Metallic Bonding

Sea of electrons model used to explain bonding between metal atoms; it is also useful in explaining characteristics of metals (they conduct heat and electricity, are maleable, are ductile, etc.)

The valence electrons of metal atoms can be modeled as a sea of electrons.

The model involves a positively charged kernel (nucleus and nonvalence electrons) and valence electrons that are free to move or drift freely from one part of the metal to another. In this model the valence electrons are mobile.

Metallic bonds consist of the attraction of the free-floating valence electrons for the positively charged kernel of the metal atom

Metallic Bond

What is Metallic Bond ?

Since all the atoms in a metal crystal are identical, these cannot be linked by ionic bonds as cations and anions are bonded together in ionic crystals, Moreover, ionic bond cannot be formed between the metal atoms, since the metal atoms have the same electronegativities.

Also, each atom in a metal crystal cannot be bonded to other 8 or 12 atoms (X-ray study of metal crystals has shown that each metal atom is surrounded by

8 or 12 other metal atoms) by the covalent bond (sharing of electrons), since in metals the number of valence electrons is insufficient for the formation of covalent bonds with all its 8 or 12 neighbouring metal atoms. For example Na atom which has only one valence electron cannot be expected to form covalent bonds with 8 nearest neighbouring Na atoms in its crystal.

Obviously, the metal atoms in a metal crystal are bonded together by a bond which is neither an ionic bond nor a covalent bond, but it is a special type of bond which is called *metallic bond*. This bond binds the metal atoms together in a metal crystal and is of its own type.

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

To Explain the Nature of Metallic Bond by Electron-Gas Theory

In order to explain how the metal atoms in a metal crystal are bonded together, a simple theory, first proposed by Drude (1900) and later on developed by Lorentz (1916), is known as *electron-cloud* or *electron-pool* or *electron-gas theory*. This theory can well explain the nature of forces holding the metal atoms together in a metal crystal (Metallic bond).

Since the ionisation energies of metals are low, they readily give up their valence electrons to form the metal ions (called *positive cores or kernels*). The electrons given by the metal atoms move from place to place through the empty valence orbitals of the closed packed metal ions and are shared simultaneously by all the atoms together by a characteristic type of bond which is called *metallic bond.*

The electrons now no longer belong to individual metal atoms but belong to the crystal as a whole. As a result of delocalisation of electrons, the positive metal ions that are produced, remain fixed in the crystal lattice while the delocalised electrons move freely in the vacant valence orbitals. Thus on the basis of this theory :

A metal is regarded as a group of positive metal ions packed together as closely as possible in a regular geometric pattern and immersed in a sea of electrons (called electron-pool or electron-gas or electron-cloud) which move about freely (mobile or delocalised electrons) in the vacant valence orbitals. The *attractive force that binds the metal ions to the mobile electrons is called* **metallic bond** *and the force of attraction between the metal ions and the mobile electrons holds the atoms together.*

The electrons which are moving from place to place through the space between the metal ions are called *electron-gas* because of their mobile nature.

Diagrammatic representation of metallic bond in sodium metal is shown in Fig. 7.22. Circles with + sign at the centre represent Na^+ ions (positive metal cores) and – sign represents an electron. Attraction between the positive metal cores and mobile electrons has been shown by arrows and this constitutes the metallic bond.

The bonding which holds the metal atoms firmly together as a result of the attraction between the positive metal ions and surrounding freely mobile electrons, is called the **metallic bonding.**

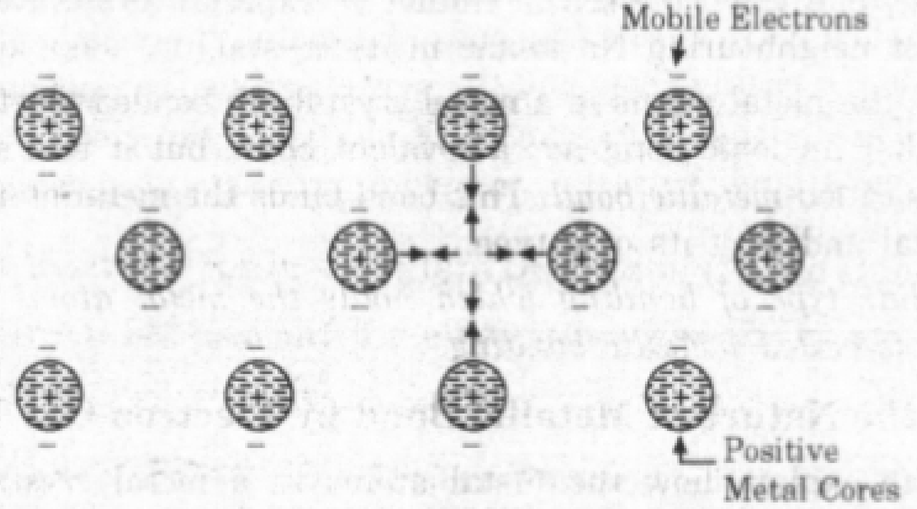

Fig. 7.22. A schematic representation of sea of mobile electrons and positive sodium metal cores. The attraction between the positive metal sodium cores and mobile electrons constitute the metallic bond. (Attraction has been shown by arrows).

The electron-gas model of metals can be compared with a locality consisting of a number of houses with lanes around them (Fig. 7.23). Children (*electrons*) from different houses (*metal atoms*) are free to play or move anywhere in the lanes (*vacant valence orbitals*) within the locality (*structure of the metal*) itself, but are not allowed by their parents (*positive metal cores*) to go away from the locality.

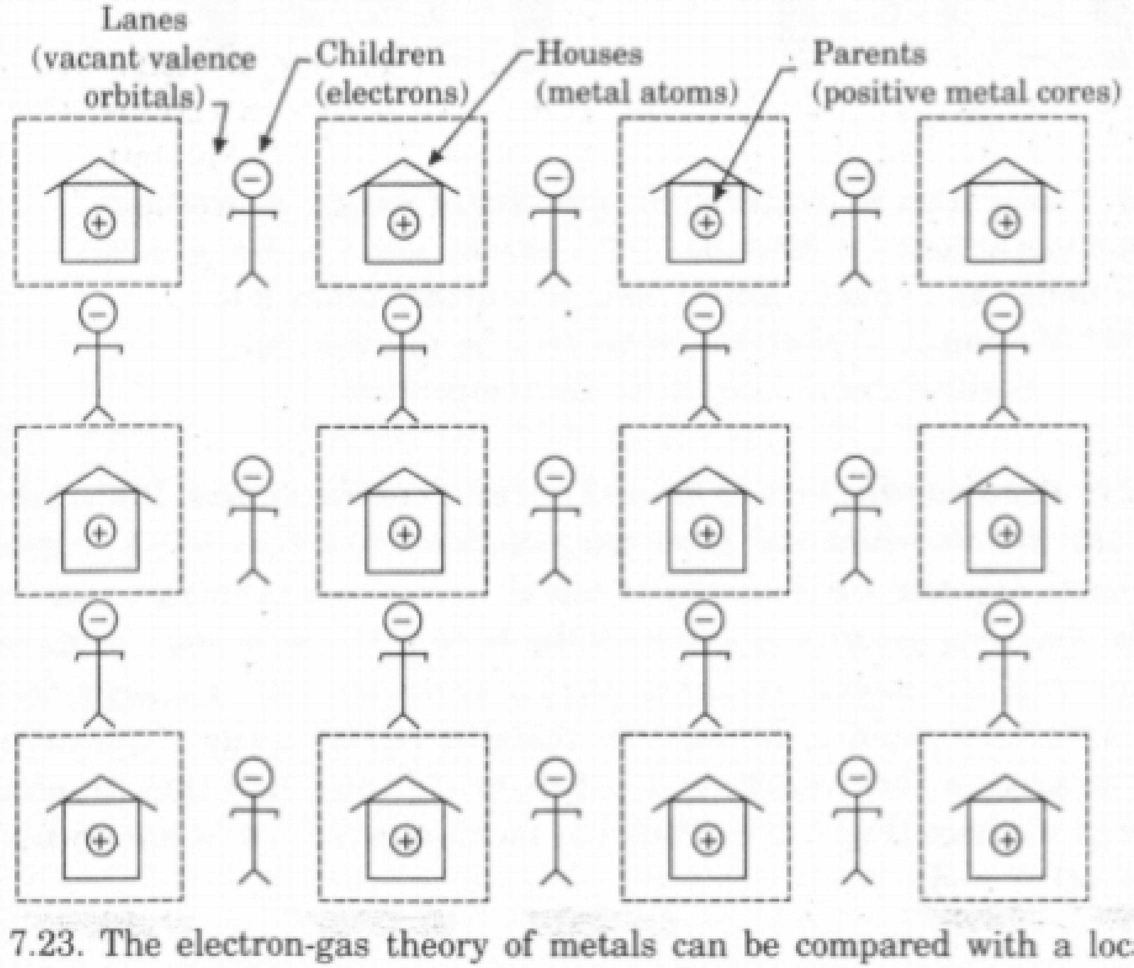

Fig. 7.23. The electron-gas theory of metals can be compared with a locality consisting of a number of houses with lanes around them.

The bonding which holds the metal atoms firmly together as a result of the attraction between the positive metal ions and surrounding freely mobile electrons, is called the **metallic bonding.**

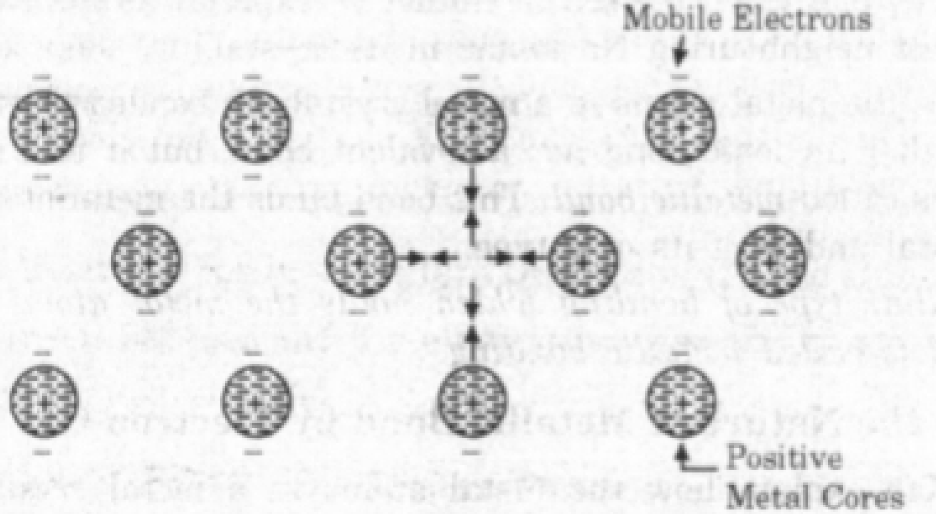

Fig. 7.22. A schematic representation of sea of mobile electrons and positive sodium metal cores. The attraction between the positive metal sodium cores and mobile electrons constitute the metallic bond. (Attraction has been shown by arrows).

The electron-gas model of metals can be compared with a locality consisting of a number of houses with lanes around them (Fig. 7.23). Children (*electrons*) from different houses (*metal atoms*) are free to play or move anywhere in the lanes (*vacant valence orbitals*) within the locality (*structure of the metal*) itself, but are not allowed by their parents (*positive metal cores*) to go away from the locality.

Ionic Bond	Covalent Bond	Coordinate Bond
(*i*) Ionic bond is formed by the transfer of electrons from a metal atom (A) which has 1, 2 or 3 valence-electrons to a non-metal (B) having 5, 6 or 7 valence electrons. $A^{\times} + \cdot\ddot{\underset{..}{B}}: \rightarrow [A] + \left[\,\overset{..}{\underset{..}{{}_{\times}B}}:\,\right]^{-}$ or $A + B^{-}$	(*i*) Covalent bond is formed by sharing two electrons between non-metal atoms having 1, 4, 5, 6, or 7 valence electrons. $\overset{\times\times}{\underset{\times\times}{{}^{\times}_{\times}A}} + :\overset{-}{\underset{-}{B}}: \rightarrow \overset{\times\times}{\underset{\times\times}{{}^{\times}_{\times}A}}\ :\overset{-}{\underset{-}{B}}:$ or A–B	(*i*) It is formed by the sharing of two electrons between two atoms, both electrons coming from one atom. $\overset{\times\times}{\underset{\times\times}{{}^{\times}_{\times}A{}^{\times}_{\times}}} + \overset{..}{\underset{..}{B}}: \rightarrow \overset{\times\times}{\underset{\times\times}{{}^{\times}_{\times}A{}^{\times}_{\times}}}\overset{-}{\underset{-}{B}}:$ or $A \rightarrow B$
(*ii*) Ionic bond consists of electrostatic force between cations and anions.	(*ii*) Covalent bond consists of two electrons that hold the atoms together.	(*ii*) It consists of an electron pair between the linked atoms.
(*iii*) It is a weak bond, since the electro-static force can be broken easily.	(*iii*) It is a strong bond, since the paired electrons cannot be separated easily.	(*iii*) It is also a strong bond, since the paired electrons cannot be separated easily.
(*iv*) It is a polar bond (A^{+}–B^{-})	(*iv*) It is a non-polar bond (A–B)	(*iv*) It is a semi-polar bond ($A^{+} - B^{-}$)

Explanation of Physical Properties of Metals

The electron gas theory of metals can well explain various physical properties of metals. This has been shown as follows :

1. *Metals are good conductors of electricity (Electrical conductivity).* When an electric field is applied between the two ends of a metal, the mobile electrons begin to move towards the positive pole and the new electrons from negative pole take their position. Thus with the movement of electrons, the electric current starts to flow in the metal and the metal, therefore, acts as a good conductor of electricity [See Fig. 7.24 (*a*)].

It has been observed that the electrical conductivity of most of the metals decreases with the increase of temperature. This is because of the fact that with increase of temperature the positive metal ions also begin to vibrate and their motion hinders the free movement of the mobile electrons between the positive metal ions [Fig. 7.24 (*b*)]. Thus the vibrating positive metal cores create resistance to the flow of the electrons towards the positive pole and hence the movement of the electrons towards the positive pole falls and so does the electrical conductivity of the metals at higher temperature.

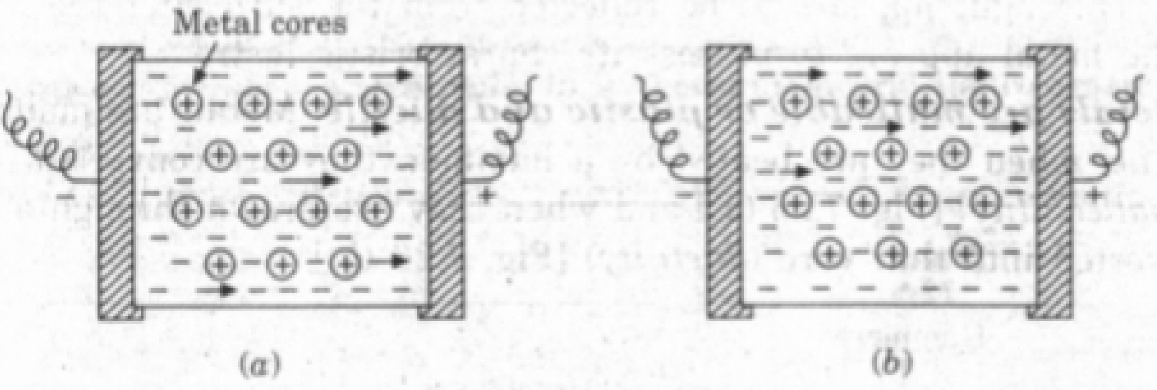

Fig. 7.24. Explanation of electrical conductivity of metals on the basis of electron gas theory. (*a*) Movement of electrons towards the positive pole under an applied electric field at ordinary temperature (*b*) Movement of electrons is hindred by the vibrating positive metal ions at higher temperature.

2. *Metals are good conductors of heat (Thermal conductivity).* It has been observed that the metals which are good conductors of electricity are also good conductors of heat. Thermal conductivity of metals can also be explained on the basis of mobile electrons present is the metallic lattice. When a piece of metal is heated at one end, the mobile electrons at this end absorb heat energy from this end and move very rapidly through the metallic lattice towards the cooler end. During this process they collide with adjacent electrons and thus transfer their heat energy to them (Fig. 7.25). Thus the mobility of electrons allows heat transfer to the other end.

Only such metals can form the alloys the atoms of which when mixed can fit into the crystal lattice of the other. This is only possible, if the geometry of the mixing atoms allows this fitting in, *i.e.* if the diameter of the atom of one metal is much greater than that of the other, no alloy can be formed by the two metals.

6. *Metals have elasticity.* Under the influence of comparatively less force, temporary deformation of metal crystal takes place and the cores with their electron-cloud return to their original positions as soon as the force is removed. This explains the elasticity in metals.

7. *Metals possess high tensile strength.* This property means that a large weight can be supported by a small cross section of a metal. This property is also explained on the same basis on which the malleability and ductility of metals has been explained. Obviously the property of tensile strength is due to the great attraction between the positive metal ions and the mobile electrons.

8. *Metals are solids and have high density.* Metals are solids (mercury being the only exception) and have high density. The high density is due to the fact that the metallic bond keeps the metal atoms closely packed in the metallic crystal.

9. *Melting and boiling points.* In general, metals have intermediate melting and boiling points as compared to those of covalent and ionic compounds. This is due to the reason that the attractive forces (*i.e.* metallic bonds) that hold the metal atoms together in metallic crystal are intermediate between those in covalent and ionic compounds.

10. *Metals are usually hard solids.* Because of the strong metallic bonds between the metal atoms, metals are usually hard solids. The strength of metallic bond usually increases

(*a*) *with the increase of valence electrons.*

(*b*) *with the increase of the charge on the nucleus.*

(*c*) *with the decrease of the size of the metal positive ion (core).*

For example the alkaline earth metals (Ca, Sr, Ba) which have two valence electrons are harder than the alkali metals (Li, Na, K etc.) which have one valence-electron.

Similarly the hardness of Li, Na and K is in the order

$$Li > Na > K,$$

because the size of Li^+, Na^+ and K^+ ions is in the order :

$$Li^+ < Na^+ < K^+$$

11. *Metals can emit electrons (Photoelectric effect).* When enough heat energy is applied to a metal to overcome the attraction between the positive metal ions (metal cores) and electrons, the electrons are emitted from the metallic atom. When the frequency and, therefore, the energy of the light that strikes the metal is great enough to overcome the attractive forces, the electrons escape from the metal with a resultant decrease in the energy of the incident photon. *The removal of electrons from the surface of a metal by heat energy is called photoelectric effect.*