TT 38: f-Electron Systems and Heavy Fermions

Time: Wednesday 9:30–12:45 Location: H23

Invited Talk TT 38.1 Wed 9:30 H23

A new heavy-fermion superconductor $CeRh_2As_2$ with Rashba and quadrupolar interactions — •Seunghyun Khim, Jacintha Banda, Daniel Hafner, Ulrike Stockert, Manuel Brando, and Christoph Geibel — Max Planck Institut für Chemische Physik fester Stoffe, Dresden, Germany

One of the hot topic in the field of superconductivity is the effect of breaking inversion symmetry in the presence of strong spin-orbit interactions. This leads to a spin-splitted Fermi surface with unique momentum-locked spin polarization. Superconductivity appearing from such polarized bands is robust against Zeeman pair-breaking effect and can host mixed-parity pairing providing exotic superconducting states. Here, we report the discovery of heavy-fermion superconductivity in $CeRh_2As_2$ with $T_c \sim 0.25$ K. This compound crystallizes in the $CaBe_2Ge_2$-type structure where inversion symmetry is locally broken at the Ce site. We observe a huge upper critical field of $\gtrsim 12$ T for the out-of-plane direction surpassing the Pauli-paramagnetic limit of ~ 0.5 T. This provides a clear signature of a Rashba-type in-plane spin polarization arising from an alternating asymmetric potential due to the broken local inversion symmetry. In addition, our results indicate this system to be very close to a quantum critical point (QCP) with a further transition at $T_o \sim 0.4$ K, likely of quadrupolar nature. Therefore, $CeRh_2As_2$ is a promising candidate for studying how heavy-fermion superconductivity behaves under the influence of Rashba-type interactions and a possible multipolar QCP.

TT 38.2 Wed 10:00 H23

Study of the low-temperature resistivity of the locally non-centrosymmetric heavy-fermion superconductor $CeRh_2As_2$ — •Daniel Hafner, Jacintha Banda, Seunghyun Khim, Christoph Geibel, and Manuel Brando — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

$CeRh_2As_2$ is a novel locally non-centrosymmetric heavy fermion superconductor with a transition temperature $T_c \approx 0.3$ K. A second weak transition has been observed in specific heat at a temperature T_0 just above T_c and it is suspected to be of quadrupolar nature. We present a comprehensive study of the low temperature resistivity of $CeRh_2As_2$ in which we could observe signatures of both phase transitions. We have investigated the evolution of T_c and T_0 and the resistivity exponent n, with $\rho(T) = \rho_0 + AT^n$, in magnetic field parallel and perpendicular to the crystallographic c-axis up to 18 T. The resulting phase diagrams are presented. We then discuss the evolution of the observed phases in relation to the lack of local inversion symmetry in the Ce sites, quadrupolar order and quantum criticality.

TT 38.3 Wed 10:15 H23

The high-field/high-pressure relationship of magnetic order and nematicity in the heavy-fermion superconductor $CeRhIn_5$ — •Toni Helm[1,2], Audrey Grockowiak[4], Fedor Balakirev[5], John Singleton[5], Kent R. Shirer[2], Markus König[2], Eric D. Bauer[6], Filip Ronning[6], Stanley W. Tozer[4], and Philip J.W. Moll[2,3] — [1]High Magnetic Field Laboratory Dresden (HLD-EMFL), HZDR, Germany — [2]MPI for Chemical Physics of Solids, Dresden, Germany — [3]Institute of Materials, EPFL, Lausanne, Switzerland — [4]Tallahassee NHMFL, FL, USA — [5]Los Alamos NHMFL, NM, USA — [6]Los Alamos National Laboratory, NM, USA

Recently, a nematic signature, i.e., a sudden resistivity anisotropy above a critical field $B^* = 28$ T, has been observed in $CeRhIn_5$. This heavy-fermion antiferromagnet ($T_N = 3.85$ K) superconducts under pressure above $p_c = 23$ kbar, associated with an antiferromagnetic quantum critical point (QCP). The reported nematic behavior survives at ambient pressure only until magnetic order is suppressed at a critical field of $B_c = 51$ T, associated with a second QCP. An open question is if and how the two QCPs, B-induced nematicity and p-induced superconductivity (SC) are related. Here we report high-field (up to 65 T) / high-pressure (up to 40 kbar) studies of magnetotransport in $CeRhIn_5$. The combination of plastic diamond-anvil-cells, pulsed magnets, and focused-ion-beam microstructures enables us to investigate this region in the (p, T, B) phase diagram. We show that nematicity and SC reside in distinct regions. Our experiments reveal an unexpected enhancement of magnetic order in high fields with pressure.

TT 38.4 Wed 10:30 H23

Spin-dependent Masses in High Magnetic Field: Minimal Model for *CeCoIn*$_5$ — •Andrzej P. Kadzielawa[1,2], Dominik Legut[2], Maciej Fidrysiak[1], and Józef Spałek[1] — [1]Insytut Fizyki, Uniwersytet Jagielloński, Kraków, Poland — [2]IT4Innovations, Vysoká škola báňská - Technická univerzita Ostrava, Ostrava, Czech Republic

The intertwinement of superconductivity **[1]** and magnetism **[2]** in *CeCoIn*$_5$ is an arduous problem, often approached by accurate but time-consuming methods like Dynamical Mean-Field Theory **[3]**. In contrast, we provide a minimal, two-dimensional (after **[4]**), model to understand the mechanism of spin-split masses in this heavy-fermion system. Using the band Hubbard U technique (DFT+U calculations), we retrieve the precise energy scale for the strong correlations. To account for this we use a minimal model of the Periodic Anderson Lattice solved using the so-called Statistically-consistent Gutzwiller Approximation. We obtain the proper, experimentally confirmed, qualitative behavior of the spin-dependent masses, as well as overall half-metallic nature of the heavy fermion behavior in this compound.

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[1] C. Petrovic *et al.*, J. Phys. Condens. Matter **13**, L337 (2001)
[2] I. Sheikin *et al.*, Phys. Rev. Lett. **96**, 077207 (2006)
[3] K. Haule *et al.*, Phys. Rev. B **81**, 195107 (2010)
[4] A. Gyenis *et al.*, Nat. Comm. **9**, 549 (2018)

TT 38.5 Wed 10:45 H23

Switching the propagation vector of the hidden-order phase in $Ce_3Pd_{20}Si_6$ with a magnetic field — •Pavlo Y. Portnichenko[1], Stanislav E. Nikitin[2], Andrey Prokofiev[3], Silke Paschen[3], Jean-Michel Mignot[4], Jacques Ollivier[5], Andrey Podlesnyak[6], Siqin Meng[7,8], Zhilun Lu[8], and Dmytro S. Inosov[1] — [1]IFMP, TU Dresden, Germany — [2]MPI-CPfS, Dresden, Germany — [3]Vienna Univ. of Technology, Austria — [4]LLB, France — [5]ILL, France — [6]SNS, Oak Ridge, USA — [7]CIAE, Beijing, China — [8]HZB, Berlin, Germany

Hidden-order phases that occur in a number of correlated *f*-electron systems are among the most elusive states of electronic matter. The heavy-fermion compound $Ce_3Pd_{20}Si_6$ exhibits magnetically hidden order that occurs at subkelvin temperatures, known as phase II. Additionally, only in a magnetic field applied parallel to the [001] cubic axis, another field-induced phase II′ was observed in magnetization measurements, yet the nature of the II-II′ phase transition has remained a mystery. Here we use inelastic neutron scattering to demonstrate that this transition is associated with a switching in the propagation vector of the antiferroquadrupolar order from (111) to (100) with a simultaneous change in the type of the ordered quadrupole from O_2^0 to O_{xy}. Despite the absence of magnetic Bragg scattering in the phase II′, its propagation vector was revealed by the location of an intense soft mode in the excitation spectrum along the (100) direction, orthogonal to the applied field. Our experiment also reveals collective excitations in the field-polarized paramagnetic phase, after phase II′ is suppressed.

15 min. break.

TT 38.6 Wed 11:15 H23

Probing Fermi-surface evolution and crystal-field excitations in heavy-fermion systems by THz time-domain spectroscopy — •Shovon Pal[1], Christoph Wetli[1], Farzaneh Zamani[2], Oliver Stockert[3], Hilbert v. Loehneysen[4], Manfred Fiebig[1], and Johann Kroha[2] — [1]ETH Zurich, Switzerland. — [2]Bonn University, Germany. — [3]MPI-CPFS Dresden, Germany. — [4]KIT, Germany.

An enlarged Fermi volume ratifies the existence of heavy quasiparticles (QPs) in heavy-fermion (HF) compounds. The energy scale for the heavy QP formation is believed to be the Kondo lattice temperature. However, recent observations of large Fermi volume at temperatures much higher than the Kondo lattice temperature raised controversies on the validity of this long-known scale. We measure the QP weight in the HF compound $CeCu_{6-x}Au_x$ ($x = 0, 0.1$) by time-resolved THz spectroscopy for temperatures from 2 K to 300 K. This method distinguishes contributions from the heavy Kondo band and from the crystalelectric-field (CEF) split satellite bands by different THz response delay times [1]. We find that an exponentially enhanced, high-energy Kondo scale controls the formation of heavy bands, once the CEF states become thermally occupied [2]. We corroborate these observations by temperature-dependent, high-resolution dynamical mean-field calculations for the multi-orbital Anderson lattice model and discuss its relevance for quantum critical scenarios.

[1] C. Wetli, S. Pal *et al.*, Nat. Phys. **14**, 1103 (2018)
[2] S. Pal *et al.*, arXiv:1810.07412 (2018)

TT 38.7 Wed 11:30 H23

Exploring quantum criticality in strain-tuned heavy fermion thin films by THz spectroscopy — •C.-J. Yang[1], S. Pal[1], F. Zamani[2], M. Trassin[1], H. v. Loehneysen[3], J. Kroha[2], and M. Fiebig[1] — [1]ETH Zurich, Switzerland. — [2]Bonn University, Germany. — [3]KIT, Germany.

Quantum phase transition (QPT) refers to a second-order phase transition between the ground states of a many-body system occurring around T = 0 K, governed by critical fluctuations. In heavy fermion compounds, $CeCu_{6-x}Au_x$, Cu-substitution by Au expands the lattice thereby inducing a QPT from a paramagnetic Fermi-liquid state to an antiferromagnetically ordered ground state at $x = 0.1$. In this contribution, we take a novel approach, replacing the role of Au by strain-tuning in $CeCu_6$ epitaxial thin films. Films of various thicknesses are sputtered from a pure $CeCu_6$ target onto single-crystal substrates. The crystallinity and orientation of the thin films are investigated by X-ray diffraction. To understand the dynamic evolution of Kondo quasiparticle weight and of optical properties, we perform time-resolved THz measurements as function of temperature. For the sample of a 30 nm thick $CeCu_6$ film, our results show similar temperature-dependent Kondo response as observed in bulk samples [1]. We find a logarithmic onset of the Kondo spectral weight at 100 K. This behavior is further corroborated by the temperature-dependent mass enhancement ratio and the inverse scattering rate. We also observe a non-linear temperature-dependence of the optical resistivity.

[1] C. Wetli, S. Pal *et al.*, Nat. Phys. **14**, 1103 (2018)

TT 38.8 Wed 11:45 H23

Thermal Transport Measurement on Heavy Fermion Compound LiV_2O_4 — •Mohammad Pakdaman, Yosuke Matsumoto, Masahiko Isobe, Jan Bruin, and Hidenori Takagi — Department of Quantum Materials,Max Planck Institute for Solid State Research,Heisenbergstraße 1, 70569 Stuttgart

LiV_2O_4 is the only d-electron heavy fermion compound. The HF state in this compound was proved using different experimental techniques. However the mechanism for heavy fermion is still unknown. We performed the thermal transport measurement in order to reveal the mechanism for HF behavior.

TT 38.9 Wed 12:00 H23

Development of microstructure strain rig and investigations into PrV_2Al_{20} — •Po-Ya Yang[1], Jack Bartlett[1,2], and Clifford Hicks[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Scottish Universities Physics Alliance, School of Physics and Astronomy, University of St. Andrews, St. Andrews, United Kingdom

Uniaxial stress is a powerful method to explore the electronic states of materials. By lifting the symmetry of a lattice, it enables direct probing of symmetry-related phenomena. Reducing the size of the sample and improving surface quality are expected to improve the achievable precision and the maximum achievable stress before the sample fractures. Here, I will present methods and apparatus for applying uniaxial stress to samples that have been microstructured with a focused ion beam, and demonstrate with measurements on PrV_2Al_{20}.

TT 38.10 Wed 12:15 H23

Electronic structure and valence-to-core RIXS of europium sulfide — •Jindrich Kolorenc[1] and Lucia Amidani[2,3] — [1]Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic — [2]Institute of Resource Ecology, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]ESRF, Grenoble, France

We investigate the electronic structure of europium sulfide (EuS) with the aim to understand the valence-to-core resonant inelastic x-ray scattering (RIXS) spectra measured at the europium L_3 edge. We employ LDA+DMFT for the theoretical modeling of the valence-band electronic structure as well as the RIXS spectra. More specifically, we use a generalization of the method described recently in [1].

We show that the main signal comes from the direct RIXS: an Eu 2p core electron is excited to an empty Eu 5d band above the Fermi level, and then another electron from an Eu 5d state hybridized with the S 3p bands (located below the Fermi level and hence occupied) fills back the Eu 2p core hole. Besides this straightforward channel, the measured RIXS spectra display a number of satellite features that we attempt to identify with indirect RIXS processes where additional excitations are induced by the Coulomb potential of the core hole.

[1] J. Kolorenč, Physica B **536**, 695–700 (2018).

TT 38.11 Wed 12:30 H23

Electronic structure, magnetism, lattice dynamics and thermodynamic stability of fcc UH_2 — •Lukas Kyvala[1], Ladislav Havela[2], and Dominik Legut[1] — [1]VSB - Technical University of Ostrava, 17. listopadu 15, 70833 Ostrava-Poruba, Czech Republic — [2]Charles University, Ke Karlovu 5, 12116 Prague, Czech Republic

Uranium metal is known to form two different hydrides with the stoichiometry 1:3 (α and β UH_3). Although the other 5 f-elements as Pu, Np or Th exist in dihydride form, UH_2 was not reported for very long time. Hovewer, recent work [1] showed that *fcc* uranium dihydride can exist, if it is synthetized as a thin film.

Using the density funcitonal theory calculations employing VASP code we investigated electronic structure, mechanical and magnetic properties, lattice dynamics and thermodynamic stability of *fcc* uranium dihydride. The change of the magnetic order as well the thermodynamic stability vs. parent structure of UH3 is discussed.

A detailed comparison of thermodynamics and electronic structure of UH_2 with UH_3 shed on the light on the question why UH_2 can be stabilized as thin film and not in a bulk form.

[1] L. Havela, M. Paukov, M. Dopita, L. Horak, D. Drozdenko, M. Divis, I. Turek, D. Legut, L. Kyvala, T. Gouder, A. Seibert, and F. Huber, Inorganic Chemistry (2018)