International Conference

NANOELECTRONICS 2006

Novel Nanomaterials, Quantum Transport, and Noise of Electrons and Photons

8 - 11 January 2006, Lancaster University, UK

School on Counting Statistics

7-8 January 2006, Lancaster University, UK

Organisers

Gerrit Bauer (TU Delft)
Carlo Beenakker (Leiden)
Vadim Cheianov (Lancaster)
Henning Schomerus (Lancaster)

This conference & school focuses on rapidly growing topics and advances in mesoscopic physics and nanoscopic systems including:

- Counting statistics, noise and mesoscopic quantum-optics
- Spin-dependent transport and SF structures
- Edge states and quantum-Hall systems
- Ultra-thin graphitic films

Invited Speakers

Rámon Aguado (Madrid)
Boris Altshuler (Columbia University)
Tsuneya Ando (Tokyo)
Konstantin Arutyunov (Jyvaskyla)
Miles Blencowe (Dartmouth)
Tobias Brandes (Manchester)
Arne Brataas (Trondheim)
Christoph Bruder (Basel)
Alexei Bykov (ISP Novosibirsk)
John Chalker (Oxford)
Hervé Courtois (CRTBT Grenoble)
Per Delsing (Chalmers)
Sergey Dorozhkin (Chernogolovka)
Véronique Dupuis (Lyon)
Pablo Esquinazi (Leipzig)
Guiseppe Falci (Catania)
Andre Geim (Manchester)
Matthew Grayson (Munich)
Francisco Guinea (Madrid)
Frank Hekking (Grenoble)
Philip Kim (Columbia University)
Renaud Leturcq (ETH Zurich)
Chris Marrows (Leeds)
Edward McCann (Lancaster)
Peter Michler (Stuttgart)
Yuli Nazarov (TU Delft)
Marek Potemski (HMFL Grenoble)
Ben Simons (Cambridge)
Jurgen Smet (MPI-FKF Stuttgart)
Carlos Tejedor (Madrid)
Yaroslav Tserkovnyak (Harvard)

Lecturers at the School

Wolfgang Belzig (Konstanz)
Yaroslav Blanter (TU Delft)
Tobias Brandes (Manchester)
Eugene Sukhorukov (Geneva)

EXT NanoElectroPhotonics
MARIE CURIE ACTIONS
STREP SFINx
RTNNANO Research Training Networks
INTAS
EPSRC
Institute of Physics

www.lancs.ac.uk/users/esqn/nano2006

School and Conference Timetable

Saturday	
8:00	Breakfast
9:00	**T Brandes**
10:00	Coffee
10:30	**Y Blanter**
11:30	Break
12:00	**W Belzig**
13:00	Lunch
14:30	**T Brandes**
15:30	Coffee
16:00	**E Sukhorukov**
17:00	Break
17:30	**Discussion**
19:30	Dinner

Sunday	
8:00	Breakfast
9:00	**Y Blanter**
10:00	Coffee
10:30	**W Belzig**
11:30	Break
11:45	**E Sukhorukov**
12:45	Lunch
14:00	**R Leturcq**
14:30	**F Hekking**
15:00	**L DiCarlo**
15:20	**A Braggio**
15:40	**T Novotny**
16:00	Coffee
16:30	**T Brandes**
17:00	**G Falci**
17:30	**C Bruder**
18:00 -18:20	**A Morpurgo**
18:30	**Posters up**
19:30	Welcome Party

Monday	
8:00	Breakfast
9:00	**Y Tserkovnyak**
9:30	**K Arutyunov**
10:00	**J Smet**
10:30	Coffee
11:00	**A Brataas**
11:30	**C Marrows**
12:00	**V Dupuis**
12:30 -12:50	**M Zareyan**
13:00	Lunch
14:30	**M Blencowe**
15:00	**A Donarini**
15:20	**D Rodrigues**
15:40	**A Bykov**
16:00	Coffee
16:30	**T Ando**
17:00	**F Guinea**
17:30	**A Geim**
18:00	**B Simons**
18:30 -19:30	**Poster session**
20:00	Dinner

Tuesday	
8:00	Breakfast
9:00	**H Courtois**
9:30	**R Melin**
9:50	**I Sosnin**
10:10	**D Sanchez**
10:30	Coffee
11:00	**R Aguado**
11:30	**Y Nazarov**
12:00	**P Delsing**
12:30 -12:50	**J Cserti**
13:00	Lunch
14:30	**P Michler**
15:00	**C Tejedor**
15:30	**A Vagov**
16:00	Coffee
16:30	**P Kim**
17:00	**E McCann**
17:30	**P Esquinazi**
18:00 -18:20	**L Brey**
18:30 -19:30	**Poster session**
20:00	Dinner

Wednesday	
8:00	Breakfast
9:00	**J Chalker**
9:30	**S Roddaro**
9:50	**I Adagideli**
10:10	**B Nikolic**
10:30	Coffee
11:00	**S Dorozhkin**
11:30	**M Potemski**
12:00	**M Grayson**
12:30	**B Altshuler**
13:00	Lunch
14:00	Bus departure

Program – School on Counting Statistics

Saturday 7th January

8:00-8:45 **Breakfast *(Langdales Restaurant)***

Conference Centre

MR1 Morning Session (Chair: Henning Schomerus)

9:00-10:00	Tobias Brandes *Photoelectron counting in quantum optics I*	S1
10:00-10:30	Coffee	
10:30-11:30	Yaroslav Blanter *Shot noise in nanostructures I*	S2
11:30-12:00	Break	
12:00-13:00	Wolfgang Belzig *Full counting statistics in mesoscopic electronics I*	S3

13:00-14:30 **Lunch (Foyer)**

MR1 Afternoon Session (Chair: Edward McCann)

14:30-15:30	Tobias Brandes *Photoelectron counting in quantum optics II*	S1
15:30-16:00	Coffee	
16:00-17:00	Eugene Sukhorukov *Stochastic path integral approach to counting statistics I*	S4
17:30-19:00	Discussion	

19:30-21:00 **Dinner (*Langdales Restaurant)***

Sunday 8th January

8:00-8:45 **Breakfast (*Langdales Restaurant*)**

Conference Centre

MR1 Morning Session (Chair: Rámon Aguado)

9:00-10:00	Yaroslav Blanter *Shot noise in nanostructures II*	S2
10:00-10:30	Coffee	
10:30-11:30	Wolfgang Belzig *Full counting statistics in mesoscopic electronics II*	S3
11:30-11:45	Break	
11:45-12:45	Eugene Sukhorukov *Stochastic path integral approach to counting statistics II*	S4

12:45-14:00 **Lunch (Foyer)**

Program – International Conference Nanoelectronics 2006

Sunday 8th January

Conference Centre

MR1 Noise and Counting Statistics I (Chair: Wolfgang Belzig)

14:00-14:30	Renaud Leturcq *Counting statistics of single electron transport in a quantum dot*	N1
14:30-15:00	Frank Hekking *Finite frequency quantum noise in an interacting mesoscopic conductor*	N2
15:00-15:20	Leonardo DiCarlo *Shot Noise of a Quantum Point Contact in a Magnetic Field*	N3
15:20-15:40	Alessandro Braggio *Full Counting Statistics & Non-Markovian Effect in Strongly Interacting Systems*	N4
15:40-16:00	Tomas Novotny *Charge transport statistics of quantum shuttles*	N5
16:00-16:30	**Coffee (Foyer)**	

MR1 Noise and Counting Statistics II (Chair: Elisabetta Paladino)

16:30-17:00	Tobias Brandes *Coherence and noise in transport through coupled quantum dots*	N6
17:00-17:30	Guiseppe Falci *Adiabatic passage in superconducting nanocircuits*	N7
17:30-18:00	Christoph Bruder *Current cross-correlations in mesoscopic devices*	N8
18:00-18:20	Alberto Morpurgo *Non-local Andreev reflection: experimental observation and relevance for entangler devices*	N9
18:30-19:30	**Posters up (MR1)**	

Barker House Farm

19:30-21:30 **Dinner/Welcome party with barrels of local beer**

Monday 9th January

8:00-8:45	**Breakfast (*Langdales Restaurant)***	

Conference Centre

MR2 Quantum Transport I (Chair: John Chalker)

9:00-9:30	Yaroslav Tserkovnyak *Momentum-resolved tunneling into a short cleaved-edge wire*	T1
9:30-10:00	Konstantin Arutyunov *Quantum size phenomena in ultra-narrow 1D nanowires*	T2
10:00-10:30	Jurgen Smet *Polarization dependence and local probe studies of the microwave induced zero resistance in the two dimensional electron system*	T3
10:30-11:00	**Coffee (Foyer)**	

MR2 Hybrid Structures I (Chair: Gerrit Bauer)

11:00-11:30	Arne Brataas *Magnetoelectronic Circuits: Torque, Pumping, and Noise*	H1
11:30-12:00	Chris Marrows *Spin polarisation at finite temperature*	H2
12:00-12:30	Véronique Dupuis *Single magnetic clusters embedded in matrix*	H3
12:30-12:50	Malek Zareyan *Shot noise in magnetoelectronic structures*	H4
13:00-14:30	**Lunch (Foyer)**	

MR2 Quantum Dynamics (Chair: Christoph Bruder)

14:30-15:00	Miles Blencowe *Cooper-Pair Molasses: Cooling a Nanomechanical Resonator with Quantum Back-Action*	D1
15:00-15:20	Andrea Donarini *Electromechanical properties of a biphenyl transistor*	D2
15:20-15:40	Denzil Rodrigues *The SET Resonator: Quantum Master Equations*	D3
15:40-16:00	Alexey Bykov *Effect of DC and AC excitations on the magnetoresistance in high-density high-mobility GaAs quantum well systems*	D4
16:00-16:30	**Coffee (Foyer)**	

MR2 Graphene and Graphite I (Chair: Pablo Esquinazi)

16:30-17:00	Tsuneya Ando *Exotic transport properties of two-dimensional graphite*	G1
17:00-17:30	Francisco Guinea *Interaction effects, disorder, and transport in graphene layers*	G2
17:30-18:00	Andre Geim *QED in a Pencil Trace*	G3
18:00-18:30	Ben Simons *Electronic Structure of the Superconducting Graphite Intercalates*	G4
18:30-19:30	**Poster session I (MR1)**	
20:00-21:30	**Dinner (*Langdales Restaurant)***	

Tuesday 10th January

8:00-8:45 **Breakfast (*Langdales Restaurant)***

Conference Centre

MR2 Hybrid Structures II (Chair: Alberto Morpurgo)

9:00-9:30	Hervé Courtois *Local spectroscopy of superconducting hybrid nanostructures*	H5
9:30-9:50	Regis Mélin *Non local transport at FS and NS double interfaces*	H6
9:50-10:10	Igor Sosnin *Superconducting proximity effect in conical ferromagnets*	H7
10:10-10:30	David Sánchez *Magnetic-field asymmetry in nonlinear mesoscopic transport*	H8
10:30-11:00	**Coffee (Foyer)**	

MR2 Quantum Transport II (Chair: Angus McKinnon)

11:00-11:30	Rámon Aguado *SU(4) Kondo effect in Carbon Nanotubes*	T4
11:30-12:00	Yuli Nazarov *G_q corrections in circuit theory of Quantum Transport*	T5
12:00-12:30	Per Delsing *Current measurement by counting of single electrons*	T6
12:30-12:50	József Cserti *Rashba Billiards*	T7
13:00-14:30	**Lunch (Foyer)**	

MR2 Mesoscopic Quantum Optics (Chair: Tobias Brandes)

14:30-15:00	Peter Michler *Photon correlation measurements on semiconductor nanostructures*	O1
15:00-15:30	Carlos Tejedor *Quantum optics with quantum dots in microcavities: photon pairs emission*	O2
15:30-16:00	Alexei Vagov *Ultra-fast dynamics of optically excited quantum dots*	O3
16:00-16:30	**Coffee (Foyer)**	

MR2 Graphite and Graphene II (Chair: Tsuneya Ando)

16:30-17:00	Philip Kim *Unusual Transport Properties in Carbon Based Low Dimensional Materials: Nanotubes and Graphene*	G5
17:00-17:30	Edward McCann *Landau level degeneracy and quantum Hall effect in a graphite bilayer*	G6
17:30-18:00	Pablo Esquinazi *Magnetic order in carbon structures*	G7
18:00-18:20	Luis Brey *Quantum Hall Effect and Edge States in Graphene*	G8

18:30-19:30 **Poster session II (MR1)**

20:00-21:30 **Dinner *(INFOLAB café)***

Wednesday 11th January

8:00-8:45 **Breakfast (*Langdales Restaurant*)**

Conference Centre

MR2 Quantum Hall Effect and Transport I (Chair: Vadim Cheianov)

9:00-9:30 John Chalker — Q1
Electron Interactions and Transport
Between Coupled Quantum Hall Edge States

9.30-9:50 Stefano Roddaro — Q2
Non-linear transport and particle-hole symmetry in a quantum Hall device

9:50-10:10 İnanç Adagideli — Q3
Intrinsic Spin Hall Edges

10:10-10:30 Branislav Nikolić — Q4
Mesoscopic spin Hall effect in multiterminal spin-orbit coupled nanostructures:
Local spin densities, total pure spin currents, and their shot noise

10:30-11:00 **Coffee (Foyer)**

MR2 Quantum Hall Effect and Transport II (Chair: Henning Schomerus)

11:00-11:30 Sergey Dorozhkin — Q5
Interplay of inter and intra-Landau-level transitions in
microwave photoresponse of two-dimensional electron systems

11:30-12:00 Marek Potemski — Q6
Quasi-excitons and fractionally charged excitons in the vicinity
of the ν =1/3 fractional quantum Hall state

12:00-12:30 Matthew Grayson — Q7
Bending the quantum Hall effect: Novel metallic and insulating states
in one dimension

12:30-13:00 Boris Altshuler — Q8
Dephasing without Heating: New Experiments and Old Theory

13:00-13:45 **Lunch (Foyer)**

Poster Presentations

P1 Babak Abdollahi Pour
Spin-polarized shot noise in diffusive spin-valve systems with non-collinear magnetizations

P2 Ilias Amanatidis and Steven Bailey
Carbon nanotube electron turbines: a novel design for man-made nano-motors

P3 Alistair Armstrong-Brown
Observation of multiple soliton-like modes in the quantum Hall edge dynamics

P4 Sophie Avesque
Correlations vs impurities: or how to go from fractions to integers in the quantum Hall effect

P5 Christian Flindt
FCS of NEMS

P6 Heidi Förster
Full counting statistics for voltage and dephasing probes in a Mach-Zehnder interferometer

P7 Mihai Gabureac
Spin-polarized transport in atomic-size ferromagnetic constrictions

P8 Iain Grace
Electron Transport in Molecular Wires

P9 Alexander Grishin
Low Temperature Decoherence in Josephson Junction Qubits

P10 Fabian Hassler
Using Qubits for Measuring Fidelity in Mesoscopic Systems

P11 Christopher Hooley
To Be Announced

P12 Babak Hosseinkhani
Magnetization Dynamics and Spin Pumping in Ferromagnetic Nanoclusters

P13 Daniel Huertas-Hernando
Spin and interactions in chaotic quantum dots

P14 Anna Kauch
Local momentum approach to multiorbital single impurity Anderson model with applications to transport in quantum dots

P15 Pengshun Luo
Transport properties of Superconductor/Ferromagnet hybrid structures

P16 Mohammad Ali Maleki
Superconducting proximity effect in ferromagnetic domain structures

P17 Ghadir Mohammadkhani
Non-sinusoidal current-phase relations in diffusive ferromagnetic Josephson junctions

P18 Jan Petter Morten
Spin transport in superconductors

P19 Marcin Mucha-Kruczynski
Electronic bands of a graphite bilayer – comparison of AB and AA stacking

P20 Kostantin Novoselov
Electric Field Effect in Thin Graphitic Films

P21 Elisabetta Paladino
Decoherence and decoupling in superconducting nanocircuits

P22 Theodoros Papadopoulos
Symmetry Breaking in Molecular Wires

P23 Cyril Petitjean
Dynamically induced entanglement and decoherence. (The quantum to classical crossover)

P24 Peter Polinak
Andreev Drag Effect via Magnetic Quasiparticle Focusing in SN Hybrid Waveguides

P25 Alessandro Potenza
Superconducting critical temperature dependence on the layer sequence in Nb/Pd bilayers

P26 John P. Robinson
Geometrical oscillations in the SAW induced acousto-electric effect

P27 Stanislas Rohart
Magnetic anisotropy of mixed Co based clusters embedded in matrix

P28 Adam Rycerz
Entanglement and transport through correlated quantum dot

P29 Valentin Rytchkov
Quantum versus classical division of current fluctuations

P30 Ken-ichi Sasaki
Stabilization mechanism of edge states in graphene

P31 Skon Sirichantaropass
Even-Odd Effects in Monovalent Atomic Chains

P32 Janine Splettstößer
A diagrammatic approach to adiabatic pumping

P33 Tihomir Tenev
Modeling spin resolved transport through InSb quantum well

P34 Oleksandr Tsyplyatyev
Spin current generated by a thermal flow, magnetothermopower and magnetoresistance in metals embedded with magnetic nanosclusters

P35 Daniel Urban
Spin-dependent transport through quantum dots connected to three ferromagnetic leads

P36 Jing Zou
Variable-polarization source of spin-polarized current

School Abstracts

Photoelectron counting in quantum optics (T. Brandes)

This tutorial gives an overview over photoelectron counting statistics in quantum optics. Many of the original ideas were developed in the 1950s and 1960s, and I will therefore start with Mandel's semiclassical counting formula that promotes a simple (short time) Fermi-Golden rule calculation to a (long-time) probability distribution. Much of the tutorial will be devoted to the quest for a quantum version of that formula, a quest that appears to have had a great importance for the development of quantum optics as a whole and which is characterised by the subtleties of theoretically describing sources, fields, and detectors in a consistent manner. I will explain and in part (re)-derive in detail the approaches by Kelley/Kleiner [1], Scully/Lamb [2], and Ueda [3] whereby particular use is made of Scully and Lamb's photodetector model that describes the detector's backaction on the field. I will use a slightly modernised form of this model in order to briefly introduce calculational tools such as quantum master equations and Glauber's P-representation for single mode (cavity) fields without sources, before moving on to the more intriguing case of multimode fields with sources. I will then discuss practical questions such as how to obtain the counting distribution $p_n(t, t+T)$ from simplified master equations involving only sources. Here, motivated by single ion experiments, important contributions were made by several groups in the 1980s that lead towards the quantum jump (quantum trajectory) approach which in hindsight can be regarded as a 'by-product' of counting statistics. I will discuss resonance fluorescence and its conceptual similarities with quantum transport, such as Cook's early use in 1981 [4] of counting variables and generating functions in his counting statistics calculation.

Literature: introductory quantum optics texts such as Walls/Milburn [5] (some general stuff, spontaneous emission, resonance fluorescence, P-representation, correlation functions $g^{(1)}$ and $g^{(2)}$ etc.) or Carmichael [6] (master equations, photodetection, quantum trajectories, cf. my own lecture notes on quantum dissipation http://theoserv.phy.umist.ac.uk/~brandes), Mandel/Wolf [7]. Also parts of the original literature, in particular Scully and Lamb [2] (introductory parts), Ueda [3] (part III), and Cook [4].

References

[1] P. L. Kelley and W. H. Kleiner, Phys. Rev. **136**, A316 (1964).

[2] M. O. Scully and W. E. Lamb, Jr., Phys. Rev. **179**, 368 (1969).

[3] M. Ueda, Phys. Rev. A **41**, 3875 (1990).

[4] R. J. Cook, Phys. Rev. A **23**, 1243 (1981).

[5] D. F. Walls and G. J. Milburn, *Quantum Optics* (Springer, Berlin, 1994).

[6] H. J. Carmichael, *An Open System Approach to Quantum Optics*, Vol. m 18 of *Lecture Notes in Physics* (Springer, Berlin, Heidelberg, 1993).

[7] L. Mandel, E. Wolf, *Quantum coherence and quantum optics* (Cambridge University Press, Cambridge, USA, 1995).

Shot noise in nanostructures

Ya. M. Blanter

Delft University of Technology

In the first lecture, general properties of shot noise will be discussed: two-terminal noise in various structures; multi-terminal configurations; interference effects; hybrid systems. In the second lecture, we concentrate on two subjects related to recent developments: quantum noise and measurement of non-symmetrized cumulants, and observations of super-Poissonian noise.

Full Counting Statistics in Mesoscopic Electronics

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In the first part we will introduce the concept of full counting statistics, in particular, how it is applied to mesoscopic electronics. The counting statistics of a simple quantum contact (Levitov formula) is derived and consequences are discussed. In the second part we introduce the powerful Keldysh Green's function approach to full counting statistics. As examples we discuss the counting statistics of transport between normal and superconducting contacts.

One goal of this lecture to derive and understand the full counting statistics of simple quantum contacts. Some typical questions, which will be answered are the following

- What is *full counting statistics*?
  Imagine, we observe a current through a conductor over a certain time period t_0. The charge passing through some cross section will fluctuate in each observation. The reason for the fluctuations might be thermal or quantum origin. To describe this observation, we therefore need to know *the probability that a charge Q has passed the conductor in the time period* t_0, viz. the full counting statistics.

- What quantity do we consider?
  Instead of the probability $P_{t_0}(N)$ it is more convenient to consider the *cumulant generating function* (CGF), defined by

$$e^{-S_{t_0}(\chi)} = \sum_N P_{t_0}(N) e^{i\chi N} \, . \tag{1}$$

  From the CGF we generate by differentiation the cumulants, which characterize the distribution, in particular its

  – mean value: $\bar{N} = i\partial_\chi S_{t_0}(\chi)|_{\chi=0}$

  – width: $\overline{N^2} - \overline{N}^2 = \partial_\chi{}^2 S_{t_0}(\chi)|_{\chi=0}$

  Mean value and width are related to the average current and the low-frequency noise, respectively.

- What is the full counting statistics of a quantum contact?
  By a quantum contact we mean a coherent scatterer with probability T between two normal fermionic leads, characterized by (Fermi-)distributions $f_{1/2}(E)$. The answer is then given by the Levitov formula

$$S_{t_0}(\chi) = -\frac{2t_0}{h}\int dE \ln\left[1 + Tf_1(1-f_2)\left(e^{i\chi}-1\right) + Tf_2(1-f_1)\left(e^{-i\chi}-1\right)\right] \, . \tag{2}$$

- What happens for tunnel junctions?
  If the transmission probabilities are very small, we can expand the Levitov formula and obtain

$$S_{t_0}(\chi) = -N_{12}\left(e^{i\chi}-1\right) - N_{21}\left(e^{-i\chi}-1\right) \, . \tag{3}$$

  This corresponds to a bidirectional Poisson distribution, and $N_{12(21)}$ are the average number of electrons transfered from 1 to 2 (2 to 1). At zero temperature only one of the terms survive and we find Poissonian statistics, corresponding to independent tunneling events

- What happens at zero temperature?
  Electrons can only be transfered in one direction (i.e. $f_1 = 1 = 1 - f_2$) in the energy window eV determined by the bias voltage. The statistics reduces to a binomial form

$$S_{t_0}(\chi) = -M_{t_0} \ln\left[1 + T\left(e^{i\chi}-1\right)\right] \;\leftrightarrow\; P_{t_0}(N) = \binom{M_{t_0}}{N} T^N (1-T)^{M_{t_0}-N} \tag{4}$$

  The number of attempts is given by $M_{t_0} = 2eVt_0/h$.

Stochastic Path Integral Approach to Counting Statistics

Eugene Sukhorukov

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During recent years two theoretical methods have been developed that address the physics of electron transport and shot noise in mesoscopic conductors. One widely used method is based on the scattering states formulation of transport [1] and on the second quantization. It basically relies on solving the Schrödinger equation and semi-classical expansions, and assumes the phase coherent transport. The second method is classical right from the beginning, because it relies on solving Boltzmann kinetic and Langevin equations [1]. Despite such a dramatic deference, both methods were giving exactly same results for most of noise problems and for a number of experimental situations. This fact appeared to be so surprising that, for instance, Rolf Landauer could not believe that 1/3 noise suppression factor in diffusive conductors obtained by two methods reflects the same physics.

Although a rigorous justification of the Langevin approach to shot noise is still an open problem, the simplicity and the efficiency of the method was so appealing that it stimulated its further development and generalization. The new method has been proposed [2,3], which solves the shot noise problem by considering the time evolution of a mesoscopic system on a classical level and representing it with the help of the ”stochastic path integral” (SPI). This can be done in three steps: (1) Identify conserved quantity (generalized charge) Q. For instance, in the case of the elastic transport, the occupation function f(E) is conserved and plays the role of the generalized charge. The charge conservation is imposed by the Lagrange multiplier, P, which become a canonical conjugated variable. (2) Introduce the statistics of the fast current I=dQ/dt via its cumulant generating function H(P,Q), which generally depends on the charge Q. (3) Find a saddle-point solution of the canonical action: S=$\int dt[PdQ/dt + H(P,Q)]$, which becomes the cumulant generator of the full counting statistics. The saddle-point solution is justified by the large parameter: the number of electrons participating in transport.

Recently, the SPI method has been successfully applied to a number of noise problems. In my lectures I will mention some of them. In the first lecture I will briefly introduce the Langevin equation method, and will present the SPI solution. I will then discuss the cascade diagrammatics [4,3] which follows from SPI as a perturbation expansion and provides a simple method of evaluating low-order cumulants. In the second lecture I will present some applications of the SPI method, in particular, non-perturbative solutions which lead to the super-Poissonian noise [5].

[1] For a review on shot noise, see Ya. M. Blanter and M. Büttiker, Physics Reports 336, 1-166 (2000).
[2] S. Pilgram, A. N. Jordan, E. V. Sukhorukov, and M. Büttiker, Phys. Rev. Lett. 90, 206801 (2003).
[3] A. N. Jordan, E. V. Sukhorukov, and S. Pilgram, J. Math. Phys. 45, 4386 (2004).
[4] K. E. Nagaev, Phys. Rev. B66, 075334 (2002).
[5] A. N. Jordan, E. V. Sukhorukov, Phys. Rev. Lett. 93, 260604 (2004).

Notes

Conference Abstracts

Counting statistics of single electron transport in a quantum dot

S. Gustavsson[1], R. Leturcq[1], B. Simovič[1], R. Schleser[1], T. Ihn[1], P. Studerus[1], K. Ensslin[1], D. C. Driscoll[2], A. C. Gossard[2]

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[2]*Materials Department, University of California, Santa Barbara, CA-93106, USA*

We demonstrate the measurement of current fluctuations in a semiconductor quantum dot by using a quantum point contact as a charge detector [see Fig. 1]. Electrons traveling through the quantum dot are counted one by one. In addition to the shot noise, this method gives access to the full distribution of current fluctuations, known as full counting statistics [see Fig. 2]. We demonstrate experimentally the suppression of the second moment (variance, related to the shot noise) and the third moment (skewness) in a tunable semiconductor quantum dot [1], in agreement with theoretical predictions [2].
In semiconductor quantum dot systems it is envisioned that shot noise measurement provides a way to demonstrate entanglement of electrons [3]. However, this measurement is difficult with conventional methods, due to the very low current levels in quantum dots of the order of 10 fA. Our experimental technique allows to measure currents in the aA regime. Also the experimental resolution of the noise signal is 5-6 order of magnitude better than in previous experiments.

References

[1] S. Gustavsson, R. Leturcq, B. Simovič, R. Schleser, T. Ihn, P. Studerus, K. Ensslin, D. C. Driscoll and A. C. Gossard, cond-mat/0510269.
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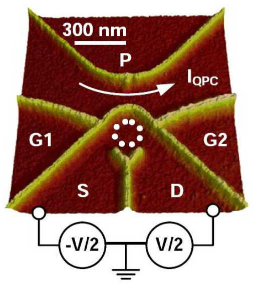

Figure 1: AFM micrograph of the sample, consisting of a quantum dot connected to two leads S and D, and a nearby quantum point contact.

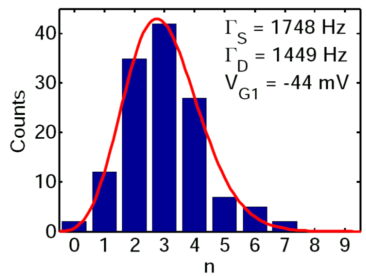

Figure 2: Distribution function of the fluctuations of the number of electrons traveling through the quantum dot in a given time. The parameters Γ_S and Γ_D are the tunneling rates (resp. from source and to drain), determined experimentally, and allowing to calculate the theoretical distribution (plain line).

Finite frequency quantum noise in an interacting mesoscopic conductor

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Shot Noise of a Quantum Point Contact in a Magnetic Field

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We report detailed simultaneous measurements of shot noise and dc transport in a quantum point contact as a function of source-drain bias, gate voltage and in-plane magnetic field. The magnetic field evolution of the *0.7 structure* in both conductance and noise is clearly visible and is compared to a simple model, giving good quantitative agreement.

Full Counting Statistics & Non-Markovian Effect in Strongly Interacting Systems

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We present a theory of Full Counting Statistics (FCS) for transport through interacting electron systems with non-Markovian dynamics [1]. In deriving a general expression for the cumulant generating function, we generalize previous approaches by properly accounting for non-Markovian effects [2].
The FCS, for strongly interacting systems, is obtained in the generalized master equation framework, with the introduction of a non-Markovian expansion [3]. With this tool we are able to systematically order the peculiar information on the memory effects contained in higher moments. On the other side, we formulate a perturbative approach grounded on the previous expansion opening the possibility to apply our theory and to study the relative importance of non-Markovian corrections in real cases. As a result we conclude that the importance of memory effects depends crucially both on the order of the considered moment and on the order of perturbation expansion.
We illustrate our approach calculating the FCS through a single-level quantum dot and a metallic single-electron transistor up to second order in the tunnel-coupling strength. To derive the generalized master equation we make use of the real-time technique for the time evolution of the reduced density matrix formulated on a Keldysh contour [4]. We explicitly show, in the examples, that non-Markovian effects become increasingly important for higher moments of the current fluctuations. We identify the limits of the Markovian approximation discussing under which circumstances non-Markovian effects appear in the transport properties. For the considered example we also clearly identify the effect of the renormalization of the level position and the coupling strength induced by the quantum fluctuations [5].
We hope our theory will contribute to develop new insight in the problem of the FCS for strongly interacting systems that, recently, has attracted the attention of the community both for the intermediate [6] as well as for the strong coupling regime [7].

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Charge transport statistics of quantum shuttles

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I will present a short overview of our work on shuttling instability. After introducing the concept of classical shuttling instability I will discuss its quantum counterpart and then focus on the charge transport characteristics of the shuttles. The numerical results for the mean current, zero- and full-frequency current noise and the third cumulant will be presented together with simpler (semi-) analytical theories of different regimes of the transport.

The talk should briefly cover topics found in the following papers:
PRL 90, 256801 (2003) - shuttling instability in the quantum regime
PRL 92, 248302 (2004) - zero-frequency current noise
EPL 69(3), 475 (2005) - FCS, third cumulant
Physica E 29, 411 (2005) - frequency dependent current noise

Coherence and noise in transport through coupled quantum dots

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Abstract

I will discuss some recent developments in the combination of quantum optics and electronic transport in low-dimensional mesoscopic systems[1], such as semiconductor quantum dots or superconducting Cooper-pair qubits. A double quantum dot model in presence of Coulomb-interactions and dissipation serves as a tool in order to study quantum optical effects (such as Rabi-oscillations, dark resonances and STIRAP, Dicke superradiance) in the context of electronic transport in the solid-state. After a glimpse of the theoretical machinery of counting statistics, spin-boson models and non-equilibrium transport master equations, I will discuss the electron current noise spectrum[2] from which for weak dissipation, dephasing and relaxation rates are extracted.

I finally present new results on charge entanglement in two Coulomb-coupled double quantum dots under stationary non-equilibrium transport conditions. The entanglement exhibits a switching threshold and various limits due to suppression of tunneling by Quantum Zeno localisation or by an interaction induced energy gap, which again can be extracted from quantum noise spectra.

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Adiabatic passage in superconducting nanocircuits

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With the rapid technological progress in quantum-state engineering in superconducting devices there is an increasing demand for techniques of quantum control. Stimulated Raman adiabatic passage (STIRAP) is a powerful method in quantum optics which has remained largely unknown to solid-state physicists. It is used to achieve highly efficient and controlled population transfer in (discrete) multilevel quantum systems [1].
Apart from other potential applications in solid-state physics, adiabatic passage offers interesting possibilities to manipulate qubit circuits, in particular for the generation of nonclassical states in nanomechanical or electromagnetic resonators [2].
In this presentation, we explain the idea of the method and describe examples of controlled quantum dynamics in superconducting nanocircuits by applying adiabatic passage. We show that STIRAP can be realized in a single superconducting charge-phase nanodevice and we calculate the effect of solid state noise on the fidelity of the population transfer [2].

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Current cross-correlations in mesoscopic devices

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In this talk, I would like to present two examples of electronic (fermionic) systems that exhibit positive current cross correlations [1].
The first example is a three-terminal device with one superconducting terminal and two normal-metal terminals [2]. We calculate the full distribution of transmitted charges into the two symmetrically biased normal terminals. In a wide parameter range, we find large positive crosscorrelations [3] between the currents in the two normal arms. We also determine the third cumulant that provides additional information on the statistics not contained in the current noise.
As a second example [4], we study current fluctuations in an interacting three-terminal quantum dot with ferromagnetic leads. For appropriately polarized contacts, the transport through the dot is governed by a novel dynamical spin blockade, i.e., a spin-dependent bunching of tunneling events not present in the paramagnetic case. This leads for instance to positive zero-frequency cross-correlations of the currents in the output leads even in the absence of spin accumulation on the dot. We include the influence of spin-flip scattering and identify favorable conditions for the experimental observation of this effect with respect to polarization of the contacts and tunneling rates.

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Non-local Andreev reflection: experimental observation and relevance for entangler devices

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Momentum-resolved tunneling into a short cleaved-edge wire

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Momentum-resolved tunneling between two parallel cleaved-edge GaAs quantum wires gives a tremendous amount of information on electron correlations in 1D. I will discuss our theoretical work motivated by experiments performed at Weizmann Institute. At high electron densities, 1D features in the nonlinear tunneling conductance and diffraction patterns due to the finite length of the tunnel junction allow to directly probe elementary excitations in the wires, which reflect spin-charge fractionalization in 1D, in good agreement with Luttinger-liquid (LL) theory [1]. Depleting electron density by a top gate, it is possible to tune the strength of electron interactions [2]. We can theoretically understand measured excitation velocities down to a low critical density when LL picture breaks down and electrons form a localized state. I will discuss this regime introducing the concept of quasi-wavefunction and considering strongly-interacting Wigner-crystal and spin-incoherent pictures [3].

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Quantum size phenomena in ultra-narrow 1D nanowires

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Are there any size limitations for a narrow normal metal channel to conduct an electric current? Is zero resistance still an attribute of a superconducting nanowire well below the critical temperature? Recent experiments give evidence that size does matter: below a certain limit quasi-one-dimensional normal metal wire turns into an insulator; and a superconducting channel with ~ 10 nm effective diameter acquires finite resistance. We have developed a method of progressive reduction of a nanowire cross section by ion beam sputtering. The method enables measurements in between the sessions of the ion bombardment giving an opportunity to study truly size phenomena on a same sample.

Textbook quantum mechanics states that when a particle with mass m^* is placed in a potential 'box' with characteristic dimension L, the energy spectrum is quantized: $E_n = (h^2/8m^*L^2)n^2$. The same is applicable for free electrons in metals: when the corresponding dimension is sufficiently small the discreetness of the conducting band should come into play. Two related effects might be observed: periodic modulation of kinetic properties as a function of the effective dimension L, and metal-insulator transition at $L < \lambda_{dB}$, where $\lambda_{dB} = h / (8m^*E_F)^{1/2}$ is the conducting electron de-Broglie wavelength and E_F is the Fermi energy. For observation of these phenomena it is mandatory that the energy level broadening $\delta E_n = \max (k_BT, hv_F / \ell)$ is smaller than the energy level spacing $\Delta E_{n,\, n+1}$, where T is the temperature, ℓ is the mean free path and v_F is the Fermi velocity. For 'good' metals with $E_F \sim 1$ eV and the effective mass m^* of the order of the free-electron mass m_0 dimensions ~ 1 Å are required, which makes experimental study rather problematic. However, for semimetals with low effective masses $m^* \sim 0.01m_0$ and the Fermi energy $E_F \sim 25$ meV systems with characteristic dimension ~ 40 nm are under consideration. We report experimental study of these quantum size effects in 1D and 2D bismuth structures.

Below a certain temperature T_c (typically cryogenic) some materials lose their electric resistance R entering a superconducting state. Following the general trend towards a large scale integration of greater number of electronic components it is desirable to use superconducting elements in order to minimize heat dissipation. It is expected that the basic property of a superconductor, i.e. dissipationless electric current, will be preserved at reduced scales required by modern nanoelectronics. Unfortunately, there are indications that for a certain critical size limit of the order of ~ 10 nm below which a 'superconducting' nanowire is no longer a superconductor in a sense that it acquires a finite resistance even at temperatures close to absolute zero. We report an experimental evidence for a superconductivity breakdown in ultra-narrow quasi-1D aluminium nanowires due to the so-called quantum phase slip phenomena.

Polarization dependence and local probe studies of the microwave induced zero resistance in the two dimensional electron system

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The recent discovery of zero resistance induced by microwave radiation in ultra-clean two-dimensional electron systems over extended regions of an applied perpendicular magnetic field has triggered a remarkably large and diverse body of theoretical works. The sheer multitude of theoretical models and their divergence underline that no consensus has been reached on the precise origin of this non-equilibrium phenomenon. In order to assist in isolating the proper microscopic picture, we have carried out a detailed polarization dependent study using an all-optical approach to guide the microwave radiation onto the sample and to produce any circular or linear polarization state. Circular polarization offers for instance the perspective of activating and deactivating the cyclotron resonance absorption by reversing the rotation for a given magnetic field orientation. Knowledge of the influence of the microwave polarization state on the microwave induced resistance oscillations may turn out an important litmus test to exclude certain theoretical models. We report also preliminary results on the use of local probe methods in the context of these microwave induced magnetoresistance phenomena. Such methods appear promising to measure microwave induced changes in the local electrostatic potential as well as the compressibility and, hence, may be particularly powerful to unravel the microscopic origin.

*Parts of this work have been carried out in collaboration with C. Jiang, B. Gorshunov, B. Verdene, A. Yacoby, L. Pfeiffer, K. West, R.Meisels, F. Kuchar, M. Dressel, K. von Klitzing.

SU(4) Kondo Effect in Carbon Nanotubes *

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The electronic states of a carbon nanotube (CNT) form one-dimensional electron and hole sub-bands. They originate from the quantization of the electron wavenumber perpendicular to the nanotube axis, $k_\perp$, which arises when graphene is wrapped into a cylinder to create a CNT. By symmetry, for a given sub-band at $k_\perp = k_0$ there is a second degenerate sub-band at $k_\perp = -k_0$. Semiclassically, this orbital degeneracy corresponds to the clockwise (↻) or counterclockwise (↺) symmetry of the wrapping modes[1]. In a CNT quantum dot, quantum fluctuations between orbital and spin degrees of freedom may dominate transport at low temperatures. This increased degeneracy yields an enhanced Kondo temperature. In some cases, the system obeys perfect SU(4) symmetry, and hence the spin and the orbital degrees of freedom are fully entangled[2]. We also point out that the orbital degeneracy in the dot itself is not enough for having SU(4) Kondo physics. In general, SU(2) Kondo physics is also possible. We show that neither an enhanced Kondo temperature nor linear conductance measurements can distinguish between the two symmetries. Instead, the non-linear conductance in the presence of a *parallel* magnetic field shows a four-peak structure, with different splittings for the spin and the orbital sectors, which unambiguously signals SU(4) Kondo physics. Our theoretical results are in good agreement with recent experiments by Jarillo-Herrero *et al*[3].

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* Work done in collaboration with Mahn-Soo Choi and Rosa López.

G_Q-corrections in Circuit Theory of Quantum Transport

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We develop a finite-element technique that allows one to evaluate correction of the order of G_Q to various transport characteristics of arbitrary nanostructures. Common examples of such corrections are weak localization effect on conductance and universal conductance fluctuations. Our approach, however, is not restricted to conductance only. It allows in the same manner to evaluate corrections to noise characteristics, superconducting properties, strongly non-equilibrium transport and transmission distribution. To enable such functionality, we consider Green functions of arbitrary matrix structure. We derive finite-element technique from Cooperon and Diffusion ladders for these Green functions. The derivation is supplemented with application examples. Those include transitions between ensembles and Aharonov-Bohm effect.

Current measurement by counting of single electrons

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We report measurements of a very small electrical current, I, (5 fA - 1 pA) by direct counting of the single electrons that tunnel through a one-dimensional series array of metallic islands separated by small tunnel junctions. The electrons were detected using a fast single electron transistor. We observe a well defined peak in the frequency spectrum of the signal at a frequency which corresponds to $f = I/e$. We present experimental and numerical studies of the line-width of these Single Electron Tunneling oscillations. We have numerically simulated the electron transport in the array using a direct Monte Carlo method, and compared the results with the experimental data. Both experimental and numerical power spectra are fitted to a Lorentzian around a center frequency f0, with a half width (see the figure below). We find that the line width of the oscillation is proportional to the frequency f. The experimental data agrees well with numerical simulations, except at very low currents where the experimental line-width is most probably increased due to difficulties in maintaining a stable bias.

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Rashba billiards

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We studied the energy levels of non-interacting electrons with spin-dependent dynamics due to Rashba spin splitting in confined two-dimensional billiard regions. The area and the perimeter term of the density of states and the smooth counting function for arbitrary shapes of Rashba billiards, and the next leading term for circular Rashba billiards are calculated by constructing the Green's function for these systems. We showed that such Rashba billiards always possess a negative energy spectrum unlike billiards with zero Rashba spin splitting. A semi-classical analysis is presented to interpret the singular behavior of the density of states for the negative energy spectrum. From the detailed analysis of the spin structure of Rashba billiards we found a finite spin projection in the out–of–plane direction.

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Magnetoelectronic Circuits:Torque, Pumping, and Noise

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An electric current sent through multilayers of normal metals (N) and ferromagnets (F) can excite the ferromagnetic order parameter and even reverse the magnetization [1]. Similarly, a precessing ferromagnet emits spin-currents to adjacent conductors [2]. Additionally, spin current noise in normal electric conductors in contact with nanoscale ferromagnets can be detected by an increase in the magnetization noise by means of a fluctuating spin-transfer torque [3]. Johnson-Nyquist noise in the spin current is related to the the increased Gilbert damping due to spin pumping, in accordance with the fluctuation-dissipation theorem. We will discuss all these phenomena in a unified picture using magnetoelectronic circuit theory [4].

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Spin-polarisation at finite temperature

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Spintronic devices rely the spin-polarisation of carrier electrons. Whilst this is straightforward to determine in 0 K band structure calculations and can be measured absolutely using superconducting tunnel or ballistic contacts, real devices will operate at room temperature or above. Recent measurements at Leeds have determined the temperature dependence of the polarisation of a ferromagnet in two cases: an ordinary diffusive current and also the tunnelling current in a magnetic tunnel junction.

By reformulating the well-known Levy-Zhang theory [1] for domain wall resistance it is possible to extract the spin-polarisation from measurements of this quantity. We have done so for epitaxial layers of FePd, revealing particularly heavy spin-flip magnon scattering in this material. This reduces the spin-asymmetry of the carriers to roughly one-third of its low temperature value at 300K. [2]

We have also investigated the relationship between polarisation and magnetic moment in an alloy of CuNi over the full magnetic phase diagram by tunnelling into a calibrated Co electrode. The tunnelling magnetoresistance, and hence polarisation, vanishes at the Curie point of the material as measured by VSM. A parametric plot of polarisation against magnetisation reveals an slight deviation from true proportionality [3].

We have also performed spectroscopic measurements of the resistance and magnetoresistance of our junction. This shows a sudden and unexpected motion of a fully-polarised minority spin band at about 200K, roughly 50K below the Curie point [4]. This band motion corresponds to the inflection of the polarisation with magnetisation. We are able to fit this data within the framework of the band motion revealed by the spectroscopy, using an extended, multi-band, version of the Stearns model for tunnelling spin polarisation [5].

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Single magnetic clusters embedded in matrix

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We will report the experimental device used to produce isolated magnetic clusters pre-formed in the gas phase from the Low Energy Cluster Beam Deposition (LECBD) technique [1]. Co-deposited in a superconducting matrix, the study of their magnetic properties will be performed using a micro-lithographied niobium matrix as a sensor to detect their uniform macrospin reversal under magnetic field in the 3D space [2]. On an other hand, we will interest in the origin and the structure of sub-gap spectra of Andreev bounds states in a superconducting film faced with embedded magnetic cluster [3] obtained at very low temperature from local density of state STM measurements [4]. Finally, we will also present preliminary results of electron tunnelling via discrete electronic levels in one 2nm-diameter CoPt cluster (300 atoms) embedded in an isolating MgO matrix. We focus our discussions on the correlations between the specific structure, morphology and the resulting electronic properties, attempting to describe at a nanoscale level the role of various contributions to the magnetic and superconducting behaviour of the systems, in particular the dominant role of the surface/interface effects.

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Shot noise in magnetoelectronic structures

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Shot noise is the low temperature temporal fluctuations of the electrical current through a conducting structure caused by the randomness of the electron scattering and the Fermi statistics. [1]. In this talk we employ the semiclassical Boltzmann-Langevin kinetic theory to study spin-polarized current fluctuations in several magnetoelectronic structures [2]. We explain the influence of spin polarization and spin-flip scattering on current fluctuations in a three-terminal spin-valve system which consists of a diffusive normal metal connected by tunnel contacts to three ferromagnetic terminals. It is shown that in such a multi-terminal spin-valve structure the shot noise and the cross correlations measured between currents of two different ferromagnetic terminals can deviate substantially from the unpolarized values, depending on the relative orientation of the magnetizations, the degree of spin-polarization of the terminals and the strength of the spin-flip scattering in the normal conductor [3]. We then propose a similar three-terminal spin-valve setup, to determine experimentally the shot noise of spin-current, which carries information on the spin-relaxation processes. We show that the spin Fano factor, defined as the spin shot noise to the mean charge current, strongly depends on the spin-flip scattering rate in the normal wire. We also show that in contrast to the charge current Fano factor, which varies appreciable only in the antiparallel configuration of the magnetizations at the two ends of the wire, the spin Fano factor allows for a more sensitive determination of the spin-flip scattering rate [4].
Finally we explain the shot noise in a fully ferromagnetic structure in which two ferromagnetic terminals are contacted by tunnel barriers to a diffusive ferromagnetic metal. We show that shot noise can probe the intrinsic density of states and the extrinsic impurity scattering spin-polarization contributions in the polarization of the wire conductivity. The effect is more pronounced where the electrodes are perfectly polarized in the opposite directions. While in this case the shot noise has a weak dependence on the impurity scattering polarization, it is strongly affected by the polarization of the density of states. For a finite spin-flip scattering rate the shot noise increases well above the normal state value and can reach the full Poissonian value when the density of states tends to be perfectly polarized. For the parallel configuration we find that the shot noise depends on the relative sign of the intrinsic and the extrinsic polarizations.

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Local spectroscopy of superconducting hybrid nanostructures

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I will review some of our recent experiments of STM spectroscopy of hybrid superconducting systems.
We studied the proximity effect between a superconductor (Nb) and a diluted ferromagnetic alloy (CuNi) in a bilayer geometry. We measured the local density of states on top of the ferromagnetic layer, which thickness varies on each sample, with a very low temperature Scanning Tunneling Microscope. The measured spectra display a very high homogeneity. The analysis of the experimental data shows the need to take into account an additional scattering mechanism. By including in the Usadel equations the effect of the spin relaxation in the ferromagnetic alloy, we obtained a good description of the experimental data.
Recently, we developed a very low temperature AFM-STM that combines the possibility to make force images of a mesoscopic structure, that can be only partially metallic, and the ability to perform tunnel spectroscopy. I will show that, with this unique tool, we have been able to perform the local spectroscopy of a submicron superconducting wire patterned by e-beam lithography.

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Non local transport at FS and NS double interfaces

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We review the theoretical understanding of crossed transport between two ferromagnetic or normal leads connected to a superconductor at a distance d smaller than the coherence length ξ, with an emphasis on the role of the geometry and interfaces transparencies. Crossed transport results from the combination of several processes:

1. Crossed Andreev reflection by which the Andreev reflected hole propagates in an electrode different from the incoming electron.
2. Elastic cotunneling by which an electron from one electrode tunnels through the superconductor in an another electrode.
3. Sequential tunneling.
4. Weak localization.

We show by different methods that the elastic cotunneling channel dominates for normal metals and localized interfaces. By contrast, crossed Andreev reflection is favored with a sufficient spin polarization in the antiparallel alignment. Weak localization can contribute to non local transport with normal metals and extended interfaces. Sequential tunneling due to out-of-equilibrium populations in the superconductor is expected for localized contacts. Finally we present recent results on the possibility of probing solely crossed Andreev reflection by the fluctuations of the Josephson effect involving spatially separated correlated pairs.

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Superconducting proximity effect in conical ferromagnets

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We report superconducting phase-periodic conductance oscillations in ferromagnetic wires with interfaces to conventional superconductors. The ferromagnetic wires were made of Ho, a conical ferromagnet. The distance between the interfaces was much larger than the singlet superconducting penetration depth. We explain the observed oscillations as due to the long-range penetration of an unusual ”helical” triplet component of the order parameter that is generated at the superconductor/ferromagnet interfaces and maintained by the intrinsic rotating magnetization of Ho.

Magnetic-field asymmetry in nonlinear mesoscopic transport

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The Onsager relations applied to electronic transport state that the conductance of a two-terminal conductor is an even function of the magnetic field. However, breakings of this symmetry may take place in the nonlinear regime. We find that magnetic-field asymmetries arise in mesoscopic systems only as a consequence of the charge response of the conductor, thus being a pure interaction effect [1]. We obtain for a a ballistic chaotic cavity connected to quantum point contacts an asymmetry in the fluctuations of the nonlinear conductance. We also investigate the nonlinear conductance of a Coulomb-blockaded quantum dot attached to chiral edge states and show that the out-of-equilibrium polarization charge is asymmetric under magnetic-field reversal.

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Cooper-Pair Molasses: Cooling a Nanomechanical Resonator with Quantum Back-Action

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We report on the detection of the measurement back-action of a superconducting single-electron transistor (SSET) which is tightly coupled to the position of a radio-frequency nanomechanical resonator. Due to the far from equilibrium conditions, the SSET exhibits non-trivial quantum noise properties, acting as an effective thermal bath which depends sensitively on the SSET bias point. Surprisingly, when biasing near a transport resonance, we observe cooling of the nanomechanical mode from 550 mK to 300 mK. The implications of this experiment range from ultra-sensitive force microscopy and the readout of quantum information devices, to the possibility of producing ultra-cold states of condensed matter. *Work in collaboration with: A. Armour (U. Nottingham), A. Clerk (U. McGill), O. Buu, A. Nayak, M. LaHaye, K. Schwab (L.P.S., U. Maryland).*

Electromechanical properties of a biphenyl transistor

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Since a few years electrical transport through gated single molecules has become an active research field both theoretically and experimentally [1,2]. We investigate the interplay between electrical and mechanical degrees of freedom in transport across a biphenyl molecule in the Coulomb blockade regime. In particular, we analyze the role played in the electrical transport by the twisting mode between the two phenyl rings.

At low biases we can restrict our analysis to the neutral and anionic (one extra electron) state of the molecule only. The neutral molecule has two stable configurations at finite dihedral angles ($\theta \approx \pm\pi/4$) while the anion state is planar. Charge transitions between the electrical states are thus modulated by Franck Condon amplitudes that account for the torsional degree of freedom yielding big phonon blockade effects [3,4].

We study the system using a generalized master equation for the reduced density matrix. We find that, due to the mechanically degenerate neutral state, the coherences and not only the populations of the reduced density matrix determine the transport characteristics [5]. We also consider an extension of the model to parameters which are not typical of biphenyl to capture the main features of a Hamiltonian that is quite generic for conjugated molecules.

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The SET - Resonator: Quantum Master Equations

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We analyse the quantum dynamics of a nanomechanical resonator coupled to a normal-state single-electron transistor (SET). Starting from a microscopic description of the system, we derive a master equation for the SET island charge and resonator which is valid in the limit of weak electromechanical coupling. Using this master equation we show that, apart from brief transients, the resonator always behaves like a damped harmonic oscillator with a shifted frequency and relaxes into a thermal-like steady state. We find that the magnitude of the resonator damping rate and frequency shift depend very sensitively on the relative magnitudes of the resonator period and the electron tunnelling time. We then derive reduced master equations which describe just the resonator dynamics. By making slightly different approximations, we obtain two different reduced master equations for the resonator. Apart from minor differences, the two reduced master equations give rise to a consistent picture of the resonator dynamics which matches that obtained from the master equation including the SET island charge.

Effect of DC and AC excitations on the magnetoresistance in high-density high-mobility GaAs quantum well systems

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Nonlinear properties of highly mobile two-dimensional electrons in AlGaAs/GaAs heterojunctions is a subject of considerable current interest. Several new transport phenomena have been observed in these systems recently. In the pioneer work [1] strong oscillations of the longitudinal resistance induced by microwave radiation have been observed at magnetic fields, which satisfy the condition $\omega = n\omega_c$, where ω is the microwave frequency and ω_c is the cyclotron frequency. The effect has been attributed to the indirect inter-Landau-level transitions due to photon-assisted scattering [2]. The minima of these oscillations can reach very low values, which are close to zero [3]. This so-called zero resistance state (ZRS), initiated extensive interest to the problem.

Another interesting nonlinear phenomenon has been observed in the response of the 2D highly mobile electrons to dc excitation [4]. Oscillations of the longitudinal resistance, which are periodic in inverse magnetic field, have been found at dc biases, satisfying the condition $h\omega_c/2\pi = 2R_cE_H$, where R_c is Larmor radius of electrons at Fermi level and E_H is Hall electric field, induced by the dc bias in the magnetic field. The effect has been attributed to Zener tunneling between Landau orbits, tilted by the Hall electric field.

In this work we report an observation of the resistance oscillations with magnetic field in a dc biased GaAs quantum well with a 2D electron gas density of an order of magnitude higher than that reported earlier. Moreover we have found resistance oscillations with magnetic field in response to a low frequency (10 KHz and 100 KHz) and a high frequency (10 MHz to 140 GHz) ac excitation. The particular form of the resistance oscillations under an ac excitation is markedly different from the dc case.

We show experimentally that for the low frequencies (10 KHz and 100 KHz) this difference is due to the averaging of the dc differential resistance over the period of the ac excitation. Although at high frequencies we were not able to measure correctly the magnitude of the ac current through the sample, we suppose, that a similar averaging could be taking place for the resistance oscillations, induced by rf and microwave excitation up to 40 GHz. In the ac excitation regime from 50 GHz up to 140 GHz the resistance oscillates with the external magnetic field similar to that observed earlier in AlGaAs/GaAs heterostructures [1, 3].

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Exotic Transport Properties of Two-Dimensional Graphite

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In two-dimensional honeycomb lattices such as a monolayer graphite and a triangular antidot lattice, electronic states are described by Weyl's equation for a massless neutrino when each site is occupied by an electron on average [1]. The system has a topological singularity at the origin of the wave vector ($\boldsymbol{k} = 0$), giving rise to nontrivial Berry's phase when $\boldsymbol{k}$ is rotated around the origin [2]. The singularity causes various zero-mode anomalies such as discrete jumps in the conductivities such as the diagonal conductivity [3], the off-diagonal Hall conductivity [4], the dynamical conductivity [5], etc. at the energy corresponding to $\boldsymbol{k} = 0$. In the absence of a magnetic field, the system belongs to a symplectic universality class even in the presence of scatterers unless their potential range is smaller than the lattice constant. Being combined with the presence of an odd number of current carrying channels, this leads to the absence of backward scattering [6] and the presence of a perfectly conducting channel [7], making a metallic carbon nanotube a perfect conductor with ideal conductance. In the presence of scatterers with range smaller than the lattice constant, the system crossovers from the symplectic to an orthogonal class [8,9], and to a unitary class if higher order $\boldsymbol{k}\cdot\boldsymbol{p}$ terms causing trigonal warping are considered [10] or in magnetic fields [11]. These symmetry crossovers manifest themselves as strong difference in localization effects due to disorder in both two-dimensional graphite and a carbon nanotube.

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Interaction effects, disorder, and transport in graphene layers.

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A single graphene layer shows unusual electronic properties because: i) The dispersion is linear near the Fermi level, describing a two dimensional Dirac equation and ii) Long range interactions are not efficiently screened, leading to a two dimensional analog of Quantum Electrodynamics. We review here recent work[1-7] which discusses novel features which can be expected in graphene sheets associated to these properties:

- Local and extended defects lead to the formation of localized electronic states near the Fermi level. Localized states lead to a finite elastic scattering time and an universal value of the low temperature conductivity. Extended defects induce self doping effects, although the bulk of the system can be considered a M'clean metal ".
- A magnetic field induces the formation of Landau levels and edge states, which can be hole like and electron like. These edge states interact with other surface states which can exist near a boundary, modifying the properties of the system in the Integer Quantum Hall and Fractional Quantum Hall regimes.
- Electron-electron interactions polarize the localized states near lattice defects, which can behave like lokal moments. The RKKY interaction mediated by the conduction band does not show oscillations, and favors ferromagnetism at low temperatures.
- A clean graphene layer is close to a ferromagnetic exchange instability. This tendency is enhanced by disorder.
- We also discuss how the features above mentioned are modified in multilayered systems.

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QED in a Pencil Trace

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Electronic properties of materials are commonly described by quasiparticles that behave as non-relativistic electrons with a finite mass and obey the Schrödinger equation. I will describe our experimental study of graphene (a free-standing single layer of carbon atoms) in which electron transport is essentially governed by Dirac's (relativistic) equation and charge carriers mimic relativistic particles with zero rest mass and an effective "speed of light" of 10^6m/s. We have found a variety of unusual phenomena characteristic of two-dimensional Dirac fermions. In particular, we have observed that a) the integer quantum Hall effect in graphene is anomalous in that it occurs at half-integer filling factors; b) graphene's conductivity never falls below a minimum value corresponding to the conductance quantum, even when carrier concentrations tend to zero; c) the cyclotron mass of massless carriers in graphene is described by Einstein's equation $E = mc^2$; and d) Shubnikov-de Haas oscillations in graphene exhibit a phase shift of π due to Berry's phase.

Electronic Structure of the Superconducting Graphite Intercalates

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Although not an intrinsic superconductor, it has been long-known that, when intercalated with certain dopants, graphite is capable of exhibiting superconductivity. Motivated by the recent discovery of superconductivity in the intercalated compounds C_6Yb and C_6Ca, with transition temperatures greatly in excess of that presently reported for other graphite-based compounds, we explore the architecture of the states near the Fermi level and identify characteristics of the electronic band structure generic to graphite intercalates. In particular, we show that, in all those — and only those — compounds that superconduct, an interlayer state, well-separated from the carbon sheets, becomes occupied. We comment on the significance of this band for superconductivity.

Unusual Transport Properties in Carbon Based Low Dimensional Materials: Nanotubes and Graphene

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The massless Dirac particle moving at the speed of light has been a fascinating subject in relativistic quantum physics. Graphene, an isolated single atomic layer of graphite, now provides us an opportunity to investigate such exotic effect in low-energy condensed matter systems. The unique electronic band structure of graphene lattice provides a linear dispersion relation where the Fermi velocity replaces the role of the speed of light in usual Dirac Fermion spectrum. In this presentation I will discuss experimental consequence of Dirac Fermion spectrum in charge transport, realized in two representative low dimensional graphitic carbon systems: 1-dimensional carbon nanotubes and 2-dimensional graphene. Combined with semiconductor device fabrication techniques and the development of new methods of nanoscaled material synthesis/manipulation enables us to investigate mesoscopic transport phenomena in these materials. The exotic quantum transport behavior discovered in these materials, such as room temperature ballistic transport, unusual half-integer quantum Hall effect, and a non-zero Berrys phase in magneto-oscillations will be discussed in the connection to Dirac Fermion description in graphitic systems. In addition, I will discuss our most recent measurement of Landau level splitting in strong magnetic fields up to 45 T.

Landau level degeneracy and quantum Hall effect in a graphite bilayer

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We derive an effective two-dimensional Hamiltonian to describe the low energy electronic excitations of a graphite bilayer, which correspond to chiral quasiparticles with a parabolic dispersion. The graphite bilayer is modelled as two coupled hexagonal lattices including inequivalent sites A, B and $\tilde{A}, \tilde{B}$ in the bottom and top layers, respectively. These are arranged according to Bernal ($\tilde{A}$-B) stacking , as shown in Fig. 1(a). A lattice with such symmetry supports a degeneracy point at each of two inequivalent corners of the hexagonal Brillouin zone, which coincide with the Fermi point in a neutral structure and determine the centres of two valleys of a gapless spectrum. At the degeneracy point, electron states on inequivalent (A/B or $\tilde{A}/\tilde{B}$) sublattices in a single layer are decoupled, whereas interlayer coupling $\gamma_{\tilde{A}B} \equiv \gamma_1$ forms "dimers" from pairs of $\tilde{A}$-B orbitals in a bilayer [solid circles in Fig. 1(a)], thus leading to the formation of high energy bands. The low energy states of electrons are described by the effective Hamiltonian [1]

$$\hat{H} \;=\; -\frac{1}{2m}\begin{pmatrix} 0 & (\pi^\dagger)^2 \\ \pi^2 & 0 \end{pmatrix}, \quad \text{where} \quad \pi = p_x + ip_y,$$

taking into account $A \rightleftharpoons \tilde{B}$ hopping via the $\tilde{A}$-B dimer state, with mass $m = \gamma_1/2v^2$. The high-magnetic-field Landau level spectrum consists of almost equidistant groups of four-fold degenerate states at finite energy and eight zero-energy states as shown on the left of Fig. 1(b) (here, spin is also taken into account). This can be translated into the Hall conductivity dependence on carrier density, $\sigma_{xy}(N)$, which exhibits plateaus at integer values of $4e^2/h$ and has a "double" $8e^2/h$ step between the hole and electron gases across zero density (solid line), in contrast to $(4n+2)e^2/h$ sequencing in a monolayer (dashed line). Note that recent Hall effect studies of ultra-thin films [2] featured both types of $\sigma_{xy}(N)$ dependence shown in Fig. 1(b).

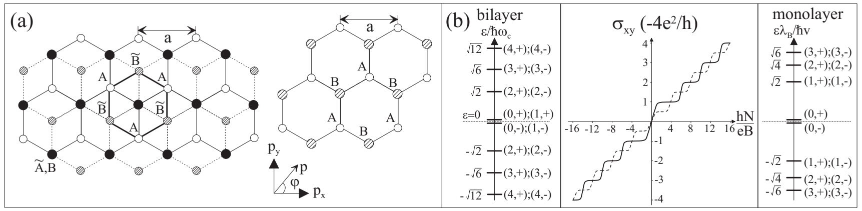

Figure 1: (a) left: schematic of the bilayer lattice (bonds in the bottom layer A, B are indicated by solid lines and in the top layer $\tilde{A}, \tilde{B}$ by dashed lines) containing four sites in the unit cell: A (white circles), $\tilde{B}$ (hashed), $\tilde{A}B$ dimer (solid). (a) right: the lattice of a monolayer. (b) Landau levels for a bilayer (left) and monolayer (right). Brackets (n, ξ) indicate LL number n and valley index $\xi = \pm 1$. In the centre the predicted Hall conductivity σ_{xy} as a function of carrier density for a bilayer (solid line) is compared to that of a monolayer (dashed line).

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Magnetic order in carbon structures

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I will discuss rather unknown theoretical and experimental studies published several years ago on the possible magnetic order and the ferromagnetic-like response in some carbon-based materials, which did not attract the necessary attention in the magnetism community. This scepticism may be well founded since not always a careful and systematic impurity study was provided to quantify the influence of ferromagnetic impurities. However, it appears now that this exaggerated scepticism was based on prejudices and not on scientific evidence. SQUID and MFM results on the ferro-(ferri)magnetism observed recently in highly oriented graphite and in light-polymerised fullerenes provide further evidence for magnetic ordering. A further proof for this ordering is given by the ferromagnetism induced by proton irradiation in different carbon-based samples, like oriented graphite, carbon-films and -nanowalls, and fullerene films. The impurity concentration is measured by PIXE with the same protons used for irradiation. Furthermore, I will show that with a proton microbeam one is able to produce magnetic spots of micrometer size on the surface of graphite samples. The influence of room-temperature aging has been studied on the microspots and will be shortly presented. I will review the recent theoretical work that supports the existence of room-temperature ferromagnetism in metal-free carbon structures containing only s- and p-electrons. Finally, I will describe briefly future research in this topic including the magnetic order in polymers and magnetic ions free oxides.

Quantum Hall effect and edge states in graphene

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Recently it has been possible to fabricate atomic monolayer thick free-standing monocrystalline graphite films[1]. This material, which does not exist in nature, is called graphene. The samples are deposited on a semiconductor, and applying a gate voltage it has been possible to create a high mobility two-dimensional electron gas moving on the graphene sheet. The experimentally observed quantum Hall effect in graphene[2,3] gives clear evidence of the two-dimensional character of the motion of the carriers. It has been claimed that the quantum Hall effect in graphene has an unconventional form and the precise Hall quantization has been explained by means of the Dirac-like dynamics of electrons in graphene or by performing microscopic calculations of the edge states.[4,5]
In this work we study some properties of graphene in presence of a high magnetic field.
1) We discuss the precise form of the quantization of the Hall conductivity. We argue that, once the valley degeneracy occurring in graphene is included, the Hall conductance can be understood in the general framework of the theory of the quantum Hall effect in two-dimensional systems.
2) We study the properties of undoped graphene in the quantum Hall regime. We find that the Zeeman coupling combined with the electron-electron interaction favors a spin-polarized ground state rather than a valley-polarized state. This ground state supports low energy collective excitations that are combinations of spin density waves and valley density waves. We discuss the possibility that spin texture excitations, Skyrmions, become the low energy charged excitations in the spin-polarized ground state.
3) Finally we analyze the properties of the edge states in the quantum Hall regime. Due to the valley degeneracy occurring in graphene, electron-like and hole-like Landau levels with different spin and valley orientation cross at the edge of the sample. In the undoped samples the Coulomb interaction produces repulsion between the states and forces the states to anti-cross, creating a valley and spin coherent stripe at the edge of the sample. We analyze the excitations occurring in this stripe and discuss their possible relevance in tunneling experiments.

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Photon correlation measurements on semiconductor nanostructures

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In the past, remarkable progress has been achieved in the development of tailored semiconductor micro-resonator structures which recently also enabled breaking experiments in fundamental cavity QED research. Especially regarding microcavity lasers, the very promising concept of *"thresholdless"* lasers has been theoretically predicted which might open the way for new applications in the field of quantum information processing. With increasing values of the coupling constant $\beta \rightarrow 1$, a gradual decrease of a clear "threshold" signature in the output intensity trace is expected which therefore complicates a direct identification of the lasing onset. Therefore, an appropiate interpretation of this feature might be given by an analysis of the second-order coherence of the emitted photon field [1].

Low-temperature µPL measurements under non-resonant pulsed optical excitation revealed the distinct narrow longitudinal emission mode structures of the resonators. The assignment of the mode spectra was verified by detailed theoretical simulations based on an extended transfer-matrix method. From our experimental data, high cavity quality factors up to $Q = E/\Delta E \approx 7700 - 12300$ have been measured for the fundamental mode. Power-dependent µPL studies over a wide range of excitation have revealed non-linear emission dynamics of up to 8 orders of magnitude where a *smooth transition* from spontaneous to stimulated emission could be clearly observed. With the aim to analyse this onset behaviour of stimulated emission in terms of photon statistics, a series of second-order coherence measurements have been performed under variable pump power. Our measurements revealed a strong positive correlation $g^{(2)}(0) > 1$ ("bunching") over a limited range peaked at the "threshold" region of excitation. This behaviour can be interpreted in terms of significant fluctuations in the corresponding photon field.

Furthermore, we report the direct observation of lateral quantum coupling between two self-assembled InGaAs/GaAs quantum dots. This coupled system (lateral quantum dot molecule) exhibits a distinctive spectrum consisting of both excitonic and biexcitonic emission lines. Photon cross-correlation measurements between these transitions display pronounced antibunching thus confirming the presence of quantum coupling. In addition, we show that the coupling between the dots can be manipulated using static electric fields, and that the electron occupation probability can be shifted to either dot. In this way, the system can be used as a tunable single-photon emitter simply by applying a small voltage.

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QUANTUM OPTICS WITH QUANTUM DOTS IN MICROCAVITIES: PHOTON PAIRS EMISSION

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Quantum dots are artificial atoms with a discrete electronic spectrum. A discrete photonic spectrum can be also built up by means of a semiconductor microcavity. By embedding quantum dots in microcavities, the electronic and photonic states become coupled allowing the manipulation of their quantum properties. In this talk, we will show how this combination of condensed matter and quantum optics is nowadays an excellent candidate for implementing quantum information processes. In particular, we will describe currently existing sources of photon pairs and we will theoretically analyze a new proposal for improving the quality of such emitters.

Ultra-fast dynamics of optically excited quantum dots

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Precise knowledge of the dynamics of nano-size quantum dots excited by external light pulses is necessary for many proposed applications, which require controlled quantum manipulations of the dot carrier states. Furthermore, there are a growing number of experiments capable of an accurate testing of the dynamics of small dot arrays and even of a single dot in the time domain from femtoseconds to picoseconds. Our theoretical research concentrated on this ultra-fast dynamics of the quantum dots in the strong confining limit, where only few carrier levels are excited [1,2]. We have demonstrated that the ultra-fast dynamics at low temperatures is mainly defined by the pure dephasing caused by the coupling with acoustic phonons, which does not change the occupation of the dot carrier states. Using the formalism of the generating functions [1] we have obtained exact analytical expressions for the dynamics of the density matrix of a single quantum dot containing exciton [1] as well as bi-exciton [2] states, which are excited by an arbitrary sequence of ultra-short light pulses. Our modeling of the four-wave-mixing (FWM) and of the pump-and-probe (PP) experiments has demonstrated an excellent agreement with the available experimental data [3]. In order to investigate the role of pure dephasing in the quantum manipulation of the dot states by external driving pulses of an arbitrary shape and duration we have calculated the dynamics of the density matrix of a few level dot using the numerical real-time path integral formalism [4]. The calculations revealed an unexpected phenomenon of suppressing of the phonon-induced decoherence and of the revival of the Rabi rotations in the system when the pulse amplitude exceeds a certain threshold value.

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Electron Interactions and Transport Between Coupled Quantum Hall Edge States

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A set of stacked two-dimensional electron systems in a perpendicular magnetic field exhibits a three-dimensional version of the quantum Hall effect if interlayer tunneling is not too strong. When such a sample is in a quantum Hall plateau, the edge states of each layer combine to form a chiral metal at the sample surface. We study the interplay of interactions and disorder in transport properties of the chiral metal, in the regime of weak interlayer tunneling. Our starting point is a system without interlayer tunneling, in which the only excitations are harmonic collective modes: surface magnetoplasmons. Using bosonization and working perturbatively in the interlayer tunneling amplitude, we express transport properties in terms of the spectrum for these collective modes, treating electron-electron interactions and impurity scattering exactly. We calculate the conductivity as a function of temperature, finding that it increases with increasing temperature as observed in recent experiments. We also calculate the autocorrelation function of mesoscopic conductance fluctuations induced by changes in a magnetic field component perpendicular to the sample surface, and its dependence on temperature. We show that conductance fluctuations are characterised by a dephasing length that varies inversely with temperature.

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Non-linear transport and particle-hole symmetry in a quantum Hall device(*)

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I shall present recent experimental results on edge-state transport through quantum point contacts in the quantum Hall (QH) regime. Finite-bias backscattering measurements between edge channels at filling factor $\nu = 1$ will be presented at different temperatures. Transport through the constriction displays a non-linear Luttinger-like behavior even in the integer QH regime in contrast with the linear tunneling predicted for integer edge states [1,2]. Both zero-bias enhancement and suppression of the inter-edge tunneling will be shown in a controllable way as a function of gate bias [2,3]. The observed evolution is connected to the local charge depletion in the constriction region and offers new insight into the link between QH charge-conjugation and Luttinger liquid description of edge channels [2]. I shall discuss the relevance of these experimental results in the context of the dynamics of the highly-correlated edge channels in the fractional QH regime [4]. Finally I shall demonstrate how charge-conjugation can be exploited in the design of new QH circuits where the transport properties of the hole component of a partially filled Landau level can be directly addressed.

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Intrinsic Spin Hall Edges

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The prediction of intrinsic spin Hall currents by Murakami *et al.* [1] and Sinova *et al.* [2] raised many questions about methods of detection and the effect of disorder. We focus on a contact between a Rashba type spin orbit coupled region with a normal two-dimensional electron gas and show that the spin Hall currents, though vanishing in the bulk of the sample, can be recovered from the edges. We also show that the current induced spin accumulation in the spin orbit coupled system diffuses into the normal region and contributes to the spin current in the leads.

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Mesoscopic spin Hall effect in multiterminal spin-orbit coupled nanostructures: Local spin densities, total pure spin currents, and their shot noise

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A plethora of theoretical approaches have recently converged toward the conclusion that the spin Hall effect of intrinsic origin, which is driven by the spin-split electronic band structure and carried by the whole spin-orbit (SO) coupled Fermi sea, vanishes in the bulk of a two-dimensional electron gas (2DEG) with Rashba SO interaction and arbitrarily small disorder [1]. However, in quantum-coherent multiterminal nanostructures made of such spin-split 2DEG it is possible to generate a sizable pure spin Hall current in the transverse electrodes when longitudinal conventional unpolarized charge current is injected through simply or multiply-connected sample geometries [2,3]. We have recently shown that such pure spin Hall flow, which is not accompanied by any net charge current in the transverse direction, is governed by the processes on the spin precession length scale induced by the quantum-mechanical transverse SO "force" [4,5], and it is resilient to weak disorder within the metallic diffusive regime [2,6]. Moreover, we propose an *all-electrical* scheme for the detection of (conserved and Fermi-surface determined) nonequilibrium total pure spin Hall currents by measuring voltages on multiple Aharonov-Casher rings [3], as well as an *optical* detection scheme of local spin fluxes by imaging the steady-state flowing spin densities [6]. Finally, we discuss insights into the induction and experimental detection of spin Hall quantum transport offered by the zero-frequency shot noise power spectrum of pure spin currents and its relation to shot noise of zero charge currents (whose noise is still non-zero due to the opposite flow of spin-↑ and spin-↓ electrons comprising the pure spin current) in the transverse leads of Rashba SO coupled nanostructures.

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Interplay of inter- and intra-Landau-level transitions in the microwave photoresponse of two-dimensional electron systems

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The observation of large magneto-resistance oscillations and zero-resistance in the main oscillation minima [1,2] induced by microwave radiation incident on high quality two-dimensional electron systems (2DES) at weak magnetic fields when the microwave frequency ω exceeds the cyclotron frequency ω_c has attracted great interest. The two mainstream approaches to explain these oscillations are based on indirect inter-Landau-level transitions [3,4] or on the creation of a non-equilibrium electron energy distribution [5,6]. Here we report about (i) a strong suppression of the magneto-resistance over a wide magnetic field range where $\omega < \omega_c$ as well as (ii) magnetic field intervals or 'windows' where the magneto-resistance is insensitive to the microwaves.

The suppression occurs at radiation frequencies below some sample dependent threshold $\omega_{\rm th}$. The resistance drops nearly all the way down to zero with increasing mobility of the 2DES and as the temperature is lowered. Magnetic field windows where the magneto-resistance does not respond to incident radiation appear for frequencies above $\omega_{\rm th}$. When close to the threshold, such a window is centered at the magnetic field for which $\omega \approx \omega_c/2$. At the same magnetic field, another window of no response appears for the frequency $\omega \geq 3\omega_{\rm th}$.

We show that the existence and position of these windows where the 2DES does not respond to microwaves can be quantitatively explained in terms of the single-particle energy spectrum of the two-dimensional electron system, which is comprised of disorder-broadened Landau levels with a level width which increases with increasing magnetic field. The threshold frequency $\omega_{\rm th}$ can be used to estimate the homogeneous Landau-level broadening. Both, the microwave induced oscillations and the suppression of the magneto-resistance, can be explained in terms of a non-equilibrium distribution function [5,6] for which under appropriate conditions the electron occupation is inverted, i.e., the derivative of the distribution function with respect to the energy has a positive sign for certain energy ranges. Whereas inter-Landau level transitions account for the magneto-resistance oscillations within this model, the strong suppression of the magneto-resistance is brought about by transitions within the Landau levels.

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Quasi-excitons and fractionally charged excitons in the vicinity of the $\nu = 1/3$ fractional quantum Hall state

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Two dimensional electrons subjected to a magnetic field form a rich physical system in which different regimes are possible. One of these is the Fractional Quantum Hall Effect (FQHE) regime, occurring at magnetic fields such that only a fraction of the lowest Landau level is populated and hence the electron-electron interactions dominate the properties of two-dimensional electrons. At precise values of the magnetic field, corresponding to special (fractional) values of the Landau level filling factor ν, electrons form incompressible liquids whose ground states are separated from the excited states by an energy gap. In the intermediate regions of magnetic fields and/or at higher temperatures the system is metallic-like. Magnetic field- and/or temperature-driven transitions from the incompressible to metallic states are well pronounced in magneto-resistance measurements. Our experiments show that clear signatures of the ν=1/3, 2/5, 3/7, 3/5, 2/3, 1 sequence of the FQHE states can also be clearly visible in magneto-photoluminescence spectra. A very specific feature of the physics of the FQHE are quasi-particles with fractional charge. They may appear as excitations of the incompressible states and can be monitored in the shot-noise of electric measurements. For a long time however they have also been anticipated to influence the optical emission spectra of the 2DEG via formation of fractionally charged excitons.

In this report we focus on the investigations of the most pronounced and representative, ν=1/3 FQHE state. The sample studied was a 200 Å wide GaAs/AlGaAs quantum well with a two–dimensional electron gas with concentration of $n_e \simeq 2 \times 10^{11}$ cm^{-2} and high mobility up to $\mu \simeq 4 \times 10^6$ cm^2/Vs.

The comparison of experimental results with theoretical calculations suggests that the observed, red shift of emission energy at the Hall plateau boundary may be due to the appearance of additional free charged quasi – particles that bind to an exciton, forming a fractionally charged exciton whose emission energy is expected to be lower, in analogy to well known charged excitons in n-type semiconductors. Emission in the insulating state of 2DEG at $\nu = 1/3$ is attributed to a neutral quasi–exciton whose complicated energy dispersion results in an emission doublet with its low energy line due to the recombination from excited excitonic states.

Bending the quantum Hall effect: Novel metallic and insulating states in one dimension

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One-dimensional conductors are the wires that will connect the circuits of tomorrow's nanoworld, so it is important to characterize their possible conducting phases. We study a novel one-dimensional wire state which arises at the corner of two quantum Hall systems joined at a 90 degree angle, and observe one-dimensional metallic and insulating states. Such non-planar confinement structures are unconventional for the quantum Hall effect and reveal the striking observation of a macroscopic one-dimensional state whose conductance increases with decreasing temperature. This single system can map out generic properties of disordered one-dimensional conductors since the metallic, critical, or insulating character is tunable with an external parameter, the magnetic field.

Dephasing without Heating: New Experiments and Old Theory

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Spin-polarized shot noise in diffusive spin-valve systems with non-collinear magnetizations

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Shot noise is the fluctuations of current through a mesoscopic system due to the discreteness of the electron charge. Correlations of the current fluctuations at low temperatures provide unique information about the charge, the statistics and the scattering of the current carriers. In magneto-electronics structures, in which the transport involves both charge and spin degrees of freedom, the current fluctuations are expected to contain spin-resolved information on the conductance process. Consequently spin-polarized current correlations can be used to extract information about spin-polarization degree, spin-dependent scattering and spin accumulation in ferromagnet-normal-metal structures. In this paper we study the shot noise in a spin-valve which consists of a diffusive normal metal wire of length L connected by tunnel contacts to two ferromagnetic reservoirs with non-collinear magnetizations.

To calculate shot noise we develop a spin-polarized semiclassical Boltzmann-Langevin [1] approach which accounts for spin-flip scattering in addition to the usual scattering at impurities and tunnel junctions. For non-collinear configuration the semiclassical distribution function in the normal metal is a 2×2 matrix in spin space. In the diffusive limit we derive basic equations for the fluctuating distribution function matrix and the charge and the three spin components of the current density matrix. The solution of these equations are implemented by the boundary conditions which are temporal current conservation rules at the contacts. In the contacts the fluctuations of current are written as sum of the intrinsic fluctuations due to the scattering into the contacts and the fluctuations due to fluctuations of the distribution functions.

Solving the diffusion equations and imposing the boundary conditions as described above, we obtain the mean charge and spin currents and the correlations of the corresponding fluctuations. To calculate the correlations of intrinsic fluctuations we used the results obtained by Tserkovnyak and Brataas [2]. For a symmetric double tunnel barriers case our final results for the Fano factor (charge shot noise divided by mean current ratio) are expressed as a function of the tunnel contact conductance $G = G^{\uparrow} + G^{\downarrow}$, the polarization $p = (G^{\uparrow} - G^{\downarrow})/G$, the mixing conductance $G^{\uparrow\downarrow}$, the spin-flip rate $\lambda = L/\ell_{sf}$ and the angle between the magnetizations of the ferromagnets θ. We found that the behavior of shot noise as a function of θ depends on ratio G/G_N, where G_N is the conductance of normal metal. For small values of this ratio shot noise behaves as a monotonic function, but by increasing this ratio shot noise reveals non-monotonic behavior.

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Carbon nanotube electron turbines: a novel design for man-made nano-motors

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We propose a new design for carbon nanotube motors, based on the torque generated by an electron wind driven through a chiral nanotube. Through a detailed analysis of electrons passing through such an electron-turbine, we find that the generated torque is sufficient to overcome frictional forces. Results for a variety of chiral nanotubes are presented.

P3

Observation of Multiple Soliton-Like Modes in Quantum Hall Edge Dynamics

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We probe the dynamics of high mobility quantum Hall systems using a novel coplanar wave-guide geometry, which gives us a huge dynamic range for high frequency measurements in continuous wave (CW) mode as well as time resolved measurements in the sub-nanosecond regime. Our 20ps time resolved measurements allowed us to identify new soliton-like modes propagating on top of edge magnetoplasmons. Other results include high order EMPs, high frequency Onsager relations, and dissipative attenuation.

P4

Correlations VS Impurities; or How to Go From Fractions to Integers in the Quantum Hall Effect

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We developed a novel ion implantation technique that allows us to vary the amount of disorder in high mobility 2-dimensional electron structures without affecting the density and the local interactions. This method can also be used in existing devices. Here, we used this method to probe the effect of impurities on the transport and quantum lifetimes of the system. we also quantified the correlation strength in relation to the gradual destruction of fractional states with increasing defect concentration.

FCS of NEMS

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In a recent series of papers, we have developed and applied a formalism for the calculation of the cumulants of the full counting statistics (FCS) and the finite-frequency noise for a large class of nano-electromechanical systems (NEMS) [1]. The formalism is applicable to transport setups described by a Markovian generalized Master equation. We apply the formalism to two models of quantum shuttles [2,3] and find that both systems in certain parameter regimes exhibit a dynamical bistability [4] leading to random telegraph noise with clear signatures in the FCS and the finite-frequency noise. In particular, we find for the zero-frequency noise that the bistabilities lead to a giant enhancement of the Fano factor F, reaching values ($F \sim 500$) far above the Poisson limit ($F = 1$).

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Full counting statistics for voltage and dephasing probes in a Mach-Zehnder interferometer

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We present a stochastic path integral method to calculate the full counting statistics of conductors with energy conserving dephasing probes and dissipative voltage probes. The approach is explained for the experimentally important case of a Mach-Zehnder interferometer, but is easily generalized to more complicated setups. For all geometries where dephasing may be modeled by a single one-channel dephasing probe we prove that our method yields the same full counting statistics as phase averaging over a slowly fluctuating phase.

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Spin Polarized transport in atomic-size ferromagnetic constrictions

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Ferromagnetic atomic contacts are the ultimate limit in the study of the spin polarized transport through a nanocontact. When the contact is made through only one atom the transport is in the quantum regime and one can safely use the Landauer formalism, by assuming that the opened channels are given by the overlap of the atomic orbitals.

In our experimental approach we used the break junction technique (BTJ) which, given the very good mechanical stability, allows us to study the electronic transport while narrowing the contact, from a 100 nanometers down to the tunneling regime. We use electron beam lithography (EBL) to define two electrodes with different coercive fields, connected by a 150nm x 100 nm x 30 nm bridge. The sample is then connected and fitted in a pendular cryostat which stands between the polar pieces of an electromagnet. Thus, the magnetic field is always in the plane of the junction and we can vary both its amplitude and angle. During the breaking the resistance is monitored using a standard 4 points AC setup.

In order to characterize a stable atomic contact, the anisotropic magneto-resistance (AMR) is recorded first, by varying the angle between the saturation field and the current lines. Then standard MR measurements are made for the angles corresponding to the minimum and the maximum of the AMR. In the tunneling regime IV curves and dynamical conductance are recorded which allows us to study the tunneling through a tiny gap (less then 1 A) in vacuum, and also can be used to rule out any contamination within the contact.

During the first experiments with suspended bridges, huge MR effects were observed [1], which were accounted for by magneto-elastic effects, which induce changes in the contact area of the two electrodes touching in an atomic constriction when changing the field. This was clearly evidenced in the tunneling regime were any tiny variation in the gap has a large resistive signature. By measuring the resistivity dependence with the angle of the (large) applied field, we could show the correlation between the expected changes in the gap and the length over which the bridge was suspended.

Measurements carried out without moving parts (no undercut below the bridge) revealed the intrinsic MR properties in these ferromagnetic contacts. Two different MR effects were evidenced: an orbital effect, for which the resistance varies as a consequence of the changes in the orbital overlap induced by the Spin-orbit interaction, and a DWR/TMR-like spin effect, where the resistance changes due to the difference in the available density of states at the Fermi level whenever an antiparallel configuration in the magnetization on the two sides of the contact is available.

Our measurements evidenced a new kind of MR contribution the atomic AMR [2], whose amplitude dominates the transport in the single atomic contact regime. This rather unexpected result may open new perspectives in the exploiting of this effect for practical applications.

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Electron Transport in Molecular Wires

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Molecular electronics represents a large step in device miniaturization and due to advancements in techniques useful devices have been built on the basis of individual molecules. The aim of this work is to theoretically model the transport properties of newly synthesized, candidate molecular switches that are contacted between gold electrodes. The molecular wires that are studied here have been designed and synthesised based on flourinone structures with added benzene rings. The conductance of molecules with lengths varying from 4 to 10nm are calculated. It is necessary to study these longer molecules, as they will impose a less stringent requirement on the contact lithography in a scalable device.

The computational approach that is used is a combination of the first principles DFT code SIESTA and previously developed transport codes, which uses a Greens function scattering approach to calculate the conductance. The molecule and contact regions are included in the quantum mechanical calculation and the size of the contact region is increased until a convergence in the conduction of the single molecule is found. The results are then compared to recent STM measurements of these molecules.

Low Temperature Decoherence in Josephson Junction Qubits

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Recent experiments give strong evidence that the main contribution to decoherence in charge Josephson qubits is coming from their coupling to fluctuating background charges (BC), impurities which can trap an electron. The BC model was studied in a number of theoretical papers [1,2] using a classical random telegraph process approach, which enables one to obtain the decoherence rate in the high temperature regime. Applying Keldysh formalism to the model, we found the exact long-time asymptote of the decoherence function at arbitrary temperature. At high temperature it coincides with the known result, while in the low temperature regime decoherence was found to be a linear function of temperature, exhibiting non-trivial non-monotonic behaviour as a function of coupling parameter. Our formula provides a clear guideline for how to check experimentally a) at which (high- or low-temperature) regime real experiments are conducted, b) the relevance of the model. Our calculations of relaxation rate at low temperature provide a possible explanation of the most striking feature of the experiment [3] (Astafiev et al.), namely quasi-linear dependence of spectral density of noise with humps at certain frequencies. Together with our estimations for the probability to have a low-energy impurity this gives us grounds to argue that the existing charge Josephson junction qubits are operating in a low-temperature regime.

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Using Qubits for Measuring Fidelity in Mesoscopic Systems

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We point out the similarities in the definition of the ‘fidelity’ of a quantum system and the generating function determining the full counting statistics of charge transport through a quantum wire and suggest to use flux- or charge qubits for their measurement. As an application we use the notion of fidelity within a first-quantized formalism in order to derive new results and insights on the generating function of the full counting statistics.

To Be Announced

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Magnetization Dynamics and Spin Pumping in Ferromagnetic Nanoclusters

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Abstract

We study magnetization dynamics in ferromagnetic nanoclusters or nanoparticles embedded in paramagnetic conductors. The precession of the magnetization of a ferromagnetic nanocluster is shown to transfer spins into surrounding normal metal. The additional Gilbert damping due to the spin pumping can be expressed within the same phenomenology of the Landau-Lifshitz-Gilbert formulation. The damping enhancement is governed by the mixing conductance or spin-torque parameter of the ferromagnetic-normal-metal interface. While discussing the results compare to the layered structured, we address the spin pumping induced collective behavior of dynamic exchange between such ferromagnetic nanoclusters within ballistic approximation.

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Spin and interactions in chaotic quantum dots

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I present an overview of our work on the Coulomb blockade phenomena in relation with spin physics in chaotic quantum dots. The effect of exchange interaction, spin-orbit coupling, finite temperature and external magnetic field on the Coulomb blockade peaks is studied. The interplay between spin-orbit coupling and external magnetic field brings new universality classes into the statistical description of chaotic quantum dots [1]. We show how spin-orbit coupling, exchange interaction, temperature effects and applied magnetic field significantly affect the statistical properties of Coulomb blockade phenomena.

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Local moment approach to multiorbital single impurity Anderson model with applications to transport in quantum dots

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Using a local moment approach of Logan *et al.* we developed an impurity solver for a single- and multi-orbital Anderson model. The existence of the local moment is taken from the outset and its value is determined through variational principle by minimizing the corresponding thermodynamical potential. The method is used to solve the Anderson impurity model with different number of orbitals. This system corresponds to quantum dots where the Kondo effect is expected in transport experiments. We study in details how the inter and intra orbital couplings affect the conductance in the low temperature limit. These couplings between electron spins at different orbitals destroy the Kondo effect.

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Transport Properties of Superconductor/Ferromagnet Hybrid Structure

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We have investigated the transport properties of superconductor/ferromagnet nanostructures, where two superconducting aluminum reservoirs are connected through two parallel ferromagnetic iron ellipsoids. The dimensions of the iron ellipsoids determine different switching fields that enable us to control their magnetization independently. In this sample geometry, electron co-tunneling between two iron leads is expected be canceled in measurement current. The subgap conductance is mainly contributed from Andreev reflection in each iron ellipsoid and crossed Andreev refelction from one iron ellipsoid to another. We have measured the magnetic field dependent transport properties and the primary results are presented in this poster.

Superconducting proximity effect in ferromagnetic domain structures

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Proximity effect in hybrid structures of superconductors and ferromagnets provides the possibility for the controlled studies of the coexistence of ferromagnetism and superconductivity. These structures show many interesting phenomena due to the interplay between ferromagnetic exchange interaction and the singlet superconductivity. One of the most important effects is the long range penetration of the superconducting correlations into the ferromagnetic systems with local inhomogeneity of the magnetizations. It is shown, theoretically, that in this case not only the singlet but also the triplet component of the superconducting condensate is induced in the ferromagnet due to proximity to the superconductor[1,2]. The singlet component has an oscillatory variation and penetrates into the ferromagnet over a short length, whereas the triplet component can spread over the full mesoscopic length of the ferromagnet, similar to the thermal penetration of the superconducting correlations into a normal metal. Very recently there has been experimental evidences, for the long range superconducting proximity effect in ferromagnets which are attributed to the induced triplet component [3,4].
In this paper we find a new type of long range superconducting correlations which can be induced into a ferromagnet domain structure consisting of two layered domains F1 and F2 with thicknesses d_1 and d_2, respectively, and an antiparallel orientation of the exchange fields $sign(h_1) = -sign(h_2)$. Using the quasiclassical Eilenberger equation in the clean limit, we obtain the proximity density of states and the superconducting pair amplitude function in the structure. We show that the exchange fields in each domain causes oscillations of the pair amplitude function. While the oscillating pair amplitude has an decreasing amplitude with the distance from superconductor in F1, it can have an increasing amplitude in F2 over a distance which depends on an effective exchange field $h_{\rm eff} = (h_1 d_1 - h_2 d_2)/(d_1 + d_2)$. For $h_{\rm eff} = 0$ the amplitude of oscillations increases over whole the thickness d_2 and reaches to the value of the pair amplitude function for a normal metal structure. If $h_{\rm eff} \neq 0$, then the amplitude of the oscillations will enhance up to some point and damp after that. The density of states at the Fermi level oscillates as a function of $h_2 d_2 / v_{\rm F}$ with a period of $\pi/2$. [5] The oscillations are amplified up to the point for which $h_{\rm eff} = 0$, at which the density of states becomes zero. After this point, the oscillations are damping. We show that this effect is originated from the cancellation of the exchange field induced phase of the Andreev reflected electrons-holes due to the antiparallel orientation of the exchange fields in two domains of the ferromagnetic structure.

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Non-sinusoidal current-phase relations in diffusive ferromagnetic Josephson junctions

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Ferromagnet-superconductor hybrid structures exhibit novel and interesting phenomena which have been studied extensively in the recent years. One of the most interesting effect is the possibility of the forming the so-called π Josephson junction in superconductor-ferromagnet-superconductor (SFS) structures. The existence of the π-junction in the layered SFS systems, which was first predicted by Bulaevskii *et al.* to occur for certain thicknesses and the exchange field energies of the F-layer, has been observed in the experiments[1,2]. In these experiments, the π-junction in diffusive SFS junctions is appeared as a cusp in the temperature dependence of the absolute values of the critical current. This nonmonotonic behavior is manifestation of a transition from 0 to π-state, in which the critical current at the crossover temperature is vanished.

Very recently a new experiment revealed another characteristic of the $0-\pi$ transition in SFS junctions, which was not detected before[3,4]. They reported the existence of a finite small supercurrent at the transition temperature $T_{0\pi}$ in diffusive SFS junctions for a certain thickness of the F-layer.

Recently, several authors have studied behavior of the finite critical current at the crossover in SFS junctions[5,6] in which the necessary equations implemented by the Kuprianov and Lukichev boundary conditions at the FS-interfaces[7]. We investigate the effect of the disorders at the FS-interfaces on the Josephson supercurrent in diffusive F-contact between two conventional superconductors. We adopt quasiclassical Green's functions method in the diffusive limit implemented by the general boundary conditions of Nazarov[8], which allow us to obtain the Josephson current through the contact for an arbitrary strength of the barrier at the FS-interfaces.

In two limits of high and low transparent interfaces for different exchange field and thicknesses of the F-layer, the current-phase relation (CPR) is sinusoidal provided that the weak proximity approximation is hold. This implies a zero supercurrent at the $0-\pi$ transition. We show that the corrections to these results, both in high and low transparent cases, produce a second harmonic term $\propto \sin(2\varphi)$. While for the low transparent interfaces the second harmonic term is so small to be neglected. For some of the values of the thickness and the exchange fields of the F-layer which lead to positive value of the second harmonic, the critical current at the $0-\pi$ transition has a small finite value. This finding is consistent with the experiment[3,4]. We also show that the second harmonic term at the $0-\pi$ transition can be of the same order of the first harmonic for an intermediate value of FS-interface transparency leading to a large residual supercurrent at the transition.

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Spin Transport in Superconductors

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In this study, we have derived transport equations that describe the flow of charge, spin and energy in a superconductor [1, 2]. The equations apply to a superconductor in a nonequilibrium state which may occur by contacting to ferromagnets, voltage biasing etc. which is relevant to recent experiments. We take into account the effect of spin flipping by magnetic impurities and spin orbit interaction which relaxes the spin current in the superconductor. Calculations for superconducting spin valves and relaxation of spin currents in a superconductor have been performed.

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Electronic bands of a graphite bilayer - comparison of AB and AA stacking

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We model a graphite bilayer as two coupled hexagonal lattices including inequivalent sites A, B and $\tilde{A}, \tilde{B}$ in the bottom and top layers, respectively. We consider two possible ways of arranging the two layers: (i) Bernal ($\tilde{A}$-B) stacking, as shown in Fig. 1(a), in which $\tilde{A}$ sites on the top layer are directly above B sites on the bottom (solid circles), and (ii) $\tilde{A}$-A stacking, Fig. 1(b), in which $\tilde{A}$ sites on the top layer are directly above A sites on the bottom and $\tilde{B}$ sites are directly above B sites. Our microscopic analysis uses the tight-binding model of graphite and the Slonczewski-Weiss-McClure parameterization of relevant couplings including nearest neighbour intralayer hopping γ_0, hopping γ_1 between closely coupled sites on different layers, as well as taking into account weaker coupling parameters. Typical dispersion relations are shown in Fig. 2.

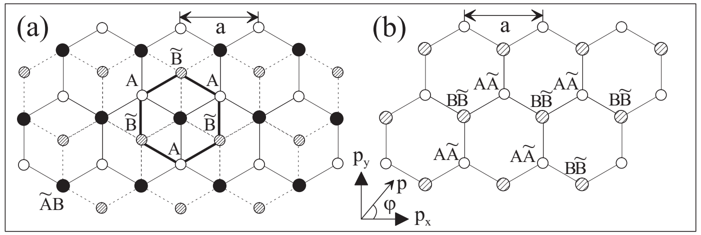

Figure 1: (a) plan view of the $\tilde{A}$-B bilayer lattice (bonds in the bottom layer A, B are indicated by solid lines and in the top layer $\tilde{A}, \tilde{B}$ by dashed lines) containing four sites in the unit cell: A (white circles), $\tilde{B}$ (hashed), $\tilde{A}B$ dimer (solid). (b) the lattice of a bilayer with $\tilde{A}$-A stacking.

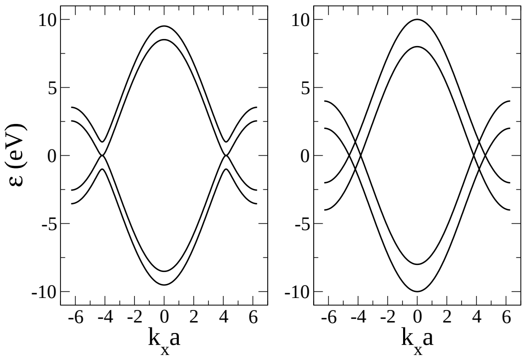

Figure 2: Left: energy dispersion for a bilayer with Bernal ($\tilde{A}$-B) stacking, and Right: energy dispersion for a bilayer with $\tilde{A}$-A stacking, taking into account one π electron per atomic site, using $k_y = 0$ and parameters describing intralayer hopping $\gamma_0 = 3.0eV$ and interlayer hopping $\gamma_1 = 1.0eV$, $\gamma_3 = \gamma_4 = 0$.

Electric Field Effect in Thin Graphitic Films

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2D gases have proved to be one of the most pervasive and reach-in-phenomena systems and, deservedly, they have been attracting intense interest of physicists and engineers for several decades, leading to the discovery of a whole range of new applications and phenomena including the widely-used field-effect transistor and the integer and fractional quantum Hall effects. So far, all 2D systems (2DS) have been based on semiconducting materials where carriers are induced by either local doping or the electric field effect[1]. As concerns metallic materials, many earlier efforts have proven it difficult to change intrinsic carrier concentrations by EFE even in semimetals (see, e.g., [2,3]), and a possibility of the formation of 2D gases in such materials was never discussed. The origin of these difficulties lies in the fact that charge densities induced by EFE cannot normally [4] exceed $10^{13}\ cm^{-2}$, which is several orders of magnitude smaller than area concentrations in a nm-thin film of a typical metal. Accordingly, possible EFE would be obscured by a massive contribution from bulk electrons. Prospects of the observation of a fully-developed 2DS in a metallic material seem to be even more remote, because locally-induced carriers could merge with the bulk Fermi sea without forming a distinct 2DS. Furthermore, because the screening length in metals never exceeds a few Å, EFE-induced carriers may also end up as a collection of puddles around surface irregularities rather than form a continuous 2DS.

Here we report a strong ambipolar field effect at the surface of graphite. We have investigated EFE-induced carriers in this semimetal by studying their Shubnikov-de Haas (SdH) oscillations and analyzing the oscillations' dependence on gate voltage Vg and temperature T. This has allowed us to fully characterize the carriers and prove their 2D character. The 2D electron and hole gases (2DEG and 2DHG, respectively) exhibit a surprisingly long mean free path $l \approx 1\ \mu m$, presumably due to the continuity and quality of the last few atomic layers at the surface of graphite where the 2D carriers are residing. Our results are particularly important in view of current intense interest in the properties of thin [5-9] and ultra-thin [10,11] graphitic films.

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Decoherence and decoupling in superconducting nanocircuits

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Solid state devices potentially offer scalable solutions for the implementations of quantum bits. However they are subject to broadband noise originated from different sources. Typically impurities located close to the device or at tunnel barriers may give rise to $1/f$ noise at low frequencies, which coexists with noise at typical operating frequencies (GHz). The broadband character of the noise, as well as its non-Gaussian and non-Markovian character, require special methods in the theoretical analysis and special techniques for protection against decoherence.

The time evolution of a superconducting qubit in the simultaneous presence of low frequency non-Markovian and non-Gaussian noise, and of high frequency quantum noise is analyzed. We present different techniques ranging from analytical treatments based on generalized master equation and on path-integrals to numerical approaches based on stochastic Schrödinger simulations and exact diagonalization methods. By exploiting these different techniques we are able to deal with the various typical scenarios for decoherence in the solid state.

In some situations a simple picture encompassing various regimes emerges. The effect of noise in a series of standard protocols operated on single qubits may be analyzed. Experimental data on superconducting qubits are well explained.

Non-Markovian low frequency classical noise due to switching impurities determines inhomogeneous broadening of the signal. The theory is extended to include the effects of high-frequency quantum noise, generated by impurities or by the electromagnetic environment. The interplay with intrinsically non-Gaussian noise sources may explain the rich physics observed in the spectroscopy and in the dynamics of charge based devices [1].

We also study echo and bang-bang protocols showing that for non-Gaussian colored noise the recovery of the coherence is possible for very large pulse frequencies. The possibility of faster decay if the control field is operated at lower frequencies, a phenomenon reminiscent of the anti-Zeno effect, is evidenced. We argue that the rich variety of behaviors under a control field suggests that control techniques may be a useful tool to get insight on noise at otherwise hardly accessible high frequencies [2].

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Symmetry breaking in molecular wires

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We present a theoretical study of electron transport through molecules connected between metallic electrodes. The systems investigated are the terphenyl dithiol (TPD1) and a three ring oligomer of phenylene ethynylene with dithiol molecule (TPD2); both of which are contacted between gold leads on the (111) surface. We report first–principles calculations of the conductance through these molecules and show that breaking the symmetry by rotating sections of the molecule, causes the position of the transmission resonances to shift and change in magnitude.

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Dynamically induced entanglement and decoherence. (The quantum to classical crossover)

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In the decades since its inception, no observed phenomenon, nor experimental result ever contradicted quantum theory. Yet, the world surrounding us, though being made out of quantum mechanical building blocks, behaves classically most of the time. This suggests that, one way or another, classical physics emerges out of quantum mechanics. Today's common understanding of this quantum-classical correspondence is based on the realization that no finite-sized system is ever fully isolated. It is then hoped that a large regime of parameters exists where the coupling of the system to external degrees of freedom destroys quantum interferences without modifying the system's classical dynamics. I will discuss the link between entanglement and decoherence in dynamical systems. Firstly, I will show how a classically vanishing interaction generates entanglement between two initially non-entangled particles, without affecting their classical dynamics. As illustration, I will show that the one-particle Wigner function, follows classical dynamics better and better as one goes deeper and deeper in the semiclassical limit. Finally, I will present a few preliminary results on dynamical multipartite entanglement and decoherence with a bath of coupled chaotic systems.

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Abstract

When two fully polarized ferromagnetic (F) wires with opposite polarizations make contact with a spin-singlet superconductor, a potential-induced current in wire 1 induces a non-local current of equal magnitude and sign in wire 2. The magnitude of this current has been studied in the tunneling limit and found to decay exponentially with the distance between the contact. Later on it has been shown that inserting a normal conductor between the ferromagnetic contacts and the superconductor enhances the effect. In this paper we propose a new structure in which this novel non-local effect is also increased by orders of magnitude compared to the tunneling case, while no ferromagnetic contacts are needed. We study the electronic transport of a NS hybrid π-nanojunction when an external magnetic field is applied, and demonstrate that when a normal region is placed between the leads and superconductor, the non-local current exhibits oscillations as a function of the external magnetic field, making the effect tuneable with the field.

Superconducting critical temperature dependence on the layer sequence in Nb/Pd bilayers

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The use of quasimagnets (QM) like Pd as spacer layers between a superconductor (SC) and a ferromagnet (FM) can offer new tools in the design of devices based on SC/FM proximity structures. The main benefit is the possibility of tuning the magnetism by varying the thickness of the QM. Superconducting spin-switch devices, where the superconductivity is switched on and off by changing the magnetic moment alignment of the two FM layers in a FM/SC/FM structure, are an example of devices whose success relies on the careful optimisation of magnetism-related parameters. Design based on trilayered structures assume perfect symmetry between the top and bottom non-superconducting layers. This in reality is not always the case, as we show for the sputtered Nb/Pd system.
The value of the superconducting critical temperature, T_C, when Nb is grown on to of Pd (Pd/Nb) is consistently and reproducibly higher than in the case of Pd as top layer (Nb/Pd), up to a difference of 0.7K in the thick Pd limit ($\approx 30nm$). Low T resistivities are also different, with ρ(Pd/Nb) $>$ ρ(Nb/Pd). Furthermore ρ(Pd/Nb) shows a clear dip at $T \approx$230K.
By interpolating the data with both proximity effect and transport models, the main difference between the two bilayers is the mean free path in the Pd/Nb sample.
We interpret the previous results as possibly linked to the effect of an increased disorder in the Pd under-layer, which quenches the magnetism and favors the superconductivity.

Commensurability oscillations in the surface-acoustic-wave-induced acoustoelectric effect in a two-dimensional electron gas

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We study the acoustoelectric effect generated by surface acoustic waves (SAW) in a high-mobility two-dimensional electron gas with isotropic and especially small-angle impurity scattering. In both cases the acoustoelectric effect exhibits Weiss oscillations periodic in B^{-1} due to the commensurability of the SAW period with the size of the cyclotron orbit and resonances at the SAW frequency $\omega = k\omega_c$ multiple of the cyclotron frequency. We describe how oscillations in the acoustoelectric effect are damped in low fields where $\omega_c\tau^* \lesssim 1$ (with the time scale τ^* dependent on the type of scattering) and find its nonoscillatory part, which remains finite to the lowest fields.

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Structural and magnetic properties of CoPt mixed clusters embedded in matrix

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Nanomagnets have attracted a considerable interest for their fundamental properties as well practical applications in magnetic storage. In those structures the ratio between surface and volume atoms cannot be neglected and new properties such as enhanced magnetic moments and/or enhanced magnetic anisotropy energy (MAE) at the lower coordinated atoms are observed [1]. In the application field, the main problem is the superparamagnetic limit: above the so-called blocking temperature, the thermal energy is comparable to the MAE and the magnetization direction is no more stable. In this study we determine the structure and magnetic properties of mixed CoPt nanomagnets, which could display a high MAE when produced in the $L1_0$ ordered phase.

The nanomagnets are truncated octahedron shaped clusters produced by the condensation of a stoichiometric vapor with an inert gas (helium). They are co-deposited in UHV condition with an atomic beam (Nb or MgO) to produce an assembly of clusters embedded in a matrix. Their structure is investigated using transmission electron microscopy. We find that clusters have a mean diameter of about 2 nm, which means that they are composed of about 300-400 atoms. Using the diffraction pattern, we have found that CoPt clusters adopt the A1 FCC disordered phase [2].

The clusters magnetic properties in MgO and Nb matrix are first investigated using the X-ray Magnetic Circular Dichroism (XMCD) at the ESRF - ID08 beamline. For both matrix, the Co spin and orbital moments determined at the Co $L_{2,3}$ edges are found to be very low as compared to the bulk. This is interpreted as core-shell structure where some surface layers are non magnetic and where the center atoms moments are close to the bulk value. In the MgO matrix, this is attributed to the formation of an antiferromagnetic CoO shell whereas, in the Nb matrix, the non magnetic layers are interpreted as the formation of a CoNb alloy for the two first layers, which is coherent with previous results on pure Co clusters [3]. As a result, the 'magnetic size' is reduced in both cases and corresponds respectively to about 200 and 60 atoms respectively in MgO and Nb. The cluster MAE was determined with hysteretic loops and zero field cooled (ZFC) measurements by SQUID magnetometry. The blocking temperature T_B, defined as the temperature below which coercively and remanance appear, is found to be 40 K and 12 K respectively for clusters in MgO and Nb. This fact is mainly attributed to the higher magnetic cluster volume when embedded in the MgO matrix. We fit the ZFC curve taking into account the clusters magnetic size distribution. This enables us to distinguish between a volume and a surface anisotropy. The volume anisotropy is found to be 10^5 J/m^3 in both cases, much higher than for pure Co clusters [3-4], which points out the effect of Pt even in non ordered clusters. The surface anisotropy is quite high and represents about 80 % of the total MAE. Once more, this surface anisotropy is found to be higher in the MgO matrix than in the Nb matrix, certainly due to the antiferromagnetic shell, which causes an exchange anisotropy [5].

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Entanglement and transport through correlated quantum dot

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The local entanglement was recently used to identify the quantum phase transitions in the extended Hubbard model [1]. We present the similar approach to study the correlated quantum dot in a linear–response regime. The results show, that maximal quantum value of the conductance $2e^2/h$ not always match the maximal entanglement. The pairwise entanglement between the quantum dot and the nearest atom of the lead is also analyzed by utilizing the two–qubit Wootters formula [2] for *charge* and *spin* degrees of freedom separately. The coexistence of zero concurrence and the maximal conductance is observed for low values of the dot–lead hybridization $V \leqslant V_c$. The critical value V_c gradually increase with the electron interaction U. Moreover, the pairwise concurrence vanish simultaneously for charge and spin degrees of freedom, when the Kondo resonance is present in the system.

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Quantum versus Classical division of current fluctuations.

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We investigate the current shot noise at a three terminal node in which one of the branches contains a noise generating source and the correlations are measured between the currents flowing through the other two branches. Interestingly, if the node is macroscopic, the current correlations are positive, whereas for a quantum coherent mesoscopic node anti-bunching of electrons leads to negative correlations. We present specific predictions which permit the experimental investigation of the crossover from quantum mechanical noise division to macroscopic noise noise division.

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Stabilization mechanism of edge states in graphene

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A single layer of graphite or graphene is an element of various carbon-based materials such as carbon nanotubes and fullerenes. These materials are promising candidates for future nanotechnology and deep understanding of their properties is indispensable. In particular, the electrical property has attracted much attention. It is mainly determined by the π-electrons near the Fermi level of graphene. The energy spectrum near the Fermi level consists of not only delocalized bulk states but also localized edge states. Theoretically, edge states are zero energy eigenstates relative to the Fermi energy and are predicted to make a certain magnetic ordering[1]. Experimentally, a direct measurement by scanning tunneling microscopy and spectroscopy of graphite edge has been observed a peak in local density of states[2,3], which can be identified as the edge states. An interesting point is that the peak is located not just at the Fermi energy but below the Fermi energy by about 20-30 meV.

Since several possible perturbations shift the energy eigenvalues above the Fermi energy, it is not a simple problem to find a consistent perturbation that can reduce or stabilize the energy of the edge state. We propose a mechanism, which reduces the energy of the edge states with respect of the Fermi energy. The mechanism consists of next nearest-neighbor (nnn) hopping process in addition to the original nearest-neighbor (nn) tight-binding model. The energy reduction of the edge states is calculated by first order perturbation theory and numerically. The resultant model is consistent with the peak of the measurements[4].

The importance of the nnn hopping process is also emphasized by Pereira *et al.*[5] The effects of nnn hopping on the edge states in the presence of a magnetic field are analyzed by Peres *et al.*[6] and Castro *et al.*[7]

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Even-Odd Effects in Monovalent Atomic Chains

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Over the last ten years many advances in experimental setup to create monatomic wires of Au, Pt and Ir have been made [1]. These systems exhibit an interesting phenomena called even-odd effect. Since the emergence of this phenomena, many attempts have been made to describe it, but as such an all-encompassing theory does not yet exist. In this poster, a very simple and general formulation of transport equation is presented. The equation predicts that the even-odd effect aditionally depends on a phase shift due to the coupling to the leads. The phase shift was verified in various systems by using the ab-initio code SMEAGOL [2] to perform electron transport simulations on Au and Na chains. The results demonstrate the highly non-universal behaviour of the conductance. Therefore, it is now possible to reconcile a large number of apparently contradictory results in recent literature.

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A diagrammatic approach to adiabatic pumping

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We consider adiabatic charge pumping through an interacting single-level quantum dot. We present a general perturbation theory approach for the adiabatic expansion using a diagrammatic technique [1,2] and apply it to the pumped current up to second order Γ contributions in the self energy. It turns out that second leading order contributions of the perturbation expansion of the adiabatically pumped charge are exclusively due to level renormalization effects.

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Modeling Spin-Resolved Transport Through InSb Quantum Well

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In this work we try to model the spin resolved transport in one of the possible schemes for spin-transistor. The basic idea behind this device is to control the flow of electrons not by using their charge but their spin degree of freedom. This is can be achieved by using the Rashba spin-orbit coupling, which is strong effect in narrow gap semiconductors. The simulations are done for InSb quantum well, using the Lancaster Transport Codes. We report data for the conductivity and conductance for the two possible states of the transistor on and off. We also look at the case when the device is not perfect and noise is present at the gate.

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Spin current generated by a thermal flow, magnetothermopower and magnitoresistance in metals embedded with magnetic nanosclusters

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We analyse breaking of electron-hole symmetry in metalls with embedded ferromagnetic nano clusters showing that a spin current occurs as a response to an applied temperature gradient and magneto-themoelectric power is relalated to the polarisation of this systems in the same way as magneto-resistance. Simultanious measurements of MTP and MR are proposed to extract ratio between single cluster parameter parameters, exchange energy J and scalar potential U

Spin-dependent Transport through Quantum Dots connected to Three Ferromagnetic Leads

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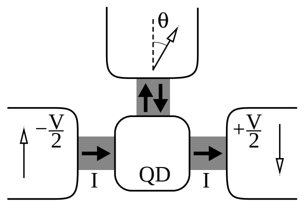
Transport through a non-magnetic, single-level quantum-dot with ferromagnetic leads is investigated in the sequential tunnelling regime by a real-time diagrammatic technique. If a current is forced through the system, spin accumulates on the dot, which reduces transport (spin-valve effect). The interplay of Coulomb interaction and ferromagnetism gives rise to an exchange field [1], in which the spin precesses so that transport is enhanced. In addition the spin decays, but due to the finite polarizations this decay is anisotropical and depends on the orientation of the lead magnetizations.
We consider setups in which a current flows only between two of the leads. The third lead is kept current-free and enters only by its ferromagnetic properties, i.e. exchange field and anisotropic spin decay. In this way the spin on the dot can be modified without additional charge currents.



The two systems analysed are a quantum dot spin-flip transistor with coplanar magnetizations (see picture) and a setup with pairwise orthogonal lead magnetizations. In both cases spin precession due to the third lead further enhances transport while in the latter we additionally predict asymmetries in the conductances under current reversal.

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Variable-polarization source of spin-polarized current

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We present low temperature measurements of Co/Al spin valve system with double-electrode spin injector. Using in-plane magnetic field, the injector electrodes were put in antiparallel magnetization state. The spin polarization of the injected current was varied by changing current ratio through the two electrodes and could be continuously changed from $\pm 40\%$, the maximum spin polarization of Co. This result was verified by measuring spin valve signal using the third, detector, electrode magnetized to align with one of the injectors. The source demonstrated here can be used for spintronics applications as well as in research on hybrid ferromagnet/superconductor structures.

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