STOCKHOLMS UNIVERSITET
FYSIKUM

Examination in Condensed Matter Physics I, FK3004, 7.5 hp
Saturday, March 27, 2010, 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. a) Discuss the Drude model: basic assumptions, its use, limitations, and relation to the Sommerfeld theory. (2p)
b) The relaxation time τ for electrons in the Drude model is defined to give a probability dt/τ for an electron to collide during a short time dt. Use this definition to find an expression for the probability of the electron not colliding during a time t. Interpret the result. (2p)

2. a) Describe in general terms the difference between Fermi energy and chemical potential μ. (0.5p)
b) Use Sommerfeld expansion technique to show that $\mu - \varepsilon_F \propto T^2$ in the free electron model. Determine the prefactor. Answer in such a way that the prefactor contains ε_F. (2.5p)
c) Define the concepts of Bravais lattice and reciprocal lattice. (1p)

3. a) For a monoatomic *fcc* lattice, the Miller indices (hkl) should follow a certain rule for diffraction to occur. Find this rule by calculating the structure factor for the *fcc* lattice. (1.5p)
b) The sodium chloride structure can be described as an *fcc* lattice with a basis consisting of one type of ion at $\mathbf{0}$ and another at $(a/2)(\hat{\mathbf{x}} + \hat{\mathbf{y}} + \hat{\mathbf{z}})$. Give a simple motivation why this structure, in general, should follow the same rule for diffraction as the *fcc* lattice does. (0.5p)
c) Potassium chloride (KCl) has the sodium chloride stucture. However, some of the Bragg reflections expected for the *fcc* lattice are missing. Give a possible explanation and show that only the all-even reflections (with an even sum $h^2 + k^2 + l^2$) remain. (2p)

4. Aluminium (Al) has *fcc* structure with a lattice parameter $a = 4.05\,\text{Å}$.
a) Determine an expression for the k-volume of the 1:st Brillouin zone for Al. (1p)
b) Describe the basic assumptions of the Debye model and find an expression for the volume of the Debye sphere for Al. (2p)
c) Compare the Debye sphere radius with the distance from the center Γ of the Brillouin zone to the zone boundary in the [100] direction and the [111] direction for Al. (1p)

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5. a) The colors of gemstones often arise due to trace amounts of transition metal ions having incomplete 3d shells. In such a case, visible light causes electronic transitions between the 3d orbitals. Some gemstones and crystals, however, display color without any traces of 3d metals. Give a possible explanation for the mechanism behind such colors. (1.5p)
b) Discuss heat conduction in non-metals, especially thermal conductivity at low and high temperatures and why heat conduction is diffusion-like. (2.5p)

6. a) Pauli paramagnetism is a weak form of paramagnetism, involving itinerant (as opposed to localized) electrons. Make suitable assumptions and deduce an expression for the susceptibility of a Pauli paramagnet. (2p)
b) In superconductivity, there are two different length scales, the *coherence length* ξ and the *penetration depth* λ. Explain their roles and motivate why the response of a superconductor to magnetic fields could be expected to be very different for the cases when $\lambda < \xi$ and $\lambda > \xi$. (2p)