Journal of Magnetism and Magnetic Materials 76 & 77 (1988) 138-140
North-Holland, Amsterdam

MAGNETOSTRICTION OF (Ce,La)Ru_2Si_2 ALLOYS

A. LACERDA, A. DE VISSER, L. PUECH, P. LEJAY and P. HAEN

*Centre de Recherches sur les Très Basses Températures *, CNRS, BP 166 X, 38042 Grenoble-Cédex, France*

Magnetostriction measurements have been performed on single-crystalline samples of $Ce_{1-x}La_xRu_2Si_2$ 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 $CeRu_2Si_2$ exhibits a metamagnetic-like transition at low temperatures for a field $H^* \cong 8$ T along the tetragonal c-axis [1]. This transition, observed up to ~ 10 K in magnetization and up to ~ 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 ~ 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 $CeRu_2Si_2$ can be scaled with one single volume-dependent magnetic parameter: H^*. It follows that at $T = 0$, the volume magnetostriction, $\Delta V/V$, is proportional to $\int B\, dM$. 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 $CeRu_2Si_2$ 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 $T_N \cong 6.3$ K [5]. The metamagnetic-like transition, observed at 7.9 T at 1.4 K for pure $CeRu_2Si_2$ 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 $x \geq 0.20$ [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 $Ce_{1-x}La_xRu_2Si_2$ ($x = 0.05$, 0.10 and 0.20). These samples were cleaved from single crystals grown by the Czochralski technique, to yield plan parallel surfaces perpendicular to the tetragonal axis. They were mounted in a capacitance cell that was also used for experiments on pure $CeRu_2Si_2$ [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 λ along the a direction (with $B \parallel c$) in order to derive the magnetic volumes associated with these spin reorientations. In the case of $CeRu_2Si_2$, 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 λ 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,

* Laboratoire associé à l'Université Joseph Fourier, Grenoble.
' Supported by CNPq, Brazil.

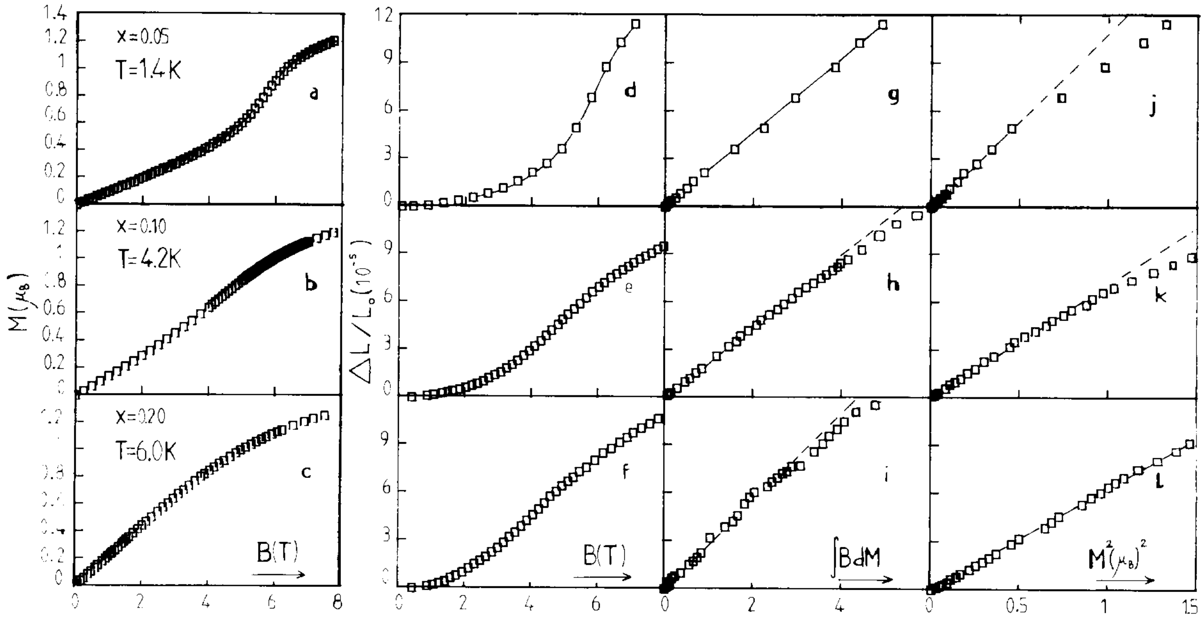

Fig. 1. Magnetization M and magnetostriction $\Delta L/L$ along the c-axis of $Ce_{1-x}La_xRu_2Si_2$ single crystals, for $B \parallel c$. $x = 0.05$, 0.1 and 0.2 from top to bottom, respectively. Plots of M vs. B and $\Delta L/L$ vs. B, $\Delta L/L$ vs. $\int B\,dM$ and $\Delta L/L$ vs. M^2 are shown from left to right hand side.

4.3 and ~ 3 T for $x = 0.05$, 0.10 and 0.20, respectively. Comparing these $\lambda(B)$ with the corresponding $M(B)$ curves reproduced from ref. [5] which are plotted in fig. 1a–c (first column of fig. 1), we conclude that for $x = 0.05$ and $x = 0.10$ the inflection points reflect the metamagnetic-like transition, as observed at $H^* \cong 8$ T for pure $CeRu_2Si_2$. For the 20% La sample the magnetization (at 6 K) follows a Brillouin-type of curve (fig. 1c). The inflection point at ~ 3 T (fig. 1f) is in this case the result of the departure of the low-field proportionality of M and B.

Figs. 1g–i show plots of $\Delta L/L$ ($\propto \Delta V/V$) as function of $\int B\,dM$. Figs. 1g and h illustrate that the scaling law of ref. 3 holds for $x = 0.05$ and $x = 0.10$. The proportionality between $\Delta L/L$ and $\int B\,dM$ is very good for $x = 0.05$ since the data where taken at 1.4 K. For $x = 0.10$, however, a small deviation from linearity is present at high fields (fig. 1h) which is probably caused by the relatively high temperature (4.2 K), at which a corrective term to the scaling integral is needed [3] and where the broad metamagnetic-like transition reveals perhaps the presence of other contributions to M. For $x = 0.20$, the scaling law is certainly not valid.

In figs. 1j–l we have plotted λ as function of 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. 1l 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 magnetostriction and magnetization data for $Ce_{1-x}La_xRu_2Si_2$ 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 $Ce_{1-x}La_xRu_2Si_2$ 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

[1] P. Haen, F. Lapierre, J. Flouquet, P. Lejay and G. Remenyi, J. Low. Temp. Phys. 67 (1987) 391.

[2] L.P. Regnault, W.A.C. Erkelens, J. Rossat-Mignod, P. Lejay and J. Flouquet, Phys. Rev. B, to be published. J.L. Jacoud, L.P. Regnault, J. Rossat-Mignod, C. Vettier, P. Lejay and J. Flouquet, Proc. Intern. Conf. on Neutron Scattering, Grenoble 1988, to be published.
[3] L. Puech, J.-M. Mignot, P. Lejay, P. Haen, J. Flouquet and J. Voiron, J. Low. Temp. Phys. 70 (1988) 237.
[4] S. Quezel, P. Burlet, J.L. Jacoud, L.P. Regnault, J. Rossat-Mignod, C. Vettier, P. Lejay and J. Flouquet, J. Magn. Magn. Mat. 76 & 77 (1988) 403.
[5] P. Haen, F. Lapierre, J.P. Kappler, P. Lejay, J. Flouquet and A. Meyer, J. Magn. Magn. Mat. 76 & 77 (1988) 143. P. Haen, J.P. Kappler, F. Lapierre, P. Lehmann, P. Lejay, J. Flouquet and A. Meyer, Intern. Conf. Magn., Paris 1988, to be published.
[6] H. Wada, K. Yoshimura, G. Kido, M. Shiga, M. Metaka and Y. Nakamura, Solid State Commun. 65 (1988) 23.