TT 26: CE: Heavy Fermions

Time: Wednesday 14:00–18:45 Location: H21

TT 26.1 Wed 14:00 H21

Evolution of the Electron Spin Resonance (ESR) in the $CeFeAs_{1-x}P_xO$ doping series — •Tobias Förster, Anton Jesche, Cornelius Krellner, Jörg Sichelschmidt, Christoph Geibel, and Frank Steglich — Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden

The $CeFeAs_{1-x}P_xO$ compounds are structural homologues of the RTPnO (R: rare earth, T: transition metal, Pn: P or As) high temperature superconductors. The doping series owns a rich magnetic phase diagram driven by chemical pressure: CeFeAsO shows spin density wave (SDW) type order of Fe at $T_{SDW} \approx 140$ K and antiferromagnetic order (AFM) of Ce^{3+} at $T_N = 4$ K. By substituting P for As the SDW order disappears and the Ce magnetism initially becomes ferromagnetic (FM). Finally CeFePO is a heavy fermion metal with a large Sommerfeld coefficient and no magnetic order[1,2].
In our contribution we present the results of an ESR study on high quality poly- and single crystalline samples from the $CeFeAs_{1-x}P_xO$ doping series, covering the hole doping range. We find no signal, neither from Fe nor from Ce, in the samples with SDW and Ce-AFM. The ESR, which originates from the Ce^{3+} ions, appears when the SDW order of Fe vanishes and the Ce magnetism becomes FM. This is in agreement with our earlier work on CeRuPO and CeOsPO[3]. We will discuss the temperature and doping dependence of the ESR parameters.

[1] Y. Luo et al., arXiv **0907** 2961v1 (2009)
[2] E. Brüning et al., Phys. Rev. Lett. **101**, 117206 (2008)
[3] C. Krellner et al., Phys. Rev. Lett. **100**, 066401 (2008)

TT 26.2 Wed 14:15 H21

Complex interplay of Ce 4f and Fe 3d magnetism in CeFe(As,P)O as seen from ^{31}P and ^{75}As NMR. — •Rajib Sarkar, Michael Baenitz, Anton Jesche, Frank Steglich, and Cristoph Geibel — Max-Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

The rare earth (R) transition metal (T) pnictides RTPnO(Pn:P or As) earn special attention because of the high T_C superconductivity in $CeFeAsO_{1-x}F_x$, whereas the magnetism of the undoped system stays unexplored. CeFePO is a heavy fermion metal with a high γ value (700 mJ/mol K^2) in the vicinity of a ferromagnetic (FM) instability [1]. Here magnetism is solely governed by Ce-4f state whereas in CeFeAsO Fe 3d states themself order AFM at about T≅150 K. Therefore investigation on CeFe(As,P)O allows to study the crossover between Kondo and RKKY physics to 3d magnetic order. Yongkang Luo et. al. recently published a rather complex phase diagram with two critical points obtained from bulk properties. NMR provides a microscopic tool for studying the interplay between Ce 4f and Fe 3d magnetism. We report on ^{31}P (I=1/2) and ^{75}As (I=3/2) NMR studies on $CeFeAs_{1-x}P_xO$ with x=0, 0.05, 0.3, and 0.9.

[1] Brüning et . al., PRL 101, 117206 (2008).
[2] Luo et . al., arXiv:0907.2961v1.

TT 26.3 Wed 14:30 H21

Ferromagnetic $4f$ Correlations in the Oxypnictides $CeFe_{1-x}Ru_xPO$: A ^{31}P NMR Study — •Eva Maria Brüning, Cornelius Krellner, Michael Baenitz, Christoph Geibel, and Frank Steglich — Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany

CeTPO (T = Ru, Os, Fe), homologues of the new oxypnictide superconductors, show dissimilar types of ground states. CeRuPO is a rare example of a ferromagnetically ordered Kondo-lattice system ($T_C = 15$ K), whereas CeOsPO shows antiferromagnetic order and weak Kondo interaction ($T_N = 3.5$ K) [1]. CeFePO is a paramagnetic heavy fermion system in the vicinity of ferromagnetic order [2]. Therefore it became very interesting to investigate the solid solution series $CeFe_{1-x}Ru_xPO$ ($x = 0.1, 0.2$) to trace the crossover from a ferromagnetically correlated heavy fermion system ($x = 0$) to a ferromagnetically ordered metal ($x = 1$) through a possible quantum critical point. We applied the microscopic NMR method on polycrystals and performed a temperature and field dependent ^{31}P NMR study. The investigations of the Knight shift $^{31}K(T)$ and spin-lattice-relaxation rate $^{31}(1/T_1)$ of the new systems $CeFe_{1-x}Ru_xPO$ ($x = 0$, $x = 0.1$, $x = 0.2$) are presented.

[1] C. Krellner, N. S. Kini, E. M. Brüning, K. Koch, H. Rosner, M. Nicklas, M. Baenitz, C. Geibel *Phys. Rev. B*, **76**; 104418 (2007)
[2] E. M. Brüning, C. Krellner, M. Baenitz, A. Jesche, C. Geibel, F. Steglich, *Phys. Rev. Lett*, **101**; 117206 (2008)

TT 26.4 Wed 14:45 H21

Electronic structure and thermodynamic properties of $Ce_{3+x}Rh_4Sn_{13-x}$. — •Monika Gamza[1,2], Walter Schnelle[1], Roman Gumeniuk[1], Michael Nicklas[1], Ulrich Burkhardt[1], Andrzej Slebarski[3], Lev Akselrud[4], and Helge Rosner[1] — [1]MPI CPfS, Dresden, Germany — [2]Institute of Materials Science, University of Silesia, Katowice, Poland — [3]Institute of Physics, University of Silesia, Katowice, Poland — [4]Ivan Franko National University of Lviv, Ukraine

Recently we reported on the electronic structure and the magnetic properties of the strongly correlated compound $Ce_3Rh_4Sn_{13}$ [1]. The combined theoretical and experimental study indicated an unusual sensitivity of the magnetic ground state on the local composition. This prompted us to inspect the homogeneity range of Ce and Sn in this system.
Here, we present the results of magnetization, resistivity and specific heat measurements on the series of compounds $Ce_{3+x}Rh_4Sn_{13+x}$ ($0 \leq x \leq 0.6$) for temperatures down to 350 mK and in applied magnetic fields up to 7 T. The experimental study is accompanied by first principles electronic structure calculations. The changes in electronic structure and ground state properties for the series of $Ce_{3+x}Rh_4Sn_{13+x}$ are analysed with respect to the substitution of Sn by Ce. Furthermore, the crystal structure of the parent compound $Ce_3Rh_4Sn_{13}$ has been reinvestigated in detail. Superstructure has been found.

[1] Gamza M *et al.*, J. Phys.: Condens. Matter **20** 395208 (2008)

TT 26.5 Wed 15:00 H21

Investigation of the metamagnetic transition in $Ce_{1-x}La_xTiGe$ polycrystals — •Micha Deppe, Nubia Caroca-Canales, Franziska Weickert, Stefan Lausberg, Manuel Brando, Christoph Geibel, and Frank Steglich — Max-Planck-Institute for Chemical Physics of Solids, 01187 Dresden, Germany

CeTiGe is a new heavy Fermion system with a Kondo energy scale of the order of 50 K. Our investigations of the specific heat, magnetic susceptibility and resistivity of polycrystals evidenced a paramagnetic heavy Fermi liquid with a Sommerfeld coefficient $\gamma_0 \approx 300$ mJ/molK^2 at low temperatures. The temperature dependence of the susceptibility and of the specific heat reveal a maximum at 24 K and 16 K, respectively, indicating that the full $J = 5/2$ state of Ce^{3+} is involved in the formation of the heavy Fermion ground state [1].
DC magnetization measurements at 1.8 K up to 14 T on pure CeTiGe showed a step like increase of the magnetization $\Delta M \approx 0.7\ \mu_B$/Ce at $B_{MM} \sim 13.5$ T, which evidences a pronounced metamagnetic transition (MM). Here we shall focus on the development of the MM phase boundary in $Ce_{1-x}La_xTiGe$ upon increasing La content using $\rho(B)$ and $M(B)$ measurements. The observation of a hysteresis in $\rho(B)$ and $M(B)$ at B_{MM} for $Ce_{1-x}La_xTiGe$, which vanishes at $x = 0.6$, is a strong hint for a first order phase transition, in contrast to the crossover behavior reported for $CeRu_2Si_2$[2]. Thus the metamagnetic transition in CeTiGe represents a unique case among Kondo lattice systems.

[1] M. Deppe et al. J. of Phys.: Condensed Matter 21, (2009) 206001.
[2] P. Haen et al. J. of Low Temp. Phys. 67 (1987).

15 min. break

TT 26.6 Wed 15:30 H21

Field-induced coupled superconductivity and spin density wave order in the heavy fermion compound $CeCoIn_5$ — •Johannes Spehling[1], Hans-Henning Klauss[1], Robert Heffner[2], Eric Bauer[2], Jeff Sonier[3], and Nicholas Curro[4] — [1]Institut für Festkörperphysik, TU Dresden, Germany — [2]Los Alamos National Laboratory, Los Alamos, New Mexico , U.S.A. — [3]Department of Physics, Simon Fraser University, Burnaby, Canada — [4]Department of Physics, UC Davis, California, U.S.A

In strong magnetic fields the Heavy Fermion superconductor $CeCoIn_5$

shows a first order transition from the normal state into the SC phase [1]. Several modulated SC phases are suggested at high magnetic fields in $CeCoIn_5$, e.g., the spin singlet FFLO [2] and mixed singlet/triplet phases (Q-phase) [3]. We have carried out transverse field muSR measurements between 2 T and 5 T (H parallel c-axis) on single crystalline $CeCoIn_5$ in a temperature range between 25 mK and 7 K. In addition to the standard modulation perpendicular to the applied field due to the vortex lattice, a longitudinal modulation is expected. For the modulated high field phases in a local probe experiment an additional line or a static line broadening should occur. Our data clearly evidence the fielddriven change from second to first order transition at an applied field of 4.8 T. Temperature and field dependence of the muon spin relaxation rate support the formation of a mode-coupled SC and AFM ordered phase in $CeCoIn_5$ for fields directed parallel to the c-axis.

[1] A. Bianchi et al., PRL 91, 187004 (2003).
[2] P. Fulde and R.A. Ferrell, Phys. Rev. 135, A550 (1964).
[3] A. Aperis et al., arXiv:0902.0553.

TT 26.7 Wed 15:45 H21

Planar cross-type junctions on microcrystals of $CeCoIn_5$ thin films — •Oleksandr Foyevtsov and Michael Huth — Johann Wolfgang Goethe University, Frankfurt am Main, Germany

We present results on the preparation and electrical measurements of superconductor-insulator-superconductor cross-type junctions with variable barrier strength on microcrystal isolated from $CeCoin_5$ thin films.

The films have been grown by molecular beam epitaxy. The morphology of the films grown by this method demonstrates a strong tendency to form microcrystals, which makes it difficult to obtain reliable tunneling contacts. Nevertheless, it is still possible to prepare such junctions with an artificial barrier on individual microcrystals.

Films were pre-patterned by optical lithography for contact pad preparation. Then, ion/electron beam induced deposition (FIBID/FEBID) techniques were used for the preparation of both, the barriers and the counter electrodes on selected microcrystals. As artificial barriers we used carbonaceous deposits prepared with FEBID. The counter electrodes prepared using FIBID from $W(CO)_6$ precursor, which was also previously characterized on cross-type planar junctions with aluminum counter electrode.

TT 26.8 Wed 16:00 H21

Scanning Tunneling Spectroscopy studies of heavy fermion metals — •Stefan Ernst[1], Steffen Wirth[1], Cornelius Krellner[1], Christoph Geibel[1], Frank Steglich[1], Zachary Fisk[2], John L. Sarrao[3], and Joe D. Thompson[3] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [2]Department of Physics and Astronomy, University of California at Irvine, USA — [3]Los Alamos National Laboratory, Los Alamos, USA

We report Scanning Tunneling Microscopy/Spectroscopy (STM/S) experiments on single crystals of the heavy fermion intermetallic compounds $CeCoIn_5$, $CeIrIn_5$, and $YbRh_2Si_2$. The tunneling experiments were conducted at temperatures down to 300 mK under ultra–high vacuum conditions. Methods have been established to facilitate *in-situ* sample cleaving.

$CeCoIn_5$ and $CeIrIn_5$ exhibit unconventional superconductivity (SC) at ambient pressure. A gap compatible with d-wave symmetry of the order parameter was observed in the conductance spectra of $CeCoIn_5$. The presence of a gap–like feature in a temperature range above T_c may indicate the existence of a precursor state to SC. Based on atomically resolved topography data, the possible influence of a modified surface structure on STS is discussed.

For the case of $YbRh_2Si_2$, we speculate that the tunneling spectra reveal signatures of a Kondo resonance related to the Yb ions.

TT 26.9 Wed 16:15 H21

Electron Spin Resonance of $YbRh_2Si_2$ under pressure — •J. Sichelschmidt[1], H.-A. Krug von Nidda[2], D. Zakharov[2], I. Fazlishanov[3], J. Wykhoff[1], T. Gruner[1], C. Krellner[1], C. Klingner[1], C. Geibel[1], F. Steglich[1], and A. Loidl[2] — [1]MPI Chem. Physik fester Stoffe, 01187 Dresden — [2]EP V, EKM, Univ. Augsburg, 86135 Augsburg — [3]E. K. Zavoisky Phys. Techn. Inst., 420029 Kasan, Russia

We investigated the electron spin resonance (ESR) in the heavy-fermion metal $YbRh_2Si_2$ by applying hydrostatic pressure up to 3 GPa. We found that pressure increases the temperature dependence of the g factor and broadens the ESR line. These effects are similar to those observed in $Yb(Rh_{1-x}Co_x)_2Si_2$ where Co substitution for Rh induces chemical pressure. However, the effect of chemical and external pressure on the ESR is not identical indicating the relevance of Co induced disorder on the spin dynamics. We compare our pressure ESR results with the behavior of the Gd ESR in $CeAl_3$ [1]. This reveals a similar behavior pointing on one hand to a local character Yb^{3+}-ESR, on the other hand on the properties of a heavy quasiparticle spin resonance upon changing the hybridization strength between $4f$ and conduction electrons [2]. Both findings are consistent with the properties of a collective $4f$-conduction electron spin mode which is supported by the Kondo effect [3].

[1] B. Elschner, A. Loidl, Handb.Phys.Chem.Rare Earths **24**, 221(1997)
[2] P. Wölfle, E. Abrahams, arXiv **0909** 3552v1 (2009)
[3] B.I. Kochelaev et al., Eur. Phys. J. B **72** (2009)

TT 26.10 Wed 16:30 H21

Evidence for unconventional d-wave superconducting state in $CeCu_2Si_2$ — •Hugo A. Vieyra[1], David Parker[2], Hirale S. Jeevan[3], Christoph Geibel[1], Frank Steglich[1], and Niels Oeschler[1] — [1]Max Planck Institute for Chemical Physics of Solids. Dresden 01187, Germany — [2]US Naval Research Laboratory. Washington, DC 20375, USA — [3]I. Physik. Institut, Georg-August-Universität Göttingen, Göttingen 37077, Germany

The heavy-fermion $CeCu_2Si_2$ represents a prime system to study unconventional superconductivity in the vicinity of a magnetic instability. Within the homogeneity range of pure $CeCu_2Si_2$ different ground states can be obtained. S-type crystals exhibit a superconducting transition at T_c=0.6 K, whereas A/S-type show in addition antiferromagnetic order at T_N=0.8 K. In recent years, the synthesis techniques have been optimized in order to obtain large high-quality single crystals with well defined ground state properties. This allows the systematic study of the superconducting order parameter and its variation at the border with magnetic order. In this work, we present angular dependent resistivity measurements on high-quality S- and A/S-type single-crystalline $CeCu_2Si_2$ samples. The experimental results for the angular dependence of the upper critical field B_{c2} as well as theoretical calculations taking into account effects like the strong Pauli paramagnetism, hint towards an unconventional d-wave symmetry of the order parameter in $CeCu_2Si_2$.

TT 26.11 Wed 16:45 H21

Study of the temperature dependence of the magnetic excitations in $CeCu_2Ge_2$ — •Astrid Schneidewind[1], Oliver Stockert[2], Karin Schmalzl[3], Enrico Faulhaber[1], Micha Deppe[2], and Michael Loewenhaupt[4] — [1]Joint Research Group Helmholtz-Zentrum Berlin - Technische Universität Dresden, Garching, Germany — [2]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [3]Jülich Centre for Neutron Science at Institut Laue-Langevin, Grenoble, France — [4]Institut für Festkörperphysik, Technische Universität Dresden, Dresden, Germany

Long-range antiferromagnetic order establishes in the heavy fermion compound $CeCu_2Ge_2$ below $T_N = 4.15$ K with an amplitude modulated structure and an ordering wave vector $\mathbf{Q}_{AF} = (0.28\ 0.28\ 0.543)$ [1]. Due to the Kondo effect the ordered moment is slightly reduced to $m \approx 1.0\mu_B$ at low temperatures [1].
We performed inelastic neutron scattering on a $CeCu_2Ge_2$ single crystal to study the low energy magnetic excitations in the ordered state. At lowest temperatures, dispersive spin waves have clearly been observed. At the magnetic zone centre the spin waves are gapped with $\Delta E \approx 0.55$ meV. The excitation spectrum changes with increasing temperatures and the gap closes giving rise to quasielastic scattering just below T_N. The distinct behaviour of the magnetic excitation spectra can be related to the different magnetically ordered phases in $CeCu_2Ge_2$.

[1] A. Krimmel et al., Phys. Rev. B 55 (1997) 6416.

15 min. break

TT 26.12 Wed 17:15 H21

Drude response of slow and fast electrons in the heavy-fermion compound UNi_2Al_3 — •Marc Scheffler[1], Julia P. Ostertag[1], Katrin Steinberg[1], Martin Dressel[1], and Martin Jourdan[2] — [1]1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany

The unusual metallic behavior of heavy-fermion compounds at low temperatures is caused by mobile charge carriers with a large effective mass. This mass enhancement (compared to normal electrons) goes hand in hand with a reduction of the transport scattering time, which can directly be studied with optical spectroscopy: the characteristic Drude roll-off moves to very low frequencies. Here we combine microwave and THz spectroscopy to study thin films of the heavy-fermion compound UNi_2Al_3 in a broad frequency range.

At frequencies of a few GHz, a full Drude response indicates the dynamics of the heavy electrons in UNi_2Al_3. Surprisingly, at considerably higher frequencies (around 300 GHz) we observe a similar structure that is very reminiscent of Drude behavior. We interpret these two features as the Drude response of - at low frequencies - correlated, slow electrons and - at higher frequencies - uncorrelated, fast electrons. The temperature dependence and anisotropy of these two Drude roll-offs correspond to each other. These results also shed new light on previous studies of the related compound UPd_2Al_3.

TT 26.13 Wed 17:30 H21

Enhanced thermoelectricity and strong correlations in $FeSb_2$ — •Niels Oeschler[1], Peijie Sun[1], Simon Johnsen[2], Bo B. Iversen[2], and Frank Steglich[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Department of Chemistry, University of Aarhus, Aarhus, Denmark

$FeSb_2$ was recently identified as a narrow-gap semiconductor with indications of strong electron-electron correlations. Around 10 K the thermopower S assumes huge absolute values of more than 40 mV/K. It has been shown that the thermopower of $FeSb_2$ is of diffusive nature and strongly enhanced due to the appearance of strong correlations.
By substituting Te on the Sb site, an atom with one extra electron relative to Sb, an evolution from a semiconducting ground state into a metallic one is observed for small Te content. The thermopower of $FeSb_{1.98}Te_{0.02}$ is linear in T as expected for metals, however, with enhanced slope compared to the free-electron predictions. Deduced from specific heat and Hall effect measurements the effective charge-carrier mass m^* is determined to be as large as 15 times the free electron mass, consistent with the enhanced thermopower.

TT 26.14 Wed 17:45 H21

Theory of spin exciton in the Ce-based unconventional superconductors — •Alireza Akbari[1], Ilya Eremin[1], Peter Thalmeier[2], and Peter Fulde[1] — [1]Max Planck Institute for the Physcis of Complex Systems, D-01187 Dresden, Germany — [2]Max Planck Institute for the Chemical Physics of Solids, D-01187 Dresden, Germany

The feedback spin resonance was observed in inelastic neutron scattering (INS) experiments for numerous unconventional superconductors. In particular a different kind of feedback has been found in the Ce-based ferropnictides. We analyze the influence of unconventional superconductivity on crystalline electric field (CEF) excitations of rare-earth ions. Our theoretical model shows that the resonant magnetic excitations of the conduction electrons below T_c is a result of the formation of the bound state in the 4f-electron susceptibility at energies well below the CEF excitation energy. The transition between CEF split Ce-4f states has anomalous shift and line-width which is explained as an effect of coupling to resonant 3d spin excitations below T_c giving evidence for a $S^{\pm}$ state.

[1] S. Chi et al Phys. Rev. Lett. 101, 217002 (2008).
[2] G. Yu, et al, arXiv:0803.3250 (unpublished).
[3] A. Akbari, I. Eremin, P. Thalmeier, and P. Fulde, Phys. Rev. B, 80, 100504R (2009).

TT 26.15 Wed 18:00 H21

Phonons and the coherence scale of models of heavy fermions — •Marcin Raczkowski[1], Peng Zhang[1,2], Fakher F. Assaad[1], Thomas Pruschke[3], and Mark Jarrell[2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Department of Physics and Astronomy, Louisiana State University, Baton Rouge LA 70803, USA — [3]Institute for Theoretical Physics, University of Göttingen, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany

We consider models of heavy fermions in the strong coupling or local moment limit and include phonon degrees of freedom on the conduction electrons [1]. Due to the large mass or low coherence temperature of the heavy fermion state, it is shown that such a regime is dominated by vertex corrections which leads to the complete failure of the Migdal theorem. Even at weak electron-phonon couplings, binding of the conduction electrons competes with the Kondo effect and substantially reduces the coherence temperature, ultimately leading to the Kondo breakdown. Those results are obtained using a combination of the slave boson method and Migdal-Eliashberg approximation as well as the dynamical mean-field theory approximation. [1] arXiv:0910.2954v1

TT 26.16 Wed 18:15 H21

Charge Fluctuations and the Valence Transition in Yb under Pressure — Erik R. Ylvisaker[1], •Jan Kuneš[2], Andrew K. McMahan[3], and Warren E. Pickett[1] — [1]Department of Physics, University of California, Davis, California, USA — [2]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, Augsburg, Germany — [3]Lawrence Livermore National Laboratory, Livermore, California, USA

Materials, whose atomic state cannot be approximated by a single Slater determinant, are said to have fluctuating or intermediate valence. Using dynamical mean-field theory we investigate the physics of elemental Yb, which exhibits a valence transition under pressure accompanied by a crossover from the fluctuating to the intermediate valence behavior. By comparison to other rare-earth materials (Ce, Nd, Pr) we show that fluctuating and intermediate valence regimes can be distinguished by the charge susceptibility. A large charge susceptibility can explain the softness of Yb in the valence transition region.

TT 26.17 Wed 18:30 H21

Phase diagram of heavy fermions and valence fluctuators — •Veljko Zlatic — Institut für Festkörperforschung, Forschungszentrum Jülich, 52428 Jülich, Germany

The phase diagram of heavy fermions is obtained by the scaling solution of the periodic Anderson model with the crystal feld split states. The results explain the phase boundaries revealed by pressure and doping experiments on intermetallic compounds with Ce, Yb and Eu ions. A detailed comparison with the pressure experiments on $CeRu_2Ge_2$, Yb_2Pd_2Sn and doping experiments on $EuCu_2(Si_xGe_{1-x})_2$ is provided as an illustration.