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Magnetic collapse in $Ce_{1-x}La_xRu_2Si_2$ studied by thermal expansion

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Abstract

The variation of T_N of $Ce_{1-x}La_xRu_2Si_2$ single crystals with concentrations ($x = 0.08, 0.1, 0.13$ and 0.2) larger than the critical value $x_c = 0.075$ for which the system shows an antiferromagnetic ground state is reexamined by thermal expansion experiments. The dependence of T_N near x_c is discussed.

Keywords: Heavy fermions; Thermal expansion

An interesting question as regards the study of the magnetic collapse in the vicinity of a quantum critical point is whether the (generally antiferromagnetic (AFM)) ordering temperature, T_N, can reach 0 K at the critical point. However, it might be difficult to answer this question, because T_N becomes hard to determine when the anomalies associated with the AFM order vanish on approaching the critical point, following the reduction of the magnetic moment. From this point of view, the $Ce_{1-x}La_xRu_2Si_2$ system is very interesting, because it is rather well documented. Replacing Ce by La in the heavy fermion compound $CeRu_2Si_2$ expands the volume and reduces the Kondo temperature, T_K. Neutron-diffraction experiments have shown that single crystals with $x = 0.08$, 0.1, 0.13 and 0.2 exhibit a modulated AFM order with a wave vector $\boldsymbol{k} = [0.31, 0, 0]$ [1]. T_N and the ordered moment M_0 both show a sharp increase on increasing x to 0.2. The critical concentration in this system is now well known: $x_c = 0.075$ [2]. Some of these crystals were studied by specific heat, $c(T)$, measurements ($x = 0.1$ and 0.13 [3], $x = 0.075$ [4]), and magnetic measurements ($x = 0.1$ and 0.13 [3], $x = 0.2$ [5]).

We have performed thermal expansion experiments using a capacitance cell on the same cystals in the case of $x = 0.08$, 0.1 and 0.13 and on a new $x = 0.2$ crystal, of which $c(T)$ was also measured [6]. The crystals were spark cut in order to obtain surfaces perpendicular to the tetragonal a- and c-axis, respectively. Here, we report only the variation of the thermal expansion coefficient, $\alpha(T) = (1/L)(dL/dT)$, along the c-axis (top of Fig. 1). We know from measurements for $x = 0.2$ [6], that $\alpha(T)$ along the a-axis exhibits exactly the same variation as along c, but its value is 2.5 times smaller. For $x = 0.2$, 0.13 and 0.1, $\alpha(T)$ shows a drop at T_N on cooling, with a change of sign. The second drop is seen for $x = 0.2$, at $T_L = 1.8$ K, which temperature, coincides with an anomaly in the T dependence of the third harmonic $3\boldsymbol{k} = [0.93, 0, 0]$ of the AFM ordering vector [1,7], i.e. to some squaring of the modulation. T_L also exists for $x = 0.13$ (and equals 0.6 K [3]), but has not been detected for lower x. For $x = 0.08$, the $\alpha(T)$ curve (measured down to 0.5 K) shows no clear trace of ordering. The maximum near 5 K is similar to those occurring at 9 and 6 K for non-ordered $CeRu_2Si_2$ and the $x = 0.05$ alloy, respectively [8]. These temperatures scale with T_K. For the $x = 0$ and 0.05 compounds, the variation of $\alpha(T)$ as well as that of other properties is quite well accounted for by the SCR model [4,9].

The bottom part in Fig. 1 represents the derivatives $d\alpha/dT$ of the curves plotted in the top panel. The

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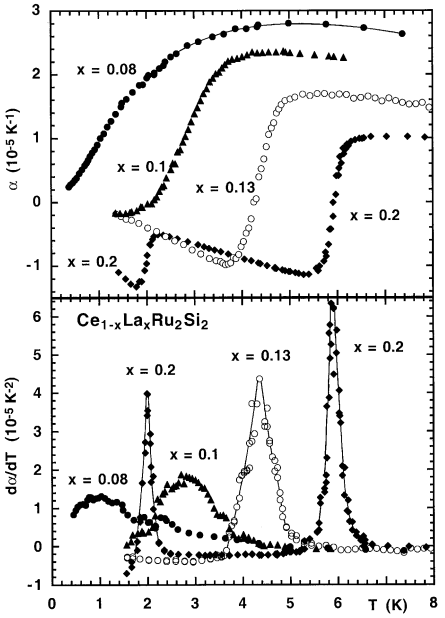

Fig. 1. Top: Temperature dependence of the thermal expansion coefficient $\alpha(T) = (1/L)(dL/dT)$ along the c-axis of $Ce_{1-x}La_xRu_2Si_2$ single crystals with $x = 0.08$, 0.1, 0.13 and 0.2. Bottom: Temperature dependence of the derivatives $d\alpha/dT$ of the curves shown in the upper part.

well-defined peaks seen for $x = 0.2$ and 0.13 become broad maxima for $x = 0.1$ and 0.08. This smearing of the $d\alpha/dT$ peak when x is lowered can be attributed to weak crystalline disorder. A relative uncertainty of 3% in the value of x is sufficient to account for the tiny residual static moment measured for the $x_c = 0.075$ crystal [2]. Similar weak disorder can be expected for all the crystals studied here, but its effect is most important for small x.

The temperatures of the peaks or maxima in $d\alpha/dT$ can be taken to represent T_N (and T_L for $x = 0.2$). The T_N values are plotted in Fig. 2. This figure also shows the temperatures of the $c(T)$ peaks, when they exist, which are slightly lower. In fact, for $x = 0.2$ and 0.13, the $c(T)$ peak temperatures coincide with the $\alpha(T)$ minima. For all concentrations, the $d\alpha/dT$ maximum corresponds to the inflection of the jump of $c(T)/T$ on cooling. This jump is also smeared on decreasing x (see Ref. [3]). We also report in Fig. 2 T_N values derived from magnetic measurements for $x = 0.13$ and 0.1. In these cases, the initial susceptibility, $\chi(T)$, shows no peak, but T_N could be defined as the temperature above which no steps (resulting from the crossing of metamagnetic lines) appear in the magnetization curves [3,5]. These T_N values are in excellent agreement with those of the maxima in $d\alpha/dT$. Metamagnetic steps have not been detected for $x = 0.08$, even not at 0.1 K. The $x = 0.2$ alloy shows a $\chi(T)$ peak but, according to the data in Ref. [5], this peak is located a bit lower than the present $d\alpha/dT$ peak.

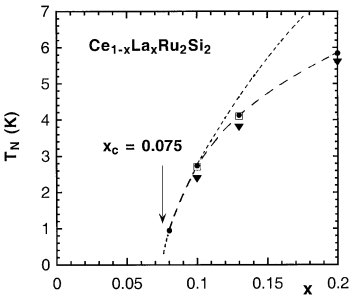

Fig. 2. Experimental T_N vs. x variation in $Ce_{1-x}La_xRu_2Si_2$ (dashed line), as determined from the temperatures of the $d\alpha/dT$ maxima in the bottom panel of Fig. 1 (●) and, for $x = 0.1$ and 0.13 from magnetic measurements (□, [3]). For comparison: peak temperatures of $c(T)$ (▼) for $x = 0.1$,0.13 [3] and 0.2 [5]. Dotted line: calculated $(x - x_c)^{2/3}$ variation adjusted on the T_N value for $x = 0.1$.

The T_N values derived from neutron-diffraction experiments are not reported in Fig. 2 because large error bars should be associated with these values, especially for low x due the existence of a tail near T_N in the magnetic intensity.

The T_N variation in Fig. 2 seems to scale with the power $\frac{2}{3}$ predicted by theoretical models [10]. (This contrasts with the almost linear variation observed in $CeCu_{6-x}Au_x$ for $0.1 \leqslant x \leqslant 1$ [11] which is also theoretically expected.) However, it appears that T_N in Fig. 2 cannot be accounted for by a simple $(x - x_c)^{2/3}$ variation, except in a quite narrow concentration range ($x \lesssim 0.1$). A correction can be made for the Ce concentration, but this does not ameliorate the fits. However, replacing the true control parameter considered in the models by $(x - x_c)$ is an oversimplification which might be valid close to x_c only. The study of other crystals with $x_c \leqslant x \lesssim 0.13$ should give a more detailed T_N variation in this range, and allow to improve the comparison with theoretical models.

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