CHALMERS UNIVERSITY OF TECHNOLOGY — 2006-08-28
Mikrotechnology och nanoscience — Kl: 09.00-13.00

Exam in FMI036, Superconductivity and low temperature physics

Teacher: Per Delsing, phone: 772 3317, 070-3088317

Allowed aids: Tefyma, Physics Handbook, Stand Math Tables and similar handbooks, calculator, and one A4 sheet with handwritten notes.

Answer problem 1 and 5 of the following 6 problems (i.e. problem 2-7). Motivate your answer in a logical way. You are welcome to illustrate with readable diagrams. Answer in Swedish or English.

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1. Short questions to test the understanding of concepts.

Give short descriptions or definitions (use diagrams if appropriate) of the following:

(a) Sketch the low temperature phase diagram (P vs T) for ^{4}He. Which are the different phases. Give the most important temperatures and pressures.
(b) How can a dilution refrigerator be used for cooling, what temperatures and cooling powers can be reached?
(c) Sketch the BCS-density of states for excitations in an ordinary superconductor such as tin.
(d) Sketch the dispersion relation (E versus p) for excitations in superfluid ^{4}He, point out the two most important types of excitations?
(e) What does u_k and v_k describe in the BCS theory?
(f) What is the meaning of the critical velocity in a superfluid.
(g) Sketch how the critical current of a SQUID changes with external magnetic field.
(h) What is the Josephson penetration depth?
(i) Sketch the specific heat for a superconductor above and below the transition temperature. What happens with the electronic and phononic contribution below Tc
(j) Scetch the atomic structure of YBCO. (0.5p per sub-problem, 5p)

2. BCS theory

The BCS ground state is given by $|BCS\rangle = \prod_k \left(u_k + e^{i\theta} v_k c^\dagger_{k+s,\uparrow} c^\dagger_{-k+s,\downarrow}\right)|0\rangle$

(a) Explain in simple terms how the electron phonon interaction can give rise to an attractive interaction between electrons that leads to (Cooper-)pairing. (1p)
(b) Explain the different parts of the ground state. What is |0> and θ. Why do the two operators $c^\dagger$ do and what would to conjugate operator c do? (1p)
(c) What is the isotope effect? How can it be explained? (1p)

3. Tunneling in a Superconductor-Insulator-Normal metal (SIN) tunnel junction.

Derive the integral expression for the current in the SIN junction at finite temperature, include both the left and the right going currents and simplify the expression and solve the integral. Use a figure to explain the used variables. (3p)

4. Superconducting devices

Discuss "single electron tunneling". What are the conditions that have to be met in order to observe the phenomenon? What are the main features? What is meant by Coulomb blockade? How can the phenomenon be used to measure small shifts in the charge distribution? What is the principle behind the Coulomb blockade thermometer application? (3p)

5. High Temperature superconductors

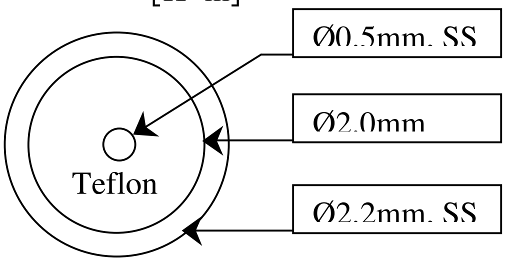
(a) Make a drawing, which outlines a typical HTS doping-phase diagram and indicate how the material behaves when it is underdoped (or undoped), optimally doped, and overdoped (1p)
(b) Give at least 2 examples on ways of making Josephson junctions in HTS. Describe the different steps in the fabrication. (2p)

6. Cryogenics.

A stainless steel (SS) coaxial cable with Teflon isolation is mounted in a dilution refrigerator, it is heat sunk at the Still (0.8K) and at the mixing chamber, which is at 30mK. The coax is 30 cm long and has a cross-section as shown in the figure below.

The heat conductivity for stainless steel is

$\kappa = 0.12 \cdot T \left[\frac{\mathrm{W}}{\mathrm{K \cdot m}}\right]$, and for teflon $\kappa = 0.004 \cdot T^2 \left[\frac{\mathrm{W}}{\mathrm{K \cdot m}}\right]$



(a) Calculate the power with which the coax heats the mixing chamber. (2p)

(b) How much worse would it be if the coax was not heat sunk at the Still, but was mounted directly between the IVC (4.2K) and the mixing chamber but twice as long. (1p)

7. Superfluid Helium

(a) Describe how a Bose Einstein condensation comes about? What is the condensate? (1p)

(b) Describe what different symmetry breaking mechanisms that can be found in superfluid Helium–3 and explain how the superfluid A and the B phases relate to these mechanisms. (2p)