INSTITUT NÉEL Grenoble

Topic for Master 2 internship – Academic year 2025-2026

Quantum electronic waves crossing 2D junctions

General Scope. Charge density waves are macroscopic quantum states consisting in a coherent spatial modulation of the charge in a crystal. Their role has been pivotal in solid state physics, as they came along with a theory, elaborated by Frölich in his seminal 1954 paper (*Proc. Roy. Soc. London A, 223, p. 296-305*), that later turned out to be a powerful approach to understand superfluids such as superconducting phases. Much like the latter, a charge density wave living in a material (let's label it "A") must leak out in a second material ("B"), not naturally hosting a charge density wave, but placed in contact with material A. Indeed, a quantum state cannot abruptly vanish from one material to another. This proximity effect is the alter ago of the one that is exploited in superconducting conducting circuits to implement the famous Josephson junction and design qubits accordingly. The **charge density wave proximity effect**, however, has not yet been demonstrated so far. The starting point of the internship, and of the Ph.D. thesis that should follow (funding secured), is that a certain class of **two-dimensional (2D) crystals** is ideally suited to demonstrate and study it.

Research topic and facilities available. The internship will focus on three-atom-thick crystals, transition metal dichalcogenides, some that host charge density waves, some that do not, and which can form lateral junctions (see figure). They represent an ideal platform to probe the proximity effect. The internship will include efforts to prepare the materials and identify signatures of charge density waves, including those generated by proximity in the B-type material. For that purpose, we will seek optical evidences of (ii) collective excitations that are characteristic of charge density waves (so-called amplitude and phase modes), (ii) of softening of phonons versus temperature as the charge density waves appear, and (iii) directly measure an order parameter of the charge density waves as function of temperature, via diffraction experiments.

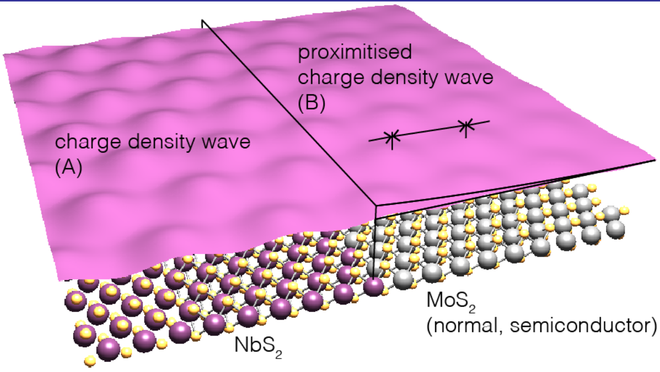

***Figure:** 2D transition metal dichalcogenides NbS_2 (type-A material) and MoS_2 (type-B) forming a lateral junction; by proximity effect the charge density of the former leaks out into the latter, over a certain distance before vanishing. The period and phase of the quantum wave might change upon crossing the boundary.*

Possible collaboration and networking. The project is a national collaboration between four groups located in Grenoble and Saclay. Their expertise includes preparation of the materials, cryogenic scanning probe microscopy, optical spectroscopy and diffraction, as well as ab initio calculations. Frequent interactions are planned during the internship and the Ph.D. thesis.

Possible extension towards a Ph.D. thesis: Funding secured for a three-years grant.

Required skills: Solid background in solid state physics, and special taste for experimental physics.

Starting date: February to April 2026.

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