# *ECE 659 Spring'09*

## *Weeks 1-3: Semiclassical Transport*

## *HW#1, Due Friday January 23, 2009 in class*

***Fermi function:*** $f(E) = 1/(1+\exp((E-\mu)/kT))$

***Current*** $I = \frac{q}{h}\int dE\ \pi\gamma D(E)(f_1(E) - f_2(E))$

Ballistic and diffusive transport: $\gamma = \hbar v_x / L$ , $\pi\gamma D \equiv M(E)$

$$I = \frac{q}{h}\int dE M(E)(f^+(E) - f^-(E))$$

***Electron density*** $n(x,E) = \frac{D(x,E)}{2}(f^+(x,E) + f^-(x,E))$

$$\frac{df^+}{dx} = \frac{df^-}{dx} = -\frac{f^+ - f^-}{\lambda} \quad , \qquad \lambda \equiv 2 v_x \tau$$

$$f^+(x,E) - f^-(x,E) = \frac{\lambda}{\lambda + L}(f_1(E) - f_2(E))$$

***Problem 1:*** Show that for diffusive transport the conductance can be written as (A: cross-sectional area)

$$G = \frac{\sigma A}{L+\lambda}, \text{ where } \qquad \sigma = q^2 \int_{-\infty}^{+\infty} dE \left(-\frac{\partial f}{\partial E}\right)\frac{D(E)}{AL} v_x{}^2(E)\tau$$

Noting that the electron density is given by $n = \int_{-\infty}^{+\infty} f(E)\frac{D(E)}{AL}$

show that $$\mu_n(mobility) \equiv \frac{\sigma}{qn} = \frac{q\int_{-\infty}^{+\infty} dE\ f(E)\frac{d}{dE}\left(D(E)v_x{}^2(E)\tau\right)}{\int_{-\infty}^{+\infty} dE\ f(E)D(E)} \qquad (1)$$

assuming that the density of states D(E) is zero as E $\rightarrow -\infty$.

***Problem 2:*** Typically semiconductors a parabolic E(k) relation, $E = \hbar^2 k^2 / 2m$, the density of states can be written in the form $D(E) = D_0\, E^{(d/2)-1}$ where d is the number of dimensions and $D_0$ is a constant. Also, $v_x^2(E) = v^2(E)/d = 2E/md$. Using these relations in Eq.(1) and assuming $\tau$ to be independent of energy, show that $\mu_n = q\tau/m$.

***Problem 3:*** A two-dimensional graphene sheet has a linear E(k) relation, $E = \hbar v_f\,|k|$, where $v_f$ is a constant. The density of states can be written in the form $D(E) = D_0\, E$ where $D_0 = \dfrac{WL}{2\pi(\hbar v_f)^2}$. Also, $v_x^2(E) = v_f^2/2$. Using these relations in Eq.(1) and assuming $\tau$ to be independent of energy, show that $\mu_n = q\tau/m$, if we define the "mass" as

$$m = \frac{2 < E >}{v_f^2} \quad \text{where} \quad < E > \equiv \frac{\int dE\; E\; f(E)}{\int dE\; f(E)}$$

(ignoring the states below E=0)

***Finally,*** please look over Prob.1 of HW#6 and Prob.1 of HW#7 from ECE 495N. Both homeworks and solutions are posted at

http://sites.google.com/site/ece495n/

You do not need to submit these, but reviewing them should be helpful in the coming discussions.