PHYS4450 Solid State Physics Problem Set 6 Due: No later than 30 April 2013 (Tuesday)
All problem sets should be handed in not later than 5pm on the due date. Drop your assignment in the Box in Rm.213.
Please work out the steps of the calculations in detail.

6.0 *Reading Assignment:* Kittel's Chapters 7-9 cover band theory, including semiconductor band structures. Class notes Chapter XIII discuss some semiconductor physics. Kittel's Chapter 8 treated some basic semiconductor physics (see also Chapter 15 for discussion on Wannier excitons). Chapter XIV of class notes discusses some more transport properties. In Kittel's book, transport properties are scattered in different places, e.g. Chapter 5 (thermal conductivity), Chapter 6 (electrical conductivity and thermal conductivity of metals), Chapter 8 (thermoelectric effects in semiconductors that we didn't cover).

FINAL EXAM ANNOUNCEMENT

Coverage: The final exam will be comprehensive, i.e., covering everything from the beginning of the course to the end of Chapter XIV (more on transport properties). Materials in class notes, lectures, sample questions, and problem sets are included.

TAs: The two TA will stand-by during the period before the final exam. You may e-mail them your questions or make an appointment with me via e-mail to seek help.

6.1 **(See SQ25.)** Two semiconductors have the same crystal structure and the same unit cell size. Each has a single parabolic valence band, characterized by the same effective mass m_h. Each also has a single parabolic conduction band, characterized by the same effective mass m_e. They differ only by their energy gap. The gap between the VB and the CB is $E_{g1} = 0.8$ eV for the first semiconductor and $E_{g2} = 1.5 E_{g1}$ for the second semiconductor. Assume that $|\epsilon - \mu| \gg kT$ for all states. Sketch the band structures.

(a) Compare their Fermi energies, each measured from the top of the VB.

(b) Compare the changes in their chemical potentials as the temperature is raised from 0 to 300 K.

(c) Compare the numbers of conduction band electrons at 300 K.

(d) For a semiconductor, what would you expect in a plot of the $log(\rho)$ as a function of $1/T$, where ρ is the resistivity and T is the temperature.

6.2 **More semiconductor statistics. Related to Problem 5.4.** It is useful to go through the section on semiconductor statistics carefully. In class, we derived the relationship $n_c p_v = n_i^2$, where n_i is the **intrinsic carrier concentration** that depends on the temperature. An important point of this relation is that it is applicable to intrinsic (pure) and doped semiconductors. The point is: Right-hand side is a number that only depends on the materials (electron and hole effective masses and energy gap) and the temperature. The relation can then be used to determine the minority carrier in doped semiconductors.

(a) Let's consider a very simple semiconductor in which the effective electron mass and effective hole mass are the same and they are equal to the free (bare) electron mass. The energy gap is 0.8 eV. Calculate $n_i(T)$ for T=300 K and T=600 K. [Remark: It is educational to pay attention to how sensitive the different factors (a prefactor and an exponential factor) are to the temperature.]

(b) Now, the semiconductor is doped with a donor concentration of 10^{17} donor atoms per cm^3. These donors will be ionized at T=300 K. Find n_c and p_v at T=300 K.

(c) Fixing the chemical potential in doped semiconductor (as a function of temperature). In our derivation (see Ch. XIII p.14-26), we obtained another equation

$$n_c(T) = n_c^* e^{-(E_c - \mu)/kT}$$

This can be used to determine μ for a doped semiconductor. Find μ for the situation in part (b).

6.3 **(Excitons)** For GaAs, look up the following parameters: the dielectric constant (or called relative permittivity), electron effective mass, light hole effective mass, and heavy hole effective mass [remember to cite source of data.]

(a) With these parameters, sketch a model band structure for GaAs near $\mathbf{k} = 0$ consisting of 3 bands.

(b) An exciton is a bound state of an electron and a hole. Estimate the exciton binding energy for an exciton formed by an electron in the CB and a light hole in the VB. Also estimate the exciton binding energy for an exciton formed by an electron in the CB and a heavy hole in the VB.

Important: For every PHYS4450 Problem Set, you must attach a SIGNED copy of the academic honesty declaration form given below. It is a university policy. Homework without a signed declaration form will NOT be graded and thus will carry zero mark.

I declare that the assignment here submitted is original except for source material explicitly acknowledged, and that the same or related material has not been previously submitted for another course. I also acknowledge that I am aware of University policy and regulations on honesty in academic work, and of the disciplinary guidelines and procedures applicable to breaches of such policy and regulations, as contained in the website http//www.cuhk.edu.hk/policy/academichonesty.

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Name	Student ID
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Course code	Course title