Coulomb blockade and transport in disordered nanowires
C. Deroulers, M. Fogler (UCSD) and T. Nattermann
Institut für Theoretische Physik • Universität zu Köln
Department of Physics • University of California San Diego

Introduction

We aim at explaining, through analytic calculations and numerical simulations, the behaviour of electrical conductivity in disordered and quantum conductors. To be specific, we explain the experimentally observed power laws for the conductivity $G(T)$.

We restrict ourselves here to the Ohmic regime, where the applied electric field $V(x)$ remains constant along the wire. For stronger fields, the corresponding Ohmic regime is a network of resonances. Three possible methods:

- Continuation of the path beyond which yields an upper bound that should be a good approximation at low temperatures. In the VRH regime, this yields the correct absolute resistance at high temperatures, but fails completely at low temperatures.

- Reducing the circuit by repetitive application of the star-cluster transformation (see below). This method avoids small local VRH with an exact method starting from the best path approximation. Works well and relatively fast at high temperatures, but fails completely at low temperatures.

Numerical simulations

We restrict ourselves to the Ohmic regime ($E = 0$). We have to solve a linear system for the admittance of the wire, whose solution is the wire resistance divided by the number of dots in the wire, corresponding to a network of resonances. Three possible methods:

- Continuation of the best path. Yields an upper bound that should be a good approximation at low temperatures. In the VRH regime, this yields the correct absolute resistance at high temperatures, but fails completely at low temperatures.

- Reducing the circuit by repetitive application of the star-cluster transformation (see below). This method avoids small local VRH with an exact method starting from the best path approximation. Works well and relatively fast at high temperatures, but fails completely at low temperatures.

- The log of the cumulative distribution of the admittance $G$ of the wires is well fitted by a power law (VRH-like) and accurate at all temperatures. This is characteristic of extreme value statistics.

- The resistance $R$ of the wire is the sum of the resistances of the strongest barriers, which are exponentially distributed, independent, identically distributed numbers $\omega$ (law (9)). Therefore, if $R$ has a broad distribution, it is tightly distributed from sample to sample, unless one sample is composed of many parallel channels with uncorrelated disorder (no charged impurities).

- From (4), the distribution of the resistance of one break may be approximated by

$$ P(R) \sim \frac{R}{R_{\text{max}}} \exp \left(-\frac{R_{\text{max}}}{R} \right) $$

with a number and, typical length of a maximal break (yields lognormal corrections).


Conclusions and plans

- The model accounts for VRH-effects at low and moderate temperatures, and more complicated laws, that can take into strong dependence on the mixed set of temperatures, at higher temperatures. The VRH regime (VRH-like) is open to other types of disorder.

- The model especially captures the major differences compared to the Ohmic regime, in the use of the concept of disorder, in the study of coupled wires.

- Numerical simulations of the non-Ohmic regime, study the thermal conductivity, study of coupled wires.