

# Homework 5

Due 2/10/2011

1. [10 points] Kittel 5.1
2. [10 points] Kittel 5.4
3. [10 points] Ferromagnetic magnons are waves of atomic magnetic moments that satisfies  $\omega_{\vec{k}} \propto k^2$  at low energy. What would be the temperature dependence of  $C_V$  arising from these waves as  $T \rightarrow 0$ ? For this problem and the previous problem, the qualitative method can be used (cf. "Qualitative table" of Lecture 09).
4. [10 points] Consider the Lennard-Jones potential 
$$U(r) = A \left[ \left( \frac{\sigma}{r} \right)^{12} - 2 \left( \frac{\sigma}{r} \right)^6 \right]$$
, which is quite appropriate for molecular crystals such as Ar. (a) Show that the classical equilibrium position  $a$  of this potential is  $\sigma$ . (b) Find the Grüneisen constant  $\gamma$  for the phonon frequency, arising from this potential. [Hint: Look up the definition in my lecture note.  $\gamma$  should be just a number independent of  $\sigma$  and  $A$ .]
5. [10 points] (a) Show that the kinetic energy of a free electron gas at absolute zero temperature is given by  $E_0 = \frac{3}{5} N \epsilon_F$ . (b) Derive the expression for the pressure  $P = -\partial E / \partial V$  and the bulk modulus  $B = -V \partial P / \partial V$ , at  $T = 0$ . [cf. Kittel 6.2] (c) Estimate the contribution of the conduction electrons to  $B$  for potassium and compare your answer to the experimentally measured bulk modulus  $0.37 \times 10^{10} \text{ Nm}^{-2}$ . You can use the data given in table 1 of page 139.