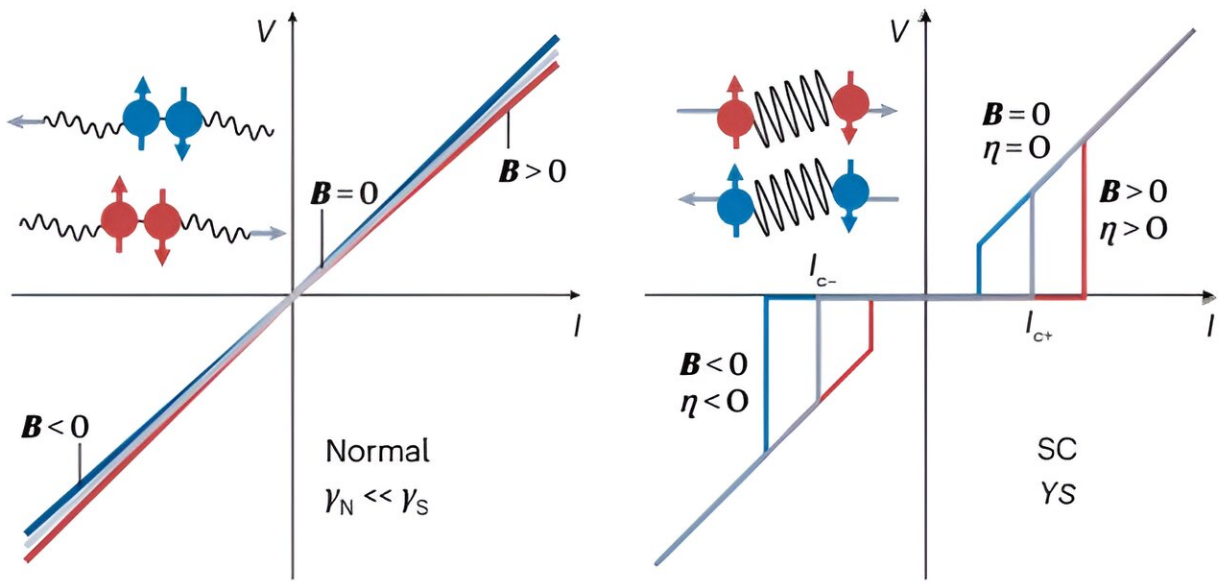
Examining the superconducting diode effect

October 2 2023



Credit: FLEET

A collaboration of FLEET researchers from the University of Wollongong and Monash University have reviewed the superconducting diode effect, one of the most fascinating phenomena recently discovered in quantum condensed-matter physics.

A superconducting diode enables dissipationless supercurrent to flow in only one direction, and provides new functionalities for superconducting circuits.

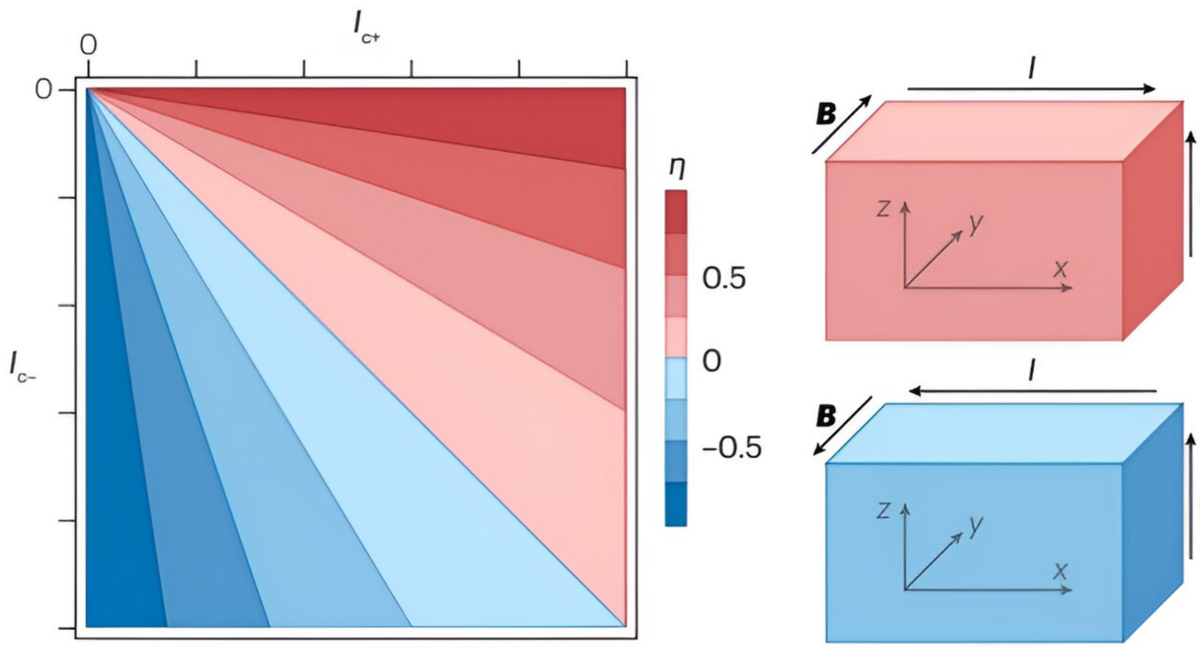
This non-dissipative circuit element is key to future ultra-low energy superconducting and semiconducting-superconducting hybrid quantum devices, with potential for quantum technologies in both classical and quantum computing.

Superconductors and diode effects

A superconductor is characterized by zero resistivity and perfect diamagnetic behavior, which leads to dissipationless transport and magnetic levitation.

"Conventional" superconductors and the underlying phenomenon of low-temperature superconductivity are explained well by microscopic Bardeen–Cooper–Schrieffer (BCS) theory proposed in 1957.

The prediction of Fulde-Ferrell-Larkin-Ovchinnikov ferromagnetic superconducting phase in 1964–65 and the discovery of "high-temperature" superconductivity in antiferromagnetic structures in 1986–87, has set the stage for the field of unconventional superconductivity wherein superconducting order can be stabilized in functional materials such as magnetic superconductors, ferroelectric superconductors, and helical or chiral topological superconductors.



Credit: FLEET

Unlike conventional semiconductors and normal conductors, electrons in superconductors constitute pairs, known as Cooper pairs, and the flow of Cooper pairs is called a supercurrent.

Recently, researchers have observed nonreciprocal supercurrent transport leading to diode effects in various superconducting materials with different geometric structures and designs, including single crystals, thin films, heterostructures, nanowires, and Josephson junctions.

The study

The FLEET research team reviewed theoretical and experimental progress in the superconducting diode effect (SDE) and provided a prospective analysis of future aspects. This study sheds light on various materials hosting SDE, device structures, theoretical models, and symmetry requirements for different physical mechanisms leading to SDE.

"Unlike the conventional semiconducting diode, the efficiency of SDE is widely tunable via extrinsic stimuli such as temperature, magnetic field, gating, device design and intrinsic quantum mechanical functionalities such as Berry phase, band topology and spin-orbit interaction," explains Dr. Muhammad Nadeem (University of Wollongong), who is a Research Fellow at FLEET.

The direction of supercurrent can be controlled either with a magnetic field or a gate electric field. "The gate-tunable diode functionalities in the field-effect superconducting structures could allow novel device applications for superconducting and semiconducting-superconducting hybrid technologies," says co-author Prof Michael Fuhrer (Monash University), who is Director of FLEET.

SDE has been observed in a wide range of superconducting structures, made from conventional superconductors, ferroelectric superconductors, twisted few-layer graphene, van der Waals heterostructures, and helical or chiral topological superconductors. It reflects the enormous potential and wide usability of superconducting diodes, which markedly diversifies the landscape of quantum technologies, says Prof Xiaolin Wang (University of Wollongong), who is a Chief Investigator of FLEET.

The superconducting diode effect was published in *Nature Reviews Physics*.

More information: Muhammad Nadeem et al, The superconducting diode effect, *Nature Reviews Physics* (2023). DOI: 10.1038/s42254-023-00632-w

Provided by ARC Centre of Excellence in Future Low-Energy Electronics Technologies

Citation: Examining the superconducting diode effect (2023, October 2) retrieved 27 April 2024 from https://phys.org/news/2023-10-superconducting-diode-effect.html

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