MODULE – 1

ELECTRICAL PROPERTIES OF MATERIALS

1.5. Classification of materials & Band theory

On the basis of forbidden gap solids are classified into insulators, semiconductors and conductors.

1.5.1. Insulators

- In case of insulator, the forbidden energy band is very wide as shown in figure. Due to this, electrons cannot jump from valence band to conduction band. In insulator, the valence electrons are bound very tightly to their parent atoms.

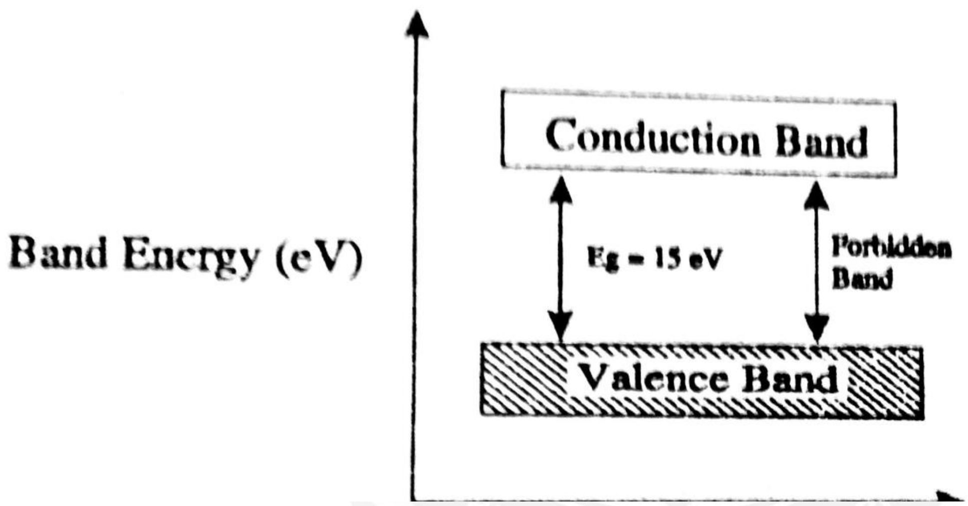


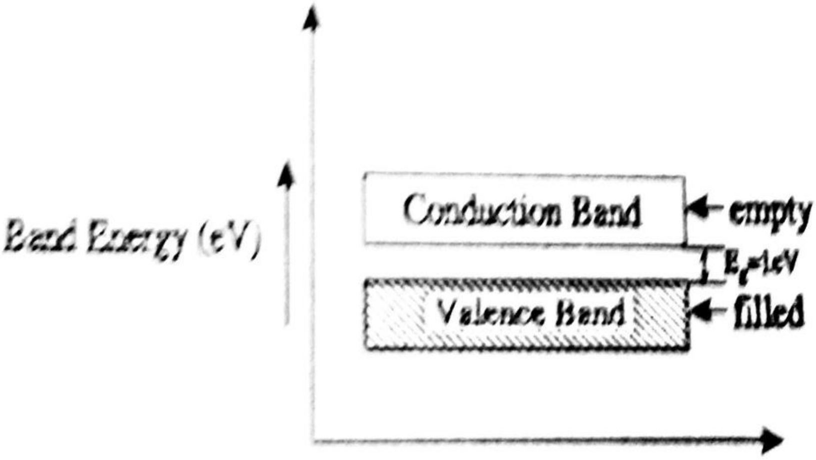
Fig 1.12.1 –Band gap for semi conductor

- For example, in the case of material like glass, the valence band completely full at 0K and the energy gap between valence band and conduction band is of the order of 10eV.
- Even in the presence of high electric field, the electrons cannot jump from the valence band to conduction band.
- When a very large energy is supplied, an electron may jump across the forbidden gap. Increase in temperature also enables some electrons to go to the conduction band.
- This explains why certain insulators become conductors at high temperature. The resistivity of insulators is of the order of 10^7 Ωm (ohm metre).

1.5.2.Semiconductors

- In semiconductors, the forbidden gap is very small as shown in figure. Germanium and Silicon are the best examples of semiconductors.

- In Germanium, the forbidden gap is of the order of 0.7 eV while in case of silicon, it is of the order of 1.1 eV.

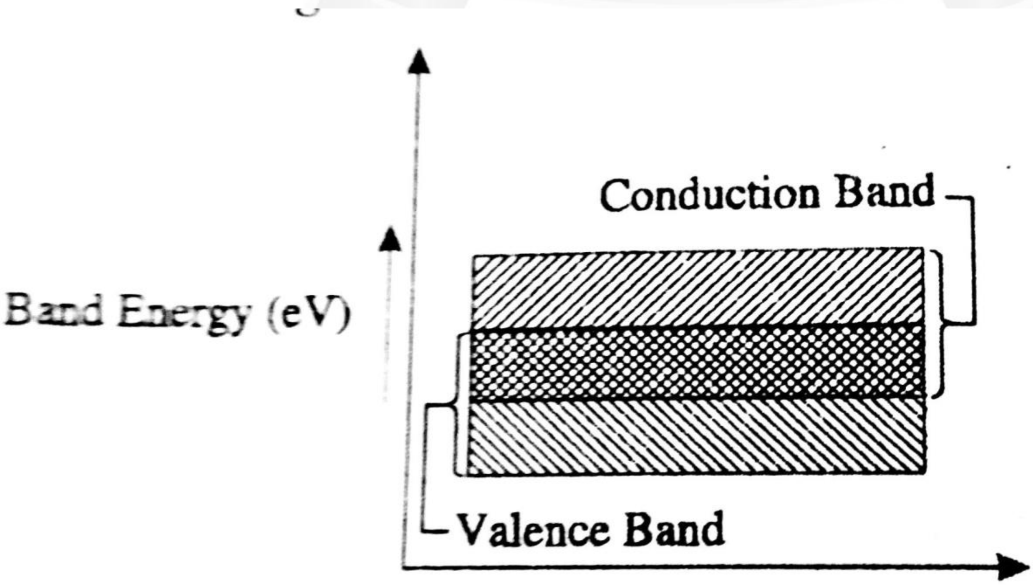


- Actually, a semiconductor is one whose electrical properties lies between those of insulators and conductors. At 0K there are no free electrons in conduction band and valence band is completely filled.
- When a small amount of energy is supplied, the electrons can easily Move from valence band to conduction band.

1.5.3Conductors:

There is no forbidden energy gap between valence & conduction band.

In conduction band it has large number of electrons for producing current. And also the electrons can easily move from valence band to conduction abnd. In conductor the total current is only due to electrons



1.5.4.The origin of energy band in a solid.

Energy Bands in Solids

According to the energy band theory of solids, the free electrons move in a periodic potential produced by positive ion cores. The electrons are treated as weakly perturbed by the periodic potential.

In solid solution, the electrons experience a periodic potential since the atomic arrangement is periodic.

A simple qualitative explanation of the formation of energy bands in a solid is given below.

A solid contains an enormous number of atoms packed closely together. Each atom when isolated has a discrete set of electron energy level, 1s, 2s, 2p, …

If we imagine has N atoms on the solid to be isolated from one another, they would have completely coinciding schemes of energy levels.

The energies of electrons within any one isolated atom obey the following conditions.

(i) There are specific electronic energy levels in each atom (fig.). Electrons cannot occupy space.

(ii) Electrons fill the lowest energy levels first; A specific quantity of energy, called a quantum of energy must be supplied to move an electron to the next higher level.

(iii) Pauli's exclusion principle states that no two electrons can occupy the same quantum state. Not more than two electrons can occupy any one energy level.

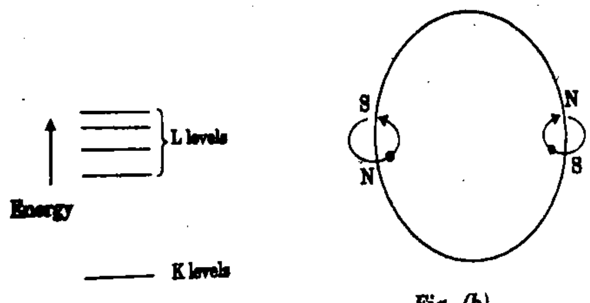


Fig. (a) *Fig. (b)*

Two electrons shall occupy the same energy level because they have opposite electron spins (fig. (b)).

When the atoms are brought in close proximity to form a solid, the valance electrons of adjacent atoms interact and constitute a simple system of electrons common to the entire crystal, and their outermost electronic orbits overlap.

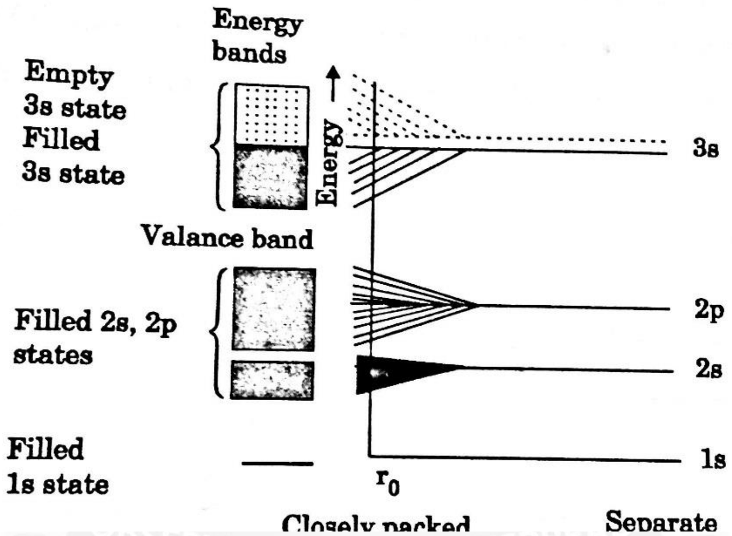
Therefore, N electrons will now have to occupy different energy levels, which may be brought about by the electric forces exerted on each electron by all N nuclei.

As a result of these forces, each atomic energy level is split up into a large number of closely spaced energy levels.

A set of such closely spaced energy levels is called an energy band.

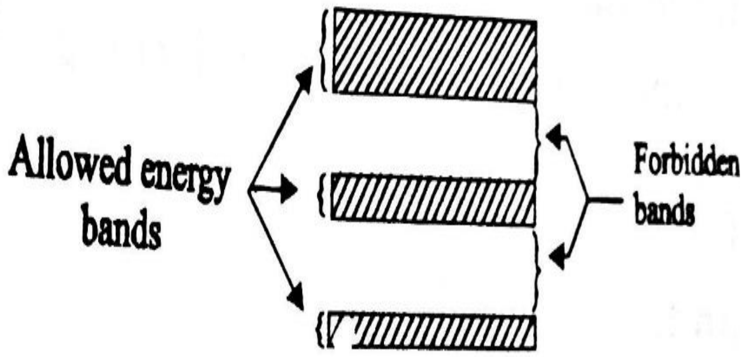
Consider 11 electrons of a neutral sodium atom, each occupying a specific energy level as indicated in fig. The energy levels of sodium become bands when the atoms lie close together.

In figure, r_o represents the spacing between atoms in solid sodium. When the atoms are part of a solid, they interact with each other, and the electrons have slightly different energies.



In an energy band, allowed energies are almost continuous. These energy bands are separated by ranges of energies that have no allowed energy levels.

These regions are known as forbidden bands or energy gaps

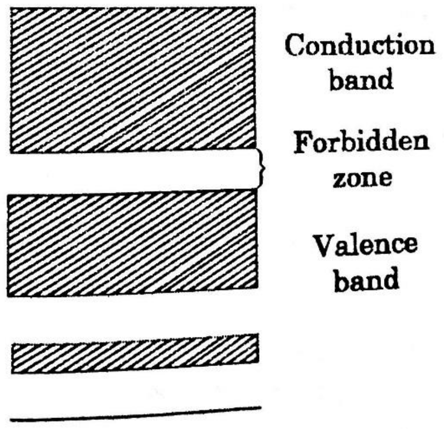


The amount of splitting is not the same for different levels. The levels filled by valence electrons are distributed to a greater extent, while those filled by electrons of inner shells are distributed only slightly.

If there are N atoms in a solid, there are N allowed quantum states in each band. Each quantum state is occupied by a maximum of two electrons with opposite spins. Thus, each energy band can be occupied by 2N electrons.

The valence band consists of a group of states containing the outermost electrons or valence electrons of an atom. The band formed from atomic energy levels containing valence electrons is called valence band.

These electrons have the highest energy. The band is obviously the highest occupied band.



Above the valence band, there exists the band of next higher permitted energies called conduction band. It is separated from the valence band by a gap

The gap represents the range of energy which electrons cannot possess.

The conduction band corresponds to the first excited states and it is normally the lowest unfilled energy band.

In conduction band, the electrons can move freely and they are generally called conduction electrons.