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MAGNETIC FIELD DEPENDENCE OF THE ELECTRICAL RESISTIVITY IN NON-FERMI LIQUID $U_{0.05}Y_{0.95}Al_2$, $U_{0.2}Y_{0.8}Pd_3$ AND $UCu_{5-x}Pd_x$ ($x = 1.0, 0.9$)

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We investigate the influence of applied magnetic fields up to $B = 8$ T on the electrical resistivity attemperatures down to 1.5 K for three established non-Fermi liquid systems $U_{0.05}Y_{0.95}Al_2$, $U_{0.2}Y_{0.8}Pd_3$ and $UCu_{5-x}Pd_x$ ($x = 1.0, 0.9$). We follow the approach that an unconventional Kondo mechanism is often seen to be operative at low temperatures in some non-Fermi liquid systems where there are logarithmic or power-law divergences in the temperature dependences of magnetic susceptibility, the specific heat, and the electrical resistivity. In the above systems the incoherent Kondo scattering dominates the electrical resistivity $\rho(T)$ at higher temperatures, while at low temperatures $\rho \sim T^n$ with $n \approx 1$, instead of $n = 2$ as expected for a Fermi-liquid. We show how the power-law dependence is affected by a magnetic field. The isothermal magnetoresistivity as a function of field is analysed in terms of the *Bethe ansatz* description in order to extract values of the characteristic Kondo temperature T_K.

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1. Introduction

Non-Fermi liquid (nFL) behaviour in strongly correlated electron systems has attracted significant interest [1]. In several uranium and cerium based compounds an increasing number of experiments report nFL signatures such as logarithmic or power-law divergent low-temperature specific heat, magnetic susceptibility, and electrical resistivity. On the other hand, there have been theoretical efforts devoted to research the origin of a generalized Fermi-liquid state. Most nFL materials are chemically substituted alloys in which the concentration of the f-electron ion has been reduced to bring about a description of the low-temperature electronic transport that is often closely associated with a single-ion Kondo description [2, 3]. The undercompensated screening of localized moments in a lattice has been recognized [4] in terms of a multichannel Kondo effect as a possible mechanism for nFL behaviour.

This contribution attempts to further investigate the low-temperature behaviour, using the effects of an externally applied magnetic field on the temperature dependence of electrical resistivity, $\rho(T,B)$, in three well-established nFL systems. We selected the two dilute systems $U_{0.05}Y_{0.95}Al_2$ and $U_{0.2}Y_{0.8}Pd_3$ in addition to $UCu_{5-x}Pd_x$ ($x = 1.0, 0.9$) where the U-sublattice is left unsubstituted. In all three systems the Kondo effect is known to play a meaningful role [1]. For the two U-dilute systems we also measured synchronously the non-f electron counterparts, respectively YAl_2 and YPd_3, in order to account for the non-f electron scattering effects.

2. Experiment and results

Our polycrystalline samples were prepared following procedures described elsewhere [3] using elements of purities (in atomic weight percent) U (99.98), Y (99.99), Al (99.9999), Pd (99.99), and Cu (99.99). Our experimental methods for resistivity and magnetoresistivity measurements are given in Ref. [3].

2.1. $UCu_{5-x}Pd_x$

The region between the magnetic ordered state and that of spin-glass freezing in cubic $UCu_{5-x}Pd_x$ ($0.9 \le x \le 1.5$) has been an active testing ground for the mechanisms of nFL behaviour. Among these there have been the scenarios of a distribution of single-ion Kondo temperatures due to the Pd/Cu site interchange as supported by NMR and muon-spin resonance data [1], and the prediction by Castro Neto et al. [5] based upon the proximity to a quantum critical point in the presence of competition between the Kondo effect and RKKY interactions. We have shown in data of $\rho(T)$ down to 50 mK that the linear temperature dependence at low temperature remains practically intact in fields up to 14 T [6].

In Fig. 1a we show magnetoresistivity data for UCu_4Pd. We have fitted our data to the single-ion, spin-1/2 *Bethe ansatz* description of $\rho(T,B)/\rho(T,0)$ in terms of

$$\frac{\rho(B=0)}{\rho(B)} = \frac{1}{2j+1}\sin^2\left(\frac{\pi n_f}{2j+1}\right)\sum_{l=0}^{2j}\sin^{-2}(\pi n_l),$$

$j = 1/2$ and the f-level occupation numbers n_l in the integer-valence limit [7] and with

$$B^*(T) = B^*(0) + \frac{k_B T}{g\mu_K} = \frac{k_B}{g\mu_K}(T_K + T). \tag{1}$$

The least-squares analyses for UCu_4Pd yield values of $T_K = 96(2)$ K and a Kondo moment of $\mu_K = 0.16(1)\mu_B$. For $UCu_{4.1}Pd_{0.9}$ (not shown) we find $T_K = 125(2)$ K and $\mu_K = 0.17(1)\mu_B$, which are in qualitative agreement with the T_K values used for a description of bulk magnetic susceptibility of $UCu_{5-x}Pd_x$ ($x = 1, 1.5$) [1].

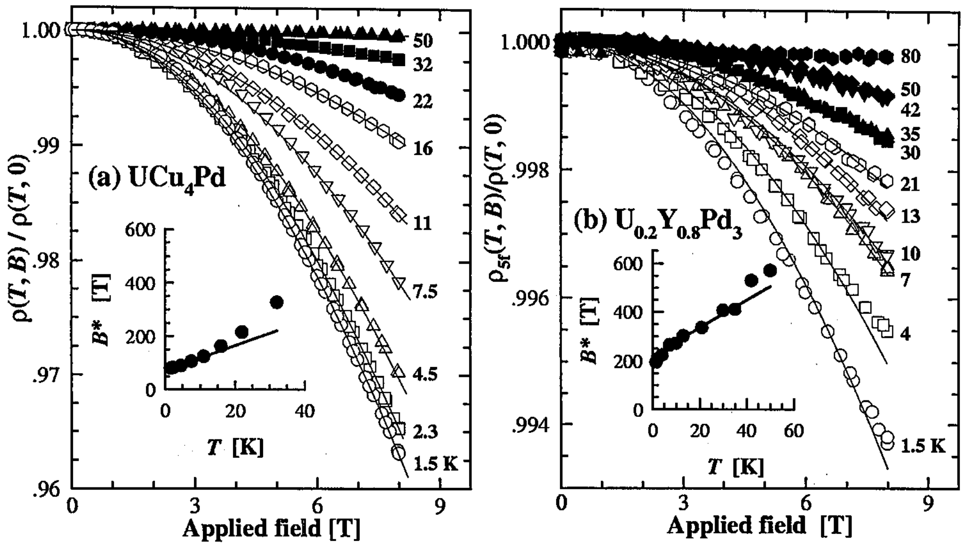

Fig. 1. Magnetoresistivity isotherms $\rho(T,B)/\rho(T,0)$ as a function of magnetic field for UCu_4Pd (a) and $U_{0.2}Y_{0.8}Pd_3$ (b). The solid lines illustrate least-squares fits to the data using Eq. (1) with the resulting $B^*(T)$ shown in the insets.

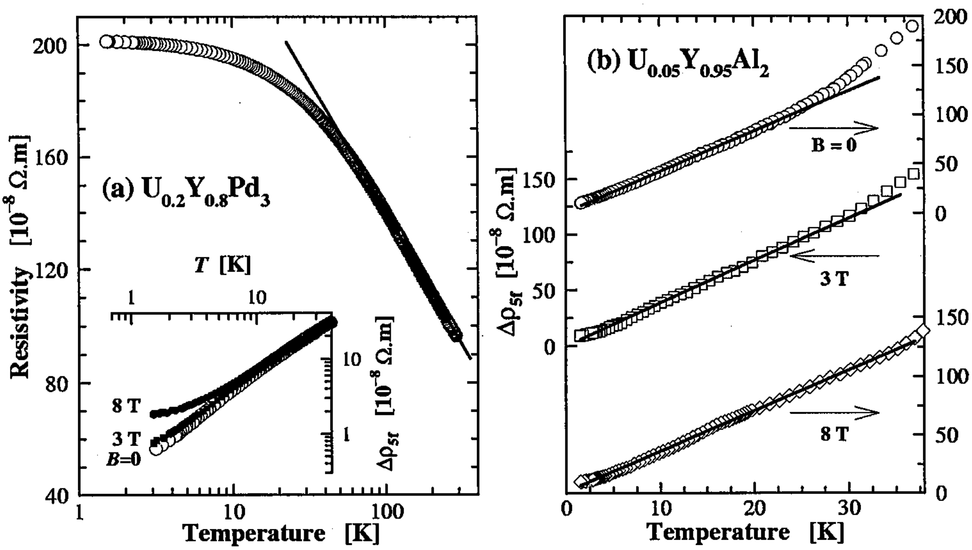

Fig. 2. (a) The temperature dependence of electrical resistivity for $U_{0.2}Y_{0.8}Pd_3$ showing the $\rho \sim -\ln T$ behaviour for $T \geq 70$ K on a logarithmic temperature axis. The straight line is a guide to the eye. The inset shows the effect on $\Delta\rho_{5f}(T)$ of applying a magnetic field at low temperatures. (b) The effect of magnetic field on $\Delta\rho_{5f}(T)$ for $U_{0.05}Y_{0.95}Al_2$. The solid lines illustrate least-squares fits to the data of $\Delta\rho_{5f}(T) = AT^n$ with $n = 1$ and A — the electron–electron scattering coefficient.

2.2. $U_xY_{1-x}Pd_3$

One of the first systems to have been studied as an nFL system was $U_xY_{1-x}Pd_3$ [8] for which the incoherent Kondo effect is seen for compounds with $x \leq 0.3$ [1]. In Fig. 2a we illustrate the $\rho \sim -\ln T$ dependence for $U_{0.2}Y_{0.8}Pd_3$ over the region $70 \leq T \leq 300$ K. A value of $T_K = 50$ K was found [1] for this compound using single-ion scaling at low temperatures where $\rho \sim T$ ($0.2 \leq T \leq 20$ K) [2], $C \sim \ln T$ ($0.1 \leq T \leq 5$ K) and $\chi \sim \ln T$ ($0.6 \leq T \leq 100$ K) [1]. $\rho(T = 0.36$ K) in magnetic field of 14 T was reported to be reduced by about 2% [8]. In Fig. 1b we plot our data of $\rho_{5f}(T,B)/(T,0)$ vs. B for $U_{0.2}Y_{0.8}Pd_3$ using YPd_3 as a non-f electron reference compound. We obtain reasonably good least-squares fits using Eq. (1) for isotherms with $1.5 \geq T \geq 50$ K, yielding $T_K = 40(3)$ K and $\mu_K = 0.13(1)\mu_B$. In the inset to Fig. 2a, we plot our $\Delta\rho_{5f}$ data for $U_{0.2}Y_{0.8}Pd_3$. These are obtained by subtracting the non-$5f$ contributions to $\rho(T,B)$, found by measuring $\rho(T,B)$ for YPd_3, and then by also subtracting the temperature- and field-independent $\rho(T = 0, B = 0)$ from the data. We find it possible to induce in $B = 8$ T a significant deviation below about 10 K from the zero-field $\rho \sim T$ dependence. We associate this with a tendency towards Fermi-liquid dynamics as the magnetic field lifts multichannel screening degeneracy.

2.3. $U_{1-x}Y_xAl_2$

Non-Fermi liquid behaviour was indicated in the U-dilute phase region of cubic $U_{1-x}Y_xAl_2$ [9]. The substitution of Y increases the cubic lattice parameter with 1.2% between UAl_2 and YAl_2. This results first in spin-glass behaviour with a characteristic temperature of $T_f = 5.1$ K for $0.3 \leq x \leq 0.7$, and eventually in nFL behaviour for $x \geq 0.875$ over the region $0.4 \leq T \leq 15$ K as witnessed by a logarithmic divergence in the electronic specific heat $\Delta C/T$. Our study of the nFL intermetallic alloy $U_{0.05}Y_{0.95}Al_2$ was prompted by the importance of single-site effects associated with $5f$ electrons in $U_{1-x}Y_xAl_2$, as shown *inter alia* using electrical resistivity data [10] at low temperatures. In Fig. 2b we illustrate our measurements of electrical resistivity for $U_{0.05}Y_{0.95}Al_2$ measured in $B = 0, 3$, and 8 T. The depicted $5f$-electronic data $\Delta\rho_{5f}(T)$ are obtained as described above for $U_{0.2}Y_{0.8}Pd_3$, using the non-$5f$ electron reference compound YAl_2. We illustrate the dominant power-law dependence, $\rho \sim T^n$ with $n = 1$, using least-squares fits to the data. There is in all three values of field a deviation from the power-law below about 3 K. More significant however is the observation that the magnetic field seems to stabilise the nFL phase in that the high-temperature limit of applying a power-law is extended from $T \approx 24$ K in $B = 0$ to $T \approx 36$ K in $B = 8$ T. This behaviour of $\rho(T,B)$ in $U_{0.05}Y_{0.95}Al_2$ is not presently understood. It differs from what has been measured in other nFL systems like $U_{0.2}Y_{0.8}P_3$ (see the previous section) and in $U_{1-x}Th_xPd_2Al_3$ [3] where the effect of a magnetic field is seen to limit the validity of the $\rho \sim T$ behaviour.

We have illustrated various effects of applied magnetic field on the nFL phase of single-ion Kondo systems. More studies are needed to understand these observations within the context of the possible mechanisms that lead to the nFL behaviour.

Acknowledgment

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