Giant orbital Zeeman effects at the interface of graphene and Fe_3GeTe_2

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Van der Waals (vdW) heterostructures allow the engineering of electronic and magnetic properties by the stacking different two-dimensional vdW materials. For example, orbital hybridisation and charge transfer at a vdW interface may result in electric fields across the interface that give rise to Rashba spin-orbit coupling. In magnetic vdW heterostructures, this in turn can drive the Dzyaloshinskii-Moriya interaction which leads to a canting of local magnetic moments at the vdW interface and may thus stabilize novel 2D magnetic phases. While such emergent magnetic "interphases" offer a promising platform for spin-based electronics, direct spectroscopic evidence for them is still lacking. We report Zeeman effects with Landé *g*-factors up to ≈230 at the interface of graphene and the vdW ferromagnet Fe_3GeTe_2 [1]. They arise from a magnetic interphase in which local-moment canting and itinerant orbital moments generated by the non-trivial band topology of Fe_3GeTe_2 conspire to cause a giant asymmetric level splitting when a magnetic field is applied. Exploiting the inelastic phonon gap of graphene [2], we can directly access the buried vdW interface to the Fe_3GeTe_2 by scanning tunneling spectroscopy (STM). Systematically analyzing the Faraday-like screening of the tip electric field by the graphene, we demonstrate the tunability of the constitutional interface dipole, as well as the Zeeman effect, by tip gating. Our findings are supported by density functional theory and electrostatic modelling.

References

[1] T. Wichmann *et al.*, arXiv:2510.26662 (2025)
[2] Zhang *et al.*, Nat. Phys. 4, 627 (2008)

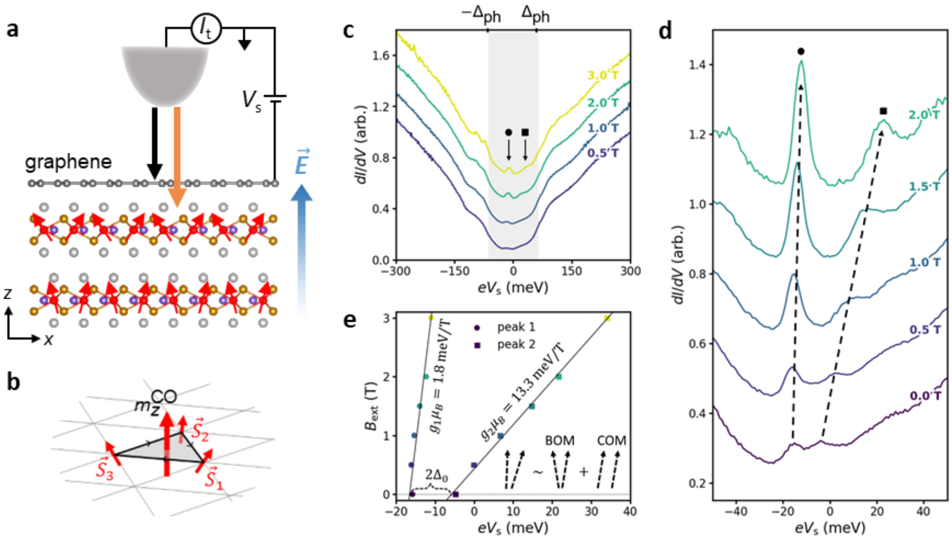

Fig 1. (a) Schematic side view of the sample and STM setup. (b) Schematic of non-collinear spin arrangement in the Fe sublattice, where a canting of localized spins results in a conical spin structure. (c) Tunneling spectra for different out-of-plane B fields. For clarity, curves are offset. In the inelastic gap of graphene (shaded region), two peaks emerge with increasing B field, as shown in detail in panel (d). (e) Peak positions as function of applied B field, corresponding to *g*-factors of ≈30 and ≈230, respectively.