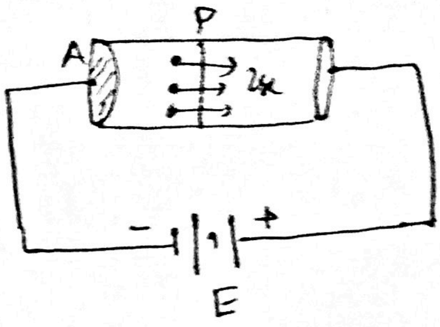
Semiconductor Physics

Conductivity of Conductors

Consider a conductor of length L and area of cross-section 'A' connected to a battery 'E'. Let n be the no. of electrons per unit volume and v_d be the drift velocity of the electrons.



The no. of electrons crossing any plane (P) of cross-section area A in one second $= n \times (v_d \times A)$

If 'e' be the charge on each electron, then charge carried by the electrons in one second $= e n v_d A$

The electric current I is defined as charge flowing per second hence

$$I = e n v_d A \quad \text{—— (1)}$$

The current density J is defined as current per unit area

$$J = \frac{I}{A}$$

$$J = \frac{e n v_d A}{A}$$

$$J = e n v_d \quad \text{—— (2)}$$

It is observed that drift velocity is proportional to E.

$$\therefore \; v_d \propto E$$

$$v_d = \mu_e E \quad \text{—— (3)}$$ where μ_e is electron mobility.

Now substituting the value of v_d from eqn (3) in eqn (2)

$$J = e n \mu_e E$$

$$\sigma \cancel{E} = e n \mu_e \cancel{E} \qquad [\because J = \sigma E]$$

$$\boxed{\sigma = e n \mu_e}$$ This expression shows that the σ depends upon n and their mobility.

or $\rho = \frac{1}{\sigma} = \frac{1}{e n \mu_e}$

Conductivity of Semiconductors

Semiconductor is a bipolar device, in semiconductor the charge carriers are electrons as well as holes while in metal conduction takes place by electrons only. So ~~that~~ the conductivity of semiconductor is different from a metal.

The conductivity of a metal is given by

$$\sigma = n e \mu_e \quad \text{--- (1)}$$

On the basis of eqn (1), the conductivity of semiconductor material can be obtained on the basis of electrons and holes.

The conductivity σ_e of semiconductor due to electrons in the conduction band is given by

$$\sigma_e = n e \mu_e \quad \text{--- (2)}$$

n = electron density in conduction band {$\mu_e \rightarrow$ electron mobility}

Similarly, the conductivity σ_h of the semiconductor due to holes is given by

$$\sigma_h = p e \mu_h \quad \text{--- (3)}$$

where μ_h is hole mobility
p is positive hole density in valence band

∴ total conductivity σ is given by

$$\sigma = \sigma_e + \sigma_h$$

$$\sigma = n e \mu_e + p e \mu_h$$

$$\boxed{\sigma = e[n\mu_e + p\mu_h]} \quad \text{--- (4)}$$

$$\sigma = e(n\mu_e + p\mu_h)$$

Conductivity of Intrinsic Semiconductor

A semiconductor in an extremely pure form is known as intrinsic semiconductor.

In case of intrinsic semiconductor (Ge or Si) the number of conduction electrons is equal to the number of holes.

i.e. $n = p = n_i$ (intrinsic concentration of electrons or holes)

Thus the conductivity σ_i of ~~intrin~~ intrinsic semiconductor is given by

$$\sigma_i = e(n_i\mu_e + n_i\mu_h)$$

$$\boxed{\sigma_i = e n_i (\mu_e + \mu_h)} \quad \text{--- (5)}$$

Conductivity of N-type Semiconductor

When a small amount of pentavalent impurity is added to a pure semiconductor crystal during the crystal growth, the resulting crystal is called as N-type extrinsic semiconductor,

In case of N-type semiconductor, the electron concentration is far-far greater than the hole concentration i.e. $p = 0$. The electron concentration is now represented by N_D ($n = N_D$) from equ^n (4) we have

$$\boxed{\sigma_n = e N_D \mu_e}$$

$[\because n >> p]$.

Conductivity of P-type Semiconductor

When a small ~~amou~~ amount of trivalent impurity is added to a pure crystal during the crystal growth, the resulting crystal is called a P-type extrinsic semiconductor,

In case of P-type semiconductor, the electron concentration is negligible (small) in comparision to hole concentration.

i.e. $n = 0$, $P = N_A$ (where N_A is hole concentration)

Then equ^n (4) becomes.

$[\because p >> n)$

$$\boxed{\sigma_p \simeq e N_A \mu_h}$$

Fermi- Dirac Probability Distribution Function

~~For~~ Fermi - Dirac probability distribution function ~~controlls~~ controls the distribution of electrons among the energy levels as a function of temperature.

Fermi - Dirac probability distribution function $f(E)$ is expressed as —

$$f(E) = \frac{1}{1+e^{(E-E_f)/KT}} \quad \text{—} \quad (1)$$

where E = energy of electrons eV

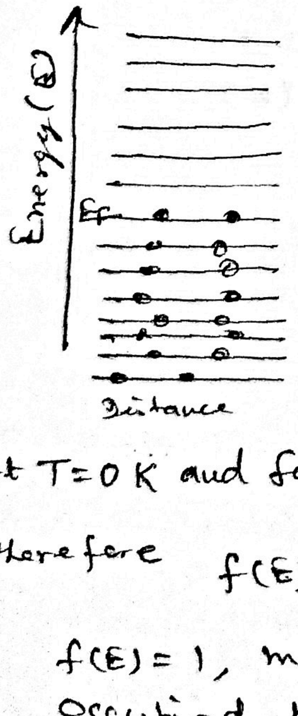
E_f = Fermi energy in eV

K = Boltzmann's Constt. (eV/K)

T = Absolute Temperature

The function $f(E) = 1$, ~~if~~ when an energy level is filled by electrons and $f(E) = 0$ for an empty energy level.

[Fermi level E_F is defined as the highest filled energy level in Conductor at 0K.



i) At T=0K and for $E < E_f$, $(E-E_f)$ is -ve. then $(E-E_f)/KT = -\infty$

therefore $f(E) = \frac{1}{1+e^{-\infty}} = \frac{1}{1+0} = 1$

$f(E) = 1$, means that all the energy levels below E_f are occupied by electrons.

ii) At T=0 and for $E > E_f$, $(E-E_f)$ is +ve, then $(E-E_f)/KT = +\infty$

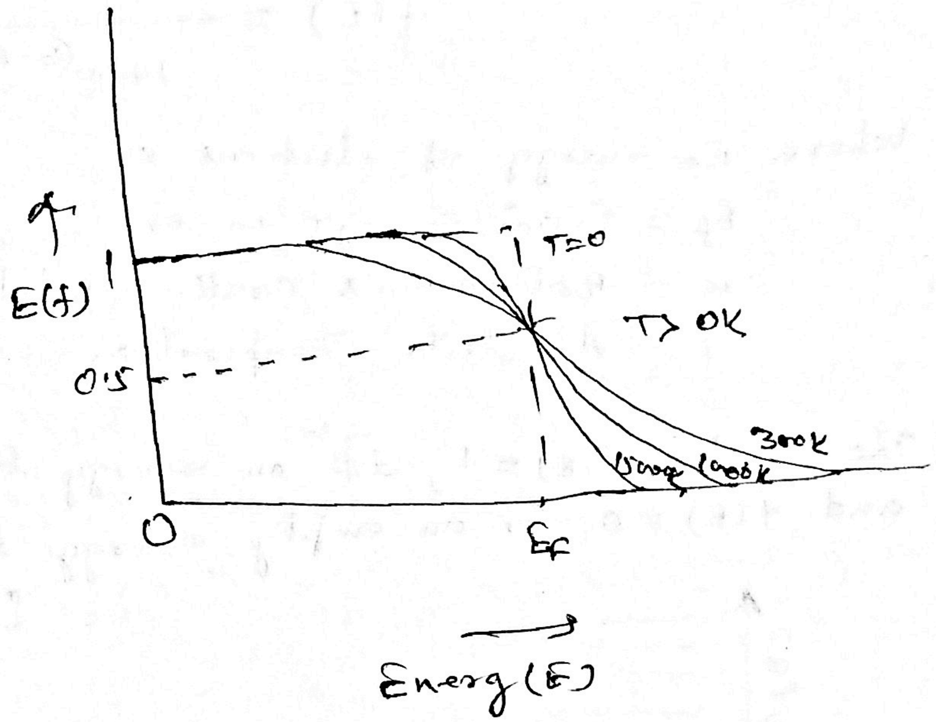
therefore $f(E) = \frac{1}{1+e^{+\infty}} = \frac{1}{1+\infty} = 0$

$f(E) = 0$, indicates that all the energy levels above E_f remains unfilled.

iii) ~~At T>0K~~ for $E = E_f$, $(E-E_f) = 0$ and $(E-E_f)/kT = 0$

therefore
$$F(f) = \frac{1}{1+e^0} = \frac{1}{1+1} = \frac{1}{2}$$

It ~~thus~~ implies that probability of occupation of fermi level at temp. greater ~~that~~ than absolute zero is $1/2$.



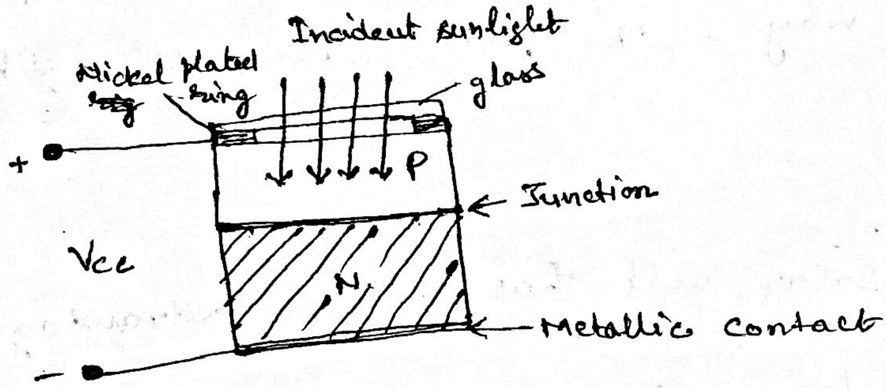
PHOTOVOLTAIC EFFECT

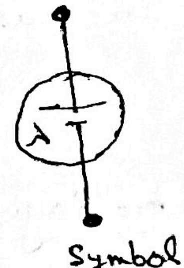
When a pair of electrodes dipped into an electrolyte and the light is allowed to incident on one of the electrodes, a potential difference is created b/w these electrodes. The phenomenon is known as photovoltaic effect.

SOLAR CELL

The solar cell is semiconductor (P-N) junction device which is used for converting sunlight (optical radiation) into electrical energy. The generated electric voltage is proportional to the intensity of incident light.

Construction





The solar cell is a P-N junction diode with doped semiconductor. The top P-type layer is made of very thin layer so that the light radiation may penetrate to junction.

P-type material is surrounded by a nickel plated ring which serves as the +ve terminal of the cell. A metallic contact at the bottom of N-type material acts as the -ve terminal of the cell.

Working

When a photon of light energy collides with the valence electron either in P-type material or N-type material, it imparts energy to the electron to leave its parent atom. As a result, free electrons and holes are generated on each side of the junction.

In P-type material, the newly generated electrons are minority carriers. These electrons move freely across the junction with no applied bias. Similarly in N-type material the newly generated holes are minority carriers. These holes move freely across the junction with no applied bias. In this way, the photo current flow through the circuit.

Advantage

Solar cell has several advantage — which are given below

i) The solar cell does not require any external power source.
ii) It is pollution free energy conversion system.
iii) The internal emf and current generated by solar cell is enough.
iv) The solar cell can be operated satisfactorily over a wide range of Temperature.