FINAL REPORT, ESF SHORT VISIT GRANT: M. HAQUE

Short visit grant

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Host Institute: Université Paris Diderot - Paris 7
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Host Scientist: Dr. Edouard Boulat

Grant reference number: **3307**

Started from Dresden February 21, 2010, returned March 01, 2010.

Total 9 days

Purpose of the visit

The purpose of this research visit was to investigate nonequilibrium issues in situations of current flow through an impurity, through exact wavefunctions.

Two setups/approaches were considered:

(1) the standard setup of an impurity connecting two leads at different chemical potentials, for which we propose to examine issues of entropy and entanglement in a non-equilibrium steady-state wavefunction proposed for transport through quantum impurities [1].

(2) A finite lattice 'ring' in which one site acts as the impurity, and a current is driven through it by a magnetic flux threading the ring.

We took some steps toward a calculation involving the first setup above, but the main focus during the visit was the second approach, as described below.

Description of the work carried out during the visit + main results obtained

We decided on a 'ring' Hamiltonian in which the impurity used is a discrete version of the *interacting resonant level model* (IRLM), which is used, *e.g.*, in Ref. [2]. The current is driven through a complex phase ϕ in the hopping term. The Hamiltonian is

$$H \;=\; -\sum_{i=1}^{L}\left[te^{-i\phi}c_i^\dagger c_{i+1} \;+\; te^{+i\phi}c_{i+1}^\dagger c_i\right] + U\left(c_1^\dagger c_1 c_2^\dagger c_2 \;+\; c_2^\dagger c_2 c_3^\dagger c_3\right)$$

Here site 2 acts as the impurity. Periodic boundary conditions are assumed in the summation over the site index i, so that site $i = L + 1$ is identified with site

$i = 1$. The phase ϕ acts as a "magnetic flux" driving current around the ring and through the impurity, and thus is the analog of the 'voltage' V (chemical potential difference between leads) in the usual two-lead setup. Instead of the I-V curve, the function to study now is the I-ϕ curve. Here I is the current.

During the visit, we simulated the above model for small rings, and compiled a preliminary overview of related situations treated in the literature. Since the model above is almost certainly integrable (we have not proven integrability), Ref. [3] and related results might suggest that the I-ϕ curve would not depend on the interaction U. Our simulations show this expectation to be violated. From Ref. [4] one might expect the same I-ϕ curve at $U = 0$ and $U = \infty$. We find that the I-ϕ curve simplifies dramatically at U=0 and $U = \infty$, but there is no duality. Our preliminary calculations thus show that the specialization of both these pieces of existing knowledge [3, 4] to our specific 1D lattice ring case is nontrivial. These are the issues we intend to pursue next.

Future collaboration with host institution

The current project has now moved beyond the planning stage toward concrete calculations.

Collaboration with Dr. Boulat (and hence the host institution) is thus very likely to continue.

Projected publications/articles resulting from grant

I expect this research to lead to at least one publication. The time scale for the work to be completed is estimated to be 1 or 2 years.

Other comments

I thank the ESF and the INTELBIOMAT program for funding this research visit.

References

[1] P. Mehta and N. Andrei, Phys. Rev. Lett. **96**, 216802 (2006).
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[2] E. Boulat, H. Saleur, and P. Schmitteckert, Phys. Rev. Lett. **101**, 140601 (2008).
E. Boulat and H. Saleur, Phys. Rev. B **77**, 033409 (2008).

[3] J. Nilsson, H.-P. Eckle, and H. Johannesson, Phys. Rev. B 76, 073408 (2007).
Title: *Persistent currents through a quantum impurity: Protection through integrability.*

[4] A. Schiller and N. Andrei, arXiv:0710.0249v1.
Title: *Strong-to-weak-coupling duality in the nonequilibrium interacting resonant-level model.*