Exam 2 ECE-656 Fall 2009

NAME_________________________________

ID_____________________________________

This is a take home exam due at 10:30AM, Monday, November 23, 2009

The exam consists of 10 questions on the attached pages.

1) Show your work for each problem CLEARLY.

2) Mark your answers CLEARLY.

3) Make reasonable assumptions when necessary, but be sure to state them.

DO NOT DISCUSS THIS EXAM WITH ANYONE. IT SHOULD BE YOUR WORK AND YOUR WORK ALONE.

When you hand in your exam, attach this sheet as a cover sheet stapled to your work.

You must also sign the following statement.

I attest that the attached work for Exam 2, ECE-656, Fall 2009 is my work and my work alone. I have not discussed this exam with anyone and received no help with the exam.

SIGNED:_____________________________________

DATE:____

ECE-656 Take Home Exam 2: Fall 2009

1) In HW 16, I asked you to show that the procedure used in L16 to solve the Boltzmann Transport Equation for small magnetic fields would not work for graphene. The solution that I provided was NOT CORRECT – the procedure of L16 may work (but there may also be a better way to solve the problem). Explain why my solution was not correct. Hint: Examine the HW16 solution for question 2).

   Extra credit if you can solve the BTE for graphene in the presence of a z-directed B-field.

2) It is commonly stated that for "short range scattering" in graphene, the conductivity displays the unusual characteristic of being independent of the carrier density. The same also applies to acoustic phonon scattering at room temperature where it is elastic. Provide a simple, physical **explanation** for this effect. (**Hint:** Imagine yourself explaining this to a student who has not taken ECE-656.)

3) In L8, we derived the heat current by arguing that electrons at energy, E, needed to absorb $\left(E - E_F\right)$ of heat from the contact in order to flow across the device. Using this idea, define the appropriate $\phi\left(p\right)$ and derive a balance equation for the heat flux in 1D (you may assume parabolic bands). Compare your result to that obtained in L8. Also check the result of L28 to see if the Kelvin relation is satisfied.

4) When deriving balance equations in 3D, we obtained a tensor

$$W_{ij} = \frac{1}{\Omega}\sum_{\vec{p}} \frac{p_i \upsilon_j}{2} f\left(\vec{r},\vec{p},t\right)$$

In general:

$$W_{ij} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & W_{zz} \end{bmatrix}$$

Evaluate this tensor in equilibrium for a non-degenerate semiconductor and show that:

$$W_{ij}^{0} = \frac{W_0}{3}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

What is W_0 ?

5) Assume scattering by optical phonon emission as given by the expression in L24:

$$\frac{1}{\tau} = \frac{2\pi}{\hbar}\left(\frac{\hbar D_0^2}{2\rho\omega_0}\right)(N_0 + 1)\frac{D_{3D}(E - \hbar\omega_0)}{2}$$

Review L19 and then derive an expression for the microscopic energy flux relaxation rate (i.e. what I called the out-scattering rate in L19).

6) The mobility of electrons in intrinsic silicon at room temperature is about 1360 cm^2/V-s. Compute the average mean-free-path for backscattering. (**Hint:** You may find it useful to refer to L20, but remember that this problem is a 3D one - not 2D.)

7) In L27, we worked out the scattering rate for ADP intra-scattering of electrons in graphene. Follow a similar approach and derive an expression for the ODP inter-valley scattering rate for electrons in graphene.

8) In HW 26, we worked out the ODP scattering rate for 2D electrons and found:

$$\left.\frac{1}{\tau_{n,n'}}\right)^{a,e} = \frac{\pi}{\hbar}\frac{D_0^2\hbar}{\rho\omega_0}\left(N_0 + \frac{1}{2} \mp \frac{1}{2}\right)\frac{D_{2D}(E \pm \hbar\omega_0)}{2}\frac{(2 + \delta_{n,n'})}{2}$$

Let $\hbar\omega_0 = 1.1 k_B T$ and plot the absorption and emission scattering rates vs. energy for an electron in subband 1 (include 2 subbands). (**Hint:** Your plot should look something like the one in Sec. 3 of L26.)

9) Derive an energy balance equation for graphene, and then simplify it to terminate the balance equation hierarchy.

10) Use the balance equation approach and derive a current equation for a semiconductor nanowire. You may assume that only 1 subband is occupied, but DO NOT ASSUME PARABOLIC ENERGY BANDS.