Spectrum engineering with spin-orbit states via magneto-tunneling

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Spin–orbit coupling (SOC) is a well-known relativistic ingredient behind electric spin control in solids. Most discussions focus on odd-in-momentum terms - such as Rashba and Dresselhaus interactions - which define momentum-space spin–orbit fields and enable electrically driven spin rotations. Less widely appreciated is that the same relativistic origin also produces even-in-momentum SOC contributions that are intrinsically magnetic: they are linear in the applied magnetic field and act as "kinetic" Zeeman corrections. In bulk materials these terms underpin the renormalization of the electron/hole g-factor away from the bare value g=2; in nanostructures they can become strongly enhanced and highly tunable.

Here we combine analytical modeling and numerical simulations of hole spins in nanostructures to characterize these even-in-momentum SOC. Beyond a momentum-space g-renormalization, we identify a magneto-tunneling contribution that appears whenever states hybridize through tunnelling [1]. In coupled quantum dots, this generates large, gate-tunable and anisotropic corrections to the effective g-tensor that peak near charge transitions and reshape the spectrum in sparse dot arrays. We show how tuning tunnel couplings and dot chemical potentials can be used to engineer optimal sweet spot operating points where spin qubits.

Finally, we discuss implications for superconductor–semiconductor hybrids, where magneto-tunneling renormalizes the field response of subgap impurity states (Yu–Shiba–Rusinov) [2, 3, 4], leading to measurable asymmetries in the spectrum. Our results affect both electron and hole-based quantum devices and design rules for exploiting even-power SOC as a generic, gate-controllable resource across quantum-dot and hybrid superconducting platforms.

References

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Figures

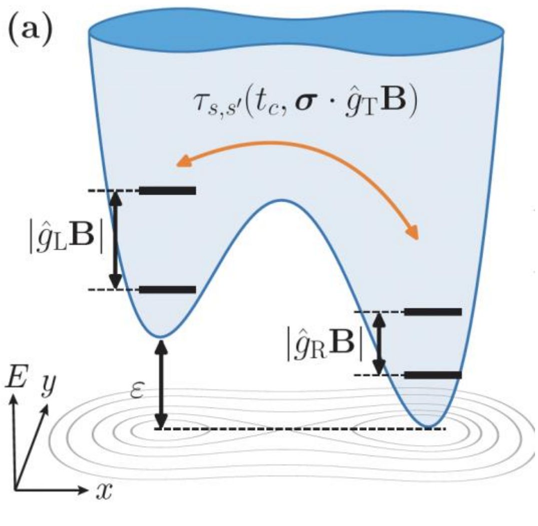

Figure 1: (a) Schematics of a double quantum dot with a spin that acquires corrections to the g-factors through kinetic (tunnelling) events due to even-powered SOC terms.