Cavity quantum electrodynamics with mesoscopic topological superconductors

Olesia Dmytruk, Mircea Trif and Pascal Simon

Laboratoire de Physique des Solides, CNRS UMR-8502, Université Paris Sud, 91405 Orsay cedex, France
olesia.dmytruk@u-psud.fr

Condensed matter systems are an endless resource of emergent physical phenomena and associated quasiparticles. Majorana fermions, which are particles that are their own antiparticles and which have been first proposed as particles in the context of high energy physics, emerge beautifully as zero energy excitation in condensed matter setups. Electronic transport is the foremost experimental tool for investigating the Majorana fermions physics but alternative, non-invasive methods that preserve the quantum states would be highly desired to address these objects. Cavity quantum electrodynamics (cavity QED) has been established as an extremely versatile tool to address equilibrium and out-of-equilibrium electronic and spin systems non-invasively [1, 2]. Majorana fermions, too, have been recently under theoretical scrutiny in the context of cavity QED physics [3, 4].

Cavity QED with electronic systems allows one to extract various properties of the latter, such as its spectrum and its electronic distribution function, from photonic transport measurements. Such photonic transport is quantified by the complex transmission coefficient that relates the output and input photonic fields. We evaluate the electronic susceptibility for the case of a one-dimensional p-wave superconductor coupled to a microwave cavity. The reduction of the output signal compared to the input one gives information about the imaginary part of the electronic susceptibility, while the phase shift gives access to the real part of the susceptibility. We show that such a method allows us to ascertain the topological phase transition point, the occurrence of Majorana fermions and the parity of the ground state, all in a global and non-invasive fashion [5].

In a finite wire coupled to the cavity, there are two Majorana fermions emerging in the topological region, each localized at one of the two ends of the chain. Taken together, they give rise to a zero-energy fermionic state in the infinite wire limit, which can be either empty or occupied, thus labeling the parity of the one dimensional p-wave superconductor. There are couplings between all the levels in the superconductor via the cavity field, and that includes transitions between the Majorana and the bulk modes. However, correlations between Majorana states only are equal to zero, and the only contribution from the Majorana modes is due to the interplay between the Majoranas and the bulk states via either virtual or real transitions taking place between the two where the transitions are mediated by the photonic field. The bulk-Majorana susceptibility shows oscillations as a function of the chemical potential on top of the average value, which are opposite in sign for the two parities.

[1] M. Trif, V. N. Golovach, D. Loss, *Spin dynamics in InAs nanowire quantum dots coupled to a transmission line*, Phys. Rev. B **77**, 045434 (2008).

[2] K. D. Petersson, L. W. McFaul, M. D. Schroer, et al., *Circuit quantum electrodynamics with a spin qubit*, Nature **490**, 380 (2012).

[3] M. Trif and Y. Tserkovnyak, *Resonantly tunable Majorana polariton in a microwave cavity*, Phys. Rev. Lett. **109**, 257002 (2012).

[4] A. Cottet, T. Kontos, B. Douçot, *Squeezing light with Majorana fermions*, Phys. Rev. B **88**, 195415 (2013).

[5] O.Dmytruk, M.Trif, P.Simon, *Cavity quantum electrodynamics with mesoscopic topological superconductors*, arXiv:1502.03082 (2015).