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Thermodynamics of CeNiSn at low temperature and in weak magnetic field

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Abstract

Experimental and theoretical description of low-temperature spin-liquid contribution to the thermal expansion and magnetostriction of Kondo-lattice compound CeNiSn is presented. Together with the previously published interpretation of inelastic neutron scattering spectra and low-temperature specific heat, these studies give the consistent picture of low-T thermodynamics of a Kondo lattice whose properties are determined by the interplay between the spin-liquid excitations and the soft crystal-field excitations. © 1999 Elsevier Science B.V. All rights reserved.

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Based on the theoretical interpretation of experimental data on the low-energy/low-temperature properties of CeNiSn, we claimed recently [1] that the unusual behavior of CeNiSn and related compounds is due to interplay between the spin-liquid and crystal-field (CF) excitations in a Kondo lattice. This idea was confirmed [2] by successful quantitative description of the inelastic neutron scattering spectra of CeNiSn.

In this paper we summarize the results of experimental measurements and theoretical analysis of spin contribution to the dilatation properties which can be expressed in terms of effective Grüneisen parameters (GPs) characterising the spin subsystem of CeNiSn. We base on the free energy of the spin liquid $\mathscr{F}_{\mathrm{sp}} = T/2\sum_{ij}\int_0^T I_{ij}\langle|\varDelta_{ij}|^2\rangle_\beta \,\mathrm{d}\beta - TS_\infty$, where I_{ij} is the effective Heisenberg exchange in a Kondo lattice and $\varDelta_{ij} = \sum_\rho f_{i\rho}^\dagger f_{j\rho}$ is the operator creating the spin-fermion pair. The spectrum of spin fermions (SF) was restored in [2] from the neutron scattering spectra and the specific heat at low T. All the branches ρ of the spectrum are controlled by the energy scale T^* (characteristic energy of SF), the CF splitting parameter $\varDelta < T^*$ and the parameter g of mixing between SF and CF. Then the thermal expansion $\alpha = \partial \log V/\partial T$ can be represented in a form

$$\frac{\alpha}{T} = W + \frac{\kappa_T}{T}\left\{\gamma_{\tilde{\varDelta}_{\mathrm{CF}}}\left(\frac{\partial S_{\mathrm{sp}}}{\partial \log \tilde{\varDelta}_{\mathrm{CF}}}\right)_T + \gamma_g\left(\frac{\partial S_{\mathrm{sp}}}{\partial \log g}\right)_T\right\}. \tag{1}$$

Here W incorporates the contributions which are T-independent at $T \ll T^*$. The spinon part of entropy S_{sp} is extracted from the free energy $\mathscr{F}_{\mathrm{sp}}$. Two GPs $\gamma_{\tilde{\varDelta}_{\mathrm{CF}}} = \partial \log \tilde{\varDelta}_{\mathrm{CF}}/\partial \log V$ and $\gamma_g = \partial \log g/\partial \log V$ characterise the volume dependence of the CF splitting $\tilde{\varDelta}_{\mathrm{CF}}$ and the mixing parameter g, respectively. So, in the temperature range $T \leqslant \tilde{\varDelta}_{\mathrm{CF}}$ there are at least two mechanisms of the volume dependence of spinon spectrum. Therefore, there is no single characteristic scaling energy, and the treatment within the standard scheme with one GP is irrelevant. Our two-parameter procedure is in good agreement with experimental data [3] (see Fig. 1) with the parameters $\gamma_{\tilde{\varDelta}_{\mathrm{CF}}} = -30$ and $\gamma_g = -20$. The signs of both GPs are reasonable: the expansion of the lattice leads to the decrease of CF splitting and to the decrease of intersite intermixing parameter g.

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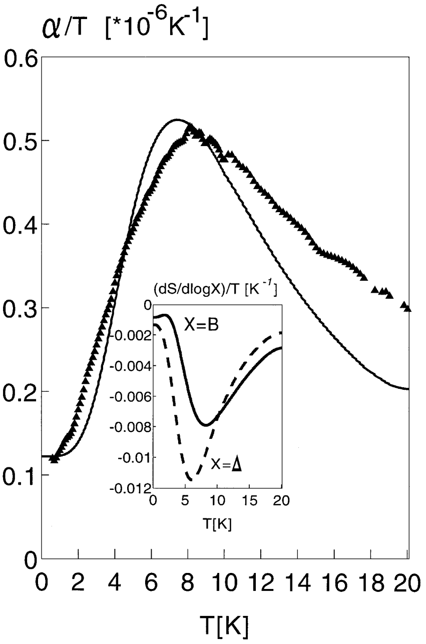

Fig. 1. Calculated linear coefficient of volume expansion (line) compared with experimental data (triangles). Inset: Temperature dependence of logarithmic derivatives of entropy.

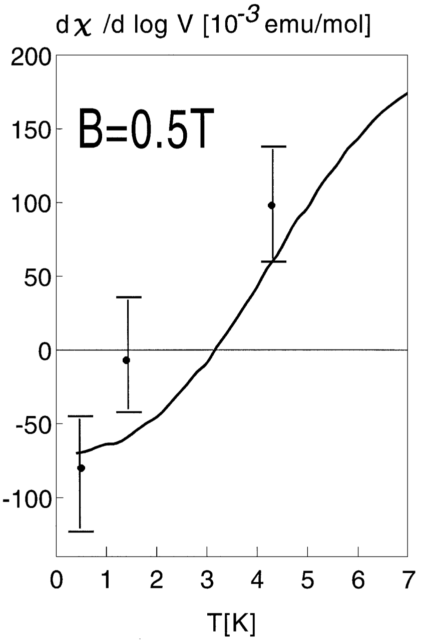

Fig. 2. Calculated temperature dependence of logarithmic derivative of magnetic susceptibility (line) compared with experimental data (circles).

To analyse the influence of magnetic field B on the dilatometric properties we extracted the logarithmic derivative of magnetic susceptibility χ from the experimental data (Fig. 2) using the relation [4] $(\partial\chi/\partial\log V)_{V,T} = (d\lambda/dB)_{V,T}/B\kappa_T$. Here $\lambda = V^{-1}\,\mathrm{d}V/\mathrm{d}B$ is the volume magnetostriction. To calculate the corresponding volume derivative we use the relation

$$\left(\frac{\partial\chi}{\partial\log V}\right) = \tilde{W} + \left\{\gamma_{\tilde{\Delta}_{\mathrm{CF}}}\left(\frac{\partial\chi_{\mathrm{sp}}}{\partial\log\tilde{\Delta}_{\mathrm{CF}}} = \right)_T + \gamma_g\left(\frac{\partial\chi_{\mathrm{sp}}}{\partial\log g}\right)_T + \gamma_a\left(\frac{\partial\chi_{\mathrm{sp}}}{\partial\log a}\right)_T\right\} \qquad (2)$$

(again, $\tilde{W}$ incorporates all temperature-independent contributions). Here χ_{sp} is the spinon part of magnetic susceptibility which was calculated by taking into account only Zeeman mechanism of the influence of magnetic field at the spinon spectrum. The third GP $\gamma_a = \partial\log a/\partial\log V$, which is absent in the expression (1), characterises the volume dependence of the CF wave function $|G\pm\rangle = a|\pm 1/2\rangle + \sqrt{1-a^2}|\mp 5/2\rangle$. This dependence does not influence the linear expansion at zero field.

The last term dominates in the magnetostriction because the contribution of first two terms give the value which is of smaller magnitude than the experimental data. The fit with $\gamma_{\tilde{\Delta}_{\mathrm{CF}}}$ and γ_g found above, $\tilde{W} = -1.59$ emu/mol, and $\gamma_a = 230$ gives the reasonable agreement with experimental data at low magnetic fields (Fig. 2).

It should be mentioned that the model suggested is valid only for the low B: it cannot reproduce the field dependence of the magnetostriction at high fields. This result is evidently connected with the fact that the influence of magnetic field on the spin liquid is not exhausted by the Zeeman effect.

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References

[1] K.A. Kikoin, A. de Visser et al., Phys. B 94 (1994) 79.
[2] Yu. Kagan et al., Phys. Rev. B 55 (1997) 12348.
[3] A.J. Nolten et al., Physica 206–207 (1995) 825.
[4] B.S. Chandrasekhar, F. Fawcett, Adv. Phys. 20 (1971) 775.