Electrical properties of solids

Solids show very wide range of electrical conductivity. Accordingly solids are classified into the following three categories: conductors, insulators and semiconductors.

i. **Conductors:** Solids having electrical conductivities in the range 10^4 to 10^7 $Ohm^{-1}m^{-1}$ are called conductors. Metals and electrolytes (ionic solids) are examples of electrical conductors. Metals conduct electricity by movement of electrons while electrolytes conduct electricity by movement of ions.

ii. **Insulators:** Solids having low electrical conductivities in the range 10^{-20} to 10^{-10} $Ohm^{-1}m^{-1}$ are called insulators. Most nonmetals and molecular solids belong to this category.

iii. **Semiconductors:** Solids having electrical conductivities in the range 10^{-6} to 10^4 Ohm^{-1} m^{-1} are semiconductors. This range is intermediate between conductors and insulators. Metalloids like silicon, germanium belong to this category.

Band theory: Electrical conductivities of solid metals, nonmetals and metalloids are explained in terms of band theory. A band is made of closely spaced electronic energy levels. Band formation can be correlated to formation of molecular orbitals (MOs) by interaction of atomic orbitals. According to MO theory interaction of atomic orbitals of combining atoms results in formation of equal number of MOs which spread over the entire molecule. Similar to this, interaction of energy levels of electrons in the closely spaced constituent atoms in solids result in formation of bands. Band theory considers formation of two types of bands, namely, conduction band and valence band.

a) **Conduction band:** The highest energy band containing electrons is the conduction band. It is formed by interaction of the outermost energy levels of closely spaced atoms in solids. Conduction band may be partially occupied or vacant. Electrons in conduction band are mobile and delocalized over the entire solid. They conduct electricity when electrical potential is applied.

b) **Valence band :** The band having lower energy than conduction band is the valence band. The electrons in valence band are not free to move because they are tightly bound to the respective nuclei.

c) **Band gap :** The energy difference between valence band and conduction band is called band gap. Size of the band gap decides whether electrons from valence band can be promoted to vacant conduction band or not when band gap is too large to promote electrons from valence band to vacant conduction band by thermal energy, it is called **forbidden zone**. When band gap is small, electrons from higher energy levels in valence band can be promoted to conduction band by absorption of energy (such as thermal, electromagnetic).

The electrical properties of metallic conductors, insulators and semiconductors are explained in terms of band theory as follows :

Metals: Metals are good conductors of electricity. The outermost electrons of all the atoms in the metallic crystal occupy conduction band. The number of electrons in conduction band of metals is large. Hence metals are good conductors of electricity. The conduction bands in metals can be further labeled as '*s*' band, overlapping *s* and *p* bands and so on. This depends on the atomic orbitals involved in band formation. Band formation in metallic conductors, thus, results in delocalization of the outermost electrons of all the metal atoms leaving behind metal ions. This is described as ‘cations of metal are immersed in the sea of electrons’.

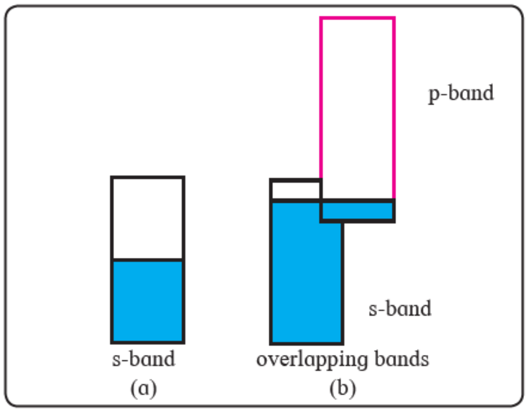

Fig. *Metalic conductor*

The cations of metal atoms occupying lattice sites vibrate about their mean positions. At higher temperatures, metal cations undergo increased vibrational motion about their lattice sites. The flow of electrons is interrupted by increased vibrational motion. As a result conductivity of metals decreases with increase in temperature.

Insulators: In insulators the valence band is completely filled with electrons and the conduction band is empty.
The valence band and conduction band in insulators are separated by a large energy gap called forbidden zone. Here, thermal energy is insufficient to promote electrons from valence band to conduction band. As a result the conduction band remains vacant. The material is, therefore, an insulator.

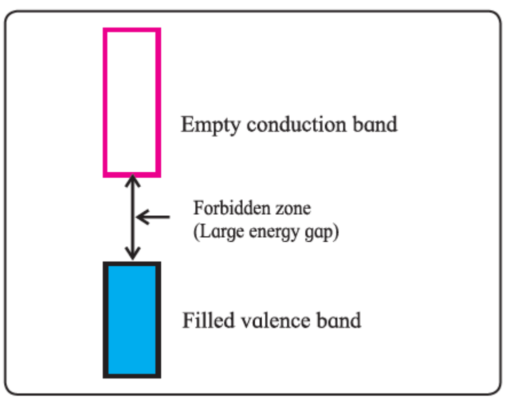

Fig. *Insulator*

Semiconductors: Electrical conductivity of a semiconductor material is intermediate between that of metals and insulators. The metalloids Si and Ge are semiconductors. Like insulators, the valence band in semiconductor is completely filled with electrons and conduction band is empty. However, the energy gap between the two bands is smaller than that in an insulator. At a temperature above absolute zero a few electrons in the valence band have enough thermal energy to jump through the small band gap and occupy higher energy conduction band. The conduction band, thus, becomes partially filled and the valence band becomes partially empty. The electrons in conduction band are free to move. When electric potential is applied to a semiconductor, it conducts a small amount of electricity.

Such a pure semiconductor material which has a very low but finite electrical conductivity is called **intrinsic semiconductor**. The electrical conductivity of a semiconductor increases with increasing temperature. This is because, the number of electrons with sufficient energy so as to get promoted to the conduction band increases as temperature rises. Thus, at higher temperatures, there are more mobile electrons in the conduction band and more vacancies in the valence band than at lower temperature. In fact semiconductors are insulators at low temperatures and conductors at high temperatures.

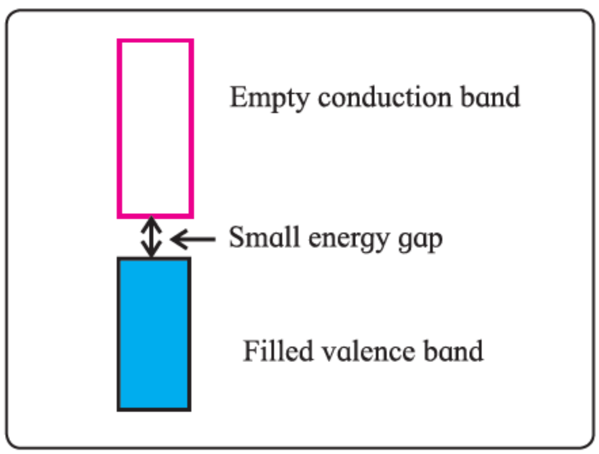

Fig. *Semiconductor*