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Conference on

"Quantum Phenomena in Confined Dimensions"

(4 – 8 June 2007)

ABSTRACTS

of

INVITED TALKS

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Conference on "Quantum Phenomena in Confined Dimensions"
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Eva Y. ANDREI
Rutgers University, Piscataway, U.S.A.

Title:
Observation of Dirac Fermions in Graphene and Graphite.

Abstract:

The recent synthesis of graphene (a single layer of graphite) has uncovered a fountainhead of remarkable electronic properties that are linked to the emergence of a new class of quasiparticles, Dirac-fermions, whose properties are governed by quantum-relativistic dynamics. I will describe scanning tunneling spectroscopy and transport experiments that provide access to these quasiparticles. Our findings include the direct observation of Landau levels of massless Dirac-fermions in graphene, evidence of the coexistence of massless and massive Dirac-fermions on the surface of graphite and the observation of induced superconductivity in single layer graphene.

* In collaboration with Guohong Li, Xu Du and Ivan Skachko

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Leon BALENTS
UCSB, Physics, Santa Barbara, USA

Title:
Semiclassical dynamics and long time asymptotics of the central spin problem

Abstract:

The spin of an electron trapped in a quantum dot is a promising candidate implementation of a qubit for quantum information processing. We study the central spin problem of the effect of the hyperfine interaction between such an electron and a large number of nuclear moments. Using a spin coherent path integral, we show that in this limit the electron spin evolution is well described by classical dynamics of both the nuclear and electron spins. We then introduce approximate yet systematic methods to analyze aspects of the classical dynamics, and discuss the importance of the exact integrability of the central spin Hamiltonian. This is compared with numerical simulation. Finally, we obtain the asymptotic long time decay of the electron spin polarization. We show that this is insensitive to integrability, and determined instead by the transfer of angular momentum to very weakly coupled spins far from the center of the quantum dot. The specific form of the decay is shown to depend sensitively on the form of the electronic wave function.

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Klaus ENSSLIN
ETHH - Lab. fuer Festkorperphysik, Zurich, Switzerland
and
F. Molitor, D. Graf, C. Stampfer, T. Ihn and K. Ensslin

Title:
Raman imaging and transport properties of graphene

Abstract:

Raman spectroscopy can be used to unambiguously identify single-layer graphene. We employ a scanning Raman set up to map out few-layer graphene flakes with various thicknesses. Using a disorder sensitive Raman line we show that structural disorder is minimal within a given flake and maximal at the edge of a flake as well as at the crossover between flake areas of different thickness. For a 7 monolayer thick graphene flake which is several microns long and 300 nm wide we investigate weak localization as well as universal conductance fluctuations. The data can be analyzed using the theory for one-dimensional diffusive metals. We obtain a phase coherence length of 2 microns at a temperature of 2 K. The carrier density can be tuned by the usual back gate (doped Si substrate) as well as by metallic side gates patterned by electron beam lithography next to the graphene wire. Single layer graphene flakes are investigated by transport experiments around the charge neutrality point and for various temperature treatments.

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Karsten FLENSBERG
Univ. of Copenhagen, Denmark

Title:
In-elastic electron-electron scattering in quantum wires

I discuss the role of electron-electron interactions in one-dimensional quantum wires in the clean limit on condutance and thermopower. For single subband long wires, where momentum is conserved, two-particle scattering has no effect and the dominant contribution comes from three-particle scattering. With more subbands e-e scattering can take place at specific values of the Fermi energy, which results in features in the transport properties. I also discuss the case of short wires where non-momentum conserving scattering leads to a reduced conductance with increasing temperature and relate this to the experimental observations.

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Yuval GEFEN
Department of Condensed Matter Physics, The Weizmann Institute of Science, Rehovot 76199 Israel

Title:
Phase Lapses and Population Switching in Quantum Dots:
A Quantum Phase Transition?

Abstract:

A set of experiments at Weizmann Institute a decade ago revealed unexpected features of the behavior of the transmission phase, θ, in transport through a quantum dot. Most surprisingly was the observation that as the gate voltage, V_g, is varied continuously, the evolution of θ involves an increase by π as V_g sweeps through a resonance (a Coulomb peak), and a sharp decrease by π (a phase lapse) between consecutive peaks. This systematic behavior was left unaccounted for till recently.

I will review the major theoretical steps that recently led to an understanding of the effect, emphasizing the role of (i) dot-lead asymmetries and (ii) non-monotonous occupation of the dot's levels known as "population switching" [1,2].

Recent studies of the population switching provide conflicting evidence as to whether this effect is smooth or abrupt [3]. The latter would suggest a zero-temperature phase transition.

References:

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2. D. Golosov and Y. Gefen, New J. Phys. vol. 9 (2007), in press [preprint cond-mat/0612494].
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Alex Greilich[1], D. R. Yakovlev[1], A. Shabaev[2], Al. L. Efros[2], I. A. Yugova[1], R. Oulton[1], D. Reuter[3], A. Wieck[3], and M. Bayer[1]
[1]Experimentelle Physik II, Universität Dortmund, D-44221 Dortmund, Germany
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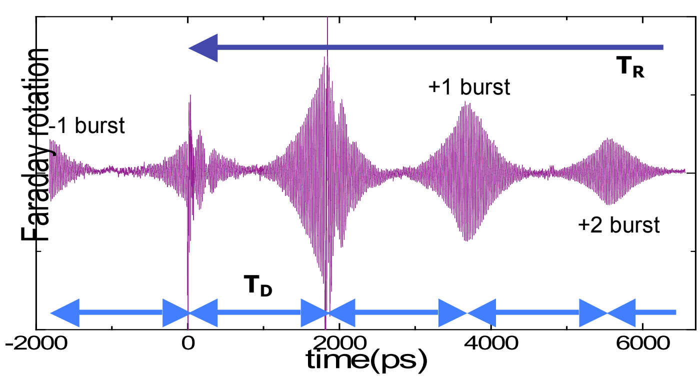
[3]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Title:
Electron spin coherence in singly charged InGaAs/GaAs quantum dots

Abstract:
Electron spins in ensembles of quantum dots (QDs) offer one possible pathway to implement quantum information technologies in a solid-state environment. Unfortunately, inhomogeneities within an ensemble lead to the rapid loss of coherence among the phases of the spins, typically on the scale of nanoseconds.

We report an optical technique based on time-resolved Faraday rotation measurements of the electron spin dynamics in an ensemble of QDs to recover the coherence time of a single QD. The measured spin coherence time T_2 is 3 microseconds, which is three orders of magnitude longer than the ensemble dephasing time of about 2 nanoseconds. A periodic train of circularly polarized light pulses from a mode-locked laser synchronizes the precession of the spins to the laser repetition rate T_R, transferring the mode-locking into the spin system. This synchronization leads to constructive interference of the electron spin polarization in time. The interference gives also the possibility for all-optical coherent manipulation of spin ensembles: the electron spins can be clocked by two trains of pump pulses with a fixed temporal delay T_D. After this pulse sequence, the QD ensemble shows multiple echo-like Faraday rotation signals with a period equal to the pump pulse separation.



[1] A. Greilich, R. Oulton, E. A. Zhukov, I. A. Yugova, D. R. Yakovlev, M. Bayer, A. Shabaev, Al. L. Efros, I. A. Merkulov, V. Stavarache, D. Reuter, and A. Wieck, Phys. Rev. Lett. **96**, 227401 (2006).
[2] A. Greilich, D. R. Yakovlev, A. Shabaev, Al. L. Efros, I. A. Yugova, R. Oulton, V. Stavarache, D. Reuter, A. Wieck, and M. Bayer, Science **313**, 341 (2006).

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Francisco GUINEA
CSIC – Instituto de Ciencias de Materiales de Madrid, Spain

Title:
Graphene quantum dots

Abstract:

We analyze simple models of graphene quantum dots, and study their transport properties. It is shown that charging effects are significantly influenced by localized states at zero energy, between the valence and conduction bands. The presence of these states also lead to non equilibrium effects. The role of disorder and magnetic fields are also analyzed. We finally show how charging effects can reduce the electron coherence and modify the transport properties of graphene nanoribbons.

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Philip KIM
Columbia University, Physics, New York, U.S.A.

Title:
Electric Transport in Graphitic Carbon Materials

Abstract:

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 charged Dirac Fermion spectrum 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 and unusual half-integer quantum Hall effect. In addition, the promise of these materials for novel electronic device applications will be discussed.

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Karyn LE HUR
Yale University, Physics, New Haven, CT, USA

Title:
Charge Fractionalization and Transport in low dimensions

Abstract:

Quantum one-dimensional systems such as quantum wires or carbon nanotubes can carry charge in units smaller than a single electron charge. According to Lüttinger theory which describes low-energy excitations of such systems, the resulting charge and spin waves are predicted to carry fractional charge and spin that propagate at different velocities. Observing fractionalization physics in an experiment is a considerable challenge in those low-dimensional systems which are adiabatically coupled to metallic (measuring) leads. We theoretically discuss the possibility of observing charge fractionalization as well as the associated electron lifetime which varies as 1/T (with T being the temperature) in coupled wire geometries. We also present recent experimental data from Amir Yacoby et al. which confirms the charge fractionalization in quantum wires. This work has been done in collaboration with Amir Yacoby and Bertrand I. Halperin.

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Alexander LICHTENSTEIN
University of Hamburg, Institute of Theoretical Physics, Hamburg, Germany

Title:
Molecular Doping and Impurity States of Graphene

Abstract:

Graphene has been attracting an increasing interest due to its remarkable physical properties ranging from the Dirac electron spectrum to ballistic transport under ambient conditions. The latter makes graphene a promising material for future electronics and the recently demonstrated possibility of chemical doping without significant change in mobility has improved graphene's prospects further. We address the question of impurity formation in graphene [1]. Results of tight-binding calculations as well as DFT studies will be presented to explain the peculiar nature of impurity states in this material, the consequences for STM experiments as well as the possibility of strong exchange interactions between magnetic impurities. Furthermore, recent results on graphene's chemical sensor properties [2], in particular, the possibility to detect a single NO2 molecule, will be discussed from a theoretical point of view.

[1] T. O. Wehling, K. S. Novoselov, S. V. Morozov, E. E. Vdovin, M. I. Katsnelson, A. K. Geim, A. I. Lichtenstein, cond-mat/0703390
[2] F. Schedin, K.S. Novoselov, S.V. Morozov, D. Jiang, E.H. Hill, P. Blake, A.K. Geim, cond-mat/0610809

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Nadya MASON
Univ. Illinois at Urbana-Champaign, Dept. Physics, Urbana, U.S.A.

Title:
Electron Interactions in Carbon Nanotube Quantum Wires

Abstract:

Carbon nanotubes are tubes of rolled-up graphite, with diameters as small as a nanometer and lengths up to a millimeter. This amazing aspect ratio allows nanotubes to be studied as one-dimensional wires, with quantum effects that can be seen for a wide range of length and energy scales. In this talk, I will discuss several transport experiments on carbon nanotubes, which demonstrate one-dimensional, interacting physics in these systems. I will first show how point contacts fabricated over nanotubes create the quantized conductance steps expected for one-dimensional systems. However, the steps in nanotubes have an anomalous spacing, perhaps indicative of broken band and spin degeneracies. I will then discuss tunneling measurements designed to measure interacting electron states—particularly Luttinger liquid effects – in nanotubes of varying length scales. We find an unusual length-dependence of the Luttinger exponent, particularly for very short (<<1 micron) and very long (>> 1 micron) nanotubes.

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Kostya NOVOSELOV
The University of Manchester, School of Physics & Astronomy
Manchester, U.K.

Title:
QED in a Pencil Trace

Abstract:

When one writes by a pencil, thin flakes of graphite are left on a surface. Some of them are only one angstrom thick and can be viewed as individual atomic planes cleaved away from the bulk. This strictly two dimensional material called graphene was presumed not to exist in the free state and remained undiscovered until the last year. In fact, there exists a whole class of such two-dimensional crystals. The most amazing things about graphene probably is that its electrons move with little scattering over huge (submicron) distances as if they were completely insensitive to the environment only a couple of angstroms away. Moreover, whereas electronic properties of other materials are commonly described by quasiparticles that obey the Schrödinger equation, electron transport in graphene is different: It is governed by the Dirac equation so that charge carriers in graphene mimic relativistic particles with zero rest mass.

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Aron PINCZUK
Department of Physics and of Applied Physics
Columbia University, New York, 10027 NY, USA

Title:
Spectroscopy of electrons and phonons in graphene structures (*†)

Abstract:

Single layers of graphene were probed by Raman scattering measurements of the long wavelength optical phonon (the G-band). Gate-modulated low-temperature Raman spectra reveal that the electric-field-effect (EFE), that has pervasive presence in contemporary electronics, has marked impacts on the G-band optical phonons of graphene. The EFE in the two dimensional honeycomb lattice of carbon atoms creates large density modulations of carriers with linear dispersion (known as Dirac fermions). The EFE Raman spectra display the interactions of lattice vibrations with these unusual carriers. The changes of phonon frequency and line-width demonstrate optically the particle-hole symmetry about the charge-neutral Dirac-point. The linear dependence of the phonon frequency on the EFE-modulated Fermi energy is explained as the electron-phonon coupling of mass-less Dirac fermions.

(*) Collaboration with J. Yan, Y. Zhang, and P. Kim
(†) Supported by ONR, NSF and DOE

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Eli Rotenberg, A. Bostwick[1], T. Ohta[1,2], J. McChesney[1], K. V. Emtsev[3], Th. Seyller[3], and K. Horn[2]

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Title:
Many-body interactions in clean and alkali-adsorbed Graphene

Abstract

The study of many-body interactions among the charge carriers in graphene is of interest owing to their contribution to superconductivity in carbon nanotubes and graphite intercalation compounds (GICs). I will report the characterization of graphene thin films using angle-resolved photoemission spectroscopy (ARPES). We determined the spectral function for monolayer graphene, which encodes the many-body interactions in the system–namely the charge and vibrational excitations. The bands around the Dirac crossing point E_D are heavily renormalized by electron-electron, electron-plasmon, and electron-phonon couplings, which must be considered on an equal footing to understand the quasiparticle dynamics in graphene and related systems.

At alkali coverages comparable to graphite intercalation compounds (GICs), renormalization of the carrier mass near E_F becomes significant. The electron-phonon coupling has an overall strength and anisotropy which cannot be explained by conventional models. We propose a significant enhancement of the coupling strength by the presence of a van Hove Singularity (VHS) at or just above E_F, which can account for the enhanced coupling in both doped graphene and potentially for the similar situation encountered in the high T_c cuprate superconductors.

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M.S. SKOLNICK
Department of Physics & Astronomy, University of Sheffield
Sheffield S3 7RH, U.K.

Title:
The Macroscopically Occupied Polariton State in Semiconductor Microcavities

Abstract:

Recent work on the high density macroscopically occupied polariton state which can be excited in planar semiconductor microcavities will be reviewed.

Following a general introduction, attention will be focused principally on the driven optical parametric oscillator system, where high density states are formed at zero and finite wavevector are formed. There will be discussion of the important effects of interactions in such systems, both polariton-polariton and polariton-exciton/electron, which are shown to limit the temporal coherence of the condensed phase which is formed, in strong contrast to the case of non-interacting photons in a laser. Evidence for phase transitions as the threshold is crossed from the spontaneous to coherent regimes will be presented. Finally comparison will be made with the high density polariton state which condenses from an exciton reservoir excited non-resonantly.

I would like to acknowledge the contributions of D N Krizhanovskii, D Sanvitto, D M Whittaker and A P D Love to this work.

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Title:
Kondo effect and spin correlation in single InAs self-assembled quantum dots with nanogap electrodes of normal, superconducting and ferromagnetic metal

Abstract:

Quantum dots are tiny solid-state system suffering from strong effects of quantum confinement and interaction. The electron transport through a pair of electrodes with a quantum dot in between is thoroughly influenced by the feature of the quantum dot. This has been used to study the electronic properties of quantum dot itself and also manipulate the charge and spin degrees of freedom in the conduction. Particularly, associated with the latter, there has been growing interest in controlling the spin-related phenomena, such as Pauli effect and the Kondo effect. Use of superconductor or ferromagnet instead of normal metal for making contacts to quantum dots can further expand the freedom of spin correlation in the transport property. In this work we use an InAs self-assembled quantum dot coupled to contact electrodes made from different types of metal, i.e. normal, superconducting, and ferromagnetic metal, to explore the Kondo effect depending on the interplay with superconductivity and ferromagnetic order.

We initially observe the spin-half Kondo effect for an InAs quantum dot coupled to normal metal (Ti-Au) electrodes. The Kondo effect arises from an anti-ferromagnetic coupling of a local electron spin in a quantum dot to Fermi sea in the electrodes. When the electrode metal is replaced by Al-Ti (Ni-Ti), competition between two different types of ordering, i.e. the Kondo singlet and Cooper-pair states (ferromagnetic states) can appear. For the Al-contact device we observe coexistence of first order Andreev reflection and the Kondo effect. The Andreev process is enhanced by the Kondo effect in such a way that the zero-bias peak develop side-peaks the superconducting gap energy D. We find that the zero-bias conductance measured for various D's and Kondo temperature T_K's falls on a single curve with D/T_K as the only relevant energy scale. This can represent a new type of Kondo universality. On the other hand, for the Ni-contact device, we study tunneling magneto-resistance (TMR) as a function of gate voltage, and observe different types of TMR in the Kondo and non-Kondo valley. The TMR is always positive in the non-Kondo valley, and changes the sign at the Coulomb peaks. In contrast, the TMR sign change occurs at the center of the Kondo valley. We argue that the observed TMR feature can be influenced by the phase shift of electrons tunneling though the dot, although the underlying physics is not yet clear.

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R. Young[1], R. M. Stevenson[1], A. Hudson[1,2], S. Dewhurst[1,2], P. Atkinson[2], K. Cooper[2], D. A. Ritchie[2] and A. J. Shields[1]
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[2]Cavendish Laboratory, University of Cambridge, CB3 0HE, UK.

Title:
Quantum light generation and imaging using quantum dots

Abstract:
Semiconductor Quantum dots are potentially an attractive source of non-classical light. They can confine bound electron-hole pairs, excitons, in all three spatial dimensions giving them discrete optical emission energies, much like the electronic states in atomic systems. The semiconductor nature of the system allows quantum dots to be integrated into complicated device structures including optical cavities [1] and electrical injection [2].

The radiative exciton emission from a semiconductor quantum dot can provide the simplest form of quantum light, a single photon source [2]. The finite re-excitation time following the radiative decay of an exciton in a quantum dot prevents the dot from emitting more than one photon if excited with a short optical or electronic pulse. In a similar fashion excitation of the biexciton state, consisting of two electrons and holes, in the quantum dot results in the emission of a pair of photons at the energy of the biexciton and exciton transitions. The biexciton state was, in fact, proposed as a possible source of polarisation-entangled photons in 2000 by Benson et al. [3] as it consists of two polarisation-correlated decay paths which could potentially be indistinguishable. The condition of indistinguishability is fundamental to the generation of entangled photons and is, in general, not true of the two decay paths from the biexciton state in a quantum dot; physical anisotropy causes the intermediate exciton states to hybridise and separate in energy providing 'which-path' information about the route taken through the biexciton decay.

We demonstrate how the splitting between the intermediate exciton states in a single InAs quantum dot can be controlled by growth [4], rapid thermal annealing [5] and the application of an external magnetic field [6]. Each of these three techniques can be used to make the intermediate exciton states degenerate allowing the biexciton decay to produce singe pairs of entangled photons triggered by short laser pulses [7,8]. Entangled photon pair sources are essential for applications such as entanglement based quantum key distribution, and optical quantum computing. For these applications it is important that no more than one entangled photon pair is generated in a cycle, a requirement met by our quantum dot source which is not possible with traditional methods for generating entangled pairs of photons.

Entanglement also enables quantum interferometry and metrology, the basis of image resolution beyond that possible with equivalent classical light. Biphoton interferometry using entangled emission from the biexciton decay reveals fringes with half the period of classical light [9], and less that that of the laser. In addition, interferometry suggests that this type of entangled light source is not limited by decoherence, we fine the biphoton is surprising robust against dephasing, in stark contrast to the devastating effect of decoherence upon single photons emitted by similar structures.

[1] Gevaux et al. *APL* **88**, 131101 (2006) [2] Yuan et al. *Science* **295**, 102 (2002) [3] Benson et al. *PRL* **84**, 2513 (2000) [4] Young et al. *PRB* **72**, 113305 (2005) [5] Ellis et al. *APL* **90**, 011907 (2007) [6] Stevenson et al. *PRB* **73**, 033306 (2006) [7] Stevenson et al. *Nature* **439**, 179 (2006) [8] Young et al. *New J. Phys.* **8**, 29 (2006) [9] Stevenson et al. to be published in Optics Express.