MAGNETOSTRICTION OF (Ce,La)Ru$_2$Si$_2$ ALLOYS

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Magnetostriiction measurements have been performed on single-crystalline samples of Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ in magnetic fields up to 8.5 T. The data are discussed within a simple scaling model, and provide further support for the existence of a single energy parameter in the heavy-fermion state ($x \leq 0.05$).

The heavy-fermion compound CeRu$_2$Si$_2$ exhibits a metamagnetic-like transition at low temperatures for a field $H^* \equiv 8$ T along the tetragonal c-axis [1]. This transition, observed up to $\sim 10$ K in magnetization and up to $\sim 70$ K in magnetoresistance measurements, is thought to originate from the field induced collapse of antiferromagnetic correlations, that were found to be present in zero field below $\sim 70$ K, as proven by their direct observation in neutron scattering experiments [2]. Recently, Puech et al. [3] have shown that the pressure dependence of the magnetization obeys a simple scaling law: $M(H,P) / \mu_B = f(H/H^*(P))$. This implies that the low-temperature magnetic properties of CeRu$_2$Si$_2$ can be scaled with one single volume-dependent magnetic parameter: $H^*$. It follows that at $T = 0$, the volume magnetostriiction, $\Delta V/V$, is proportional to $f_B dM$. The justification of this simple scaling law consists of a comparison of the field dependence of the magnetic moment, the lattice parameters and the sound velocity.

On alloying CeRu$_2$Si$_2$ with La, long-range antiferromagnetic (AF) order occurs for $x \geq 0.08$ [4] and up to $x \approx 0.9$ [5], with a maximum Néel temperature $T_N \approx 6.3$ K [5]. The metamagnetic-like transition, observed at 7.9 T at 1.4 K for pure CeRu$_2$Si$_2$ shifts towards lower fields on alloying: $H^*$ equals 5.7 T at 1.4 K for $x = 0.05$ (nonordering alloy) and 4.35 T at 4.2 K (i.e. above $T_N \approx 2.5$ K) for $x = 0.10$ and has not been observed in the paramagnetic state of compounds with $x > 0.20$ [5].

In order to further investigate the validity of the forementioned scaling law, we have performed magnetostriction, $\lambda(B) = \Delta L/L$, measurements on single-crystalline samples of Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ ($x = 0.05$, 0.10 and 0.20). These samples were cleaved from single crystals grown by the Czochralski technique, to yield planar surfaces perpendicular to the tetragonal axis. They were mounted in a capacitance cell that was also used for experiments on pure CeRu$_2$Si$_2$ [3]. Both the field and the dilatation direction, were taken along the c-axis. Magnetic fields up to 8 T were produced by a superconducting magnet. Measurements were performed at various temperatures between 1.4 and 6 K. We shall compare these with magnetization data performed at the same temperatures on the same samples or on samples cleaved from the same single crystals [5].

For the 10% and the 20% La samples ($T_N = 5.6$ K for the latter), the $\lambda(B)$ curves in the AF phase exhibit interesting anomalies that reflect field-induced changes in magnetic structure, as inferred from magnetization experiments [5]. These data for $T < T_N$ need to be completed by measurements of $\lambda$ along the a direction (with $B \parallel c$) in order to derive the magnetic volumes associated with these spin reorientations. In the case of CeRu$_2$Si$_2$, however, the field dependences of the lattice parameters, $a(B \parallel c)$ and $c(B \parallel c)$ were found [3] to be proportional to each other. Under the assumption that this proportionality also holds in the paramagnetic phase of the substituted compounds, we shall focus here on the data for $c(B \parallel c)$ above $T_N$ which we consider to be proportional to $\Delta V/V$.

Figs. 1d f (second column of fig. 1) show the $\lambda(B)$ curves for $x = 0.05$ at 1.4 K, for $x = 0.10$ at 4.2 K and for $x = 0.20$ at 6 K. The absolute value of $\lambda$ should only be taken as indicative in all three cases, due to the provisional calibration of the capacitance cell (see discussion in ref. [3]). Inflection points in the $\lambda(B)$ curves are found at 5.7.
Fig. 1. Magnetization $M$ and magnetostriction $\Delta L/L$ along the $c$-axis of Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ single crystals, for $B || c$. $x = 0.05, 0.1$ and 0.2 from top to bottom, respectively. Plots of $M$ vs. $B$ and $\Delta L/L$ vs. $B$, $\Delta L/L$ vs. $\int B \, dM$ and $\Delta L/L$ vs. $M^2$ are shown from left to right hand side.

$M^2$. For $x = 0.05$ and $x = 0.10$ these plots work only at low fields where $M$ is almost proportional to $B$ (thus $\Delta V/V \propto B^2$) whereas large deviations from linearity are seen at higher fields, which brings, a contrario, another confirmation of the scaling law of ref. [3]. On the other hand, fig. 11 shows that for $x = 0.20$, the relation $\Delta L/L \propto M^2$ is well obeyed in the entire field range.

In summary, a comparison of magnetostriiction and magnetization data for Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ gives further support for the existence of a single energy parameter for the heavy-fermion state in the concentration range $x \leq 0.05$. For $x = 0.20$, above $T_N$, where the magnetization is of Brillouin-type, the magnetostriction is simply proportional to $M^2$. On the other hand, our preliminary magnetostriction data on Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ alloys in the AF phase do not seem to obey to any of the above scalings. Comparisons with other magnetic systems would be interesting. For instance, magnetostriction data on the itinerant electron metamagnet Y(Co$_{1-x}$Al$_x$)$_2$ were recently reported [6] to be well proportional to $M^2$.

**References**


