

Superconductors' dripping faucet

New insights on how magnetic fields trickle through stacks of high-temperature superconductors

Superconductors show many intriguing magnetic phenomena including their well-known penchant for expelling magnetic fields. This effect is the origin of popular images where superconductors hover weightlessly above a magnet. However, sufficiently strong magnetic fields can enter certain superconductors in tiny units known as magnetic flux quanta. In particular, magnetic field infiltration of so-called Josephson junctions formed by the interface of two superconducting materials is complex, and how such flux quanta tunnel across these junctions is not clearly understood.

Now, a team of researchers from RIKEN's Frontier Research System in Wako and the University of Michigan has established a theory that describes tunneling across Josephson junctions of layered high-temperature superconductors¹. Until its recent experimental demonstration, this process was considered to occur only in conventional superconductors and be suppressed in high-temperature ones, as the latter show fundamentally different properties.

A complex quantum theory developed by the researchers now explains these observations. "The tunneling of a magnetic flux quantum has a close analogy with water dripping from a tap," explains Franco Nori, who is part of the team. If a tap is not turned off tightly, water slowly leaks out and forms a droplet. As soon as a critical mass is reached, the droplet falls (Fig. 1).

A similar effect occurs in layered superconducting materials. When the externally applied electric current across

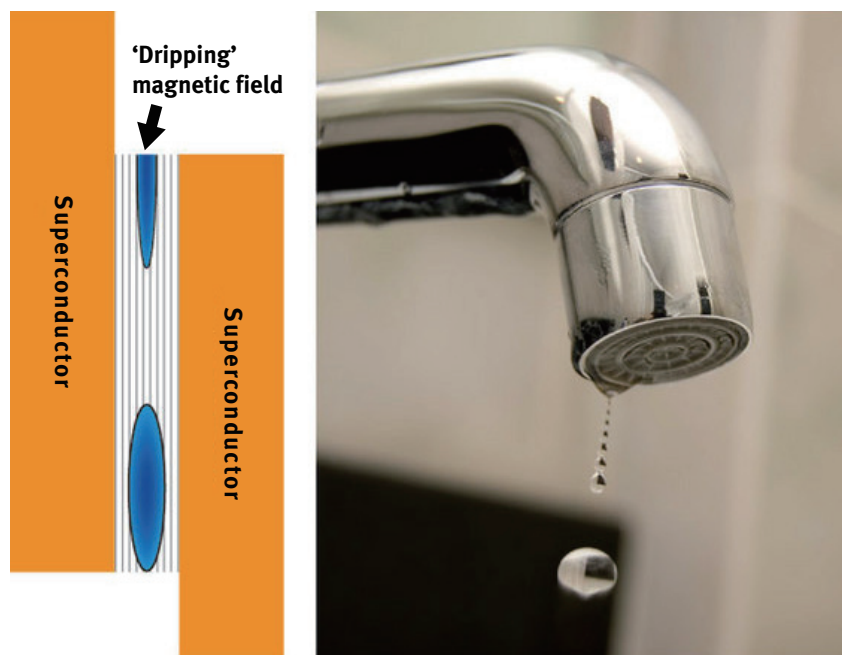


Figure 1: Dripping faucets. The schematic diagram (left) shows how quanta of magnetic flux (blue ellipses) first form and then successively slide down between stacks of Josephson junctions between two high-temperature superconductors (orange). The process is similar to a dripping water faucet (right).

the Josephson junction is far below the maximum superconducting current, the 'droplets' of magnetic flux quanta cannot pass through the junction: the tap is closed. However, sufficiently high external currents can result in the leakage of magnetic flux quanta, says Sergey Savel'ev from the RIKEN team. "As soon as a flux quantum is created, it passes through the junction, just like a falling drop of water."

According to Nori, the discovery of this novel behavior could have practical implications. "These results could open a new avenue of using such high-temperature layered superconductors for quantum electronics applications," he says. In particular, such structures could

be used as sensitive read-out devices for superconducting quantum computers.

While such applications will not be realized in the near future, the theory proposed by the researchers offers a fundamentally new view into the subtle interactions between magnetic flux quanta and the superconducting state. ■

See also animations at:

<http://dml.riken.jp/MQT/mgt.swf>

1. Savel'ev, S., Rakhmanov, A. L. & Nori, F. Quantum terahertz electrodynamic and macroscopic quantum tunneling in layered superconductors. *Physical Review Letters* **98**, 077002 (2007).