Solid State Physics I 2012-2013

Examination 29th October 2012

This is a closed book exam. You are not allowed to bring books, notes etc. You can use a basic or scientific calculator, but no other electronic equipment having capabilities to display or pronounce the course content.
Do not forget to indicate your full name and student number on **each** sheet.
Please write in a clear way!
Total points 80. Passing is with 40 points. Marks will be re-normalized to 10.

1) Semiconductors and more
(total 20 points, questions *a* and *b and c* 4 points; e 8 points)

Answer with few sentences the following questions and when necessary use drawings.

a. Sketch the Planck and the Fermi-Dirac distributions at $T = 0$ K, and at room temperature (T =300K).
b. Define the Fermi energy for a metal.
c. Define what are extrinsic and intrinsic semiconductors and direct and indirect semiconductors. (Make a sketch if necessary!)
d. The law of mass action for semiconductors tells that:

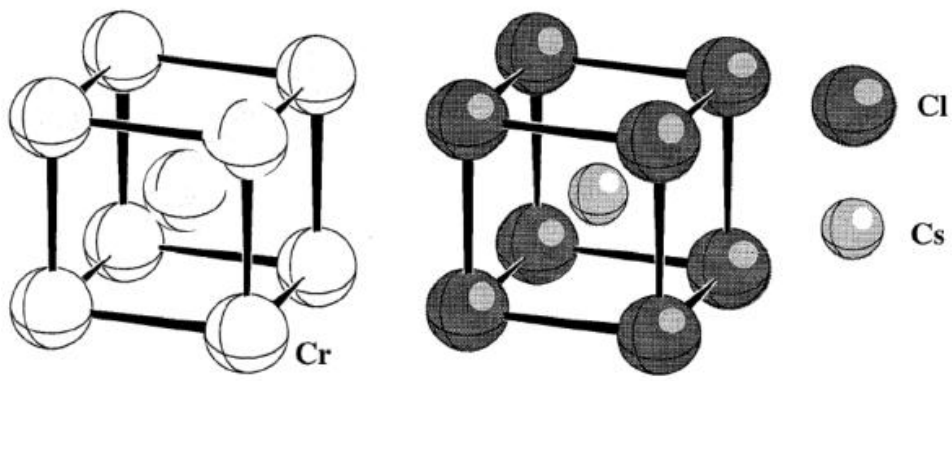
$$n \cdot p = 4\left(\frac{k_B T}{2\pi\hbar^2}\right)^3 (m_e * m_h *)^{3/2} \cdot e^{-\frac{E_g}{k_b T}}$$

By using this equation derive an expression for the chemical potetial μ, in the special case of an intrinsic semiconductor (i.e. n=p).

2) Crystal structure
(total 20 points; *a, b and c 4* points; *d* 8 points each)

Cr and ClCs crystal have similar arrangement (cubic lattice family) as from the following figure. The lattice constant of Cr is 2.880 Å; the lattice constant of ClCs is 4.123 Å.

a. Write which is the lattice of the two materials and which is the basis.
b. Are the drawings both primitive cells? Explain.
c. Which is their reciprocal lattice?
d. Calculate the volume packing fraction for the Cr crystal.



3) Phonons and heat capacity
(total points 20; a and b 4 points each, *c* and *d* 6 points each)

a. What is the difference between the Einstein and Debye heat capacity theories?
b. Are these two theories able to explain heat capacity in metals? Explain.
c. Derive the expression for the density of states (modes) D(ω) for a 2-dimensional system, within the Debye approximation.
d. Suppose that an optical phonon branch has the form $\omega(K) = \omega_0 - AK^4$ near *K* = 0, in two dimensions 2D systems. Show that:

$$D(\omega) = \frac{\pi}{2A^{1/2}}\left(\frac{L}{2\pi}\right)^2 (\omega_0 - \omega(K))^{-1/2}$$ for $\omega < \omega_0$,

and $D(w) = 0$ for $w > w_0$

4) Free and nearly free electron model
(total points 20; *5* points each)

The dispersion relation (electronic bands) for electrons in a 3D periodic crystal can be simplified as:

$$E = E_n + (-1)^{n+1}\Delta E_n Coska \qquad n=1,2,3\ldots\ldots \qquad \text{(eq.1)}$$

a. Derive the group velocity of electrons as a function of k.

b. Plot the group velocity of electrons as a function of k for free electron in reduced 1D-Brillouin zone scheme.

c. Derive the effective mass of the carriers if the electronic band is the one described by the equation 1.

d. Plot the effective mass as a function of k for a free electron gas in the reduced 1D-Brillouin zone scheme.