STOCKHOLMS UNIVERSITET
FYSIKUM

Examination in Condensed Matter Physics I, FK3004, 7.5 hp
Wednesday, June 17, 2009, 09.00-15.00.

Allowed help:
- periodic table and fundamental constants (distributed)
- formula sheet (distributed)
- pocket calculator, BETA / mathematics handbook or similar

Instructions:
All solutions should be easy to read and have enough details to be followed. The use of nontrivial formulas from the formula sheet should be explained. *Summarize each problem* before its solution, so that the solution becomes self-explained. State any assumptions or interpretation of a problem formulation.

Good luck! / A.R.

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1. Copper has *fcc* structure. A certain alloy between gold and copper is obtained by replacing Cu in the corners of the conventional *fcc* cell by Au. The unit cell of the alloy has a lattice parameter $a = 3.75$ Å.
a) Draw the crystal structure. Indicate the lattice parameter of the alloy. (1p)
b) Which chemical composition (Cu_xAu_y) does the alloy have? (1p)
c) Calculate the density of the alloy. (1p)
d) Specify the coordination number (i.e. the number of nearest neighbors) for the Au atoms. (1p)

2. Aluminium has three valence electrons per atom.
a) The lattice parameter of pure aluminium is $a = 4.05$ Å. Show that the Fermi energy of Al is $\varepsilon_F = 11.7$ eV using suitable assumptions. (1p)
b) At room temperature the resistivity of aluminium $\rho_{Al} = 2.45$ $\mu\Omega$cm. Estimate the mean free path for conduction electrons in Al. (2p)
c) Discuss the relationship between defects and resistivity and explain why the resistivity of absolutely pure Al is not zero. (1p)

3. A polycrystalline sample with bodycentered tetragonal structure was studied with monochromatic x-ray, $\lambda = 1.5405$ Å. The four lowest Bragg angles were measured to $\theta = 21.00°$, $22.06°$, $28.78°$, and $32.09°$.
a) Give an expression for a general reciprocal lattice vector $\mathbf{G}(hkl)$ for the tetragonal lattice, which has lattice vectors $a\hat{x}$, $a\hat{y}$, and $c\hat{z}$. (0.5p)
b) Start with the diffraction condition $\Delta\mathbf{k} = \mathbf{G}$ and deduce the quadratic form for a tetragonal lattice. (1.5p)
c) For *bcc* structures, the allowed reflexes have $h + k + l = 2n$, where n is an integer. Motivate that this is also the case for the bodycentered tetragonal structure. (0.5p)
d) Index the structure and determine the lattice parameters a and c. (1.5p)

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4. Transversal, optical lattice vibrations in germanium have a frequency $f \approx 9 \cdot 10^{12}$ Hz, which can be assumed independent of wavelength and propagation direction. Germanium has diamond structure and lattice parameter $a = 5.66\,\text{Å}$.
a) Calculate the average number of transversal, optical phonons in a 1 cm^3 Ge-crystal at room temperature. Hint: the number of allowed wave vectors in the 1st Brillouin zone equals the number of primitive cells. (2p)
b) Calculate the thermal energy associated with these lattice vibrations for the given crystal. (1p)
c) Estimate the contribution from these lattice vibration to the heat capacity of the crystal at room temperature (1p)

5. a) Discuss four different experiments that can be used to study semiconductors. Address how the experiments are performed and what information the experiments can give. (2p)
b) Can the effective mass of an electron in a certain Bloch state be both positive and negative? Find the answer to the question for two-dimensional and one-dimensional crystals. (2p)

6. a) Show how to obtain the Curie law, i.e., that the magnetic susceptibility $\chi \propto 1/T$, for a free spin paramagnet with $J = 1/2$. (2.5p)
b) Describe the magnetic response of type-I and type-II superconductors. Discuss the difference. (1.5p)