TT 39: Correlated Electrons: Heavy Fermions 1

Time: Thursday 9:30–13:00 Location: HSZ 304

Invited Talk TT 39.1 Thu 9:30 HSZ 304

Electron spin resonance in Kondo systems — •Peter Wölfle — Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, 76128 Karlsruhe

Well-defined electron spin resonance (ESR) lines have been detected recently in several heavy fermion compounds, in which ferromagnetic correlations appear to be present [1]. We first discuss [2] the theory of ESR for the Kondo impurity system at temperatures T<<TK (Kondo temperature) , where the local spin ESR line has a width of order TK and is therefore unobservably broad.. By contrast, in the Anderson lattice system in the Kondo regime the ESR linewidth is narrow, and gets broadened by spin lattice relaxation and quasiparticle interaction processes. We show [2] that the spin lattice induced ESR linewidth is greatly reduced by an effective mass factor. The quasiparticle induced linewidth is small in the Fermi liquid regime, proportional to max(Tˆ2,Bˆ2) (T=temperature, B=Zeeman energy). The total ESR linewidth is reduced by exchange narrowing induced by a ferromagnetic exchange interaction. This explains the available ESR data.

[1] C. Krellner et al., Phys. Rev. Lett. 100, 066401 (2008).
[2] E. Abrahams and P. Wölfle, Phys. Rev. B78, 104423 (2008).

TT 39.2 Thu 10:00 HSZ 304

Tuning the Kondo Effect in $YbRh_2Si_2$: Electron Spin Resonance under Pressure and Doping — •Jan Wykhoff[1], D. V. Zakharov[2], H.-A. Krug von Nidda[2], I. Fazlizhanov[3], J. Sichelschmidt[1], C. Krellner[1], C. Geibel[1], A. Loidl[2], and F. Steglich[1] — [1]MPI for Chemical Physics of Solids, D-01187 Dresden — [2]EP V, EKM, University of Augsburg, D-86135 Augsburg — [3]E. K. Zavoisky Physical Technical Institute, 420029 Kazan, Russia

The observation of a well defined Electron Spin Resonance (ESR) signal below the Kondo temperature T_K in the heavy-fermion compound $YbRh_2Si_2$ refutes a common believe that concentrated rare earth ions in Kondo-lattice intermetallic compounds would be ESR silent in the Kondo regime. The signal shows distinct properties of the Yb^{3+} $4f$ spin and, hence, should contain valuable microscopic information on the dynamical Kondo coupling to the conduction electrons [1]. We investigated the effect of tuning the $4f$ - conduction electron hybridization strength by Co-doping and hydrostatic pressure up to 3 GPa. Both stabilize antiferromagnetic order, lead to a reduction of T_K, and yield pronounced changes in the ESR parameters. By comparing the quantitatively different effect of pressure and Co doping on the ESR parameters we found a relation of the zero temperature residual ESR linewidth to the residual resistivity and the linear in temperature slope of the linewidth as was similarly reported for the La-doping case [1].

[1] J.W. *et al.* Physica C 460-462, 686 (2007); J.Sci.Tech.Adv.Mat. 8 389 (2007); J.S. *et al.* Phys. Rev. Lett. 91 156401 (2003).

TT 39.3 Thu 10:15 HSZ 304

Do heavy charge carriers entail a large Nernst coefficient? — •Ulrike Köhler[1,2], Cornelius Krellner[1], Niels Oeschler[1], Christoph Geibel[1], and Frank Steglich[1] — [1]MPI for Chemical Physics of Solids, Dresden, Germany — [2]present address: Leibniz Institute for Solid State and Materials Research (IFW) Dresden, Germany

The Nernst effect is the development of a transverse thermal voltage in a magnetic field perpendicular to a heat current. During the past years unusually large Nernst coefficients ν have been observed in several Ce- and U-based heavy-fermion (HF) compounds. It has been speculated, that the huge Nernst signals are related to the enhanced effective charge carrier masses $m^\star$ of these systems. So far, however, investigations on Yb-based HF metals are lacking to corroborate this picture. We therefore studied the Nernst effect in $YbRh_2Si_2$, an archetype non-Fermi-liquid compound with a Kondo temperature T_{K} of 20 K. The Nernst coefficient is presented between 6 K and 200 K, i.e. covering the crossover from low effective charge carrier masses above T_{K} to the HF regime at $T \ll T_{\mathrm{K}}$. ν is found to be negative with a minimum close to T_{K}, thus supporting the speculation about a relation between large ν and enhanced $m^\star$. The absolute values of the Nernst coefficient, however, are more than one order of magnitude smaller than in other HF systems. We discuss our findings in consideration of recent investigations on the correlated semiconductor CeNiSn, which point to a predominant importance of a low charge carrier density instead of a large $m^\star$ for the occurrence of a strong Nernst effect.

TT 39.4 Thu 10:30 HSZ 304

Concentration tuning of magnetic order in $CePd_{1-x}Ni_xAl$ compounds — •Nadezda Bagrets[1], Veronika Fritsch[1], Gernot Goll[1], and Hilbert v. Löhneysen[1,2] — [1]Physikalisches Institut, Universität Karlsruhe, 76128 Karlsruhe, Germany — [2]Institut für Festkörperphysik, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany

The intermetallic alloys $CePd_{1-x}Ni_xAl$ are examples of antiferromagnetic (AF) heavy-fermion compounds which can be tuned to quantum critical point (QCP). CePdAl is well known as geometrically frustrated Kagomé-like lattice [1]. The substitution of Pd with Ni in CePdAl induces chemical pressure. The transition temperature decreases with increasing Ni content [2]. We performed specific-heat measurements on $CePd_{1-x}Ni_xAl$ compounds down to 30 mK. The AF transition is still visible for x=0.1. From the T_N vs. x dependence we expect the QCP at about $x = 0.12 - 0.13$. Surprisingly, our measurements show that the magnetic moment per formula unit at low temperature increases with increasing Ni content (chemical pressure) in contrast to a hydrostatic pressure [3]. We will present the specific heat and susceptibility measurements at very low temperatures as well as magnetization measurements up to a room temperature.

[1] H. Kitazawa, *et al.*, Physica B **199/200**, 28 (1994).
[2] Y. Isikawa, *et al.*, Physica B **281/282**, 365 (2000).
[3] S. Hane, *et al.*, Physica B **281/282**, 391 (2000).

TT 39.5 Thu 10:45 HSZ 304

Magnetic Anisotropy in Tetragonal Rare Earth Compounds — •Veronika Fritsch[1], Michael Marz[1], and Hilbert v. Löhneysen[1,2] — [1]Physikalisches Institut, Universität Karlsruhe, 76128 Karlsruhe, Germany — [2]Institut für Festkörperphysik, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany

We have investigated single crystals of $R\mathrm{Au_2Ge_2}$ with R = Ce and Pr as well as $\mathrm{Ce_2}M\mathrm{Ga_{12}}$ with M = Ni, Pd and Pt, grown by a flux growth method with Au-Ge flux for $R\mathrm{Au_2Ge_2}$ and Ga flux for $\mathrm{Ce_2}M\mathrm{Ga_{12}}$. The latter crystallizes in a tetragonal structure with layers of Ce atoms separated by segments of Ga only alternating with $GaPd_6$ segments [1]. Measurements of the dc susceptibility χ revealed a strong magnetic anisotropy. For the magnetic field along the c-axis, antiferromagnetic order sets in at 9.6 K (Ni), 10.6 K (Pd) and 5.7 K (Pt), as evidenced by sharp maxima in $\chi(T)$, for the magnetic field perpendicular to the c-axis $\chi(T)$ continues to increase monotonically down to 2 K. In $R\mathrm{Au_2Ge_2}$ compounds, crystallizing in the considerably simpler $ThCr_2Si_2$ structure [2], a similar situation was found: with the magnetic field parallel to the c-axis antiferromagnetic order was found at 11.9 K (Ce) and 10.8 K (Pr), but with the magnetic field aligned perpendicular to the c-axis, no evidence for magnetic order is found down to 2 K. We will present measurements of magnetization and electrical resistivity exploring the possible proximity of these systems to a field-induced quantum critical point.

[1] R. T. Macaluso *et al.*, J. Sol. State Chem. **178** (2005) 3547.
[2] A. Loidl *et al.*, Phys. Rev. B **46** (1992) 9341.

15 min. break

TT 39.6 Thu 11:15 HSZ 304

Low-energy optics of the heavy-fermion compound UNi_2Al_3 — •Marc Scheffler[1], Julia 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

Heavy-fermion materials are intermetallic compounds with unusual metallic behavior at low temperatures. From the optical point of view, the Drude response (the transport relaxation time is enhanced in the same way as the effective mass) and the so-called hybridization gap (a signature of the peculiar band structure due to electronic interactions) are of particular interest. The low energy scales of heavy fermions call for optics at very low frequencies and in a broad range, but the only material studied in detail so far is UPd_2Al_3, where we found an extremely narrow Drude response (around 5GHz) and an optical excitation at 100GHz in the antiferromagnetic state.

To generalize those previous results, we focus here on the related heavy-fermion compound UNi_2Al_3. We have grown high-quality thin films and studied them with a combination of microwave and optical techniques in a very broad frequency range. At temperatures below 30K, we find a strongly frequency-dependent optical conductivity: the Drude roll-off resides below 20GHz, but above 100GHz another broad conductivity maximum occurs. In addition to the frequency and temperature dependence of the conductivity, we also present its anisotropy, and we discuss them in the context of the different energy scales of this material.

TT 39.7 Thu 11:30 HSZ 304

Superconductivity in $CeCu_2Si_2$: evidence of fermisurface change — •Enrico Faulhaber[1], Oliver Stockert[2], Wolfgang Schmidt[3,4], Karin Schmalzl[3,4], Christoph Geibel[2], Frank Steglich[2], and Michael Loewenhaupt[1] — [1]TU Dresden; Institut für Festkörperphysik; D-01062 Dresden — [2]Max-Planck-Institut für Chemische Physik fester Stoffe; D-01187 Dresden — [3]Forschungszentrum Jülich GmbH; Institut für Festkörperforschung; D-52425 Jülich — [4]Institut Laue-Langevin; F-38042 Grenoble

The first discovered heavy fermion superconductor $CeCu_2Si_2$ has been investigated for nearly 30 years now. Key properties of the material are an antiferromagnetic order below 1 K dominated by a nesting of the Fermi surface and a superconducting phase below ≈0.6 K. This phase seems to depend on the magnetism in the material, possibly pointing towards a magnetically mediated superconductivity.

In a recent experiment we investigated the delicate relationship between the magnetic and superconducting phases. We used the neutron scattering technique to observe the magnetic propagation vector. Also, the instrument was complemented with a unique in-situ *ac*-susceptibility setup to record the superconductivity of the sample during the neutron diffraction. Applying a magnetic field, we found an unexpected change of the magnetic propagation vector which correlates well with the superconducting volume. This shift is absent in non-superconducting samples, indicating a strong entanglement of both phenomena (superconductivity and magnetism) and might point to a change of the Fermi surface caused by the superconductivity.

TT 39.8 Thu 11:45 HSZ 304

Investigation of $Yb_2Pt_6AL_{15}$ single crystals: heavy fermion system with a large local moment degeneracy — •Micha Deppe, Stefanie Hartmann, Monica E. Macovei, Niels Oeschler, Michael Nicklas, and Christoph Geibel — Max-Planck-Institute for Chemical Physics of Solids, 01187 Dresden, Germany

Possible new Cerium or Ytterbium based heavy fermion compounds for the study of a quantum critical point (QCP) are of high interest. We studied $Yb_2Pt_6AL_{15}$ because it exhibits an interesting quasi 2D crystal structure. It crystallizes in the hexagonal structure type $Sc_{1.2}Fe_4Si_{9.8}$ and this structure presents RE_2Al_3 - layers separated by two Pt-Al layers in a large distance $c/2 = 8.18$ Å between the RE_2Al_3 - layers and a large c/a ≈ 4 ratio.
Here we present our investigations of the magnetic properties by means of susceptibility $\chi(T)$, specific heat $C(T)$, resistivity $\rho(T)$ and thermoelectric power $S(T)$ measurements. While all properties follow in general the behavior typical for Kondo-lattice systems, $\chi(T)$ and $C_p(T)/T$ present broad maxima in the T range 17-35 K, which matches nicely the prediction of the Coqblin-Schrieffer model for $J = 7/2$. A large degeneracy of the local moment is also supported by a reduced Kadowaki-Woods ratio. Thus, the analysis of all investigated properties evidences $Yb_2Pt_6Al_{15}$ to be a paramagnetic Kondo-lattice system with the whole $J = 7/2$ multiplet involved in the formation of the Kondo state, a Kondo temperature of the order of 60 K, and a heavy Fermi-liquid ground state with a Sommerfeld coefficient $\gamma_0 = 0.33$ $J/mol{-}Yb\,K^{-2}$ corresponding to a mass enhancement of the order of 30.

TT 39.9 Thu 12:00 HSZ 304

Normal state magnetoresistance in the heavy fermion superconductor $CeCo(In_{0.925}Cd_{0.075})_5$ — •Sunil Nair[1], S. Wirth[1], M. Nicklas[1], A. D. Bianchi[2], Z. Fisk[3], and F. Steglich[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany. — [2]Départment de Physique, Université de Montréal, Montréal, Quebec H3C 3J7, Canada. — [3]University of California, Irvine, California 92697, USA.

The CeMIn$_5$ (where M: Co,Ir) family of heavy fermion systems is currently in vogue due to the delicate interplay between unconventional superconductivity and magnetism observed in these systems. A putative quantum critical point – which lies in the vicinity of the superconducting regime in the temperature-magnetic field phase space of these systems – manifests itself in a host of novel properties. An additional ambient pressure phase space was opened up by Cd substitution on the In site, which acts as an efficient electronic tuning agent and shifts the ground state from a superconducting to an antiferromagnetic one. Here, we present sensitive measurements of the magnetoresistance in the $CeCo(In_{0.925}Cd_{0.075})_5$ system in the temperature range 0.05 K $\leq T \leq$ 4 K and with magnetic fields of up to 15 T. At fields larger than the superconducting upper critical field, features corresponding to a possible destabilization of the antiferromagnetic order are observed. Measurements performed with the magnetic field applied along different crystallographic directions indicate that this feature is strongly anisotropic. The implications of our results are discussed in the context of the crystallographic and magnetic anisotropy of these systems.

TT 39.10 Thu 12:15 HSZ 304

μSR-studies on the Heavy-Fermion-Superconductor $CeCoIn_5$ at high magnetic fields — •Johannes Spehling[1], Hans Henning Klauss[1], Jeff Sonier[2], Eric Bauer[3], and Robert Heffner[3] — [1]Institut für Festkörperphysik, Technical University Dresden, D-01069 Dresden, Germany — [2]Department of Physics, Simon Fraser University, Burnaby, BC, Canada — [3]Los Alamos National Laboratory, Los Alamos, New Mexico 87545, U.S.A

In strong magnetic fields the Heavy Fermion superconductor $CeCoIn_5$ shows a first order transition from the normal state into the superconducting phase [1]. It is suggested that a specifically modulated superconducting state is formed, the FFLO state, theoretically predicted by Fulde, Ferrell, Larkov and Ovchinnikov in 1964/1965 [2]. We have carried out transverse field μSR-measurements between 2T and 5T ($\hat{c} \parallel H$) on single-crystalline $CeCoIn_5$ in a temperature range between 25mK and 7K. In addition to the standard modulation perpendicular to the applied field due to the flux line lattice, a longitudinal modulation is expected. In that case an additional broadening of a local probe spectrum due to hyperfine fields should occur. The data clearly evidence the fielddriven change from second to first order-like transition at an external field of 4.8T. On the other hand no additional line broadening is observed at very low temperatures below T_c, which disagrees with the assumptions of a static FFLO state.

[1] A. Bianchi *et al.*, Phys. Rev. Lett. **91**, 187004 (2003).
[2] P. Fulde and R. A. Ferrell, Phys. Rev. **135**, A550 (1964).

TT 39.11 Thu 12:30 HSZ 304

Electronic transport properties of c-axis oriented $CeCoIn_5$ thin films — •Oleksandr Foyevtsov and Michael Huth — Johann Wolfgang Goethe University, Frankfurt am Main, Germany

We report results of the growth of c-axis oriented thin films of the heavy-fermion superconductor $CeCoIn_5$ prepared by molecular beam epitaxy. The films were grown by co-deposition of the constituent elements on chemically cleaned a-plane α-Al_2O_3 substrates. X-ray (XRD) diffraction, atomic force (AFM) and scanning electron microscopy (SEM) were used for film characterization. The films show a pronounced c-axis growth preference with a moderate tendency for epitaxial in-plane order driven by substrate crystallographic planes. In general the films' morphology is rough, which we assume is driven by the weak wetting tendency of the In component. Comparative growth studies done on the parent compound $CeIn_3$ support this assumption. By optimization of the growth process, samples with improved surface morphology were obtained. Electronic transport measurements (resistivity, magneto-resistivity, Hall effect) were performed in the temperature range from 1.8 K to 270 K in magnetic fields up to 9 T. We prepared superconductor-insulator-superconductor tunnel junctions on selected thin films using thin amorphous AlO_x layers as insulating barrier and In layers as counter electrode. These tunnel diodes were prepared in-situ by a stencil mask technique. First results on the tunneling spectroscopy of these diodes will be presented.

TT 39.12 Thu 12:45 HSZ 304

The magnetisation dynamics in the superconducting state of UBe_{13} investigated by inelastic neutron scattering — •Arno Hiess[1], Oliver Stockert[2], and Zachary Fisk[3] — [1]Institut Laue - Langevin, Grenoble, France — [2]MPI-CPfS, Dresden, Germany — [3]Univ. California, Irvine, USA

Inelastic neutron scattering experiments continue to shed light on the interplay of magnetism and superconductivity. Previously such experiments established that the magnetisation dynamics of several high-temperature superconductors differs in the superconducting and in the normal state. Such an effect has also been reported in three intermetallic superconductors, e.g., UPd_2Al_3, $CeCoIn_5$ and $CeCu_2Si_2$. We here report high-resolution inelastic neutron scattering experiments on a large UBe_{13} single crystal using the cold neutron three-axis spectrometer IN14 at ILL, Grenoble. UBe_{13} is a cubic material which at low temperatures exhibits a large electronic contribution to the specific heat and becomes superconducting below $T_{sc} = 0.85$ K. In agreement with previous experiments and below about 30 K we observed short-lived and short-ranged magnetic fluctuations at selected momentum space positions. The measurements in the normal state show a quasi-elastic signal. Upon entering the superconducting state a reduction of magnetic intensity is observed below 0.5 meV, suggesting the magnetic response becomes inelastic below T_{sc}. Our results will be compared to those obtained in other superconductors and rationalised within a simple scenario of superconductivity.