TT 6: Correlated Electrons: Heavy Fermions

Time: Monday 9:30–12:45 Location: EB 202

TT 6.1 Mon 9:30 EB 202

Crystal-field ground states of CeX_2Si_2 (X= Cu, Ru, Rh,Pd, and Au) determined by linear polarized soft x-ray absorptionat the Ce $M_{4,5}$ edges — •T. Willers[1], A. Severing[1], C.-F. Chang[1], P. Hansmann[1], M.W. Haverkort[1], N. Hollmann[1], Z. Hu[1], H.J. Lin[2], C.T. Chen[2], H. Aoki[3], E. Bauer[4], C. Geibel[5], P. Lejay[6], and L.H. Tjeng[1] — [1]Institute of Physics II, University of Cologne,Germany — [2]National Synchrotron Radiation ResearchCenter, Taiwan — [3]Center for Low TemperaturePhysics, Tohoku University, Sendai, Japan — [4]LosAlamos National Laboratory, NM, USA — [5]MPI fürChem. Physik fester Stoffe, Dresden, Germany — [6]Institut Néel, CNRS, Grenoble, France

Knowledge of the spatial distribution of the 4f wave function in rare-earth Heavy-Fermion systems forms one of the basic ingredients for the modelling of their unusual and exotic properties. In the past, neutron scattering as the standard technique to determine the crystal-field scheme has often given contradicting results Here we use an alternative method. We have recently shown that polarization dependent soft-x-ray absorption spectroscopy is a powerful tool to probe the charge distribution of the crystal-field ground state of Ce ions. Through the polarization dependence we obtain direct spectroscopic information about the various Jz admixtures of the ground state. The so-called linear dichroic signal at the Ce $M_{4,5}$ edges can be very large and is easily measured, thereby providing accurate quantitative information. A systematic investigation of the 4f ground state wave function will be presented for the CeX_2Si_2 series (X=Cu, Ru, Rh, Pd, Au).

TT 6.2 Mon 9:45 EB 202

Do magnetism and superconductivity coexist in $CeCu_2Si_2$ with 2 % and 10 % Ge doping? — •J. Arndt[1,2], O. Stockert[1], M. Deppe[1], H.S. Jeevan[1], K. Schmalzl[3], A. Schneidewind[2,4], C. Geibel[1], and F. Steglich[1] — [1]MPI für Chemische Physik fester Stoffe, Dresden, Germany — [2]Institut für Festkörperphysik, TU Dresden, Germany — [3]Institut Laue-Langevin, Grenoble, France — [4]FRM-II, TU München, Germany

$CeCu_2Si_2$, the first discovered heavy-fermion superconductor, exhibits different ground states in subtle dependence on the exact stoichiometry: It shows either incommensurate magnetic order (A), superconductivity (S), or both phenomena (A/S). Ge doping decreases the hybridisation between the localised Ce 4f and the conduction electrons, and therefore allows for studying the evolution of superconductivity in the presence of a stabilised magnetic A phase. Cu-NQR measurements on polycrystals of $CeCu_2(Si_{0.98}Ge_{0.02})_2$ give indications of a coexistence of superconductivity and antiferromagnetism. We performed elastic neutron scattering on a single crystalline sample, which was mounted on a susceptibility set-up. The simultaneous recording of the susceptibility during the neutron measurement gives us the opportunity to follow the onset of superconductivity in-situ. Our results clearly indicate that, analogous to the situation in A/S $CeCu_2Si_2$, a phase separation between magnetic and superconducting volumes takes place, with a small magnetic volume fraction persisting down to low temperatures. These findings will be compared to results on 10 % Ge doped $CeCu_2Si_2$.

TT 6.3 Mon 10:00 EB 202

Investigation of the magnetic and the superconducting states of $CeCu_2(Si_{1-x}Ge_x)$ using single crystals — •Hirale S Jeevan[1], Takeshi Nakanishi[1], Julia Arndt[1], Enrico Faulhaber[2], Oliver Stockert[1], Micha Deppe[1], Tomasz Cichorek[1], Frank Steglich[1], and Christoph Geibel[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Gemany — [2]TU Dresden, IAPD, D-01062 Dresden, Germany

The discovery of superconductivity in $CeCu_2Si_2$ in 1979 opened the field of unconventional superconductivity in strongly correlated systems. Later on, another unconventional phase, the A-phase, of magnetic character was found to compete with the superconducting phase in $CeCu_2Si_2$. Recent neutron experiment confirms that the A-phase is nothing but the long range antiferromagnetic order, spin density wave type due to nesting of heavy Fermi surface. And in pure $CeCu_2Si_2$ it was shown that the long range magnetic phase and superconducting phase compete each other. Here we investigate the magnetic and the superconducting states in a series of Ge substituted single crystals $CeCu_2(Si_{1-x}Ge_x)$ with x = 0.02 and 0.1. Ge substitution has two effect, stabilises the magnetic phase due to expansion of the lattice, but it also induce disorder effect. Based on the earlier results on polycrystalline samples, we expect the possible co-existing of both long range magnetic phase and superconducting phase in some Ge concentration range. We shell analyse and discuss the single crystal growth, physical properties and neutron scattering measurements of these Ge substituted single crystals.

TT 6.4 Mon 10:15 EB 202

Magnetoresistance and anomalous Hall effect in ferromagnetic $CeSi_{1.81}$ — •Robert Ritz[1], Andreas Neubauer[1], Stefan Legl[1], Christian Pfleiderer[1], Dmitri Souptel[2], and Günter Behr[2] — [1]Physik-Department E21, Technische Universität München, D-85748 Garching, Germany — [2]Leibniz-Institut für Festkörper-und Werkstoffforschung(IFW) Dresden, P.O. Box 270116, D-01171 Dresden, Germany

As function of Si content the series $CeSi_x$ changes from an antiferromagnetic ground state for $x = 1$ to paramagnetism for $x = 2$. An abrupt magnetic to non-magnetic transition is observed just below $x = 2$, where single crystals with $x = 1.81$ exhibit an essentially ferromagnetic ground state below $T_C \approx 9.5\,\mathrm{K}$ that vanishes rapidly under pressure [1]. We report a comparison of the low-temperature magnetoresistance and anomalous Hall effect in $CeSi_{1.81}$ with the uniform magnetization and specific heat. The longitudinal magnetoresistance suggests the additional formation of a density wave below $T_x \approx 3\,\mathrm{K}$. We also find that the spontaneous anomalous Hall effect initially tracks the ordered moment, where deviations below $\sim T_C/2$ suggests the emergence of additional magnetic modulations. Well below T_C a small hysteresis in the Hall effect exists up to $B_m \sim 4\,\mathrm{T}$, the location of an S-shaped increase in the magnetization that is naively interpreted as itinerant metamagnetism. This may hint at a novel interplay between itinerant metamagnetism and structural defects. [1] S. Drotziger, et al., Phys. Rev. B **73**, 214413 (2006).

TT 6.5 Mon 10:30 EB 202

A precursor state to unconventional superconductivity in the heavy fermion superconductor $CeIrIn_5$ — •Sunil Nair[1], S. Wirth[1], M. Nicklas[1], J. L. Sarrao[2], J. D. Thompson[2], Z. Fisk[3], and F. Steglich[1] — [1]Max Planck Institute for Chemical Physics of Solids, Noethnitzer Str. 40, Dresden 01187, Germany. — [2]Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA. — [3]University of California, Irvine, California 92697, USA.

The $CeMIn_5$ (where M: Co, Rh or Ir) family of heavy fermion systems is currently in vogue; not only for the host of novel properties they exhibit in its normal and superconducting states, but also for the rather striking resemblance many of these properties have with the cuprate high temperature superconductors. Here, we present sensitive measurements of the Hall effect and magnetoresistance in $CeIrIn_5$, in the temperature range 0.05 K $\leq T \leq$ 2.5 K and magnetic fields up to 15 T. The magnetoresistance is used to demarcate the presence of a low temperature Kondo coherent state. Furthermore, by means of Kohler's scaling plots, the crossover from a Landau-Fermi liquid to a non-Fermi liquid regime is inferred. The functional form of the Hall resistivity is observed to be in concurrence with that expected for a compensated metal. The most striking observation pertains to the presence of a precursor state to superconductivity characterized by a change in the Hall scattering rate, in similarity to the pseudogap state in the cuprates. Moreover, the critical fields of the precursor state and the superconducting one can be scaled on to each other, implying that they could arise from the same underlying physical mechanism.

TT 6.6 Mon 10:45 EB 202

Pressure and concentration tuning of $CeNi_xPt_{1-x}$ compounds — •Nadezda Bagrets[1], Veronika Fritsch[1], and Hilbert v. Löhneysen[1,2] — [1]Physikalisches Institut, Universität Karlsruhe (TH), D-76128 Karlsruhe, Germany — [2]Forschungszentrum Karlsruhe, Institut für Festkörperphysik, D-76021 Karlsruhe

The intermetallic alloys $CeNi_xPt_{1-x}$ are examples of heavy-fermion compounds that can be tuned to the quantum critical point (QCP) by applying hydrostatic pressure [1] or by changing the ratio between Pt and Ni constituents (chemical pressure). The pure CePt compound orders ferromagnetically (FM). With increasing Ni content, FM order is suppressed and disappears completely at x = 0.95 possibly indicating a QCP [2]. CeNi is a Pauli paramagnet. At the same time, these compounds have orthorhombic CrB type of crystal structure for all compositions. We compare the effects of hydrostatic and chemical pressure on the magnetic properties of the series $CeNi_xPt_{1-x}$ in the whole concentration range between x = 0 and 1 and, in particular, in the vicinity of the QCP. We have performed measurements of the magnetization in the temperature range 2.5 - 300 K in magnetic field up to 0.1 T under hydrostatic pressure up to 1.2 GPa for $CeNi_xPt_{1-x}$ samples with different Ni content.

[1] J. Larrea at al., Phys. Rev. B 72, 035129 (2005)
[2] J. Espeso at al., Phys. Rev. B 63, 014416 (2000)

15 min. break

TT 6.7 Mon 11:15 EB 202

Relevance of the pseudogap for the thermopower of CeNiSn

— •Ulrike Köhler[1], Peijie Sun[1], Toshiro Takabatake[2], Silke Paschen[3], Niels Oeschler[1], and Frank Steglich[1] — [1]MPI for Chemical Physics of Solids, Dresden, Germany — [2]Hiroshima University, Japan — [3]Vienna University of Technology, Austria

CeNiSn has been classified as a correlated semimetal with a low charge carrier concentration. The opening of an anisotropic pseudogap below 10 K has been confirmed from various experimental probes. The gap formation can be suppressed significantly by application of magnetic fields of 10 T along the easy a axis.

We performed thermopower and Nernst effect measurements on high-purity single crystals of CeNiSn in the temperature range between 1.5 K and 200 K and in magnetic fields up to 7 T. Special care has been taken to correct the thermopower S for contributions from transverse components in a magnetic field. Our data clearly demonstrate the relevance of the pseudogap for the low-T thermopower. $S(T)$ exhibits a large negative minimum below the temperature, at which the gap opens. Upon increasing magnetic field the minimum shifts to lower T wheras the absolute values at the minimum increase. We apply a simple model to describe this unusual field dependence of the thermopower.

TT 6.8 Mon 11:30 EB 202

The new Heavy Fermion System CeFePO: A ^{31}P NMR study

— •Eva Maria Brüning, Michael Baenitz, Cornelius Krellner, Christoph Geibel, and Frank Steglich — Max-Planck-Institut für Chemische Physik fester Stoffe

Among the CeTPO system (T = Ru, Os, Co, Fe), CeFePO is particular interesting because it presents Heavy Fermion behavior. Specific heat measurements above 400 mK clearly show the absence of magnetic order and a strongly enhanced Sommerfeld ratio $\gamma = 700\,\mathrm{mJ/molK^2}$, comparable to $CeCu_2Si_2$. ^{31}P NMR field sweep measurements were performed at different fields (4.4 T and 1.5 T) and temperatures (2 K to 300 K). ^{31}P Knight shift $^{31}K(T)$ shows a field independent Curie-Weiss like behavior above 100 K consistent with $\chi(T)$ measurements, whereas towards lower temperatures a saturation occurred due to Kondo interaction. $^{31}K(T)$ vs. $\chi(T)$ gives a hyperfine coupling constant of $A_{\mathrm{hf}} = 2\,\mathrm{kOe}/\mu_B$. $^{31}(1/T_1)$ measurements were carried out at different fields (4.4 T and 1.5 T). $^{31}(1/T_1T)(T)$ is field independent and shows a strong increase towards lower temperatures and a saturation towards an enhanced Korringa value for $T \rightarrow 0$, indicating a large $N(E_F)$ value. $^{31}(1/T_1T)$ is qualitatively similar to the ^{29}Si NMR results on $CeCu_2Si_2$ (7 T). Using ^{31}P as a local probe, our ^{31}P NMR results strongly confirm the Heavy Fermion scenario for this new compound.

TT 6.9 Mon 11:45 EB 202

ESR Study on CeRuPO single crystals

— •Tobias Förster, Jörg Sichelschmidt, Cornelius Krellner, and Christoph Geibel — Max Planck Institut f. Chemische Physik Fester Körper, Nöthnitzer Str. 40, 01187 Dresden, Germany

Until 2003 it was believed that the Electron Spin Resonance signal (ESR) from a Kondo ion in a dense Kondo system is not observable, because of the strong broadening due to 4f/5f- conduction electron hybridization. Hence the first observation of such a signal in $YbRh_2Si_2$ was a big surprise[1]. Very recently we found further Yb- and Ce-compounds that show well defined ESR signals [2].

In this contribution we will concentrate on single crystal data from the ferromagnetic Kondo-lattice system CeRuPO[3]. The recorded spectra show an asymmetry which is related to the local Ce^{3+}ion (Γ_6 wave function) in tetragonal point symmetry. This is surprising because to the best of our knowledge an ESR signal due to dense Ce^{3+} magnetic moments in an environment with conduction electrons has only been reported for CeP. This unexpected result is neither specific to Ce-based compounds nor to compounds with Kondo-like properties nor to the proximity of a (quantum) critical point. It turns out that strong ferromagnetic correlations in the electronic system are essential for the ESR observability of concentrated magnetic ions in intermetallic systems.[2]

[1] J. Sichelschmidt et al., Phys. Rev. Lett. 91, 156401 (2003)
[2] C. Krellner et al., submitted to Phys. Rev. Lett.
[3] C. Krellner et al., Phys. Rev. B 76,104418 (2007)

TT 6.10 Mon 12:00 EB 202

Low-temperature thermodynamic and magnetic properties of the geometrically frustrated Kondo lattice $Pr_2Ir_2O_7$

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The ground state of f-electron Kondo-lattice systems is determined by the interplay of the Kondo- and the RKKY interaction, leading to a quantum critical point separating long-range magnetic order from paramagnetism. The interesting question arises, how this situation is modified in the presence of strong magnetic frustration. Here, we focus on the iridate $Pr_2Ir_2O_7$ which crystallizes in the highly frustrated pyrochlore structure and has recently been proposed as a realization of a metallic spin liquid [1]. We present low-temperature thermodynamic (specific heat and thermal expansion) and magnetic properties of slightly off-stoichiometric $Pr_2Ir_2O_7$ single crystals.

[1] S. Nakatsuji *et al.*, PRL **96**, 087204 (2006)

TT 6.11 Mon 12:15 EB 202

Enhanced thermopower and related phenomena in the narrow-gap semiconductor $FeSb_2$

— •peijie sun[1], niels oeschler[1], ulrike köhler[1], simon johnsen[2], bo brummerstedt iversen[2], and frank steglich[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Department of Chemistry, University of Aarhus, Denmark

A huge Seebeck coefficient of several tens of mV/K around 10 K was found in $FeSb_2$ [1], which shares considerable similarity with the Kondo insulator FeSi with a narrow semiconducting gap. The origin of the enhanced thermopower is yet to be understood. Strong electronic correlation producing enhanced DOS near Fermi level seems to be one possible reason.

We report new results of the Hall effect, specific heat and Nernst effect on high quality single crystals to study the effect of strong correlation. A smaller energy gap of about 50 K was detected in electrical resistivity and Hall coefficient, besides the well known gap at above 300 K. The appearance of the smaller gap accompanies a shoulder in resistivity and a huge peak in Hall coefficient, and thus could be closely related to the enhanced Seebeck coefficient that occurs in the same temperature range.

[1] A. Bentien et al., Europhys. Lett. 80 (2007) 17008.

TT 6.12 Mon 12:30 EB 202

Optical Studies on the Strongly Correlated Semiconductor $FeSb_2$ and on $RuSb_2$

— •Alexander Herzog[1], Michael Marutzky[1], Jörg Sichelschmidt[1], Anders Bentien[1], Frank Steglich[1], Shin-ichi Kimura[2], Simon Johnsen[3], and Bo Iversen[3] — [1]MPI Chemical Physics of Solids, 01187 Dresden, Germany — [2]UVSOR, Institute for Molecular Science, Okazaki 444-8585, Japan — [3]Dep. of Chemistry, University of Aarhus, 8000 Århus C, Denmark

The narrow band gap semiconductor $FeSb_2$ has similar properties to FeSi and both materials are discussed in the framework of a Kondo insulator model. We measured the optical conductivity of single crystals of $FeSb_2$ from 3 meV up to 30 eV by means of reflectivity spectroscopy. We compare the spectra of $FeSb_2$ with those of its non-magnetic homologue $RuSb_2$. In contrast to previous reports [1], our samples of $FeSb_2$ are semiconducting for all crystal axes. The far-infrared optical spectra are characterized by both phononic and electronic contributions. The phononic part displays a strong electron-phonon coupling at elevated temperatures whereas the electronic part presents an indirect gap of 30 meV which agrees well with the value inferred from transport measurements [2]. Another gap feature at 6 meV is probably related to the extraordinary large Seebeck coefficient of $FeSb_2$ [2].

We observed a temperature dependent spectral weight redistribution within a large energy range which clearly extends 1 eV indicating the presence of strong electronic correlations.

[1] A. Perucchi et al., Eur. Phys. J. B **54**, 175 (2006)
[2] A. Bentien et al., Europhys. Lett. **80**, 39901 (2007)