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SPECIFIC HEAT OF (Ce,La)Ru$_2$Si$_2$ IN HIGH MAGNETIC FIELDS

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ABSTRACT

Specific heat (C) measurements on Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ were made in order to observe the change in C on going from a long range magnetically ordered system ($x<0.07$) to a paramagnetic system. Magnetic field measurements of C show that a maximum of the effective mass occurs at the metamagnetic-like transition.

Keywords

High field, specific heat, effective mass enhancement, heavy fermion

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The compound CeRu$_2$Si$_2$ exhibits interesting magnetic features \[1\]. Its magnetization (M) for H parallel to the tetragonal c-axis displays a metamagnetic-like transition at \(H_M \approx 8\)T, although no long range magnetic order could be detected. This field corresponds to the quenching of the antiferromagnetic (AF) correlations occurring below 60K \[2\]. In Ref. 1, it was argued by comparing the temperature dependences of the resistivity at various fields that the electronic effective mass \(m^*\) would go through a maximum at \(H_M\). In order to check this suggestion, we have made specific heat measurements on single crystals of Ce$_{1-x}$La$_x$Ru$_2$Si$_2$ \((x=0, 0.05, 0.10\) and 0.13). Substituting La for Ce reduces \(H_M\) \[3\] and induces AF order for \(x \geq 0.08\) \[4\]. The corresponding critical fields are respectively 7.9, 5.7, 3.8 and 3.65T at \(=1.4\)K (i.e., below \(T_N\) for the two last systems) \[3\]. For \(H=0\), the measurements extended from \(-0.1\)K to \(-27\)K. Magnetic fields up to 7.5T were applied along the c-direction for \(T \geq 0.4\)K.

The \(H=0\) data are displayed in Fig. 1; the inset shows the low temperature region as \(C/T\) vs. \(T\). They are consistent with previous results for polycrystals \[5\]. The value of \(C/T\) extrapolated to \(T=0(\gamma_o)\) increases from 360 \text{mJ mol}^{-1}\text{K}^{-2} for \(x=0\) to 585 \text{mJ mol}^{-1}\text{K}^{-2} for \(x=0.1\) and then decreases again. \(\gamma_o\) may reach a critical value \(\gamma_{oc} = 600\) \text{mJ mol}^{-1}\text{K}^{-2} at the magnetic-non-magnetic (M-NM) transition which occurs near \(x=0.08\) as shown by neutron diffraction experiments \[4\]. Indeed, for \(x=0.13\), AF ordering leads to a peak in \(C\) at \(T_N=3.8\)K. This anomaly is very similar to that reported \[6\] for CePb$_3$, a typical long range magnetically ordered heavy fermion compound. Although no peak in \(C(T)\) is observed for \(x=0.1\), it is worth noticing the similarity between the \(x=0.1\) and \(x=0.13\) data in the \(C/T\) representation, i.e., a sharp increase followed by an almost flattening (see Fig. 1 inset). This suggests that our \(x=0.1\) crystal orders below \(-2.5\)K which is consistent with \(T_N=2.7\)K determined by neutron experiments \[4\]. On the non-magnetic side of the M-NM transition (\(x=0\) and 0.05), the smooth increase of \(C/T\) on cooling is very similar to that reported \[7\] for CeCu$_6$.

Fig. 2 shows the field dependence of \(\gamma_o\). A clear increase of \(\gamma_o\) towards \(H_M\) is observed for the two NM compounds. For \(x=0.05\) for which it was possible to perform experiments well above \(H_M\), \(\gamma_o(H)\) goes through a maximum at a field of \(-5.5\)T, consistent with the value of \(H_M\) derived from magnetization data \[3\]. While \(\gamma_o=500\) \text{mJ mol}^{-1}\text{K}^{-2} at \(H=0\), \(\gamma_o(H_M)=655\) \text{mJ mol}^{-1}\text{K}^{-2} (an increase of 30\%).
Magnetization experiments at 1.5K lead to an increase of the differential susceptibility ($\chi=\partial M/\partial H$) by a factor of 2.7 at $H_M$. Such a dependence of $\gamma_{oc}$ with $H$ stresses the importance of the magnetic correlations [1,2]. $\gamma_{oc}(H_M)=655$ mJ mol$^{-1}$K$^{-2}$ is roughly the same value as the critical value $\gamma_{oc}$ defined above, which suggests that this critical magnitude of $\gamma_o$ drives the magnetic instabilities induced either by $H$ or by addition of La.

No maximum in $\gamma_o(H)$ can be seen for $x=0.1$. This may be due to the fact that $\gamma_o$ is already very close to $\gamma_{oc}$. However, the occurrence of a new feature (the existence of maxima in the C/T vs T curves in magnetic fields, connected to the crossing of lines of the [H,T] magnetic phase diagram [3]) prevents accurate extrapolations of C/T to T=0, making measurements at lower temperatures desirable.

Finally, $\gamma_o(H)$ decreases rapidly with $H$ above $H_M$ where high magnetic polarization is achieved. Further studies of these polarized phases will lead to a better understanding of the heavy fermion compounds.

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Figure Captions

Fig. 1. Specific heat of Ce$_{1-x}$La$_x$Ru$_2$Si$_2$. The insert shows C/T vs T.

Fig. 2. Field variation of C/T extrapolated to T=0K.
Fig. 1