Physics 3313, Homework #3 (due 2/15)

P1 In the Kronig-Penney model, calculate the distance between the tops of two subsequent allowed energy bands if the potential width $a = 3.2$ Å.

P2 (a) The $E(k)$ dependence in some material can be parameterized in the conduction band as $E(k) = E_0 + E_1 \cos ka$, where $E_0 = 21.6$ eV, $E_1 = 2$ eV, $a = 10$ Å, and in the valence band as $E(k) = E_0 + E_1(\cos ka)^{2.4}$, where $E_0 = 14$ eV, $E_1 = 4$ eV, $a = 5$ Å. Determine the effective mass of the electron at the minimum in the conduction band energy and the effective mass of the hole at $k = 0$. Is the material direct or indirect?

(b) The $E(k)$ dependence in some other material can be parameterized in the conduction band as $E(k) = E_0 - E_1 \cos ka$, where $E_0 = 21.4$ eV, $E_1 = 2$ eV, $a = 10$ Å, and in the valence band as $E(k) = E_0 + E_1 \cos ka$, where $E_0 = 16$ eV, $E_1 = 2$ eV, $a = 6$ Å. Determine the effective masses of the electron and the hole at $k = 0$. Is the material direct or indirect?

P3 In the previous problem, case (a), the electrons transiting from the bottom of the conduction band to the top of the valence band release their energy in the form of lattice excitations (phonons). Assuming conservation of energy and momentum, estimate the effective mass of the phonons.

P4 The energy bandgap in Si changes with temperature $T$ according to the formula

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta},$$

where $E_g(0) = 1.170$ eV, $\alpha = 4.73 \times 10^{-4}$ eV/K, $\beta = 636$ K. At what temperature $T$ the bandgap energy decreases by 0.01 eV compared to its value at room temperature 300 K?