Study unveils contributions to superconductivity in the vortex lattice structure of 2H-$NbSe_2$

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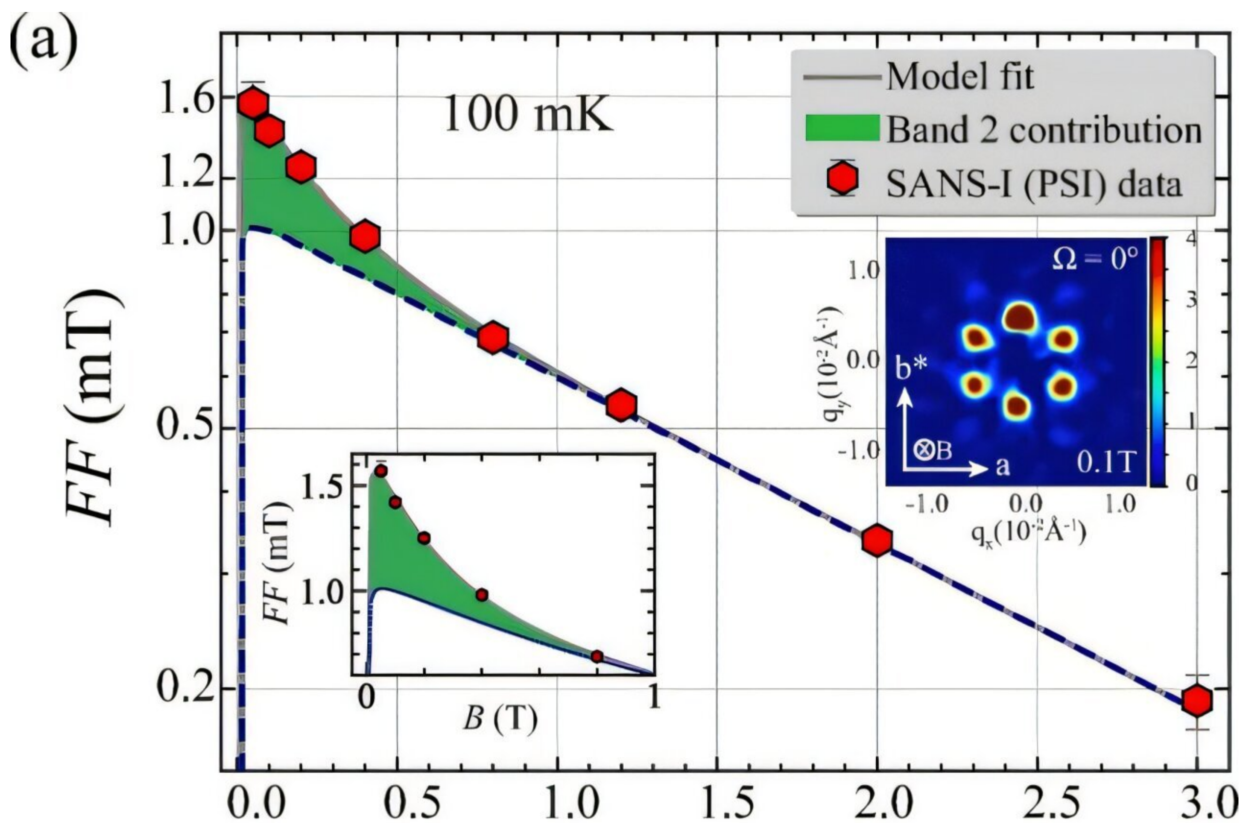


The field dependence of the first order vortex lattice form factor, FF, at (a) 100 mK and (b) 1.5 K. Credit: *Physical Review Letters* (2025). DOI: 10.1103/PhysRevLett.134.116001

Superconductivity is a quantum property of materials entailing an electrical resistance of zero at very low temperatures. In some materials, multiple electronic bands are known to contribute to the emergence of superconductivity, leading to multiple superconducting energy gaps. This phenomenon is referred to as multiband superconductivity.

Researchers at Lund University in Sweden, Institut Laue Langevin in France and other institutes in Europe recently carried out a study aimed at better understanding the multiband superconductivity emerging in the transition metal dichalcogenide 2H-$NbSe_2$, which exhibits a vortex lattice when exposed to a magnetic field.

Their findings, published in *Physical Review Letters*, unveil two key contributions to the superconducting state observed in this material.

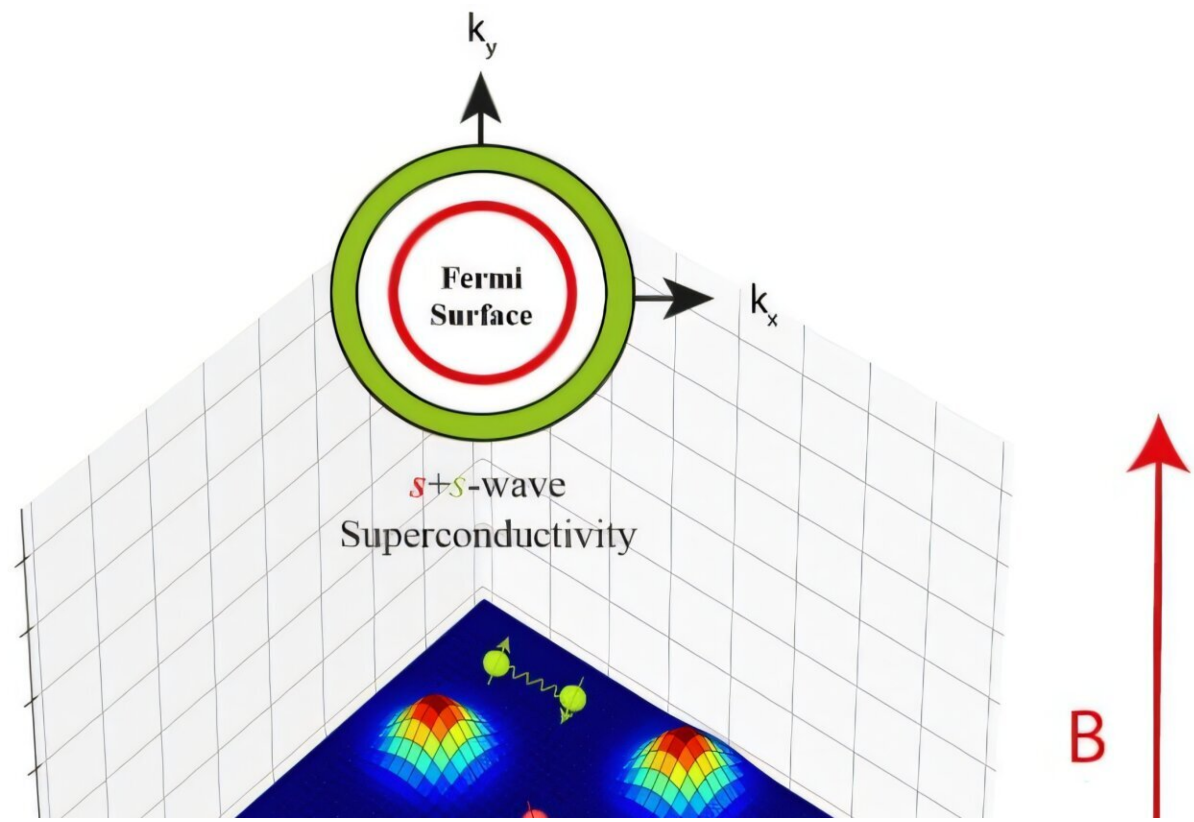
"Our recent study was motivated by the longstanding mystery of how the existence of multiple electronic bands influence superconductivity—materials conducting electricity without resistance," Dr. Ahmed Alshemi, Postdoc fellow at Lund University and the first author of the paper, told Phys.org.

"Specifically, we were inspired by previous theoretical predictions and experimental indications that superconductors like 2H-$NbSe_2$ host multiple bands of electrons, each contributing differently to superconductivity."

The main objective of the recent study by Alshemi and his colleagues was to delineate and characterize the role of multiple electron bands in the emergence of superconductivity. They hoped that this would in turn allow them to determine how these bands shape the superconducting behavior of materials, especially in the presence of a magnetic field.

"In our experiments, we used Small-Angle Neutron Scattering (SANS), a powerful bulk-sensitive probe that allows us to observe the arrangement of a quantized magnetic vortices inside superconductors," explained Alshemi.

"When we applied a magnetic field to the superconducting material 2H-$NbSe_2$, it created lines of magnetic flux—called a 'vortex lattice'—where magnetic flux penetrates the material. By scattering neutrons off this vortex lattice, we could precisely measure changes in its structure and how it evolves with temperature and magnetic field strength."



Schematic illustration of two-band superconductivity in 2H-$NbSe_2$, highlighting the coexistence of two distinct superconducting gaps, each associated with its own characteristic length scale Cooper pair size. Credit: Ahmed Alshemi, Postdoctoral Fellow—Lund University.

The measurements collected by this team of researchers offered valuable information about how each band of electrons in 2H-$NbSe_2$ contributes to the emergence of superconductivity. Moreover, they shed light on how the contribution of the electronic bands changed when the material was subjected to magnetic fields of varying intensity.

"The most notable achievement of our study is the precise experimental demonstration that 2H-$NbSe_2$ exhibits two distinct superconducting gaps, meaning two separate electronic bands that are simultaneously superconducting with different properties," said Alshemi.

"Remarkably, we discovered that under moderate magnetic fields (around 0.8 Tesla), the superconductivity in one of these bands begins to significantly diminish, even though the material as a whole remains superconducting.

"Our work on 2H-$NbSe_2$ also helps refine theoretical models of superconductivity and provides insights into how interband coupling affects superconducting properties, in particular leading to the superconductivity varying over multiple length scales."

Notably, the results of the recent study by Alshemi and his colleagues challenge some previous theoretical assumptions, while also offering new insight into the fundamental properties of multiband superconductivity in 2H-$NbSe_2$.

In the future, this insight could inform the search for new superconducting materials that can be specifically tailored to support the functioning of various advanced technologies, including ultra-efficient power systems and quantum computers.

"Looking ahead, we plan to extend this research by examining how different external stimuli, such as varying the direction of applied magnetic fields, influence the behavior of multiband superconductors like $NbSe_2$," added Alshemi.

"We also aim to explore other intriguing physical phenomena speculated to exist in this material, including orbital Fulde-Ferrell-Larkin-Ovchinnikov (orbital FFLO) states, charge density waves (CDW), and pair density waves (PDW), using advanced neutron scattering techniques.

"These studies will contribute significantly toward a universal understanding of how these superconductors function, ultimately enabling further advancements in sustainable and innovative superconducting technologies."

More information: A. Alshemi et al, Two Characteristic Contributions to the Superconducting State of 2H−$NbSe_2$, *Physical Review Letters* (2025). DOI: 10.1103/PhysRevLett.134.116001.