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 $UCu_{5-x}Pdx$ ($x = 1.0, 0.9$)

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We investigate the influence of applied magnetic fields up to $B = 8$ T on
the electrical resistivity at temperatures 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 $UCu_{5-x}Pdx$
($x = 1.0, 0.9$). We follow the approach that an unconventional Kondo mech-
anism 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 scatter-
ing 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 com-
ounds an increasing number of experiments report nFL signatures such as log-
arithmic or power-law divergent low-temperature specific heat, magnetic suscep-
tibility, 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 concentra-
tion 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 \( \text{U}_{0.05}\text{Y}_{0.95}\text{Al}_2 \) and \( \text{U}_{0.2}\text{Y}_{0.8}\text{Pd}_3 \) in addition to \( \text{UCu}_{5-x}\text{Pd}_x \) (\( x = 1.0, 0.9 \)) 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 \( \text{YAl}_2 \) and \( \text{YPd}_3 \), 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. \( \text{UCu}_{5-x}\text{Pd}_x \)

The region between the magnetic ordered state and that of spin-glass freezing in cubic \( \text{UCu}_{5-x}\text{Pd}_x \) (\( 0.9 \leq x \leq 1.5 \)) 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 \( \text{UCu}_4\text{Pd} \). 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

\[
B^*(T) = B^*(0) + \frac{k_B T}{g \mu_K} = \frac{k_B}{g \mu_K}(T_K + T).
\]

The least-squares analyses for \( \text{UCu}_4\text{Pd} \) yield values of \( T_K = 96(2) \) K and a Kondo moment of \( \mu_K = 0.16(1) \mu_B \). For \( \text{UCu}_{4.1}\text{Pd}_{0.9} \) (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 \( \text{UCu}_{5-x}\text{Pd}_x \) (\( x = 1, 1.5 \)) [1].
Fig. 1. Magnetoresistivity isotherms $\rho(T, B)/\rho(T, 0)$ as a function of magnetic field for UCu$_4$Pd (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 $\Delta \rho_{sf}(T)$ of applying a magnetic field at low temperatures. (b) The effect of magnetic field on $\Delta \rho_{sf}(T)$ for U$_{0.05}$Y$_{0.95}$Al$_2$. The solid lines illustrate least-squares fits to the data of $\Delta \rho_{sf}(T) = AT^n$ with $n = 1$ and $A$ — the electron-electron scattering coefficient.
One of the first systems to have been studied as an nFL system was $U_x Y_{1-x}Pd_3$ [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 UA1$_2$ and YA1$_2$. 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 YA1$_2$. 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.
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References