Fun Phys Master2 internship project 2019

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Nanophysics team E6

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Subject's title: **Andreev Reflection for a normal metal/BCS (or Topological) superconductor junction in the presence of a periodic Lorentzian voltage drive**

Subject description:

The nanophysics team of CPT is looking for a motivated M2 student to study time-dependent quantum transport between a BCS or topological superconductor nano-wire and a normal metal lead. Transport is characterized by the charge or spin current, but also by more involved quantities giving additional information, like the current-current correlations in time, called noise. The study of hybrid structures containing BCS superconductors or new materials like topological superconductors offer new perspectives in this domain.

Applying periodic time-dependent voltages between metallic electrodes is a way to create electronic excitations between these electrodes. The type of excitations created depends on the precise properties of the voltage drive. It was shown by Levitov and co-workers that a periodic Lorenztian drive is quite exceptional, as it allows to excite a single electron per period, without any other disturbance to the system. These single electron excitations have been called Levitons. Extending levitons to structures containing superconductors offer interesting perspectives. A recent work by Belzig on normal metal/BCS superconductor junctions found an optimal quantization for half-integer Levitons. The first goal of this work is to understand Belzig's paper and to compute the current and noise characteristics with Lorentzian voltage drives.

In hybrid structures containing superconductors, when voltage biases are applied to the leads, one has to resort to specific methods, in particular the Keldysh Green's function formalism. The CPT nanophysics team has a strong tradition in using these tools to study the current and noise correlations in superconducting hybrid structures, where a special transport channel called Andreev Reflection operates (the reflection of an electron incident on the superconductor into a hole). When two normal leads are connected to a central superconductor, an additional channel opens where an electron (a hole) incident on the superconductor can be reflected as a hole (an electron) in the other lead, a process called Crossed Andreev Reflection (CAR). The latter process, which describes the destruction of a Cooper pair accompanied by the propagation of spin entangled electrons in the two normal metal leads corresponds to Cooper pair splitting.

In topological superconductors, a lot of attention was drawn recently to the possibility for detecting the presence of Majorana fermions at their extremities: excitations which are their own antiparticle. Such excitations have been studied a century ago in the context of particle physics, but they are now believed to occur in the collective phenomena of condensed matter systems. It is therefore natural for the nanophysics team to study Andreev reflection in a device consisting of a topological superconductor nanowire and a normal metal lead. The manifestation of Majorana fermions could possess a particular signature.

During the internship, the first part of the work will be to get familiar with the bibliography on BCS and topological superconductors as well as to familiarize oneself with the non-equilibrium methods of quantum field theory. The average current and zero frequency noise can then be computed using the Keldysh Dyson equation. The boundary Green's function from the topological superconductor can be determined from the microscopic model of the Kitaev chain. The work will then focus on periodic Lorentzian voltage pulses generating electronic excitations impinging on the superconductor. If time allows, we will extend the analysis to normal metal/topological superconductor junctions. Additional extension could address transport in multi terminal junctions where CAR processes operate. This internship involves analytical calculations as well as numerical evaluations.

References:

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

‡2 Quantum Transport, Y. Nazarov and Y. Blanter, Cambridge University Press.

‡3 Hanbury Brown and Twiss noise correlations in a topological superconductor beam splitter T. Jonckheere, J. Rech, A. Zazunov, R. Egger, T. Martin, Phys. Rev. B 95, 054514 (2017)

‡4 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).

‡5 Low energy transport in Majorana wire junctions, A. Zazunov, R. Egger, and A. Levy Yeyati, Phys Rev B 94, 014502 (2016).

‡6 *Minimal Excitations in the Fractional Quantum Hall Regime,* J. Rech, D. Ferraro, T. Jonckheere, L. Vannucci, M. Sassetti, and T. Martin, Phys. Rev. Lett. 118, 076801 (2017)

‡7 *Elementary Andreev Processes in a Driven Superconductor-Normal Metal Contact*, W. Belzig and M. Vanevic, Physica E, 75, 22 (2016).

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