Nalanda Open University
B.Sc. Part-III

Course – Physics
Paper – VIII

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Topic – **Energy bands of solids**: The solid crystals are formed when the isolated atoms are brought together. Various interactions occur between the neighbouring atoms.

(1) At a particular interatomic spacing d, there is a proper balance between forces of attraction to form a crystal. In this process, the changes occur in the electron energy level configurations.

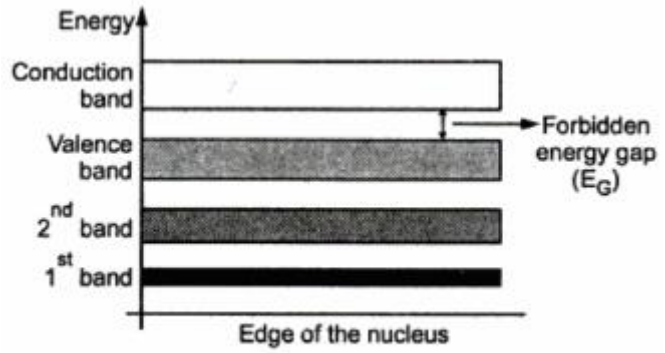
(2) In case of a single atom, there is a single energy for an electron orbit.

(3) When two atoms are brought close to each other, it leads to intermixing of electrons in the valance shell.

(4) As a result, the number of permissible energy level is formed, which is called an energy band and three bands are important form the conductivity point of view are :

(i) valence band

(ii) conduction band



Energy band diagram

(iii) Forbidden gap(band)

In the normal state, the electrons involved in the covalent bonds in the crystal occupy the valence band and the conduction band is empty. Hence

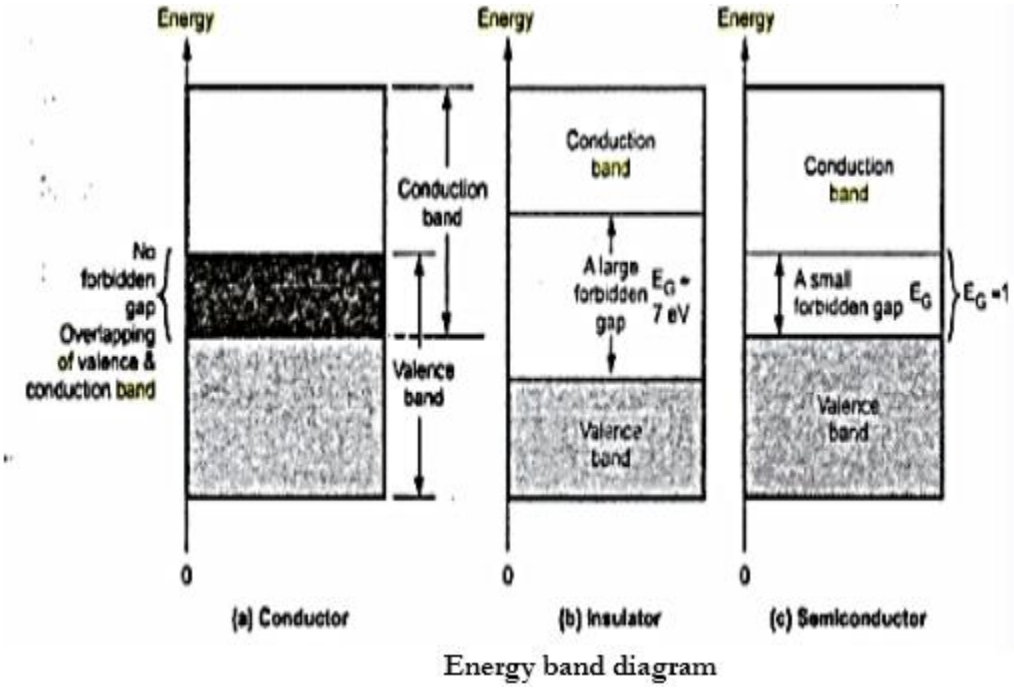
the electrons in the outermost shell are called valence electrons and the outermost shell is called valence shell. At higher temperature, these electrons acquire energy and move to the conduction band as electron is not allowed to occupy any energy state in forbidden gap. These electrons are called free electrons.

For any type of material the forbidden energy gap may be large, small or nonexistence.

Classification on the basis of energy theory – The materials are classified as conductors, insulators and semi conductors on the basis of the ability of the various materials to conduct current.

Conductors – A material having large number of free electrons can conduct very easily. For example, copper (metal) has 8.5 X 1028 free electrons per cubic meter which is a very large number. Hence copper is called good conductor. In the metals like copper, aluminium there is no forbidden gap between valence band and conduction band. The two bands overlap. Hence even at room temperature, a large number of electrons are available for conduction. So without any additional energy, such metals contain a large number of free electrons and hence called good conductors. An energy band diagram for a conductor is shown in the figure -1(a).

Insulators – In case of insulating material, there exists a large forbidden gap in between the conduction band and the valence band as shown in the fig.1(b)



Energy band diagram

Figure- (1)

It is impossible for an electron to jump from the valence band to the conduction band. Hence such materials can not conduct and called insulators. The forbidden gap is very wide; approximately of about 7eV is present in insulators. For a diamond, which is an insulator, the forbidden gap is about 6eV. Such materials may conduct only at very high temperatures or high voltage. Such conduction is rare and is called breakdown of an insulator. The other insulating materials are glass, wood, mica, paper, etc.

Semi conductors – Semi conductors are neither insulator not conductors. The forbidden gap in such materials is very narrow as shown in figure 1(c) are called semiconductors. The forbidden gap is about 1eV. For such materials, the energy provided by the heat at room temperature is sufficient to lift the electrons form the valence band to the conduction band. Therefore at room temperature, semiconductors are capable of conduction but at absolute zero (-273^{o}C), all the electrons of semiconductor materials find themselves locked in the valence band.

Hence at zero, the semiconductors materials behave as perfect insulators.

In case of semiconductors, forbidden gap energy depends on the temperature. For silicon and germanium, this energy is given by

$E_G = 1.21 – 3.6 \times 10^{-4} \times T – eV$ (for silicon)

$E_G = 0.785 – 2.23 \times 10^{-4} \times T – eV$ (for Germanium)

Where T = Absolute temperature in K.

Energy Band Theory – According to Bohr's theory, each and every shell and sub shell of atoms contains a discrete amount of energy. An atom has different energy levels. When atoms are brought closer to each other, electrons at outermost shell interact with each other. This bonding force between electrons is called inter atomic interaction, causes the change in energy levels of electrons at the outermost shell. This change will give rise to energy band theory, and hence electrons will not be at the same level, the levels of the electrons are change to a value which is higher or lower than that of the original level. Each substance consists different amount of electron energy present in the energy bands, based on these different energy levels. Energy band are then further classified as (i) valence band (ii) forbidden energy gap band (iii) conduction band.

(i) **Valence band** – At absolute zero temperature, there are the different range, of energies present in the solid and the band which is formed by the highest range of energy is called valence band and this band is filled with valence electrons and this band is formed by the electrons at an outermost shell. It is located below the Fermi level. Electrons in the valence band have lower energy than the electrons in the conduction band. In atoms, the electrons present in the valence band are loosely bound to the nucleus. The electrical conductivity of a solid depends on the capability to move the electrons form the valence band to the conduction band.

Forbidden energy gap (Fermi energy level) – it is the electronic energy band where there is no electron state exists due to quantization energy. The band obtained by separating conduction band and valence band is

called as forbidden energy band or forbidden gap. In solids, the electrons do not stay in forbidden gap as there is no energy state in this region. With the help of forbidden gap, we can determine the major factor, i.e. the electrical conductivity of the solid.

Conduction band – The energy band formed by the energy levels of the free electrons is called conduction band, it is an empty band or partially filled band, but when the external field is applied to the electrons in the valence band, the electrons jump from the valence band to the conduction band and becomes free electron. Electrons in the conduction band have higher energy than the electrons in the valence band and electrons are not bound to the nucleus of the atom in the conduction band and empty state which are broadened in a band of levels and this band is placed above the Fermi level. It is the lowest range of vacant electronic state.