Physics 617 Problem Set 7 Due Monday, Apr. 10

Note update, this was labeled Problem Set 6 when distributed in class.

1) (a) Consider a 2-D metal (such as doped graphene, or a similar 2D material) and examine the steps leading to the Bloch T^5 law. Assume a 2-D phonon spectrum which otherwise follows a Debye approximation. For temperatures much less than the Debye temperature, repeat the arguments leading to the low-temperature T^5 law and determine the exponent in the 2-D case.
(b) Examine the case for temperatures much greater than the Debye temperature; how will the behavior of the phonon contribution to resistivity (eqn. 26.48 in the text) be modified?
(c) 2D Fermi liquid resistivity. This is treated in chapter 17, giving the arguments for the T^2 resistivity exponent for metals at low temperatures. Work through the same arguments, but for the case of a 2D metal, what will be the exponent?
(d) Finally, re-examine the 3D *electrical* contribution to the *thermal* conductivity for the case of a Fermi Liquid. The resistivity exponent is T^2 as noted above; find the thermal conductivity exponent in this case.

2) Ashcroft & Mermin 28.4

3) Statistics for a semiconductor with a single donor state, having density N_d, but no acceptors. In this case the occupation probability for the donor levels is given by (28.32).

[a] Find the position of the chemical potential as T goes to zero. Note, you cannot solve the $T = 0$ situation, that is undefined; instead you need to solve for finite T and take the limit as T goes to zero. The density of hole states will be essentially zero, so you can do this by equating the density of ionized donors [use (28.32) in the low-T limit to obtain this] to the density of electrons in the conduction band.
[b] At what temperature will the donor occupation probability become equal to 1/2? Suggested method: solve (28.32) to find the chemical potential vs. T for this occupation probability. Then assume no holes as in (a), so that the density of carriers in the conduction band can be used to eliminate the chemical potential, giving T as a function of N_d, N_c, and $(\varepsilon_c - \varepsilon_d)$.
[c] For a typical shallow-donor situation suppose that $N_c = 10^{19}$ cm^{-3}, $N_d = 10^{15}$ cm^{-3}, and $(\varepsilon_c - \varepsilon_d) = 0.02$ eV. For these parameters find the temperature where half the donors are occupied. Your result should be much smaller that the temperature where $kT \approx (\varepsilon_c - \varepsilon_d)$. This illustrates why the extrinsic limit ($n = N_D$) typically covers a very wide temperature range.

4) For a compensated semiconductor, with N_D donors and N_A acceptors, and with donor and acceptor energies ε_d and ε_a, find the $T = 0$ position of the chemical potential, for
[a] the case that $N_D > N_A$.
[b] the case that $N_D < N_A$.
Note, you don't have to solve this the same way as part [a] above, this question just takes some thinking about which states would be occupied in these cases.