

CONDENSED MATTER SEMINAR

Thursday 3 November at 14.30

“Visualizing Spin-singlet and Spin-triplet Pair Density Waves in Transition Metal Dichalcogenides”

J.C. Séamus Davis

Clarendon Laboratory, University of Oxford, UK

Dept. of Physics, University College Cork, IE

Dept. of Physics, Cornell University, USA

A superconducting quantum crystal consisting of electron-pairs whose density modulates periodically at wavevector Q_P , is now referred to as a Pair Density Wave (PDW) state. Although originally mooted in 1964, such states had never been observed directly in any material. To search for a PDW state in cuprate superconductors we developed atomic resolution Scanned Josephson Tunneling Microscopy (SJTM). This new form of quantum microscopy can image both the single-electron quasiparticles and, in a different mode, the quantum condensate of electron-pairs. By using SJTM we detected the cuprate PDW state¹ exhibiting periodic modulations of the electron-pair density¹ at wavevector Q_P , the quasiparticle response to the electron-pair crystal², and of the associated electron-pair binding energy^{2,3}. To search for such states in the conventional s-wave superconductor NbSe₂, we developed high-speed atomic-resolution SJTM. We detected three PDWs, each whose electron-pair density and energy-gap modulate spatially at the wavevectors $Q_{(i=1,2,3)}$ of the preexisting charge density wave (CDW) state, but with a global $\delta\Phi \cong \pm 2\pi/3$ phase difference between the PDW and CDW states⁴. Most recently, in the topological superconductor UTe₂ we visualize the pairing energy-gap with μV -scale energy-resolution made possible by our superconductive SJTM tips. In UTe₂ we discovered three PDWs at incommensurate wavevectors $P_{(i=1,2,3)}$ that are indistinguishable from the wavevectors $Q_{(i=1,2,3)}$ of the prevenient CDW. Concurrent visualization of the PDWs and the CDWs reveals that every $P_{(i=1,2,3)}$ pair is registered to each other spatially, but with a relative phase $\delta\varphi \approx \pi$. From these observations, and given UTe₂ as a spin-triplet superconductor, this state should be a spin-triplet PDW. While such states do exist in superfluid ³He, for superconductors they are unprecedented.

References

- [1] Nature 532, 343 (2016)
- [2] Science 364, 976 (2019)
- [3] Nature 580, 6570 (2020)
- [4] Science 372, 1447 (2021)
- [5] arXiv:2209.10859 (2022)

Simpkins Lee room, Beecroft Building