Diode effects in current-driven Josephson junctions

Felix von Oppen

Dahlem Center for Complex Quantum Systems & Fachbereich Physik, Freie Universität Berlin, Germany

Current flow in electronic devices can be asymmetric with bias direction, a phenomenon underlying the utility of diodes and known as non-reciprocal charge transport. The promise of dissipationless electronics has recently stimulated the quest for superconducting diodes, which have been realized in various non-centrosymmetric systems. I will discuss superconducting diode effects observed in atomic-scale Josephson junctions realized in a scanning tunneling microscope [1]. Pristine junctions of an elemental superconductor (Pb) exhibit hysteretic behavior, typical of low-dissipation junctions, but no asymmetry between bias directions. Non-reciprocal supercurrents emerge when inserting a single magnetic atom into the junction, with the preferred direction depending on atomic species. Unlike previous measurements, the dominant asymmetry appears in the retrapping rather than switching current. After describing the experiment, I will present a general theoretical discussion of diode effects in current-biased Josephson junctions, relating asymmetries in switching and retrapping currents to distinctly different microscopic symmetry requirements [2]. This will allow for a thorough microscopic understanding of the experimental observations, which traces the observed non-reciprocity to quasiparticle currents flowing via Yu-Shiba-Rusinov (YSR) states inside the superconducting energy gap and emphasizes the importance of particle-hole-symmetry breaking. These results open new avenues for tuning Josephson diodes through single-atom manipulation and provide guidance in identifying the underlying microscopic origin.

[1] M. Trahms, L. Melischek, J.F. Steiner, B. Mahendru, I. Tamir, N. Bogdanoff, O. Peters, G. Reecht, C.B. Winkelmann, F. von Oppen, K.J. Franke, *Diode effect in Josephson junctions with a single magnetic atom*, arXiv:2212.04432 (2022).
[2] J.F. Steiner, L. Melischek, M. Trahms, K.J. Franke, F. von Oppen, *Diode effects in current-biased Josephson junctions*, arXiv:2212.06866 (2022).