Journal of Magnetism and Magnetic Materials 226–230 (2001) 57–59

www.elsevier.com/locate/jmmm

Thermal-transport properties of CeNiSn

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Abstract

We present thermopower S and thermal-conductivity κ measurements on high-quality single crystalline CeNiSn along the three crystallographic axes a, b, and c in the temperature range between 100 mK and 7 K and in magnetic fields up to 8 T, applied along the a axis. Both κ and S are highly anisotropic. However, below 10 K, characteristic features that may be attributed to the opening of a pseudogap in the charge-carrier density of states (DOS) at the Fermi energy η are seen for *all* three crystallographic directions. These features are strongly suppressed by a magnetic field of 8 T. At the lowest temperatures we have evidence for the presence of a residual charge-carrier density, again for all the three directions. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: CeNiSn; Kondo insulator; Thermal conductivity; Thermoelectric power

The claim [1] that CeNiSn is one of the rare examples of valence-fluctuating Cerium compounds with an energy pseudogap in the electronic density of states (DOS) at η triggered strong interest in this compound. Our main concern in the present work is a potential residual DOS within the pseudogap. Thermal-transport measurements at low temperatures are a valuable tool for extracting information on such a residual DOS. In particular, measurements along the three crystallographic axes provide information on the anisotropy of the residual charge-carrier density. Our single-crystalline CeNiSn samples were grown by a Czochralski method and purified by the technique of solid-state electro-transport (SSE), which is crucial for improving the sample quality [2]. The S and κ measurements to be presented below are the first on SSE-treated CeNiSn. A comparison with low-temperature data on less pure CeNiSn [3] shows that S is more sensitive to impurities than κ.

$S(T)$ is highly anisotropic and shows several well-defined structures (Fig. 1). We interpret these $S(T)$ data in terms of a diffusion thermopower, since possible phonon-drag and paramagnon-drag contributions are expected to be small in the temperature range investigated here. In systems like CeNiSn containing both almost localized 4f and delocalized conduction electrons, the thermopower may be ascribed [4] to the conduction electrons, being scattered from the 4f electrons. In a first approximation, S is proportional to $T(\partial \ln N_s/\partial\varepsilon - \partial \ln N_f/\partial\varepsilon)_{\varepsilon=\eta}$ where N_s and N_f are the conduction- and 4f-electron DOS, respectively. $(\partial \ln N_f/\partial\varepsilon)_{\varepsilon=\eta}$ may reach very large values compared to the corresponding expression in d-band metals. Also $(\partial \ln N_s/\partial\varepsilon)_{\varepsilon=\eta}$ may contribute non-negligibly to S, because the charge-carrier concentration is known to decrease steeply upon cooling below 5–10 K [5]. The anomalies (maxima along a and b, minimum along c-axis) between 2 and 7 K reflect extreme values in the energy derivative of N_s and/or N_f, which we relate to the opening of the pseudogap. They are strongly suppressed by a magnetic field of 8 T (Fig. 1). In the Kondo-lattice model, a destruction of the coherence gap is expected at low magnetic fields if the RKKY and the Kondo interactions are of similar strength [6]. The features in $S(T)$ at even lower temperatures are most probably the signs of a temperature-dependent DOS structure at the Fermi level *within* the gap. Their unusual anisotropic magnetic-field dependence indicates that the magnetic field leads to a charge redistribution in k-space.

Similar to $S(T)$, $\kappa(T)$ is highly anisotropic (Fig. 2). However, anomalous enhancements of κ are observed for

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0304-8853/01/$ - see front matter
PII: S0304-8853(00)00623-5

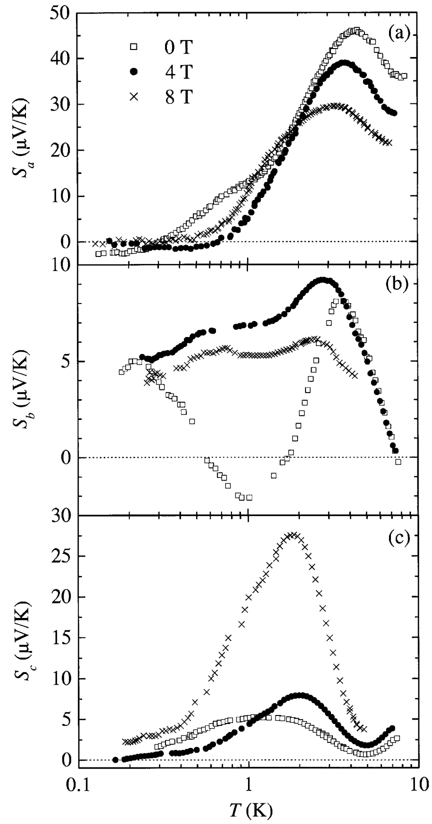

Fig. 1. Temperature dependence of the thermopower $S(T)$ of CeNiSn at 0, 4 and 8 T along the *a*-, *b*-, and *c*-axis in panel (a), (b), and (c), respectively.

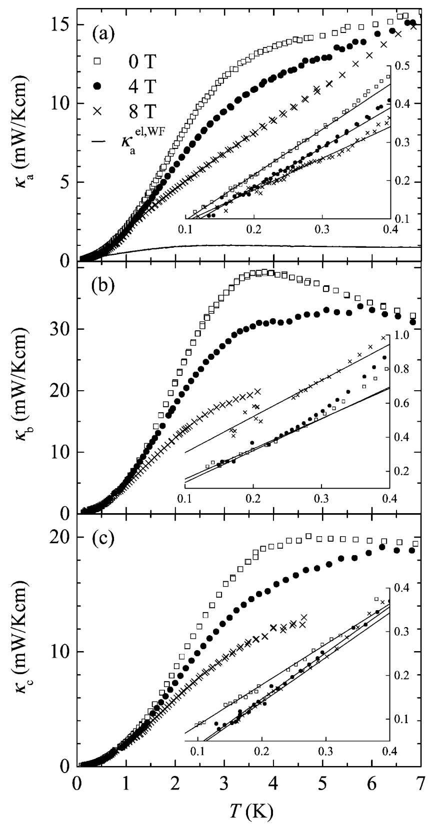

Fig. 2. Temperature dependence of the thermal conductivity κ(T) of CeNiSn at 0, 4 and 8 T along the *a*-, *b*-, *c*-axis in panel (a), (b), and (c), respectively. The solid curve in panel (a), $\kappa_a^{el,WF}(T)$, represents the electronic thermal conductivity along the *a*-axis obtained from the Wiedemann–Franz law. The insets show close-ups at low temperatures. The lines are best linear fits to the data.

all three directions: A pronounced maximum for $\kappa_b(T)$ at 3.8 K, a very shallow maximum for $\kappa_c(T)$ at 5 K, and a plateau for $\kappa_a(T)$ at 4.5 K. Application of a magnetic field leads to a reduction of all these enhancements. The electronic contribution to the thermal conductivity along the *a*-axis, calculated from the electrical resistivity along the *a*-axis under the assumption that the Wiedemann–Franz law is valid, is relevant only below 1 K (Fig. 2). Below 300 mK, κ is a linear function of T for all three directions (insets of Fig. 2) suggesting that in this temperature range the heat is predominantly carried by charge carriers. This is strong evidence for a residual charge-carrier density for all the three crystallographic directions. The anisotropic magnetic-field dependence of the linear term again points to a field-induced charge-carrier redistribution in *k*-space. Between 600 mK and 2 K, $\kappa \propto T^2$, a temperature dependence commonly attributed to a phononic thermal conductivity with predominant phonon–electron scattering. Making the reasonable assumption that phonon–electron scattering remains dominant up to at least 7 K, the abovementioned enhancements in $\kappa(T)$ can be explained as follows: When the gap starts to open upon cooling below 10 K, electrons start to freeze out which reduces the phonon–electron scattering rate and leads to the observed enhancements in $\kappa(T)$. This mechanism was already proposed in Ref. [7]. Our analysis provides strong evidence for this scenario. Finally, we would like to note that the reduced Lorenz number L/L_0 measured along the *a* axis saturates below 200 mK to the value 1.5, which is distinctly enhanced over 1. This is a striking observation which deserves further investigation. A more detailed analysis of our data will be given elsewhere [8].

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