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Transport and magnetic properties of $UCu_{5-x}M_x$ (M = Pd, Pt)

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Abstract. The substitution of transition metals for Cu in the heavy-fermion compound UCu_5 leads to unusual low-temperature properties. For example, the substitution of Pd suppresses long-range magnetic order and results in non-Fermi-liquid behaviour. In this report, we compare properties and phase diagrams for $UCu_{5-x}Pd_x$ and $UCu_{5-x}Pt_x$ based upon electrical resistivity and dc magnetic susceptibility measurements. In the Pt system, we find a rapid suppression of magnetic ordering similar to that seen in the Pd system. The electrical resistivity and dc magnetic susceptibility of $UCu_{5-x}Pt_x$ exhibit low-temperature behaviour ($T \leqslant 10$ K) for $x \geqslant 0.75$ suggestive of the non-Fermi-liquid behaviour found in $UCu_{5-x}Pd_x$ for $1 \leqslant x \leqslant 1.5$. The electrical resistivity of $UCu_{5-x}Pt_x$ for $0.75 \leqslant x \leqslant 1.75$ reaches a concentration-dependent minimum before increasing at lower temperatures. At higher Pt concentrations ($x \geqslant 2$), the electrical resistivity develops a broad peak at low temperatures, as in $UCu_{5-x}Pd_x$, suggesting short-range magnetic order although irreversibility was not seen in the magnetic susceptibility. The similarities of and differences between the two systems are discussed. The possibility of non-Fermi-liquid behaviour in $UCu_{5-x}Pt_x$ is considered.

1. Introduction

The heavy-fermion compound UCu_5 has recently attracted a great deal of interest because of the unusual low-temperature properties found when different transition metals are substituted for Cu. The compound UCu_5 is nominally a heavy-fermion antiferromagnet with a Néel temperature of 15 K. It was found that the substitution of Pd for Cu quickly suppresses the antiferromagnetic ordering. What is especially significant is that for $UCu_{5-x}Pd_x$ in the range $1 \leqslant x \leqslant 1.5$, there are weak-power-law or logarithmic divergences in the electrical resistivity, dc magnetic susceptibility, and specific heat [1]. These low-temperature properties of $UCu_{5-x}Pd_x$ ($1 \leqslant x \leqslant 1.5$) are similar to those of another U-based intermetallic, $Y_{1-x}U_xPd_3$, where non-Fermi-liquid (NFL) behaviour has been observed [2]. At even higher concentrations of Pd, spin-glass behaviour is seen for $UCu_{5-x}Pd_x$. The proximity of the NFL region to the antiferromagnetic and spin-glass regions might be an important clue for developing an understanding of the NFL state in this system.

The substitution of other noble metals has produced different types of behaviour. Substitution of Au for Cu leads to an initial increase in the Néel temperature T_N up to $x = 2$, but T_N decreases above $x = 2$ [3]. The substitution of Ag for Cu also does not show the same rapid suppression of magnetic ordering as with Pd [4]. The Au and Ag substituents have a completely filled d-electron shell and the same valence as Cu, while Pd has a partially filled d shell and a different valence. The substitution of Ag or Au for Cu did not result in any NFL behaviour.

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Uranium forms the cubic $AuBe_5$ structure only with Ni, Cu and Pt [3]. There is a concentration limit for Pd (Ag and Au as well) above which the alloy becomes a mixture of two phases. The substitution of Pt is attractive because UPt_5 crystallizes in the same structure as UCu_5, suggesting the possibility of continuous substitution from UCu_5 to UPt_5. In addition, the Pt substituent has a partially filled d shell and the same valence as Pd. In the present work, the $UCu_{5-x}Pt_x$ system has been studied in comparison with the $UCu_{5-x}Pd_x$ system. Electrical resistivity and dc magnetization measurements have been used to construct phase diagrams for the two systems. The NFL behaviour in $UCu_{5-x}Pd_x$ and the possible NFL behaviour in $UCu_{5-x}Pt_x$ will be discussed in relation to the similarities of and differences between the two systems.

2. Experimental details

The samples used in this study were prepared by arc-melting in an ultrahigh-purity argon atmosphere on a water-cooled copper hearth. High-purity U (3N7), Cu (6N), Pd (3N5), and Pt (4N) were used to make UCu_5, UPd_5, and UPt_5 master compounds from which the $UCu_{5-x}Pd_x$ and $UCu_{5-x}Pt_x$ samples were fabricated. Each sample was melted several times and turned over after each melt to promote homogeneity. X-ray powder diffraction patterns were taken for each sample and showed no impurity phases within the limit of our resolution.

The Pd-substituted samples were generally measured in the as-cast state. Annealing of samples in the $UCu_{5-x}Pd_x$ system did not result in any qualitative change in the features observed in the physical properties [1]. Some of the Pt-substituted samples were annealed at 1000 °C in quartz ampoules sealed under ultrahigh-purity argon. The samples were wrapped in tantalum foil to prevent reaction with the quartz, annealed for seven days, and then water quenched.

The arc-melted ingots were cut using a spark cutter. Bar-shaped samples (0.7 mm × 0.7 mm × 5 mm) were first cut from each ingot for electrical resistivity measurements. The remainder of each ingot was used for the dc magnetic susceptibility measurements. The electrical resistivity measurements were made using a standard four-wire ac method at a frequency of 16 Hz in a helium cryostat from 1.1 K to 293 K. The dc magnetic susceptibility was measured in a Quantum Design SQUID magnetometer between 1.8 K and 300 K. All of the samples were measured under field-cooled (FC) and zero-field-cooled (ZFC) conditions. The measurements were made in a field of 1 T for all of the samples, except those that exhibited spin-glass ordering for which a field of 10 Oe was used.

3. Results and discussion

In this study, we restrict our attention to the $UCu_{5-x}Pd_x$ and $UCu_{5-x}Pt_x$ systems for $x \leqslant 2.3$, since the cubic phase of $UCu_{5-x}Pd_x$ is maintained only for $x \leqslant 2.3$ [1, 5]. The extension of the $UCu_{5-x}Pt_x$ system to $x \geqslant 2.3$ is in progress. From dc magnetic susceptibility measurements, we constructed T–x phase diagrams for $UCu_{5-x}Pd_x$ and $UCu_{5-x}Pt_x$ which are shown in figure 1. The T–x phase diagram of $UCu_{5-x}Pd_x$ shows the three structural states of the alloy system: a cubic $AuBe_5$ structure ($x < 2.4$), a region of mixed cubic and hexagonal phases ($2.4 < x < 4$), and a hexagonal or cubic structure depending on preparation conditions ($4 < x < 5$), corresponding to the end compound UPd_5. The cubic region of the $UCu_{5-x}Pd_x$ system can be broken down into three magnetic regions: antiferromagnetic, NFL, and spin glass. The phase diagram for $UCu_{5-x}Pt_x$ shown in

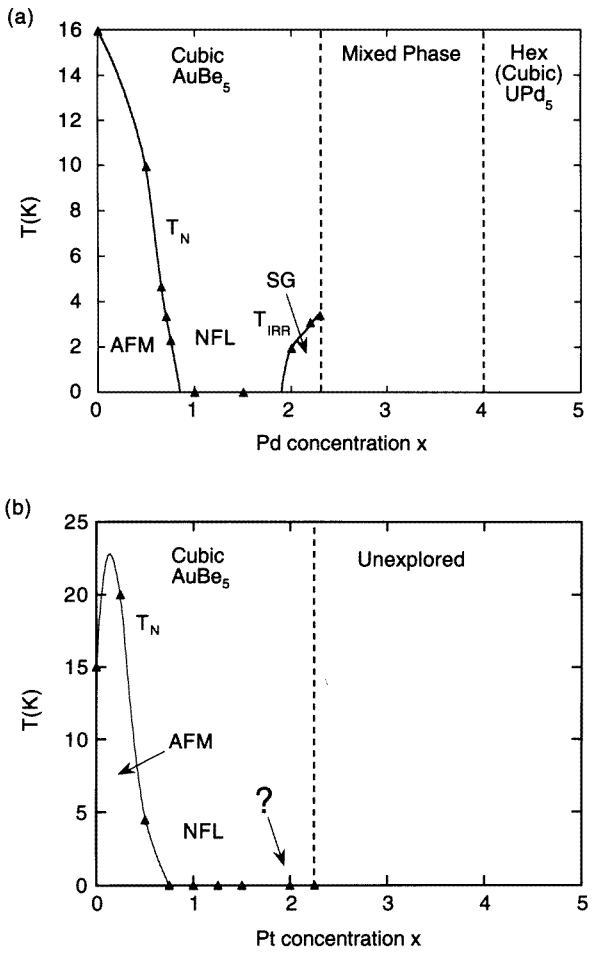

Figure 1. (a) A temperature T versus Pd concentration x phase diagram for $UCu_{5-x}Pd_x$. (b) A partial T versus Pt concentration x phase diagram for $UCu_{5-x}Pt_x$.

figure 1(b) is incomplete but shows some similarities to that for $UCu_{5-x}Pd_x$. Unlike in the case of $UCu_{5-x}Pd_x$, the $AuBe_5$ structure is expected to be maintained throughout the phase diagram for $UCu_{5-x}Pt_x$, although a miscibility gap could exist. Like the $UCu_{5-x}Pd_x$ T–x phase diagram, the $UCu_{5-x}Pt_x$ T–x phase diagram has a region of antiferromagnetic ordering and a region where there is apparently no magnetic ordering and the physical properties exhibit NFL behaviour at low temperatures. The existence of a spin-glass region at higher Pt concentrations is uncertain at this point.

Antiferromagnetic ordering is suppressed by the introduction of both Pd and Pt. Figure 2(a) shows the measured dc magnetic susceptibility, $\chi(T)$, of $UCu_{5-x}Pd_x$ for $0 \leqslant x \leqslant 0.75$. The $\chi(T)$-data all exhibit a peak or an inflection point that can be taken as a sign of antiferromagnetic ordering. We therefore define the temperature of the peak or inflection point of $\chi(T)$ to be the Néel temperature, T_N. While T_N is rapidly suppressed with increasing Pd concentration x, the magnitude of the maximum in $\chi(T)$ increases with x. As T_N drops to zero, $\chi(T)$ diverges and the antiferromagnetic feature weakens. It is

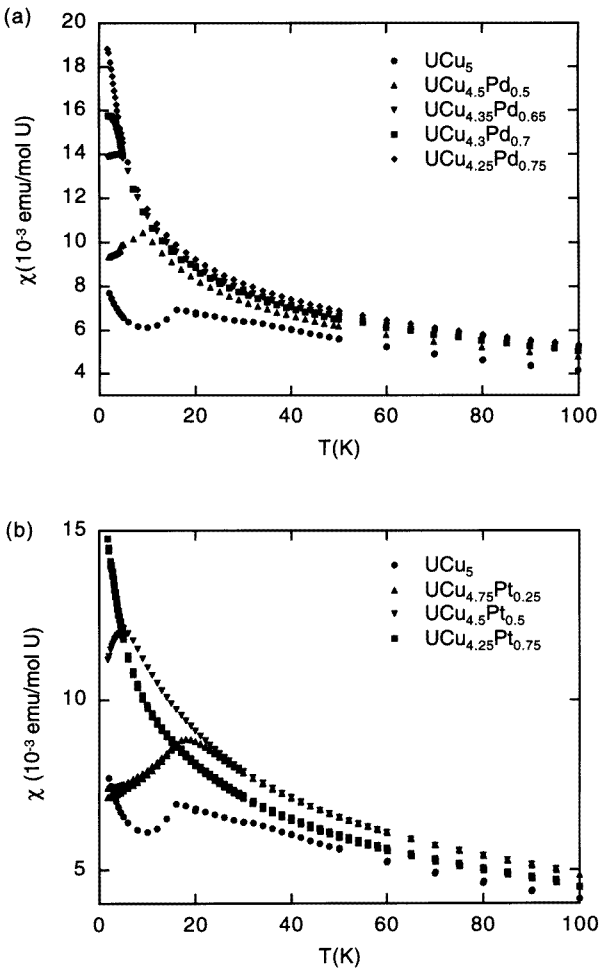

Figure 2. (a) The dc magnetic susceptibility χ versus temperature T for $UCu_{5-x}Pd_x$ for $0 \leqslant x \leqslant 0.75$. (b) χ versus T for $UCu_{5-x}Pt_x$ for $0 \leqslant x \leqslant 0.75$.

unclear whether the inflection point for $UCu_{4.3}Pd_{0.7}$ and $UCu_{4.25}Pd_{0.75}$ reflects true magnetic order. It is possible that these samples have regions in which magnetic ordering occurs and others in which NFL behaviour exists, resulting in the weak inflection. Neutron diffraction experiments are planned to address this issue.

The magnetic susceptibility of $UCu_{5-x}Pt_x$ ($0 \leqslant x \leqslant 0.75$) is shown in figure 2(b). There is an initial increase in T_N for small concentrations of Pt as in the $UCu_{5-x}Au_x$ system [3], while for concentrations above $x = 0.25$, there is a rapid decrease in T_N. At $x = 0.75$, the Pt system exhibits no sign of antiferromagnetic ordering down to 1.8 K. Instead, $\chi(T)$ diverges at low temperatures as it does in $UCu_{5-x}Pd_x$ samples in the NFL region. None of the Pt-substituted samples exhibit a weak inflection point in $\chi(T)$ at low temperatures as in $UCu_{4.3}Pd_{0.7}$. In this region of the phase diagram, the Pd and Pt systems behave nearly identically, although the suppression of magnetic ordering is much more rapid in the Pt-substituted system.

Electrical resistivity $\rho(T)$-data for $UCu_{5-x}Pt_x$ ($0 \leqslant x \leqslant 0.75$) and for $UCu_{5-x}Pd_x$

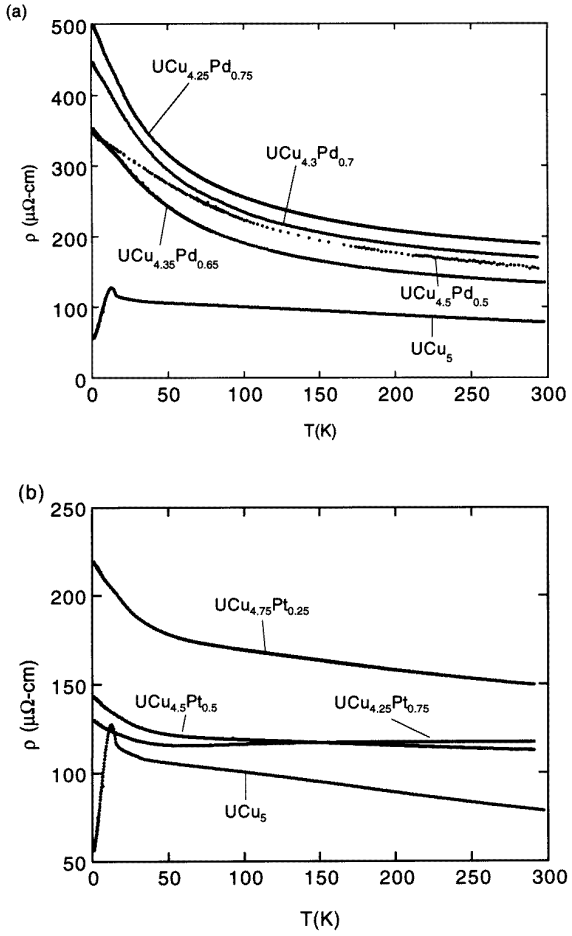

Figure 3. The electrical resistivity ρ versus temperature T for (a) $UCu_{5-x}Pd_x$ $(0 \leqslant x \leqslant 0.75)$, and (b) $UCu_{5-x}Pt_x$ $(0 \leqslant x \leqslant 0.75)$.

$(0 \leqslant x \leqslant 0.75)$ are displayed in figure 3. The $\rho(T)$-data for pure UCu_5 are shown for comparison. None of our Pt- or Pd-substituted samples show a decrease in $\rho(T)$ below T_N as occurs in pure UCu_5. There is only a weak inflection point in the $\rho(T)$-curve below 10 K in the samples that have a strong peak in $\chi(T)$. The resistivity $\rho(T)$ increases monotonically with decreasing T and does not display a peak or downturn at low temperatures. The substitution of Pt or Pd increases the overall magnitude of the resistivity in comparison with that of the pure UCu_5 compound. The resistivity of the Pt-substituted samples decreases with increasing Pt concentration after the initial increase while the resistivity of the Pd-substituted samples increases with increasing Pd concentration.

The $UCu_{5-x}Pd_x$ system has generated the most interest in the concentration range $0.75 \leqslant x \leqslant 1.5$ where NFL behaviour is found in its low-temperature physical properties. The signatures of NFL behaviour that have been most frequently observed in the electrical resistivity, magnetic susceptibility, and specific heat of f-electron systems are $\rho(T) \sim 1 - a(T/T_0)$, $\chi(T) \sim 1 - (T/T_0)^{1/2}$ or $\ln(T/T_0)$, and $C(T)/T \sim (-1/T_0)\ln(T/T_0)$, where $|a| \sim 1$, and T_0 is a scaling temperature that can often be identified with the Kondo

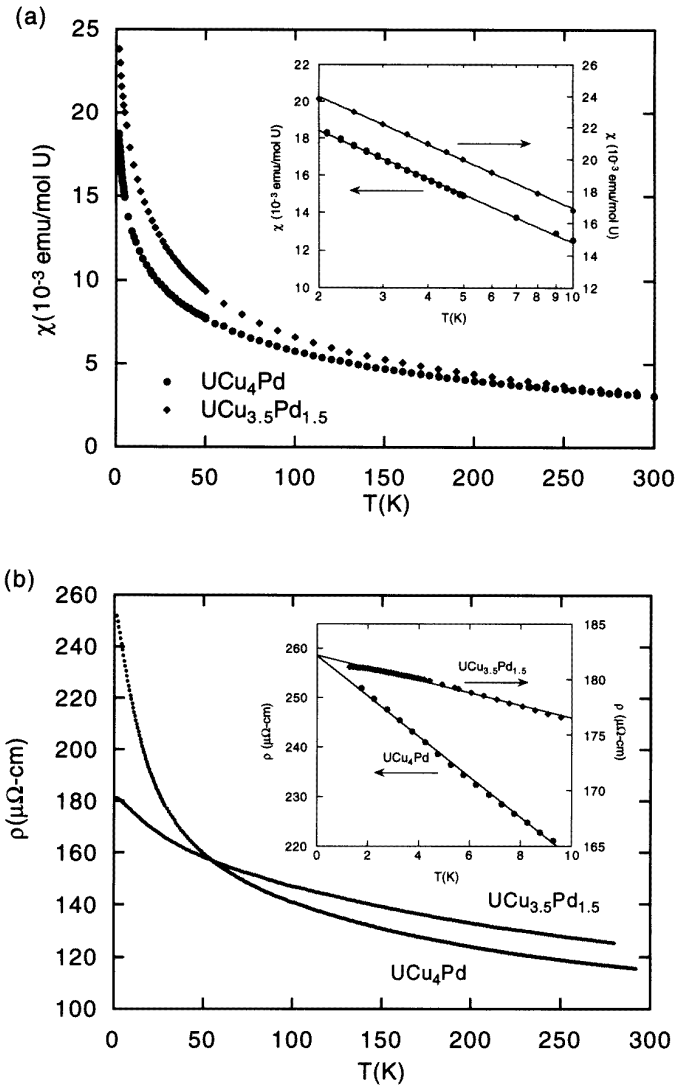

Figure 4. (a) The dc magnetic susceptibility χ versus temperature T and (b) the electrical resistivity ρ versus temperature T for UCu_4Pd and $UCu_{3.5}Pd_{1.5}$. The inset in (a) shows a fit to $\chi(T) = \chi_0 \ln(T/T_0)$ below 10 K. The inset in (b) shows a fit to $\rho(T) = \rho_0[1 - a(T/T_0)]$ below 10 K.

temperature T_K [6]. In figure 4, the NFL behaviour in $\chi(T)$ and $\rho(T)$ is illustrated for UCu_4Pd and $UCu_{3.5}Pd_{1.5}$. The insets in figures 4(a) and 4(b) show fits of the low-temperature electrical resistivity and magnetic susceptibility to $\rho(T) = \rho_0[1 - a(T/T_0)]$ and $\chi(T) = \chi_0 \ln(T/T_0)$ where we have arbitrarily set $a = 1$. For UCu_4Pd, we obtain $\rho_0 = 258\ \mu\Omega$ cm and $T_0 = 63$ K from $\rho(T)$, and $\chi_0 = 8.7 \times 10^{-3}$ emu/mol U and $T_0 = 11$ K from $\chi(T)$. For $UCu_{3.5}Pd_{1.5}$, we obtain $\rho_0 = 183\ \mu\Omega$ cm and $T_0 = 286$ K from $\rho(T)$, and $\chi_0 = 10 \times 10^{-3}$ emu/mol U and $T_0 = 14$ K from $\chi(T)$. It is not understood why T_0 is so much higher for $UCu_{3.5}Pd_{1.5}$ than for UCu_4Pd.

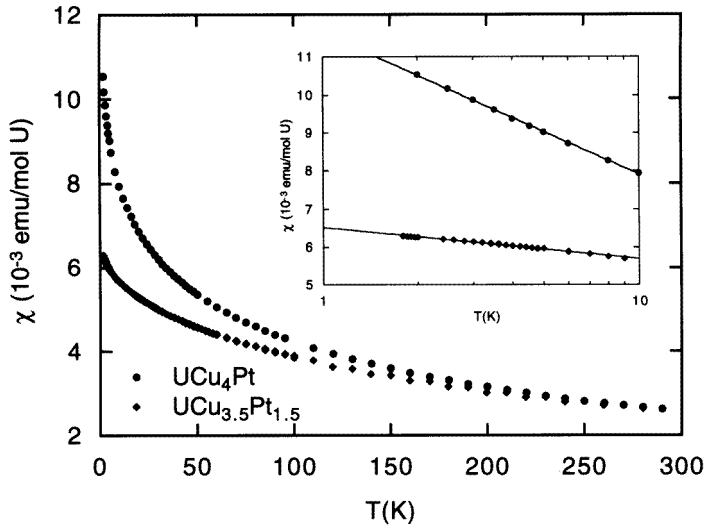

Figure 5. The dc magnetic susceptibility χ versus temperature T for UCu_4Pt and $UCu_{3.5}Pt_{1.5}$. The inset shows $\chi(T)$ below 10 K with fits to $\chi(T) = \chi_0 \ln(T/T_0)$.

In the same region, $UCu_{5-x}Pt_x$ has a behaviour that is reminiscent of the NFL scaling observed in $UCu_{5-x}Pd_x$. The magnetic susceptibility of UCu_4Pt and $UCu_{3.5}Pt_{1.5}$ is shown in figure 5. Displayed in the inset of figure 5 is a fit of the susceptibility to $\chi(T) = \chi_0 \ln(T/T_0)$. For UCu_4Pt, we find $\chi_0 = 11.6 \times 10^{-3}$ emu/mol U and $T_0 = 22.6$ K while for $UCu_{3.5}Pt_{1.5}$, we obtain $\chi_0 = 6.5 \times 10^{-3}$ emu/mol U and $T_0 = 2770$ K. The susceptibility of UCu_4Pt varies as log T from 1.8 K to 300 K and cannot be described by a Curie–Weiss law. The high-temperature susceptibility of $UCu_{3.5}Pt_{1.5}$ also diverges, but the temperature dependence cannot be described by a simple expression. Shown in figure 6(a) is the electrical resistivity of $UCu_{5-x}Pt_x$ ($x = 0.75$, 1, 1.25, 1.5). At low temperature, $\rho(T)$ can be described by $\rho(T) = \rho_0[1 - a(T/T_0)]$. For UCu_4Pt, $\rho_0 = 114$ $\mu\Omega$ cm and $T_0 = 555$ K, while for $UCu_{3.5}Pt_{1.5}$, $\rho_0 = 93$ $\mu\Omega$ cm and $T_0 = 1619$ K. Like for the $UCu_{5-x}Pd_x$ system, T_0 is much lower for UCu_4Pt than for $UCu_{3.5}Pt_{1.5}$.

It should be noted that the low-temperature fits only extend over a decade in temperature (between 1 K and 10 K). Thus, it is difficult to distinguish between a logarithmic and a weak-power-law temperature dependence. The low-temperature $\chi(T)$-data can also be fitted reasonably well below 8 K to $T^{1/3}$ in Pt- and Pd-substituted samples, but the fit to log T gives slightly better results and over a larger temperature range. Measurements to lower temperatures are required to clearly distinguish between a logarithmic behaviour and a weak-power-law one.

The scaling temperature T_0 of both systems increases with increasing Pd or Pt concentrations. In particular, the scaling temperature T_0 inferred from $\rho(T)$ or $\chi(T)$ for $UCu_{3.5}Pt_{1.5}$ is unusually high. The large value of the scaling temperature for $UCu_{3.5}Pt_{1.5}$ could indicate a significant difference in the electronic structure between $UCu_{3.5}Pt_{1.5}$ and UCu_4Pt. This conjecture is supported by the resistivity data shown in figure 6(a) for $x = 1.25$ and $x = 1.5$ which do not exhibit a strong low-temperature divergence. The same situation may also apply to UCu_4Pd and $UCu_{3.5}Pd_{1.5}$ where we also find a large difference in T_0-values. The cubic $AuBe_5$ structure crystallizes in the $F43m$ (No 216) space group.

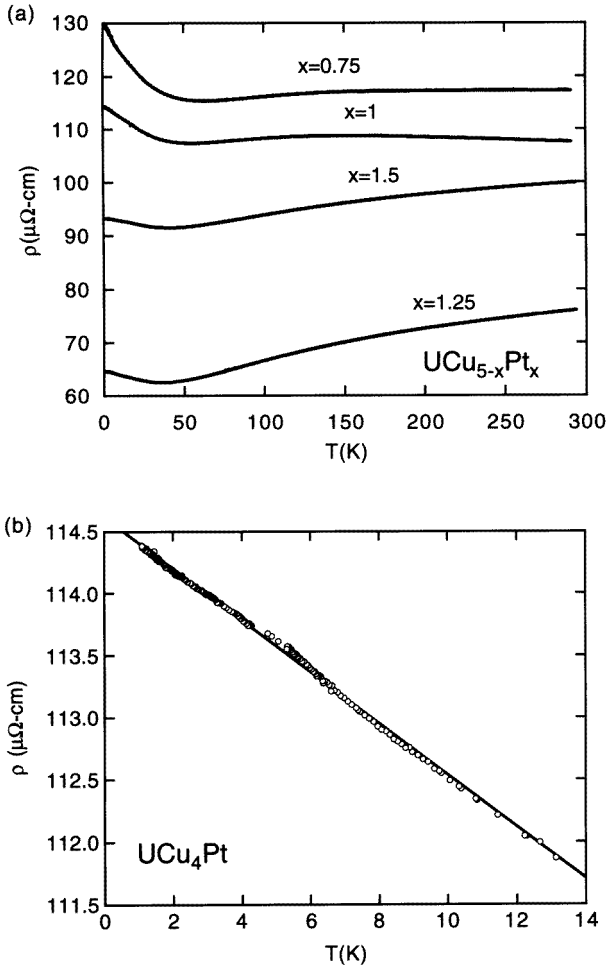

Figure 6. (a) The electrical resistivity ρ versus temperature T for $UCu_{5-x}Pt_x$ with $x = 0.75$, 1, 1.25, 1.5. (b) $\rho(T)$-data for UCu_4Pt below 12 K fitted to the following expression: $\rho(T) = \rho_0[1 - a(T/T_0)]$.

The U atoms sit on the 4a site while the Cu atoms occupy the 4c and 16e sites for UCu_5 or UPt_5. It is possible that in UCu_4(Pd, Pt), the Pd or Pt fully occupies the 4c site while the Cu resides solely on the 16e site forming an ordered compound. In compounds with higher Pd or Pt concentrations like $UCu_{3.5}Pd_{1.5}$, Pd or Pt atoms begin occupying the 16e site along with the Cu atoms. In this case, UCu_4(Pd, Pt) would form an ordered compound, while $UCu_{3.5}$(Pd, Pt)$_{1.5}$ would be disordered, which could account for the large difference in T_0. Although the variation of the lattice parameter $\boldsymbol{a}$ with x in the $UCu_{5-x}Pd_x$ and $UCu_{5-x}Pt_x$ systems is consistent with the filling of the minority site (4e), this scenario has not been confirmed.

In contrast to the $UCu_{5-x}Pd_x$ system, the $UCu_{5-x}Pt_x$ system exhibits a minimum in the resistivity for $0.75 \leqslant x \leqslant 1.75$ which shifts to lower temperatures with increasing Pt concentration x. The minimum is consistent with the Kondo effect since an increase of T_0 with x should yield a decrease in the temperature, T_m, of the minimum with increasing x.

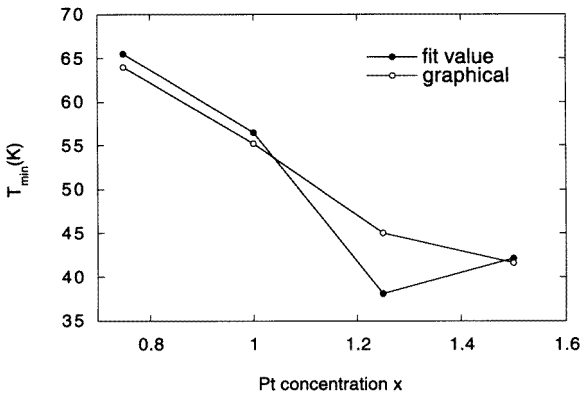

Figure 7. The temperature of the resistivity minimum, T_m, versus Pt concentration x for $UCu_{5-x}Pt_x$. The plot shows values of T_m derived from the formula $T_m = (1/2c)(\rho_0/T_0 - b)$ where b and c are determined from the phonon scattering contribution to the resistivity and also graphically from the $\rho(T)$-curves.

We consider an electrical resistivity of the form

$$\rho(T) = \rho_{nm}(T) + \rho_m(T) \approx a + bT + cT^2 + \rho_0\left(1 - \frac{T}{T_0}\right) \tag{1}$$

where $\rho_{nm}(T) = a + bT + cT^2$ is the non-magnetic contribution associated with potential scattering and scattering of electrons by phonons and $\rho_m(T) = \rho_0[1 - a(T/T_0)]$ is the contribution arising from the Kondo scattering of electrons by the U magnetic moments (the Kondo effect). The non-magnetic contribution $\rho_{nm}(T)$ was extracted from the $\rho(T)$-data by subtracting the linear magnetic Kondo contribution and fitting the data to a polynomial. For all of the samples, we find that the linear and quadratic terms dominate. From equation (1), we obtain

$$T_m = \frac{1}{2c}\left(\frac{\rho_0}{T_0} - b\right). \tag{2}$$

In figure 7, we plot T_m versus the Pt concentration x determined from equation (2), using the values of b, c, ρ_0, and T_0 deduced from fits of equation (1) to the $\rho(T)$-data, and graphically from each plot. We find that equation (2) agrees very well with the values obtained graphically. This behaviour is in direct contrast to the resistivity in UCu_4Pd and $UCu_{3.5}Pd_{1.5}$ where there is a monotonic increase in the resistivity. In this case, the magnetic Kondo contribution $\rho_m(T)$ to $\rho(T)$ dominates over the phonon contribution $\rho_{ph}(T)$.

Another important feature is the scale of the electrical resistivity. The change in resistivity of $UCu_{5-x}Pd_x$ is large between room temperature and 1.8 K, typically about a factor of two. In contrast, the resistivity of $UCu_{5-x}Pt_x$, although divergent at low temperatures, does not change appreciably between room temperature and 1.8 K. The largest change in resistivity takes place at low Pt concentrations. It is interesting to note that the magnitude of the resistivity of $UCu_{5-x}Pt_x$ drops below that of pure UCu_5 for $x > 1.25$.

At the highest concentrations studied, the Pd- and Pt-substituted systems have drastically different magnetic behaviours. Above $x = 1.5$, the $UCu_{5-x}Pd_x$ system exhibits spin-glass freezing. The spin-glass behaviour is reflected in the $\chi(T)$-data shown in figure 8(a) for samples of $UCu_{5-x}Pd_x$ with $x > 1.5$ which exhibit irreversible behaviour for samples with $x > 2$. The $\chi(T)$-curves measured upon field cooling (FC) lie above those measured upon

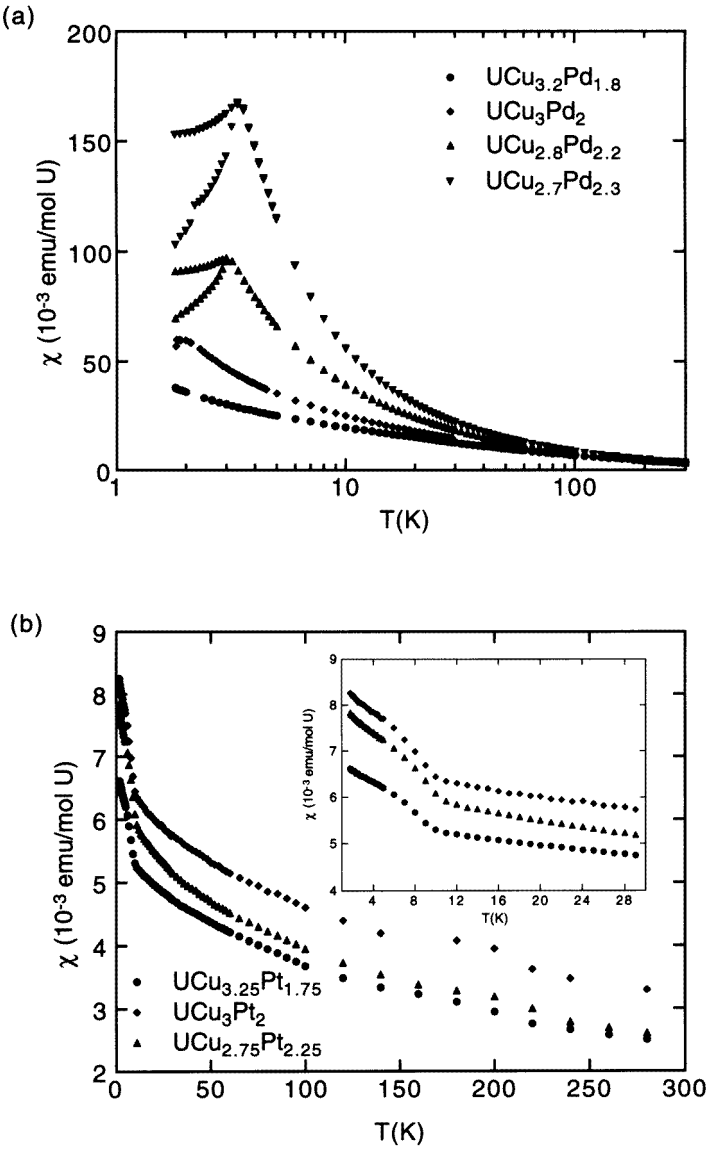

Figure 8. The dc magnetic susceptibility χ versus temperature T of (a) $UCu_{5-x}Pd_x$ ($1.8 \leqslant x \leqslant 2.3$) and (b) $UCu_{5-x}Pt_x$ ($1.75 \leqslant x \leqslant 2.25$). The inset in (b) shows the low-temperature portion of the susceptibility.

zero-field cooling (ZFC) in a field of 10 Oe, below a spin-glass freezing temperature, above which the FC and ZFC data are reversible. This behaviour is reminiscent of the spin-glass behaviour that occurs in $Cu_{1-x}Mn_x$ [7], for example. In contrast to the behaviour of $UCu_{5-x}Pd_x$, the susceptibility of $UCu_{5-x}Pt_x$, shown in figure 8(b), does not exhibit any spin-glass ordering down to 1.8 K. The susceptibility has little temperature dependence with a small sharp rise at low temperatures. The origin of this rise is not currently understood but could be due to impurities.

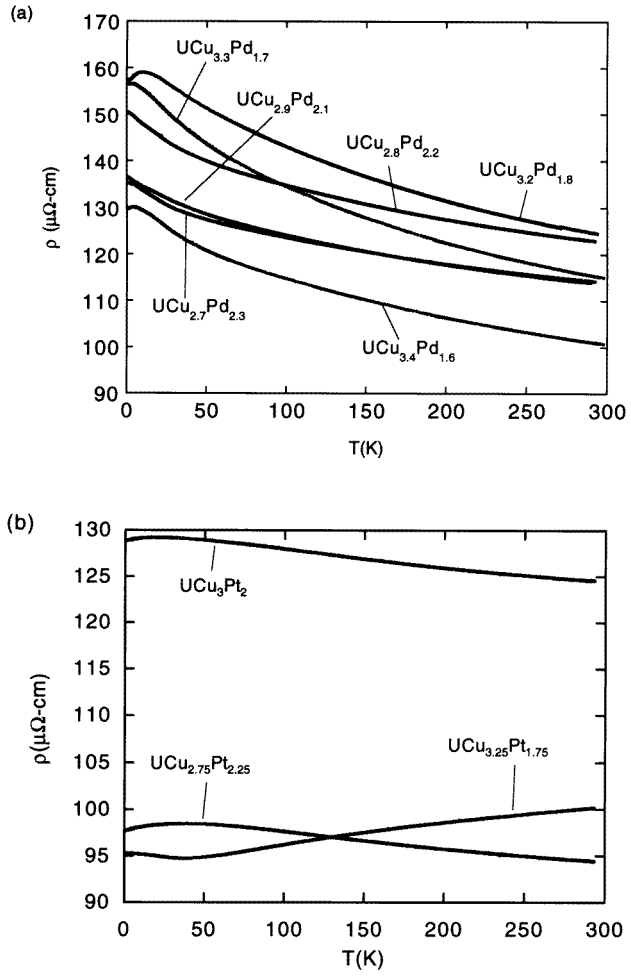

Figure 9. The electrical resistivity ρ versus temperature T of (a) $UCu_{5-x}Pd_x$ $(1.6 \leqslant x \leqslant 2.3)$ and (b) $UCu_{5-x}Pt_x$ $(1.75 \leqslant x \leqslant 2.25)$.

In figure 9(a), the resistivity of $UCu_{5-x}Pd_x$ is plotted for $1.6 \leqslant x \leqslant 2.3$. There is a broad peak in the resistivity at low temperature for samples with $1.5 < x < 2$, but these samples do not show any sign of spin-glass behaviour in the magnetic susceptibility down to 1.8 K. The spin-glass freezing temperature for these samples is expected to be below 1.8 K and magnetic susceptibility measurements down to 0.4 K are planned for a future investigation. The resistivity of the samples with $x \geqslant 2$ that display spin-glass behaviour increases monotonically down to low temperatures. A weak inflection point or cusp can be seen below 10 K. The resistivity of $UCu_{5-x}Pt_x$ for $x = 1.75$, 2, and 2.25 is shown in figure 9(b). In UCu_3Pt_2 and $UCu_{2.75}Pt_{2.25}$, there is a broad peak in the resistivity at low temperature, similar to that found in the $UCu_{5-x}Pd_x$ samples for $1.6 \leqslant x \leqslant 1.9$, and no spin-glass behaviour was observed in the magnetic susceptibility.

The possibility of some type of magnetic ordering in the Pt-substituted system at intermediate Pt concentrations ($x > 2$) is uncertain. The magnetic susceptibility shows no irreversibility in the ZFC/FC data and hence no spin-glass ordering. Instead, we find a sharp

rise in the susceptibility which could be an indication of ferromagnetic ordering, though we cannot rule out the presence of impurities. It is possible that the spin-glass freezing temperature (if it exists) is at much lower temperatures than in $UCu_{5-x}Pd_x$. Measurements on the Pt-substituted system at higher Pt concentrations and lower temperatures may reveal whether or not magnetic ordering occurs and clarify the situation.

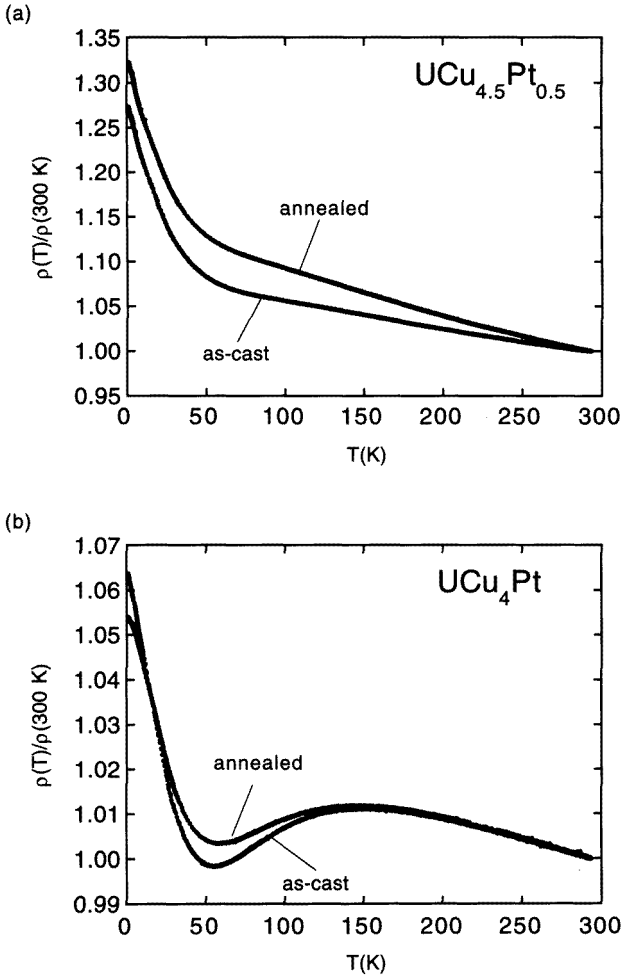

Figure 10. (a) The electrical resistivity ρ versus temperature T of $UCu_{4.5}Pt_{0.5}$ for as-cast and annealed samples. (b) ρ versus T for UCu_4Pt for as-cast and annealed samples.

An annealing study was undertaken to see whether the x-ray diffraction pattern of the $UCu_{5-x}Pt_x$ samples sharpens up and how the intrinsic electrical resistivity and magnetic susceptibility are affected. Samples of $UCu_{4.5}Pt_{0.5}$ and UCu_4Pt were annealed and their electrical resistivity and magnetic susceptibility remeasured. Figure 10 shows the $\rho(T)$-data for $UCu_{4.5}Pt_{0.5}$ and UCu_4Pt both before and after a seven-day anneal at 925 °C. The resistivity is normalized by the room temperature resistivity for ease of comparison. In both cases, the resistivity was 30% higher in the annealed sample. Qualitatively, the annealing did not significantly change the major features such as the minimum in resistivity. This is

consistent with the annealing behaviour in the $UCu_{5-x}Pd_x$ system where little change was found after annealing [1]. In $UCu_{4.5}Pt_{0.5}$, the only difference was the rate of increase in the resistivity with decreasing temperature. In UCu_4Pt, the major difference was a change in slope of the resistivity at low temperature and the fact that the minimum became shallower. The last point might indicate impurity phases or regions of slightly different concentrations in our samples. Annealing studies on other samples in the Pt-substituted system at different annealing temperatures are under way.

4. Conclusions

The $UCu_{5-x}Pt_x$ system shares many of the same features as the $UCu_{5-x}Pd_x$ system, and is a promising candidate for further studies of non-Fermi-liquid behaviour. In particular, the logarithmic T-dependence of the dc magnetic susceptibility and the linear T-dependence of the electrical resistivity in UCu_4Pt indicate non-Fermi-liquid scaling. Specific heat measurements on the $UCu_{5-x}Pt_x$ system are needed to confirm the NFL behaviour in this system. In both systems, the substitution of Pd or Pt for Cu leads to a rapid suppression of the long-range magnetic order. In systems where Au or Ag is substituted, a rapid suppression of magnetic ordering is not found and no NFL behaviour is observed. The suppression of the magnetic ordering and the occurrence of NFL behaviour seem to be intimately related. Once the NFL behaviour in the $UCu_{5-x}Pt_x$ system is fully characterized, then the similarities and differences with $UCu_{5-x}Pd_x$ and other systems will yield valuable information that will be helpful in developing an understanding of the origin of non-Fermi-liquid behaviour in f-electron materials.

The $UCu_{5-x}Pt_x$ system still has many open questions. The Pt-substituted system at the highest Pt concentrations studied does not show spin-glass behaviour, as occurs in the $UCu_{5-x}Pd_x$ system. Instead, the susceptibility shows a sharp rise at low temperatures, the origin of which is currently unclear. Possible causes for this rise in $\chi(T)$ are the presence of impurity phases or another phase transition, possibly magnetic in origin. X-ray analysis and annealing of the samples will test for the presence of impurity phases. Low-temperature measurements on the Pd-substituted samples with $1.6 \leqslant x \leqslant 1.9$ will determine whether there is spin-glass freezing below 1.8 K. This is of relevance to the Pt-substituted system since the behaviour of the resistivity is nearly identical to that of the Pd-substituted system.

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