Concentration dependence of the pseudometamagnetic transition field in heavy-fermion \textit{Ce1-}x\textit{YxRu2Si2}

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Concentration dependence of the pseudometamagnetic field in heavy fermion Ce\textsubscript{1-x}Y\textsubscript{x}Ru\textsubscript{2}Si\textsubscript{2}

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Abstract

Magnetization measurements performed on Ce\textsubscript{1-x}Y\textsubscript{x}Ru\textsubscript{2}Si\textsubscript{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\textsubscript{2}Si\textsubscript{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$^{-3}$ μB) below $T_N \approx 1.5$ K [5], the ground state of CeRu\textsubscript{2}Si\textsubscript{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\textsubscript{2}Si\textsubscript{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, $\Gamma \approx 180$, 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 ($\leq 6$ kbar) [6, 7]. For higher pressures, CeRu\textsubscript{2}Si\textsubscript{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$_x$Ru$_2$Si$_2$ and Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ alloys. These variations of $T_K$ also lead to a Grüneisen parameter $\Gamma = - \frac{\partial \ln T_K}{\partial \ln V}$ 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...
Here we report on magnetization measurements performed on a series of $\text{Ce}_1 - x \cdot \text{Y}_x \text{Ru}_2 \text{Si}_2$ 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 $x = 0.1$ 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 $M(H_M) = 0.75 \mu_B/\text{Ce}$ 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

\begin{table}[h]
\centering
\caption{Characteristics of the magnetization of $\text{Ce}_1 - x \cdot \text{Y}_x \text{Ru}_2 \text{Si}_2$ alloys for a magnetic field along the easy direction}
\begin{tabular}{|c|c|c|c|}
\hline
$x$ & $H_M$ (T) & $M(H_M)$ ($\mu_B/\text{Ce}$) & $dM/dH(H_M)$ ($\mu_B/\text{Ce} \cdot \text{T}$) \\
\hline
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 \\
\hline
\end{tabular}
\end{table}
HM 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 \( V \) 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 \( T_K \), \( \Gamma \) lies between 175 and 195, within the experimental scattering, while from \( H_M \), one can derive a value of \( \Gamma \) 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 \( \Gamma \) value is the highest ever found for \( \text{CeRu}_2\text{Si}_2 \). 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 \( \Gamma \) instead of decreasing it: a value of \( \approx 200 \) has been found for 5% of La instead of \( \approx 180 \) for \( \text{CeRu}_2\text{Si}_2 \) \([10]\). The latter values were deduced assuming a compressibility, \( \kappa \), of the order of 1. Taking \( \kappa = 0.82 \), as measured \([6]\), one gets \( \Gamma \approx 200 \) for \( \text{CeRu}_2\text{Si}_2 \) and \( \approx 240 \) 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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References