# Researchers build SQUID device that demonstrates the Josephson effect

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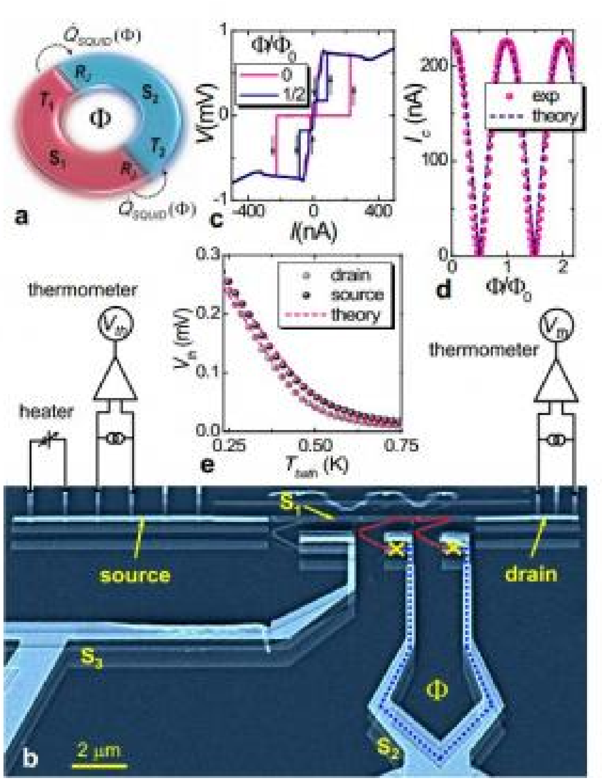


Josephson heat interferometer. Credit: arXiv:1205.3353 [cond-mat.mes-hall]

(Phys.org)—Italian nano-science researchers Francesco Giazotto and María José Martínez-Pérez have built a superconducting quantum interference device (SQUID) that confirms a theory that describes the Josephson effect, whereby the application of a magnetic field applied to such a device can cause changes in the amount of heat that flows through it. They describe their device and how it works in a paper they've published in the journal *Nature*.

Half a century ago, physicist Brian Josephson predicted that a device now known as a Josephson junction could be built. Such a device would consist of two superconductors connected together with a small amount of insulating material between them. Josephson said because of the unique properties of such a device, electrons should be able move from one of the superconductors to the other by "tunneling" through the insulator. Subsequent research proved this to be correct, and devices that incorporate it have been created to measure very small magnetic fields.

But theory also suggested that if a magnetic field were applied to the device, the amount of heat that moved between the two superconductors could be impacted. Until now, this had not been demonstrated with a real device. To create one, the researchers fashioned two Y shaped pieces of a superconductor then connected them together at their tops, with a small amount of insulating material between them. In this setup the conjoined materials formed a loop.

To test the heat transfer properties, the researchers heated one side of the loop and cooled the other, then measured the amount of heat transfer between the two as variable strength magnetic fields were applied. They found that varying the strength of the magnetic field did indeed cause more or less heat to move from one side of the SQUID to the other. They even found that in some cases, heat could be caused to move from the cold side to the hot.

The researchers explain that varying the magnetic field can cause changes in heat flow because of the quantum phase difference between the two superconductors. Changes in the strength of the magnetic field can cause peaks in the wavefunctions of the two superconductors to line up, thereby increasing heat flow, or force the reverse, resulting in decreased heat flow.

These new findings, the researchers say might help in developing better magnetometers, or perhaps even lead the way to computing devices based on thermal transistors.

**More information:** The Josephson heat interferometer, *Nature*, 492, 401–405 (20 December 2012) doi:10.1038/nature11702 (Arxiv PDF)

**Abstract**
The Josephson effect is perhaps the prototypical manifestation of macroscopic phase coherence, and forms the basis of a widely used electronic interferometer—the superconducting quantum interference device (SQUID). In 1965, Maki and Griffin predicted that the thermal current through a temperature-biased Josephson tunnel junction coupling two superconductors should be a stationary periodic function of the quantum phase difference between the superconductors: a temperature-biased SQUID should therefore allow heat currents to interfere, resulting in a thermal version of the electric Josephson interferometer. This phase-dependent mechanism of thermal transport has been the subject of much discussion but, surprisingly, has yet to be realized experimentally. Here 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 direct-current SQUID. We find that heat transport in the system is phase dependent, in agreement with the original prediction. Our Josephson heat interferometer yields magnetic-flux-dependent temperature oscillations of up to 21 millikelvin in amplitude, and provides a flux-to-temperature transfer coefficient exceeding 60 millikelvin per flux quantum at 235 millikelvin. In addition to confirming the existence of a phase-dependent thermal current unique to Josephson junctions, our results point the way towards the phase-coherent manipulation of heat in solid-state nanocircuits.

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