STOCKHOLMS UNIVERSITET
FYSIKUM

Examination in Condensed Matter Physics I, FK7042, 7.5 hp
Tuesday, March 14, 2017, 08.00-13.00.

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 and define any introduced variables.

Good luck! / A.R.

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1. A single graphite sheet, called graphene, has a honeycomb structure with a nearest-neighbor distance of 1.42 Å.
a) Sketch the (2-dim) real-space structure of graphene. Find the number of atoms per cell. Indicate a unit cell, and give the length of the lattice parameters. (2p)
b) Draw the (2-dim) Brillouin zone of graphene. Find the area of the Brillouin zone. Hint: the reciprocal lattice of a simple hexagonal lattice is also a simple hexagonal lattice. (2p)

2. Bloch oscillations are oscillations of electrons in periodic potentials in the presence of a constant force. They are really hard to observe in nature, due to scattering, but have been observed in semiconductor superlattices.
a) Assume a tight-binding form of the dispersion relation $\varepsilon(k) = A \cos ak$, where a is a lattice parameter. Find an expression for the angular frequency of the Bloch oscillations in the presence of an electrical field E. Make suitable assumptions. (3p)
b) Explain how Bloch electrons move in reciprocal space in the presence of a magnetic field under otherwise similar conditions. (1p)

3. a) Explain the following concepts related to lattice vibrations: Phonon, normal mode, Umklapp process. (1.5p)
b) Find an expression for the lattice zero-point vibration energy expressed in nk_B and θ_D, where n is the atomic density and θ_D is the Debye temperature. Make suitable assumptions. (2.5p)

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4. The following three expressions can be found in the formula collection:

$$g_c(\varepsilon) = \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2}(\varepsilon - \varepsilon_c)^{1/2}$$

$$n_c(T) = \int_{\varepsilon_c}^{\infty} \frac{1}{e^{(\varepsilon-\mu)/k_BT} + 1} g_c(\varepsilon)\mathrm{d}\varepsilon$$

$$N_c(T) \approx \frac{1}{4}\left(\frac{2m_e k_B T}{\pi\hbar^2}\right)^{3/2}$$

Explain what they describe and and under what conditions/assumptions they apply. Also explain variables etc. in the expressions. (4p)

5. a) The paramagnetic susceptibility χ of rare-earth ions at high temperature is proportional to the square of the effective Bohr magneton number p and inversely proportional to temperature. The ions Ce^{3+}, Gd^{3+}, and Dy^{3+} have the electron configurations $4f^1 5s^2 p^6$, $4f^7 5s^2 p^6$, and $4f^9 5s^2 p^6$. Which one of these ions has the highest effective Bohr magneton number? (1.5p)
b) Pauli paramagnetism is a type of paramagnetism that is related to conduction electrons. Discuss the physics behind this type of paramagnetism. (2p)
c) Explain briefly the concept of diamagnetism. (0.5p)

6. a) We would like to study vacancies in a material. Discuss an experiment that could be used to estimate the activation energy for forming vacancies. Explain introduced concepts and the experimental execution in enough detail to understand if the proposed experiment could solve the problem. (2p)
b) Discuss thermal conductivity for metals at low temperature, including the temperature dependence. Explain why so called oxygen-free high thermal conductivity (OFHC) copper has much higher thermal conductivity than stainless steel. (2p)