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Coherent caloritronics with hybrid superconducting quantum circuits

The Josephson effect [1] represents perhaps the prototype of macroscopic phase coherence and is at the basis of the most widespread interferometer, i.e., the superconducting quantum interference device (SQUID). Yet, in analogy to electric interference, Maki and Griffin [2] predicted in 1965 that thermal current flowing through a temperature-biased Josephson tunnel junction is a stationary periodic function of the quantum phase difference between the superconductors. In this scenario, a temperature-biased SQUID would allow heat currents to interfere thus implementing the thermal version of the electric Josephson interferometer. In this talk I shall initially report the first experimental realization of a heat interferometer [3]. We investigate heat exchange between two normal metal electrodes kept at different temperatures and tunnel-coupled to each other through a thermal *'modulator'* in the form of a DC-SQUID. Heat transport in the system is found to be phase dependent, in agreement with the original prediction. Next, I will present experimental results on the first quantum *'diffractor'* for thermal flux [4, 5]. Specifically, thermal diffraction manifests itself with a peculiar modulation of the electron temperature in a small metallic electrode nearby-contacted to a Josephson junction when sweeping the magnetic flux Φ [5]. The observed temperature dependence exhibits a clear reminiscence with a Fraunhofer-like modulation pattern, as expected fingerprint for a quantum diffraction phenomenon. Our results confirm a recent prediction of quantum heat transport and, joined with double-junction heat interferometry demonstrated in [3], exemplify the complementary proof of the existence of phase-dependent thermal currents in Josephson-coupled superconductors. I shall conclude by showing the first realization of an ultra-efficient low-temperature hybrid *'heat current rectifier'* [6, 7], thermal counterpart of the well-known electric diode. Our design is based on a tunnel junction between two different elements: a normal metal and a superconducting island. Electronic heat current asymmetry in the structure arises from large mismatch between the thermal properties of these two. We demonstrate temperature differences exceeding 60 mK between the forward and reverse thermal bias configurations [8]. This device offers a remarkably large heat rectification ratio up to about 140 and allows its prompt implementation in true solid-state thermal nanocircuits and general-purpose electronic applications requiring energy harvesting or thermal management and isolation at the nanoscale. This approach combined with well-known methods for phase-biasing superconducting circuits provides with a novel tool for mastering heat fluxes at the nanoscale.

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