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EE 121B Quiz # 1 10/21/15

Write legibly and clearly and in full sentences.

Problem 1

a. Explain briefly how discrete atomic levels give rise to bands in solids.

When individual atoms get close to each other, the atomic orbitals interact with the ones nearby, forming anti-bonding and bonding states. While every atom contributes an individual level to the crystal, the large number of atoms means that these levels are spaced very close to each other giving rise to a band. The exact levels are determined by the linear combination of atomic orbitals and the periodic “Bloch” wave function.

b. How do we end up with a forbidden energy gap?

The forbidden energy gap is a consequence of bonding and anti-bonding bands described above. At the equilibrium separation of atoms in semiconductors, a region of energies where there are no states occurs. In the LCAO approximation, we can find that the off-diagonal terms in Hamiltonian (interaction between the orbitals) give rise the band gap.

c. What determines if the material is semiconducting, insulating or a metal?

The magnitude of the band gap around the Fermi level determines whether it is semiconducting, insulating or metallic. If Fermi level lies in the band gap and the band gap is large (~5 eV) so that at the temperature that we are interested, there are few mobile carriers in the upper and lower bands, the material is insulating; however, if band gap reduces when we can have some mobile carriers in the bands, the material is semiconducting; if there is no band gap, or if the bands overlap, which indicating a large quantity of mobile carriers, the material is metallic.

d. When is there no difference in the conductivity of a semiconductor and an insulator?

At low enough temperature (near absolute zero), in both upper and lower bands, there will be almost no mobile carriers for two kinds of materials. The conductivity shows little difference between semiconductor and insulator.

e. What distinguishes the conductive method in semiconductors compared to metals?

In semiconductors, besides electronic conduction in the conduction band, unfilled electronic states contribute to hole conduction in the valence band. The holes behave live positively charge carriers and this phenomenon is unique to semiconductors

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Problem 2

a. What are the three main statistical probability distribution functions?

Fermi Dirac distribution
Maxwell Boltzmann distribution
Bose Einstein distribution

b. When would you use each one of them?

For microscopic cases where the particle/quantization is indistinguishable, we will use the Fermi-Dirac distribution if it is a fermion, and the Bose-Einstein distribution if it is a boson. For macroscopic cases where the particle/quantization is distinguishable, a Maxwell Boltzmann distribution is used.

c. Give an example each of a particle that each distribution describes.

The electron is a fermion, where we can applied the Fermi Dirac distribution.
The phonon is a boson, where we can applied the Bose Einstein distribution
The atom is distinguishable in the case of the ideal gas, in which we can apply the Maxwell Boltzmann distribution.

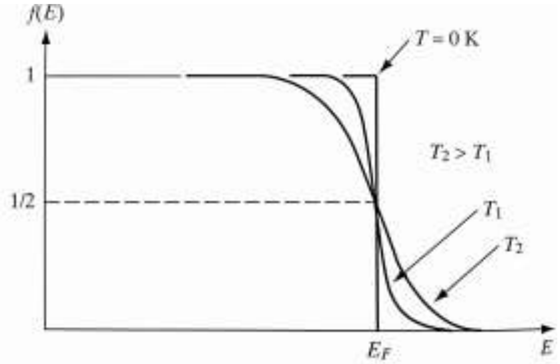
d. Write down the expression for the statistics used for electrons?

Fermi Dirac distribution

$$f_{E_F}(E) = \frac{1}{1 + e^{\frac{(E-E_F)}{kT}}}$$

e. What is the significance of the Fermi energy? Draw the FD distribution for 0K and two other temperatures T_1 and T_2 ($T_2 > T_1$)

The fermi energy is the highest energy of the electron states that an electron can occupy at 0K. (in metal). The Fermi energy is defined only at absolute zero. At other temperatures we use the term Fermi level.



f. You always will find carriers with the energy of the Fermi level – true or false?

False, when Fermi level lies in the bandgap.

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g. What other distribution function can be used to approximate the FD distribution at high energies?

When $\mathrm{E} - \mathrm{E_F} \gg \mathrm{kT}$, the Fermi Dirac distribution can be approximated by Maxwell Boltzmann by setting

$$f_{E_F}(E) = \exp\left(\frac{E_F - E}{kT}\right)$$

h. The actual carrier concentration is the product of two functions – what are they?

The carrier concentration is the integration of the product of density of states g(E) and the probability for them to be occupied f(E). To approximate this integration, the concentration can be calculated by the product of effective density of the states and the Maxwell-Boltzmann distribution at the bottom/top of the conduction/valence band.

$$\mathrm{n} = \mathrm{N_C} \exp\left(\frac{E_F - E_C}{kT}\right)$$

$$\mathrm{p} = \mathrm{N_v} \exp\left(\frac{E_v - E_F}{kT}\right)$$

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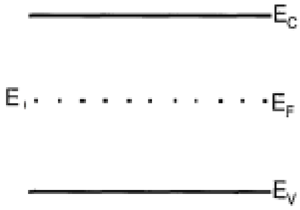
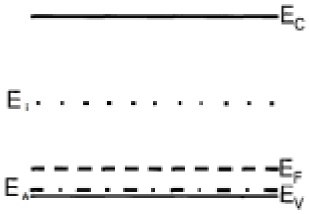
Problem 3

Draw separate equilibrium band diagrams for (conduction and valence band edges, the intrinsic level, impurity levels, the Fermi energy)

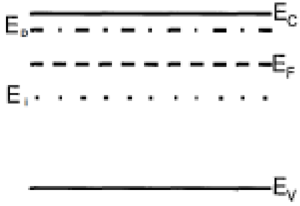
a. An intrinsic semiconductor



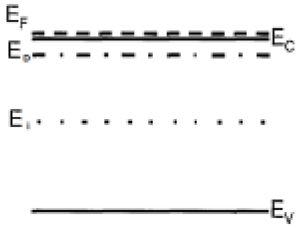
b. A highly doped p-type semiconductor



c. A moderately doped n type semiconductor



d. A degenerate n type semiconductor



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Problem 4

a. In general there are four types of currents that can be sustained in a semiconductor. What are they?

Electron diffusion current
Electron drift current
hole diffusion current
hole drift current

b. Write down separate expressions for each of them clearly defining the symbols that you use

$$J_{n,diff} = qD_n \frac{\partial n}{\partial x}$$
$$J_{n,drift} = q\mu_n n\vec{E}$$
$$J_{p,diff} = -qD_p \frac{\partial p}{\partial x}$$
$$J_{p,drift} = q\mu_p p\vec{E}$$

J – represents the corresponding current density
D – is the diffusivity
μ – the mobility
n, p, are the carrier concentrations

c. Given linear concentration gradient $n(x) = n_0(1-\alpha x)$ for electrons draw the corresponding directions for the particle fluxes and electric currents

Let x axis goes from left to right. The concentration decreases as x increases (if $\alpha>0$). Assume there is no electric field, the gradient of electron concentration shows that the electrons will flow to the right(if $\alpha>0$) while the electron current goes from right to left.

d. Do the same as in 4.c for holes

Let x axis goes from left to right. The concentration decreases as x increases (if $\alpha>0$)Assume there is no electric field, the gradient of hole concentration shows that the holes will flow to the right (if $\alpha>0$) while the hole current goes in the same direction.

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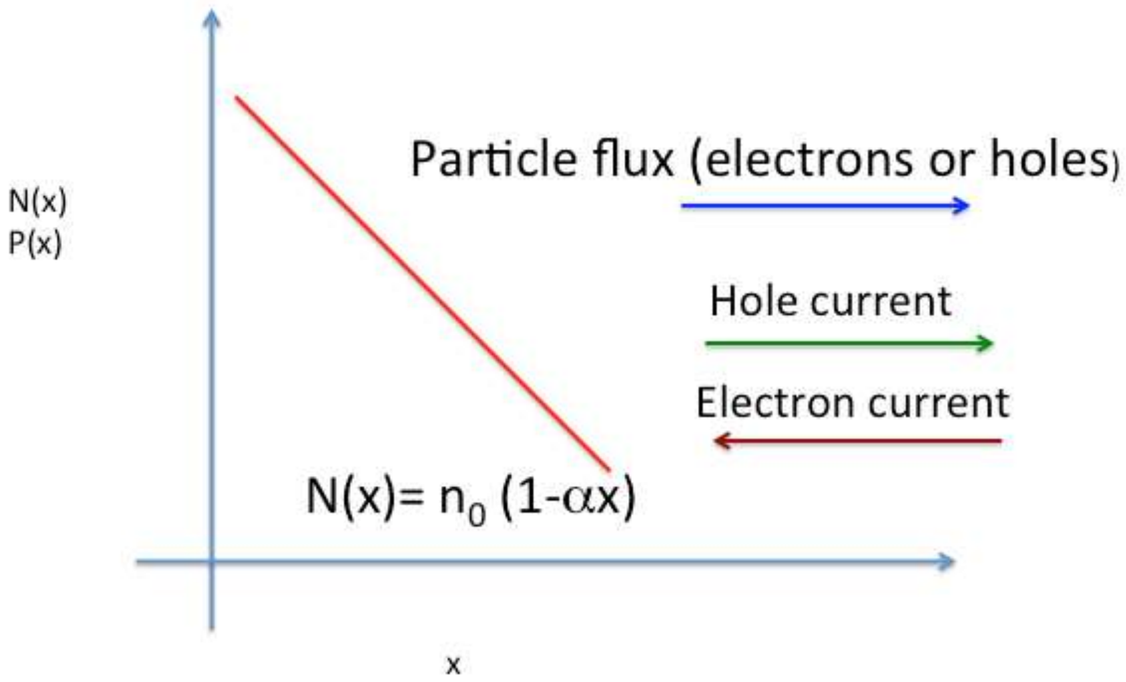

e. What is the Einstein relation?

Relationship between mobility and diffusivity

$$D_n = \frac{kT}{q}\mu_n$$

f. What are the different currents you can sustain in a metal?

In metal, we only need to worry about the electrons, so the current will be electron drift current.