Physica B 259–261 (1999) 409–411

Non-Fermi-liquid behaviour in U_2Pt_2In

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Abstract

Specific-heat $c(T)$ data taken on single-crystalline samples of the heavy-electron material U_2Pt_2In show that $c \propto -T \ln T$ in the temperature interval 0.1–6 K, which classifies U_2Pt_2In as a non-Fermi-liquid (NFL) material. Further support for a NFL ground state is provided by electrical resistivity and magnetic susceptibility data. Absence of weak-magnetic ordering is confirmed by μSR experiments. The location of U_2Pt_2In close to the magnetic/non-magnetic border line in a Doniach-type phase diagram suggests that a quantum phase transition is at the origin of the NFL behaviour. However, a Kondo-disorder scenario cannot be excluded. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: U_2Pt_2In; Non-Fermi-liquid; Specific heat; μSR

Within the family of U_2T_2X intermetallics (T = transition metal; X = In, Sn) the Pauli-paramagnet U_2Pt_2In attracts special attention because of its strongly enhanced electronic specific heat, $c(T)$, at low temperatures [1,2]. Experiments carried out on a polycrystalline sample in the temperature range 1.3–4.0 K revealed the presence of a pronounced upturn of c/T versus T below ~ 8 K, insensitive to an applied magnetic field of 5 T [1,2]. The $c(T)$ data could be fitted with a $T^3 \ln T$-term ($T < 5$ K), providing evidence for spin-fluctuation phenomena. The resulting linear coefficient of the electronic specific heat $\gamma(T \to 0\,K)$ amounted to 415 $mJ/mol_U K^2$, which classifies U_2Pt_2In as a heavy-electron compound. Within a simple band-structure model it could be shown that the evolution of magnetism across the 2 : 2 : 1 series (for In and Sn compounds) is related to the strength of the 5f-d ligand hybridization [3,4]. When tracing the ordering temperatures versus the square of the calculated hybridization matrix elements a Doniach-like phase diagram results [4]. As could be conjectured from its large γ-value, U_2Pt_2In lies close to the border line of magnetic/non-magnetic compounds.

Nowadays, compounds on the verge of magnetic ordering attract much interest because these might be candidates for the study of non-Fermi-liquid (NFL) effects arising from a quantum phase transition [5]. The most prominent features of a NFL are a specific heat which varies as $c(T) \sim -T \ln T$ and the electrical resistivity which varies as $\rho(T) \sim T^{\alpha}$ (where $\alpha = 1$ or 0.5). In the course of a systematic study of the low-temperature properties of U_2Pt_2In, we found that our single- and poly crystalline samples exhibit such NFL behaviour. The results are presented here below.

The U_2T_2X compounds crystallize in the tetragonal U_3Si_2-type of structure, space group P4/mbm, except for the Pt compounds and U_2Ir_2Sn which exhibit a superstructure (space group $P4_2/mnm$) [6,7]. Single crystals of U_2Pt_2In were prepared by the mineralization method [8]. The single-phase character of the grown crystals was checked by X-ray diffraction, optical microscopy and secondary electron microscopy. The magnetic susceptibility $\chi(T)$ was measured in the temperature range 2–350 K for fields up to 5.5 T along the a- and c-axis

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0921-4526/99/$ – see front matter
PII: S0921-4526(98)00706-6

using a SQUID magnetometer [9]. For $T > 15$ K, $\chi(T)$ follows a modified Curie–Weiss behaviour with $\mu_{eff} = 2.6(2.2)\mu_B/U$, $\theta = -62$ (-63) K and $\chi_0 = 1.1$ $(1.1) \times 10^{-8}$ m^3/mol_U for the $c(a)$ axis. For $B \| c$ a weak maximum is found around $T_{max} = 8$ K, which indicates that the antiferromagnetic interactions become dominant below T_{max}. The magnetization is linear in field up to 5.5 T at all temperatures indicating the absence of paramagnetic impurities. The specific-heat was measured for several single-crystalline samples, using a semi-adiabatic technique in a bath cryostat for $T > 1.5$ K, while data below 4.2 K were taken in a ^{3}He system and a dilution refrigerator ($T > 0.1$ K) employing the relaxation method. The results are shown in Fig. 1 in a plot of c/T versus $\ln T$. Instead of attaining a constant value of $c/T(T \to 0\ \mathrm{K})$ as expected for a Fermi-liquid, c/T diverges as $\ln T$ $(0.1\ \mathrm{K} < T < 6\ \mathrm{K})$, which yields strong support for a NFL ground state. Measurements of the electrical resistivity carried out down to 0.3 K [9] yield further support for a NFL ground state. It was found that $\rho(T) \sim T^{\alpha}$ with $\alpha \cong 1$ for $T < 1$ K(2 K) for a current along the c (a)-axis [9], in agreement with previous experiments on polycrystals [10].

The magnetic, thermal and transport properties provide evidence that the compound U_2Pt_2In is close to a magnetic instability. However, weak static magnetic order, which is quite common to heavy-electron compounds, can easily be overlooked by these techniques. In order to search for tiny ordered moments we have carried out zero-field μSR experiments on a single-crystalline sample in the GPS and LTF spectrometers at the Paul Scherrer Institute (Switzerland). Best fits to the muon relaxation curves were obtained using a two-component function, consisting of a Gaussian and an exponential term. The Gaussian term is attributed to a random distribution of In nuclear moments. The amplitude and the linewidth of the exponential term increase strongly below 10 K (Fig. 2), which corresponds to the value of T_{max} observed in $\chi(T)$ and, therefore, this term is likely to be associated with the antiferromagnetic fluctuations. The zero-field μSR data show the absence of weak static magnetic order (down to 0.3 K), although the possibility that the muons stop at sites where the dipolar fields (due to magnetic ordering) cancel, cannot be excluded from the data obtained so far.

It is important to realize that U_2Pt_2In is one of the few stoichiometric compounds which show such pronounced NFL behaviour at ambient pressure (another case study is $CeNi_2Ge_2$ [5]). Most other NFL materials which have been reported in the literature [5] show considerable deviations from stoichiometry or need the tuning of an external parameter like pressure to attain the NFL state. Nevertheless, some disorder must be present in our single-crystalline samples as the residual resistivity is large (~ 100 μΩ cm). The origin of this disorder is unclear as the Rietveld refinement of the X-ray patterns shows a close to perfect crystallographic ordering (agreement factor 4.3%) [9]. Therefore, the possibility of Kondo disorder as an alternative root to NFL behaviour [5], as was recently proposed for $U(Cu,Pd)_5$ [11], should also be investigated for U_2Pt_2In.

In summary, magnetic, thermal and transport experiments on single-crystalline samples show that U_2Pt_2In exhibits a NFL ground state. Absence of weak-magnetic

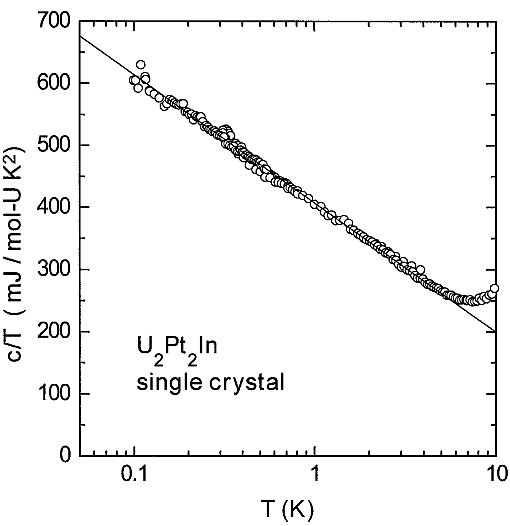

Fig. 1. Specific heat divided by temperature versus ln T for single-crystalline U_2Pt_2In.

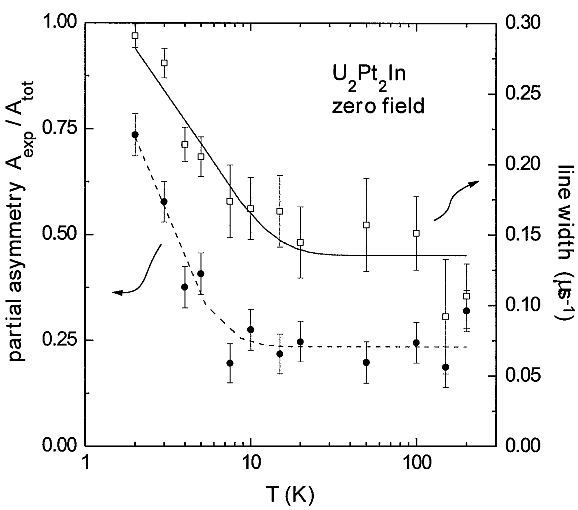

Fig. 2. Partial asymmetry (left axis) and line width (right axis) of the exponential component of the zero-field μSR signal of single-crystalline U_2Pt_2In. The lines are to guide the eye.

ordering is confirmed by μSR experiments. The location of U_2Pt_2In close to the magnetic/non-magnetic border line in a Doniach-type phase diagram suggests that a quantum phase transition is at the origin of the NFL behaviour. An alternative is the Kondo-disorder model. Clearly, the material U_2Pt_2In deserves a wide attention.

Acknowledgements

P.E. acknowledges the European Commission for a TMR grant. The authors are grateful to R.H. Heffner and A. Schenck for assistance with the μSR experiments.

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