High field magnetotransport and specific heat in YbAgCu₄

A. Lacerda a,*, T. Graf a,b, M.F. Hundley b, M.S. Torikachvili b,c, J.M. Lawrence d, J.D. Thompson b, D. Gajewski e, P.C. Canfield f, Z. Fisk b,c

a National High Magnetic Field Laboratory, Pulse Facility, Los Alamos, NM 87545, USA
b Los Alamos National Laboratory, Los Alamos, NM 87545, USA
c San Diego State University, Department of Physics, San Diego, CA 92182, USA
d Department of Physics, University of California, Irvine, CA 92717, USA
e University of California, San Diego, Department of Physics, La Jolla, CA 92093, USA
f Ames Laboratory, Ames, IA 50011, USA

Abstract

The electrical resistivity (ρ) and magnetoresistance of polycrystalline YbAgCu₄ have been measured at temperatures between 25 mK and 300 K, and at magnetic fields (B) up to 18 T. The magnetoresistance (ρ(B) - ρ(0))/ρ(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 γ² and A, the T²-coefficient of the temperature-dependent resistivity, with the applied magnetic field as the implicit parameter.

YbAgCu₄ is one of the few Yb-based intermetallic compounds with a large linear coefficient of the specific heat γ = 245 mJ/mol K² [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 T₀ = 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 Tmax, the temperature at which the resistivity is maximal, and an increase in the T²-coefficient of the resistivity (A) [4,5], suggesting that ∂T₀/∂P < 0. At sufficiently high pressures, it is distinctly possible that T₀ 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 YbAgCu₄ 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 T₀, respectively) the specific heat (C), of YbAgCu₄ was measured in fields to 10 T for temperatures 4 K ≤ T ≤ 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

* Corresponding author.
was measured in a small mass calorimeter utilizing a relaxation method.

Fig. 1(a) shows the temperature-dependent resistivity \( \rho \) 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 \( \leq 200 \) 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 \( \rho'/\rho \) versus \( T/T_0 \), where \( \rho' \) and \( T_0 \) 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 \( \rho \) 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 \( \gamma \), 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 \( \gamma \propto V/A \) found [7] for several heavy fermion compounds at zero field, \( A \) would be expected to increase as \( B^2 \). Fig. 3 shows the measured change in \( A \) as a function of \( B^2 \). Although \( A(B) \) increases superlinearly in \( B^2 \) for \( B < 12 \) T, at higher fields \( A \) varies approximately as \( B^2 \). The inset of Fig. 3 clearly demonstrates the absence of a linear correlation between \( \gamma \) and \( \sqrt{A} \) for \( B \leq 10 \) 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 \( \gamma \) increases approximately quadratically with field for \( B < 0.4T_0 \) (\( B < 95 \) 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 \( \gamma \) and \( A \), therefore it would be expected that \( A \) increases with \( B \), as found at ambient pressure. On the other hand, for \( J = 1/2 \), \( \gamma \) decreases strongly with field...
[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 $\gamma$ at 10 T is larger than predicted, at least for $J = 5/2$. The large change in $\rho_0$ 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].

Acknowledgements

Work at Los Alamos was performed under the auspices of the U.S. Department of Energy. The National High Magnetic Field Laboratory is supported by the National Science Foundation.

References