Experimental report

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Title: Magnetic excitations in the partially frustrated metal CePdAl

Research area: Physics

This proposal is a new proposal

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Samples: CePdAl

Instrument	Requested days	Allocated days	From	To
IN12	7	6	23/06/2016	29/06/2016

Abstract:

CePdAl is a unique intermetallic material, where both long-range magnetic order and magnetic frustration show up below the antiferromagnetic ordering temperature of 2.7K. Due to the arrangement of Ce ions on a distorted Kagomé lattice in the basal plane, geometric magnetic frustration is present. This results in a partially frustrated state, where only two thirds of the Ce ions participate in long-range magnetic order whereas the other third remains mainly disordered. The occurring interplay between Kondo physics and partial magnetic frustration in this metallic compound enables new investigations of strongly correlated effects, e.g. on quantum phase transitions, which occur at absolute zero temperature.

In the proposed experiment, the magnetic excitation spectrum of CePdAl shall be studied. Especially excitations resulting from the frustrated Ce moments and their influence on the evolution of spin waves are of high interest to get a better understanding of the nature and stability of the partially frustrated state. Moreover, we want to look for anisotropic excitations by investigating the magnon dispersion along the magnetically hard and easy direction.

Magnetic excitations in the partially frustrated metal CePdAl

Stefan Lucas and Oliver Stockert (Proposal 4-01-1507)

Effects of magnetic frustration on magnetic properties of materials are intensively investigated in strongly correlated electron systems. Exotic states like spin-glass, spin-liquid and spin-ice states were found, which reveal an unusual thermodynamic behavior and unusual magnetic excitations [1]. Up to now, magnetic frustration was mainly observed and investigated in insulating materials, since the magnetic moments have to be localized in order to develop magnetic frustration. However, in 4f and 5f-based metallic electron systems, the f-electrons are still strongly localized, so that magnetic frustration is possible to evolve. Heavy-fermion systems like CePdAl might be good model systems to investigate the influence of magnetic frustration in a metallic material. Theoretical models have proposed new quantum states of matter resulting from the interplay of magnetic frustration and the Kondo effect [2]. It is proposed, that a partially Kondo-screened state exists, where only two thirds of the magnetic moments located on a triangular or Kagomé lattice are long-range ordered, whereas the other third is screened and does not participate in long-range magnetic order [2,3]. Such a state might be present in CePdAl, which orders incommensurate with a propagation vector of (0.5 0 0.35) below the ordering temperature of $T_{\mathrm{N}} = 2.7\,\mathrm{K}$. There, also one third of the magnetic moments is mainly disordered, which could be caused by the partial Kondo-screening or by the strong frustration [4]. This exotic state should be investigated via inelastic neutron scattering in the proposed experiment to look for the magnetic excitation spectrum.

Using a (h 0 l) scattering plane, we were able to measure the dispersion within the hexagonal basal plane along h and along the easy axis l. The full dispersion was measured at 50 mK in order to have minimal thermal influences. A $k_f = 1.15\,\text{Å}^{-1}$ was chosen on IN12 to have a good energy resolution of about $60\,\mu\mathrm{eV}$ (FWHM). Constant Q-scans were performed in an energy range between -0.4 to 3 meV.

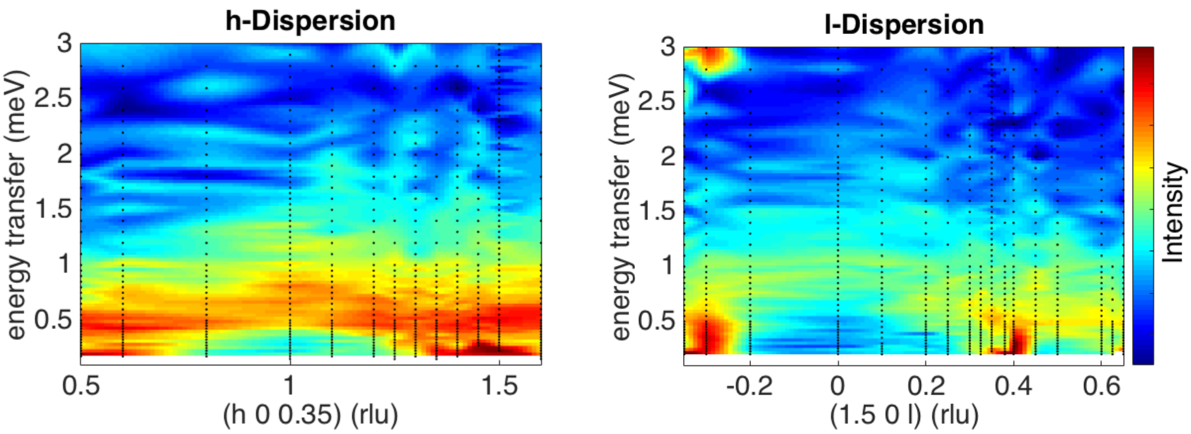

Figure 1: Magnetic excitations at $T = 50\,\mathrm{mK}$ along (h 0 0.35) (*left*) and (1.5 0 l) (*right*). The elastic part was cut off up to an energy transfer of 0.15 meV.

Fig. 1 shows contour plots of the dispersion along the h- as well as along the l-direction. A large energy gap of about 0.4 meV can be observed. The excitations at the zone boundaries of the magnetic Brillouin zone go up to about 0.2 and 0.3 meV for the h- and l-direction, respectively. Such a large energy gap and excitation energies are rather unexpected, since the energy scale of the magnetic interactions is expected to be of the order of the ordering temperature of 2.7 K or the Kondo temperature of about 5 K. An energy gap is often typical for magnetically frustrated systems. They can reflect strong correlations, which have to be broken up at first, before spin waves can evolve. Since the magnetic excitation spectrum along both, the in-plane h- and the out-of-plane l-direction are similar, the magnetic interactions can be regarded as three-dimensional in CePdAl. This means, that also the magnetic coupling along c might play an important role for the evolution of the magnetic order in CePdAl and not only the interactions in the frustrated basal plane.

Having a closer look on the magnetic intensity and the width of the excitation at the magnetic Bragg peak (1.5 0 0.35) and at the zone boundary (1.5 0 0) (see Fig. 2), one observes clear differences: At the magnetic zone center, the intensity is about a factor of 3 larger and the width about a factor of 2 smaller compared to the zone boundary. That is a strong indication for a significant damping of the excitations towards the zone boundary, which might be caused due to the strong fluctuations of the disordered moments. Also the temperature dependence shows a clear difference: While the sharp excitation at the Bragg peak is already broadened and the energy gap closed at $T = 2\,\mathrm{K}$, the broad excitation at the zone boundary remains rather unchanged. This is a very interesting observation, since it could indicate a kind of resonance point being present at the magnetic Bragg peak. Moreover, the vanishing of the energy gap could be a measure for a hidden energy scale or additional order parameter, which develops well below the ordering temperature. Therefore, a more detailed temperature dependence of this feature compared with the behavior at the zone boundary would be very interesting to investigate in another experiment. But not only the low-temperature regime, also the high-temperature regime is worth to investigate in more detail, since we have detected at $T = 10\,\mathrm{K}$ still a rather strong magnetic response, which is very similar to the broad excitation around T_N (see Fig. 2). This clearly indicates, that short-range order is already present at much higher temperatures and that the frustration prevents the system from long-range magnetic order. It would be very interesting to know, when the frustration sets in and up to which temperatures these broad excitations persist. Another experiment on IN12 is therefore highly desired.

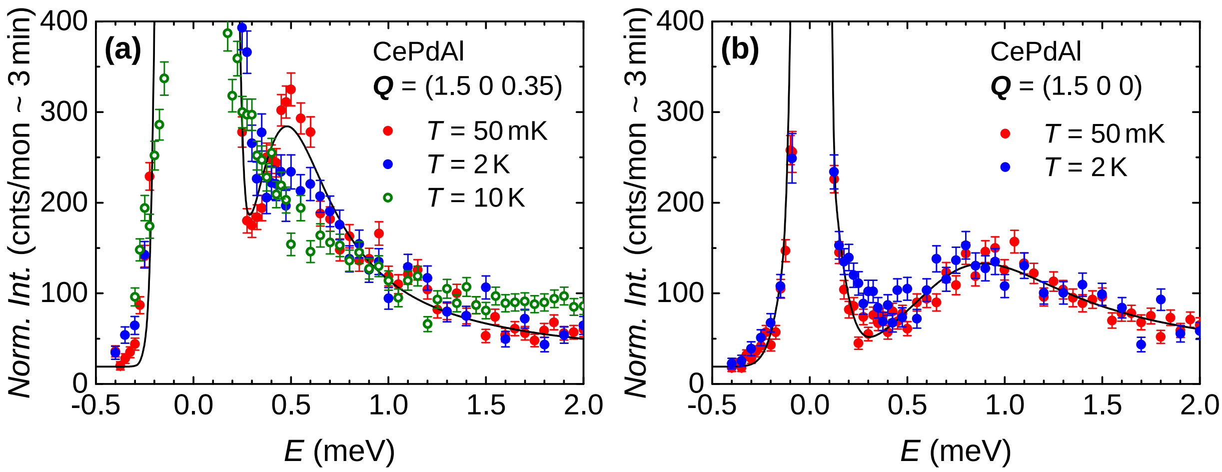

Figure 2: Magnetic response at different temperatures (a) at the magnetic Bragg peak (1.5 0 0.35) and (b) at the magnetic zone boundary (1.5 0 0). Black lines are fits of the 50 mK data.

[1] L. Balents, Nature **464**, 199-208 (2010); [2] Y. Motome et al., PRL **105**, No. 3, 036403 (2010); [3] Y. Motome et al., J. Phys. Soc. Jpn. **80**, SA133 (2011); [4] A. Dönni et al., J.Phys.: Condens. Matter, 11213-11229 **8** (1996)