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High field magnetotransport and specific heat in $YbAgCu_4$

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Abstract

The electrical resistivity (ρ) and magnetoresistance of polycrystalline $YbAgCu_4$ have been measured at temperatures between 25 mK and 300 K, and at magnetic fields (B) up to 18 T. The magnetoresistance $(\rho(B) - \rho(0))/\rho(0))$ is positive at all temperatures below 200 K and reaches its maximum of 60% at 18 T and 25 mK. The field- and temperature-dependent resistivity does not scale in a simple way. The opposite sign of the magnetoresistance at ambient and high pressure can be explained qualitatively by crystal-field effects lifting the degeneracy of the $J = 7/2$ groundstate. The linear coefficient of the specific heat (γ) measured at fields up to 10 T shows a quadratic field dependence. We did not find a linear relation between γ^2 and A, the T^2-coefficient of the temperature-dependent resistivity, with the applied magnetic field as the implicit parameter.

$YbAgCu_4$ is one of the few Yb-based intermetallic compounds with a large linear coefficient of the specific heat $\gamma = 245$ mJ/mol K^2 [1]. Its temperature-dependent magnetic susceptibility and specific heat are described well by the Coqblin–Schrieffer model with $J = 7/2$ and a characteristic energy scale $T_0 \approx 160$ K [1,2]. Inelastic neutron scattering [3] finds no evidence for well-defined crystal-field excitations consistent with the susceptibility results. Application of pressure causes a rapid decrease in T_{max}, the temperature at which the resistivity is maximal, and an increase in the T^2-coefficient of the resistivity (A) [4,5], suggesting that $\partial T_0/\partial P < 0$. At sufficiently high pressures, it is distinctly possible that T_0 becomes much smaller than the crystal-field splitting of the J-multiplet, the ground state degeneracy is at least partially lifted and spin fluctuations increasingly dominate electrical transport at low temperatures. This possibility could provide a partial explanation for the significantly different magnetoresistive behavior of $YbAgCu_4$ at low and high pressures. At ambient pressure the magnetoresistance is positive for $T < 20$ K and fields <10 T [4] but for pressures >70 kbar, the magnetoresistance is strongly negative [5]. To explore in more detail the origin of these opposite behaviors at low and high pressure (at large and small T_0, respectively) the specific heat (C), of $YbAgCu_4$ was measured in fields to 10 T for temperatures $4\,K \leq T \leq 10$ K and the electrical resistivity at fields up to 18 T and temperatures between 25 mK and 300 K.

The preparation of polycrystalline samples has been described previously [5]. The electrical resistivity was measured using a four lead AC resistance bridge (LR-400) operating at 17 Hz. The magnetic field was applied perpendicularly to the current (transverse geometry) and was generated by a 20 T superconducting magnet at the National High Magnetic Field Laboratory, Los Alamos Facility. The specific heat

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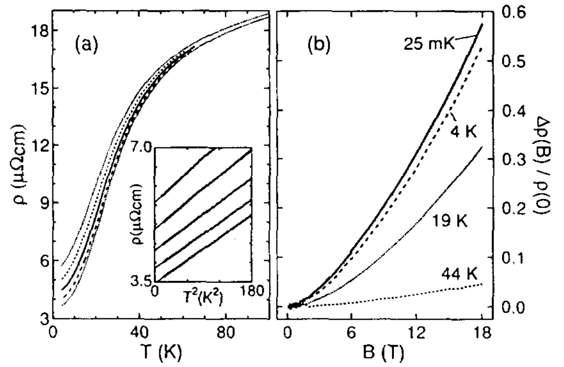

Fig. 1. (a) Resistivity ρ as a function of temperature T at magnetic fields of 0 (bottom curve), 6, 10, 14 and 18 T (top curve). Inset ρ versus T^2 at the same fields. The lines are linear fits to the data. (b) Magnetoresistance $(\rho(B)-\rho(0))/\rho(0)$ as a function of magnetic field B at different temperatures.

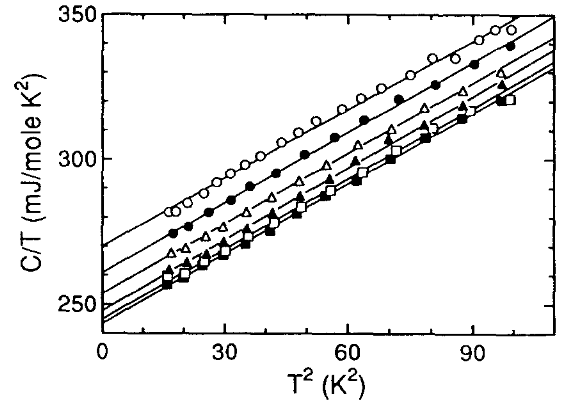

Fig. 2. Specific heat C divided by temperature T as a function of T^2 at different magnetic fields (0, 2, 4, 6, 8, 10 T, from bottom to top). The lines are linear least squares fits.

was measured in a small mass calorimeter utilizing a relaxation method.

Fig. 1(a) shows the temperature-dependent resistivity ρ of $YbAgCu_4$ in magnetic fields from 0 to 18 T. For $T < 15$ K, the curves can be fitted to $\rho(T, B) = \rho_0(B) + A(B)T^2$, which is shown explicitly in the inset of Fig. 1(a). The magnetoresistance $(\rho(B)-\rho(0))/\rho(0)$ is positive for all temperatures <200 K and reaches its maximum of 60% at 18 T and 25 mK. The monotonic evolution of the magnetoresistance with increasing temperature is shown in Fig. 1(b). At each temperature $\Delta\rho/\rho(0) \propto B^{\alpha}$, with $\alpha \approx 1.5$. The data shown in Fig. 1(a) do not scale in any simple way, contrary to what has been found for pressure-induced changes in the resistivity [6]. For example, plots of ρ/ρ_i versus T/T_i, where ρ_i and T_i are the resistivity and temperature where $\partial\rho/\partial T$ is a maximum, do not scale, nor does plotting the data in a Kohler-form $\Delta\rho/\rho(0) = f(B/\rho(0))$, or as ρ versus $T\sqrt{A}$.

The specific heat divided by temperature is plotted in Fig. 2 as a function of T^2 for various applied fields. Solid lines are least square fits to the data and yield the linear coefficients γ, which are shown in Fig. 3 to increase linearly with B^2. With the usual assumption that $\gamma \propto 1/T_0$, this implies that T_0 is inversely proportional to B^2. From the linear relation $\gamma \propto \sqrt{A}$ found [7] for several heavy fermion compounds at zero field, A would, be expected to increase as B^4. Fig. 3 shows the measured change in A as a function of B^2. Although $A(B)$ increases superlinearly in B^2 for $B \leqslant 12$ T, at higher fields A varies approximately as B^2. The inset of Fig. 3 clearly demonstrates the absence of a linear correlation between γ and $\sqrt{A}$ for $B \leqslant 10$ T. This is contrary to what was found [8] when pressure was the implicit variable.

Qualitatively the different field responses of $YbAgCu_4$ at zero and high pressures can be understood as follows. Okiji and Kawakami [9] have shown for the $J = 5/2$ Coqblin–Schrieffer model that γ increases approximately quadratically with field for $B < 0.4\,T_0$ ($B < 95$ T for $T_0 = 160$ K). A similar situation is expected to hold for $J = 7/2$, i.e. $YbAgCu_4$ at ambient pressure. From the assumed relationship between γ and A, therefore it would be expected that A increases with B, as found at ambient pressure. On the other hand, for $J = 1/2$, γ decreases strongly with field

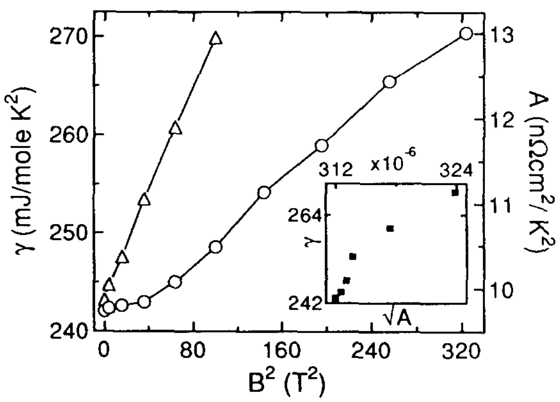

Fig. 3. Linear coefficient of specific heat γ ($\triangle$, left axis) and T^2-coefficient of resistivity A ($\bigcirc$, right axis) as a function of magnetic field squared. Inset γ versus $A^{1/2}$ with field as the implicit variable.

[9,10] and A should also be found decreasing with the field, as observed at high pressures [5]. Although, a change in ground state degeneracy appears to account qualitatively for observations at ambient and high pressure, there remain quantitative questions to be addressed. The 10% increase in γ at 10 T is larger than predicted, at least for $J = 5/2$. The large change in ρ_0 in the applied field, for either ambient or high pressures, lacks a simple explanation, as does the field dependence of A and, more generally, of $\rho(T)$. Additional high field measurements on heavy fermion systems are now in progress to identify to what extent these features are general [11].

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