Anomalous Josephson effect in semiconducting nanowires with spin-orbit coupling

<u>Konstantin N. Nesterov</u>, Manuel Houzet, and Julia S. Meyer

Univ. Grenoble Alpes, INAC-SPSMS, F-38000, Grenoble, France
CEA, INAC-SPSMS, F-38000, Grenoble, France
kn.nesterov@gmail.com

In a conventional stationary Josephson effect, a finite phase difference ϕ between two superconductors connected by a weak link results in a nonzero supercurrent $I(\phi)$. When both time-reversal and inversion symmetries are broken, the relation $I(\phi)=-I(-\phi)$ generally does not hold, and the system can display the so-called anomalous Josephson effect: a finite current at $\phi=0$. In certain limits, the current-phase relation for such a junction can be written as

$$I(\phi)=I_c \sin(\phi+\phi_0),$$

which defines a ϕ_0 - junction [1].

One of the proposals to study anomalous Josephson effect involves a magnet with Rashba spin-orbit coupling serving as a weak link between two conventional superconductors [1]. In such a system, the effect occurs because of an interplay between two Rashba bands with different phase accumulations and different densities of states. While the contribution of each band to the effect is strong, the total anomalous current is proportional to the difference between two densities of states, which makes it relatively weak. Another proposal involves helical edge states of a quantum spin-hall insulator (QSHI) placed between two superconductors [2]. Here, the total effect can be made stronger by considering a QSHI with the edges of unequal lengths, which results in only partial cancellation between the contributions coming from two edges.

In our work, we consider a semiconducting nanowire with Rashba spin-orbit coupling and with superconductivity induced by proximity effect in two regions of the nanowire. This system displays the anomalous Josephson effect in the presence of a transverse magnetic field h_z. When a magnetic field h_x along the nanowire is also present, the superconducting parts of the nanowire can be driven in and out of the topological phase [3,4]. In the topological phase, only one helical band contributes to electron transport, which strongly increases the effect. An example is shown in Figure 1, where we plot current at $\phi=0$ as a function of the chemical potential μ in the nanowire for a small transverse magnetic-field component. When the superconducting parts of the nanowire are in the topological regime, determined by the condition $\mu^2<h_x^2-\Delta^2$, the supercurrent increases dramatically.

We investigate this effect and the current-phase relation for various regimes of spin-orbit coupling, magnetic field, and chemical potential, and for the limits of short and long normal parts of the wire.

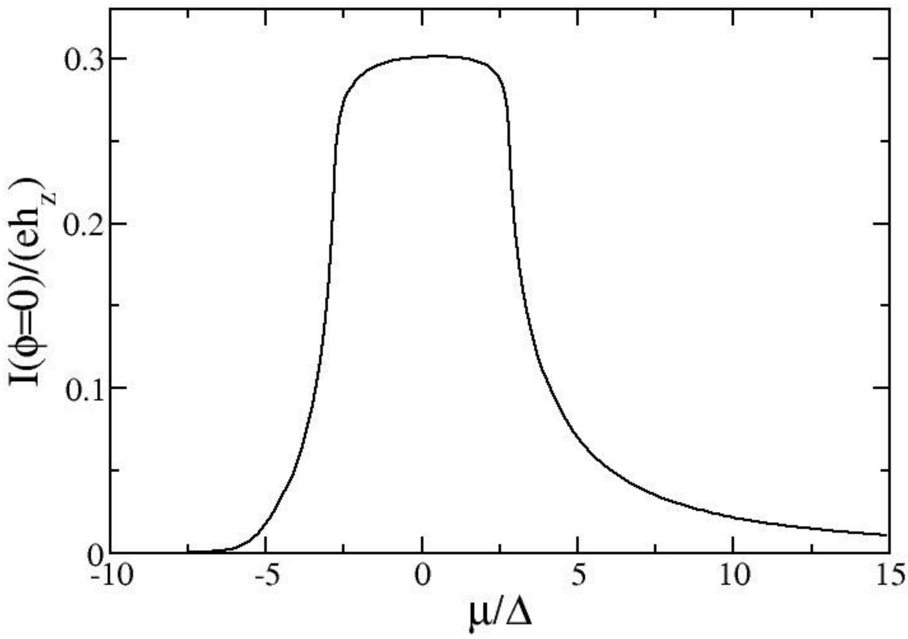

Figure 1: Current I vs chemical potential μ calculated for a nanowire with a short normal part at small transverse magnetic field $h_z/\Delta = 0.1$, and at $\phi = 0$, $h_x/\Delta = 3$, and $m\alpha^2/\Delta = 10$. Here α is Rashba spin-orbit coupling strength, Δ is the magnitude of the induced pairing potential, and e and m are the effective electron charge and mass.

[1] A. Buzdin, *Direct Coupling Between Magnetism and Superconducting Current in the Josephson ϕ_0 Junction*, Phys. Rev. Lett. **101**, 107005 (2008)

[2] F. Dolcini, M. Houzet, and J.S. Meyer, *Topological Josephson ϕ_0 -junctions*, ArXiv: 1503.01949 (2015)

[3] R.M. Lutchyn, J.D. Sau, and S. Das Sarma, *Majorana Fermions and a Topological Phase Transition in Semiconductor-Superconductor Heterostructures*, Phys. Rev. Lett. **105**, 077001 (2010)

[4] Y. Oreg, G. Refael, and F. von Oppen, *Helical Liquids and Majorana Bound States in Quantum Wires*, Phys. Rev. Lett. **105**, 177002 (2010)