PHYS 353 SOLID STATE PHYSICS STUDY GUIDE FOR PART 4

Semiconductors and Superconductors

<u>OUTLINE:</u>

A. Band gap:
   1. origin of band gap;
   2. value of E_g for various materials;

B. Equations of motion:
   1. $\Sigma \mathbf{F} = \hbar\, d\mathbf{k}/dt$;
   2. effective mass: $m^* = \hbar^2/[d^2\varepsilon/dk^2]$;
   3. apply to theory from Part 3.

C. Intrinsic carrier concentration:
   1. temperature dependence and law of mass action (Eq. 8-43);
   2. relation to conductivity and mobility.

D. Extrinsic carrier concentration: impurity conductivity
   1. donors,
   2. acceptors.

E. Thermoelectric effects

F. Diodes and transistors:
   1. pn junctions and biasing;
   2. Zener and tunnelling diodes;
   3. photo-diodes;
   4. transistors;

G. Superconductivity: experimental survey
   1. occurrence and temperature dependence;
   2. magnetic effects:
      a. type I;
      b. type II.

STUDY QUESTIONS: (for 4th test - **not** for collected homework assignment)

1. Know the definitions of:
   (a) intrinsic temperature range;
   (b) extrinsic temperature range;
   (c) direct absorption process;
   (d) indirect absorption process.

2. Write the equation of motion of an electron in an energy band and relate this to $\Sigma \mathbf{F} = m\mathbf{a}$ for the free electron.

3. Relate the following properties of holes to electrons:
   (a) k, (b) E, (c) v, (d) m, (e) equation of motion.

4. Effective mass:
   (a) Define effective mass using an equation.
   (b) Outline the theory predicting it:
      (1) indicate where the equation
      $\varepsilon_K(\pm) = \varepsilon(\pm) + [\hbar^2 K'^2/(2m)]*[1 \pm 2\varepsilon_{edge}/U]$ comes from;
      (2) indicate what the effective mass is from the above equation.
   (c) Explain the physical basis of effective mass (use words, not equations).

5. Derive the law of mass action and indicate its significance.

6. Donor ionization energies:
   (a) What is the approximate ionization energy for donor levels and how does it compare to the energy gap between valence and conduction bands?
   (b) Indicate on an energy level diagram where these donor levels are located relative to the valence and conduction bands; be sure to indicate the donor ionization energy on the diagram.
   (c) Outline the steps in the derivation of the donor ionization energy.
   (d) Indicate how this differs from the derivation of the Bohr atom and its result of 13.6 eV for the ionization energy.

7. Compare n, the electron carrier density, for intrinsic semiconductors, semi metals, and metals.

8. Explain rectification using a p-n junction, and explain the operation of a photo-diode.

9. Explain the photovoltaic effect.

COLLECTED HOMEWORK ASSIGNMENTS:

31. Make a graph of energy versus momentum and show the classical relation between the two for a free electron ($m = 9.1 \times 10^{-31}$kg) and an electron with an effective mass of 1/10 that of the free electron ($m^* = 9.1 \times 10^{-32}$ kg). Note the relation between the shapes of the two curves and the masses of the two particles.

32. (a) Verify that the following conditions will give absorption of microwave radiation in a semiconductor:

$$f = 24 \text{ GHz},\ B = 860 \text{ gauss},\ m^*/m = 0.1 .$$

(b) For the electron to make at least a good fraction of an orbit, the quantity $\omega\tau$ must be at least π radians. Check to see if this condition holds by using the ω for this frequency of 24 GHz and the value for τ you have previously calculated (7.2×10^{-15} s). If it does NOT, indicate whether heating up or cooling down the sample will help make this condition valid.

33. (a) Calculate the value of n (electron carrier density) for diamond, silicon, and germanium at T=30K, T=300K, T=3,000K by calculating the product: np (Law of Mass Action) and then taking the square root (since n = p for an intrinsic semiconductor); do this assuming that $m_e^* = m_h^* = m = 9.1\text{x}10^{-31}$ kg, and use these band gap energies for diamond = 5.4 eV; for silicon = 1.11 eV; for germanium = 0.66 eV.

[If your calculator gives you 0 for an answer, it may mean that your calculator cannot handle exponents small enough for this problem. In this case, DO NOT PUT 0 FOR YOUR ANSWER; instead solve for the power of ten and express your answer as 10 raised to this exponent.]

(b) Then recall the value of n for aluminum that you calculated for problem #21 (based on density and valence number = $1.8 \times 10^{23}/\text{cm}^3 = 1.8 \times 10^{29}/\text{m}^3$), and compare this value to the values obtained in part a for the semi-conductors.

34. Calculate the % change of total carrier concentration (n+p) compared to n = p for an increase in n of:

a) 10% ($n = 1.1 * n_o$);
b) 50% ($n = 1.5 * n_o$);
c) 500% ($n = 6.0 * n_o$).