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Concentration dependence of the pseudometamagnetic field in heavy fermion $Ce_{1-x}Y_xRu_2Si_2$

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Abstract

Magnetization measurements performed on $Ce_{1-x}Y_x Ru_2Si_2$ single crystals at low temperature for the magnetic field parallel to the easy magnetization axis (*c*-axis of the tetragonal structure) are reported. They show an increase of the metamagnetic-like field H_M, from about 8 T for $x = 0$ to a value of 20 T for $x = 0.1$. The Grüneisen parameter derived from this increase of H_M is compared to those already derived from other experiments, especially from the variation of T_K deduced from specific heat measurements.

The heavy fermion compound $CeRu_2Si_2$ is known to exhibit a metamagnetic-like transition for a field of $H_M \approx 8$ T applied along the tetragonal *c*-axis [1–3]. This transition is associated with the disappearance of short range antiferromagnetic (AF) correlations which have been observed by neutron scattering experiments [4]. Nevertheless, and although recent muon experiments suggest the appearance of tiny magnetic ordered moments ($10^{-3}\,\mu_B$) below $T_N \approx 1.5$ K [5], the ground state of $CeRu_2Si_2$ can be considered as a Pauli paramagnet [4,6]. This certainly results from a strong competition with the Kondo effect. A Kondo temperature of $T_K = 24$ K has been deduced from specific heat [1] as well as from neutron scattering [4] data.

Application of pressure drives $CeRu_2Si_2$ toward a less magnetic state, leading, especially, to an increase of H_M, a reduction of the coefficient A of the low temperature resistivity AT^2 variation and an increase of the temperature of the susceptibility maximum [6]. All these effects are witnessed by a large value of the Grüneisen parameter, $\Gamma \cong 180$, either magnetic (from the variation of H_M) or thermal (variation of a characteristic temperature derived from other parameters). This nice scaling is limited to a small pressure range ($\lesssim 6$ kbar) [6,7]. For higher pressures, $CeRu_2Si_2$ enters into an intermediate valence (IV) state.

A similar volume reduction, equivalent to a positive pressure effect, can be induced by substitution of Ce by Y, while substitution of Ce by La is in first approximation equivalent to a negative pressure effect. Although these alloying processes modify the number of Ce atoms and induce disorder in the lattice, a concomitant increase or reduction, respectively, of the value of T_K was derived [1,8] from the low temperature specific heat of $Ce_{1-x}Y_xRu_2Si_2$ and $Ce_{1-x}La_xRu_2Si_2$ alloys. These variations of T_K also lead to a Grüneisen parameter $\Gamma = -\partial \ln T_K/\partial \ln V$ of the order of 180, for a concentration range of substituted non-magnetic atoms going from 30% of La to 10% of Y. From the earlier reported [9] variation of the 4.2 K values of H_M versus concentration (from $x = 0.13$ of La up to $x = 0.05$ of Y), it is not clear whether H_M also scales with T_K in these alloys. For 5% of Y, $H_M = 13.2$ T. It seemed interesting to measure the magnetization of samples of higher Y concentrations, in order first to check the scaling law, and second to check

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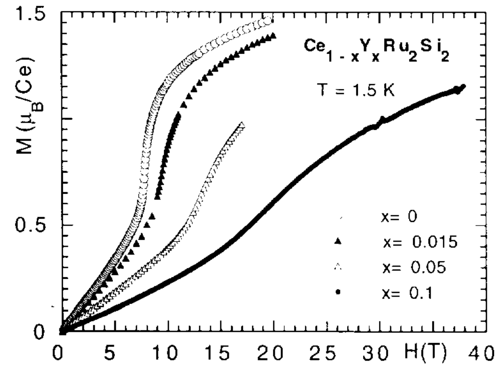

Fig. 1. Variation of the magnetization M versus H of $Ce_{1-x}Y_xRu_2Si_2$; (○): $x = 0$; (▲): $x = 0.015$; (△): $x = 0.05$; (●): $x = 0.10$.

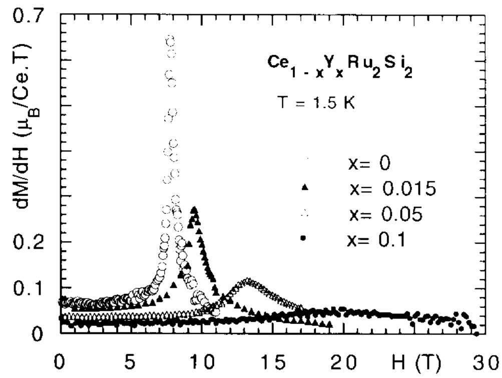

Fig. 2. Variation of the derivative of the magnetization, $\partial M/\partial H$ versus H of $Ce_{1-x}Y_xRu_2Si_2$; symbols have the same meaning as in Fig. 1.

whether the metamagnetic-like transition will disappear when the system is driven into an IV state.

Here we report on magnetization measurements performed on a series of $Ce_{1-x}Y_xRu_2Si_2$ single crystals with concentrations $x = 0$, 0.015, 0.05 and 0.1, with the field applied along the c-axis. The first two crystals are those previously used for magnetostriction experiments [10, 11]. They were measured up to 20 T at the High Field Magnet Laboratory in Grenoble by a standard extraction technique. The third is the same as in Ref. [9]. The $x = 0.10$ crystal has been measured up to 40 T in the pulse magnet at the University of Amsterdam.

The magnetization curves at 1.5 K are plotted in Fig. 1 and their derivatives are shown (only up to 30 T) in Fig. 2. The values of several parameters characterising these curves are reported in Table 1. The values of H_M are known to vary slightly with temperature [2, 3, 10, 11], but those reported here for $x = 0$ and $x = 0.015$ are close to the $T \to 0$ values already reported [10, 11]. Fig. 2 shows the dramatic reduction of the values of dM/dH at $H = H_M$ and the broadening of the peak on alloying also mentioned previously. These effects would be even stronger if we could compare dM/dH values at lower temperatures, since the peak is known to increase further and to become narrower on cooling, especially for the pure compound, while $(dM/dH)^{-1}$ saturates rapidly below 1 K in alloys [12]. Another interesting feature, seen from Table 1 is that the value of M at H_M is almost independent of x for small x; the same value $M(H_M) = 0.75\,\mu_B$/Ce is found for $x = 0.015$ of Y and for $x = 0.05$ of La, which is even slightly higher than for $x = 0$. This is a good confirmation of the scaling properties already reported [6].

The values of H_M vary quite linearly with yttrium concentration. In order to derive the corresponding Grüneisen parameter we have plotted in Fig. 3 the variations of $\ln H_M$ versus $\ln V$. We have added data points corresponding to H_M for $x = 0.05$, 0.1 and 0.13 of La (= 5.67, 5.9 and 5.6 T, respectively). (For La concentrations $x \geq 0.08$, the alloys order at low temperature, but

Table 1
Characteristics of the magnetization of $Ce_{1-x}Y_xRu_2Si_2$ alloys for a magnetic field along the easy direction

x	H_M (T)	$M(H_M)$ (μ_B/Ce)	$dM/dH(H_M)$ (μ_B/Ce T)
0	7.74	0.72	0.646
0.015	9.45	0.75	0.273
0.05	13.2	0.65	0.178
0.1	19.3	0.575	0.0557

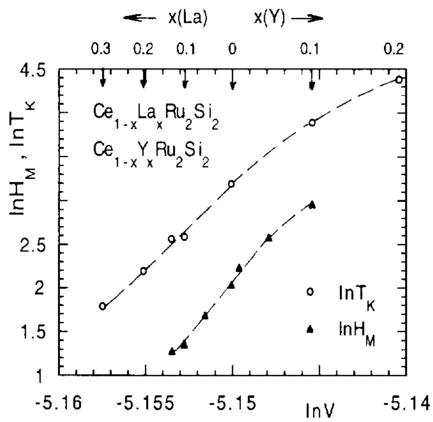

Fig. 3. Plot of $\ln H_M$ and $\ln T_K$ versus $\ln V$ for $Ce_{1-x}La_xRu_2Si_2$ and $Ce_{1-x}Y_xRu_2Si_2$. The concentrations are indicated on the top of the figure. The $\ln T_K$ values are taken from Ref. [8].

H_M disappears only for $x \geq 0.2$. However, it is not easy to determine its value below T_N [3].) The values of V were interpolated from those given in Ref. [8]. The concentrations are indicated on the top of the figure. For comparison, we have also reported in Fig. 3 the variations of $\ln T_K$ versus $\ln V$ taken from this reference. Lines are drawn through the points as guides for the eyes. In both cases, the $x = 0.1$ (Y) data point deviates from a mean straight line; this effect becomes stronger for $x = 0.2$(Y), as far as T_K is concerned. Clearly, the slope of the line around $x = 0$ is larger for H_M than for T_K. From T_K, Γ lies between 175 and 195, within the experimental scattering, while from H_M, one can derive a value of Γ ranging from about 235 to 270. (The fact that the H_M values are not taken exactly for $T = 0$, induces a negligible error compared to the apparent scattering of the data.)

Surprisingly, the above Γ value is the highest ever found for $CeRu_2Si_2$. However, this cannot be taken as an argument against the assumption [6, 10] that the thermal and magnetic Grüneisen parameters are identical in the system. Moreover, it has been noticed that alloying effects increase Γ instead of decreasing it: a value of ≈ 200 has been found for 5% of La against ≈ 180 for $CeRu_2Si_2$ [10]. The latter values were deduced assuming a compressibility, κ, of the order of 1. Taking $\kappa = 0.82$, as measured [7], one gets $\Gamma \approx 200$ for $CeRu_2Si_2$ and ≈ 240 for the 5% La alloy, which become closer to the value derived from the present study.

Finally, by extrapolating the H_M data of Fig. 3 similarly to the T_K points, one could expect a H_M value of the order of 30 T for an alloy with 20% of Y. However, according to the results in Figs. 1 and 2, the magnetization of such an alloy would show only a tiny inflexion point or perhaps no anomaly anymore.

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