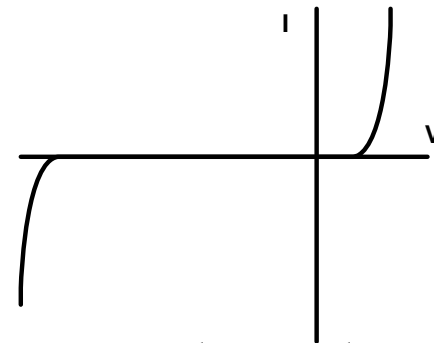


Why are diodes important?

- Small low power lasers/detectors
- Solar Cells “Free Clean Energy” from the sun. No oil required
- Detect hazardous gasses
- Used in all transistors
- Current flows easily one way, but not the other (rectifiers)
- All these functions can be integrated on one die



The contact potential

- It is the contact potential or built in electric field that controls the useful properties of diodes. It controls at what voltage a diode will turn on, and how much voltage can be extracted from a solar cell. It is the “ V_{be} ” used in calculating BJT DC operating points.

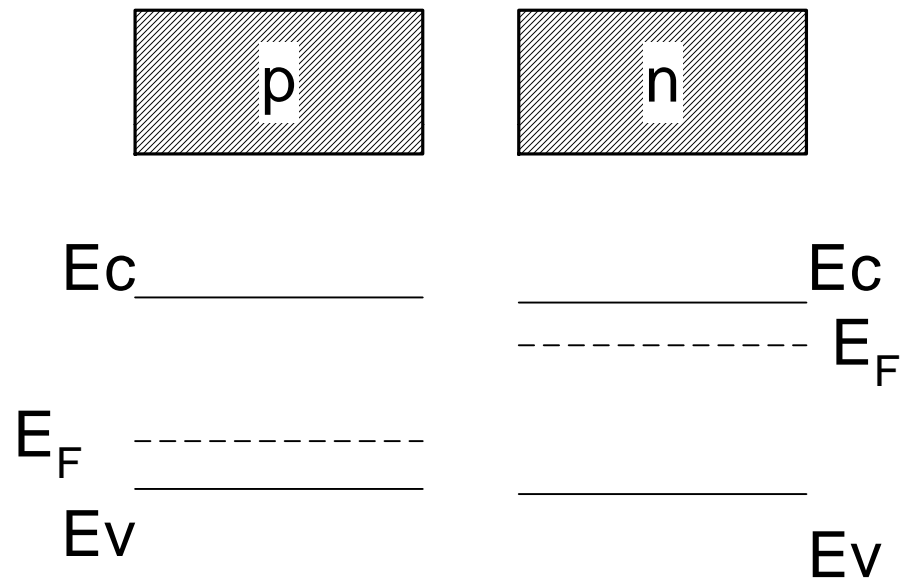
Where does the contact potential come from?

- Equilibrium (No current flows).
- When a pn junction is fabricated
 - $n_n > n_p$
 - $p_p > p_n$
- This causes the electrons to diffuse into the p side and the holes to diffuse into the n side of the semiconductor

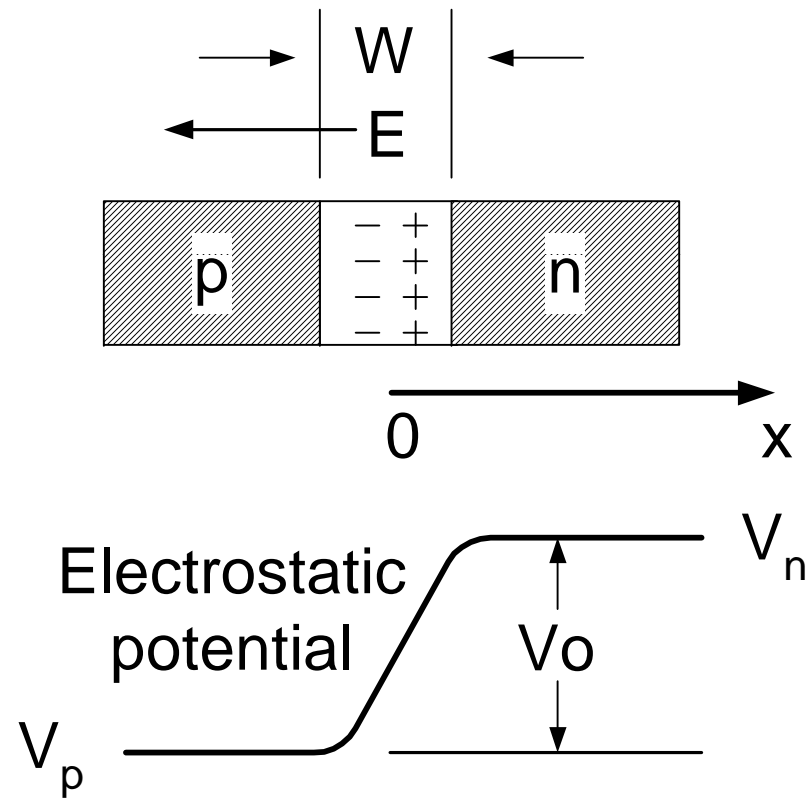
The contact potential

- This causes an electron and hole gradient which in turn causes an electric field to be set up.
- This electric field causes a drift current to occur in the opposite direction of the diffusion current.
- In thermal equilibrium these currents are equal and opposite (No current flows.)

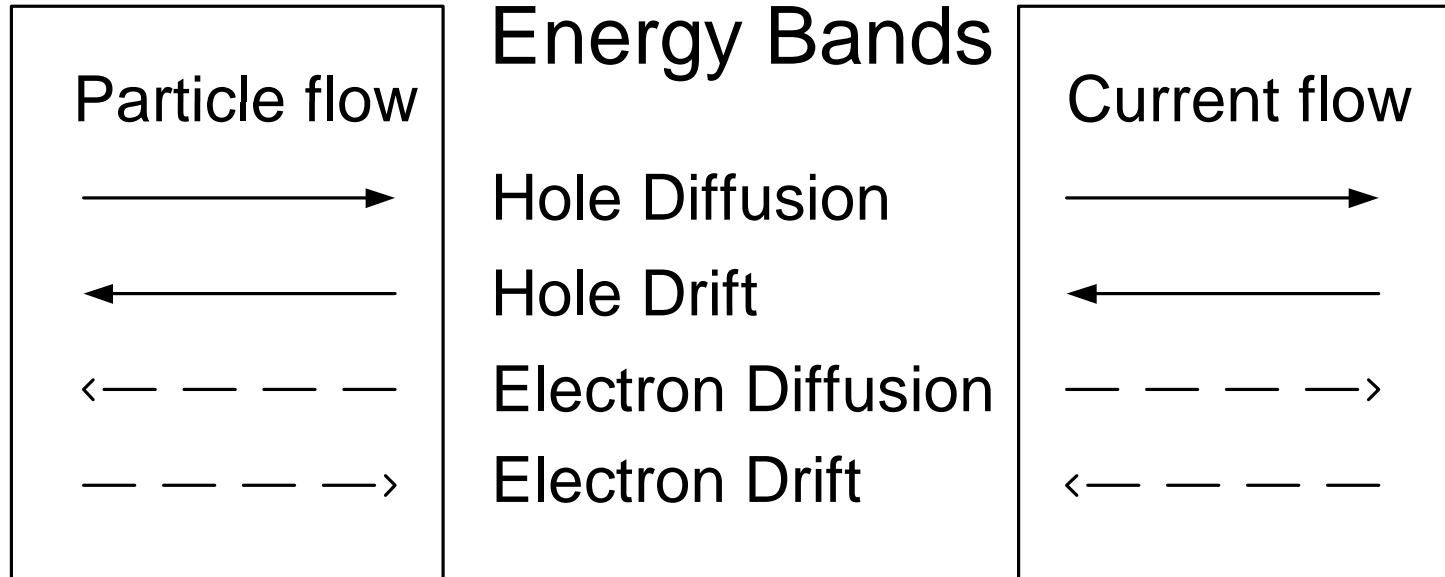
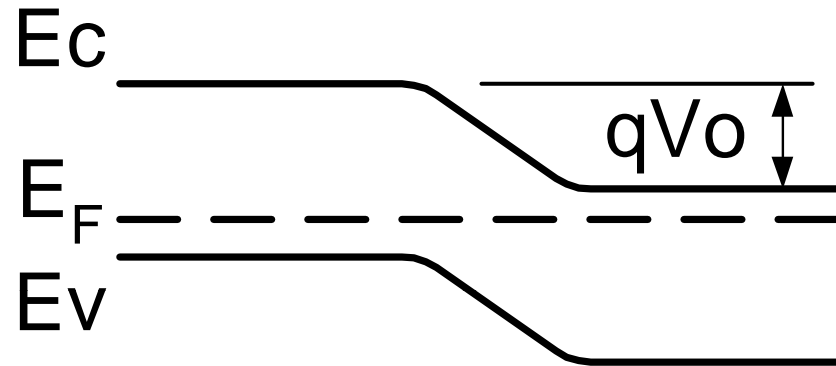
The contact potential



The contact potential



The contact potential



The contact potential

$$J_p(x) = q \left[\mu_p p(x) E(x) - D_p \frac{dp(x)}{dx} \right] = 0 \quad E(x) = -\frac{dV(x)}{dx}$$

$$-\frac{q}{kT} \int_{V_p}^{V_n} dV = \int_{p_p}^{p_n} \frac{1}{q} dp \quad \frac{D_p}{\mu_p} = \frac{kT}{q}$$

$$V_0 = \frac{kT}{q} \ln \left(\frac{p_p}{p_n} \right), \text{ assume a step junction, and that } p_p = N_a$$

and $n_n = N_d$, along with $p_p n_p = n_i^2 = p_n n_n$

$$V_0 = \frac{kT}{q} \ln \left(\frac{N_a N_d}{n_i^2} \right)$$



Equilibrium Fermi Levels

- Although the fermi level is flat throughout the semiconductor, its relative position to the conduction and valence bands is not.
- The result of this is that the distance from the Fermi level to the intrinsic level does change.
- The difference in these differences is qV_0
- Being able to interpret EBDs will demonstrate to future employers that you have a basic understanding of semiconductor physics (which would be true)

Space charge at the junction

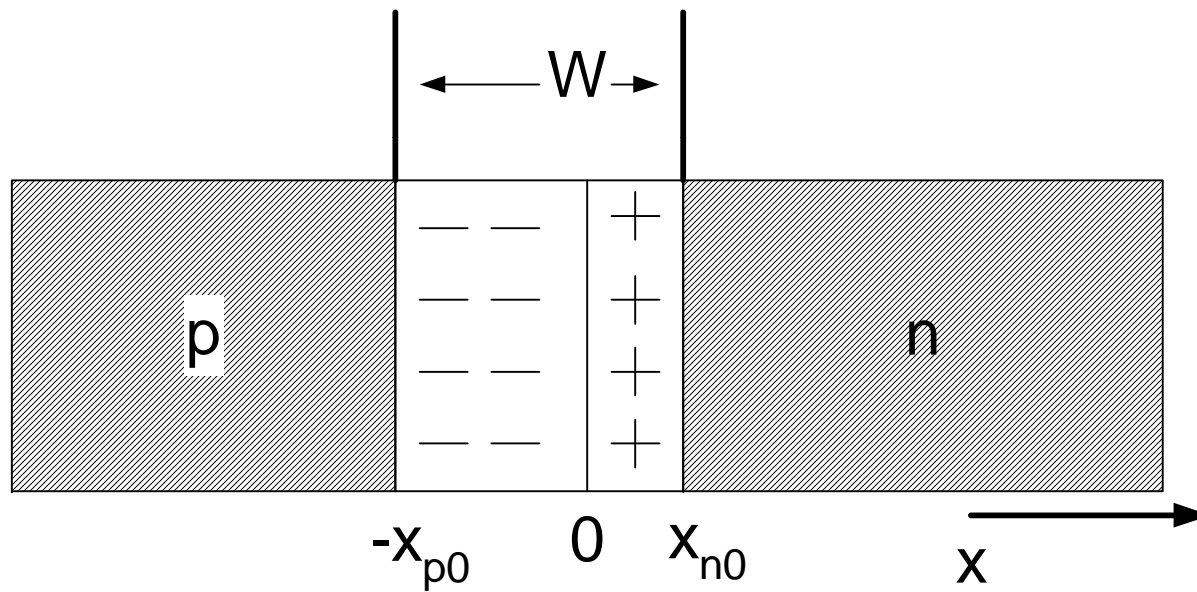
- Depletion approximation
 - All the carriers are depleted inside of W
 - Outside of W is neutral
 - At high current levels this breaks down

$$Q_+ = |Q_-|,$$

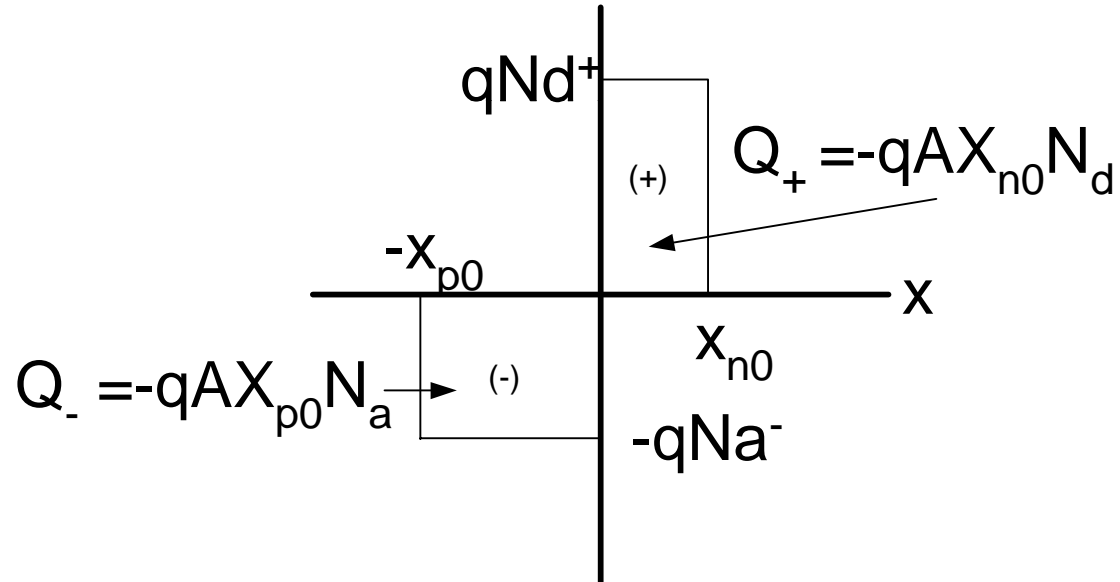
$$Q_+ = qAX_{n0}N_d$$

$$Q_- = -qAX_{p0}N_a$$

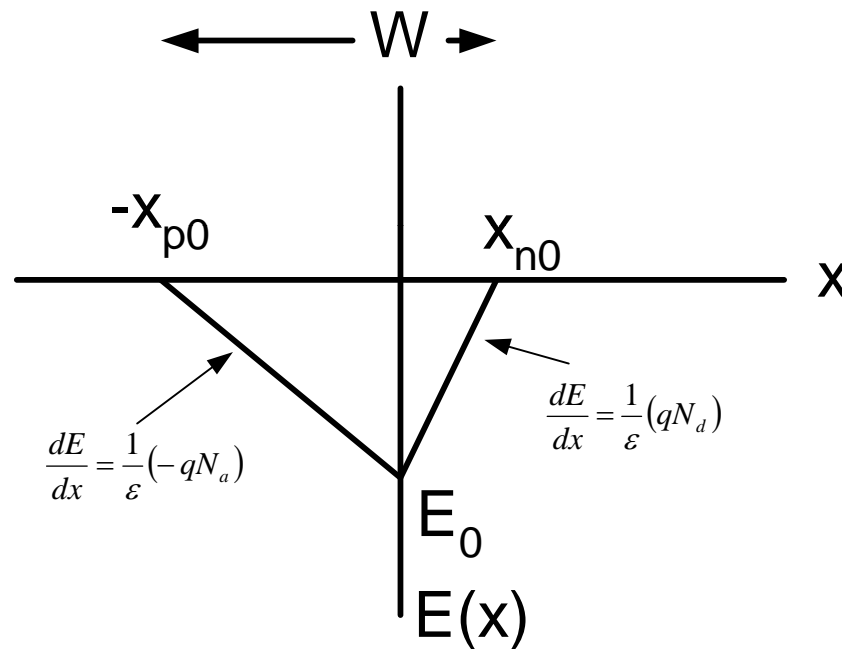
Space charge at the junction



Space charge at the junction



Space charge at the junction



Space charge at the junction

- Poisson's equation
 - Needed to calculate electric field
 - Relates the gradient of the electric field to the local space charge

$$\frac{dE(x)}{dx} = \frac{q}{\epsilon} (p - n + N_d^+ - N_a^-)$$

$$\frac{dE(x)}{dx} = \frac{q}{\epsilon} N_d, 0 < x < x_{no}, N_d^+ = N_d$$

$$\frac{dE(x)}{dx} = -\frac{q}{\epsilon} N_a, -x_{p0} < x < 0, N_a^- = N_a$$

Space charge at the junction

- Poisson's equation
 - Integrate both sides and use the fact that the electric field must be equal on both sides of the junction. Will $\langle V_x \rangle$ Saturate going through a pn junction?

$$E_0 = -\frac{q}{\epsilon} N_d x_{no} = -\frac{q}{\epsilon} N_a x_{po}$$

- Now we can find V_o by integrating Poisson's equation again

$$V_o = \frac{1}{2} \frac{q}{\epsilon} \frac{N_a N_d}{N_a + N_d} W^2$$

Space charge at the junction

- Now we can find the depletion width as a function of doping concentrations

$$W = \left[\frac{2\epsilon kT}{q^2} \left(\ln \frac{N_a N_d}{n_i^2} \right) \left(\frac{1}{N_a} + \frac{1}{N_d} \right) \right]^{\frac{1}{2}}$$

$$x_{p0} = \left\{ \frac{2\epsilon(V_o - V)}{q} \left[\frac{N_d}{N_a(N_a + N_d)} \right] \right\}^{\frac{1}{2}}$$

$$x_{n0} = \left\{ \frac{2\epsilon(V_o - V)}{q} \left[\frac{N_a}{N_d(N_a + N_d)} \right] \right\}^{\frac{1}{2}}$$



P.E.

$$N_A = 10^{16} \text{cm}^{-3}, N_D = 10^{19} \text{cm}^{-3},$$

$$n_i = 1.5 \times 10^{19} \text{cm}^{-3}, \text{Si at } 300\text{K}$$

Calculate V_o , x_{n0} , x_{p0} , E_o for this junction at