Due May. 12, Thursday
(with one day grace period for this one only)

Problem 1 (30 points) Consider, again, the electron distribution function, $g_c(E)f(E)$, and the hole distribution function, $g_v(E)(1-f(E))$ (cf. page 2 of LN 9 and Eqs. T2.6,2.7)[1].

(a) Show that $g_c(E)f(E)$ is maximized at the energy value $E_{m,n} = E_c + k_BT/2$ and $g_v(E)(1-f(E))$ is maximized at the energy value $E_{m,p} = E_v - k_BT/2$. (Consider the non-degenerate case only.)

(b) (Thermal wave vector) For Si at 300 K, calculate the value of $|k_{m,n} - k_c|$ where $k_{m,n}$ is the wave vector value corresponding to $E_{m,n}$, and the value of $|k_{m,p} - k_v|$ where $k_{m,p}$ is the wave vector corresponding to $E_{m,p}$. Express your answers in unit of $2\pi/a$ where a is the lattice constant of Si (5.43 Å). Here, k_c is the (or rather, a) wave vector value for E_c and k_v is the wave vector value for E_v. Use the following effective mass values for this problem: $m_n^* = 0.93m_e$ and $m_p^* = 0.52m_e$, corresponding to the heavy mass parts of the band structure. The effective masses that we use for this part must be different from the masses that we use for part (a)!

(c) (Thermal velocity) Calculate the corresponding magnitudes of the group velocities in unit of c, the speed of light. Compare these values with the typical velocity of electrons in a metal (HW 3.2), and the sound velocity of Si (8.4×10^3 m/s; this represents the typical velocity at which Si atoms move due to the lattice vibration).

(d) (Extra credit, 20 points) Explain why different effective masses are used for (a) and (b,c). You probably need to do a bit of research on this by yourself.

Problem 2 (20 points) Take a look at Fig. T3.5. Here, the mobility is plotted as a function of doping, for the three important semiconductors.

(a) Using Matthiessen's rule, explain why the mobility stays nearly constant on the left side of the figure, but it crosses over to a monotonically decreasing behavior as the doping increases.

(b) One may also break down the mobility due to the impurity scattering, off of many impurities, into the mobilities, each of which is due to the impurity scattering off of *one* impurity. Show that the mobility due to the impurity scattering must then be proportional to the inverse impurity density. In the double-log plot of Fig. T3.5, what should be the value of the slope if the impurity scattering dominates? Does any curve in the plot shows any

[1] As introduced in the lecture note, the prefix "T" for equation/figure/table number means "textbook"

agreement with this prediction at the right end of the plot? (Why or why not?)

Problem 3 (20 points) The following table shows the mobility values for some semiconductors at room temperature ($T = 300$ K), in the intrinsic limit. Here, D is the diffusion coefficient, and L is the diffusion length defined as $\sqrt{D\tau}$, where τ is a time scale. Use the Einstein relation (for D) and the typical minority carrier lifetime $\tau \sim 10$ ns for L to fill in the table. The choice of τ as the minority carrier lifetime makes L_n or L_p the so-called *minority carrier diffusion length.* [Notice that the symbol μ is used for two purposes here. One is the mobility and the other is the prefix "micro" as in micro-meter (μm). Well, this is unfortunate, but there is no easy fix here. Physicists tend to use the same symbol for two or three well-known meanings. Sorry about that, but nobody is perfect, especially not a physicist!]

	μ (cm^2/(Vs))		D (cm^2/s)		L (μm)	
	μ_n	μ_p	D_n	D_p	L_n	L_p
Si	1350	480				
Ge	3900	1900				
GaAs	8500	400				
InAs	22600	200				
InSb	100000	1700				

Problem 4 (30 points) Problem T3.10. (Use information in Exercise T3.1 and Figure T3.7 as you find necessary.)

Problem 5 (30 points) ET activity – Semiconductor Strand: Semiconductor Activity.