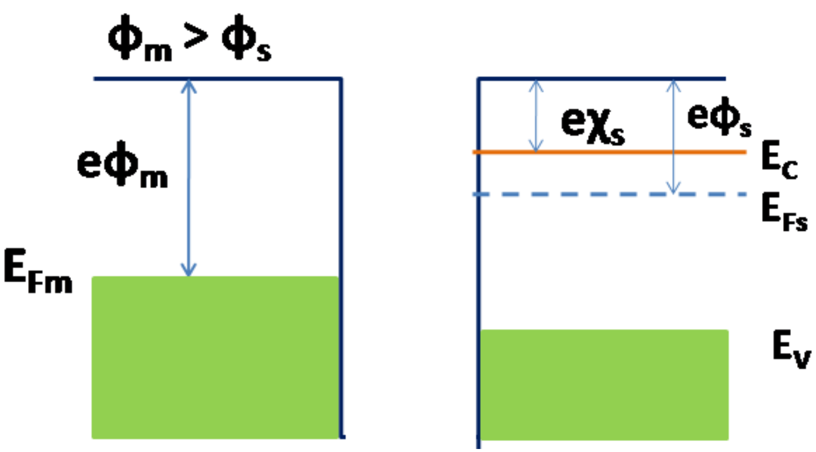
Schottky Barrier

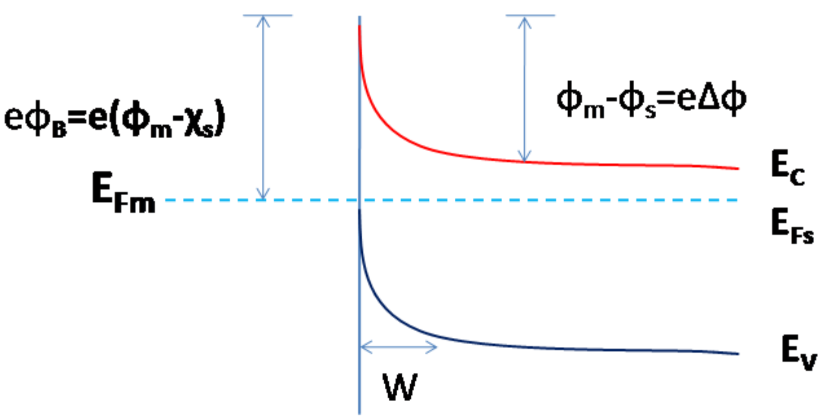
$\varphi_m > \varphi_s$ (for n type)

When the metal with the work function $e\varphi_m$ is brought in contact with a semiconductor having a work function $e\varphi_s$, charge transfer occur until the Fermi level align in equilibrium.



For example when $\varphi_m > \varphi_s$. The semiconductor Fermi level is initially higher than that of the metal before contact made. To align two Fermi levels the electron must flow from semiconductor to metal when they are made junction.

The electrons from metal side will find a barrier $e\varphi_b = e(\varphi_m - \chi_s)$



The equilibrium contact potential $\Delta\varphi$ which prevent further net electron diffusion from the semiconductor conduction band into metal in difference of work function potential $\varphi_m - \varphi_s = \Delta\varphi$

The equilibrium contact potential Δφ can be increased or decreased by the application of either forward or reverse bias voltage. The barrier height $e\varphi_b$ the metal side remain invariant with bias.
The depletion width W in the semiconductor can be calculated by using p^+-n approximation. Hence in the case depletion layer will be fully extended into the semiconductor side.

$$\frac{d^2\Phi}{dx^2} = -\frac{\rho}{\varepsilon} = -\frac{eN_d}{\varepsilon}$$

$$\frac{d\Phi}{dx} = -\frac{eN_d}{\varepsilon}x + const$$

Applying boundary condition At $x=d_n$, $\frac{d\Phi}{dx} = 0$

$$const = \frac{eN_d}{\varepsilon}d_n$$

$$\frac{d\Phi}{dx} = -\frac{eN_d}{\varepsilon}x + \frac{eN_d}{\varepsilon}d_n$$

$$\Phi = -\frac{eN_d}{\varepsilon}x^2 + \frac{eN_d}{\varepsilon}d_n x + const$$

Schottky Barrier

At $x=d_n$ $\phi=\phi_n$

$$\Phi_n = -\frac{eN_d}{\varepsilon}\frac{d_n{}^2}{2} + \frac{eN_d}{\varepsilon}d_n^2 + const$$

$$= \frac{eN_d}{\varepsilon}\frac{d_n{}^2}{2} + const$$

At $x=0$, $\varphi=\varphi_0=$ constant

Hence

$$\Phi_n - \Phi_0 = \frac{eN_d}{\varepsilon}\frac{d_n{}^2}{2}$$

$$\approx \frac{eN_d}{\varepsilon}\frac{W^2}{2}$$

$$\Delta\Phi = \frac{eN_d}{\varepsilon}\frac{W^2}{2}$$

$$W^2 = \frac{2\varepsilon}{eN_d}\Delta\Phi$$

$$W = \left(\frac{2\varepsilon}{eN_d}\Delta\Phi\right)^{1/2}$$

Schottky Diffusion Theory W>λ

Width of the depletion region exceeds the free path of electron ,The charge carrier passing over the space charge layer at forward voltage applied suffered numerous collisions and overcome by diffusing across the junction

$$J_D = eD_n \frac{\partial n}{\partial x}$$

Now to show the deficiency of electron at the boundary on the semiconductor side consider the concentration of electron in the bulk region and surface region of n type semiconductor

In the bulk region $n_b = N_C e^{(E_F - E_C)/kT}$

In the surface region i.e. x=0 $n_s = N_C e^{E_F - (E_C + e\Delta\Phi)/kT}$

$$= N_C e^{E_F/kT} e^{-E_C/kT} e^{-e\Delta\Phi/kT}$$

$$= n_b e^{-e\Delta\Phi/kT}$$

Now considering back to diffusion equation.
If we apply forward voltage V

$$J_D = eD_n \frac{\partial}{\partial x}(n_b e^{-e(\Delta\Phi - V)/kT})$$

$$= eD_n \frac{e}{kT}\left\{\frac{\partial V}{\partial x}\right\}\frac{\partial}{\partial x}(n_b e^{-e(\Delta\Phi - V)/kT})$$

$$= \frac{e^2}{kT}\frac{\mu kT}{e}\{-\xi_0\} n_b e^{-e(\Delta\Phi - V)/kT})$$

$$= -e\mu\{\xi_0\} n_b e^{-e(\Delta\Phi - V)/kT})$$

Now there will be diffusion of electrons metal to semiconductor.
But this current will not change if we apply any bias

$$J_C = -e\mu\{\xi_0\} n_b e^{-e\Delta\Phi/kT}$$

Hence the net current across the junction in bias condition

$$J = J_C - J_D$$

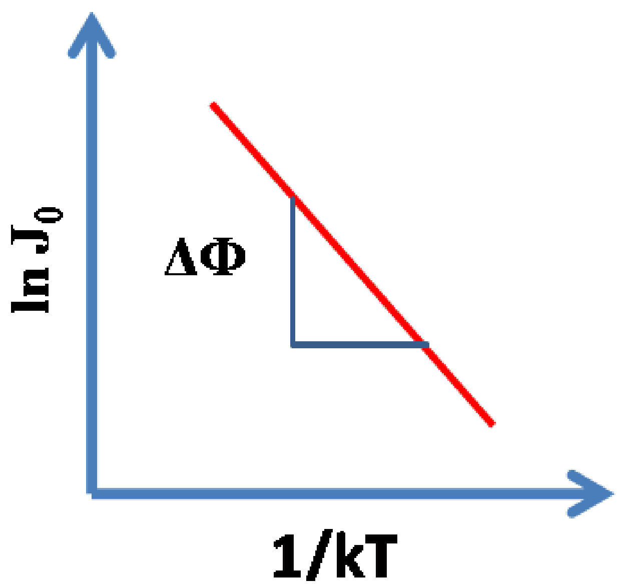
$$J = -e\mu\{\xi_0\}n_b e^{-e\Delta\Phi/kT} + e\mu\{\xi_0\}n_b e^{-e(\Delta\Phi - V)/kT})$$

$$= e\mu\{\xi_0\}n_b e^{-e\Delta\Phi/kT}\{e^{eV/kT} - 1\}$$

$$= J_0(e^{eV/kT} - 1)$$

Where $$J_0 = e\mu\{\xi_0\}n_b e^{-e\Delta\Phi/kT}$$

J_0 is controlled by electric field



If we plot lnJ_0 vs $1/kT$ we get a straight line. The slope of the straight line gives barrier height ΔΦ.