Solid State Physics I 2013-2014
Examination 1st November 2013

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 90. Passing is with 49.5 points. Marks will be re-normalized to 10.

1) Free and nearly free electron model
(total 20 points, questions *a* and *c1 and* 4 points; *b* and *c2* 6 points)

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

a. Define what is the Fermi energy for a metal.
b. Derive the expression for the Fermi energy knowing that number of electrons per volume is $N/V = 1/(3\pi^2)\ k^3$
c. Consider an intrinsic semiconductor whose electronic density of states function D(E)=N(E) is depicted in Fig. 1.

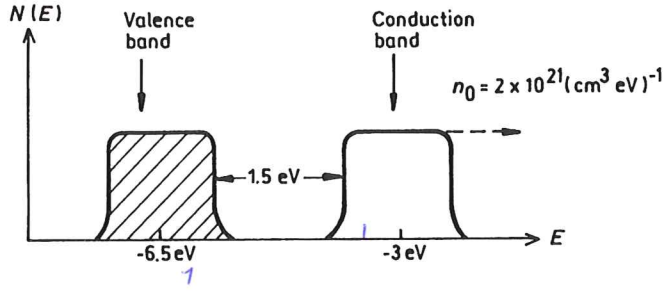

Fig.1

c1. Where is the Fermi level with respect to the valence and conduction bands?
c2. Estimate the electron density in conduction band at room temperature.

2) Crystal structure
(total 30 points; *a1, a2,* and *b2* 6 points; *b1 and b*3 4 points)

a. Atoms are approximated to hard contacting spheres, calculate the packing fraction of:
   a1. The simple cubic lattice
   a2. The fcc lattice

b. In the case of the fcc lattice
   b1. Write down the primitive lattice vectors.
   b2. Find the reciprocal vectors of this lattice.
   b3. What type of lattice is the reciprocal lattice?

3) Phonons and heat capacity
(<u>total points 15; *5* points each</u>)

a. The dispersion relation of a monoatomic linear lattice of N atoms with nearest neighbor interactions is:

$$\omega = \left(\frac{4C}{M}\right)^{1/2} \left|\sin\frac{1}{2}ka\right|$$

Where *a* is the 1D lattice distance.
From this dispersion relation, show that the density of modes is:

$$D(\omega) = \frac{2N}{\pi} \frac{1}{\sqrt{\omega_m^2 - \omega^2}}$$

where ω_m is the maximum frequency.

b. For acoustic phonons, the dispersion relation is given by:

$$\omega = \left(\frac{4C}{M}\right)^{1/2} \left|\sin\frac{1}{2}ka\right|$$

Show that the group velocity is constant in the long wavelength limit.

c. Benzene has a chemical formula C_6H_6 at low temperature forms crystals and its unit cell contains 2 molecules. Tell how many optical and acoustical bands are present in the phonon dispersion relation of benzene crystals.

4) Various topics
(<u>total points 25; *5* points each</u>)

a. What is the difference between a type I and type II superconductor? Sketch the temperature versus magnetic field phase diagram for both types.

b. What is happening to the density of states of a metal when is put in a magnetic field. (make a sketch).

c. Semiconductors can be either *n* or *p* doped, sketch the position of the doping levels respect to the conduction and valence band.
d. Sketch the band diagram of a p-n junction when the depletion region is formed.

e. Plot the energy dispersion [E(k)] in the free electron energy approximation in the reduced zone. Indicate precisely in the plot the k value interval.