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NON-FERMI-LIQUID SCALING IN U(Cu,
Al)₅ COMPOUNDS

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Non-Fermi-liquid scaling in $U(\text{Cu},\text{Al})_5$ compounds

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Abstract

We report on the electronic properties of various UCu_xAl_{5-x} compounds ($2.9 \leq x \leq 3.5$). These compounds crystallize in the hexagonal $CaCu_5$ structure. For all compounds, we find that the low-temperature specific heat diverges logarithmically, which may be taken as an indication of non-Fermi-liquid scaling in these materials. Also we find a large magnetic anisotropy in all compounds studied, and we show that the magnetic anisotropy should not be neglected in the analysis of other bulk properties. Though for some of UCu_xAl_{5-x} polycrystals non-Fermi-liquid scaling is found also in the magnetic susceptibility, comparison with single-crystal results on UCu_3Al_2 indicates that any temperature dependence may be due to averaging anisotropic response over all crystallographic directions.

KEYWORDS: non-Fermi-liquid materials, magnetic anisotropy, $U(\text{Cu},\text{Al})_5$ compounds

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1. Introduction

Recently, a number of dilute heavy-fermion materials have attracted much attention as so-called "non-Fermi-liquid" (NFL) materials, for which the low-temperature properties do not show the temperature dependencies expected from the Fermi-liquid theory. The hallmark for the occurrence of NFL behavior is a divergence of the specific heat with $C/T \propto -\ln(T/T_0)$ in the limit $T \rightarrow 0$, but for other properties similar divergencies occur as well [1].

Here, we report on some bulk properties of various UCu_xAl_{5-x} compounds. The details of the sample preparation and characterization have been reported elsewhere [2]. Our previous x-ray and neutron diffraction studies [3-5] indicate that UCu_xAl_{5-x} compounds with $2.9 \leq x \leq 3.5$ adopt the hexagonal $CaCu_5$ structure, where ordered UCu_2 planes are separated by planes with a random distribution of the remaining Cu and Al atoms which exist in a Kagome net. It is clear that, for these compounds, only interplanar interactions are affected by structural disorder, and it is this feature which distinguishes them from most other NFL materials, where some kind of randomness is found in all 3 dimensions.

For the UCu_xAl_{5-x} compounds, the low-temperature specific heats were found to be enhanced [3], and we have shown recently that this enhancement is well described in terms of NFL scaling for UCu_3Al_2 and $UCu_{3.5}Al_{1.5}$ [4]. Here, we show that non-Fermi-liquid scaling is found also for other UCu_xAl_{5-x} compounds. Furthermore, our previous single-crystal studies on UCu_3Al_2 show a huge magnetic anisotropy with a much larger magnetic response within the basal plane compared to the c-axis response [4]. The main emphasis of this paper is on the magnetic anisotropy in these compounds and its consequences.

II. Experimental results and discussion

The temperature dependence of the specific heat of UCu_xAl_{5-x} compounds is shown in Fig. 1 as C/T vs $\log T$. While compounds with $x \geq 3.2$ show a very similar temperature dependence in the specific heat, some additional contribution is seen for the compounds with $x \leq 3.1$. We have argued that this additional contribution is due to some kind of magnetic correlation (e.g. spin-glass state or long-range magnetic order of small magnetic moments [3,4]). Apart from this

'magnetic' contribution, however, we find that the specific heat of all compounds diverges logarithmically for $T \rightarrow 0$, which can be taken as a signature of NFL scaling [1].

As can be seen in Fig. 2, also the magnetic susceptibility of $\text{UCu}_x\text{Al}_{5-x}$ compounds for $x \geq 3.2$ diverges for $T \rightarrow 0$. For $\text{UCu}_{3.5}\text{Al}_{1.5}$, we found that the low-temperature part of the magnetic susceptibility scales like $\chi \propto T^{-1/3}$ [3]. Such scaling behavior was reported also for other NFL's, like UCu_4Pd and $\text{UCu}_{3.5}\text{Pd}_{1.5}$ [5]. For $x \leq 3.1$, on the other hand, we find a maximum in the magnetic susceptibility close to the temperatures where also specific-heat maxima appears. Below this temperature, the susceptibility values decrease continuously, a behavior typical for a material with antiferromagnetic correlations. However, single-crystal results [4] show that such behavior is highly anisotropic in the case of UCu_3Al_2 (curves in Fig. 2). In fact, the maximum is found only for the basal-plane response, while the response along the c -axis diverges like $\chi \propto T^{-1/3}$ similar to the compounds with $x \geq 3.2$. This may indicate that the c -axis susceptibility of UCu_3Al_2 obeys NFL scaling, while magnetic correlations dominate the in-plane response. Note that only interplanar interactions of this compound are affected by structural disorder.

The influence of the magnetic anisotropy on χ is ambiguous when dealing with polycrystalline samples. In order to check for magnetic anisotropy in the other $\text{UCu}_x\text{Al}_{5-x}$ compounds, we performed high-field magnetization studies at the Amsterdam High-Field Facility on powdered material on both, free to be oriented by the applied field and in random orientations fixed by frozen alcohol. The former measurement ('free powder') then is thought to represent the single-crystal response along the easy-magnetization direction, while the latter measurement ('fixed powder') represents the response of an 'ideal' polycrystal. Any difference in the response of 'free' and 'fixed powders' is evidence for magnetic anisotropy. As can be seen in Fig. 3, all $\text{UCu}_x\text{Al}_{5-x}$ compounds show huge magnetic anisotropy which persists up to the highest field applied (35 T). Therefore, magnetic contributions are different for different crystallographic directions, and different temperature dependencies may then be expected as well. Finally, we find a slight upward curvature in the magnetizations of $\text{UCu}_x\text{Al}_{5-x}$ compounds with $x \leq 3.1$ (which may be due to the breakdown of antiferromagnetic correlations),

while compounds with $x \geq 3.2$ show only some saturation tendency in high magnetic fields (as expected for paramagnetic material).

III. Conclusions

We have shown that the specific heat of all UCu_xAl_{5-x} compounds diverges logarithmically at low temperatures as expected for NFL materials. We have also shown that there is large magnetic anisotropy in these compounds. As a consequence, any property of these compounds studied on polycrystalline material may show an artificial temperature dependence due to averaging anisotropic response over all crystallographic directions. While many authors are now interpreting polycrystalline magnetic-susceptibility (and resistivity) data of NFL systems with no regard to possible magnetic anisotropy, we found that this would be completely unjustified in the case of $U(Cu,Al)_5$ compounds. In the view of the present results, we believe that there should be some reassessment of dilute NFL systems like $(Th,U)Pd_2Al_3$ [1], for which large magnetic anisotropy has been observed for the pure compound [6].

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Valuable discussion with R.A. Robinson and M.C. Aronson are highly acknowledged. This work was supported by the division of Basic Energy Sciences of the U.S. Department of Energy, by the "Stichting voor Fundamenteel Onderzoek der Materie" (FOM) and by the Grant Agency of the Czech Republic (Project Nr. 202/96/0207).

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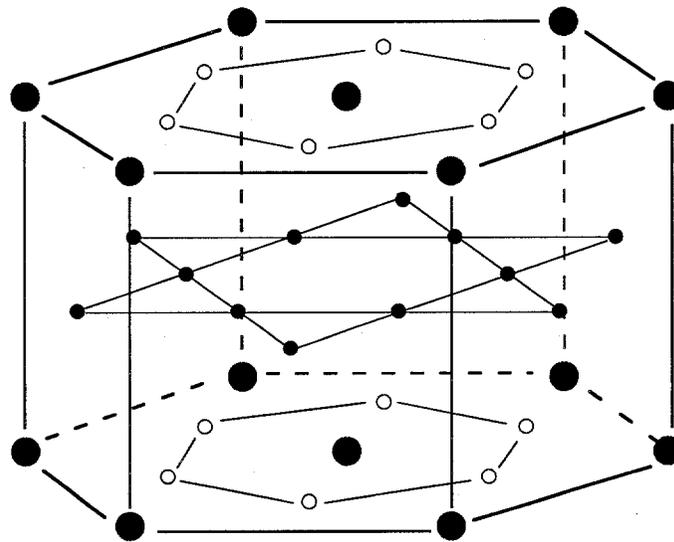
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Figure captions

Fig. 1: Temperature dependencies of the specific heat of various $\text{UCu}_x\text{Al}_{5-x}$ compounds with $2.9 \leq x \leq 3.5$ in the representation C/T vs. $\log T$. Note the logarithmic temperature dependence of the low-temperature parts of all specific heats.

Fig. 2: Temperature dependence of the magnetic susceptibility of various polycrystalline $\text{UCu}_x\text{Al}_{5-x}$ compounds (symbols). In the figure there are included also the single-crystal results on UCu_3Al_2 (taken from ref. 3) for fields perpendicular (solid line) and parallel to the c axis (dashed line).

Fig. 3: Field dependence of $\text{UCu}_x\text{Al}_{5-x}$ compounds with $2.9 \leq x \leq 3.5$ measured as 'free powder' (Δ) and 'fixed powder' (o), respectively (see text). The apparent difference in the free- and fixed-powder results is indicative for magnetic anisotropy in all compounds. The lines are guides to the eye and indicate the deviation from linearity in the magnetic response.



● U ○ Cu • Cu/Al (random distribution)

Fig. 1

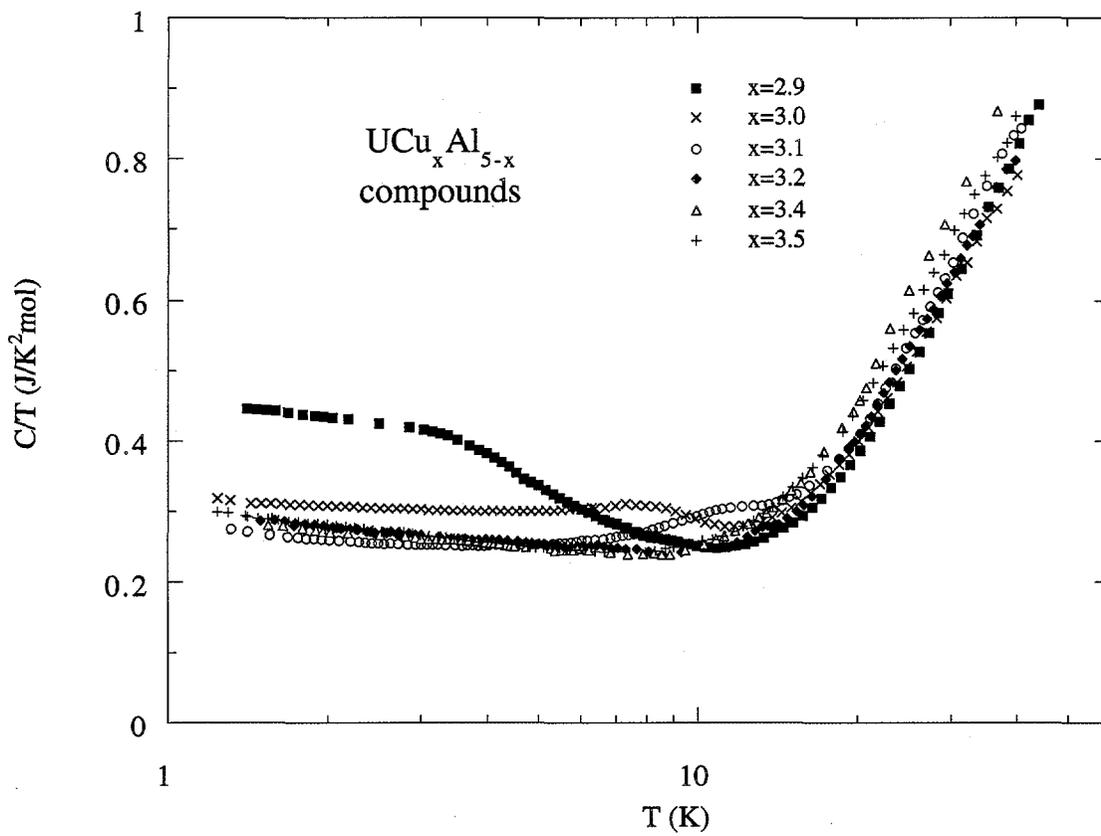


Fig. 2

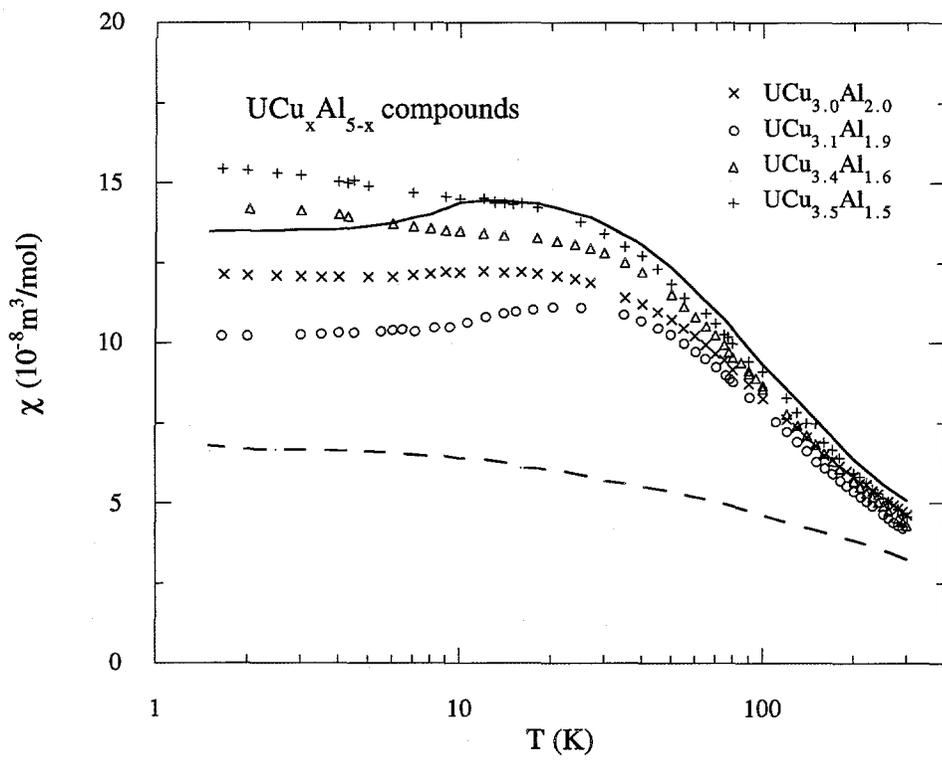


Fig. 3

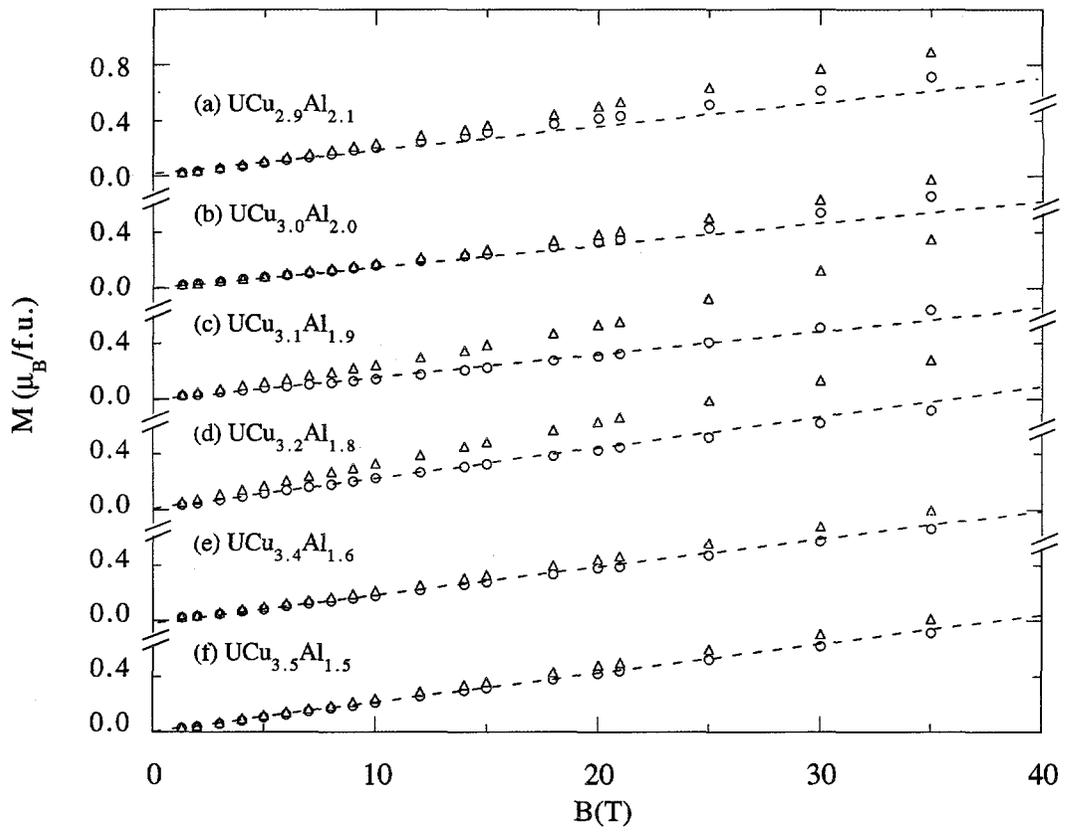


Fig. 4