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MAGNETORESISTANCE OF UBe_{13} AT HIGH PRESSURES

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We have measured the temperature dependence of the electrical resistivity of UBe_{13} for magnetic fields up to 8 T and pressures to 95 kbar. Pressure increases the temperature range over which $\rho = \rho_0 + AT^2$, while the pressure and magnetic field dependences of ρ_0 and A reflect changes in the quasiparticle interactions.

The development of coherent scattering at low temperatures is characteristic of a lattice of Kondo impurities. The establishment of Kondo coherence is heralded by such observations as the appearance of bandlike character in the transport properties, perhaps most notably [1] a quadratic temperature dependence of the resistivity $\rho(T) = \rho_0 + AT^2$. The residual resistivity ρ_0 is taken as a measure of the amount of incoherent scattering resulting from lattice defects and impurities remaining in the predominantly coherent low temperature state. Accordingly, ρ is substantially affected by doping [2]. In contrast, external perturbations such as pressure and magnetic field are expected to affect the strength of conduction electron interactions in the coherent state, while leaving the lattice periodicity unaffected. In this paper, we describe the effects of pressure and magnetic field on both the residual resistivity ρ_0 and the magnitude A of the quadratic term in the temperature dependent resistivity of the heavy fermion superconductor UBe_{13} . We find that ρ_0 and A are highly sensitive to both pressure and magnetic field, reflecting changes in the density of states at the Fermi surface caused by variation of conduction electron interactions in the coherent state.

Polycrystalline samples of UBe_{13} were prepared by arc melting high purity uranium and beryllium in an argon atmosphere [3]. The sample and a lead manometer were placed in series in a Bridgman anvil cell [4]. Platinum leads were attached to both with silver filled epoxy. The pressure in the cell was determined from the depression of the lead superconducting transition temperature [5]. Nonmagnetic tungsten carbide anvils are used to minimize the effects of residual fields, which are estimated to be several hundred oersteds.

The temperature dependence of the electrical resistivity ρ is plotted in fig. 1 for pressure ranging from 1 bar to 95 kbar. The overall effect of pressure is to

increase the temperature T_m at which the resistivity is a maximum and to increase the temperature range $T < T^*$ for which $\rho(T) = \rho_0 + AT^2$, as previously observed [6]. The pressure dependences of T_m and T^* are presented in fig. 2. In accordance with our qualitative observations, both increase with pressure, most rapidly above ~ 40 kbar. We have also performed magnetoresistance measurements, reported elsewhere [7], which reveal that field H and pressure P dependences of the resistivity ρ are well described by the following expression:

$$\rho(T, H, P) = \rho_0(H, P) + A(H, P)T^2, \quad T < T^*(P). \quad (1)$$

The pressure and field dependences of the fit parameters ρ_0 and $1/\sqrt{A}$ are summarized in figs. 3a and b, respectively. Similar, but less detailed studies have also been reported by Brison [8] and by Mao [9]. Although much of the variation of ρ_0 and $1/\sqrt{A}$ at low

Fig. 1. Temperature dependence of the electrical resistivity ρ for pressures ranging from 1 bar to 95 kbar in zero magnetic field.

Fig. 2. Pressure dependence of T^* and T_m as defined in the text. Solid lines are guides for the eye.

pressure must be ascribed to uncertainty in the fit, both pressure and magnetic field rapidly depress ρ_0 to an asymptotic value of $\sim 20 \mu\Omega \text{ cm}$, while pressure is substantially more effective at increasing $1/\sqrt{A}$ than the magnetic field. While ρ_0 is only weakly field- and pressure dependent at the highest pressures, $1/\sqrt{A}$ increases even more rapidly with pressure, but begins to decrease with field at the highest pressures. It is clear on examination of fig. 3 that the negative magnetoresistance observed at low pressures results almost entirely from the field dependence of ρ_0 . However, at high pressures, the magnetoresistance results are dominated by the field dependence of $1/\sqrt{A}$.

We have qualitatively compared the pressure and magnetic field dependences of A , ρ_0 , and the electronic specific heat coefficient γ_0 in table I for a number of heavy fermion systems. It has previously been noted [10] that $A \sim \gamma_0^2$ in many systems, presumably reflecting universal effects of quasiparticle interactions on the density of states at the Fermi level. In addition, there is the observation [11] that with increasing specific heat per unit volume γ_v that the ground state of the U based heavy fermions progresses initially from spin fluctuators, to being magnetically ordered, and finally superconducting at the highest γ_v . We have tested these relationships with variable field and pressure in four materials, two superconductors (UBe_{13} and UPt_3) and two normal conductors [12] (CeAl_3 and CeCu_6), for which complete data sets are available. $A \sim \gamma_0^2$ in UBe_{13} at 0 T (variable pressure), CeAl_3 at 1 bar (variable field), and in UPt_3 for variations of both field and pressure. However, the relationship is never satisfied in CeCu_6 for variable fields or pressures. The effects of pressure and magnetic field on the residual resistivity are seemingly independent of those on A and γ_0 , perhaps reflecting the presence of several comparable scattering processes. We conclude that the balance of interactions leading to $A \sim \gamma_0^2$ is not necessarily conserved under perturbation by either magnetic field or pressure, suggesting the nonuniversal nature of quasiparticle interactions in the coherent state. However, there is apparently a strong correlation between the sign of the pressure derivatives of A and γ_0 in each material, although this correlation is not upheld in a magnetic field. These observations are consistent with dominantly magnetic

Table I

Signs of the pressure and magnetic field derivatives of A , ρ_0 and γ_0 in some heavy fermion materials. A zero (0) indicates no measurable change. Blank entries indicate lack of appropriate experimental data. Note qualitatively different behavior of Yb based compounds.

	$A(P)$	$\rho_0(P)$	$\gamma_0(P)$	$A(H)$	$\rho_0(H)$	$\gamma_0(H)$	Ref.
UBe_{13}	<60 kbar >60 kbar	- +	- -	<3 T >3 T	- +	- -	This work [7-9, 11, 13, 14]
UPt_3	-	+	-	-	-	+	[14-16]
CeCu_2Si_2	-	-	-	0	+	-	[17-20]
CeCu_6	-	-	-	-	<1.5 T >1.5 T	-	[14, 21, 22]
CeAl_3	-	-	-	-	+	-	[14, 23]
YbCuAl	+	+	+				[24, 25]
YbCu_2Si_2	+	+					[26]
YbAgCu_4	+	+					[26]

Fig. 3. Pressure and magnetic field dependences of the residual resistivity ρ_0 (a) and of $1/\sqrt{A}$ (b). Inset of fig. 3a shows details of the magnetic field dependence of ρ_0 at two fixed pressures. Solid lines are guides for the eye.

quasiparticle interactions which renormalize the density of states in such a way as to equally affect A and γ_0^2 in zero field and pressure. Such magnetic interactions might be expected to be much more sensitive to application of a magnetic field than small volume reductions. The greater sensitivity to perturbation of the Ce based compounds may result from the presence of relatively stronger magnetic interactions [27]. However, one can conclude from table I that there is no obvious connection between the pressure and magnetic field dependence of A , ρ_0 , and γ_0 and the type of ground state achieved in a particular heavy fermion system.

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