# Spin-Charge Conversion in Graphene with Random Spin-Orbit Coupling and Magnetic Impurities

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Abstract

The enhancement of spin-orbit coupling (SOC) in van der Waals materials via proximity effects and adatom engineering is responsible for a plethora of rich coupled spin-charge phenomena, ranging from “anisotropic spin precession” (ASP) [1] which directly couples the electric current and the spin density, to skew-scattering induced spin Hall effect with large spin Hall angle [2,3,4].
Fueled by an increasing number of experimental reports [5], a large body of theoretical works has been devoted to the study of spin dynamics in disordered graphene, particularly on graphene-based heterostructures with spatially-uniform proximity-induced SOC (see e.g., [6,7]). However, much less attention has been paid to the role of random SOC sources, and a unified description of spin dynamics and spin-charge conversion effects that considers spatially uniform and randomly fluctuating extrinsic spin-orbit interactions on equal footing is still missing.
Here, we present a quantum theory of coupled spin-charge transport in graphene heterostructures with spin-dependent scattering potentials, based on the Liouville and Kubo–Streda formalisms.
The first application of our microscopic theory is to graphene with spatially inhomogeneous Rashba and intrinsic-type SOC fields. In this system, we unveil a novel direct coupling between charge and spin currents activated by random Rashba-like SOC that dominates over semiclassical skew scattering-induced spin Hall effect. This new type of extrinsic spin Hall effect is mediated by an anomalous spin-orbit scattering mechanism, which involves virtual transitions between the conduction and valance bands. This mechanism is surprisingly robust in the weak impurity potential regime and is already present in first Born approximation.
As a second application, we investigate the impact of magnetic impurities in twisted bilayer graphene/transition metal dichalcogenides heterostructures. We show that the rich current-induced spin response of the system, due to the twist between the two layers, is strongly enhanced by local paramagnetic defects ubiquitous in pristine graphene sheets [8]. Such enhancement has its origins in skew scattering reinforced by the magnetic moments sitting at resonant scatterers, such as vacancies or adatoms.

References

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