LULEÅ UNIVERSITY OF TECHNOLOGY
Applied Physics

Course code	**F7045T**
Examination date	2018-06-02
Time	9.00 - 14.00 (5 hours)

Examination in: FASTA TILLSTÅNDETS FYSIK / 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), Physics Handbook, 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)

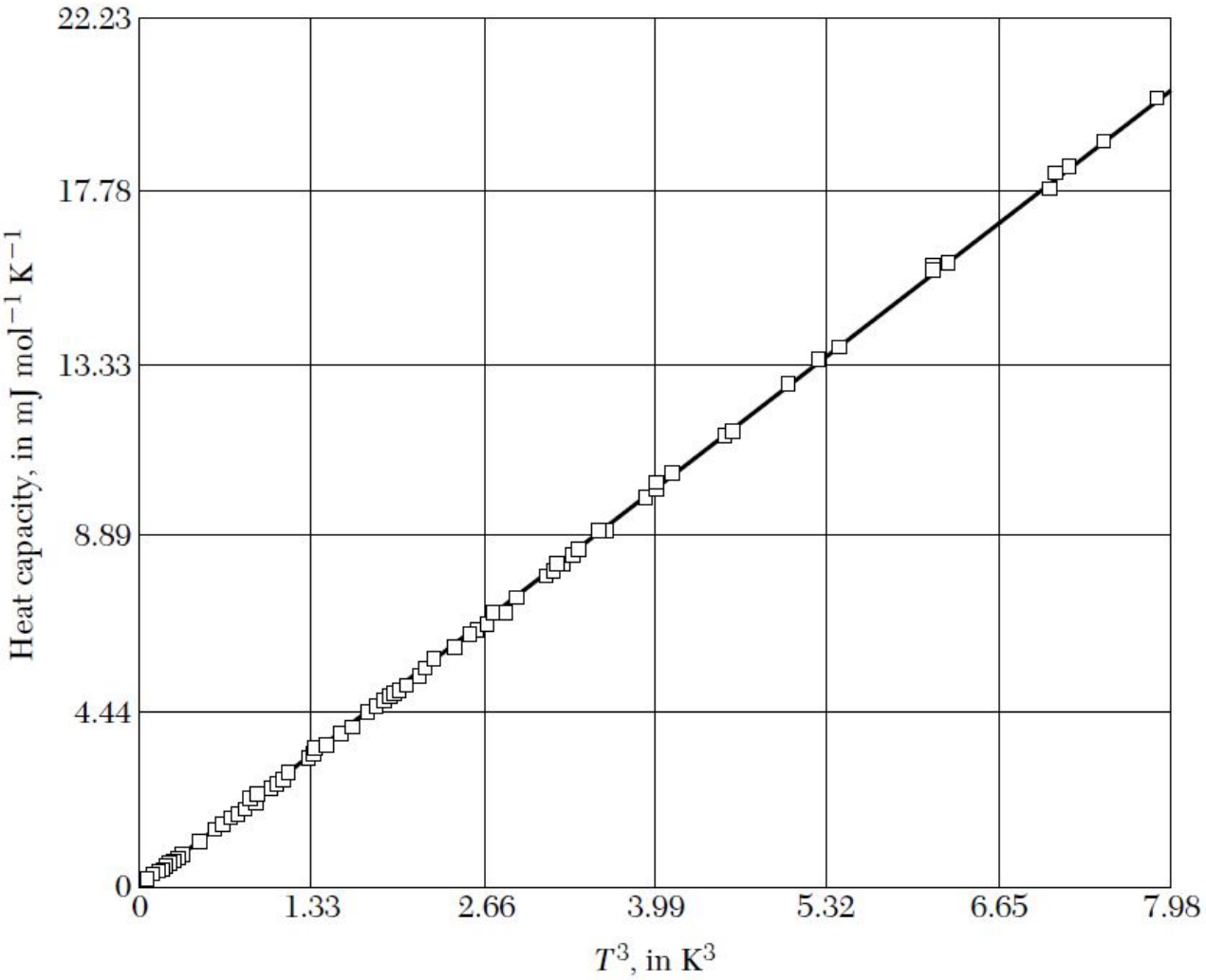

Figure 1: Figure from Kittel

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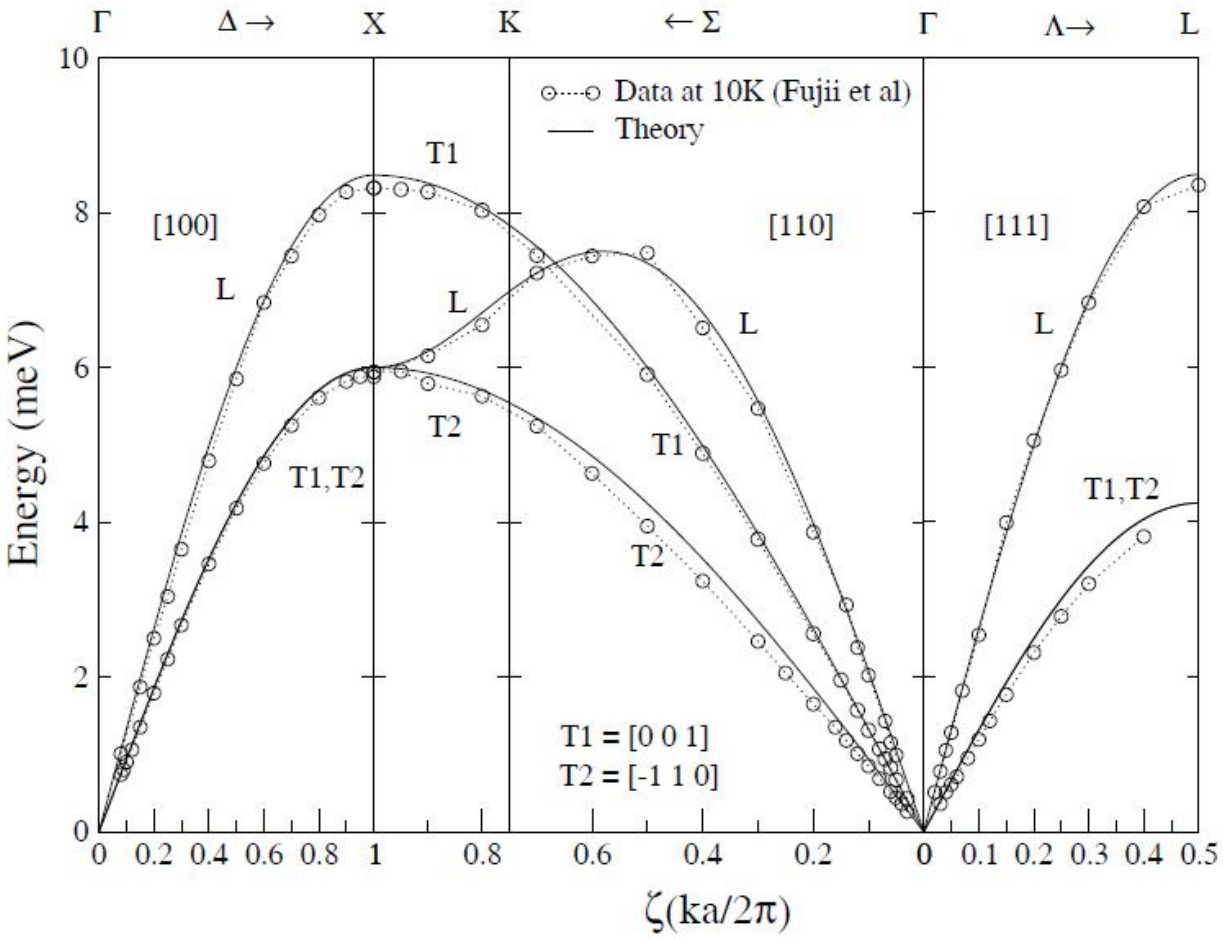

Figure 2: Phonon dispersion in solid Argon (^{36}Ar data from Phys Rev B 10, 3647)

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4. **Hund rules**

Use the Hund rules to determine the ground state (L, S, and J) and the effective number of Bohr magnetons for:

a) Cr^{3+} with the configuration $[Ar]3d^3$

b) Cu^{2+} with the configuration $[Ar]3d^9$

c) Tb^{3+} with the configuration $[Xe]4f^8 5s^2 p^6$

(3p)

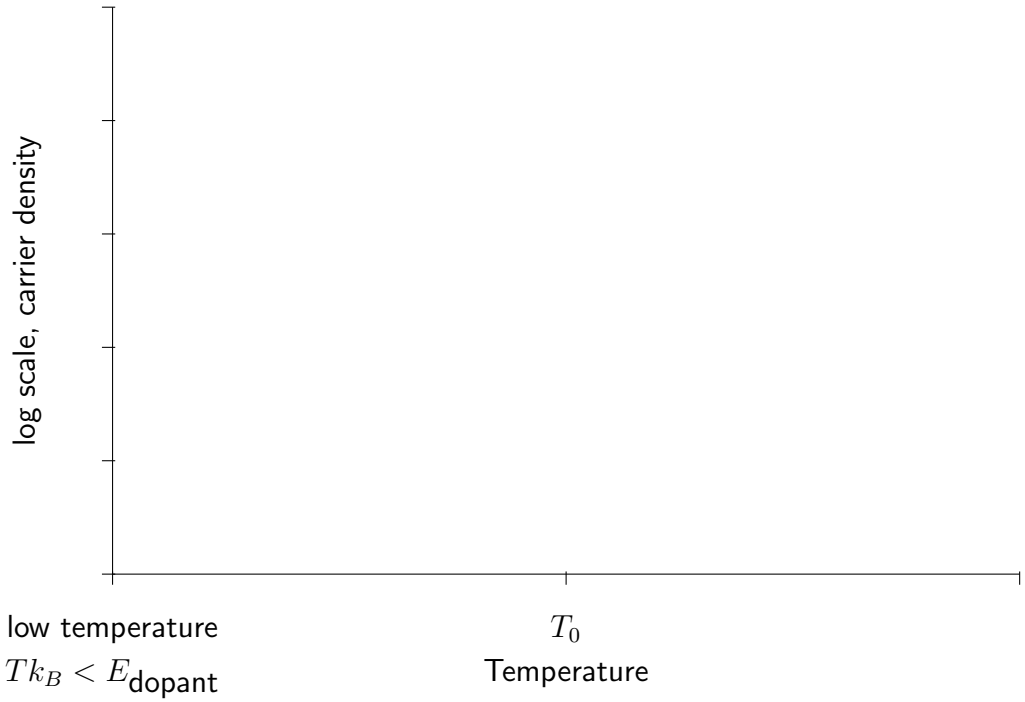
5. **Doped Semiconductor**

(a) Germanium is a semiconductor with a band gap of $E_g = 0.67$eV. Germanium has been doped with Phosphorus (P) homogeneously to a level of 3.191 mg (P) for each kilogram of Germanium. Calculate the charge-carrier population at room temperature $T = 293$K in the doped material. Express your answer in units of carriers/m^3.
Data: The effective mass for electrons in the conduction band is $m_e^* = 1.2m_0$ and for the holes in the valence band the effective mass is $m_h^* = 0.2m_0$.

(b) Name the dominant charge carrier in P-doped Ge, and specify whether the material is $p-$ or $n-$type.

(c) For P-doped Ge, on 'the plot below' (make a similar one in your solution) draw the temperature dependence of (graph marked 1) electrons in the conduction band and (graph marked 2) holes in the valence band. Label clearly each line (graph 1 and 2). T_0 is the temperature at which the contributions to the electrical conductivity from intrinsic and extrinsic behaviors are identical. E_{dopant} is the energy it takes to ionize the impurity atom.

Be qualitative - no calculation necessary.



(3p)

Good Luck !