Entanglement-based order parameter for Kondo phase transitions in graphene quantum dots

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Quantum dots in bilayer graphene (see Fig.1) have showcased experimental signatures of a SU(4) Kondo breaking and spin-1 underscreened Kondo singlet formation [1]. To characterise strongly-correlated many-body effects in graphene quantum dots, we apply a recently proposed entanglement witness for quantum impurity systems: the purity of the impurity [2]. With our novel method, we identify phase transitions where Kondo effects compete with dot valley-valley and spin-spin singlets (see Fig.2). Our results demonstrate how entanglement-based order parameters capture short- and long-ranged correlations. Thus, we advance a promising experimental prospect; the measurement of these entanglement-based observables in graphene quantum dots and other mesoscopic systems.

References

[1] A. Kurzmann et al., Nat. Commun. 12, 6004 (2021).
[2] L. Stocker et al., arXiv:2201.07461 (2022).

Figures

Figure 1: Left: Scanning electron micrograph of the experimental device from [1]. Right: The effective Hamiltonian of the graphene dot system [1] couples the closed quantum dot (QD) Hamiltonian (yellow) to two infinite leads (grey).

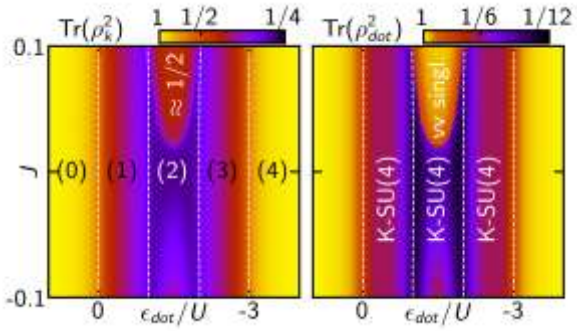

Figure 2: Characterisation of the strongly-correlated effects establishing in a graphene dot system. We show the purity of a single dot valley (left) and the whole quantum dot (right) as a function of the dot on-site energy ϵ_{dot} and the valley-valley magnetic interaction J, where U is the intra-dot Coulomb repulsion energy. Dashed lines separate the different Fock blocks of the closed system. The indicated value is the dot occupation (n_{dot}). The purity of a system with density matrix ρ is given by $\mathrm{Tr}(\rho^2)$. For an isolated system, the purity is 1, for a subsystem-environment singlet is 1/2, and for an impurity-environment Kondo SU(4) it is 1/6 for n_{dot}=2 and ¼ for n_{dot} =1,3.