Fully-gapped pairing in the new vanadium-based Kagome superconductors

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The crystal structure of CsV₃Sb₅, with V atoms forming a Kagome lattice.
Credit: Science China Press

Due to its unique geometry, the Kagome lattice intrinsically exhibits topological electronic structures and flat bands, making it an ideal platform for studying novel emergent states. In the recently discovered Kagome superconductors AV₃Sb₅ (A = K, Rb, Cs), V atoms form an ideal Kagome lattice. As a rare realization of superconductivity on the
ideal Kagome lattice, and because superconductivity emerges in the presence of topological surface states and an unusual charge order, these material have drawn immense interest from the physics community. In addition to elucidating the nature of the unusual charge order and its interplay with superconductivity, the superconducting pairing symmetry and pairing mechanism are key issues that need to be addressed.

An article by Prof. Huiqiu Yuan and Prof. Yu Song at the Center for Correlated Matter of Zhejiang University, recently published in *SCIENCE CHINA Physics, Mechanics & Astronomy* as an Editor's Focus, provides key experimental results for understanding the pairing symmetry and the pairing mechanism in this family of Kagome superconductors. Using a technique based on the tunneling diode oscillator to precisely measure the change in the magnetic penetration depth down to low temperatures, the research team offers the first experimental finding of a nodeless superconducting state in CsV₃Sb₅, with its superfluid density well-captured by a two-gap s-wave model.

The superconducting pairing symmetry is important for elucidating the pairing mechanism, with superconducting gaps under different pairing symmetries exhibiting differing features. For example, conventional superconductors typically exhibit s-wave pairing, with the superconducting order parameter being nodeless in momentum space (nodes refer to positions in the momentum space where the superconducting order parameter becomes zero), leading to the low-temperature magnetic penetration depth and electronic specific heat evolving exponentially with temperature. On the other hand, for p-wave or d-wave superconductors, the superconducting gaps respectively display point nodes or line nodes, resulting in magnetic penetration depth and electronic specific heat with power-law temperature dependences.
Temperature dependence of the magnetic penetration depth in CsV$_3$Sb$_5$. Temperature dependence for nodal superconductors fails to describe the data, while that for nodeless superconductivity agrees well with the data. Credit: Science China Press

A device based on the tunneling diode oscillator allows for highly precise measurements of the magnetic penetration depth change at very low temperatures, making it an important method for studying the structure of the superconducting order parameter, which can then be
utilized to obtain information on the pairing symmetry.

In this work, researchers used the technique based on the tunneling diode oscillator, and measured the magnetic penetration depth down to 0.07 K. From the experimental results, it was found that the magnetic penetration depth becomes nearly constant below 0.2 K, characteristic of an exponential behavior at low temperatures, indicating that the superconducting gap contains no nodes. Through further analysis, it was shown that temperature dependence of the superfluid density can be captured by a two-gap s-wave model, while nodal superconducting pairing states (such as simple p-wave and d-wave) fail to match the experimental data. To further confirm these results, the research team studied multiple samples from different research groups, carried out analysis of the specific heat, and found all the experimental results consistently point to nodeless superconductivity in CsV$_3$Sb$_5$. It should be pointed out that while the present study reveals two-gap s-wave superconductivity in CsV$_3$Sb$_5$, whether the superconducting order parameter exhibits a sign-change between different Fermi surfaces (s± or s++), awaits clarification in future studies.

This study on the Kagome superconductor CsV$_3$Sb$_5$ provides a key piece of experimental evidence for nailing down its superconducting pairing symmetry, lays the groundwork for understanding its pairing mechanism as well as how the unusual charge order may come into play, and strongly constrains theoretical models for these Kagome superconductors.
Normalized superfluid density of CsV$_3$Sb$_5$, as a function of the reduced temperature $T/T_c$. The two-gap s-wave model agrees well with experimental data. Credit: Science China Press

This work is a collaboration between researchers at Zhejiang University, the University of Science and Technology of China, and the University of California, Santa Barbara. The measurements of magnetic penetration and specific heat were carried out in the Center for Correlated Matter at Zhejiang University. High-quality single crystals were provided by Prof. Xianhui Chen's group at the University of Science and Technology of China and Prof. Stephen Wilson's group at the University of California, Santa Barbara.

Provided by Science China Press


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