M2 Internship proposal 2023
Centre de Physique Théorique
Département de Physique, Aix Marseille Université

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Nanophysics team E6

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Title: Delta T noise in in the Quantum Spin Hall effect

Subject description:

The nanophysics team of CPT, which has a long tradition in the field of electronic quantum transport, is looking for a motivated M2 student to study the non-equilibrium noise generated by a thermal gradient in two-dimensional topological insulators such as the Quantum Spin Hall Effect.

In non-equilibrium situations (with either a bias voltage, a temperature gradient, or both), a stationary current flows through the system. Yet, this current fluctuates in time, due to the stochastic nature of electron transfer: is the incident states occupied or not? (the Fermi function provides the probability for this); Does the incident electron go through the device or is it reflected back to its initial lead? (The scattering matrix specifies this). The current-current time correlation function, or its Fourier transform, characterizes such fluctuations and constitutes non-equilibrium noise.

Non equilibrium noise, introduced in the context of mesoscopic physics/quantum nanophysics in the mid-nineties, continues to this day to draw the interest of both the theoretical and experimental community in this sub-field of condensed matter physics. Noise contains more information than the current, as it depends on the quantum statistics of the charge carriers. In correlated systems when the elementary excitations may bear a fractional charge, the measurement of the Fano factor allows to identify such an anyonic charge, and possibly its anyonic statistics.

Indeed, a voltage bias gives rise to quantum shot noise, while a temperature gradient generates so-called “Delta T noise”, which was recently studied in atomic normal metal break junctions at the Weizmann institute. A peculiarity of Delta T noise is that noise can be generated while no net current flows through the device. In a two-terminal junction connecting two (non-interacting) normal metals (Landau liquid picture), Delta T noise is always positive, and it was recently shown that for the correlated state of the Fractional Quantum Hall effect, Delta T noise is negative, a property which is tied to the scaling dimension of the tunneling operators, which is also tied to the anyonic statistics of the elementary quasiparticles of the system.

The Quantum Spin Hall Effect occurs in specific two-dimensional topological insulators, which exhibit spin momentum locking. Contrary to the usual quantum Hall effect, this system is invariant under time reversal, which means that it exists in the absence of a magnetic field. While the bulk of the system is gapped and thus insulating, the one-dimensional edges of the systems have gapless excitations called edge states (similar to the edge states of the integer and the fractional quantum Hall effect) with two opposite chiralities corresponding to the spin orientation. Typical electronic transport setups imply a quantum point contact placed in the middle of the quantum Hall bar, which allow tunneling between edge states of opposite edges. When electronic correlations are neglected, current and noise can be computed via the Landauer-Buttiker formalism of quantum transport when specifying a scattering matrix which connects the incoming states on the QPC to their outgoing counterpart. On the other hand, since these two spin edge states carry electrons, Coulomb repulsion is susceptible to generate interactions both within and between edges states on a given side of the device. Such electronic correlations imply that the scattering approach fails, and one has to resort to a chiral Luttinger liquid description.

In this M2 internship, the goal is to compute the (non-equilibrium) Delta T noise in a Quantum Spin Hall bar separated by a quantum point contact, in the presence of Coulomb interactions, thus requiring a Luttinger liquid approach. While there has been to activity in this field for a purely local QPC, which results should be recoved in the context of this intership, the second goal of this project is to generalize these results for an extended QPC. In this second case, the transmission probability across the QPC becomes energy-dependent, thus allowing to selective enhance electron (positive energies) tunneling compared to hole (negative energies) tunneling. As a result, additional thermoelectric effects are expected in this case, which are completely absent in the case of local QPC where electron-hole symmetry cannot be broken. In addition, due to the fact that electrons can tunnel at different positions in an extended QPC, quantum interference would influence transport properties accross the system. The effects of quantum interference on Delta T noise are still unexplored.

This internship involves mostly analytical calculations and possibly some numerical calculations to illustrate the results.

Prerequisites: priority is given to to M2 students who have followed the 6 credit course “Advanced Quantum Statistical Physics” and the 4 credit course “Out of Equilibrium Quantum Statistical Physics”.

Warning: the candidate for this internship will have to submit his/her L3 and M1 grades, a letter of recommendation from the M1 director or the M1 internship tutor, a short CV and a short letter of motivation.

Duration: the normal duration of a Aix Marseille Université M2 internship (March-June 2023), or longer if the student has his/her own funding from his/her institution (such as Ecole Normale Supérieure).

References:

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