Solid State Physics I

Exam

Groningen, April 2009

This is a closed book exam. You are not allowed to bring books, notes etc. You can use basic or scientific calculator, but no other electronic equipment that have capabilities to display or pronounce the course content.

We prefer you write in English. Although if you find it is too difficult you can write in Dutch.

Please write in a clear way!

Do not forget to indicate your full name and student number on **each** sheet.

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1. [10 total] The following questions [1 point each] should be answered very briefly (couple of sentences).

    a. What is the primitive cell?

    b. What is the Bragg law? Write it down in the vector form for a periodic crystal.

    c. Name all types of attractive interactions that can occur in crystals.

    d. Sketch the dispersion relations for photons and phonons in one graph.

    e. What is the origin of the energy gap in the nearly free electron model?

    f. What is the difference between a direct and an indirect semiconductor?

    g. How one can experimentally determine if a semiconductor has a direct or indirect band gap.

    h. What happens to the entropy of a solid upon transition from a normal state to a superconducting state?

    i. Does a weak magnetic field penetrate a superconductor?

    j. Does a weak electric field penetrate a superconductor?

    k. What is the difference between paramagnetic and diamagnetic materials?

2. [10 total] Consider a sound wave $u = Ae^{i(kx-\omega t)}$ traveling in a one-dimensional infinite chain of atoms.

    a. [1 point] Assuming periodic boundary conditions derive the set allowed values of wavevectors k.

    b. [2 points] Derive the density of states $D(\omega)$ within the Debye approximation.

    c. [3 points] Calculate the total phonon energy at temperature T.

    d. [3 points] Calculate the heat capacity C_V in the limit $T \ll \theta$, where θ is Debye temperature.

    Note: $\int_0^\infty \dfrac{x}{e^x - 1} dx = \dfrac{\pi^2}{6}$.

    e. [1 point] What is the physical meaning of the Debye temperature?

3. [10 total] Semiconductors.

    a. [1 point] What is an intrinsic semiconductor?

    b. [1 point] What are p-type and n-type semiconductors? Draw their band diagrams.

    c. [1 point] Describe how to obtain a p-type and a n-type semiconductor from an intrinsic semiconductor.

    d. [1 point] Draw the band configuration of a p-n junction.

    e. [3 points] Consider an intrinsic semiconductor with a gap $E_G = 1$ eV and constant density of states D for both the valence and the conduction bands. Assuming that the band edges are flat, derive an expression for the number of holes in the valence band at temperature T.

    f. [3 points] If at room temperature there are 10^{10} holes per cm³ in the valence band, calculate the constant density of states D.

    Note: at room temperature $k_B T \cong 25 meV$.