Nanosciences Foundation workshop

ELECTRONIC NOISE AND RELAXATION IN NANOSTRUCTURES

April 1-2 Grenoble

Organisers: Leonid Glazman (Yale University, Chair of the Nanosciences Fondation), Frank Hekking (LPMMC, UJF and CNRS), and Manuel Houzet (SPSMS/INAC, CEA)

Program

Thursday, April 1

Electron noise and relaxation in normal and superconducting nanostructures

9h Elastic and Inelastic relaxation in long SNS bridges
Bertrand Reulet (LPS Orsay)

9h45 Electron Coherence in Quantum-Wires: The Quest for the Fermi Liquid Ground State in the Kondo Regime
Laurent Saminadayar (Institut Néel)

10h30 coffee break

11h Conductance Fluctuations in a Spin Glass Nanowire
David Carpentier (ENS Lyon)

11h45 Transport in semiconductor nanowire quantum dots with superconducting contacts
Jesper Nygård (Niels Bohr Institute, Copenhagen)

12h30 lunch

Relaxation in the edge states

14h30 Non-equilibrium edge channel spectroscopy in the integer quantum Hall regime
Carles Altimiras (CNRS, Laboratoire de Photonique et de Nanostructures)

15h15 Interaction induced edge channel equilibration
Simon Nigg (Univ. Geneva)

16h coffee break

16h30 Decoherence and relaxation in quantum Hall edge channels
Pascal Degiovanni (ENS Lyon)

Friday, April 2

Spin and phonon dynamics in Nanostructures

9h Energy Level Lifetimes in the Single-Molecule Magnets
Wolfgang Wernsdorfer (Institut Néel)

9h45 Orbitally phase coherent spintronics with carbon nanotubes
Takis Kontos (ENS-Paris)

10h30 coffee break

11h Phonon-phonon interactions and phonon damping in carbon nanotubes
Alessandro De Martino (Institute of Theor. Physics, University of Cologne)

11h45 Anderson Model out of equilibrium: decoherence effects
Raphaël Van Roermund (SPSMS/INAC, CEA)

12h30 lunch

Mesoscopic charge dynamics

14h30 Contact less investigation of electronic properties of nanoconductors coupled to a multimode microwave resonator
Hélène Bouchiat (LPS Orsay)

15h15 Dynamic response of a mesoscopic capacitor in the presence of strong electron interactions
Thierry Martin (CPT, Marseille)

16h coffee break

16h30 Universal Resistances of the Quantum RC circuit
Christophe Mora (ENS Paris)

List of abstracts

Elastic and Inelastic relaxation in long SNS bridges

Bertrand Reulet (LPS Orsay)

We use microwave excitation to elucidate the dynamics of long SNS Josephson junctions. By varying the excitation frequency in the range 10 MHz – 40 GHz, we observe that the critical and retrapping currents, deduced from the dc voltage versus dc current characteristics of the junction, are set by two different time scales. The critical current increases when the ac frequency is larger than the inverse diffusion time in the normal metal, whereas the retrapping current is strongly modified when the excitation frequency is above the electron-phonon rate in the normal metal. Therefore the critical and retrapping currents are associated with elastic and inelastic scattering, respectively

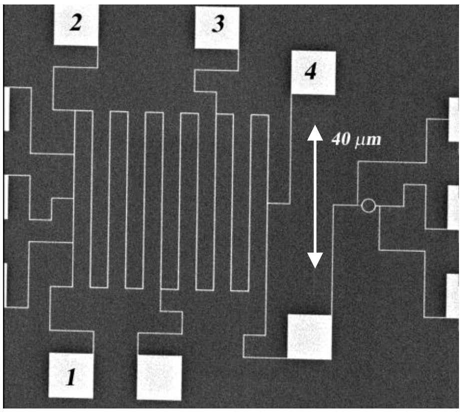
---

Electron Coherence in Quantum-Wires: The Quest for the Fermi Liquid Ground State in the Kondo Regime

Laurent Saminadayar (Institut Néel, CNRS and Université Joseph Fourier, Grenoble, France)

Probably the most fundamental property of a particle in any quantum system is the time over which it maintains its wave function. Coupling the quantum system to an environment should lead to decoherence and subsequently to a reduction of this so-called phase coherence time.

In this talk we will focus on the influence of magnetic impurities on the phase coherence time. The coupling of the conduction electrons to magnetic impurities leads to the well known Kondo effect and influences strongly the electron coherence. Going to lower and lower temperatures, the Fermi liquid ground state of a “standard” metal should be restored, as postulated in the original work of Nozières [1]. This, however, has stayed as a challenge for experimentalists.



Silver quantum wire implanted with magnetic iron impurities. The width of the wire is approximately 100nm.

Here, we present phase coherence time measurements in Ag/Fe quantum wires with different magnetic impurity concentrations [2]. We will show that the magnetic contribution to the dephasing rate per impurity is described by a single, universal curve when plotted as a function of T/TK [3]. We also show that this description remains valid for any system as long as it is a completely screened Kondo system [4].

[1] P. Nozières, J. Low. Temp. Phys. **17**, 31, (1774).
[2] C. Bäuerle, F. Mallet, F. Schopfer, D. Mailly, G. Eska, L. Saminadayar,

Phys. Rev. Lett. **95**, 266805 (2005).
[3] F. Mallet, J. Ericsson, D. Mailly, S. Ünlübayir, D. Reuter, A. Melnikov, A.D. Wieck, T. Micklitz, A. Rosch, T.A. Costi, L. Saminadayar, and C. Bäuerle, Phys. Rev. Lett. **97**, 226804 (2006).
[4] T. A. Costi, L. Bergqvist, A. Weichselbaum, J. von Delft, T. Micklitz, A. Rosch, P. Mavropoulos, P. H. Dederichs, F. Mallet, L. Saminadayar and C. Bäuerle, Phys. Rev. Lett. **102**, 056802 (2009).

Conductance Fluctuations in a Spin Glass Nanowire
David Carpentier (ENS Lyon)

In this talk, I will consider the coherent transport properties of a metallic nanowire with magnetic impurities frozen in a spin glass phase. The magneto-conductance trace G(B) of such a wire provides a unique signature of the frozen spin configuration. Hence, the correlation between two different traces G(B) gives access to the correlation between the two corresponding spin configurations, a potentially unique probe of spin glass physics. I will discuss the experimental feasability of the proposed setup.

Transport in semiconductor nanowire quantum dots with superconducting contacts
Thomas Sand Jespersen[1], Peter Dahl Nissen[1], Peter Krogstrup[1], Martin Aagesen[1], Claus B. Sorensen[1], Michael L. Polianski[4], Verena Koerting[4], Karsten Flensberg[1], Jens Paaske[1], Szabolcs Csonka[2,3], Lukas Hofstetter[3], Christian Schönenberger[3], Jesper Nygard[1]
[1] Niels Bohr Institute & Nano-Science Center, University of Copenhagen, Denmark
[2] Department of Physics, Budapest University of Technology and Economics, Hungary
[3] Institut für Physik, Basel University, Switzerland
[4] Niels Bohr International Academy, University of Copenhagen, Denmark

Semiconductor nanowires and carbon nanotubes are attractive materials for studying transport in tunable quantum dots with ferromagnetic or superconducting leads. I will focus on nanowires coupled to superconductors and give a few recent examples; strong conductance fluctuations [1], nonlinear transport in the Kondo regime [2] with enhanced subgap resonances [3], and Cooper pair splitting into double dots [4]. The latter two phenomena have also been observed in single-wall carbon nanotube devices by Eichler et al. [5] and Hermann et al. [6], respectively. All experiments reported here were based on III-V (InAs) nanowires grown by Molecular Beam Epitaxy [7].

[1] T. Sand Jespersen, M.L. Polianski, C.B. Sorensen, K. Flensberg, J. Nygard, *New Journal of Physics* **9**, 3689-3693 (2009)

[2] T. Sand Jespersen T. S. Jespersen, M. Aagesen, C. Sorensen, P. E. Lindelof, J. Nygard, *Phys. Rev.* B **74**, 233304 (2006); S. Schmaus, V. Koerting, J. Paaske, T. S. Jespersen, J. Nygard, and P. Wolfle, *Phys. Rev.* B , 45105 (2009).

[3] T. Sand Jespersen et al, *Phys. Rev. Lett*. **99**, 126603 (2007); *J. Vac. Sci. & Tech*. **B26**, 1609 (2008)

[4] L. Hofstetter, S. Csonka, J. Nygard, C. Schönenberger, *Nature* **461**, 960-963 (2009)

[5] A. Eichler, M. Weiss, S. Oberholzer, and C. Schönenberger, A. Levy Yeyati, J. C. Cuevas, and A. Martín-Rodero, *Phys. Rev. Lett.* **99**, 126602 (2007)

[6] L. G. Herrmann, F. Portier, P. Roche, A. Levy Yeyati, T. Kontos, and C. Strunk, *Phys. Rev. Lett.* **104**, 026801 (2010)

[7] P. Krogstrup et al, *Nano Letters* **9**, 3689-3693 (2009)

Non-equilibrium edge channel spectroscopy in the integer quantum Hall regime

Carles Altimiras (CNRS, Laboratoire de Photonique et de Nanostructures)

In the quantum Hall regime, the current is carried without dissipation along one-dimensional channels guided by the sample's edges. The resemblance of these edge channels with light beams calls for novel electron optics experiments and future quantum information applications in quantum Hall based circuits. However, the recent electronic Mach-Zehnder interferometers realized exploiting this analogy, exhibit phenomena unexpected within the widespread picture of free 1D chiral fermionic excitations.

In order to shed new light on this issue, we have developed a novel experimental approach that permits us to directly measure the energy transfers along an edge channel driven out of equilibrium. It relies on the measurement of the energy distribution function, f(E), of the electronic excitations carried by an edge channel in non equilibrium situations. The f(E) spectroscopy is performed using a discrete electronic level in a quantum dot as an energy filter. By measuring f(E) for different propagation distances and geometrical configurations at filling factor 2, we observe complete energy current equilibration between co-propagating channels in a few microns . We further demonstrate that these energy exchanges, and therefore quantum decoherence, can be efficiently reduced by closing one edge channel on itself.

Interaction induced edge channel equilibration

Simon Nigg (Univ. Geneva)

In the integer quantum Hall effect regime, there exist extended chiral states at the edges of the sample. In a non-interacting picture, electrons can propagate freely along such edge channels, which can be viewed as electronic waveguides. The latter are of interest for fundamental experiments on electron interferometry in solids (quantum optics with electrons). However, due to their charge, electrons couple to each other. We investigate the effect of weak inter-edge channel Coulomb interaction on the energy distribution function of two co-propagating channels [1,2,3] and compare our results with recent experiments [2,4].

References:

[1] A. M. Lunde, S. E. Nigg and M. Buttiker, Phys. Rev. B **81**, 041311(R) (2010)
[2] C. Altimiras, H. le Sueur, U. Gennser, A. Cavanna, D. Mailly and F. Pierre, Nature Physics **6**, 34 - 39 (2009)
[3] P. Degiovanni, C. Grenier, G. Fève, C. Altimiras, H. Le Sueur, F. Pierre (to appear in PRB(R)).
[4] H. Le Sueur et al. (unpublished)

Decoherence and relaxation in quantum Hall edge channels

Pascal Degiovanni (ENS Lyon)

The recent development of an on demand single-electron source [1] has opened the way to fundamental electron quantum optics experiments involving single charge excitations propagating along chiral edges of a 2D electron gas in the integer quantum Hall regime. But contrary to photons, electrons interact with their electromagnetic environment and with other electrons present in the Fermi sea thus making the concept of electron quantum optics highly non trivial.

In this talk, a unified approach to decoherence and relaxation of single electron excitations in Integer Quantum Hall edge channels is presented. This approach, based on bosonization framework, has an explicit explicit connexion with high frequency transport properties and high frequency noise. It provides a non perturbative solution to the quasi particle relaxation problem originally considered by Landau [2]. It can also be used to analyze [3] energy redistribution between edge channels of a quantum Hall system at filling fraction 2 which has recently been measured [4].

[1] Science **316** (2007) 1169
[2] Phys. Rev. B **80**, 241307(R), (2009).
[3] Preprint arxiv:0910.2642 (to appear in Phys. Rev. B (Rapid Comm)).
[4] Nature Physics **6**, 34 (2010)

Energy Level Lifetimes in the Single-Molecule Magnets
Wolfgang Wernsdorfer (Institut Néel, CNRS, BP 166, 38042 Grenoble Cedex 9, France)

Everyday life is full of useful magnets, solids, oxides, metals and alloys. On the contrary, molecules are most often considered as non-magnetic materials. However, recent discoveries show that molecules can bear large magnetic moments that can have a stable orientation like traditional magnets. They have therefore been called single-molecule magnets and they might be the ultimate limit for information storage. They do not only exhibit the classical macroscale property of a magnet, but also new quantum properties such as quantum tunnelling of magnetization and quantum phase interference, the properties of a microscale entity. Such quantum phenomena are advantageous for some challenging applications, e.g. molecular information storage or quantum computing.

After a general introduction to the physics of molecular nanomagnets, this presentation will show how we are currently inducing controlled transitions between spin energy states of assemblies of molecular nanomagnets. The spin dynamics are studied via time resolved magnetization experiments using micro-SQUID and Hall probe magnetometry [1]. We present pump-probe measurements on single-molecule magnets with nanosecond microwave pulses giving access to the energy level lifetimes of single-molecule magnets [2].

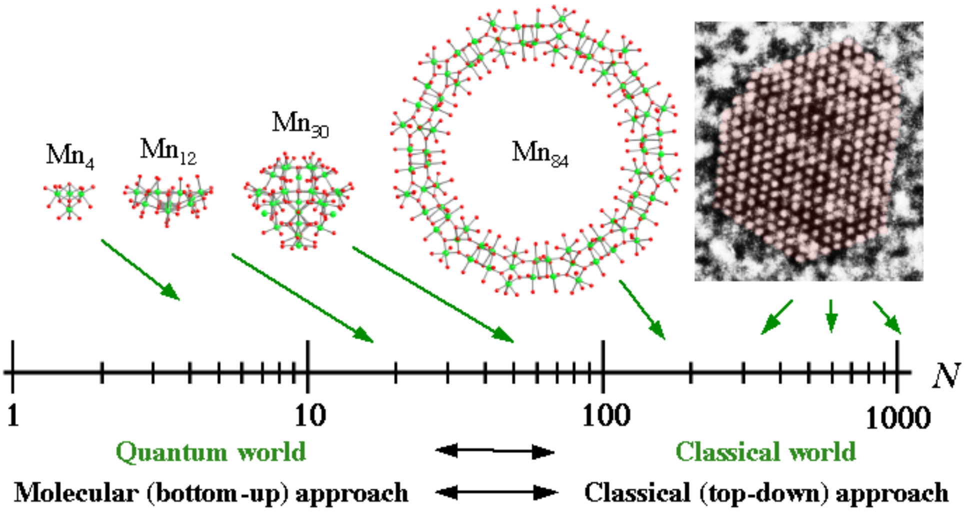


Fig. 1: Size scale spanning atomic to nanoscale dimensions. On the far right is shown a high-resolution transmission electron microscopy view along a [110] direction of a typical 3 nm diameter cobalt nanoparticle containing about 1000 Co atoms. The Mn_{84} molecule is a 4.2 nm diameter particle. Also shown for

comparison are the indicated smaller Mn nanomagnets, which are drawn to scale. An alternative means of comparison is the Néel vector (N), which is the scale shown.

[1] L. Sorace, W. Wernsdorfer, C. Thirion, A.-L. Barra, M. Pacchioni, D. Mailly, and B. Barbara, Phys. Rev. B 68, 220407 (2003) and Europhys.Lett. 66, 861 (2004) and Phys. Rev. B **72**, 060409 (2005) and Phys. Rev. B **72**, 052401 (2005).

[2] S. Bahr, K. Petukhov K, V. Mosser, W. Wernsdorfer, Phys. Rev. Lett. **99**, 147205 (2007) ; Phys. Rev. B **77**, 064404 (2008).

Orbitally phase coherent spintronics with carbon nanotubes.

C. Feuillet-Palma[1,2], T. Delattre[1,2], J.-M. Berroir[1,2], G. Fève[1,2], D. C. Glattli[1,2,3], B. Plaçais[1,2], A. Cottet[1,2] and T. Kontos[1,2]

[1]Ecole Normale Supérieure, Laboratoire Pierre Aigrain, 24, rue Lhomond, 75231 Paris Cedex 05, France

[2]CNRS UMR 8551, Laboratoire associé aux universités Pierre et Marie Curie et Denis Diderot, France

[3]Service de physique de l'état condensé, CEA, 91192 Gif-sur-Yvette, France.

The scattering imbalance between up and down spins at the interface between a non-magnetic metal and a ferromagnetic metal is at the heart of the principle of the magnetic tunnel junctions or multilayers celebrated in the field of spintronics. Although these devices use the quantum mechanical spin degree of freedom and electron tunneling, they do not exploit a crucial degree of freedom involved in quantum mechanics: the phase of the electronic wave function. In most of the devices studied so far, this aspect has not been developed owing to the classical-like motion of charge carriers in the conductors used. In this work, we report on spin dependent transport measurements in carbon nanotubes based multi-terminal circuits. We observe a gate-controlled spin signal in non-local voltages and an anomalous conductance spin signal, which reveal that both the orbital phase and the spin can be conserved along carbon nanotubes with multiple ferromagnetic contacts.

We also report on an intriguing phenomenon which has no classcal analog and is a consequence of orbital coherence : a spin valve behavior between two normal contacts with proximal ferromagnetic contacts outside the classical electron path. This realizes a "theorist's blob experiment" for spintronics, the exact counterpart of a seminal experiment in mesoscopic physics. Our findings pave the way for spintronics devices exploiting both these quantum mechanical degrees of freedom on the same footing.

Phonon-phonon interactions and phonon damping in carbon nanotubes

Alessandro De Martino (Institute of Theor. Physics, University of Cologne)

I will formulate and discuss the effective low-energy theory of interacting long-wavelength acoustic phonons in carbon nanotubes within the framework of continuum elasticity theory. I will provide a general analytical derivation of all three- and four-phonon processes, where the relevant coupling constants are determined in terms of few elastic coefficients. Special attention will be payed to flexural phonons, for their finite-temperature density diverges in the noninteracting limit and a nonperturbative approach to their interactions is necessary. I will then use this theory to compute decay rates of acoustic phonons due to phonon-phonon and electron-phonon interactions, providing upper bounds for their quality factor.

Anderson Model out of equilibrium: decoherence effects

Raphaël Van Roermund, Shiue-yuan Shiau, Mireille Lavagna
Commissariat à l'Energie Atomique de Grenoble INAC/SPSMS, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France

We study the nonequilibrium two-lead Anderson model which is believed to describe transport through a d-c biased quantum dot. Using a self-consistent equation-of-motion method generalized out of equilibrium, we analyze the decoherence of the quantum coherent many-body state induced by a bias voltage V. We discuss its effects on the density of states and on the evolution of the differential conductance with the bias voltage. The low-bias differential conductance is found to be a universal function of the normalized bias voltage V/T_K, where T_K is the Kondo temperature. The universal scaling with a single energy scale T_K at low bias voltage is also observed for the renormalized decoherence rate. Finally we discuss the effect of the decoherence rate on the crossover from strong to weak coupling regime when either the temperature or the bias voltage is increased.

Contact less investigation of electronic properties of nanoconductors coupled to a multimode microwave resonator

A. D. Chepelianskii, F. Chiodi, M. Ferrier, S. Guéron, and H. Bouchiat
LPS, Univ. Paris-Sud, CNRS, UMR 8502, F-91405 Orsay Cedex, France

Electronic properties of nanoconductors are known to be strongly dependent of their coupling to the measurement apparatus. Contact less measurements reveal some specific properties which cannot be explored in contacted systems such as electrical polarisability and orbital magnetism. We present two recent experiments illustrating this point, one on silicon nanowires, one on hybrid normal superconducting (NS) rings by measuring their response to an electromagnetic wave between 0.3 and 6GHz using a multimode superconducting resonator. On the one hand we find that whereas the bulk Si response is mainly dissipative, the nanowires exhibit a large dielectric photo induced polarizability. On the other hand investigation of the the orbital susceptibility of an ac phase bias NS ring constitutes a unique probe of the dynamics of Andreev levels close to equilibrium.

Dynamic response of a mesoscopic capacitor in the presence of strong electron interactions

Yuji Hamamoto, Thibaut Jonckheere, Takeo Kato, Thierry Martin

We consider a one dimensional mesoscopic capacitor in the presence of strong electron interactions and compute its admittance in order to probe the universal nature of the relaxation resistance. We use a combination of perturbation theory, renormalization group arguments, and quantum Monte Carlo calculation to treat the whole parameter range of dot-lead coupling. The relaxation resistance is universal even in the presence of strong Coulomb blockade when the interactions in the wire are sufficiently weak. We predict and observe a quantum phase transition to an incoherent regime for a Luttinger parameter K<1/2. Results could be tested using a quantum dot coupled to an edge state in the fractional quantum Hall effect.

Universal Resistances of the Quantum RC circuit

Christophe Mora (ENS Paris)

We discuss the capacitance and the resistance, usually called the charge relaxation resistance, of a quantum coherent RC circuit driven by a low-frequency AC voltage. This circuit is the quantum

analogue of the classical RC circuit: it comprises a dot capacitively coupled to a nearby gate and connected to a single reservoir lead. As a result of phase coherence and electronic interactions, the quantum circuit behaves quite differently and Kirchhoff's law is violated. Here we show that the charge relaxation resistance is perfectly quantized, regardless of the single lead transmission and for an arbitrary strength of the interaction. Its low-frequency value is h/2 e^2. When the driving frequency exceeds the dot level spacing, we predict a transition to a metallic regime with a doubled quantized resistance h/e^2. The novel quantized resistance h/e^2 is connected to the Korringa-Shiba relation of the Kondo model, thereby revealing the physics behind these universal charges.