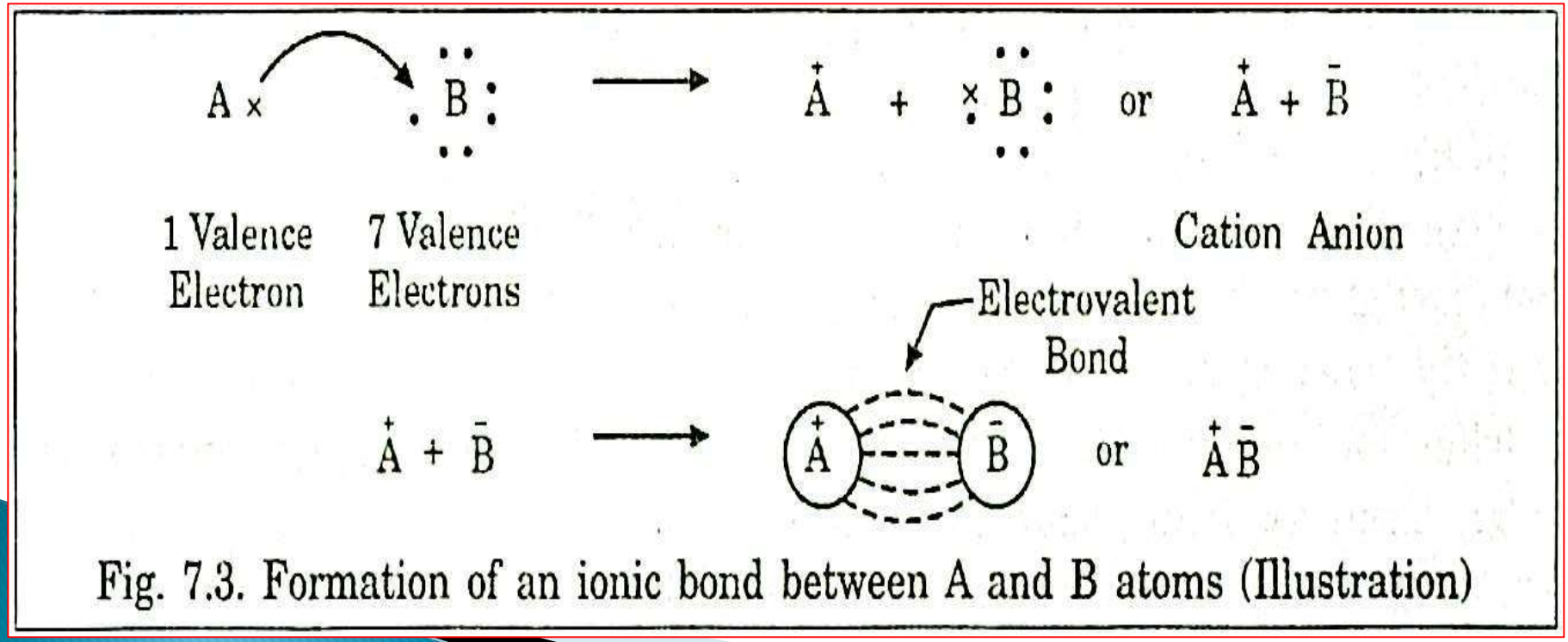
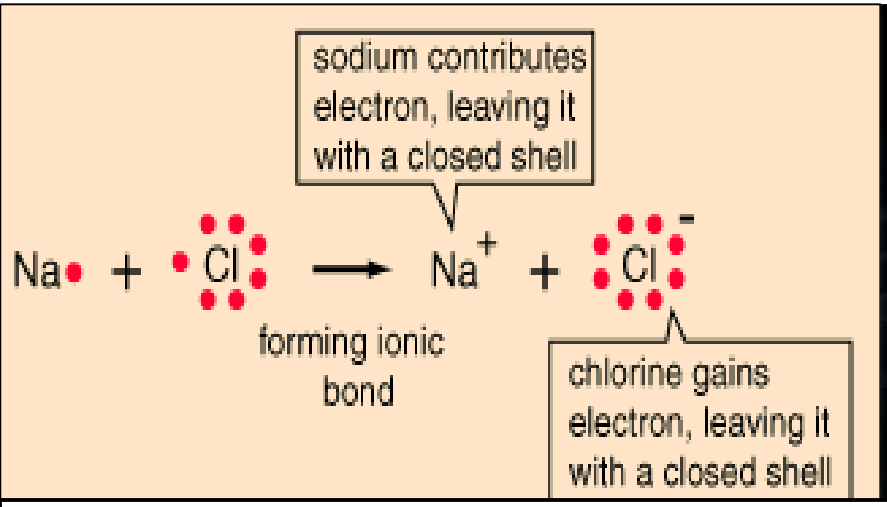


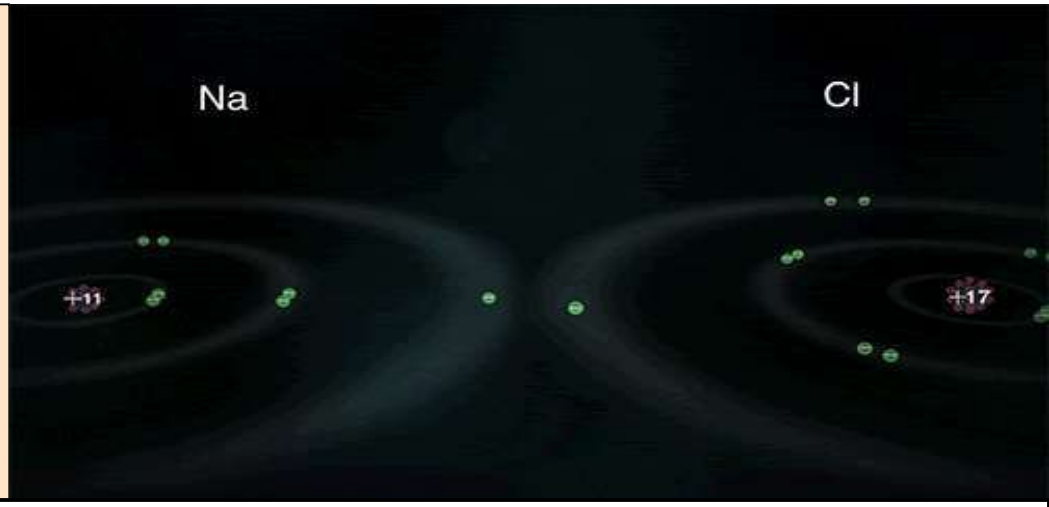
Fig. 7.3. Formation of an ionic bond between A and B atoms (Illustration)

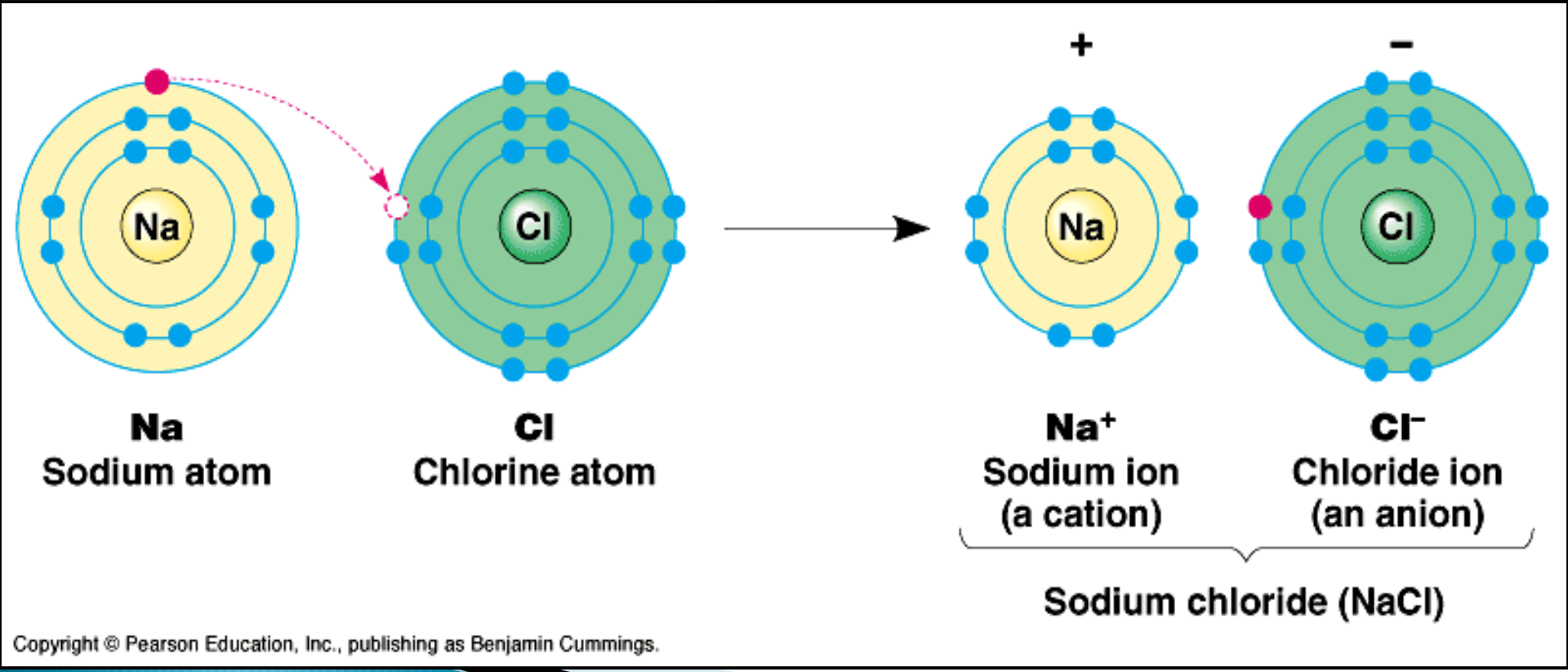
Illustration of the formation ionic bond

- Let us consider two atoms A & B ; atom A has one electrons in the valence – shell while atoms B has seven electrons. Thus A has one electron in excess and B has one electron short than the stable octet. Therefore A transfers an electron to B and converts into positive ion (cation) A^{+} ·On the other hand B accepts an electron from A and converts into negative (anion)B^{-}

- In this transaction both the atoms acquire a stable electronic configuration of their nearest inert element. The resulting cation and anion are held together by electrostatic force of attraction which is called **ionic bond** or **electrovalent bond.**







FACTORS FAVOURING THE FORMATION OF IONIC BOND

1. Number of Valence electron: The atom which is converted into **cation** should posses 1, 2 or 3 valence electrons while the atom which is converted into **anion** should have 5, 6 or 7 valence electrons. The element of group IA, IIA and IIIA satisfy this condition for the cation and those of group VA, VIA and VIIA satisfy this condition for anion.

2. The ionization energy of the metal atom should be low.

3. Electron affinity of the nonmetal should be high.

FACTORS FAVOURING THE FORMATION OF IONIC BOND

4. The lattice energy of the ionic compound formed should high:

The energy released when one gram mole a crystal is formed from its gaseous atoms is called the lattice energy of the crystal. Thus: Higher the value of the lattice energy of a crystal, the greater is the ease of its formation i.e. greater will be the stability of the crystal.

5. Electronegativity difference of the two atoms forming the ionic bond should be high: In fact a difference of 2 or more is essential for the formation of ionic bond.

For example, since the electro negativity difference between Na and Cl is 2.1 (Na=0.9, Cl=3.0) Na and Cl will form an ionic bond in NaCl molecule.

Properties of Ionic compounds

1.Solids at room temperature: On account of strong electrostatic forces between opposite ions, those ions are locked in their allotted positions in the crystal lattice. Since they lack the freedom of movement of characteristics of the liquid state , they are solid at room temperature

2. High melting points:

Ionic compounds have high melting points or boiling points, Since the cation and anions tightly held in their positions in the lattice. Only at high temperature do the ions acquire sufficient kinetic energy to over come their attractive force and attain the freedom of movement as in a liquid. Thus ionic compound need heating high temperature.

Properties of Ionic compounds

3.Electrical conductivity:

Ionic compounds do not conduct electricity when they are in solid state, because the ions are fixed rigidly in their positions. In the molten state and in water solutions, ions are rendered free to move about. Thus molten ionic compounds or their aqueous solution conduct a current when placed in an electrolytic cell.

4. Solubility: When a crystal of an ionic substance is placed in water, the polar water molecule detach the cation and anions from the crystal lattice by their electrostatic pull. These ions then get surrounded by water molecules and can lead an independent existence and are thus dissolved in water. By the same reason, non polar solvents like benzene (C_6H_6) and hexane (C_6H_{14}) will not dissolve ionic compounds.

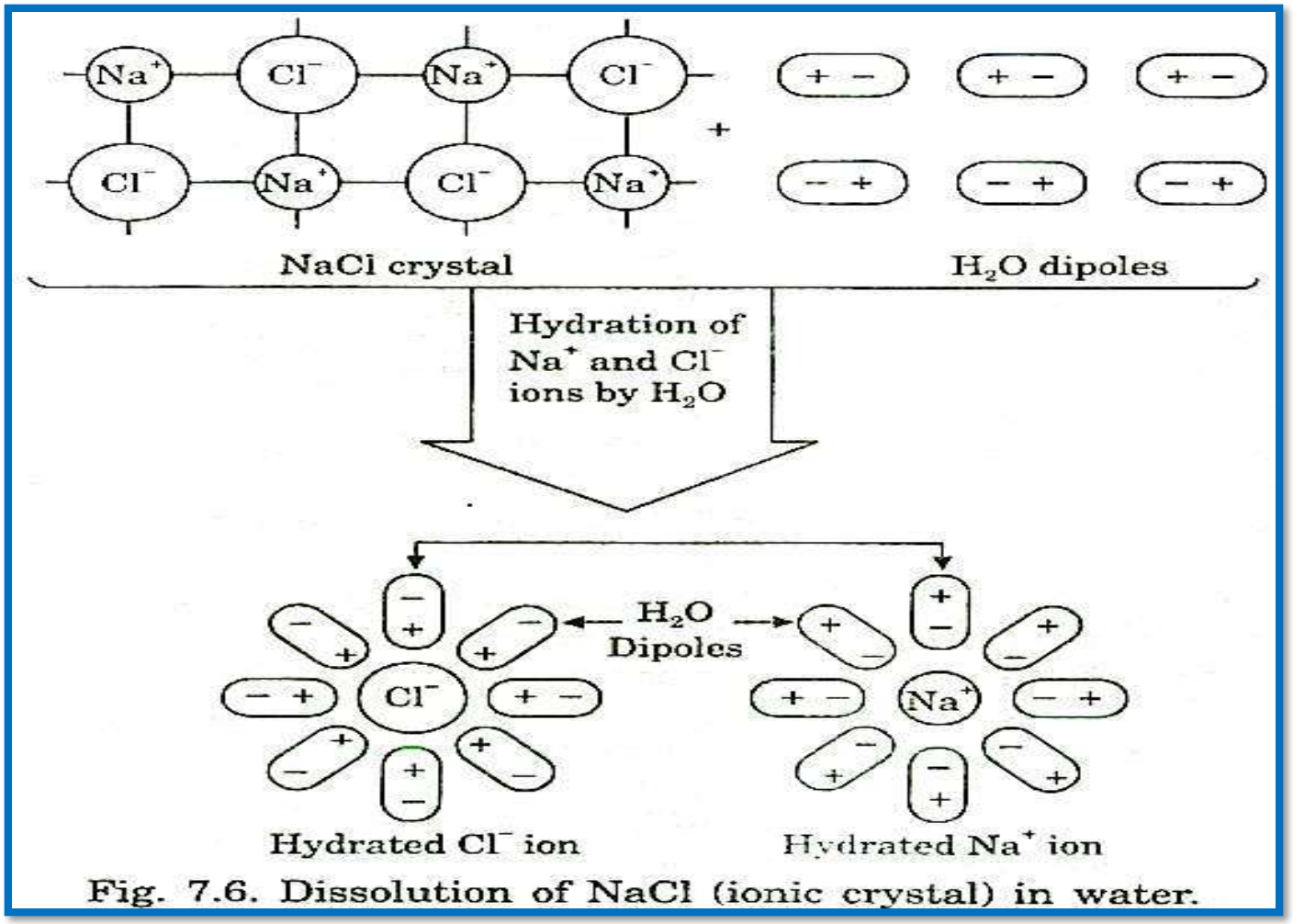
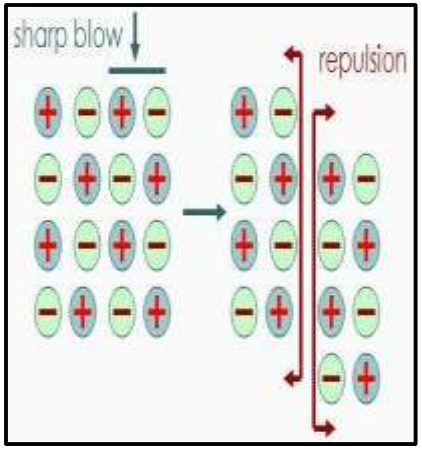


Fig. 7.6. Dissolution of NaCl (ionic crystal) in water.

5. Crystal structure: Ionic solids do not exist as individual neutral independent molecules rather they exist as three dimensional solid aggregates which have definite geometric shape.

6. Highly brittle: Ionic solids are highly brittle, i.e. if a little external force is applied on ionic crystals, they are easily broken. This property is called brittleness.

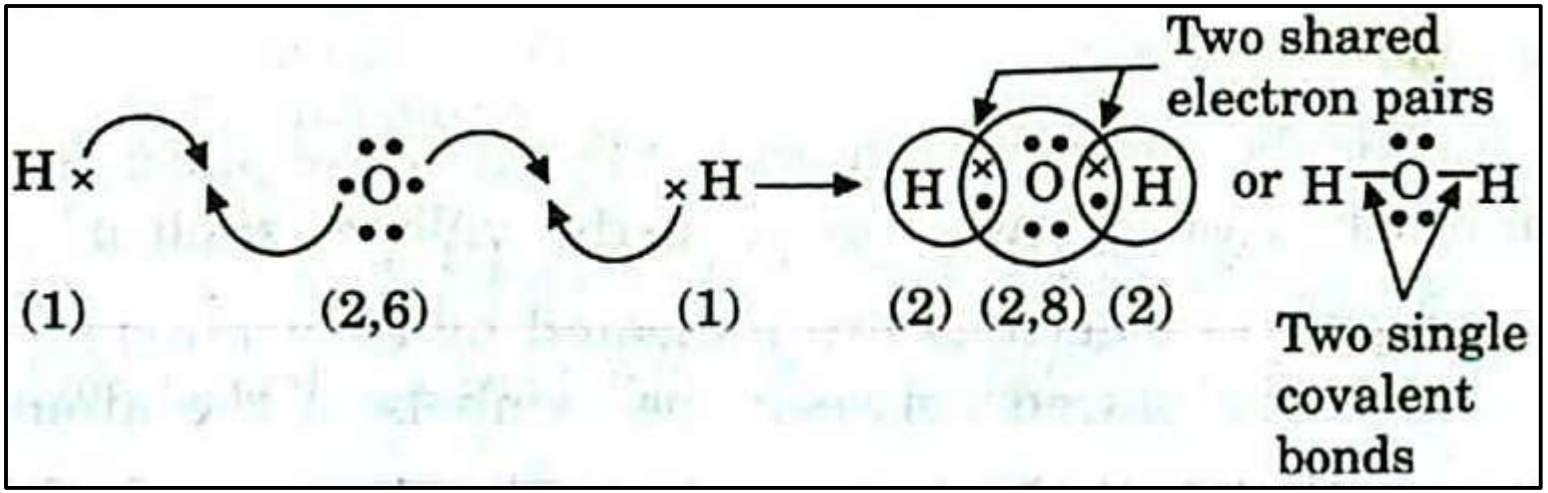


7. High density : The electrostatic force of attraction between the cation and the anion in an ionic crystal bring these ions very close to each other. This decreases the volume of crystal and as a consequence this ionic crystal has high density.

Covalent bond

The chemical bond between two atoms in which the electrons (in pair) are shared by both the participating atoms is called covalent bond.

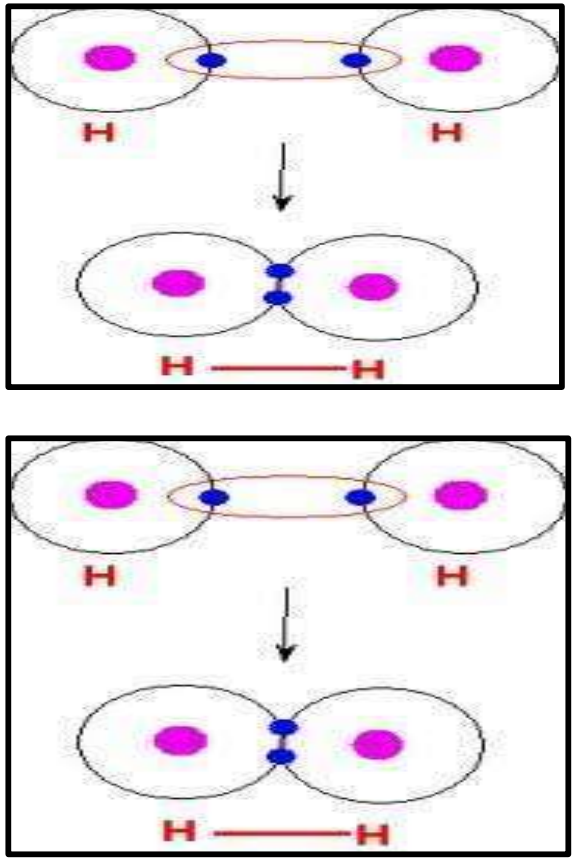
Illustration of the formation of covalent bond



Hydrogen atom has one valence electron and oxygen atom (2,6) has six valence electrons, and achieves the stable octet by sharing two electrons with two hydrogen atoms (one with each H atom.

Thus hydrogen atoms acquire 2 electrons and oxygen acquires 8 electrons in their respective outermost shells and the shared electron pair contributes a covalent bond between hydrogen atoms and oxygen.

Some Other Examples: H_2, N_2, O_2 , NH_3 ,BF_3, CH_4 molecules



Types of Covalent bond

The covalent bond formed by the sharing of one, two or three electron pairs between the participating atoms is called single, double and triple covalent bond respectively.

Double and triple covalent bonds are called **multiple covalent bonds.**

Type	Representation	No. of Electron Pairs	Example
Single Covalent bond	Single Dash (–)	1 pair=(1×2)=2 electrons	H–H, Cl–Cl H–Cl, H–O–H
Double Covalent bond	Double Dash (=)	2 pairs=(2×2)=4 electrons	O=O
Triple Covalent bond	Triple Dash (≡)	3 pairs=(3×2)=6 electrons	N≡N

FACTORS FAVOURING THE FORMATION OF COVALENT BOND

1. High ionization energy: Atoms which have high value of ionization energy are incapable of losing electrons to form cations. Thus these elements form covalent bond rather than ionic bond.

2. Equal electron affinities: For covalent bonding the two atoms must have almost equal attraction for electrons.

3. Number of valence electron: each of the two atoms should have 5, 6 or 7 valence electrons (H atom has only one electron) so that both the atoms achieve the octet by sharing 3, 2 or 1 electron pair. The nonmetals of VA, VIA and VIIA groups respectively satisfy this condition.

4. Equal electro negativity: both atoms should have equal electro negativity so that the transfer of electron(s) from one atom to another may not take place.

5. High nuclear charge and small internuclear distance: High charge on the bonding nuclei and smaller internuclear distance favor the formation of covalent bond.

6. Crystal structure:

Crystals of solid covalent compounds are of two types:

a. Those in which every atom is bonded with other atoms by covalent bonds resulting in the formation of giant molecule. **Example: Diamond, silicon carbide (SiC), aluminium nitride (AlN) etc.**

b. Those which consist of separate layers. The covalent compounds containing separate layers are said to have layer lattice structure. **Example of such compounds is: CdI_2, $CdCl_2$, BN, graphite etc.**

7. **Neither too hard nor too brittle:** Covalent compound are neither hard nor brittle. Rather they are soft and waxy, since they usually consist of separate molecules.

Comparison of the properties of ionic and covalent compounds

Property	Ionic Compounds (Electrovalent compounds)	Covalent Compounds
1. Physical State	Crystalline solids at room temperature.	Gases or liquids, solids (high molecular weight).
2. Crystal Structure	They consist of 3D solid aggregates (ionic solids).	Two types (a) giant molecules (e.g. diamond) and (b) separate layers (e.g. graphite).
3. Hardness and brittleness	Hard and brittle.	Soft and waxy.
4. Nature of reactions	They undergo ionic reactions (in solution) which are fast and instantaneous.	They undergo molecular reactions (in solution) which are slow.
5. Melting and boiling points	Usually have high melting and boiling point.	Covalent solids have low melting and boiling points (exception-giant molecules).
6. Solubility	Freely soluble in polar solvents and insoluble in or slightly soluble in non polar solvents.	Insoluble in polar solvents and readily soluble in non-polar solvents.
7. Electrical conductivity	Conduct electricity in fused state or in solution.	Poor conductors.
8. Formation	By the transfer of electrons from metal to a non-metal.	By the sharing of electrons pair (s) between non-metal atoms.
9. Isomerism	Rare	Frequent.
10. Rigidity	Non rigid and non-directional.	Rigid and directional.

Coordinate Bond

A coordinate bond is a covalent bond formed between two atoms in which the shared pair of electrons is contributed by only one of the atoms. The atom providing the electron pair is called the donor atom. The atom which accepts the electron pair is called the acceptor atom. A coordinate bond is denoted by an arrow pointing towards the acceptor atom.

Condition for the formation of coordinate bond:

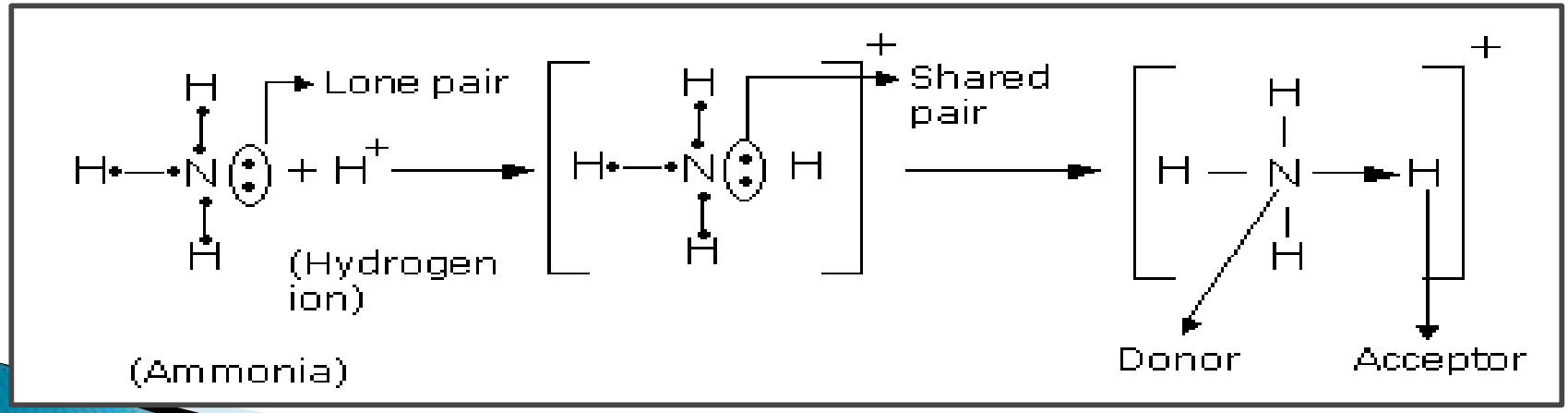
1. The donor atom should have a lone pair of electron.
2. The acceptor atom should have a vacant orbital to accept the electron pair donated by donor.

Examples :

1.Ammonium Ion Coordinate Bond

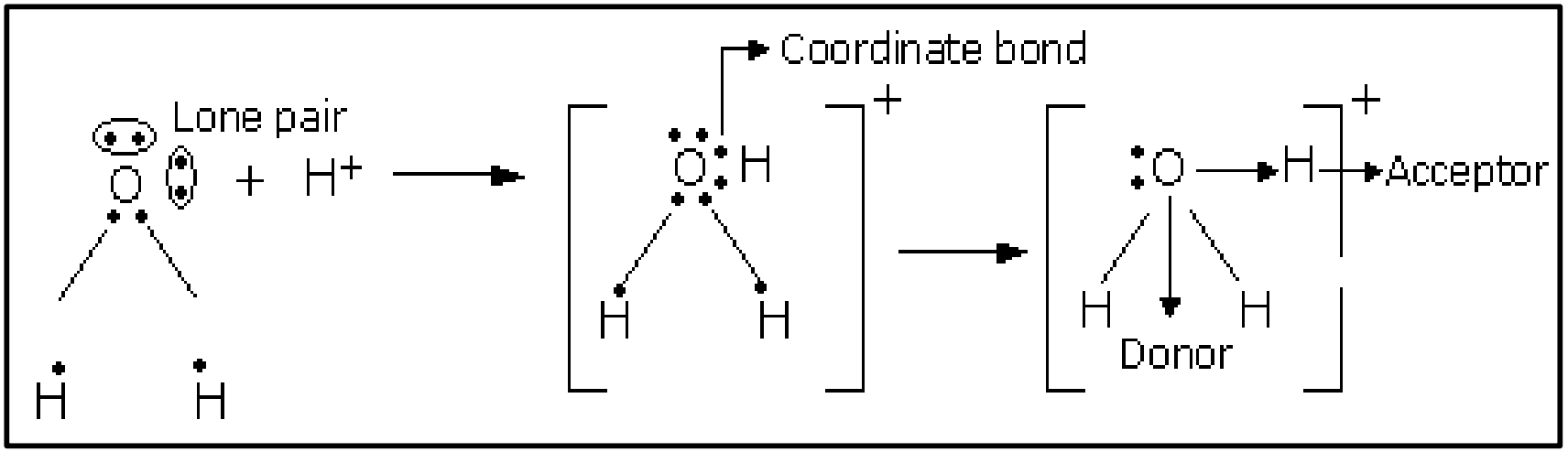
It is formed by the combination of the ammonia molecule and a hydrogen ion. In ammonia, the nitrogen atom has a lone pair of electrons after completing its octet. It donates this lone pair to the hydrogen ion.

Thus the nitrogen atom becomes the donor. The hydrogen atom becomes the acceptor. The linkage between N and H atoms is called coordinate bond. It is represented by an arrow →.



2.Hydronium Ion Coordinate Bond

It is formed by the combination of water molecule and hydrogen ion.



•The oxygen atom in a water molecule has two lone pairs of electrons.

•It donates one pair to the hydrogen ion.

•Oxygen is thus the donor and hydrogen ion, the acceptor.

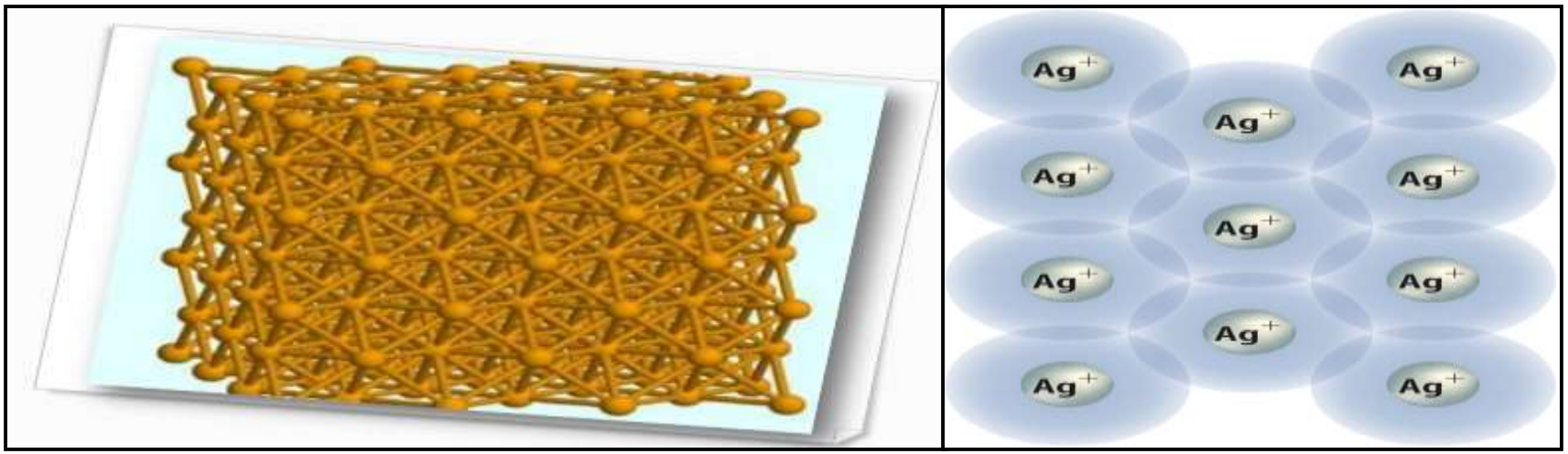
•The hydrogen ion carries over its charge to the hydronium ion

Properties of coordinate compounds

1. Co-ordinate compounds have high boiling & melting point & viscosities than covalent compounds
2. These compounds are semi-polar in character
3. These compounds are gases , liquids or solids
4. These are usually insoluble in polar solvent like water but soluble in non-polar solvent
5. Co-ordinate compounds are also non-ionic
6. They undergo molecular reaction which are slow
7. Co-ordinate compounds are stable

Metallic Bond

The peculiar type of bonding which holds the atom together in a metal crystal is called the metallic bonding.



In the **metallic bond,** most metals crystallize in close- packed structures. There is a strong electron interaction among 8 to 12 nearest neighbor atoms. Also called as coordination number. This develops the ability in metals to conduct electricity and heat.

How Metallic Bond Form?

Bonding in metals results from electrical attraction among positive charge metal ions and mobile, delocalized electrons belonging to crystal as a whole.

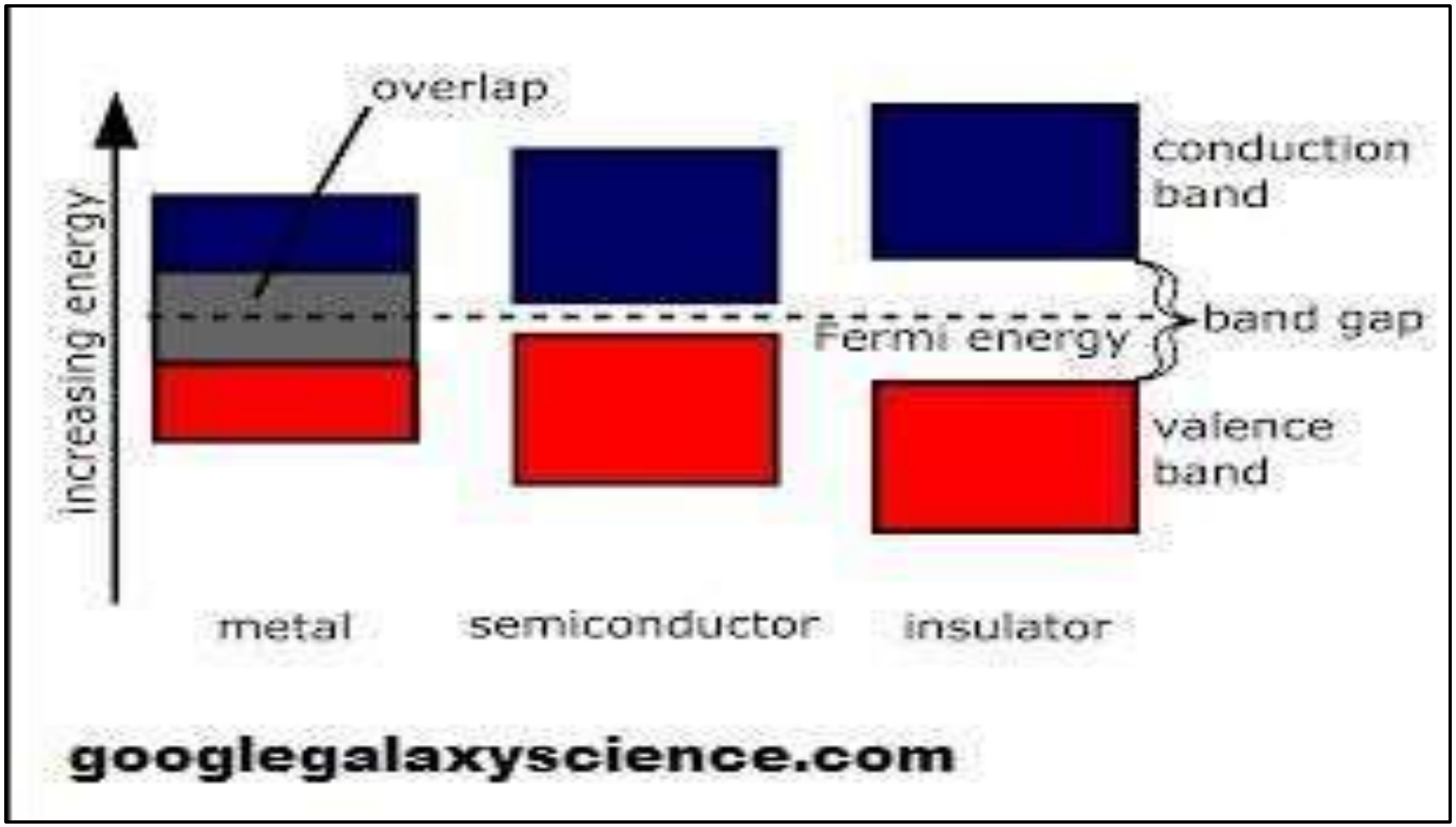
Two models.

1.Band model 2.Electron Sea model

Band model

The interaction of two atomic orbitals, say 3s- orbitals of two sodium atoms, produces two molecular orbitals, one bonding orbitals and one antibonding orbitals . If N atomic orbitals interact, N molecular orbitals are form. Atoms interact more strongly with nearby atoms than those of farther away. The energy that separates bonding and antibonding molecular decreases the interaction (overlap) between the atomic orbital decreases.

According to the band theory, the highest energy electrons of metallic crystals occupy either full band or partially band that overlap an empty band. A band within which(or into which) electrons must move to allow electrical conduction we call as conduction band. The electrical conductivity of metal decreases as temperature increases. The increase in temperature causes thermal agitation of metal ions. This impends the flow of electrons when an electric field is apply.


overlap
increasing energy
conduction band
band gap
Fermi energy
valence band
metal
semiconductor
insulator
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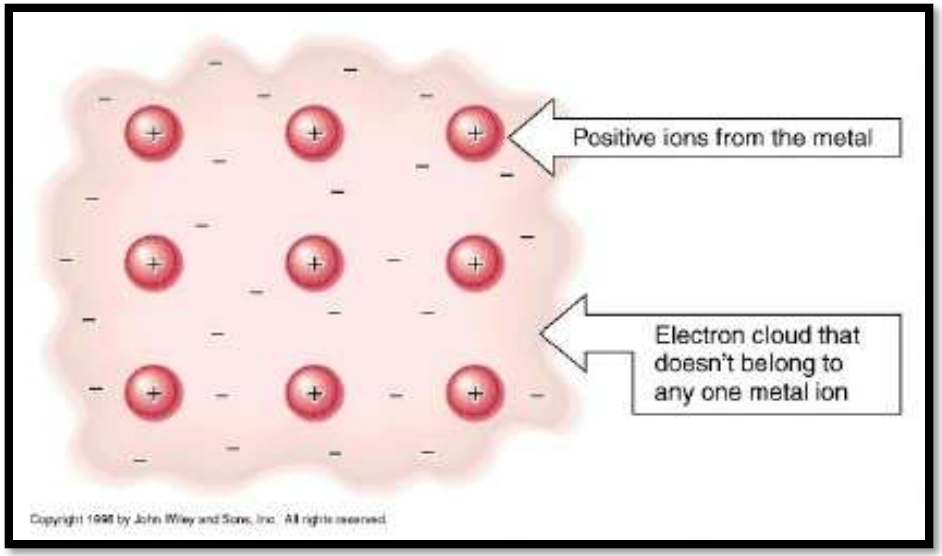
Electron Sea model:

Metals in a solid contribute their valence electrons to form a "sea of electrons". Valence electrons are not held by any specific atom and can move easily from one atom to the next

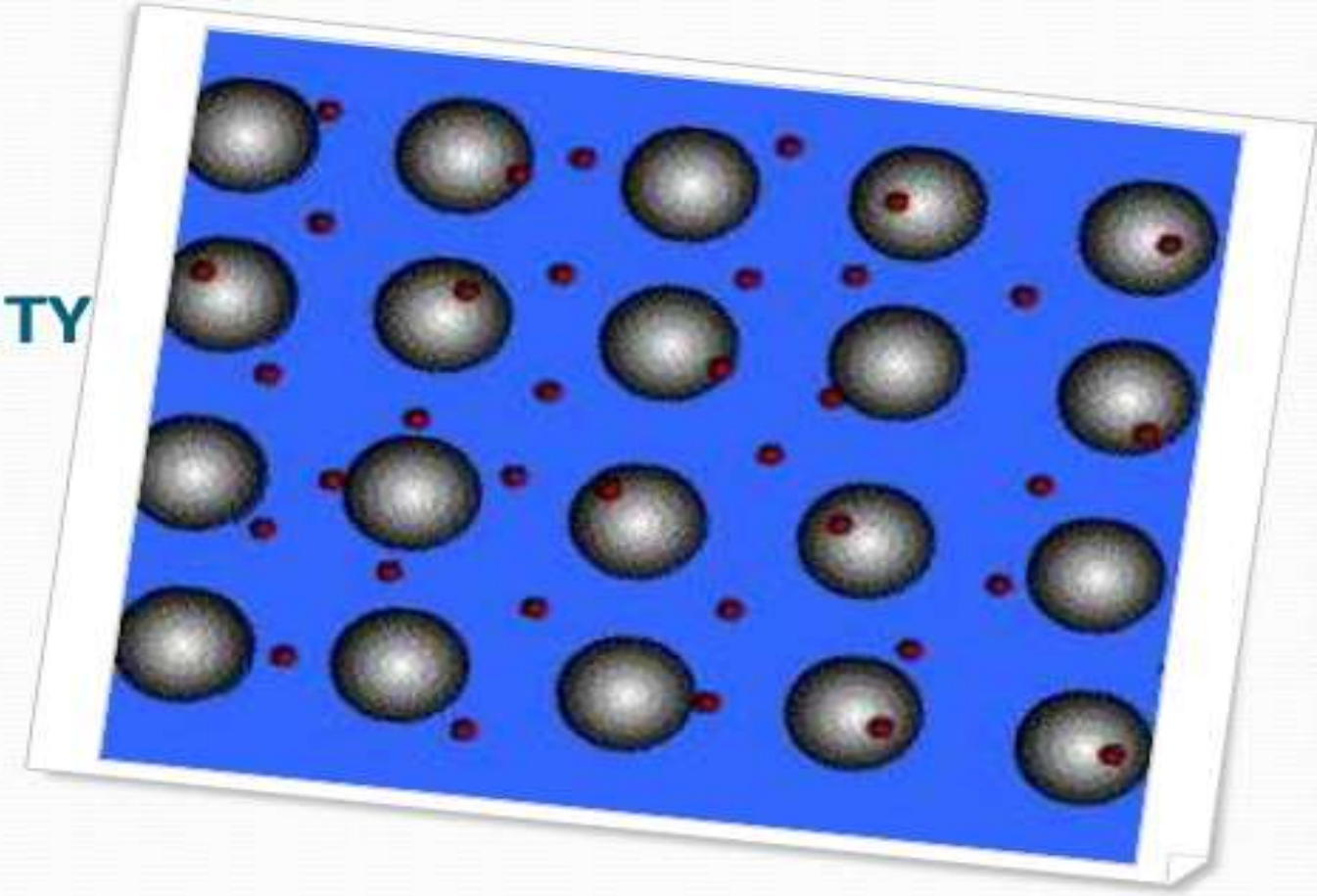
Delocalized electrons –are free to move in the "sea of electrons"



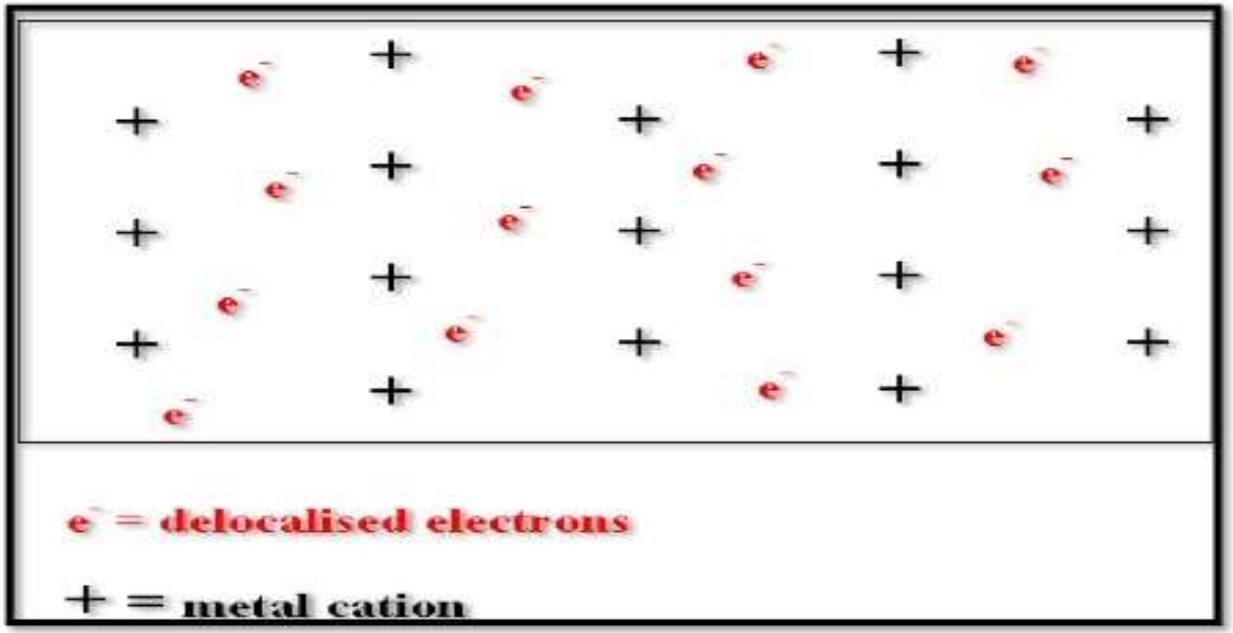
PHYSICAL PROPERTIES OF METAL

a. REFLECTIVITY

The electrons of the 'electron sea' jump into higher energy levels and again immediately return to the ground level. Then the electrons emit electromagnetic radiation or light.



Physical properties of metal



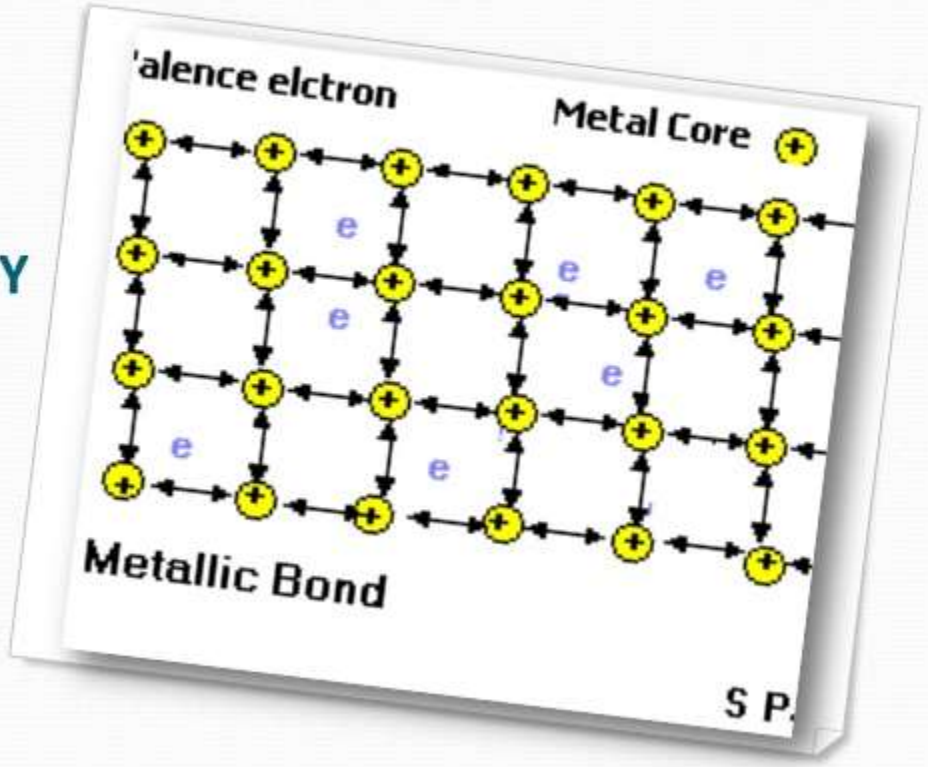
b. ELECTRIC CONDUCTIVITY

The metals are very good electric conductors of electricity. The free electrons of the 'electron sea' moves between the vacant space to metal ions which makes them most conductive to electricity.

PHYSICAL PROPERTIES OF METAL

c. HEAT CONDUCTIVITY

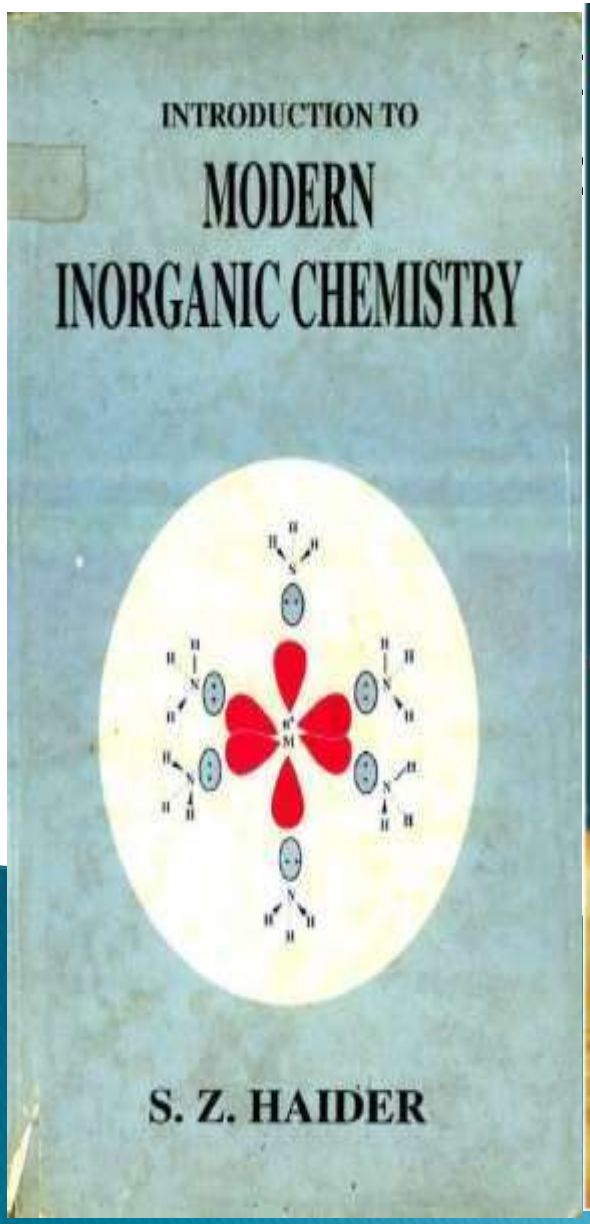
The metal atom is very good heat conductive. If heat is provided to one end of a metal then the heat gets to the other end of the metal by vibrational motion of the electron of the 'electron sea'.



MCQ – QUESTIONS:

1. **An ionic bond is formed between**
   a. Two metal atoms
   b. Two non metal atoms
   c. One metal atom and one non metal atom
   d. One metal atom and one metalloid atom
2. **Factors governing the formation of an ionic bonds are**
   a. Low ionization energy of metal and high electron affinity of non metal atom
   b. High ionization energy of metal and high electron affinity of non metal atom
   c. Low ionization energy of metal and low electron affinity of non metal atom
   d. High ionization energy of metal and low electron affinity of non metal atom
3. **A covalent bond involves**
   a. Sharing of electrons between a metal and non metal atom
   b. Sharing of electrons between two metal atoms
   c. Sharing of electrons between two atoms having similar electronegativity
   d. Sharing of electrons between two atoms having large difference in electronegativity
3. **A coordinate bond is formed by**
   a. Complete transfer of electrons
   b. Sharing of electrons contributed by both the atoms
4. **The common feature among the species O_3, SO_4^{2-}, H_3O^+ and $AlCl_3$ is that**
   a. They contain only ionic bonds
   b. They contain only covalent bond
   c. They contain coordinate bond
   d. They contain covalent and ionic bonds
5. **Metals are good conductor due to**
   a. Ionic lattices
   b. Crystalline lumps
   c. Mostly solids
   d. Delocalized electrons

References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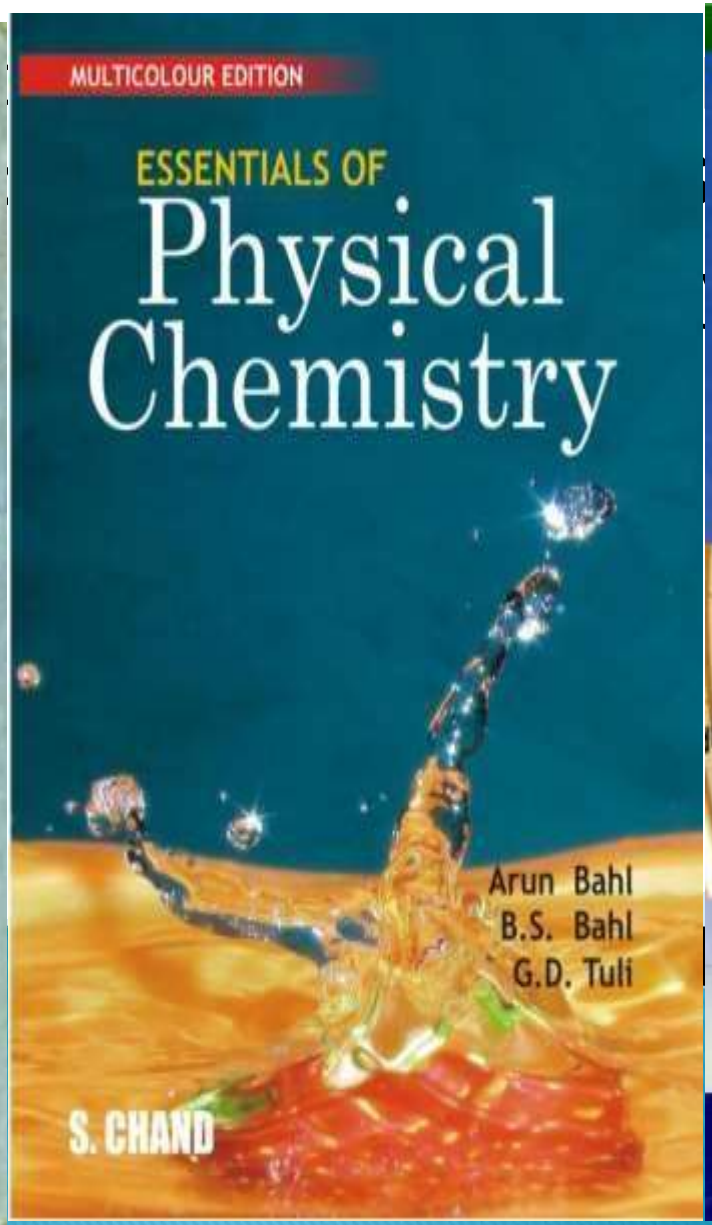
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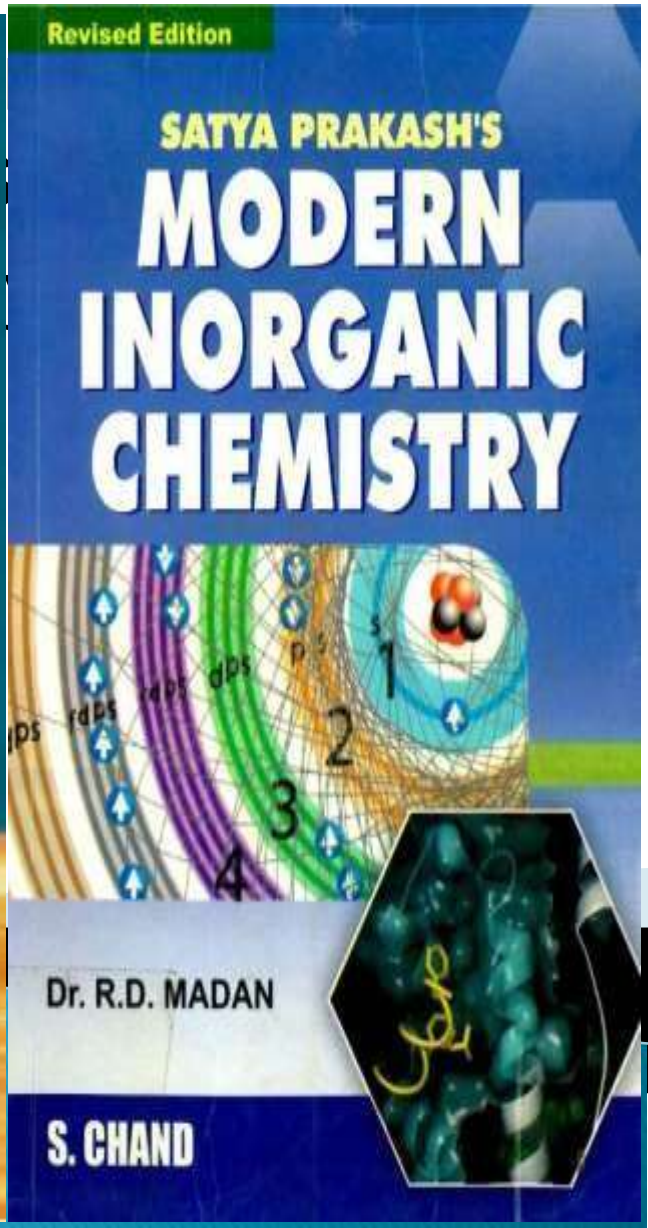
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