

INVITATION

Department of Condensed Matter Physics

Is pleased to invite you to the lecture

Ising superconductivity in bulk crystals based on NbSe₂

by

prof. Peter Samuely

*Centre of Low Temperature Physics, Institute of Experimental Physics,
Slovak Academy of Sciences and P. J. Šafárik University, Košice, Slovakia*

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Superconductors are quantum materials exhibiting zero dc resistance and perfect diamagnetism (total magnetic flux expulsion or the Meissner effect). This behavior arises because below the superconducting transition temperature T_c , conduction electrons pair up into Cooper pairs. These Cooper pairs form a coherent quantum condensate described by a single macroscopic wave function.

In superconductors, external magnetic field can break the Cooper pairs via two main mechanisms. The orbital pair breaking occurs when magnetic field acts on the Cooper pair's electrons' charge. The Cooper pair breaks when the induced Lorentz force exceeds its binding force. In two-dimensional (2D) superconductors, however, this mechanism is absent for the in-plane orientation of magnetic field. Still, in spin-singlet superconductors, the second mechanism – spin pair breaking – breaks the Cooper pair by aligning both its antiparallel spins with the magnetic field via the Zeeman effect. The minimum field necessary for spin pair breaking is known as the Pauli (or Clogston–Chandrasekhar) paramagnetic limit B_P . For conventional superconductors with critical temperature T_c , the critical magnetic field cannot exceed $B_P = 1.86 \text{ T/K} \times T_c$.

Spin-valley locking allowing for in-plane upper critical magnetic fields vastly surpassing Pauli limit was first demonstrated in fully 2D monolayers like of NbSe₂ [1] with large spin-orbit coupling and broken inversion symmetry. Surprisingly, this Ising superconductivity can be present in layered bulk materials, too. We have clarified the underlying microscopic mechanism of Ising superconductivity in bulk, based on a reduced interlayer coupling between superconducting layers due to intercalation by insulating layers and restricted inversion symmetry in misfit compounds of $(\text{LaSe})_{1.14}(\text{NbSe}_2)_m$ [2,3]. Here, we also show that in some transition metal dichalcogenide polytypes Pauli paramagnetic limit is violated even without intercalation. By the specific heat measurements up to 35 T we show that that in the pristine non-centrosymmetric bulk $4H_a$ -NbSe₂ polytype the in-plane upper critical magnetic field



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exceeds the Pauli limit three times. *Ab initio* band structure calculations based on experimentally determined crystal structure confirm the spin-valley locking. The theoretical model provides the microscopic mechanism of the Ising protection based solely on broken inversion symmetry [4].

- [1] X. Xi et al., Nat. Phys. **12**, 139 (2016).
- [2] P. Samuely et al., Phys. Rev. B **104**, 224507 (2021).
- [3] T. Samuely et al., Phys. Rev. B **108**, L220501 (2023).
- [4] D. Volavka et al., arXiv:2501.08867

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