and random matrix theory of chaotic cavities.

We further discuss the relevance of intervalley scattering on the magnitude of the weak localization peak.

TT 26.16 Wed 18:30 HSZ 03

Symmetry Classes in Graphene Quantum Dots — •Jürgen Wurm[1,2], Adam Rycerz[1,3], Inanc Adagideli[1], Michael Wimmer[1], Klaus Richter[1], and Harold Baranger[2] — [1]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg — [2]Department of Physics, Duke University, Durham, NC 27708, USA — [3]Marian Smoluchowski Institute of Physics, Jagiellonian University, 30059 Krakow, Poland

In view of the recently increased experimental activity in the field of graphene quantum dots [1-2], the need of a theoretical description of these systems is apparent. In this work we study the symmetry classes of open and closed graphene quantum dots through the conductance and energy level statistics [3]. For an abrupt lattice termination, these properties are well described by the standard orthogonal and unitary ensembles of random matrix theory. For a smooth mass confinement, the Hamiltonian and the scattering matrix are block diagonal in the valley degree of freedom. While the effect of this structure is clearly visible in the conductance of open dots, it is suppressed in the spectral statistics of closed dots, because the intervalley scattering time is shorter than the time required required to resolve a level spacing in the closed systems but longer than the escape time of the open systems.

[1] L.A. Ponomarenko et. al., Science 320, 356 (2008)
[2] C. Stampfer, et. al., Appl. Phys. Lett. 92, 012102 (2008)
[3] J. Wurm, Adam Rycerz, Inanc Adagideli, M. Wimmer, K. Richter, H.U. Baranger, arXiv:0808.1008 (2008)

TT 26.17 Wed 18:45 HSZ 03

Few electrons in magnetic graphene quantum dots — •Wolfgang Häusler[1,2] and Reinhold Egger[1] — [1]Institut für Theoretische Physik, Heinrich-Heine-Universität, D-40225 Düsseldorf, Germany — [2]Physikalisches Institut, Albert-Ludwigs-Universität, D-79104 Freiburg, Germany

We consider inhomogeneous magnetic fields to design quantum islands on graphene structures. Following the well known case of semiconducting quantum dots we investigate two interacting electrons. Without further consideration the Dirac Hamiltonian is ill defined for more than one particle. We solve this issue by projecting on positive energy states as physically justified by the presence of a chemical potential. Results of relatively demanding numerical diagonalizations will be presented for artificial graphene helium.

TT 27: Superconductivity: Vortex Dynamics, Vortex Phases, Pinning

Time: Wednesday 14:00–15:00 Location: HSZ 105

TT 27.1 Wed 14:00 HSZ 105

Vortex-vortex interaction in thin superconducting films — •Ernst Helmut Brandt — Max-Planck-Institut für Metallforschung, Stuttgart

The interaction between Pearl vortices in thin superconducting films is revisited. For infinitely extended films this problem was solved by Judea Pearl [1] who obtained the sheet current $J(r)$ around the vortex and the force $\Phi_0 J(r)$ on a second vortex with magnetic flux Φ_0 and at distance r in terms of the two rarely used Bessel functions S_1 and N_1. It is shown that the interaction potential $V(r)$ and force $-V'(r)$ can be approximated with high precision in the entire range of r by a simple logarithm. This expression directly shows the correct limits $V(r) = (\Phi_0^2/\mu_0)\ln(2.27\Lambda/r)/(2\pi\Lambda)$ for $r \ll \Lambda$ and $V(r) = \Phi_0^2/(\mu_0\pi r)$ for $r \gg \Lambda$. Here $\Lambda = \lambda^2/d$ is the effective penetration depth, λ the London depth, and $d < \lambda$ the film thickness. The effect of finite film size on the vortex interaction is discussed. The interaction now depends not only on the distance r but on both vortex positions and on the film shape [2]. It is shown how the vortex interaction in finite films of any shape and size can be computed.

[1] J. Pearl, Appl. Phys. Lett. **5**, 65 (1964).
[2] E. H. Brandt, Phys. Rev. B **72**, 024529, 1-12 (2005).

TT 27.2 Wed 14:15 HSZ 105

Intrinsic bulk vortex lattice dynamics and tilt moduli revealed by time resolved small angle neutron scattering. — •Sebastian Mühlbauer[1,2], Christian Pfleiderer[1], Peter Böni[1], Albrecht Wiedenmann[3], Ted Forgan[4], and Günter Behr[5] — [1]Physik Department E21, Technische Universität München, D-85748 Garching — [2]Forschungsneutronenquelle Heinz Maier-Leibnitz, FRM II, D-85748 Garching — [3]Institut Laue Langevin, ILL, Grenoble, France — [4]School of Physics and Astronomy, University of Birmingham, Birmingham UK — [5]IFW Dresden, D-01069 Dresden,

In contrast to the local elasticity of crystal lattices, the elasticity of Vortex Lattices (VL) in superconductors is of non-local origin. The VL elasticity, thermal stability, pinning and transport properties can be described by the temperature, field and k-dependent elastic moduli c_{11}, c_{44} and c_{66}, hence yielding important informations on the microscopic nature of superconductivity. Measurements of the VL elastic moduli are traditionally limited to macroscopic transport measurements on bulk samples or microscopic surface sensitive methods such as decoration techniques. We report on a new method to measure the VL tilt modulus c_{44} by means of stroboscopic small angle neutron scattering, combined with a time varying magnetic field setup on an ultrapure niobium single crystal with vanishing pinning. This method allows the microscopic determination of the intrinsic VL elastic moduli in large bulk samples, unhampered by surface effects. We present first data, showing a clear change of the vortex-vortex interaction at the transition from the intermediate mixed state to the mixed state.

TT 27.3 Wed 14:30 HSZ 105

Interplay of thermomagnetic and nonequilibrium effects in nonlocal vortex transport in mesoscopic NbGe channels — •Florian Otto[1], Ante Bilušić[1,2], Dinko Babić[3], Christoph Sürgers[4], and Christoph Strunk[1] — [1]Inst. for Exp. and Appl. Physics, Univ. Regensburg, Germany — [2]Fac. of Nat. Sciences, Univ. of Split, Croatia — [3]Dept. Physics, Univ. Zagreb, Croatia — [4]Phys. Inst. and DFG CFN, Univ. Karlsruhe, Germany

Amorphous $Nb_{0.7}Ge_{0.3}$, a high-κ type-II superconductor with very low pinning, allows for measurements in the flux-flow regime over large parts of the B-T-phase diagram. When a transport current is driven through a narrow wire (width 250 nm) connected to remote voltage probes via a perpendicular channel (length 2 μm) in presence of an external (out-of-plane) magnetic field, the Transversal Flux Transformer Effect can be used to produce a nonlocal voltage drop on the remote contacts caused by vortex motion in the channel. In the simplest picture, the Lorentz force acting on the vortices in the local wire creates a pressure on the vortices in the channel, such that the mutual vortex repulsion can explain the nonlocal vortex motion. However, detailed measurements of nonlocal DC voltage-current characteristics taken across the whole B-T-plane show several new aspects, including abrupt sign reversals of the vortex motion. This can be understood in terms of an interplay between Lorentz force (low currents) and Nernst effect via local electron heating (high currents) for $T \ll T_c$, and between the Lorentz force (low currents) and a force due to the local suppression of the superconducting gap (high currents) for T close to T_c.

TT 27.4 Wed 14:45 HSZ 105

Observation of nanostripes and -clusters in NEG superconductors — •Michael R. Koblischka[1], Marc Winter[1], Pintu Das[1], Anjela Koblischka-Veneva[2], Miryala Muralidhar[3], Thomas Wolf[4], Nadendla Hari Babu[5], Steve Turner[6], Gustav van Tendeloo[6], and Uwe Hartmann[1] — [1]Experimental Physics, Saarland University, Campus C 6 3, D-66123 Saarbrücken, Germany — [2]Functional Materials, Saarland University, Campus C 6 3, D-66123 Saarbrücken, Germany — [3]SRL/ ISTEC, 1-10-13, Shinonome, Koto-ku, Tokyo, 135-0062, Japan — [4]Forschungszentrum Karlsruhe GmbH, Institute of Solid State Physics, D-76021 Karlsruhe, Germany — [5]IRC in Superconductivity, University of Cambridge, Madingley Road, Cambridge, CB3 0HE, U. K. — [6]EMAT Research Group, University of Antwerp, B- 2020 Antwerp, Belgium

Nanostripes are observed in melt-textured and single-crystalline samples of the ternary light rare earth (LRE) compound $(Nd_{0.33}Eu_{0.33}Gd_{0.33})Ba_2Cu_3O_x$ (NEG) by means of atomic force microscopy, scanning tunnelling microscopy at ambient conditions, combined with TEM and electron backscatter diffraction. This enables the observation of several important features: Nanostripes are formed by chains of clusters, representing the LRE/Ba substitution. The periodicity of the nanostripes is found to range between 40 and 60 nm; the shape of the nanoclusters is elliptic with a major axis length between 300 and 500 nm and a minor axis length of about 30 to 150 nm. The dimensions of the nanostripes are similar for both types of NEG samples.

TT 28: Superconductivity: Heterostructures, Andreev Scattering, Proximity Effect, Coexistence

Time: Wednesday 15:15–18:00 Location: HSZ 105

Invited Talk TT 28.1 Wed 15:15 HSZ 105

Unconventional Superconductivity induced by Interfaces and Surfaces — •Matthias Eschrig — Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures, Universität Karlsruhe, D-76128 Karlsruhe, Germany

Ordered many-body states in solids are often characterized by an order parameter that breaks one or more of the symmetries of the crystal. Such unconventional states lead to interesting new physics associated with the spontaneously broken symmetries. However, in order that such a symmetry breaking can occur it has to be energetically favored. Some of the most interesting symmetry broken states have never been found experimentally in bulk materials for that reason.

However, symmetries can be broken also by introducing interfaces with other materials. In this case, the evasive unconventional states might be induced locally near the interface, and can then penetrate as correlations into bulk materials. The properties of the induced states depend on the scattering characteristics of the interfaces and on the proximity induced states produced by the adjacent materials.

We discuss in particular interface-induced unconventional superconductivity in heterostructures with magnetically active materials, that may exhibit e.g. odd-frequency pairing or equal-spin triplet pairing states. We study the conditions under which such unconventional pairing amplitudes are induced and demonstrate how they can be tested in experiment and used for quantum devices.

TT 28.2 Wed 15:45 HSZ 105

Broken time-reversal-symmetry in triplet superconductor junctions — •Philip Brydon[1], Christian Iniotakis[2], Dirk Manske[3], and Manfred Sigrist[2] — [1]Technische Universität Dresden, Dresden, Germany — [2]ETH Zürich, Zürich, Switzerland — [3]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany

A rich variety of unconventional Josephson effects have been predicted for junctions combining magnetism and triplet superconductivity (e.g. P. M. R. Brydon *et al.*, Phys. Rev. B **77**, 104504 (2008); P. M. R. Brydon, D. Manske and M. Sigrist, J. Phys. Soc. Japan **77**, 103714 (2008)). Previous works assume, however, that the properties of the barrier material are independent of the two superconductors. We demonstrate that this assumption fails in a scenario where time-reversal symmetry is broken by the misalignment of the **d**-vectors of the triplet superconductors on either side of the junction. This allows the stabilization of a barrier magnetization, creating an exotic Josephson state distinguished by the existence of fractional flux quanta at the junction barrier. There is also a pronounced enhancement of the critical current through the junction at temperatures below the magnetic transition.

TT 28.3 Wed 16:00 HSZ 105

Non-local transport in normal-metal/superconductor hybrid structures: the role of interference and interaction — •Jakob Brauer[1], Detlef Beckmann[1], Florian Hübler[1], and Hilbert v. Löhneysen[2] — [1]Forschungszentrum Karlsruhe, Institut für Nanotechnologie, P.O.-Box 3640, D-76021 Karlsruhe — [2]Forschungszentrum Karlsruhe, Institut für Festkörperphysik, P.O.-Box 3640, D-76021 Karlsruhe and Physikalisches Institut, Universität Karlsruhe, D-76128 Karlsruhe, Germany

We present experimental results on non-local conductance in multi-terminal hybrid structures, where two normal metal contacts are attached to a single superconductor. For contacts with an insulating tunnel barrier, and at energies below the energy gap of the superconductor, the non-local conductance is determined by the competition of crossed Andreev reflection (CAR) and elastic cotunneling (EC). The contributions of CAR and EC are expected to cancel each other in the tunneling limit. Recently [Russo et al., Phys. Rev. Lett. 95, 027002 (2005)], a non-vanishing signal has been observed in such structures, with an additional energy scale below the gap. So far, quantum interference and Coulomb interaction have been suggested to lift the cancellation of CAR and EC, but no established theory exists for this signal. We observe similar signals in our structures, and demonstrate that the origin is quantum interference.

TT 28.4 Wed 16:15 HSZ 105

Crossed Andreev reflection and dynamical Coulomb blockade — •Andreas Baumgartner, Andreas Kleine, Jelena Trbovic, and Christian Schönenberger — Institute of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

A natural source of entangled electrons is the nonlocal process of crossed Andreev reflection (CAR) [1]. In CAR the two electrons of a Cooper pair in a superconductor coherently tunnel into two spatially separated normal metal contacts. This process is expected to produce a negative nonlocal voltage, $U_{\rm nl}$, in a four terminal device with two normal (injector and detector) and two superconducting contacts. However, recent experiments have shown that elastic cotunneling (EC) and charge imbalance (CI) lead to $U_{\rm nl} > 0$ and can mask CAR [2]. In this contribution we show that $U_{\rm nl}$ can be negative for all subgap biases, which suggests that CAR can dominate all other processes, as required for a solid-state entangler. We fabricated a series of lateral multiterminal $Al/Al_2O_3/Pd$ hybrid structures with contact distances smaller than the superconducting coherence length and with different barrier resistances. We show that for a small window of injector and detector resistances CAR is the dominant nonlocal subgap process, and that for larger resistances the CAR and CI rates are reduced. We tentatively ascribe these systematic changes with barrier resistance to dynamical Coulomb blockade [1].

[1] Recher *et al.*, PRL 91, 267003 (2003).

[2] Cadden-Zimansky *et al.*, PRL 97, 237003 (2006), Russo *et al.*, PRL 95, 027002 (2005), Beckmann *et al.*, PRL 93, 197003 (2004)

15 min. break

TT 28.5 Wed 16:45 HSZ 105

Hybrid normal-superconducting systems comprising interacting quantum dots — •Michele Governale[1], Marco G. Pala[2], David Futterer[1], and Jürgen König[1] — [1]Theoretische Physik, Universität Duisburg-Essen, D-47048 Duisburg, Germany — [2]IMEP-LAHC, INP MINATEC, Centre National de la Recherche Scientifique, F-38016 Grenoble, France

Quantum dots tunnel-coupled to both normal and superconducting leads exhibit a very rich physics due to the presence of superconducting correlations, quantum fluctuations, strong electron-electron interaction, and non-equilibrium. In order to study these systems, we have developed a real-time diagrammatic expansion in the tunnel coupling to the leads [1], which describes both the equilibrium and non-equilibrium superconducting proximity effects in the quantum dot. In the limit of a large superconducting gap, all orders in the tunnel-coupling strength to the superconductors can be included within an exact resummation scheme. Corrections due to finite values of the gap are evaluated within a $1/\Delta$ expansion. This theory is applied to a single-level quantum dot tunnel coupled to two phase-biased superconducting leads and one voltage-biased normal lead. The normal lead is used to drive the dot out of equilibrium. We compute both the Josephson current between the two superconductors and the Andreev current in the normal lead, and analyze their switching on and off as well as transitions between 0- and π-states as a function of gate and bias voltage.

[1] M. Governale, M. G. Pala, and J. König, Phys. Rev. B **77**, 134513 (2008).

TT 28.6 Wed 17:00 HSZ 105