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Press Release

Superconductors Which Work by Themselves

Scientists from Tübingen, Tel Aviv and Kiel discover new possibilities in chryoelectronics

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Scientists from the University of Tübingen, working with colleagues from Tel Aviv University and the University of Kiel have proposed [1] and experimentally demonstrated [2] a new type of superconducting element – named the φ-Josephson junction. Implemented in cryogenic devices, this element will make superconducting electronic circuits work practically "by themselves" and improve functionality.

A Josephson junction is a quantum mechanical device consisting of two superconductors separated by a very thin (~2nm) barrier. In spite of the barrier, and thanks to quantum mechanics, the superconducting electrons in one superconductor "feel" their neighbors in the other superconductor and "synchronize" with them, i.e. behave coherently. This quantum mechanical coherence on a macroscopic scale allows using Josephson junctions as very precise sensors of magnetic fields e.g. for medical imaging or as basic elements for a scalable quantum computer.

In conventional Josephson junction this "synchronization" of the electron motion takes place in-phase i.e., without a phase shift. Recently it became possible to make Josephson junctions where the electrons in two superconductors are "synchronized" anti-phase, i.e., with a phase shift of π. Then one obtains what's known as the π Josephson junction. By combining the properties of conventional and π junctions the scientists from Tübingen, Tel Aviv and Kiel have proposed and demonstrated a Josephson junction with an *arbitrary* phase shift φ between electrons in two superconductors. The value of φ ($0<\varphi<\pi$) can be chosen by design. This φ Josephson junction can be used as a device which keeps a constant phase shift between two superconducting electrodes.

"One can think about the φ-junction as a battery, which provides a given phase shift φ (instead of a voltage like in the usual battery) for an attached superconducting electronic circuit. This *phase battery*, unlike the usual battery, never discharges as it causes the flow of superconducting dissipationless currents," says Prof. Roman Mints (Tel Aviv University), co-author of the idea.

“We have understood how to combine 0 and π junctions and how to prove experimentally that we have obtained a φ junction during my visit to Tel Aviv in 2011”, says Dr. Edward Goldobin – the leading scientist in this project. “Further, we discovered that this φ Josephson junction may actually be in two states – it may “synchronize” the superconductors with the phase shift being either +φ or −φ and, thus, one can use it as a bistable system or, in the future, as a quantum bit. In our experiments[2], conducted at 300mK (-273 °C), we demonstrated the existence of these two states: we can determine experimentally in which state the junction is, and we can compel the junction to switch to the desired state +φ or to −φ”. The value of the phase shift φ can be controlled by the sample parameters such as film thickness. Prior to this work, scientists thought the ground states could not be modified at will.

“The superconductor-ferromagnet-insulator-superconductor technology used to make a φ junction (composite 0-π junction) results from more than a decade of research, and to date exists in no other lab in the world. However, other groups are catching up,” says Dr. Martin Weides, who created the nano-engineered thin-film samples. “The key element of our samples is film morphology control down to the atomic scale.”

The groups involved in the collaboration are very optimistic about their results and are going to investigate this φ Josephson junction in greater detail, in particular in the quantum domain, within the Collaborative Research Center SFB/TRR-21.

Publications:

[1] E. Goldobin, D. Koelle, R. Kleiner, R.G.Mints, “Josephson junction with magnetic-field tunable ground state”, Phys. Rev. Lett. **107**, 227001 (2011).

[2] H. Sickinger, A. Lipman, M. Weides, R. G. Mints, H. Kohlstedt, D. Koelle, R. Kleiner, E. Goldobin, "Experimental evidence of a φ Josephson junction", Phys. Rev. Lett. **109**, 107002 (2012).

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