Physicists unveil a theory for a new kind of superconductivity

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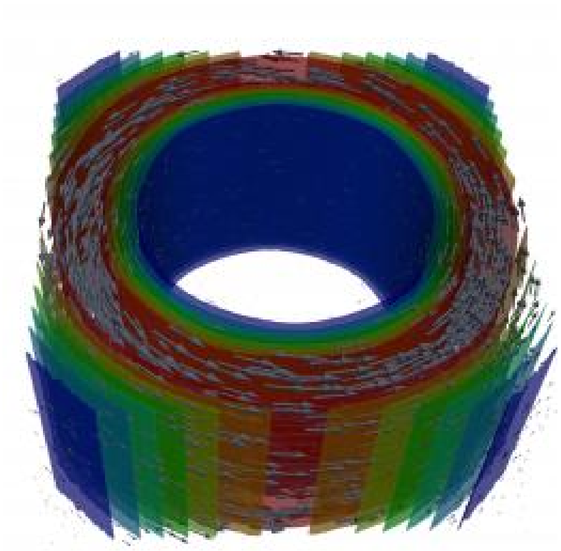


The superfow of two kinds of superconducting electrons (arrows show their velocities) as calculated on supercomputers. Graphic 2 shows superflow of the other subpopulation of electrons on the surface of a vortex cluster. Graphics courtesy of Egor Babaev.

(PhysOrg.com) -- In this 100th anniversary year of the discovery of superconductivity, physicists at the University of Massachusetts Amherst and Sweden's Royal Institute of Technology have published a fully self-consistent theory of the new kind of superconducting behavior, Type 1.5, this month in the journal *Physical Review B*.

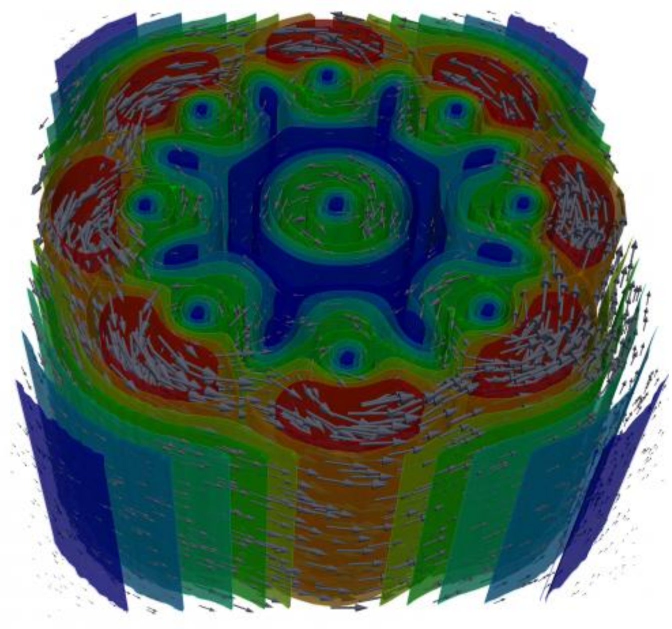
In three recent papers, the authors report on their detailed investigations to show that a Type 1.5 superconducting state is indeed possible in a class of materials called multiband superconductors.

For years, most physicists believed that superconductors must be either Type I or Type II. Type 1.5 superconductivity is the subject of intense debate because until now there was no theory to connect the physics with micro-scale properties of real materials, say Egor Babaev of UMass Amherst, currently a fellow at the technology institute in Stockholm, with Mikhail Silaev, a postdoctoral researcher there.

Their new papers now provide a theoretical framework to allow scientists to calculate conditions necessary for the appearance of Type 1.5 superconductivity, which exhibits characteristics of Types I and II previously thought to be antagonistic.

Superconductivity is a state where electric charge flows without resistance. In Type I and Type II, charge flow patterns are dramatically different. Type I, discovered in 1911, has two state-defining properties: Lack of electric resistance and the fact that it does not allow an external magnetic field to pass through it. When a magnetic field is applied to these materials, superconducting electrons produce a strong current on the surface which in turn produces a magnetic field in the opposite direction. Inside this type of superconductor, the external magnetic field and the field created by the surface flow of electrons add up to zero. That is, they cancel each other out.

Type II superconductivity was predicted to exist by a Russian theoretical physicist who said there should be superconducting materials where a complicated flow of superconducting electrons can happen deep in the interior. In Type II material, a magnetic field can gradually penetrate, carried by vortices like tiny electronic tornadoes, Babaev explains. The combined works that theoretically described Type I and II superconductivity won the Nobel Prize in 2003.



The superfow of two kinds of superconducting electrons (arrows show their velocities) as calculated on supercomputers. Graphic 1 shows the first kind of supercurrent forming vortices. Graphics courtesy of Egor Babaev

Classifying superconductors in this way turned out to be very robust: All superconducting materials discovered in the last half-century can be classified as either, Babaev says. But he believed a state must exist that does not fall into either camp: Type 1.5. By working out the theoretical bases for superconducting materials, he had predicted that in some materials, superconducting electrons could be classed as two competing types or subpopulations, one behaving like electrons in Type I material, the other behaving like electrons in a Type II material.

Babaev also said that Type 1.5 superconductors should form something like a super-regular Swiss cheese, with clusters of tightly packed vortex droplets of two kinds of electron: one type bunched together and a second type flowing on the surface of vortex clusters in a way similar to how electrons flow on the exterior of Type I superconductors. These vortex clusters are separated by "voids," with no vortices, no currents and no magnetic field.

The major objection raised by skeptics, he recalls, is that fundamentally there is only one kind of electron, so it's difficult to accept that two types of superconducting electron populations could exist with such dramatically different behaviors.

To answer this, Silaev and Babaev developed their theory to explain how real materials can give raise to Type-1.5 superconductivity, taking into account interactions at microscales. In a parallel effort, their colleagues at UMass Amherst and in Sweden including Johan Carlstrom and Julien Garaud, with Babaev, used supercomputers to perform large-scale numerical calculations modeling the behavior of superconducting electrons to better understand the structure of vortex clusters and what they look like in a Type-1.5 superconductor.

They found that under certain conditions they could describe new, additional forces at work between the Type-1.5 vortices, which can give vortex clusters very complicated structure. As more work is done on superconductivity, the team of physicists in Stockholm and at UMass Amherst say the family of multi-band superconducting materials will grow. They expect that some of the newly discovered materials will belong in Type 1.5.

"With the development of theory that works on the microscopic level, as well as our better understanding of inter-vortex interaction, we can now connect the properties of vortex clusters with the properties of electronic structure of concrete materials. This can be useful in establishing whether materials belong in the Type 1.5 superconductivity domain," says Babaev.

More information:
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