Chem 370 / ENTS 369 **DUE WEDESDAY, April 30, 2003, in class** **Spring Term 2003**
Assignment 3 **SHOW YOUR WORK!** **Instructor: R. Rossi**

Your name: ____

Note: You will need the handy "Semiconductor Data Tables" that appear at the back of the course packet!

1. The Fermi-Dirac and Maxwell-Boltzmann statistical distribution functions are widely used in semiconductor physics, with the latter commonly used as an approximation to the former. The point of this problem is to familiarize you with these distribution functions: their forms, their temperature dependencies, and under what conditions they become essentially interchangeable. **Throughout this problem, use the energy of silicon's valence band (E_{VB}) as the zero of your energy scale.**

   a. Consider a perfectly intrinsic sample of Si. Calculate the approximate location of the Fermi level (E_F) in this material at 0.001, 150.0, 300.0, and 600.0 Kelvins. Use equation (1), below, which includes an effective density of states correction, but assumes Maxwell-Boltzmann statistics apply.

   $$n_i = N_V \exp\left[\frac{-\left(E_f - E_V\right)}{kT}\right] = N_C \exp\left[\frac{-\left(E_C - E_f\right)}{kT}\right] \qquad (1)$$

   Hint: You are going to want to solve this system of equations for E_f, folks! You can do it, I promise.

   b. Plot the expected electron occupancy (the probability of finding an electron in a state at energy E) in the silicon at each of the temperatures above. Remember that electrons are fermions, and thus obey Fermi-Dirac statistics. The Fermi-Dirac distribution is given by Equation (2):

   $$f_{FD} = \frac{1}{1 + e^{\left(\frac{E - E_f}{kT}\right)}} \qquad (2)$$

      i. Plot the expected probability of occupancy on a linear scale from -0.05 to +1.05 for energies between -0.2 and +1.4 eV; use a linear scale for the energy (x) axis.

      ii. Plot the expected probability of occupancy on a logarithmic scale ranging from 10^{-10} to 1.0 for energies between -0.2 and +1.4 eV; again, use a linear energy (x) axis.

   c. Plot the Maxwell-Boltzmann distribution function, Equation (3), at the same four temperatures for the same silicon sample:

   $$f_{MB} = e^{-\left(\frac{E - E_f}{kT}\right)} \qquad (3)$$

      i. Plot the Maxwell-Boltzmann distribution function on a linear scale; use the same axis limits as you used in part (b) so that you can compare the two plots directly.

      ii. Plot the Maxwell-Boltzmann distribution function on a logarithmic scale, again using the axis limits used in part (b) so that you can compare the two plots directly.

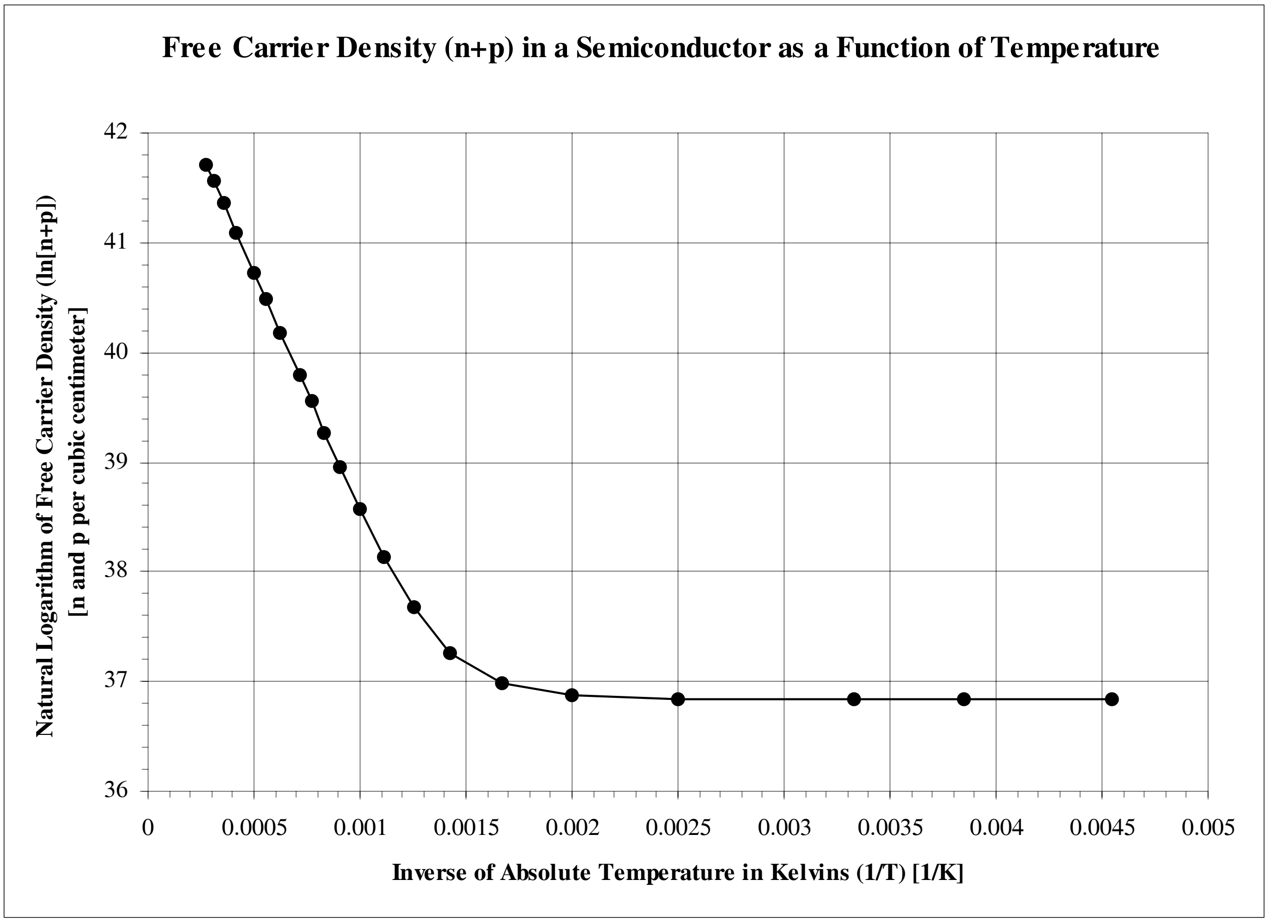
   d. Compare the two distribution functions:

      i. At what temperatures and over what energy ranges are the Fermi-Dirac and Maxwell-Boltzmann distribution functions appreciably different?

      ii. Are the two distribution functions distinguishable under any of the conditions considered here for energies in the conduction band, where states actually exist? Under what conditions might the two distributions differ appreciably for energies in the conduction band?

2. By studying the temperature dependence of the carrier concentration in a semiconductor sample, several things can be learned about its properties. The figure below shows the free carrier density (n+p) of a semiconductor sample measured as a function of temperature and plotted in a "useful" form. Based on the data in this plot, you should be able to discern:
   a. the dopant density of the sample, assuming that the dopants are all of one type and that they ionize completely in the temperature range under consideration
   b. the bandgap of the semiconductor

   Hint: This is NOT a "real" semiconductor; you will not find anything that matches its E_{gap}!



3. On the back of the reading packet there's a table of physical data for some semiconductors of interest in solar energy conversion. Use it to work this problem, but be sure you keep it for future reference, too! Calculate each of the following parameters for the five semiconducting materials Ge, Si, GaAs, CdS, and TiO_2:
   a. the intrinsic carrier concentration (n_i) at room temperature (300 K)
   b. Give an example of an atom substitution which would provide each type of dopant (donor, acceptor) in these semiconductors. (Note that in compound semiconductors the atom substituted *for* is just as relevant as the identity of the atom that replaces it, i.e. in GaP, Si in a P site acts as an acceptor, but Si in a Ga site acts as a donor!)

4. What density of extrinsic dopants would be needed to double the total free carrier (electron + hole) concentration from its intrinsic value in a sample of silicon at 300 K, assuming complete ionization of the dopants? How about in a sample of TiO_2?