Answer Set 2
Physics 240B

A&M 18.1 a) A Gaussian box containing a cross-section of the entire double layer has zero net charge, from (18.31). There is no flux through the portion of the box inside the metal or through the walls perpendicular to the metal's surface, so there must also be no flux through the wall outside the metal. The field is constant along this surface by symmetry, so it must vanish.
For the work in moving an electron from 0 to L through a double layer, $W_s = \int_0^L eE(x)dx = exE(x)|_0^L - e\int_0^L x\frac{dE(x)}{dx}dx$. The surface term vanishes because E vanishes outside the double layer. The second term becomes $-e\int_0^L x[4\pi\delta\rho(x)]dx = -4\pi eP$, from the definition of dipole moment.

b) The charge on a conducting sphere is all on the surface. For an isolated sphere, the charge is evenly distributed and the potential relative to infinity is $\frac{Q}{r}$ in cgs units. Since 1 volt is 1/300 erg/esu, the sphere in the question must have total surface charge 1/300 esu. This is $(1/300)/4.8\times10^{-10} = 6.9\times10^6$ electrons, in $4\pi r^2 = 12.6\text{cm}^2 = 12.6\times10^{16}\text{Å}^2$. Dividing does give an electron density of order 10^{-10}.

A&M 29.5 a) The total electron (i.e., conduction band) current is $J_e^{drift}(d_n) + J_e^{diff}(d_n) = J_e(d_n) = J_e(-d_p) \approx J_e^{diff}(-d_p)$, where we assume the current is *constant* (not just continuous) across the depletion layer. (Note that while the total current from both bands, $J_e + J_h$, must be constant even outside the depletion layer, this is not true of J_e. In a non-equilibrium situation where the density of conduction band electrons is a function of position, different amounts of electron/hole generation and recombination at different sites can lead to changes in how much of the total current comes from J_e versus J_h.) Since electrons are minority carriers on the p side, by (29.45) $J_e^{diff}(-d_p) = -D_n\frac{dn_c}{dx}(-d_p) = -D_n(\frac{1}{L_n})[n_c(-d_p) - \frac{n_i^2}{N_a}]$. For the diffusion current on the n-side, note that if the electric field is small in the diffusion region (which is what this question will verify), $\frac{dn_c}{dx} \approx \frac{dp_v}{dx}$. Using (29.44), $J_e^{diff}(d_n) = -D_n\frac{dp_v}{dx}(d_n) = -D_n(\frac{-1}{L_p})[p_v(d_n) - \frac{n_i^2}{N_d}]$. Combining these, $J_e^{drift}(d_n) \approx J_e^{diff}(-d_p) - J_e^{diff}(d_n) = D_n[p_v(d_n) - \frac{n_i^2}{N_d}]/L_p + D_n[n_c(-d_p) - \frac{n_i^2}{N_a}]/L_n$.

b) We need $J_e^{drift} = -\mu_n n_c E \approx -\mu_n N_d E$, or $E = -J_e^{drift}/\mu_n N_d$.

c) The terms in J_e^{drift} are all of order $D_n n_i^2/N_d L_p$, where I assume the diffusion lengths, dopant densities, and diffusion constants have the same order of magnitude on both sides of the junction. Using the Einstein relation $\mu_n = eD_n/kT$ and the expression for field from b), $|\Delta\Phi| \sim |EL_p| \sim |\frac{kT}{e}(\frac{n_i}{N_d})^2|$.

d) Compare to the change in potential across the depletion layer, $|\Delta\Phi| \sim \frac{2\pi e}{\varepsilon}N_d d_n^2$. (There is another term with $N_a d_p^2$, which I omit not for any physical reason but because this is just an order of magnitude calculation and the two terms are about the same size.) Typical numbers are $N_d \approx 10^{16}/\text{cm}^3$ $\varepsilon \approx 10$, $d_n \approx 10^{-5}$ cm and $n_i = 10^{11}/\text{cm}^3$ at room temperature (and less as T decreases). Room temperature is about 0.025 eV. Plugging in gives a change in Φ of about 2.5×10^{-12} V across the diffusion layer and 9×10^{-2} across the depletion layer.

A&M 29.6 First, from the band gap we can get $n_i = 1.8\times10^{15}$ /cm^3, assuming the effective masses are just the bare electron mass. (Use A&M equation 28.20.) On the n side, the hole concentration is $n_i^2/10^{18} = 3\times10^{12}$. To maintain this in steady state, with a recombination time of 10^{-5} seconds, there must be 3×10^{17} holes per cm^3 generated each second. The ones starting within a diffusion length of the junction, or 3×10^{13} per cm^2 of junction per second, have a good chance of getting swept across. Multiply by e to get current density. Multiply by 2 to account for an electron current flowing from the p side towards the n side. The total is about 10 μA per square cm.