**Abstract of the doctoral thesis**

# Charge and Spin Transport in Low-Dimensional Systems

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## Abstract

This dissertation examines charge and spin transport in low-dimensional electronic systems with spatially varying spin–orbit coupling and exchange interactions. Particular attention is given to the influence of the spatial distribution of these interactions on electron propagation, scattering, and transport relaxation. The analysis combines results from four coauthored publications concerning two-dimensional electron gases and surface states of three-dimensional topological insulators.

The research covers four physical models: electron transmission through a magnetic barrier on the surface of a topological insulator, a two-dimensional electron gas with spatially random Rashba spin–orbit coupling, surface transport in a topological insulator with spatially fluctuating magnetization, and electron scattering by a localized magnetic structure. The calculations employ the Kubo linear-response formalism and Green functions, including the Born approximation and vertex corrections, as well as spinor wave-function matching and the partial-wave method.

For a magnetic barrier, the analysis identifies the conditions for propagating and evanescent electronic states and establishes how the barrier parameters affect transmission. Evanescent modes give rise to tunneling, with transmission decreasing as the barrier length increases, whereas propagating modes produce interference and resonant transmission. In the two-dimensional electron gas with random Rashba coupling, the electron lifetime and the charge and spin transport relaxation times exhibit different dependences on energy and the spatial correlations of the disorder. These differences are reflected in the dependence of charge and spin conductivities on the system parameters.

For a topological insulator with random magnetization, the analysis examines how the strength and spatial correlations of the exchange field influence electron state broadening and longitudinal conductivity. Both the electron self-energy and current vertex corrections are taken into account. Scattering by a localized magnetic structure is described in terms of angular scattering amplitudes and cross sections. The results distinguish the symmetric scattering obtained in the first Born approximation from the angular asymmetry that can arise when higher-order scattering processes are included.

A comparison of the results shows that spatially inhomogeneous spin-dependent interactions affect electronic transport through different physical mechanisms. The

correlation length of the disorder influences the distribution of momentum transfers during scattering, the length of a magnetic barrier determines the conditions for tunneling and interference, and the size and strength of a localized magnetic structure influence the contributions of individual scattering channels. Both the spatial profile of the perturbation and the spinor structure of the electronic states play an essential role. The analysis relates the mechanisms of charge and spin transport considered in the individual models, while accounting for the differences between coherent transmission, disorder-averaged conductivity, and scattering by individual magnetic structures.

**Keywords:** charge transport, spin transport, topological insulators, two-dimensional electron gas, Rashba spin–orbit coupling, random magnetization, spatial correlations, electron scattering.