First results on U_2Ru_2Sn single crystals

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Abstract

The tetragonal compound U_2Ru_2Sn shares several properties with the strongly correlated semimetal CeNiSn. Here we present, for the first time, measurements of magnetic, thermal, and electrical transport properties of single-crystalline samples and compare them to results on polycrystals. The specific heat and the magnetic susceptibility provide evidence for the opening of an energy gap of approximately 150 to 160 K. Both the magnetic susceptibility and the electrical resistivity are anisotropic. The c axis is the easy magnetic axis along which the resistivity is 'metal-like'. The resistivity along the a axis is 'semiconductor-like'.

Key words: Kondo insulator; U_2Ru_2Sn; single crystal;

Heavy-fermion semiconductors or semimetals, usually referred to as 'Kondo insulators' [1], are an intriguing set of materials: The origin of the formation of a narrow gap or pseudogap at the Fermi energy is still unclear. Based on the observation that the electrical resistivity increases upon cooling below 30 K, U_2Ru_2Sn (tetragonal P4/mbm structure) has tentatively been classified as a 'Kondo insulator' [2]. More recently, it was shown [3] that U_2Ru_2Sn behaves similar to CeNiSn [4], yet with a 10 times larger energy gap. Here we present, for the first time, results on single crystalline U_2Ru_2Sn and compare them to previous results on polycrystals [5].

The single crystals investigated here were prepared by the Czochralski technique using a 3-arc furnace. a- and c-axis oriented samples were prepared by polishing Laue-oriented pieces.

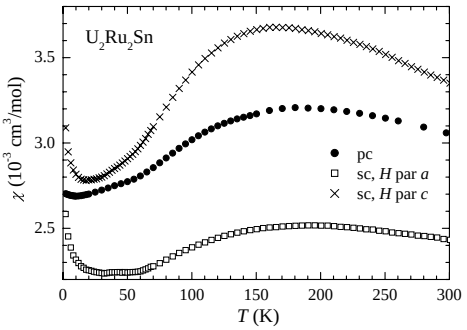

Fig. 1. Temperature dependence of the magnetic susceptibility, $\chi(T)$, of a single crystal (sc) with the magnetic field H along either the a or the c axis and of a polycrystal (pc) of U_2Ru_2Sn, in fields of 1 T (sc) and 5 T (pc).

The magnetic susceptibility $\chi(T)$ measured on a single crystalline sample both along the a and the c axis shows a pronounced anisotropy (Fig. 1). It is approximately 1.5 times larger along the c axis than along the a axis. Thus, the former may be identified as the easy magnetic axis. The data of the polycrystal fall in between the two single-crystal curves, as expected.

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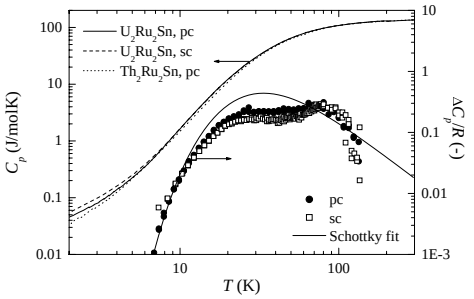

Fig. 2. Left scale: Temperature dependence of the specific heat, $C_p(T)$, of a single crystal (sc) and a polycrystal (pc) of U_2Ru_2Sn, and of a polycrystal of Th_2Ru_2Sn. Right scale: Difference of the U_2Ru_2Sn and Th_2Ru_2Sn data, ΔC_p, in units of the gas constant R, vs temperature T. The solid line shows the best Schottky fit to both (sc and pc) data sets.

The pronounced decrease of $\chi(T)$ below approximately 160 K is typical for Kondo insulators and reflects the opening of the energy gap. The temperatures of the steepest increase of $\chi(T)$ range between 74 and 80 K for the three curves in Fig. 1.

Figure 2 shows the specific heat $C_p(T)$ of a single crystal and a polycrystal of U_2Ru_2Sn, and of a polycrystal of the non-f reference compound Th_2Ru_2Sn. Displayed on the right axis is the difference between the U_2Ru_2Sn and the Th_2Ru_2Sn data. In the temperature range above approximately 8 K, where the sample-dependent and possibly extrinsic electronic contribution to $C_p(T)$ is unimportant, this difference may be regarded as magnetic contribution. It is very similar for the single crystal and the polycrystal and may reasonably well be described with a Schottky-like anomaly, $\Delta C_p/R = (T/T_0)^2 \times exp(T/T_0)/(1+exp(T/T_0))^2$ with the interlevel separation $T_0 = 80$ K, in good agreement with the 74 to 80 K deduced above from $\chi(T)$. In the band picture of two sharp density-of-states peaks around the energy gap, which is frequently employed to model Kondo insulators [6], $k_B T_0$ is the activation energy. Thus, the band gap of U_2Ru_2Sn is $2k_BT_0$ corresponding to 150 to 160 K. This is in good agreement with the 140 K extracted from ^{119}Sn NMR data [3,7].

The electrical resistivity of U_2Ru_2Sn is highly anisotropic (Fig. 3). For the current I along the a axis, ρ increases monotonically with decreasing T. For I parallel c, on the other hand, ρ passes over a maximum at approximately 140 K below which it decreases to the lowest temperatures. The polycrystal shows a mixture of both characteristics.

The temperature dependence of the Hall coefficient $R_H(T)$ of the single crystal measured with I along the a axis and the magnetic field H along the c axis shows a similar temperature dependence as the polycrystal (Fig. 4). This indicates that, unlike $\rho(T)$, $R_H(T)$ is rather isotropic. Therefore, the Hall mobility $\mu_H = R_H/\rho$ of U_2Ru_2Sn must be strongly anisotropic. Further experiments on samples of different qualities are on the way to determine whether the low-temperature transport is intrinsic or impurity dominated.

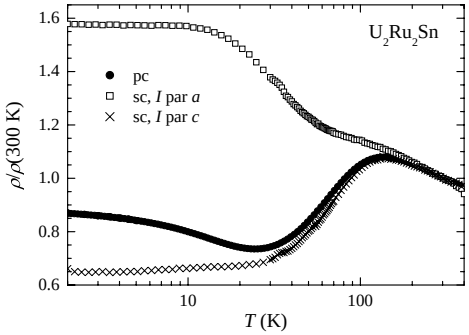

Fig. 3. Temperature dependence of the electrical resistivity normalized to room temperature, $\rho/\rho(300\,\mathrm{K})(T)$, of single crystals (sc) with I along either the a or the c axis and of a polycrystal (pc) of U_2Ru_2Sn.

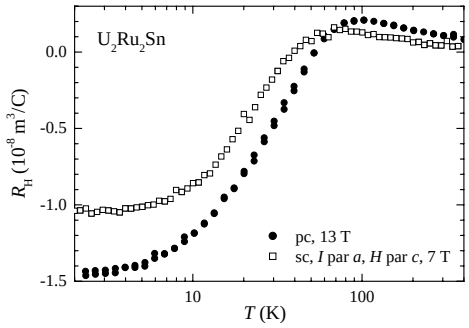

Fig. 4. Temperature dependence of the Hall coefficient, $R_H(T)$, of a single crystal (sc) with I along the a and H along the c axis, and of a polycrystal (pc) of U_2Ru_2Sn.

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