Suppression of the Gruneisen parameter of CeCu6 by a magnetic field

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Suppression of the Grüneisen parameter of $CeCu_6$ by a magnetic field†

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Abstract

In order to investigate the suppression of the heavy-fermion state of $CeCu_6$ by a magnetic field ($B \parallel c$) we have measured the coefficients of thermal expansion of a single-crystalline sample ($\alpha_a, \alpha_b, \alpha_c$) in the temperature range 0.3–10 K in fields up to 8 T. The electronic Grüneisen parameter ($\Gamma_{hf} = V_m a_v/\kappa\gamma$), which amounts to 80 in zero field ($T \to 0$), is reduced by a factor 10 in a field of 8 T. This enormous drop of Γ is attributed to a rapid suppression of the magnetic inter-site correlations.

The heavy-electron compound $CeCu_6$ exhibits an unusually large quasiparticle mass as is inferred from the large Sommerfeld coefficient in the specific heat ($\gamma \simeq 1600$ mJ/mol K^2) [1]. In general, the strong mass renormalization in heavy-fermion (HF) compounds is attributed to the presence of competing electronic interactions: the on-site Kondo screening and inter-site antiferromagnetic (RKKY-type) interactions. In the case of $CeCu_6$ this picture has been confirmed by inelastic neutron-scattering experiments [2].

Under influence of a magnetic field the HF state is suppressed albeit at a moderate rate and in a strongly anisotropic way [1]. Specific-heat measurements reveal that the largest effects are found for a field along the orthorhombic c-axis, with the γ-value reduced to ~ 500 mJ/mol K^2 for $B = 7.5$ T [3]. It has been demonstrated by inelastic neutron-scattering experiments ($B \parallel c$, $B < 5$ T) that the effect of a magnetic field on the microscopic level is to suppress primarily the inter-site interactions, whereas the on-site fluctuations persist [2]. The threshold field, B^*, for suppression of the inter-site interactions (metamagnetism) amounts to 2.5 T.

The formation of the Kondo-lattice state in $CeCu_6$ is accompanied by a pronounced maximum in the coefficient of volume expansion (α_v) at $T^* = 2.5$ K [4]. The Grüneisen parameter for the heavy-electron contribution $\Gamma_{hf} = V_m a_v/\kappa\gamma$ (where $a_v = \alpha_v/T$ is the coefficient of the linear term in the volume expansion) attains the enormous value of 80 [4, 5], implying a strong volume dependence of the width of the HF resonance ($\Gamma_{hf} = -\partial \ln T^*/\partial \ln V$). In Ref. [6] we reported a large field effect on the coefficient of linear thermal

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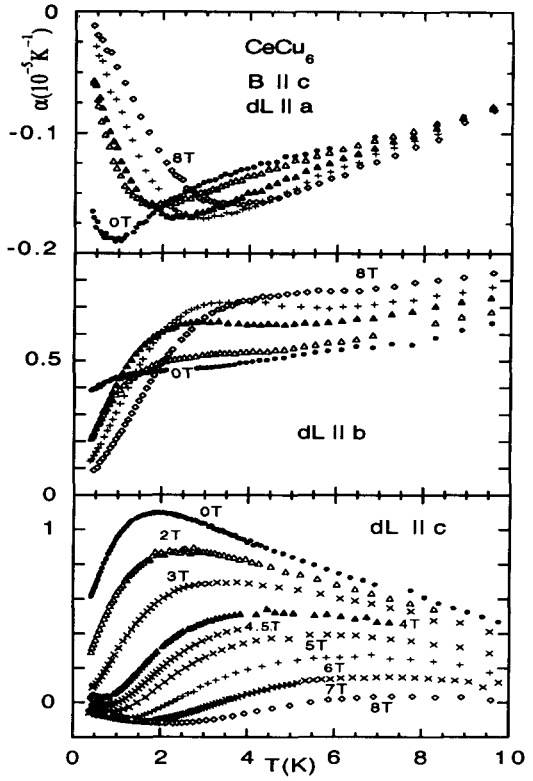

Fig. 1. Coefficient of linear thermal expansion of $CeCu_6$ versus temperature in a magnetic field along the c-axis. Upper frame α_a, middle frame α_b and lower frame α_c. (●) 0 T, (△) 2 T, (▲) 4 T, (+) 6 T and (○) 8 T. In the lower frame additional curves are given at fields of 3, 4.5, 5 and 7 T, as indicated.

expansion along the c-axis ($\alpha_c(T)$) at very low temperatures (0.1–0.5 K). In this paper we present a complete data set (including data for the a- and the b-axis), which enabled us to investigate $\alpha_v(B)$ and $\Gamma_{hf}(B)$ in relation to the suppression of the HF state by a magnetic field.

The linear coefficient of thermal expansion ($\alpha = L^{-1}dL/dT$) along the three principal orthorhombic axes (α_a, α_b, α_c) have been measured in a magnetic field ($B \parallel c$) in the temperature interval $0.3\ K < T < 10\ K$ using a sensitive capacitance dilatometer mounted in a ^3He cryostat. The experimental results (obtained on the same specimen as used in Ref. [4–6]) for α_a, α_b and α_c are shown in Fig. 1, while the calculated coefficient of volume expansion $\alpha_v = \alpha_a + \alpha_b + \alpha_c$ is shown in Fig. 2. The field dependence of $\alpha_a(T)$, $\alpha_b(T)$ and $\alpha_c(T)$ is rather complex. The largest effect is observed for α_c: the

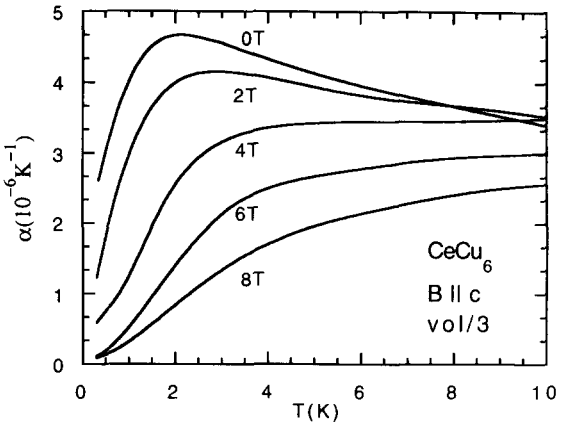

Fig. 2. Coefficient of volume expansion of $CeCu_6$ divided by 3 ($\alpha_v/3$) vs temperature at fields ($B \parallel c$) as indicated.

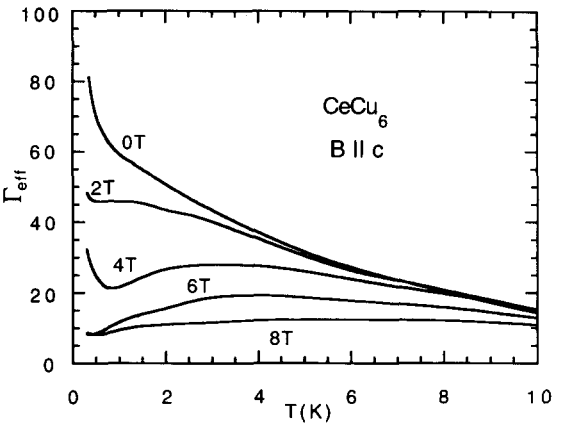

Fig. 3. The effective Grüneisen parameter of $CeCu_6$ vs temperature at fields ($B \parallel c$) as indicated.

positive contribution centered at 1.8 K in zero field is strongly suppressed and becomes of the order of α_a in a field of 8 T. Simultaneously, α_b becomes dominant. As a result α_v is strongly suppressed at low temperatures, while T^* (= 2.5 K for $B = 0$ T) shifts towards higher temperatures.

In Fig. 3 we show the effective Grüneisen parameter $\Gamma_{eff}(T) = \alpha_v(T)V_m/\kappa c(T)$ in applied fields, where we used the specific-heat data obtained for the same sample [2]. The Grüneisen parameter for the HF contribution ($\Gamma_{hf} = \Gamma_{eff}$ for $T \to 0$), which amounts to ~ 80 in zero field, is reduced by a factor 10 in a field of 8 T. This signifies that α_v is suppressed at a much faster rate than the specific

heat. More precisely, in a field of 8 T the coefficient a_v is reduced by a factor 30, whereas γ is reduced by a factor 3 only. This implies that the density of states remains fairly high in a field of 8 T, whereas its pressure dependence becomes much weaker. The enormous drop of Γ_{hf} with field is primarily attributed to a rapid suppression of the inter-site correlations. Magnetostriction measurements at very low temperature ($T < 0.4$ K) have revealed that this might occur in a two-step process [6]. Further measurements are underway in order to elucidate this point [7].

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