LULEÅ UNIVERSITY OF TECHNOLOGY
Applied Physics

Course code	**F0053T**
Examination date Time	2018-06-02 9.00 - 14.00 (5 hours)

Examination in: FASTA TILLSTÅNDETS FYSIK MED KVANTMEKANIK / QUANTUM MECHANICS AND SOLID STATE PHYSICS
Total number of problems: 5
Teacher on duty: Stephane Francois Tel: (49)2083, Room E159
Examiner: Hans Weber Tel: (49)2088, Room E163

Allowed aids: Fysika(lia), Beta, calculator, COLLECTION OF FORMULAE for Solid state physics and COLLECTION OF FORMULAE for Quantum Physics.

Define notations and motivate assumptions and approximations. Present the solutions so that they are easy to follow. Maximum number of point is 15 p. 7.5 points are required to pass the examination. Grades 3: 7.5, 4: 9.5, 5: 12.0

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1. **Crystal structure**

   Potasium (K), Copper (Cu) and Polonium (Po) are chemical elements with different crystal structures.

   (a) How many atoms does the primitive unit cell contain in these elements?

   (b) How many atoms does the conventional unit cell contain in these elements?

   (c) Calculate the nearest and next nearest neighbour distance, in Ångström, for Copper.

   (3p)

2. **Heat capacity**

   Sodium metal displays free–electron–like behaviour. The thermal effective electron mass is equal to the electron mass and the Debye temperature is 160 K. What fraction of the total heat capacity at 300 K is contributed by the electrons. (3p)

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3. **The specific heat of solid Argon**

A measurement of the heat capacity C_v of solid Argon is performed. The results are given in figure 1 below. Also results for a measurement of the phonon the dispersion relation for solid Argon are shown in figure 2.

(a) From these figures calculate the velocity of sound from the specific heat data (v_{sph}) and from the dispersion curves (v_{disp}).
NOTE For the dispersion data (figure 2) we restrict ourselves to the transverse phonons (T1 and T2) in the [1 0 0] direction (the left part of figure 2 where k goes from Γ to X).
Use the Debye approximation !

(b) Use appropriate experimental results to determine the debye temperature Θ_D for Argon.

(3p)

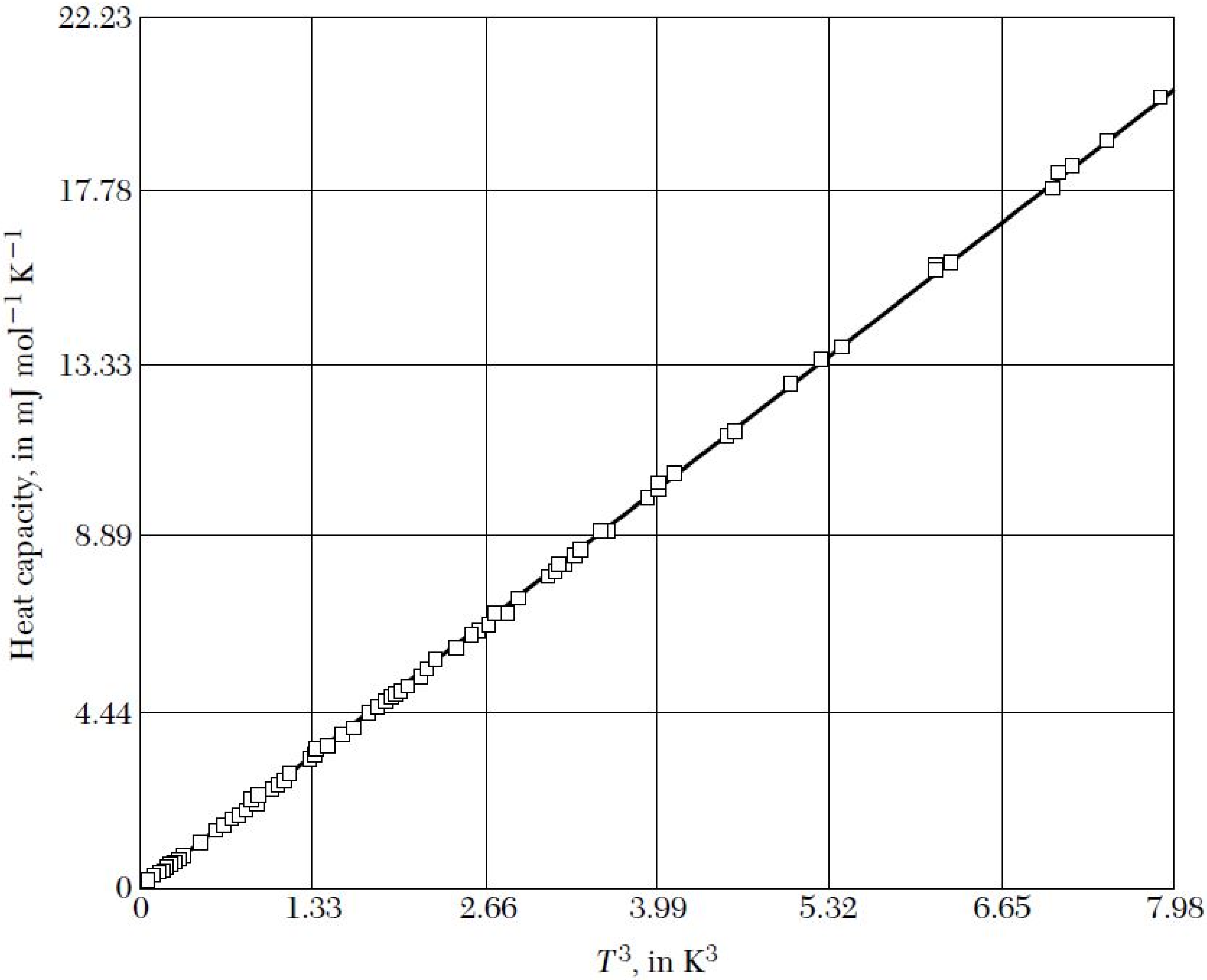

Figure 1: Figure from Kittel

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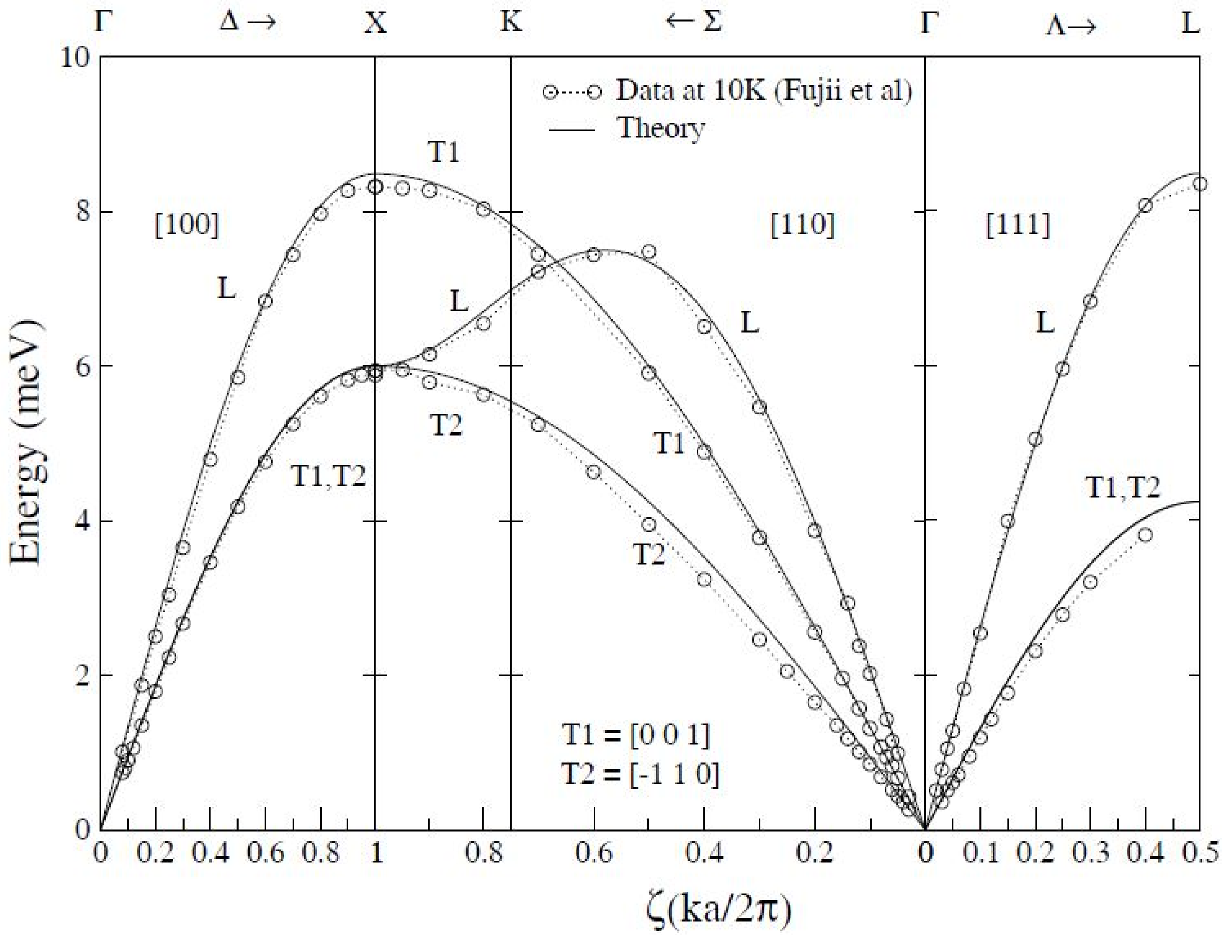

Figure 2: Phonon dispersion in solid Argon (^{36}Ar data from Phys Rev B 10, 3647)

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4. **Operators and eigenfunctions**

Are the following functions ψ eigenfunctions of the given operators $\hat{A}$?

Note: Do not make guesses, a wrong answer will be counted negative ! (No answer to one of the items is counted as zero)

(a) $\psi(t) = \sin(\omega t)\cos(\omega t)$ and $\hat{A} = i\hbar\frac{\partial^2}{\partial t^2}$.

(b) $\psi(t) = \cos^2(\omega t) - \sin^2(\omega t)$ and $\hat{A} = i\hbar\frac{\partial^2}{\partial t^2}$.

(c) $\psi(x) = \sin kx$ and $\hat{A} = \frac{\partial}{\partial x}$.

(d) $\psi(x) = kx^2$ and $\hat{A} = \frac{\partial}{\partial x}$.

(e) $\psi(z) = Cze^{-\frac{1}{2}z^2}$ and $\hat{A} = \frac{1}{2}(z^2 - \frac{\partial^2}{\partial z^2})$.

(f) $\psi(x) = e^{ikx} + e^{-ikx}$ and $\hat{A} = \frac{\partial}{\partial x}$.

(g) $\psi(x) = \cos kx$ and $\hat{A} = \hat{P}$ = the parity operator.

(h) $\psi(z) = Ce^{-\omega z}$ and $\hat{A} = -i\frac{\hbar}{2}\frac{\partial}{\partial z}$.

(i) $\psi(z) = C(1 + z^3)$ and $\hat{A} = -i\hbar\frac{\partial}{\partial z}$.

(0 – 3 p)

5. **Two dimensional Square well and parity**

A particle is placed in the potential (a 2 dimensional square well)

$$V(x) = \begin{cases} 0 & \text{for} \quad -\frac{a}{2} \leq x \leq \frac{a}{2} \text{ and } -\frac{a}{2} \leq y \leq \frac{a}{2} \\ +\infty & \text{for} \quad x > \frac{a}{2},\ x < -\frac{a}{2} \text{ and } y > \frac{a}{2},\ y < -\frac{a}{2}. \end{cases}$$

(a) Calculate (solve the Schrödinger equation !) the eigenfunctions !

(b) The Hamiltonian commutes with the parity operator P, $P\Psi(x,y) = \Psi(-x,-y) = \lambda\Psi(x,y)$ where the eigenvalue λ can take two possible values ± 1.

Write down the eigenstates corresponding to the four lowest **energies** in such a way that they are also eigenfunctions of the parity operator P. What is the parity of these states?

(3p)

Good Luck !