Fun Phys Master2 internship project 2019

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Nanophysics team E6

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Subject's title: **Circuit theory and noise characteristics of multiterminal superconductor devices**

Subject description:

The nanophysics team of CPT is looking for a motivated M2 student to study off equilibrium quantum transport in a two or three superconducting lead device where all leads are connected to a central node (a "large", metallic quantum dot). In similar devices with 3 superconducting leads only (with phases Phi_0, Phi_a, Phi_b and voltage biases V0=0, Va, Vb) it has been shown that if Va-V0 and Vb-V0 are commensurate, i.e. na Va + nb Vb = 0 (with na, nb integers), a phase-dependent, DC dissipation-less current can be generated although the system is out of equilibrium.

The physics of this phenomenon is understood to be the coherent exchange of Cooper pairs between the three leads. One crucial ingredient is the possibility to split a Cooper pair from a superconducting lead, and to redistribute its constituent electrons in the other two electrodes. This process, called Crossed Andreev Reflection (CAR), has been studied on many occasions by the nanophysics team of CPT. For 3 lead devices with Va = -Vb (V0=0), when such CAR process from superconductor 0 occurs two times in a row, while the receiving superconducting leads each absorb two electrons as a Cooper pair, the resulting 4-electron resonant process is called a "quartet": two CAR processes are required along with two "normal" Andreev reflections.

So far, this effect has been studied theoretically assuming that the junctions between pairs of superconductors involve nano-wire quantum dots. Nevertheless, the initial (pioneering) experiment for probing such multiple pair resonances has been performed in Grenoble by the group of François Lefloch at CEA, using a central metallic node connecting all three superconductors. Another recent experiment was performed by the group of M. Heiblum at the Weizmann Institute.

Our central motivation is thus to use Nazarov's circuit theory in order to study multiple Cooper pair resonances when leads are connected to a metallic node. This now well-established theory is based on the diffusive superconductor approach to quantum transport due to Usadel. At the origin is the Larkin Ovshinikov Gorkov theory of superconducting quantum transport where impurity scattering is taken into account via self-energies. This equation can be simplified by using the semiclassical approximation (averaging the fast oscillations on the scale of the Fermi wavelength), and by considering the dirty limit, where the electron motion is diffusive due to impurity scattering, and the Green functions become isotropic. This leads to the so-called Usadel equation. Nazarov circuit theory simplifies further the problem by discretizing the system in

nodes, where the Green function is homogeneous. Expressing current conservation in the nodes leads to a recursive solution for the nodes Green function. In the present case of a device with three superconductors, each lead Green's function is known, but the Green's function of the central node (the metallic island) needs to be evaluated self consistently using Nazarov's circuit theory.

During the internship, the first part of the work will be to get familiar with the bibliography on multiple pair resonances (theory and experiment) as well as to familiarize oneself with the non equilibrium methods of quantum field theory. Bibliography will also be needed for Nazarov's circuit theory. The student will not be required to proceed to the derivation of the Circuit Theory equations: he/she will need to be able to understand and specify the assumptions of this theory, and his/her crucial role will be to understand how to use this formalism. The key point will be to understand how to derive the node Green's function and how to extract from it the different current flowing into the leads.

We will start by investigating the current and noise characteristics of a two terminal BCS-dot-BCS junction. If possible we will also consider a 3-superconductor junction, in particular the quartet configuration where Va = -Vb. In this situation, all currents can be expressed in terms of harmonics of a Josephson-like frequency, as the system is time-periodic. The self-consistent solution for the node Green's function then relies on a peculiar Fourier transform which is specific to two superconductor junctions (here generalized to three when voltages are commensurate). If time allows, it will be possible to include dephasing effects on the quartet current.

This work has an analytical part (bibliography and setting up the calculations of current and noise), but soon involves numerics.

References:

·0 Noise in mesoscopic physics, Thierry Martin, les Houches Session LXXXI, H. Bouchiat et. al. eds. (Elsevier 2005). arXiv:cond-mat/0501208

·1 Quantum Transport , Y. Nazarov and Y. Blanter, Cambridge University Press.

·2 Multipair dc Josephson resonances in a biased all-superconducting bijunction, T. Jonckheere, J. Rech, T. Martin, B. Douçot, D. Feinberg, and R. Mélin, Phys. Rev. B 87, 214501 (2013)

·3 Subgap structure in the conductance of a three-terminal Josephson junction, A. H. Pfeffer, J. E. Duvauchelle, H. Courtois, R. Mélin, D. Feinberg, and F. Lefloch Phys. Rev. B 90, 075401 (2014).

·4 Proposal for the observation of nonlocal multipair production, J. Rech, T. Jonckheere, T. Martin, B. Douçot, D. Feinberg, and R. Mélin Phys. Rev. B 90, 075419 (2014).

·5 Current and noise correlations in a double-dot Cooper-pair beam splitter, D. Chevallier, J. Rech, T. Jonckheere, and T. Martin Phys. Rev. B 83, 125421 (2011).

·6 Handwritten notes on circuit theory (T. Martin)

·7 Tunable minigaps due to non-local coherent transport in voltage biased three-terminal Josephson junctions, C. Padurariu, T. Jonckheere, J. Rech, T. Martin, and D. Feinberg Phys. Rev. B 95, 205437 (2017).

Duration: the normal duration of a CPT internship

Any self-financial support? Yes, ANR One Shot reloaded

Specify whether the internship project may naturally lead to a PhD thesis.

In principle yes. I cannot provide a definite answer on this matter because it depends on the level of other CPT student who apply to the PhD program via the doctoral school ED 352