**Energy band**

We know that any matter is composed of small particles known as atom. When the atoms combine to form a molecule. The electron shell is influenced not only by its own nucleus but also by the nuclei and electrons of surrounding atoms. The nearest atoms have the greatest influence over the energy level of an atom. The energy level of each electron in a given atom is controlled by all the neighboring atoms in the molecule. The energy level of all electrons in a molecule is different. But the electron themselves arranged in such a way that their energy levels come closer to each other which forms a cluster or band known as energy band. Similarly second shell forms the second energy band and so on.

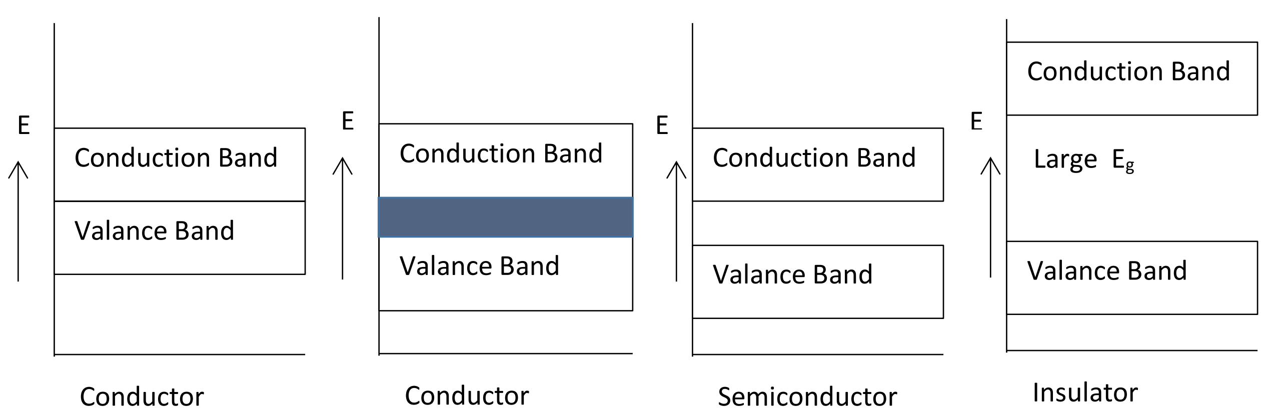
The energy band corresponds to the outermost shell is called the valance band.

The energy band just above the valance band is known as conduction band.

The gap between these two bands is called the forbidden energy gap.

The classification of solid based on band theory can be explained as follows with the help of band diagrams:

1. **Conductor:** The solid with overlapping valance band and conduction band is very good conductor. In these solid at room temperature also there are conduction electrons.
   A solid is also a conductor if it has partially filled valance band and empty conduction band with zero forbidden gap.
2. **Insulator:** A solid with completely filled valance band and empty conduction band with large forbidden gap. As energy gap is very large, by applying external electric field electrons cannot move from valance band to conduction band.
3. **Semiconductor:** A solid with half-filled Valance band and empty conduction band with small forbidden energy gap is semiconductor. By applying external electric field few electrons move from valance band to conduction band.

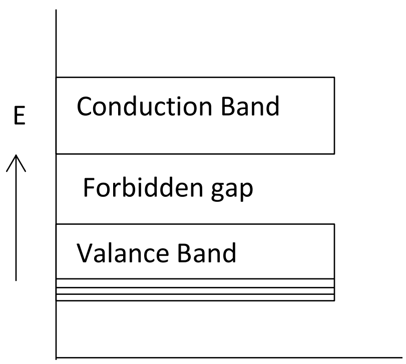


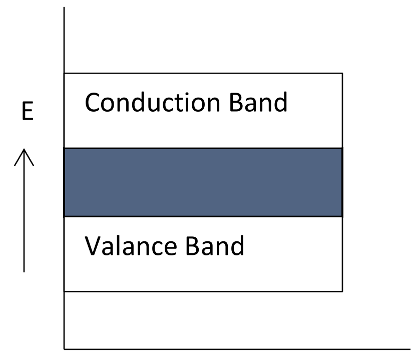
## Model energy diagram for typical metal

Metals are those solids which have vacant electron energy states immediately above the highest filled level of the valance band. This can happen in the following two ways:

i) In the first case, the valance band is only partially filled as shown in figure. When an electric field is applied electron can acquire sufficient energy and hence velocity so as to jump to higher levels.

ii) In the second case, full valance band overlaps conduction band as shown in figure. Obviously, here the forbidden energy gap is zero. Example of such elements is Mg and Be which conduct even if their valance bands are full.




**Energy diagrams of group IV elements**

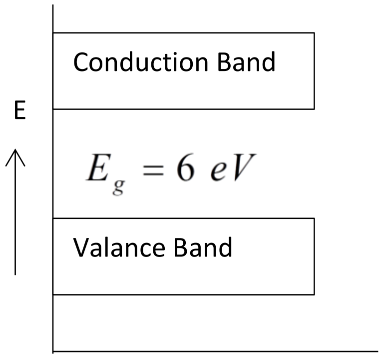
Some of the elements which belong to this group are Carbon, Silicon, Germanium, Tin and Lead. The electrons in their outermost orbits are even in numbers as in divalent metals. But usually there is no overlap between their valance band and conduction band. In the case of Diamond (a form of Carbon), the energy gap between the two band is very large ($\simeq 6\ eV$) as shown in figure.

The only way electrons can conduct electric current is by transition across the forbidden gap into the conduction band. This can be brought about in the following two ways:

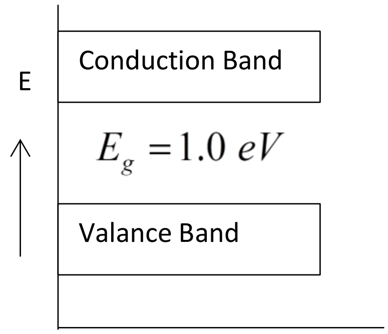
i) By applying a very strong electric field or

ii) By thermal excitation.

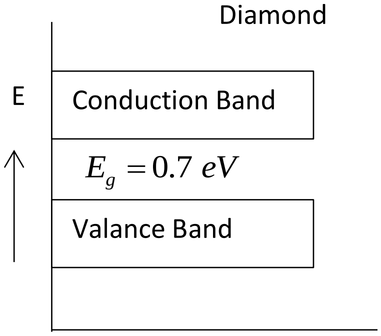
However it has been found that an electric field of many millions of Volt/meter is necessary to make the electrons jump across the forbidden energy gap. At normal room temperature, the number of electrons that can be thermally excited across the gap in diamond turns out to be extremely small. This accounts for the insulating properties of diamond.



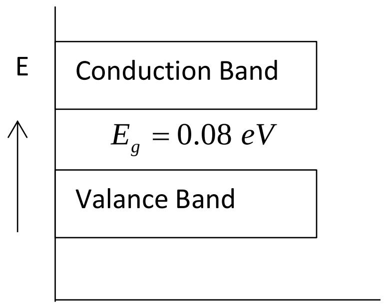

Diamond



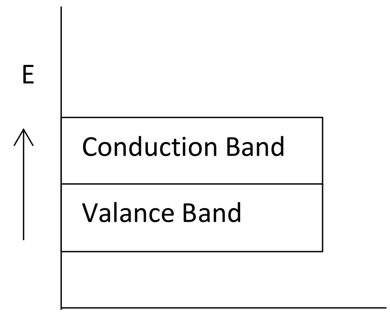

Silicon




Germanium




Tin




Lead

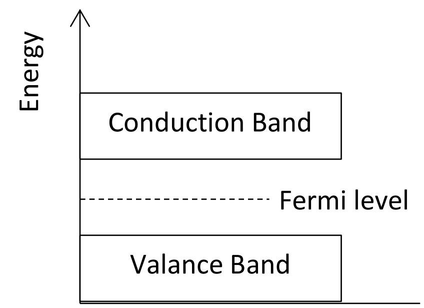
As we move down the column IV of elements in the periodic table, the electrons of outermost shells go farther away from the nucleus. This reduce the force of attraction between these electrons and the nucleus. As a result the electron becomes less tightly bound to their nucleus in the case of those elements. It means that energy gap between the valance band and conduction band is reduces.

**Semiconductor**

The material whose electrical conductivity lies in between those of conductor and insulators are known as Semiconductor. The semiconductors have almost an empty conduction band and almost filled valance band. These bands are separated by small energy gap (of the order of 1 to 2 eV)

At $0^0$ K, there is no electron in the conduction band whereas the valance band is completely filled. When the temperature is increased, some of the covalent bond breaks. As a result of this, some electron jump from valance band to conduction band. This results in the flow of current through the semiconductor. This shows that the electrical conductivity of a semiconductor increases in temperature. The common example of semiconductor is Germanium, Silicon etc.

**Classification of Semiconductor**




1. **Intrinsic Semiconductor :** A semiconductor which is made of its extremely pure form is known as Intrinsic semiconductor.
   Ex. Pure Silicon and Germanium.

   We have already discussed that in semiconductor there exists a small energy gap between valance band and conduction band. These gap is 0.72 eV for Germanium and 1.1 eV for silicon. A little consideration will show that this energy gap is so small that even at room temperature, some electrons jump from valance band to conduction band. For each electron liberated from the valance band create a vacant site in the valance band. This vacant site is called hole. This hole behaves like a positively charged particle. Whenever an electric field is applied at room temperature, the electron move in a direction opposite to the direction of electric field while a hole moves in the same direction as that of electric field. Thus in a semiconductor the current consists of two components:

   i) Current due to the movement of electrons.

   ii) Current due to the movement of holes.

   In an intrinsic semiconductor the covalent bond break up due to the thermal excitement of electrons between them. As a result of this new electron-hole pairs are produced continuously. But at the same time, other electron-hole pairs disappear due to recombination.

   At any given temperature, the number of electrons present in the conduction band is equal to the number of holes present in the valance band. Thus there exists equilibrium between concentration of holes and electrons. Thus in an intrinsic semiconductor the Fermi level lies in the middle of the energy gap.

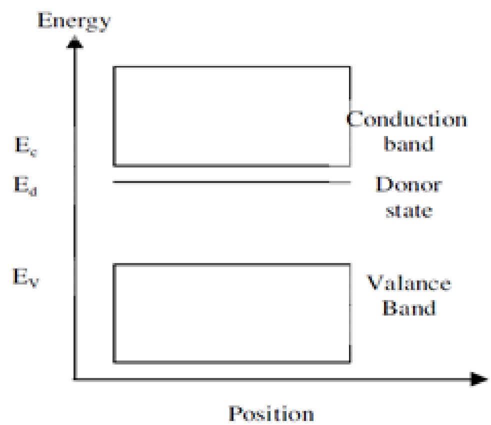
2. **Extrinsic Semiconductor:** An intrinsic semiconductor having extremely small amount of suitable impurity is known as extrinsic semiconductor. These impurities are called doping agent and the process of adding impurity is known as doping. The impurities are either of pentavalent atom or of trivalent atom. The example of pentavalent impurities are Arsenic, antimony, Phosphorous etc and the example of trivalent impurities are Boron, Aluminum etc. The addition of impurities increases the conductivity.
   The pentavalent impurity is known as Donor atom as it donates one electron to the conduction band of the intrinsic semiconductor. On the other hand, a trivalent impurity is known as acceptor atom,

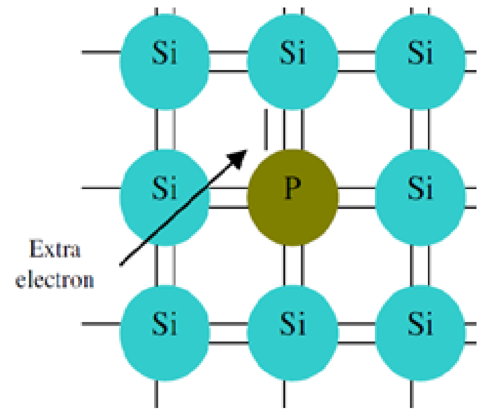
as it accepts an electron from the intrinsic semiconductor. The extrinsic semiconductor is of two types:

a) N-type Extrinsic Semiconductor

b) P-type Extrinsic Semiconductor

**a) N-type Extrinsic Semiconductor:** When a small amount of pentavalent impurity is added to an intrinsic semiconductor, it is known as N-type semiconductor. With the addition of pentavalent impurities provides large number of free electron in semiconductor.




Consider a pure Germanium crystal. The Germanium atom has four valance electrons. When a small amount of pentavalent atom like Phosphorous is added to Germanium crystal, a large number of free electrons become available in the crystal. The Phosphorous atom fits in the Germanium crystal in such a way that its four valance electron form covalent bond with four Germanium atom and fifth valence electron of Phosphorous atom becomes free. Therefore for each Phosphorous atom added provides one free electron in the Germanium crystal.

The following points are important:

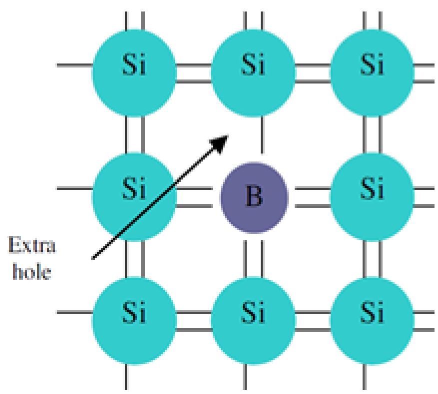
i) Many new free electrons are produced by adding the pentavalent impurity.

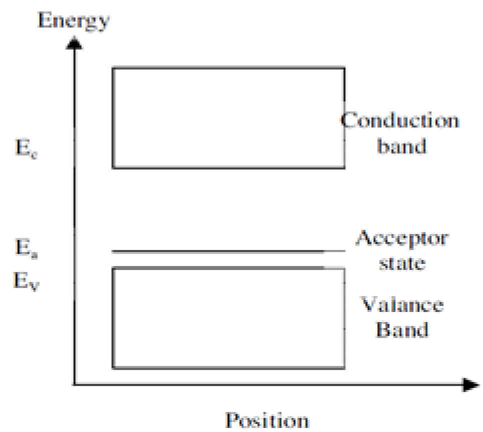
ii) Even at room temperature generates few electron-hole pairs. However the number of free electrons far exceeds the number of holes.

Due to this predominance of electron over the holes it is called N-type semiconductor.

b) **P-type semiconductor:** When a small amount of trivalent impurity is added to an intrinsic semiconductor, P-type semiconductor is formed. With the addition of trivalent of trivalent impurity provides large number of holes in semiconductor. Such impurities which produces P-type semiconductor are known as acceptor impurities because the hole created can accept the electrons.

Consider a pure Germanium crystal. When a small amount of trivalent impurity like Boron is added to Germanium crystal, a large number of holes become available in the crystal. Each atom of Boron fits in to Germanium crystal but now only three covalent bond can be formed. The fourth covalent bond, one Germanium atom contribute one valance electron while boron has no valance electron to contribute. That is the fourth bond is incomplete being short of one electron. This missing electron is called holes. Therefore for each Boron atom added one hole is created.




The addition of trivalent impurity has produced a large number of holes. However, there are a few conduction band electrons due to thermal energy associated with room temperature. Due to the predominance of holes over free electrons it is called P-type semiconductor.