Quantum bipolar thermoelectricity

Filippo Antola[1], Giorgio De Simoni[1], Francesco Giazotto[1], and Alessandro Braggio[1,2]

[1]*Istituto Nanoscienze – CNR, NEST-SNS, Piazza San Silvestro 12, Pisa, Italy*
[2]*Institute for Quantum Studies, Chapman University, Orange, CA, USA*

Thermoelectricity is generally understood as a classical effect arising from energy-dependent transport asymmetries [1]. Here [2], we uncover a purely *quantum* mechanism, where a superconducting S-I-S' tunnel junction in thermal equilibrium develops a nonlinear bipolar thermoelectric response owing to the dynamical Coulomb blockade[and the *emission-absorption imbalance* of a cold electromagnetic bath. In contrast to standard bipolar thermoelectricity [3], generated by a strong thermal gradient within the junction, the quantum effect has the cold bath given by the electromagnetic environment, and the junction is kept in equilibrium at a higher temperature. The bipolar thermoelectric effect is given by spontaneous particle-hole symmetry breaking induced by the interplay between interactions [4] and the temperature gradient, and is experimentally demonstrated [5]. Here, however, the dynamical Coulomb blockade [6] also plays a crucial role in mediating the environmental influence on the junction [2]. Two representative environments are analyzed, revealing Seebeck coefficients up to 100 μV/K for realistic junction parameters. Because the response directly reflects the spectral properties of the surrounding environment, our results suggest that bipolar quantum thermoelectricity could provide a new route for spectroscopic sensing of electromagnetic modes and for designing low-temperature thermoelectric devices with environmentally engineered performance.

The funding from PNRR MUR project PE0000023-NQSTI, the MUR-PRIN2022 Project NEThEQS (Grant No. 2022B9P8LN), the project "Thermoelectric effects in solid-state quantum devices based on multiterminal Josephson junctions" of the bilateral agreement CNR/CONICET (Italy/Argentina) 2026-2027 and the CNR Project QTHERMONANO

[1] G. Benenti, G. Casati, K. Saito, and R. S. Whitney Phys. Rep. 694, 1 (2017).

[2] F. Antola, G. De Simoni, F. Giazotto and A. Braggio in press in NPJ Quantum Information arXiv:2508.03219

[3] G. Marchegiani, A. Braggio, and F. Giazotto, Phys. Rev. Lett. 124, 106801 (2020).

[4] S. Battisti, G. De Simoni, L. Chirolli, A. Braggio, and F. Giazotto, Phys. Rev. Res. 6, L012022 (2024).

[5] G. Germanese, F. Paolucci, G. Marchegiani, A. Braggio, and F Giazotto, Nat. Nanotechnol. 17, 1084 (2022).

[6] G.L. Ingold, and Y. V. Nazarov, In *Single Charge Tunneling: Coulomb Blockade Phenomena in Nanostructures* edited by H. Grabert and M. H. Devoret, 21–107 (Springer, 1992).