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Anisotropy of the antiferromagnetic phase diagram of heavy-fermion UPd_2Al_3

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Abstract

High-field magnetoresistance experiments ($B \leq 20$ T) have been performed on heavy-fermion UPd_2Al_3 for $B \perp c$ in the temperature range 1.5–20 K in order to determine the antiferromagnetic phase boundary ($T_N = 14.4$ K). By rotating the magnetic field in the hexagonal plane, a hitherto unnoted magnetic anisotropy was detected.

The heavy-fermion compound UPd_2Al_3 attracts much attention because of the coexistence of superconductivity (SC) ($T_c = 2$ K) and long-range antiferromagnetic (AF) order ($T_N = 14.4$ K) [1]. Recent experiments revealed that the SC [2] and AF [3] phase diagrams consist of a multiplicity of phases. In the case of the SC phase diagram, this was attributed to the possible formation of a novel Fulde–Ferrell state. As regards the AF phase diagram three different phases with critical fields $B_1 = 0.6$ T [3], $B_2 = 4.2$ T [3] and $B_3 = 18$ T [4, 5] (for $B \perp c$ and $T \to 0$) have been reported, which suggests that the suppression of the long-range AF order takes place in a three-step process. In the high-field magnetization, $M(B)$, measured at 1.3 and 4.2 K [4] the AF phase boundary shows up as a sharp jump ($\Delta M = 0.94\ \mu_B$/U-atom) at $B_{af} = B_3$. In the transversal, $\rho_\perp(B)$, and longitudinal, $\rho_\parallel(B)$, magnetoresistance B_{af} appears as a sudden drop and a pronounced peak, respectively [5]. The critical fields B_1 and B_2 have been distinguished by susceptibility, magnetoresistance and magnetostriction experiments [3]. Zero-field neutron-diffraction experiments [6] have shown that the ordered moment amounts to $0.85 \pm 0.03\ \mu_B$/U-atom ($\simeq \Delta M$ at B_{af}). The ordering consists of ferromagnetic sheets parallel to the basal plane, which are coupled antiferromagnetically along the hexagonal (c-)axis, i.e. a doubling of the nuclear unit cell with an ordering vector $\boldsymbol{k} = [0, 0, 1/2]$. The magnetic structures of the field-induced phases have not been resolved yet.

In this paper we report on a further investigation of the AF phase diagram by means of magnetoresistance experiments. Firstly, we have extended our measurements of B_{af} up to T_N in order to establish the AF phase boundary over a wider temperature range and, secondly, we performed an angle resolved study ($B \perp c$) in order to investigate the presence of a magnetic basal-plane anisotropy.

In Fig. 1 we show $\rho_\perp(B)$ for $I \parallel c$ and $B \parallel a$ in the temperature interval 3.68 K < T < 19.5 K, while data for $B \parallel a$ and $B \parallel b$ (we define $a \perp b$) at $T = 3.68$ K are shown in Fig. 2. In agreement with our previous results [5] B_{af} appears as a sharp drop at the lowest temperatures. However, a small but significant anisotropy is found. B_{af} equals 18.4 and 17.8 T for $B \parallel a$ and $B \parallel b$, respectively. This anisotropy was not observed in our previous experiments [4, 5], probably because (i) the experiments for $B \parallel a$ and $B \parallel b$ were performed on different samples and therefore some sample dependence

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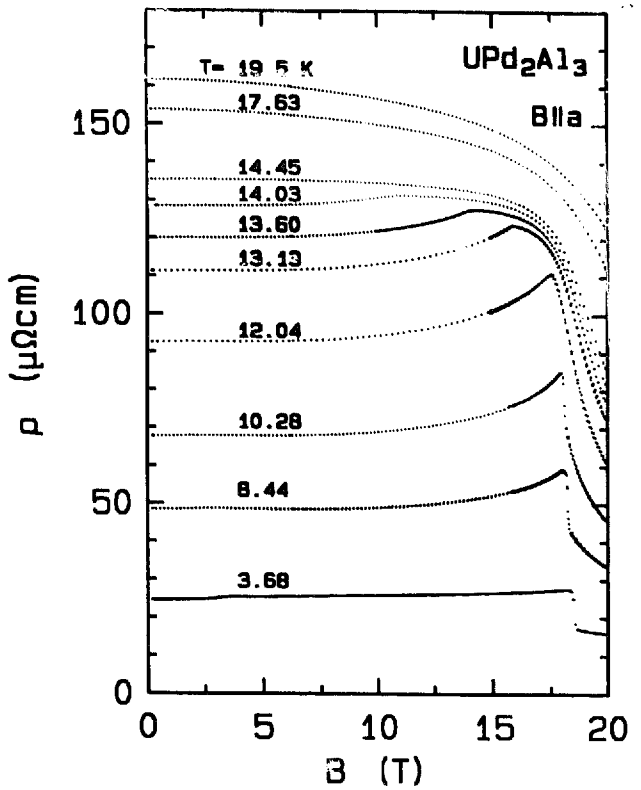

Fig. 1. Transversal magnetoresistance ($I \| c$) of UPd_2Al_3 for $B \| a$ at temperatures as indicated.

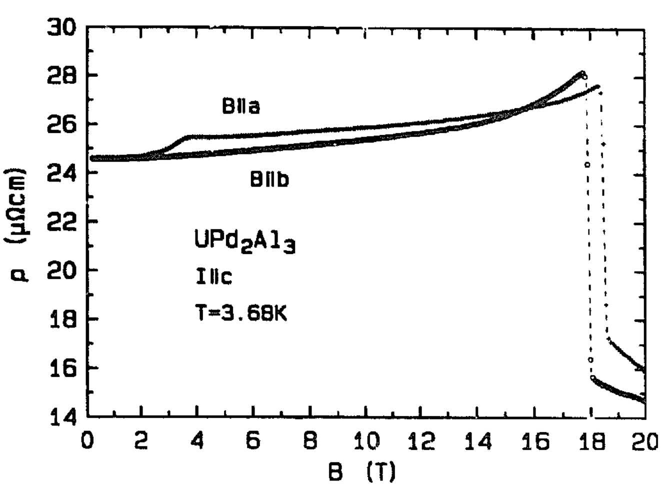

Fig. 2. Transversal magnetoresistance ($I \| c$) of UPd_2Al_3 for $B \| a$ (+) and $B \| b$ (○) at $T = 3.68$ K.

of B_{af} cannot be excluded and (ii) a not perfect alignment of the samples in the experimental setup (in situ rotation was not possible). At higher temperatures the anomaly at B_{af} develops into a well-defined maximum. A second

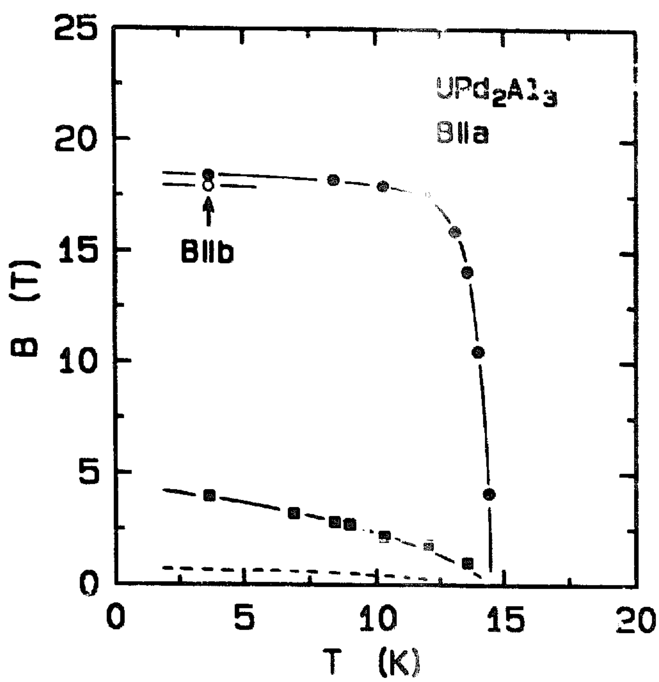

Fig. 3. Antiferromagnetic phase diagram of UPd_2Al_3 for $B \| a$. The broken line is taken from Ref. [3]. The open circle denotes the AF phase boundary for $B \| b$. The middle phase line (closed squares) is absent for $B \| b$.

anomaly is found at lower fields (B_2) *but only for* $B \| a$ (see Fig. 2). By rotating the sample around the c-axis in a field of 5 T, we observed a pronounced sixfold basal-plane anisotropy ($\rho_\perp$ varies between 25.5 and 24.7 μΩ cm for $B \| a$ and $B \| b$, respectively). In Fig. 3, we have traced B_2 and B_{af} as a function of temperature. The present data confirm that the high-field anomaly at B_3 reflects the AF phase boundary, as the low-field [3] and high-field [4, 5] data points are smoothly connected. The phase diagram (Fig. 3) contrasts with the one proposed by Sugiyama et al. [7] obtained by high-field magnetization experiments. These authors claimed the existence of a nearly temperature independent phase line (up to ~ 30 K) at a field $B_3 \approx 18$ T. However, it is likely that, for temperatures just below T_N and thereabove, the transition fields obtained in Ref. [7] are connected to a gradual suppression of the magnetic fluctuations persisting for $T \geq T_N$ and $B \geq B_{af}$, as inferred from the steady decrease of $\rho_\perp(B)$ at high fields and high temperatures (Fig. 1).

In summary, we have detected a significant basal-plane anisotropy in the antiferromagnetic state of UPd_2Al_3. In order to determine the magnetic structures of the field-induced phases neutron-diffraction experiments in a magnetic field would be most welcome.

Acknowledgement

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