Gap formation in the semimetal U_2Ru_2Sn: evidence from ^{119}Sn NMR investigations

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Abstract

We report measurements of the ^{119}Sn nuclear spin - lattice relaxation rate $1/T_1$ and the Knight shift K for polycrystalline U_2Ru_2Sn powder samples as a function of temperature. The T dependence of $1/T_1$ is very similar to that of CeNiSn with the only difference that the temperature scale is increased roughly by a factor of 10. Therefore a first estimate gives a (pseudo-) gap value of $\Delta/k_B \approx 140$ K (≈ 14 K for CeNiSn). At low temperatures similar to CeNiSn a $T_1T = constant$ behaviour is observed which indicates the presence of a residual density of states at the Fermi level $N(E_F)$ in the pseudo - gap. Knight shift measurements on oriented polycrystalline powder samples show nearly no magnetic anisotropy, whereas the temperature dependence roughly follows the behaviour of the magnetic susceptibility. First investigations on the non-magnetic reference compound Th_2Ru_2Sn are also discussed.

Key words: Low-carrier-density system; Kondo insulator; NMR; gap formation

1. Introduction

U_2Ru_2Sn belongs to the 221 compounds U_2T_2X (T: d-electron transition metal Fe, Co, Ni, Ru, Rh, Pt and X:=In or Sn) which form an ordered version of the tetragonal U_3Si_2 lattice [1]. First investigations on U_2Ru_2Sn indicated itinerant paramagnetism [2], whereas more recent investigations of Menon et al.[3] and du Plessis et al. [4] assign U_2Ru_2Sn as a Kondo insulator due to its semiconducting behaviour in the resistivity accompanied by loss of the local moment at low temperatures. Triggered by this interesting results we started the preparation of polycrystalline samples according to Ref. [3]. Up to now all Kondo insulators have a cubic symmetry ($Ce_3Bi_4Pt_3$ for example) with the exception of the orthorhombic systems CeNiSn, CeRhSb and CeRhAs [5][6]. It would be straightforward to speculate that tetragonal systems also might exist in this class of materials. One of the key features of Kondo insulators is the formation of a narrow gap at the Fermi level at low temperatures, frequently related to the hybridization of 4f (or 5f) and conduction electrons [5]. The signature of the gap formation is usually found in transport (resistivity, thermopower) and specific - heat measurements. Strong experimental evidence comes often from magnetic resonance techniques (NMR and NQR) on various nuclei. To overcome problems in the gap determination due to the magnetic anisotropy and/or granularity in polycrystalline samples, this local probe is very suitable. We performed $^{117,119}Sn$ (I=1/2) NMR measurements on polycrystalline powder samples of U_2Ru_2Sn. NMR spectra were obtained by Fouier-transforming the digitized spin echoes using a conventional pulsed NMR spectrometer (Bruker, MSL 300, $\mu_0 H = 7.05$ T).

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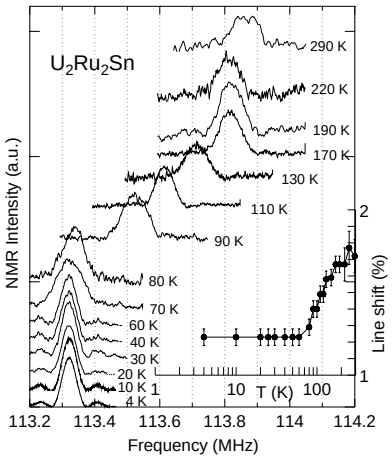

Fig. 1. ^{119}Sn NMR spectra at different temperatures. The shift is determined with the Lamor frequency of ^{119}Sn (111.91 MHz)

2. ^{119}Sn NMR spectra and Knight shift

Typical ^{119}Sn NMR spin echo spectra at different temperatures are shown in Fig. 1. At low temperatures the spectrum has a symmetrical Lorenzian line shape with a linewidth of approximately 122.5 kHz (FWHM, at 4 K) and a Knight shift of 1.23 % (4 K). For the non - magnetic reference compound Th_2Ru_2Sn we found at 4 K a linewidth of 41.8 kHz and a Knight shift of 0.18 %. At low temperatures the NMR line shows practically no shift, whereas between 80 K and approximately 150 K the line is shifted strongly to higher frequencies, and the linewidth is increased (see inset of Fig. 1). Susceptibility measurements on oriented polycrystalline powder and single crystals shows a magnetic anisotropy (χ_c(T) > χ_a(T)) [7]. The Knight shift $K(T)$ roughly tracks both components of the susceptibility. First NMR measurements on oriented powder samples show that in contrast to the susceptibility the effect of the magnetic anisotropy on the Knight shift is negligible ($K_a - K_c \leq 0.1$ % over the entire temperature range). From this we conclude that the hyperfine coupling constant A_{hf} should be larger in the a- than in c- direction.

3. Nuclear spin relaxation time T_1

The spin - lattice relaxation rate $1/T_1$ as a function of temperature obtained from the NMR signals is plotted in Fig. 2. Due to the different orientations in the polycrystalline sample the T_1 values presented here are averaged. Investigations on single crystals are currently under progress. $1/T_1$ for U_2Ru_2Sn is plotted together with the data for CeNiSn ($\mu_0 H = 1.26$ T) from Ref. [8]. Below approximately 150 K the rate

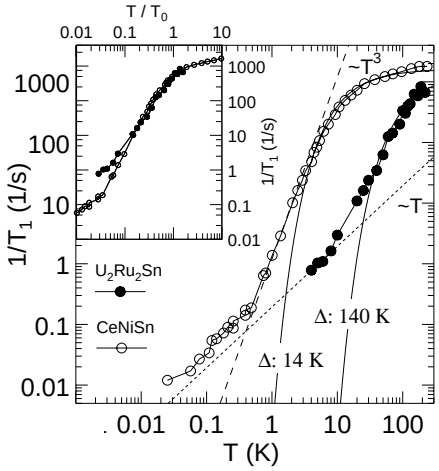

Fig. 2. T dependence of $1/T_1$ for U_2Ru_2Sn and CeNiSn (data from Ref. [8]). Solid lines represent an fit to the data (see text). Inset show the data on a normalized T scale.

for U_2Ru_2Sn decreases drastically over three orders of magnitude whereas at the very low temperatures a linear temperature dependence is observed. As a first approach we fit the rate with an exponential curve: $1/T_1 \propto exp(-\Delta/k_B T)$. This relation is well known for spin Peierls systems or conventional superconductors. If one fits an exponential to the published data for CeNiSn [8], one obtains a gap value of $\Delta/k_B = 14$ K. The striking deviation from the exponential curve observed below $T \approx 4$ K has been ascribed to a "V-shaped gap" in combination with a residual density of states within the gap [8]. For U_2Ru_2Sn our results reveal a gap value of $\Delta/k_B = 140$ K, about ten times larger than for CeNiSn. The plot versus normalized temperature T/T_0 ($k_B T_0 = \Delta$) indicates the same overall behaviour for both systems (cf. inset of Fig. 2).

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