Exploring 2D landscapes with metal chalcogenides

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Transition metal chalcogenides are well-known layered materials that have been studied for more than 50 years. Among them, different phases can be found ranging from superconductors to insulators and from ferromagnets to antiferromagnets. Even though, there are still several open questions and new physical phenomena that emerge in these systems such as superconductivity or spin liquid behaviour, specially when they are thinned down to the two-dimensional (2D) limit.

In this work, the synthesis and characterization of transition metal chalcogenides (TMCs) is summarized. As well, the obtention and manipulation of 2D materials will be briefly discussed.

First, transport measurements in thin layers of 2H-TaS$_2$ are presented. Interestingly, it is observed a superconducting temperature (T$_c$) enhancement by decreasing the number of atomic layers (from 0.6 K in the bulk sample to ca. 2K in a ~3 nm layer, as seen in Figure 1) [1]. This behaviour is the opposite of the one reported in other 2D superconductors, as NbSe$_2$ [2]. From the theoretical point of view, the interplay between charge density waves (CDW) and superconductivity in these systems is still under debate [1, 3].

Then, 1T-TaS$_2$ is explored as a quantum spin liquid (QSL) [4, 5]. A QSL ground state is an intriguing possibility for a magnetic spin system, however identifying specific QSL states provides a significant experimental challenge. Previous studies of spin liquid candidates have generally assumed a single topological phase without exploring the possibility of crossover between different topological phases in a QSL. Here, by combining temperature dependent muon spin relaxation and specific heat measurements, the experimental data can be described as a sequence of three distinct QSL phases in 1T-TaS$_2$, whose critical exponents are compared with those predicted by theory. The intermediate phase between 25 K and 110 K indicates a $Z_2$-linear spin liquid, whereas at lower and higher temperatures $Z_2$-gapless spin liquids are found. Such thermal transitions between distinct quantum phases provide a new perspective on spin liquid behaviour.

Finally, we will discuss the fabrication of hybrid heterostructures formed by molecular 2D layers (based on 2D molecular magnets [6]) and inorganic 2D materials (such as TaS$_2$ or NbSe$_2$) and its transport characteristics in vertical and horizontal devices (Figure 1, right).

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Figure 1.- (Left) Variation of T$_c$ as a function of the thickness of the 2H-TaS$_2$ flakes. Devices exhibiting a non-zero residual resistance are plotted in red. (Right) Vertical junction formed by two flakes of NbSe$_2$ (yellow and pink) that sandwich a coordination polymer. The whole device is encapsulated in h-BN.