



ELSEVIER

Physica B 312–313 (2002) 472–474

PHYSICA B

www.elsevier.com/locate/physb

Investigation of the dynamical susceptibility of $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ by inelastic neutron scattering

J.-Y. So^{a,*}, J.-G. Park^{b,e}, D.T. Adroja^c, K.A. McEwen^d, S.-J. Oh^{a,e}^a School of Physics, Seoul National University, Seoul 151-747, South Korea^b Department of Physics and Institute of Basic Science, Sung Kyun Kwan University, Suwon 440-746, South Korea^c ISIS Facility, Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, UK^d Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK^e Center for Strongly Correlated Materials Research, Seoul National University, Seoul 151-747, South Korea

Abstract

Following the observation that the specific heat of $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ shows non-Fermi liquid behavior, we have investigated the inelastic neutron scattering from this compound over the temperature range 10–100 K, using the HET spectrometer at ISIS. We have found that the spectral function of $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ displays a power law dependence of energy, i.e. $S(\omega) \sim \omega^{-\alpha}$, with $\alpha = 0.33$. The dynamical susceptibility obtained from the inelastic scattering spectra displays E/T scaling behavior as in other compounds showing non-Fermi liquid behavior. With increasing energy transfer above 10 meV, $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ shows a more localized behavior with two broad crystalline electric field transitions around 20 and 30 meV. © 2002 Elsevier Science B.V. All rights reserved.

PACS: 71.70.Ch; 71.20.Eh; 78.70.Nx

Keywords: Non-Fermi liquid; Kondo semi-metal; Inelastic neutron scattering; Crystal electric field

Heavy fermion systems close to a magnetic–nonmagnetic boundary have attracted much recent interest, since their bulk properties show deviations from the predictions of Fermi liquid theory [1]. This so-called non-Fermi liquid behavior has since been found in several heavy fermion compounds. In studying these systems, an investigation of their spin dynamics using inelastic neutron scattering has proved to be very interesting and revealing. For example, the dynamical susceptibility of $\text{UCu}_{5-x}\text{Pd}_x$ and $\text{CeCu}_{6-x}\text{Au}_x$ shows a clear E/T scaling behavior [2]. Our recent studies on $\text{Ce}(\text{Rh},\text{Pd})\text{Sb}$, which are also located at a magnetic–nonmagnetic boundary, have shown similar results too [3].

CeRhSb is a low carrier density Kondo system with a small gap of 10 K. Upon Th doping, the small gap

feature disappears quickly and at the same time the Ce 4f electrons of $\text{Ce}_{1-x}\text{Th}_x\text{RhSb}$ become localized. For $x \geq 0.5$, an antiferromagnetically ordered state is eventually stabilized [4]. For $0.2 \leq x \leq 0.4$ at which there exists a cross-over from nonmagnetic to magnetic states, the specific heat data show strong deviations from the usual Fermi liquid behavior by showing $C \propto -T \ln T$.

We have studied the inelastic neutron scattering from $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ over the temperature range of 10–100 K, using the HET spectrometer at ISIS, UK. Measurements were made on an 18 g powdered sample, with incident neutron energies of 23 and 60 meV. We also measured LaRhSb , which has the same crystal structure as CeRhSb , as a phonon blank sample. All our data have been corrected for phonon contributions by following a conventional phonon subtraction procedure [5].

Fig. 1 shows the magnetic scattering, taken with an incident neutron energy of 23 meV at 10, 50, and 100 K, of $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ in a log–log plot. As can be clearly

*Corresponding author. Tel.: +82-2-880-8985; fax: +82-2-877-6796.

E-mail address: echol@escalab.snu.ac.kr (J.-Y. So).

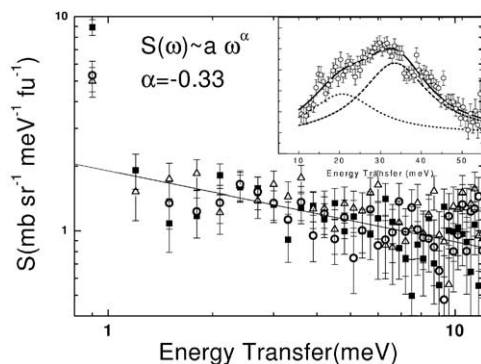


Fig. 1. Inelastic neutron scattering spectrum of $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ with $E_i = 23$ meV. The square, open circle and open triangle represents 10, 50 and 100 K data, respectively. The solid line is fit of the data to $S(\omega) = a\omega^\alpha$, where $\alpha = -0.33$. The insert shows higher energy excitations and the line underneath the data points is calculation results using trigonal symmetry for Ce^{3+} .

seen in the figure, all the spectra collapse on a single line in the energy range of 1–10 meV with scaling behavior of $S(\omega) \approx \omega^{-0.33}$. Below 1 meV, the spectra begin to deviate from the scaling behavior. As noted above, similar scaling behavior has previously been found in $\text{UCu}_{5-x}\text{Pd}_x$ and $\text{CeCu}_{6-x}\text{Au}_x$ with scaling exponent $\alpha = 1/3$ and 0.74, respectively [2]. What is a distinct feature of our data compared with the previous two studies, however, is the higher energy excitations. With further increasing energy, we observe broad magnetic excitations centered at around 30 meV, probably due to crystalline electric field (CEF) splittings (see the inset). The intrinsic width of these excitations probably reflects the strong hybridization between the Ce 4f electrons and the conduction electrons. This observation of CEF excitations clearly indicates that with increasing energy, $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ transforms from a non-Fermi liquid regime to a localized regime. This kind of cross-over has not been seen in $\text{UCu}_{5-x}\text{Pd}_x$ and $\text{CeCu}_{6-x}\text{Au}_x$, but we have found a similar cross-over in our recent studies of $\text{Ce}(\text{Rh},\text{Pd})\text{Sb}$ [3].

For a further comparison with the previous studies, we have plotted the dynamical susceptibility, $\chi''(\omega)T^\alpha$, of $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ with $\alpha = 0.33$ using the following relation:

$$S(\omega) = \frac{1}{1 - \exp(-\frac{\hbar\omega}{k_B T})} \chi''(\omega, T),$$

where $S(\omega, T)$ is the scattering function (see Fig. 2). Scaling behavior is again evident, i.e. $\chi''(\omega)T^\alpha = g(\omega/T)$. In order to fit the data, we have used two empirical functions that were successfully used for $\text{UCu}_{5-x}\text{Pd}_x$ and $\text{CeCu}_{6-x}\text{Au}_x$ [2]. Aronson et al. used $g(y) \propto y^{-\alpha} \tanh(y/b)$ to fit $\text{UCu}_{5-x}\text{Pd}_x$ for

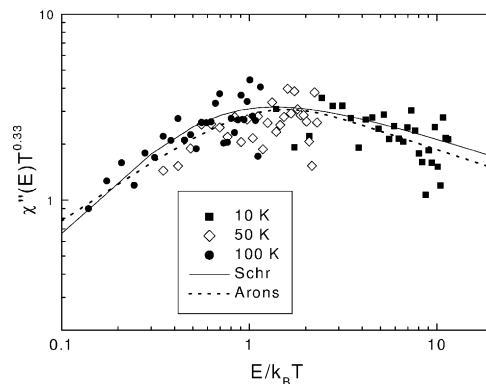


Fig. 2. Universal scaling behavior of $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$.

$x = 1.0$ and 1.5 while Schröder et al. have used $g(y) \propto \sin(\alpha \tan^{-1}(y))/(y^2 + 1)^{(\alpha/2)}$ to fit $\text{CeCu}_{5.9}\text{Au}_{0.1}$. In our analysis, we found that both functions fit our data reasonably well with $\alpha = 0.33$. Therefore, within our resolution we cannot distinguish between the two functions.

For the analysis of the broad excitations around 30 meV, we have used a crystal field Hamiltonian with a trigonal point symmetry for Ce^{3+} ions as in CeNiSn [6]. We have obtained the best fit with $B_2^0 = 0.393$ meV, $B_4^0 = -0.090$ meV, and $B_4^3 = 0.858$ meV. With this set of parameters, the ground state wave function is a strong mixture of $|\pm \frac{1}{2}\rangle$ and $|\mp \frac{5}{2}\rangle$ and the first excited state is at 20.50 meV with a mixture of $|\pm \frac{1}{2}\rangle$ and $|\mp \frac{5}{2}\rangle$. The second excited state is purely $|\pm \frac{3}{2}\rangle$ at 33.46 meV. The positive value for B_2^0 is consistent with the fact that CeRhSb has a magnetic easy ab plane [7]. Interestingly, our inelastic neutron scattering studies using single crystal CeNiSn , another low carrier density Kondo system with the same crystal structure as CeRhSb , found a broad excitation centered at around 40 meV [8].

To summarize, we have studied the inelastic neutron scattering from $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ which exhibits non-Fermi liquid behavior in the heat capacity, to find that the dynamical susceptibility shows E/T scaling behavior for $1 \leq \hbar\omega \leq 10$ meV. We also found that $\text{Ce}_{0.7}\text{Th}_{0.3}\text{RhSb}$ has crystal field excitations centered around 20–30 meV, consistent with trigonal symmetry for Ce^{3+} .

One of us (J.G.P.) has been supported by Korea Research Foundation (Grant: KRF-2000-015-DP0111) and the nuclear R&D program of the Ministry of Science and Technology.

References

- [1] For review, Proceedings of the Conference on non-Fermi liquid behavior, J. Phys.: Condens. Matter 8 (1996).

- [2] M.C. Aronson, et al., Phys. Rev. Lett. 75 (1995) 725;
A. Schröder, et al., Phys. Rev. Lett. 80 (1998) 5623.
- [3] J.-G. Park, et al., J. Phys.: Condensed Matter, submitted for
publication.
- [4] B. Andraka, Phys. Rev. B 49 (1994) 348.
- [5] A.P. Murani, Phys. Rev. B 28 (1983) 2308.
- [6] K.A. Kikoin, et al., Phys. Rev. B 59 (1999) 15070.
- [7] T. Yoshino, et al., J. Phys. Soc. Japan 67 (1998)
2610.
- [8] J.-G. Park, et al., Phys. Rev. B 58 (1998) 3167.