Examination in MCC015: Superconducting Devices – Fundamentals and Applications

Samhällsbyggnad

Wednesday May 30th 2018 14.00 – 18.00

Responsible teachers: Alexei Kalaboukhov 073-7084195, Floriana Lombardi 031 772 3318,

Allowed material: Your choice of calculator and a handwritten A4 single page with your own notes.

You have to answer all problems

Total credits: 15.0: 7 credits passed, 10 credits well passed, 13 credits excellent.

All home assignments and lab reports will be valued and can be used in the evaluation of the exam. You will get, from home assignments and lab reports, max 3 credits if exam score is < 4 and max 2 credits if exam score is > 4.

---

1. SHORT PROBLEMS (3 credits total):

1.1 Draw the I-V characteristic of the Josephson junction for Q<<1 (strong damping). By considering the mechanic analog of the junction draw the time dependent voltage across the junction for $I \approx I_C$ and $I >> I_C$, with I_C being the critical current of the junction. (0.5 credits)

1.2 Draw the magnetic field dependence of the Josephson current for a rectangular short junction (which has a uniform current distribution at zero external field ($\Phi(B_{ext})$)=0). Derive the current distribution when the applied magnetic flux is $\Phi(B_{ext})= 2\ \Phi_0$, where Φ_0 is the flux quanta (0.5 credit)

1.3 On what length scale does microwave radiation penetrate a bulk superconductor and how does it depend on frequency? (0.5 credit)

1.4 In which limit is the kinetic inductance per unit length of a thin superconductive strip much larger than the geometrical inductance $L \approx \mu_0$? (0.5 credit)

1.5 A dc SQUID with a voltage modulation depth of ΔV_{pp}=30 µV is included into the flux-locked loop with negative feedback. The feedback loop resistance is R_f= 1 kΩ and mutual inductance is M_f= 1 nH. Calculate external magnetic flux that can be applied to produce $1/8\Phi_0$ in the SQUID loop. Voltage gain of the preamplifier is G_{LNA}=10000. (0.5 credit)

1.6 How does the IV curve change for an SET when the electrodes become superconducting? (0.5 credit)

2. Josephson junction in the ring

Consider a Josephson junction with a critical current I_c =1 μA incorporated in a superconducting ring of inductance L = 1 nH (see Figure 1). On the side opposite to the junction, a small piece is cut out, as illustrated in the figure. An external current source, connected across the opening, supplied a current I =0.4 μA. Find the phase difference of the macroscopic wave function between the points 1 and 2,φ_{12}.

(3 credits)

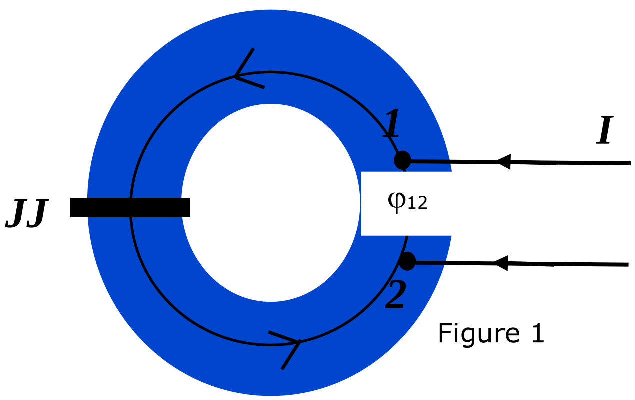


Figure 1

3. Two-fluid model of a superconductor

Consider the two fluids model for a superconductor. Derive the expression of the complex conductivity of a superconductor in presence of an external ac electromagnetic field and discuss the equivalent circuit.

(3 points)

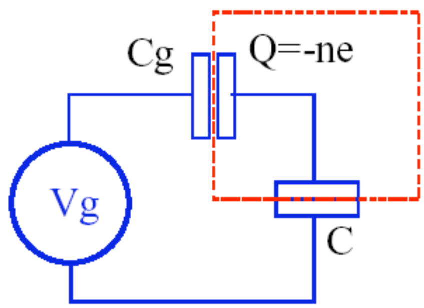
CHALMERS UNIVERSITY OF TECHNOLOGY
Department of Microtechnology and Nanoscience
SE-412 96 Göteborg, SWEDEN
Visiting address: Kemivägen 9

4. Single electron transistor

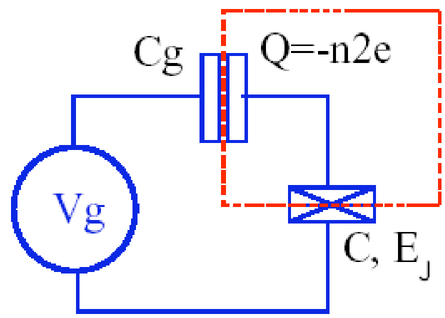
Figure below shows the schematic of a single electron box SEB (a) and of a single Cooper–pair box SCB (b).

a) For both physical systems, draw and comment the diagram of the energy of the box as a function of the gate voltage Vg, and for different numbers, n, of the charges on the box (omit the terms not dependent on n). Discuss the main differences between the two energy diagrams. (1.5 credits)

b) For both physical systems draw and comment the dependence of the charge on the box as a function of the gate voltage (i.e. Coulomb staircase). Discuss what determines the smearing of the staircase for a SEB and a SCB. (1.5 credits)



(a)



(b)

MC2
CHALMERS UNIVERSITY OF TECHNOLOGY
Department of Microtechnology and Nanoscience
SE-412 96 Göteborg, SWEDEN
Visiting address: Kemivägen 9

5. SQUIDs

Derive magnetic flux dependence of the maximum critical current of the asymmetric DC SQUID with $I_{C,1} > I_{C,2}$ (with negligible self-induced flux, $\beta_L << 1$). Show that the ratio of the maximum to minimum total critical current for the two-junction SQUID is given by $(\alpha + 1) / (\alpha - 1)$, where $\alpha = I_{C,1} / I_{C,2}$.

(3 credits)

CHALMERS UNIVERSITY OF TECHNOLOGY
Department of Microtechnology and Nanoscience
SE-412 96 Göteborg, SWEDEN
Visiting address: Kemivägen 9