Diodic transport in graphene moiré systems

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The discovery of magic-angle graphene moiré systems has unlocked a wide variety of intriguing emergent phenomena. Inside the nearly dispersionless band structures, the combination of isospin symmetry breaking and strong correlation gives rise to an intricate landscape of emergent quantum phases, such as superconductivity and orbital ferromagnetism. The subtle interplay between the flat moiré band and strong Coulomb interaction provides an ideal venue for exploring novel electronic orders. For instance, a recent experiment reported a prominent zero-field superconducting diode effect in twisted trilayer graphene, revealing a new type of symmetry breaking order [1]. The nonreciprocal superconducting transport behavior, evidenced by the direction-dependence in the critical current points towards spontaneous breaking of both parity and time-reversal symmetry in the superconducting state, which motivates our search for a parity-breaking electronic order in metallic states of graphene-based moiré systems.

Such an electronic order can be identified based on highly nonreciprocal, diode-like current-voltage characteristics throughout the moiré flatband, which exhibits a one-fold or three-fold symmetric angular dependence as a function of the azimuth direction of current flow (Figure 1). We show that this parity-breaking order can be described as a valley-polarized loop current state, which is highly tunable with magnetic field, current flow, and field-effect doping. Our findings point towards the universal presence of valley-polarized isospin order and rotational symmetry breaking across the moiré flatband, with important implications for understanding intertwined and competing orders, such as ferromagnetism, nematicity, and superconductivity, in graphene-based moiré systems.

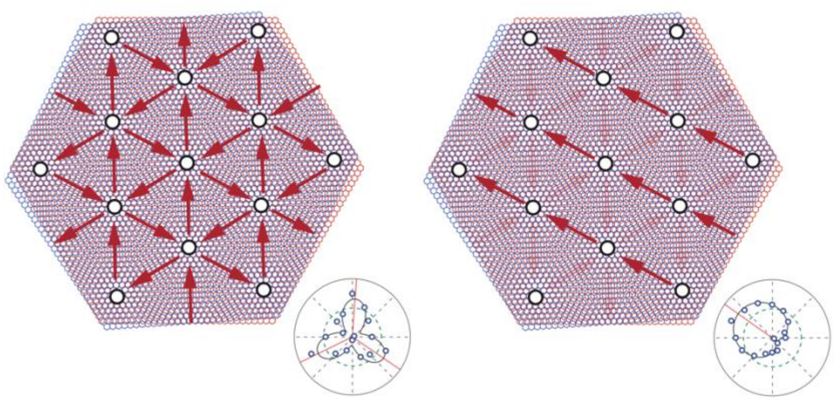

Figure 1, schematic diagram of the diodic order in graphene moiré systems with simultaneous parity and time-reversal symmetry breaking. Depending on experimental parameters, the three-fold rotational symmetry is either preserved (left panel) or broken (right panel).

[1] Lin, J-X. et al. Zero-field superconducting diode effect in small-twist-angle trilayer graphene. Nature Physics, in press (2022).

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