

**Department of Electronics**  
**L.S College, Muzaffarpur**

## **Fermi Level**

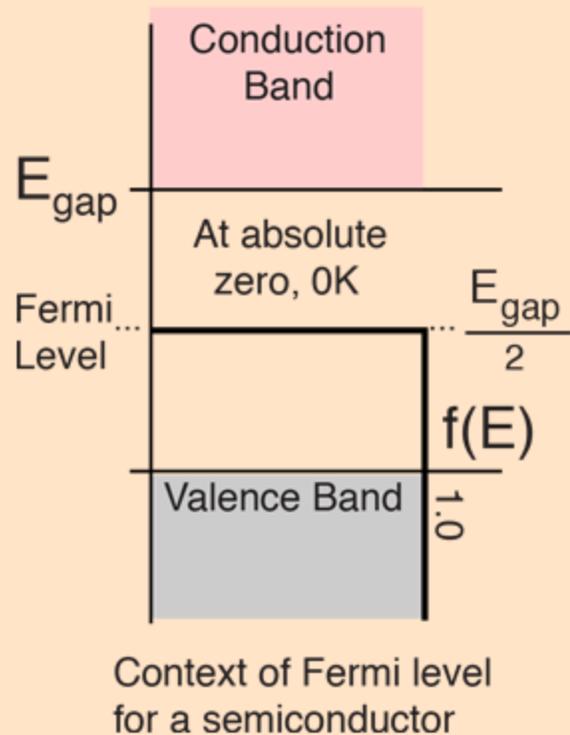
The Fermi Level is the energy level which is occupied by the electron orbital at temperature equals 0 K. The level of occupancy determines the conductivity of different materials. For solid materials such as metals, the orbital occupancy can be calculated by making an approximation based on the crystalline structure. These orbitals, combined with the energy level, determine whether the material is an insulator, semi-conductor, or conductor. The orbitals are categorized according to its energy. The lower energy orbitals combine and form a band called the valence electron band, and the higher energy orbitals combine to form a band called the conduction band. There is a gap between the valence and conduction band called the energy gap; the larger the energy gap, the more energy it is required to transfer the electron from the valence band to the conduction band.

Fermi level" is the term used to describe the top of the collection of electron energy levels at absolute zero temperature. This concept comes from Fermi-Dirac statistics. Electrons are fermions and by the Pauli exclusion principle cannot exist in identical energy states. So at absolute zero they pack into the lowest available energy states and build up a "Fermi sea" of electron energy states. The Fermi level is the surface of that sea at absolute zero where no electrons will have enough energy to rise above the surface. The concept of the Fermi energy is a crucially important concept for the understanding of the electrical and thermal properties of solids. Both ordinary electrical and thermal processes involve energies of a small fraction of an electron volt. But the Fermi energies of metals are on the order of electron volts. This implies that the vast majority of the electrons cannot receive energy from those processes because there are no available energy states for them to go to within a fraction of an electron volt of their present energy.

In metals, the Fermi energy gives us information about the velocities of the electrons which participate in ordinary electrical conduction. The amount of energy which can be given to an electron in such conduction processes is on the order of micro-electron volts (see copper wire example), so only those electrons very close to the Fermi energy can participate. The Fermi velocity of these conduction electrons can be calculated from the Fermi energy.

$$v_F = \sqrt{\frac{2E_F}{m}} \quad \text{Table}$$

This speed is a part of the microscopic Ohm's Law for electrical conduction. For a metal, the density of conduction electrons can be implied from the Fermi energy.



The Fermi energy also plays an important role in understanding the mystery of why electrons do not contribute significantly to the specific heat of solids at ordinary temperatures, while they are dominant contributors to thermal conductivity and electrical conductivity. Since only a tiny fraction of the electrons in a metal are within the thermal energy  $kT$  of the Fermi energy, they are "frozen out" of the heat capacity by the Pauli principle. At very low temperatures, the electron specific heat becomes significant.

### Energy Band Diagram

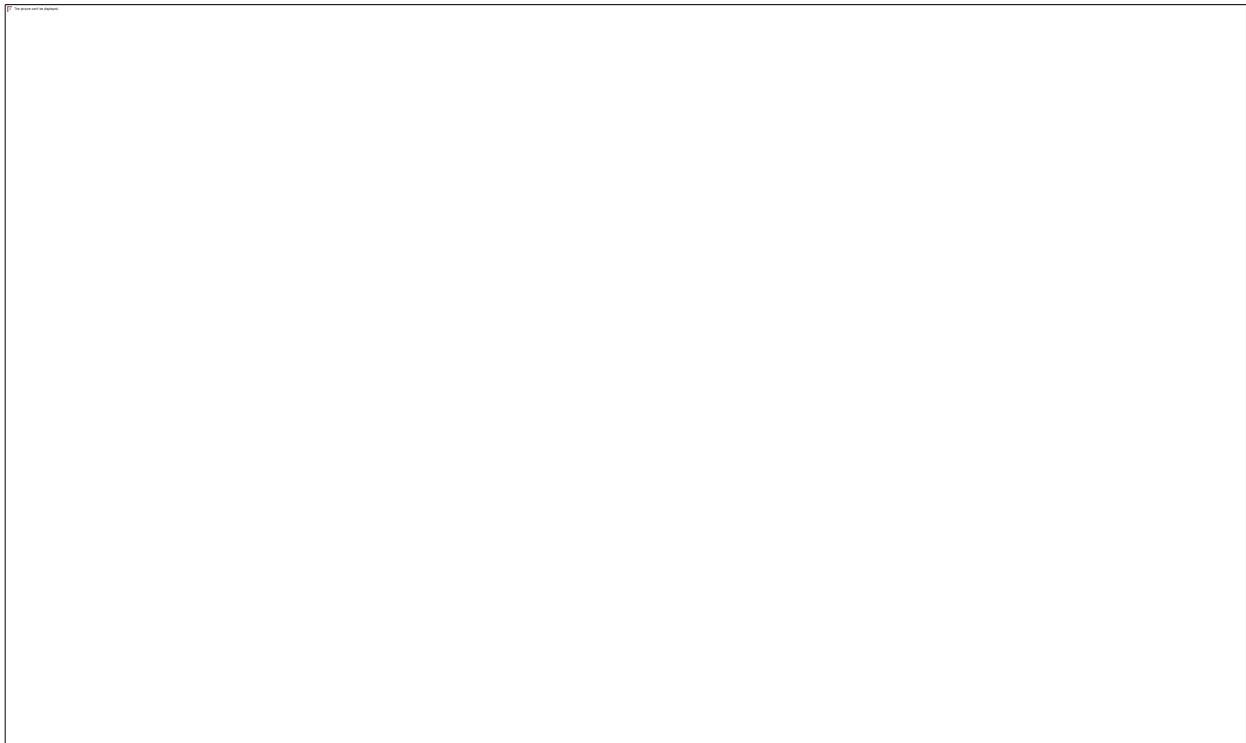
The diagram below is an example of an energy band diagram. The upper box represents the conduction band, the lower box represents the valence band, and the yellow is the occupancy level of electrons. The conductivity of a material can be determined by the energy diagram. In order to conduct electricity, an electron must make a transition into another state since electrons cannot occupy the same quantum states. When the electron cannot make that transition, it will be not be able to conduct electricity. When the band is completely filled, the closest state an electron to transfer to will be the states in the conduction band, and that would require the electron to jump over the band gap, thus making it more difficult to conduct electricity. With this rule, it is easy to tell the difference between insulator, semi-conductor, and conductors. The energy band on the left

side is an insulator because if an electron wants to go into a higher energy state, it will need to jump through that huge energy gap. Since it requires a large amount of energy to move the electron, the material will have a difficult time conducting electricity. The energy band in the middle is a semi-conductor because although the electrons have to jump across the energy gap, the energy gap is small. If an electron wants to make a transition, it will require very little energy since they are all in the same energy band. Thus, for the material in the middle, although it will have difficulty conducting electricity, it is not impossible. The energy band in the right is a conductor. Although the valence band is filled just like the insulator and semi-conductor, the conduction band overlaps the valence band. If an electron wants to make a transition, it will require very little amount of energy. Which means the material on the right can conduct electricity very easily.

### Fermi Level

The electrons that occupies the orbits are described by Fermi-Dirac distribution as the figure below, the distribution takes on the form of:

$$f = \frac{1}{1 + \exp\left[\frac{E - u}{KT}\right]}$$



Where E is the energy of the system, u is the fermi level, K is the Boltzmann constant, and T is the temperature. The Fermi-Dirac distribution accounts for the population level at different

energies. The Fermi level is at  $e/u=1$  and  $KT=u$ . Whenever the system is at the Fermi level, the population  $n$  is equal to  $1/2$ . The tail part in the exponential is very important for the conductivity of semi-conductors. If you can bring the Fermi level high enough, then part of the tail will go over to the conduction band. Thus, the electron will have an easier time making a transition to the conduction band and the conductivity will increase. The conductivity can also be affected by factors such as temperature and purity. From the distribution, the temperature has a direct effect on how the energy states are populated. When temperature increases the tail of the exponential gets longer and wider, thus making the conduction band level population more accessible. For Semi-conductor materials, having an access to the conduction band level means it can conduct electricity with energy, which means the conductivity of the material is increased. The purity also affects the Fermi level. Purity defects with atoms that have excess electrons would bring the Fermi level up, and making it easier for electrons to jump into the conduction band.