HL 80: Transport: Carbon nanotubes (organized by TT)

Time: Wednesday 16:30–18:30 Location: HSZ 304

HL 80.1 Wed 16:30 HSZ 304

Revealing the carbon nanotube quantum dot fine structure by transport spectroscopy — •Daniel R. Schmid[1], Alois Dirnaichner[1,2], Magdalena Marganska[2], Peter L. Stiller[1], Milena Grifoni[2], Andreas K. Hüttel[1], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany

Transport spectroscopy on an ultra-clean carbon nanotube quantum dot allows us to measure the level spectrum of the very first electron above the band gap, which can be understood by an underlying minimal Hamiltonian. This includes curvature induced spin-orbit coupling and KK'-mixing terms. The sample orientation in an external magnetic field can be adjusted from perpendicular to parallel alignment with the nanotube axis. Magnetic fields up to 17 T enable us to get an insight on the full dispersion of the first longitudinal modes.

HL 80.2 Wed 16:45 HSZ 304

Valley-mixed states and energy splitting as a finite size effect in chiral carbon nanotubes — •Magdalena Marganska, Piotr Chudzinski, and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, Regensburg, Germany

The two main degrees of freedom of an electron in a carbon nanotube (CNT) are valley and spin. The electronic spectra obtained in transport experiments on CNT quantum dots in parallel magnetic field often show an anticrossing of spectral lines assigned to the opposite valleys. One source of this phenomenon could be the disorder, with impurity induced scattering. However, we show that this effect can be reproduced also in ultraclean CNTs, where it is caused solely by the presence of the boundaries. It is therefore a finite size effect, not an inherent property of the CNT. We identify the nanotube chirality class which supports this phenomenon and analyze its dependence on the CNT parameters and on the distance from the charge neutrality point.

HL 80.3 Wed 17:00 HSZ 304

Large scale *ab initio* study of extended metal-CNT contacts — •Artem Fediai[1,2,3], Dmitry Ryndyk[1,2,3], and Gianaurelio Cuniberti[1,2,3] — [1]Institute for Materials Science and Max Bergmann Center of Biomaterials, TU Dresden, Germany — [2]Center for Advancing Electronics Dresden, TU Dresden, Germany — [3]Dresden Center for Computational Materials Science, TU Dresden, Germany

In experimental samples of carbon nanotube transistors (CNT-FETs) the electrical contact and current inflow occur along relatively long portion of a CNT embedded into a metal. Only very few theoretical studies were done with geometries and materials close to realistic ones. The most common simplified approaches are using the models of point-like or very slightly embedded contacts.We perform large-scale modeling of extended metal-CNT contacts by density functional theory accompanied by Green function method in order to elucidate electrical properties of realistic metal-CNT contacts. We have obtained smooth shrinking of the band gap inside embedded portion of a semiconductor nanotube and induced by the metal doping of the embedded and freestanding part of a CNT. It causes geometry and material dependent behavior of the transmission coefficient and density of states along a CNT. We also analyze the electrostatic potential and charge redistribution and formulate an ab initio based effective transport model to calculate the current-voltage characteristics of large scale CNT-FETs.

HL 80.4 Wed 17:15 HSZ 304

A carbon nanotube in the strong coupling regime: Fabry-Perot interference in a ballistic electron wave guide. — •Alois Dirnaichner[1], Miriam del Valle[2], Andreas Hüttel[1], Christoph Strunk[1], and Milena Grifoni[2] — [1]Institute of Experimental and Applied Physics Regensburg — [2]Institute for Theoretical Physics Regensburg

We present low-temperature measurements of transport through a ultra clean suspended carbon nanotube with strong coupling to the leads. The sample exhibits strikingly high conductance and little reflection at the interfaces between tube and metal, as can be seen from pronounced Fabry-Perot interference patterns in the conductance. The measurements are compared to theoretical results obtained from a scattering matrix calculation where the reflection at the contacts is treated as a perturbation. Furthermore, we discuss the evolution of the patterns in a magnetic field perpendicular to the nanotube axis.

HL 80.5 Wed 17:30 HSZ 304

Signatures of quanta of 1D collective modes in inelastic co-tunneling through a metallic carbon nanotube. — Daniel Steininger[1], •Piotr Chudzinski[2], Amit Kumar[1], Martin Gaim[1], Milena Grifoni[2], Andreas K. Hüttel[1], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany

We report low temperature transport properties of an individual single wall carbon nanotube contacted to superconducting leads. Coulomb diamonds with sharp elastic and inelastic co-tunneling features at applied bias voltages of $2\Delta/e$ and $(2\Delta+\delta)/e$ (with the BCS gap Δ), respectively, are observed. Higher order transport processes generate subgap features at bias voltage Δ/e via the Andreev reflection process. In contrast to previously reported co-tunneling spectra [1], the elastic/in-elastic co-tunneling features we observe are horizontal lines on the bias-gate voltage plane (no bending effect) and do not display any effect related to even and odd electron occupancy of the quantum dot. The in-elastic part has a rich internal structure consisting of several equidistant sub peaks. We analyze various possibilities for the occurrence of such harmonic spectrum. Among these are vibrational excitations of the carbon lattice or the many body bosonic modes that are expected from the Tomonaga-Luttinger liquid description of single wall carbon nanotubes.

[1] Phys. Rev. B 79, 134518

HL 80.6 Wed 17:45 HSZ 304

Fingerprints of thermal quasiparticle excitations in CNT-superconductor hybrid junctions — •Sebastian Pfaller[1], Andrea Donarini[1], Markus Gaass[2], Andreas K. Hüttel[2], Thomas Geiger[2], Christoph Strunk[2], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institute for Exp. and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

We present a study of a electronic transport through a carbon nanotube quantum dot coupled to superconducting contacts. By increasing the temperature above 300mK additional transport features are observed in the stability diagrams. They appear as lines in the Coulomb blockade region, and are attributed to sequential tunneling of thermally excited quasiparticles. Whenever two of these lines cross at zero bias, a conductance peak is observed. In particular, we observe two of these peaks in the vicinity of the charge degeneracy point. The nature of these lines as well as their temperature dependence can be explained by a transport theory based on a generalized master equation approach to lowest order in the tunnel coupling [1].

[1] S. Pfaller *et al.* Phys. Rev. B **87**, 155439 (2013)

HL 80.7 Wed 18:00 HSZ 304

Fine structure of the Kondo resonance in carbon nanotube quantum dots — Daniel R. Schmid[1], Sergey Smirnov[2], Magdalena Margańska[2], Alois Dirnaichner[1], Peter L. Stiller[1], Milena Grifoni[2], •Andreas K. Hüttel[1], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany

Ultraclean carbon nanotubes enable spectroscopy of the unperturbed quantum mechanical properties of electronic states in transport experiments with a high degree of precision. This applies to the case of opaque tunnel barriers between nanotube and leads and, e.g., the excitation spectrum of one or two electrons trapped in the quantum dot as well as to the case of many electrons and strong coupling to the leads.

Manybody correlations in carbon nanotubes with a quadruplet of both spin and valley (K-K') degenerate quantum states can give rise to the so-called SU(4) Kondo effect. We demonstrate a highly regular carbon nanotube quantum dot, where SU(4) symmetry is broken by intrinsic both spin-orbit interaction and valley mixing. This leads to a characteristic Kondo peak in differential conductance at zero bias along with satellite peaks at finite bias. The evolution of these peaks is strikingly different at finite perpendicular and parallel magnetic fields. We demonstrate how their combined spin and orbital origin and their evolution at finite magnetic fields can be understood in detail in terms of the discrete symmetries of the carbon nanotube Hamiltonian.

HL 80.8 Wed 18:15 HSZ 304

Theory of the Kondo effect in carbon nanotube quantum dots with broken SU(4) symmetry — •Sergey Smirnov[1], Magdalena Margańska[1], Daniel R. Schmid[2], Alois Dirnaichner[2], Peter L. Stiller[2], Andreas K. Hüttel[2], Christoph Strunk[2], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

We develop an effective low energy field theory for the Kondo effect in a quantum dot where the original four-fold degeneracy of the dot level is partially removed. The SU(2) Keldysh effective action approach [1,2] is generalized to the case of the broken SU(4) Anderson model with spin and orbital degrees of freedom. The theory is valid in the strong and weak coupling regimes as well as in the crossover. It provides universal differential conductance with the scale having the correct limiting behavior for the SU(2) and SU(4) cases. As an application to a physical system, we explore the Kondo effect in a quantum dot made of a carbon nanotube with strong spin-orbit interaction and valley mixing. The symmetry properties of the carbon nanotube Hamiltonian are exploited to identify the structure of the Keldysh effective action. We further investigate in detail the Kondo resonance and its behavior in perpendicular and parallel magnetic fields and compare it with recent experiments on the Kondo effect in ultraclean carbon nanotubes.

[1] S. Smirnov and M. Grifoni, Phys. Rev. B 87, 121302(R) (2013).
[2] S. Smirnov and M. Grifoni, New. J. Phys. 15, 073047 (2013).