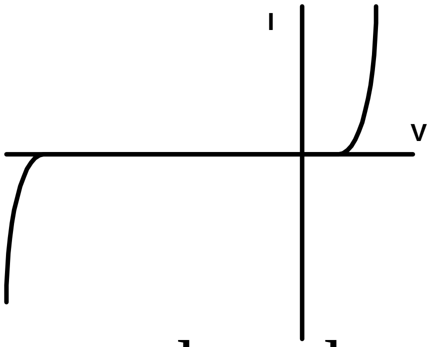
Why are diodes important?

- 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 “Vbe” used in calculating BJT DC operating points.

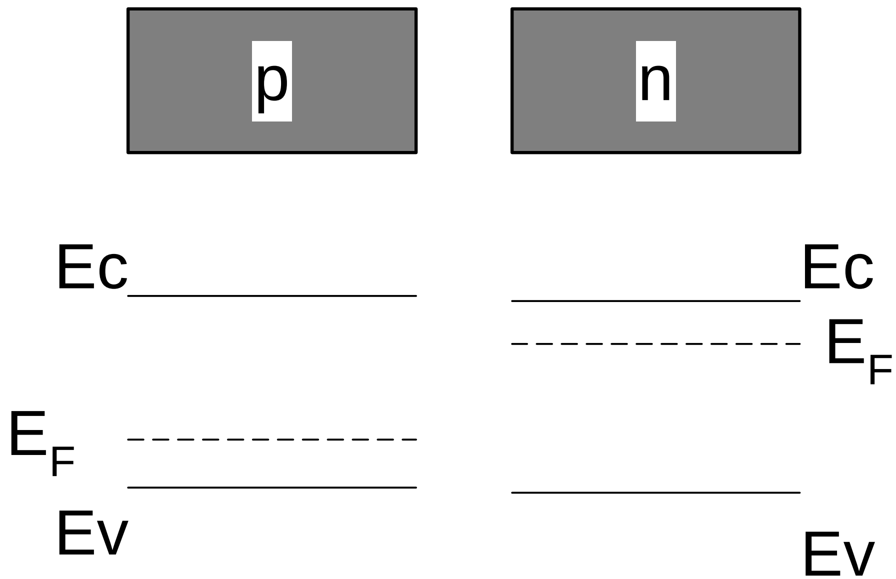
Where does the contact potential come from?

- 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

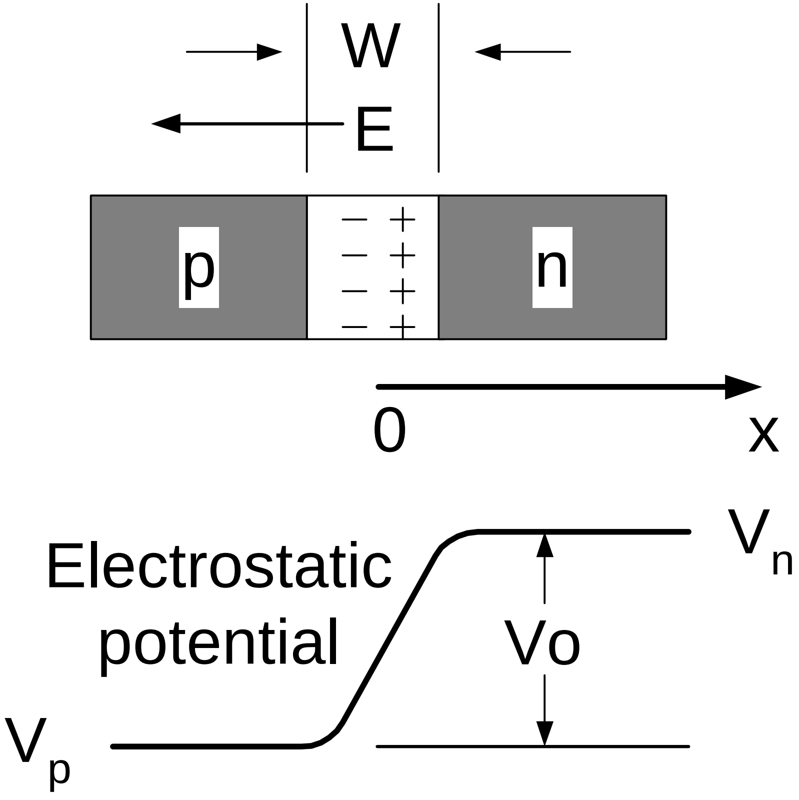
The contact potential

- 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.)

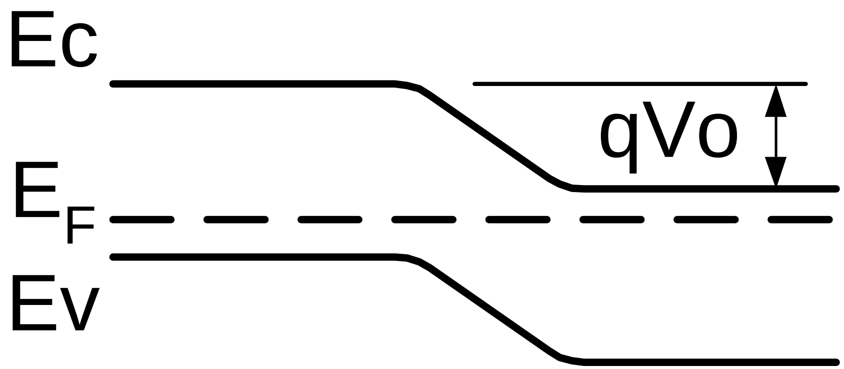
The contact potential



The contact potential



The contact potential



Energy Bands

Particle flow		Current flow
→	Hole Diffusion	→
←	Hole Drift	←
⇠	Electron Diffusion	⇢
⇢	Electron Drift	⇠

The contact potential

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

$$-\frac{q}{kT}\int_{Vp}^{Vn} dV = \int_{p_p}^{p_n} \frac{1}{q} dp \qquad \frac{D_p}{m_p} = \frac{kT}{q}$$

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

$$\text{and } n_n = N_d, \text{ along with } p_p n_p = ni^2 = p_n n_n$$

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

*

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 qVo
- 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

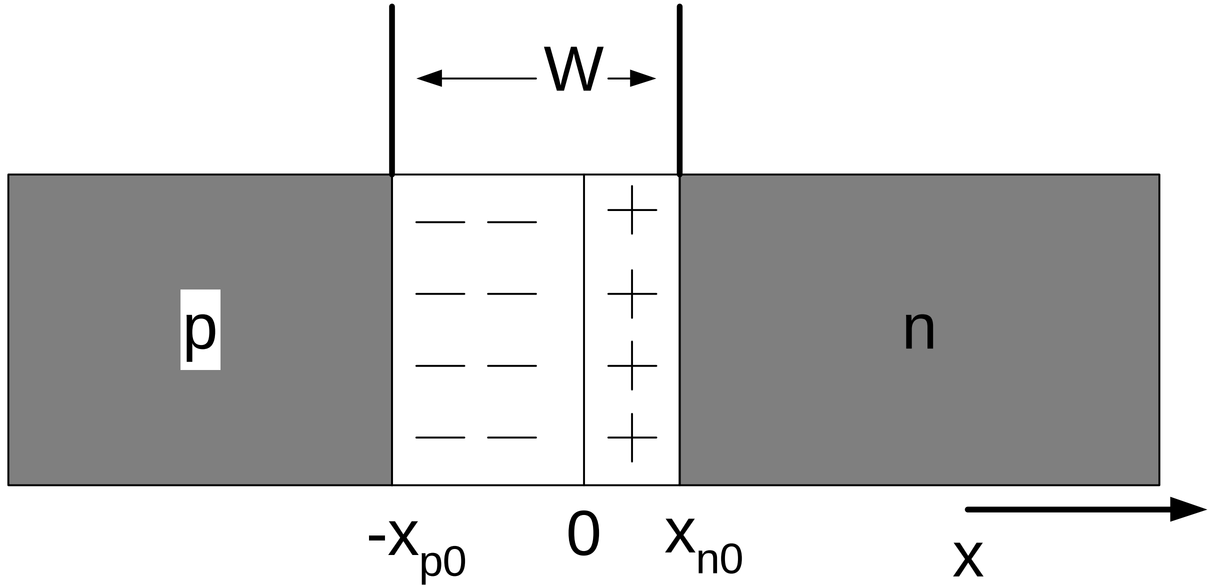
- Depletion approximation
  - All the carriers are depleted inside of W
  - Outside of W is neutral
  - At high current levels this breaks down

$$Q_+ = \left| Q_- \right|,$$

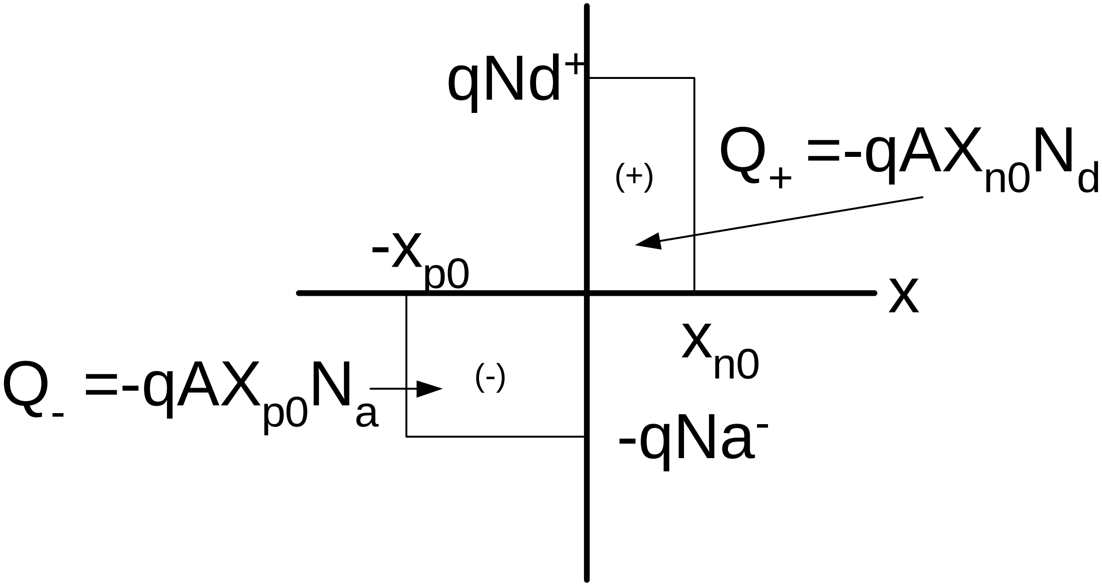
$$Q_+ = qAX_{n0}N_d$$

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

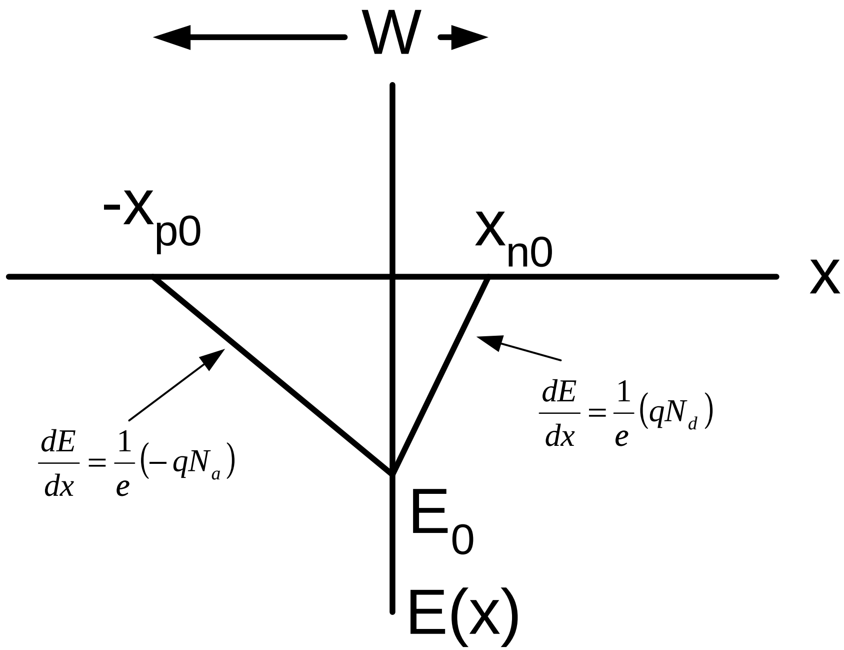
Space charge at the junction



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

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

$$\frac{dE(x)}{dx} = \frac{q}{e} N_d, 0 < \mathrm{x} < \mathrm{x}_{\mathrm{no}}, N_d{}^{+} = N_d$$

$$\frac{dE(x)}{dx} = -\frac{q}{e} Na, \text{-} \mathrm{x}_{\mathrm{p0}} < \mathrm{x} < 0, N_a{}^{-} = N_a$$

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 <Vx> Saturate going through a pn junction?

$$Eo = -\frac{q}{e} N_d x_{no} = -\frac{q}{e} N_a x_{po}$$

- Now we can find V_o by integrating Poison’s equation again

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

Space charge at the junction

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

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

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

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

*

P.E.

- Nitrogen ($N_a=10^{16}cm^{-3}$) and Chlorine ($N_d=10^{18}cm^{-3}$) are used to make an abrupt pn junction in ZnSe and the radius of the circular device is .02in.
- Calculate V_o, x_{n0}, x_{p0}, E_o for this junction at equilibrium for 300K.
- Eg=2.7eV, $m_e^*=.17$, $m_h^*=1.1$, dielectric constant=$9\times8.85\times 10^{-14}$ F/cm