MAGNETIZATION STUDY OF A URhSi SINGLE CRYSTAL*

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The ferromagnetic compound URhSi is a close analogue of the well-known "ferromagnetic superconductor" URhGe. We have measured, for fist time on a single crystal, the magnetization and susceptibility as functions of magnetic field and temperature. Arrott-plot analysis points to the Curie temperature $T_{\rm C}$ = 10.5 K. At temperatures below $T_{\rm C}$ we observe a strong magnetic anisotropy with the dominant spontaneous magnetic moment (0.47 $\mu_{\rm B}$) along the c-axis, similar to URhGe. Along the a- and b-axis, much smaller, nevertheless non-negligible, magnetic moments are indicated. A strong anisotropy is observed also in paramagnetic range.

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The ferromagnetic compound URhSi [1] is a close analogue of URhGe, which has recently attracted strong interest because of coexistence of ferromagnetism and superconductivity at low temperatures [2]. Both compounds crystallize in the orthorhombic structure of the TiNiSi type. Whereas URhGe was studied also in the single-crystal form [3], for URhSi up to now only polycrystalline data were available (for review, see [4]). Experimentally determined bulk properties of this compound point to a ferromagnetic order below $T_{\rm C}$ = 9.5 K. A spontaneous magnetic moment $M_{\rm s} \approx 0.3\ \mu_{\rm B}$/f.u. was derived from magnetization data measured on an oriented-powder sample at 4.2 K [5]. The obtained low-temperature neutron powder-diffraction results were interpreted in terms of a collinear ferromagnetic structure with U moments oriented along the c-axis [6, 7]. We have grown a single crystal of URhSi and present first magnetization data obtained on this crystal.

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The single crystal of URhSi was grown from a stoichiometric melt in a tetra-arc furnace by a modified Czochralski method under Ar atmosphere. At least 99.9 % pure materials were used. No subsequent heat treatment was given to the crystal. The crystal quality was checked by the Laue X-ray technique and by the electron microprobe analysis. The magnetization and the magnetic susceptibility along the principal axes were measured in the PPMS-9 magnetometer (Quantum Design) in fields up to 9 T in the temperature range 2–300 K.

The top and bottom parts of the crystal checked by electron-probe microanalysis were found to be single phase and homogeneous. The composition of the crystal was determined as U 35.5 at.% , Rh 34.4 at.% and Si 30.1 at.% that corresponds to the notation $U_{1.06}Rh_{1.03}Si_{0.91}$ with 3 atoms per formula unit.

Magnetization curves measured in a field applied along the principal axes of the crystal at various temperatures are shown in Fig. 1. The highest

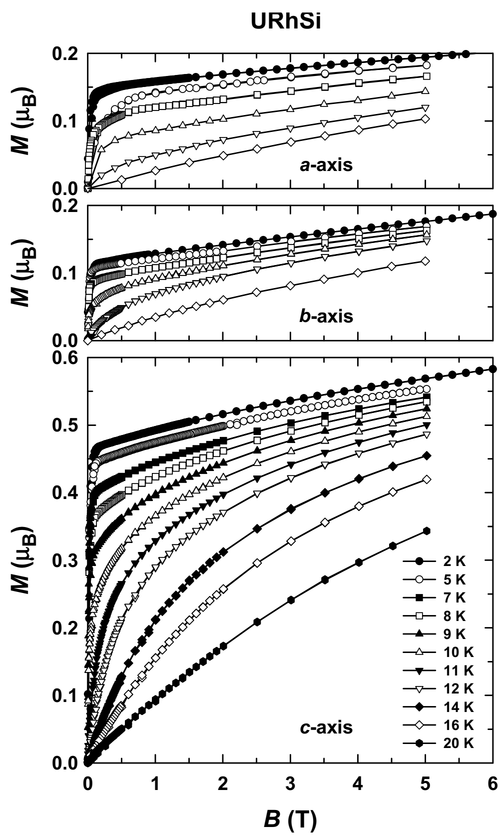

Fig. 1. Magnetization isotherms of a URhSi single crystal along the principal axes at different temperatures.

spontaneous magnetic moment (M_s = 0.47 μ_B at 2 K) is observed for the c-axis. Much smaller but non-negligible values of M_s are indicated along the a and b-axis (0.14 and 0.12 μ_B, respectively). These results may be considered in first approximation in terms of the uniaxial magnetic anisotropy with the easy c-axis, which contradicts previous conclusions about the easy-plane anisotropy based on high-field magnetization data of de Boer *et al.* [5] done on field-oriented and random fixed-powder samples, respectively. On the other hand, the easy c-axis agrees with results of neutron diffraction studies on powder [6, 7] and on single crystal (this work).

As in many other uranium intermetallics, the magnetic anisotropy energy of URhSi is very high but its quantitative estimate is difficult because the easy-axis magnetization curve shows no tendency to saturation up to the highest applied field. Moreover, the c-axis high-field susceptibility in 9 T (8.2×10^{-8} m^3/mol) exceeds considerably that along a and b axes (4.9×10^{-8} and 7.1×10^{-8} m^3/mol, respectively). The large easy-axis high-field susceptibility probably reflects the itinerant character of $5f$ magnetic moment. T_C is determined from Arrott plots as 10.5 K. The difference to previously reported T_C = 9.5 K may be tentatively attributed to the Si deficiency in the crystal.

The temperature dependence of the inverse magnetic susceptibility below 180 K (Fig. 2) strongly deviates from the Curie–Weiss (C–W) behavior at higher temperatures. The C–W fit at 200–300 K gives reasonable value 3.0–3.1 μ_B of effective magnetic moment $\mu_{\rm eff}$. It is considerably smaller than the expectation value for the $5f^2$ or $5f^3$ localized configuration (3.6 μ_B). On the other hand it is a typical value for the UTX family of uranium intermetallics (T is a late transition metal, X is a p-metal) [4]. The observed difference between the paramagnetic Curie temperature $\Delta\Theta_p$ along the principal axis is a sort of measure of the magnetic anisotropy energy, which in case of URhSi amounts 185 K. This value can be considered as moderate in comparison with the hexagonal UTX compounds. For example, in UPtAl $\Delta\Theta_p$ = 420 K [8].

The results of a first single-crystalline study of URhSi with a slight Si deficiency are presented. This material is a ferromagnet with T_C = 10.5 K and exhibits a strong magnetic anisotropy of an unusual type, which can be considered in a first approximation as uniaxial. The highest spontaneous magnetic moment (0.47 μ_B) is observed for the c-axis, but it has nonzero components also along the a and b-axis. A strong anisotropy is observed also in paramagnetic range. At temperatures above 180 K, the magnetic susceptibility obeys the Curie–Weiss law with $\mu_{\rm eff}$ = 3.0–3.1 μ_B and Θ_p = –305 K (a-axis), –200 K (b-axis) and –120 K (c-axis). The structure and magnetic properties of URhSi are very close to those of the well-known "ferromagnetic superconductor" URhGe.

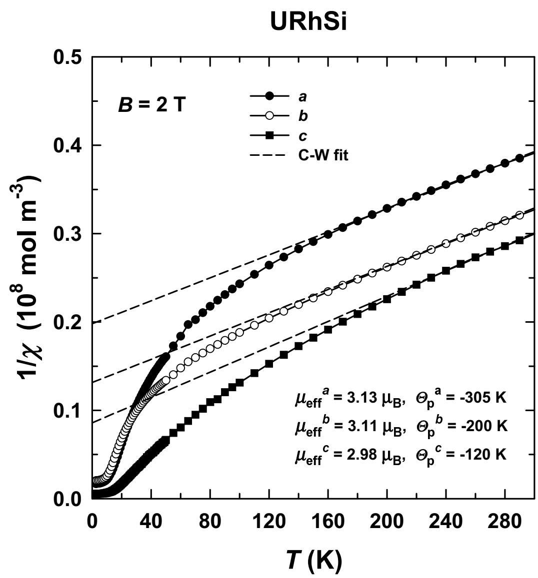

Fig. 2. Temperature dependence of inverse magnetic susceptibility $1/\chi$ along the principal axes in a 2 T field. The dashed lines represent the Curie–Weiss law.

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