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ECE 656 Exam 3: Fall 2013

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Mark Lundstrom
Purdue University

This is a closed book exam. You may use a calculator and the formula sheet at the end of this exam.

There are three equally weighted questions. To receive full credit, you must **show your work** (scratch paper is attached).

The exam is designed to be taken in 50 minutes.

Be sure to fill in your name and Purdue student ID at the top of the page.

DO NOT open the exam until told to do so, and stop working immediately when time is called.

The last page is an equation sheet, which you may remove, if you want.

30 points possible, 10 per question

- 1) 2 points per part – 10 points total
 - 2a) 4 points
 - 2b) 3 points
 - 2c) 3 points
- 3) 10 points

Answer the **five multiple choice questions** below by choosing the **one, best answer**.

1.1) Some of the thermoelectric transport coefficients are **proportional** to each other. Two are related fundamentally (independent of details of bandstructure and scattering) and two are related phenomenologically, in a way that depends on details of bandstructure and scattering. Which of the following is correct?

- a) Fundamental: σ and S . Phenomenological: π and κ_e .
- b) Fundamental: σ and π . Phenomenological: S and κ_e .
- c) Fundamental: σ and κ_0 . Phenomenological: κ_0 and κ_e .
- d) Fundamental: π and κ_e . Phenomenological: π and S .
- e) Fundamental: π and S . Phenomenological: σ and κ_e .

1.2) What are the most general driving forces for current flow?

- a) Gradients in the electrostatic potential and carrier concentration.
- b) Gradients in the electric field and temperature.
- c) Gradients in the electrochemical potential and temperature.
- d) Gradients in the carrier concentration and temperature.
- e) Gradients in the electron affinity and temperature.

1.3) Consider the expression for the electrical conductivity: $\sigma = \frac{2q^2}{h} \int \lambda(E) \frac{M(E)}{A} \left(-\frac{\partial f_0}{\partial E} \right) dE$

When can we use it?

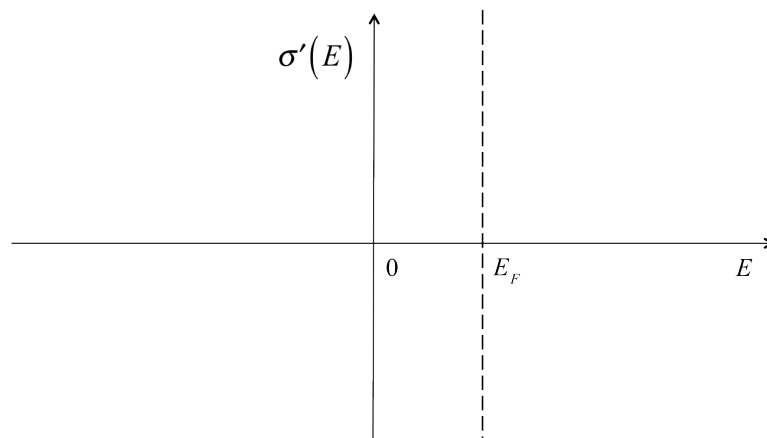
- a) When the current flows in the conduction band.
- b) When the current flows in the valence band.
- c) When the current flows in both the conduction and valence bands.
- d) When the temperature is constant.
- e) All of the above.

- 1.4) How do the lattice thermal conductivity, κ_L , and the electronic thermal conductivity, κ_e compare?
- a) $\kappa_L \gg \kappa_e$ for a metal and for a semiconductor.
 - b) $\kappa_L \ll \kappa_e$ for a metal and for a semiconductor.
 - c) $\kappa_L \ll \kappa_e$ for a metal and $\kappa_L \approx \kappa_e$ for a semiconductor.
 - d) $\kappa_L \ll \kappa_e$ for a metal and $\kappa_L \gg \kappa_e$ for a semiconductor.
 - e) $\kappa_L \approx \kappa_e$ for a metal and a semiconductor.
- 1.5) If the Peltier coefficient is -0.3 V, contact 1 is at a temperature of 300 K and contact 2 at 310 K, then what open circuit voltage would be measured on contact 2 with respect to contact 1 (i.e. what is $V(2) - V(1)$)?
- a) +0.3 V
 - b) -0.3V
 - c) +310 millivolts
 - d) -10 millivolts
 - e) +10 millivolts

- 2) Consider a metallic carbon nanotube, which has a linear dispersion $E(k_x) = \pm \hbar v_F k_x$. The density of states in this case is a constant, independent of energy, $D(E) = 2g_v / (\pi \hbar v_F)$, where $g_v = 2$ is the valley degeneracy for a carbon nanotube, and v_F is a velocity.

- 2a) Determine the number of channels vs. energy, $M(E)$.

- 2b) **Work out** an expression for the differential conductivity, $\sigma'(E)$, and make a **sketch** of $\sigma'(E)$ vs. E . You should assume that the mean-free-path is independent of energy. **SHOW YOUR WORK.**



- 2c) Find an expression for the Seebeck coefficient for an arbitrary location of the Fermi level. **HINT:** You can find the answer without a lot of work, but you must give a **mathematical explanation** of the result.

3) For this problem you will make use of the two coupled current equations:

$$\mathcal{E}_x = \rho J_x + S \frac{dT}{dx}$$

$$J_{Qx} = \pi J_x - (\kappa_L + \kappa_e) \frac{dT}{dx}$$

Assume that we have a sample of length, L , and that we force a current J_x through it and measure the voltage across it. The voltage consists of two components, one due to the resistance, V_R and one due to the Seebeck effect, V_S . Assume that we perform this measurement under adiabatic conditions (no heat flow).

What is the ratio of the two voltage components, V_R and V_S , in terms of the thermoelectric transport coefficients?

SCRATCH PAPER

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