Blockade and counterflow supercurrent in exciton-condensate Josephson junctions

Fabio Taddei[1], Sebastiano Peotta[1], Fabrizio Dolcini[2], Marco Gibertini[1], Marco Polini[1], Diego Rainis[3], Lev B. Ioffe[4], Rosario Fazio[1], and Allan H. MacDonald[5]

[1]*NEST, Istituto Nanoscienze-CNR & Scuola Normale Superiore, Piazza S. Silvestro, 12, I-56127, Pisa, Italy*

[2]*Dipartimento di Fisica del Politecnico di Torino, Torino, Italy*

[3]*Department of Physics, University of Basel, Basel, Switzerland*

[4]*Center for Materials Theory, Department of Physics and Astronomy, Rutgers University, Piscataway, USA*

[5]*Department of Physics, University of Texas at Austin, Austin, USA*

The terms superconductivity and superfluidity refer to dissipationless flow in charged and neutral systems, respectively. Superfluid exciton condensates, in which macroscopic phase coherence is established among pairs composed of electrons and holes in different bands, have been realized only recently. Signatures of exciton condensation have been reported in quantum Hall bilayers, in which electrons and holes are located in two separate two-dimensional electron layers [1]. When the two layers of a bilayer exciton condensate (EC) are contacted separately, it can exhibit remarkable transport anomalies associated with its neutral supercurrents. These properties provide an appealing platform for spectacular electrical effects in EC-superconductor hybrid systems in which the charged superconducting order parameter interfaces with the neutral EC order parameter. In this work we demonstrate that when two superconducting circuits are coupled through a bilayer EC, the superflow in both layers is drastically altered. If the same phase bias is applied to both junctions, no Josephson current can flow through the system, a phenomenon we refer to as exciton blockade. When a phase bias is applied to only one layer, on the other hand, it induces a superdrag counterflow supercurrent of the same magnitude in the unbiased layer.

In our calculations we assume that the superconducting electrodes in each layer are separated by a distance L much larger than the exciton coherence length, and an independent phase bias is applied to the top and bottom contacts. In the presence of these biases, Josephson currents flow through the double layer. Because the EC is gapped, only dissipationless counterflow can contribute to the Josephson current when L is long. We have considered both the short- and long-junction regimes, with respect to the superconducting coherence length, and the effect of a finite temperature.

[1] Yu. E. Lozovik and V. I. Yudson, JETP Lett. 22, 274 (1975).