Quantum nanodevices as charge and heat circulators

Background

The trend towards miniaturization during the last 50 years have made it possible to build smaller and smaller electronic devices and investigate their transport properties. When reaching the nanoscale and low enough temperatures, quantum effects become visible and have to be properly taken into account to describe the behavior of these nanodevices and eventually use them as circuit elements. On the one hand, completely confined systems, such as small metallic islands, are sensitive to the addition or removal of even few electrons and made it possible to implement the so-called single-electron transistors. On the other hand, the wave-like nature of electrons is such that quantum interference effects play an important role. These phenomena have a direct impact on the transport properties of nanodevices; for instance, they can completely suppress or enhance their electric or heat conductivity without changing the material properties.

A key feature in nanostructures is the possibility of controlling in a tunable way the charge and heat flows: circulators are important tools in this context. A circulator is a multi-terminal system (as the one in the figure) where the signal incoming in any terminal is transferred only (or mainly) to the next terminal in a given direction of rotation. This can happen due to some interference mechanism, which can arise from the wave-like nature of electrons in the quantum regime.

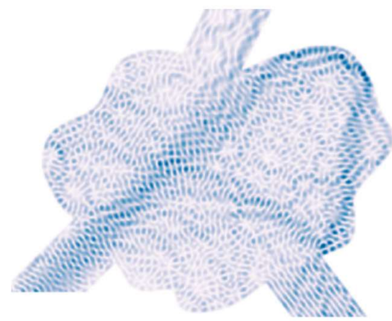

Image taken from https://kwant-project.org

Problem description

This project will investigate how realistic nanostructures perform as charge and heat circulators, by using scattering theory. Despite its conceptual simplicity, this approach has proven to be very powerful to describe lots of experimentally relevant systems. We will start with very simple setups which can be treated analytically and then move to realistic devices which will be analysed numerically.

Activities

During this project, you will become familiar with the scattering approach to describe quantum transport and fluctuations in generic nanostructures. You will also learn how to simulate their transport properties with Kwant, an efficient software package for quantum transport simulations. The main goal of the project is the investigation of realistic three-terminal nanostructures (as the one shown in the picture above) and their characterization as charge and/or heat circulators.

Group size: Ca. 3-4 students.

Target group: F, GU-Fysik

Literature tips

Introduction of the book T. Ihn, “Semiconductor Nanostructures”, Oxford University Press, 2010.
General introduction on thermal transport in nanostructures: https://arxiv.org/abs/1805.04297.
Kwant website, with some examples of what can be done with it: https://kwant-project.org.

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