PH102: Modern Physics Homework 4 (Due: 2/27/2012)

1. (5 points) Textbook: Harris, Chapter 10 Conceptual Question #7

For the four kinds of crystal binding-covalent, ionic, metallic, and molecular-how would the density of valence electrons vary throughout the solid?

Would it be constant, centered on the atoms, or largest between the atoms? Or would it alternate, with a net charge density positive at one atom and negative at the next?

For each type of solid, determine how the density of valence electrons varies throughout the solid. Then, explain why the density should vary that way.

2. (5 points) Textbook: Harris, Chapter 10 Conceptual Question #13
The bonding of silicon in molecules and solids is qualitatively the same as that of a carbon. Silicon atomic states become molecular states analogous to those in Figure 10.14 and in a solid, these effectively form the valence and conduction bands. Which of silicon's atomic states are the relevant ones and which molecular state corresponds to which band?

3. (5 points) Textbook: Harris, Chapter 10 Conceptual Question #15
Based only on the desire to limit minority carriers, why would silicon be preferable to germanium as a fabric for doped semiconductors?

4. (5 points) Textbook: Harris, Chapter 10 Conceptual Question #16
Why does the small current flowing through a reverse-biased diode depend much more strongly on temperature than on the applied (reverse) voltage?

5. (20 points) Textbook: Harris, Chapter 10 Exercises #39
The effective force constant of the molecular "spring" in HCL is 480 N/m and the bond length is 0.13 nm.

(a) Determine the energies of the two lowest-energy vibrational states.
(b) For these energies, determine the amplitude of vibration if the atom could be treated as oscillating classical particles.
(c) For these energies, by what percentage does the atomic separation fluctuate?
(d) Calculate the classical vibrational frequency $\omega_{vib} = \sqrt{k/\mu}$ and the rotational frequency $\omega_{rot} = \frac{L}{I}$. For the rotational frequency, assume that L is its lowest nonzero value, $\sqrt{l(l+1)}\hbar$, and that the moment of inertia I is μa^2.
(e) Is it valid to treat the atomic separation as fixed for rotational motion while changing for vibrational?

5. (15 points) Textbook: Harris, Chapter 10 Exercises #76 (modified)

In Chapter 4, we learned that the uncertainty principle is a powerful tool. Here we use it to estimate the size of a Cooper pair from its binding energy. Here, the electron-phonon interaction provides the attractive interaction for the binding of the two electrons with opposite momenta. Obtain a rough estimate of the physical extent of the electron's wave function, by proceeding as follows. By general argument ("virial theorem"), the change in the kinetic energy of an electron upon the formation of a Cooper pair is of the same order as the binding energy of a Cooper pair. The change in the kinetic energy can be estimated by multiplying the uncertainty of the momentum introduced and the differential of the free electron energy with respect to the momentum. In addition to the binding energy, you will need to know the Fermi energy. (As noted in section 10.9, each electron in the pair has an energy of about the Fermi energy). Use 0.001 eV (binding energy) and 9.4 eV (Fermi energy), respectively, values appropriate for Indium.