Proposition de sujet de stage de M1 2021
Centre de Physique Théorique
Département de Physique, Aix Marseille Université

Name of the laboratory: Centre de Physique Théorique CNRS UMR 7332
http://www.cpt.univ-mrs.fr/
Nanophysics team E6

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Title: Non-equilibrium noise in low temperature nanodevices from second quantized scattering theory

Titre: Bruit quantique hors équilibre dans les nanosystèmes par l'approche de deuxième quantification de la théorie de la diffusion).

Subject description:

At very low temperatures, and/or in devices at the nanoscale, the usual Drude formula or the Botzmann formalism fails to predict correctly the transport properties of electrons: one has to resort to a full quantum mechanical treatment of tranport using quantum statistical mechanics.

The nanophysics team of CPT, which has a long tradition in this field, is looking for a motivated M1 student to study the non-equilibrium noise generated by a voltage bias or/and a thermal gradient in normal metal/semiconductor devices. In such systems, a stationary current flows through the system when a constant voltage is imposed. 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).

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.

In this M1 internship ("stage de M1"), the goal is to compute non-equilibrium noise from the second quantized version of the Landauer-Buttiker scattering theory of quantum transport. The first step will be to get familiar with second quantization (with creation and annihilation operators), with the calculation of grand canonical thermal averages of quantum mechanical operators, and to apply this to the calculation of the average current and the calculation of the current-current correlation function in time. The Fourier transform of this correlator corresponds to the finite frequency noise. This first part will be devoted to spinless fermions for simplicity.

After covering this basic formalism (the main part of the internship), if time allows, there are several possibilities to go further and to perform original research:

a) Extension to spinful fermions, with a scattering matrix which allows for electrons to flip spins when they go through the device, with the subsequent calculation of spin current and spin noise (rather than charge current and charge noise).
b) Computation of Delta T noise (non-equilibrium noise generated by a thermal gradient in the absence of a voltage bias) at finite frequencies, either when the temperature of the two leads are comparable, or when one lead is set to zero temperature.
c) An extension of this noise formalism to include electron-phonon interactions (the coupling of electrons to lattice vibrations) using the independent boson model (using the Feynman disentangling of operators).
d) The application of this noise formalism to a nanodevice composed of a quantum dot connected to normal metal leads, with discreet energy levels, using Breit-Wigner theory.
e) Generalization of the above to multi-lead, multichannel systems.

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

Prerequisites: basic quantum mechanics; course on quantum statistical physics including the grand canonical formalism; some knowledge about second quantization (although not required). If possible, knowledge of the “Latex” software.

Warning: the candidate for this internship will have to submit his/her L3 (and if possible 1st semester M1) grades transcripts, and to provide his/her M1 course program.

Duration: the normal duration of a Aix Marseille Université M1 internship (44 days weekend excepted), or longer if the student has his/her own funding from his/her institution (such as Ecole Normale Supérieure).

Working conditions: if Covid 19 pandemic restrictions apply during the internship, the internship can be performed in teleworking mode using skype/zoom.

References:

[1] Noise in mesoscopic physics, Thierry Martin, les Houches Session LXXXI, H. Bouchiat et. al. eds. (Elsevier 2005). arXiv:cond-mat/0501208
[2] Quantum Transport, Y. Nazarov and Y. Blanter, Cambridge University Press.
[3] M. Büttiker, Phys. Rev. Lett. 65, 2901 (1990).
[4] T. Martin and R. Landauer, Phys. Rev. B 45, 1742 (1992).
[5] Y. Imry, Introduction to mesoscopic physics (Oxford University Press, 1997).
[6] O. Lumbroso, L. Simine, A. Nitzan, D. Segal, and O. Tal, Nature 562, 240 (2018).