Problem Set 3
Physics 240B

Due Thursday January 29, 2009
Late HW accepted until class on Tuesday February 3

1. Consider a pn junction made from the semiconductor in Problem 2, Set 1. The bandgap is 2 eV and effective masses are $m/4$ for electrons and $m/7$ for holes. The p side has 10^{11} acceptors per cm^3, and the n side has 4×10^{11} donors per cm^3. Assume the acceptors are 10 meV above the top of the valence band and the donors are 20 meV below the bottom of the conduction band. The dielectric constant is $\epsilon = 10$.

a) What would the chemical potential at 300 K be for the n- and p-type semiconductors if they were not in contact with each other? State your answer relative to the center of the energy gap. (For the p-type material, you may simply quote the answer from the previous problem set.)

b) In class we used a step-function model of the charge in the depletion region. Find the size of the depletion region on each side of the junction, d_p and d_n, in this model.

c) At any location in the crystal, the homogeneous chemical potentials and the electrostatic potential $\phi(x)$ together define the location of the conduction, valence, and dopant bands relative to the chemical potential. From these relative energies, you can calculate the carrier densities n_c and p_v, as well as the densities of carriers bound to dopant sites, n_d or p_a. Do this calculation, and from it find the charge density $\rho(x)$, at $x = -0.9d_p, -0.75d_p - 0.5d_p, -0.1d_p 0.1d_n, 0.5d_n, 0.75d_n, 0.9d_n$. (Alternatively, you can write a program that calculates and graphs n_c, p_v, dopant density, and ρ as a function of x.) Your numbers should illustrate the "depletion" effect that gives the depletion layer its name, the near-complete ionization of dopants, and how good the original step function guess at ρ is. (The next step in a self-consistent calculation would be to calculate a new $\phi(x)$ from the new $\rho(x)$...)

2. Consider a metal and a p-type semiconductor, where the work function of the metal is larger than that of the semiconductor.

a) Sketch the relevant energies (the vacuum energy, μ for each, and ε_c and ε_v for the semiconductor) if the two are well separated from each other.

b) Sketch the relevant energies if the two are in contact. Do this part "both ways"; that is, using only the energies of the crystal states in one sketch and the crystal energies plus the contribution of any induced electric field in another. Identify regions of filled states, empty states, and no states.

c) Explain how the hole currents from metal to semiconductor valence band and vice versa balance each other in equilibrium.

d) If an applied voltage V reduces the metal's voltage relative to that of the semiconductor far from the junction, how are the hole currents in each direction affected? Does the net current increase with V or level out?

e) Repeat part d) for an applied voltage in the opposite direction.

f) One could also consider how a bias voltage affects the electron currents to and from the conduction band, but this is less important. Why?