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Thermal expansion of $CeCu_{5.8}Ag_{0.2}$

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Abstract

We present low-temperature thermal expansion measurements on the heavy fermion system $CeCu_{5.8}Ag_{0.2}$, which is located at an antiferromagnetic (AF) quantum critical point (QCP). At zero magnetic field, the volume expansion coefficient divided by temperature shows a logarithmic divergence upon cooling below 1 K. This temperature dependence is incompatible with the predictions of the itinerant spin-density wave theory for an AF QCP. The application of magnetic fields leads to a cross-over to Landau Fermi liquid behavior as expected for a zero-field QCP.

Keywords: Non-Fermi liquid; Quantum critical point; $CeCu_{6-x}Ag_x$

The quantum critical point (QCP) at which long-range antiferromagnetic (AF) order in heavy fermion (HF) systems is suppressed to zero temperature has attracted the interest of many researchers in the last years [1]. Recently, it has been recognized that the thermal expansion is a highly sensitive probe of quantum critical behavior [2]. The volume thermal expansion β, defined as $\beta = (1/V)\partial V/\partial T$ (V is the sample volume) is thermodynamically given by the pressure dependence of the entropy, $\beta = -(1/V)\partial S/\partial p$ and thus complementary to the specific heat $C = T\partial S/\partial T$. Whereas specific heat probes the response to changes of temperature, β depends on changes of the pressure, which is the relevant control parameter in the case of QCPs in HF systems. Theoretical work has shown that for any pressure-driven QCP, β/T is stronger divergent than C/T [2]. Therefore, it is the most sensitive thermodynamic probe to study quantum critical behavior.

In this paper, we use thermal expansion measurements to investigate the QCP in $CeCu_{6-x}Ag_x$ at the critical concentration $x_c = 0.2$ [3]. This system belongs to the class of $CeCu_6$-based HF systems in which an AF QCP is induced

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by doping the Cu-site [4,5]. Common to all of these systems is a universal $C/T \propto \log(T_0/T)$ dependence ($T_0 \approx 6\,\mathrm{K}$) of the specific heat coefficient over nearly two decades in temperature down to 50 mK. This behavior would be compatible with theoretical predictions of the Hertz–Millis scenario [6,7] for an AF QCP in the presence of 2D critical spin-fluctuations [8]. Indeed, inelastic neutron scattering experiments on $CeCu_{5.9}Au_{0.1}$ revealed rod-like structures of high intensity in q-space translating to quasi-2D fluctuations in real space [9]. The 2D SDW picture, however, has been questioned by the observation of energy over temperature scaling in the dynamical susceptibility with an anomalous fractional exponent virtually independent of wave vector [10]. One might argue that inelastic neutron scattering has not enough precision to distinguish the fractional exponent 0.75 from 1. Therefore, it is of great importance to disprove from thermodynamics the correctness of the 2D version of the itinerant picture. This will be shown in the following.

For our study, we use a polycrystalline sample of $CeCu_{5.8}Ag_{0.2}$ prepared as described in Ref. [11]. Thermal expansion measurements have been performed in a dilution refrigerator by utilizing a high-resolution capacitive dilatometer.

Previous specific heat measurements on $CeCu_{5.8}Ag_{0.2}$ sample have shown a logarithmic increase of C/T upon cooling from 2 K to at least 50 mK [3]. Fig. 1 displays corresponding thermal expansion data obtained along the three perpendicular directions of the same sample studied in Ref. [3]. Texture of the polycrystalline sample might cause the anisotropic behavior. The deduced volume expansion coefficient $\beta(T)/T$ shows a pronounced increase upon cooling and diverges logarithmically below 0.8 K (see inset Fig. 1). Although this divergence is stronger than that observed in C/T, it is much weaker than the one predicted by the itinerant scenario both in the 3D and 2D case [2].

As shown in Fig. 2, this behavior changes upon applying magnetic fields. At $B>0$, the thermal expansion coefficient divided by temperature saturates upon cooling, indicating the formation of a field-induced Landau Fermi liquid state. This provides clear evidence for the non-Fermi liquid behavior observed at $B=0$ being related to a zero-field QCP. Similar behavior has been observed in other systems, e.g. in $CeNi_2Ge_2$ [12] as well.

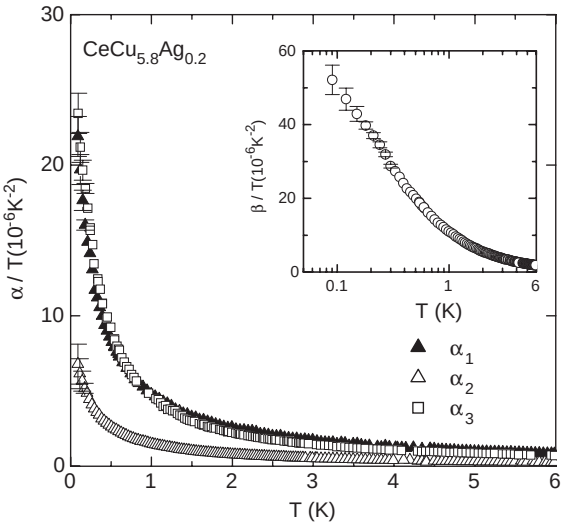

Fig. 1. Linear thermal expansion divided by temperature of $CeCu_{5.8}Ag_{0.2}$ measured along three perpendicular directions for a polycrystalline sample. Inset displays volume expansion coefficient $\beta = \alpha_1 + \alpha_2 + \alpha_3$ as β/T vs. T (on a logarithmic scale).

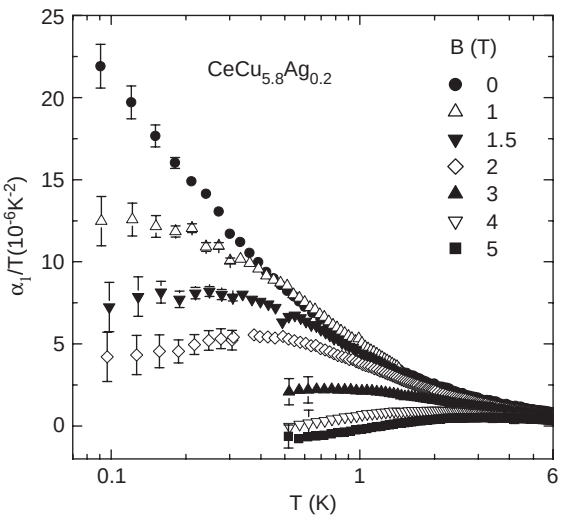

Fig. 2. Linear thermal expansion coefficient α_1 of $CeCu_{5.8}Ag_{0.2}$ (cf. Fig. 1) as α_1/T vs. T (on a logarithmic scale) at various fields applied parallel to measurement direction.

At last, we compare our results with previous observations on the two systems $CeNi_2Ge_2$ and $YbRh_2(Si_{0.95}Ge_{0.05})_2$ [12]. Whereas in the former system both thermal expansion and specific heat could be described consistently by the predictions of the 3D version of the Hertz–Millis theory, in the latter system strongly different behavior has been observed. Here, $C/T \propto T^{-1/3}$ [13] and $\beta/T \propto T^{-1}$ [12] has been observed at low temperature. Thus for $YbRh_2(Si_{0.95}Ge_{0.05})_2$, the specific heat coefficient diverges *stronger* and the thermal expansion coefficient diverges *weaker* than expected for the 2D case. For $CeCu_{5.8}Ag_{0.2}$, a *weaker* than predicted β/T divergence is observed as well. A detailed analysis of the Grüneisen ratio of the thermal expansion to the specific heat in $CeCu_{5.8}Ag_{0.2}$ and its comparison to $YbRh_2(Si_{0.95}Ge_{0.05})_2$ is given elsewhere [14].

To summarize, we have studied the low-temperature thermal expansion of $CeCu_{5.8}Ag_{0.2}$ which is a system located at an AF QCP. The observed behavior provides the first thermodynamic evidence for the breakdown of the itinerant Hertz–-Millis theory in case of $CeCu_6$-based systems.

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