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Inhomogeneous magnetic order in Th-doped UPt_3 detected by μSR

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Abstract

We report on a μSR study of $U_{1-x}Th_xPt_3$ ($0 \leqslant x \leqslant 0.05$) conducted to investigate the onset of "large-moment antiferromagnetism" (LMAF). At low Th content ($x \leqslant 0.002$) magnetic ordering on the time scale of the μSR experiment (10^{-8} s) is not detected. For $x = 0.005$ a weak magnetic signal appears below $T = 2$ K, while for $0.006 \leqslant x \leqslant 0.05$, spontaneous oscillations in the μSR spectra signal the presence of the LMAF phase. Analysis of the μSR spectra with a three-component depolarization function reveals that the magnetic phase transition is quite broad. The broadening may be the effect of disorder on the fluctuation spectrum of the small-moment antiferromagnetic state reported for UPt_3 below $T_N \sim 6$ K.

Keywords: Muon spin spectroscopy; Antiferromagnetism; (U, Th)Pt_3

The interplay of small-moment antiferromagnetism (SMAF) and superconductivity in the heavy-electron compound UPt_3 is an ardent topic of research. Substitution studies on the pseudo-binary compounds $U(Pt_{1-x}Pd_x)_3$ (see Ref. [1] and references therein) showed that the Néel temperature, $T_{N,SMAF} \sim 6$ K, of the SMAF phase is relatively stable against alloying up to at least 1 at% Pd. Additionally, a large-moment antiferromagnetic phase (LMAF) sets in at ~0.6 at% Pd with a maximum $T_{N,LMAF}$ of ~6 K for optimal doping ($x = 0.05$). The LMAF and SMAF have the same magnetic structure, indicating that they are closely linked. Interestingly, superconductivity vanishes where LMAF emerges [2]. The existence of a mutual critical point in the phase diagram,

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$x_{c,sc} = x_{c,af} \approx 0.006$, provides evidence for pairing mediated by ferromagnetic spin fluctuations. In order to test the generality of this phase diagram, we have conducted a study of the thermal and magnetic properties of a series of (U,Th)Pt_3 pseudobinaries, as Th doping also induces the LMAF phase [3].

In this paper, we report on the low-temperature ($T < 10$ K) magnetic behaviour as deduced from a systematic μSR study [4] on polycrystalline $U_{1-x}Th_xPt_3$ with $x = 0$, 0.002, 0.005, 0.006, 0.009, 0.01, 0.02, and 0.05. For samples with $x =$ 0 and 0.002, the zero field (ZF) μSR spectra show a weak muon depolarization which is well described by a Kubo–Toyabe function, with a temperature independent $\Delta_{KT} \sim 0.07 - 0.10\,\mu s^{-1}$. This is consistent with depolarization primarily due to ^{195}Pt nuclei. No sign of the SMAF phase was observed, which is explained by its fluctuating nature (faster than the timescale of the muon experiment, 10^{-8} s). For all samples with $x \geqslant 0.005$, the ZF data show signatures of static (timescale $> 10^{-8}$ s) magnetic order. For samples with $x \geqslant 0.01$, this is substantiated by the presence of spontaneous muon precession frequencies in the spectra. The data have been analysed with a three-component depolarization function, which was also used to analyse the ZF spectra of U(Pt,Pd)$_3$ [5]. The LMAF phase is characterized by depolarization due to a polycrystalline antiferromagnet, characterized by strongly damped oscillations, and a Kubo–Lorentzian decay. Both components were found to have equal weight: $A_{osc} = A_{KL}$. In the paramagnetic regime the depolarization is of the Kubo–Toyabe-type (with an asymmetry A_{KT}) and mainly due to nuclear moments. Fitting the data in the temperature range 1–8 K to this three-component function, while fixing the total asymmetry at $A_{tot} = A_{osc} + A_{KL} + A_{KT}$, revealed that the magnetic transitions for $x = 0.01$ and 0.02 are quite broad. This is illustrated in Fig. 1, where we have plotted the fractional magnetic signal, $(A_{osc} + A_{KL})/A_{tot}$, as a function of temperature, together with similar data for $U(Pt_{1-x}Pd_x)_3$.

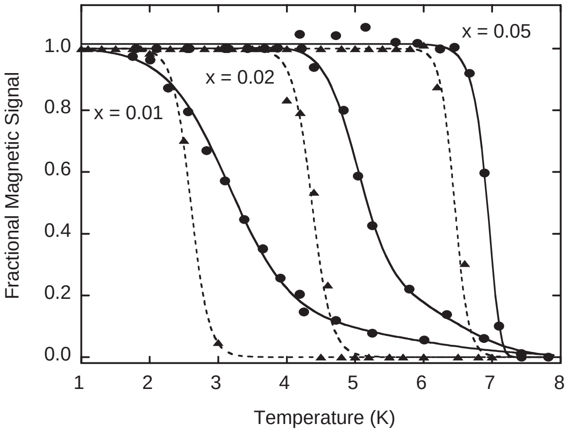

Fig. 1. Transition widths as illustrated by the temperature-dependent fractional amplitude associated with magnetism. Circles are for $U_{1-x}Th_xPt_3$ while triangles are for $U(Pt_{1-x}Pd_x)_3$ with equivalent x values. Solid and dashed lines are guides to the eye.

Clearly, for $x \leqslant 0.02$ our $U_{1-x}Th_xPt_3$ samples show an inhomogeneous magnetic phase over a wide temperature range, while the sample with $x =$ 0.05 and all Pd-doped samples exhibit sharp transitions. We conclude that the $U_{1-x}Th_xPt_3$ pseudobinaries exhibit a high degree of inhomogeneity, which hampers an accurate determination of the magnetic and superconducting phase diagrams and thus a comparison with $U(Pt_{1-x}Pd_x)_3$. Transport, specific heat and materials analysis [4,6] hitherto seem to rule out material or chemical inhomogeneity as a possible cause for the broad transitions.

An appealing explanation for the broadening of the magnetic transitions involves the effect of Th-doping-induced disorder on the anomalous SMAF phase. This is corroborated by the onset of the magnetic transitions for $x = 0.01$ and 0.02 being always around 7 K, i.e. close to $T_{N,SMAF}$ for pure UPt_3. If the SMAF phase is indeed a time-fluctuating version of the LMAF phase, then Th impurities may serve to slow down the fluctuations. When the fluctuation timescale becomes comparable to, or longer than, the typical muon spectroscopy timescale one would expect to observe a magnetic signal. If so, the muon measurements would signal magnetic behaviour near the onset temperature of the SMAF phase. At present, we have no explanation as to why Th is apparently much more effective than Pd in slowing down the SMAF fluctuation. Notice that this scenario implies that the SMAF-to-LMAF

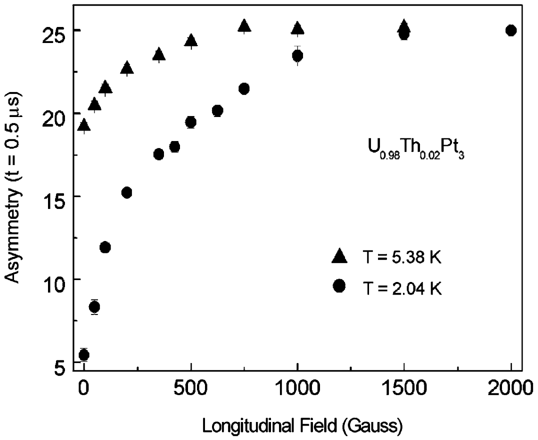

Fig. 2. Asymmetry at $t = 0.5\,\mu s$ as a function of longitudinal field for $U_{0.98}Th_{0.02}Pt_3$ at two different temperatures.

transition is not a true phase transition but rather a type of crossover behaviour. The details of the magnetic phase diagram will then depend on the characteristic timescale of the measuring probe, at least in some critical crossover region.

In order to investigate this idea further we have recently investigated the muon response of $U_{1-x}Th_xPt_3$ ($x = 0.005$, 0.01, 0.02 and 0.05) to a longitudinal field (LF). Typical results are shown in Fig. 2 for $x = 0.02$, where at $T = 5.4$ and 2 K, a clear suppression of the muon depolarization is observed. The low field values necessary to suppress the depolarization are consistent with nearly static magnetism in the broad transition range. A more detailed analysis of the LF spectra is currently underway.

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References

[1] A. de Visser, Physica B 319 (2002) 233.
[2] A. de Visser, et al., Phys. Rev. Lett. 85 (2000) 3005.
[3] A. Ramirez, et al., Phys. Rev. Lett. 57 (1986) 1072.
[4] M.J. Graf, et al., Phys. Rev. B 68 (2003) 224421.
[5] R.J. Keizer, et al., J. Phys.: Condens. Matter 11 (1999) 8591.
[6] J.D. Hettinger, et al., this conference.