LPS ORSAY | université PARIS-SACLAY | האוניברסיטה העברית בירושלים THE HEBREW UNIVERSITY OF JERUSALEM | מכון רקח לפיסיקה The Racah Institute of Physics

PhD Vacancy: 2D Superconducting Spintronics

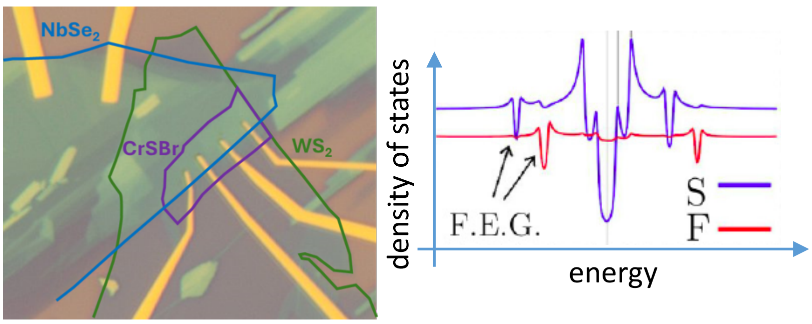
Superconducting spintronics (and spin caloritronics) is an emergent field at the intersection of spin(-orbit) physics and superconductivity, traditionally studied in metals. Van der Waals materials, which can be exfoliated down to the monolayer limit, and cover the whole gamut of electronic properties, open new possibilities for the study of superconducting devices and unconventional superconductivity. Our collaboration has shown that semiconducting transition metal dichalcogenides (TMDs) are excellent tunnel barriers, which we have used, *inter alia*, to obtain spectral evidence for a possible equal-spin triplet superconducting (ESTS) state in the TMD $NbSe_2$. Recently, magnetism has been demonstrated in in few-layer 2D materials (CrSBr, VX_2…). Such magnetic properties were used for efficient spin-filtering in devices with magnetic insulators such as CrI_3.

We offer two possible projects related to the interplay of spins and superconductivity. **The first project** considers few-layer semiconducting vdW flakes acting as spin-filter tunnel-barriers in contact with conventional superconductors (e.g. Al) with low spin-orbit coupling. Such tunnel junctions would enable novel detection schemes for spin-dependent energy transport (spin caloritronics) in superconductors, the investigation of the effect of quasiparticle spin imbalance on the superconducting order parameter. Ultimately, we seek for the quasiparticle 'spin mode' - the last quasiparticle eigenmode to be pinned down, excited e.g. by different chemical potentials for spins up and down.

The 2nd project considers the interface between vdW ferromagnets and TMD superconductors. In such materials which have Ising spin-orbit coupling at the ultrathin limit, vdW ferromagnetic semiconductors are expected to have similar effects to in-plane magnetic fields: this includes inducing ESTS and other unconventional states in the superconducting condensate. vdW materials bring new flexibility to these questions, e.g. the superconductor-ferromagnetic semiconductor coupling, as well as all proximity effects, have been predicted to be strongly gate-tunable.

The student will study spin-filtering and proximity effects, and unconventional superconductivity in novel superconducting spintronics devices based on vdW ferromagnetic semiconductors and insulators. Candidates should have a strong background in quantum mechanics and condensed matter physics, and solid laboratory experience. Familiarity with nano-fabrication, vdW materials and low-noise low-temperature electronic transport would be a plus.

This co-supervised project is part of a **long-standing collaboration between the Université Paris-Saclay (Charis Quay *et al.)* and the Hebrew University (Hadar Steinberg *et al.*)**. The successful candidate will spend most of their time at the Laboratoire de Physique de Solides, with occasional visits to the Hebrew University in Jerusalem (subject to international travel regulations).



(left) Optical image of a typical TMD superconductor-ferromagnet tunnel device made at the Racah Institute by the Steinberg lab. **(right)** Expected spectral features in ferromagnetic semiconductor-superconductor TMD heterostructures, indicative of equal-spin triplet superconductivity (cf. references).

References

H Steinberg *et al.*, 'Transition Metal Dichalcogenide Superconductor Tunneling Devices: A Review', *Journal of Superconductivity and Novel Magnetism* **38**, 103 (2025).

M Kuzmanović *et al.*, 'Evidence for spin-dependent energy transport in a superconductor', *Nat. Commun.* **11**, 4336 (2020).

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