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Journal of Magnetism and Magnetic Materials 157/158 (1996) 409–410

journal of magnetism and magnetic materials

High-field magnetization and specific heat of $TmNi_5$

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Abstract

High-field magnetization on two single-crystalline samples from different batches of $TmNi_5$ has been measured along the crystallographic *a*, *b* and *c* directions up to 38 T at 1.5 K. A small high-field susceptibility $\chi_{HF} = 6.3 \times 10^{-3}$ μ_B/T f.u. was observed along the easy *c*-axis. The magnetization measured along both *a*- and *b*-axis shows hysteresis and a magnetic transition between 5 and 15 T. Specific heat has been measured from 1.5 to 160 K. A λ-type peak found at about 3.7 K originates from the magnetic system.

Keywords: High-field magnetism; Specific heat; Crystal fields; Rare earth–transition metal compound

$TmNi_5$ crystallizes in a hexagonal crystallographic structure and orders ferrimagnetically below 4.5 K [1,2]. The magnetic system consists of two sublattices: a R (thulium) and a T (nickel) subsystem. Within each of these sublattices the R-moments or the small induced T-moments point in the same direction. R- and T-sublattices are coupled by Heisenberg exchange interactions of the anti-ferromagnetic type.

In this paper measurements are presented on three single-crystalline samples of $TmNi_5$. Two of them (samples 1 and 2) were spark-cut from the same batch newly grown at the Material Centre ALMOS of the University of Amsterdam. The third one (sample 3) has been obtained from a batch grown in Grenoble. We present our results of measurements of the high-field magnetization (sample 1) and the specific heat (sample 2) of $TmNi_5$. The high-field magnetization was also measured on sample 3.

The high-field magnetization experiments on sample 1 have been performed at 1.5 K. Sample 1 has a spherical shape (3 mm diameter) with a mass of about 126 mg. In Fig. 1 the magnetization along the main crystallographic directions is shown. The magnetization along the easy *c*-axis has been measured up to 21 T. The saturation magnetization amounts to 6.7 μ_B/f.u. and the magnetization along the easy *c*-axis increases linearly with a high-field susceptibility χ_{HF} of 6.3×10^{-3} μ_B/T f.u. The magnetization in the basal plane along the *a*-axis and *b*-axis has been measured up to 38 T. From Fig. 2 which shows a blow-up of a part of Fig. 1, we see that along both *a*- and *b*-axis the magnetization shows hysteresis which is in contrast to other measurements [1–3]. On increasing field applied along the *a*-axis, a small, possibly metamagnetic, transition appears at 16 T; thereafter it increases

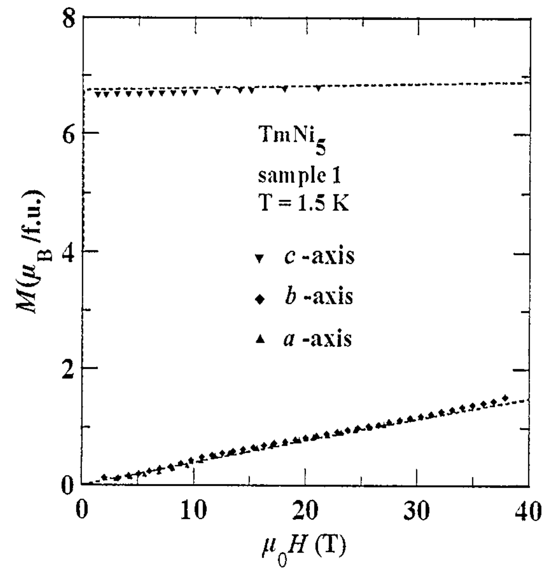

Fig. 1. Magnetization of $TmNi_5$ along *a*-, *b*- and *c*-axis at 1.4 K. The dashed lines show the calculated magnetization.

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linearly, with $\chi = 39 \times 10^{-3}$ μ_B/T f.u. In decreasing field, above 12 T the magnetization decreases with the same slope as with increasing field, between 12 T and 7 T the magnetization decreases more strongly, and below 7 T it coincides with the magnetization curve of the increasing field. The magnetization along the b-axis shows a similar behaviour. In order to be sure that the hysteresis and transition which were not found before are intrinsic properties, indeed, we also performed magnetization measurements on sample 3, a cube ($2 \times 2 \times 2$ mm^3) with a mass of 51 mg. Fields were applied along the c-axis up to 27 T and along the a-axis up to 38 T. In sample 3 the magnetization was somewhat lower than in sample 1. Hysteresis and the magnetic transition were seen, however, also in sample 3. Along the c-axis the saturation magnetization is 6.62 μ_B/f.u. and $\chi_{HF} = 5.3 \times 10^{-3}$ μ_B/T f.u.

Preliminary attempts have been made to reproduce the magnetization by calculations. We used the same model as described in Refs. [1,2]. We took crystal electric field (CEF) and other parameters reported earlier [1–3] ($B_2^0 = -3.80$ K, $B_4^0 = -12.6$ mK, $B_6^0 = 183$ μK, $B_6^6 = -760$ μK, $n_{RR} = -0.196$ T f.u./μ_B, $n_{RT} = -9.4$ T f.u./μ_B and $\chi_{Ni} = 3.6 \times 10^{-3}$ μ_B/T f.u.). Using these parameters in a calculation of the magnetization resulted in plots (Fig. 1 and 2, dashed lines) which follow the measurement adequately, but fail to describe the hysteresis and magnetic transition.

The specific-heat measurements on sample 2 (137 mg) have been performed in the temperature range from 1.5 to 160 K. The magnetic contribution to the specific heat of $TmNi_5$ is shown in Fig. 3, where is plotted the difference of the measured (molar) specific heat of $TmNi_5$ and $LaNi_5$. The experimental points correspond to measurements reported earlier [1,3]. The λ-type peak of $TmNi_5$ with its maximum at about 3.7 K is associated with the Curie temperature. A large magnetic contribution to the specific heat is observed above the Curie temperature which is believed to correspond to a Schottky anomaly. Fig. 3 also shows the calculated magnetic specific-heat based on the same model and parameters as described before. We see that the calculated results, which fitted well the specific heat data of Refs. [1] and [3], differ from our measured specific heat only at higher temperatures where the nonmagnetic contribution to the specific heat is uncertain.

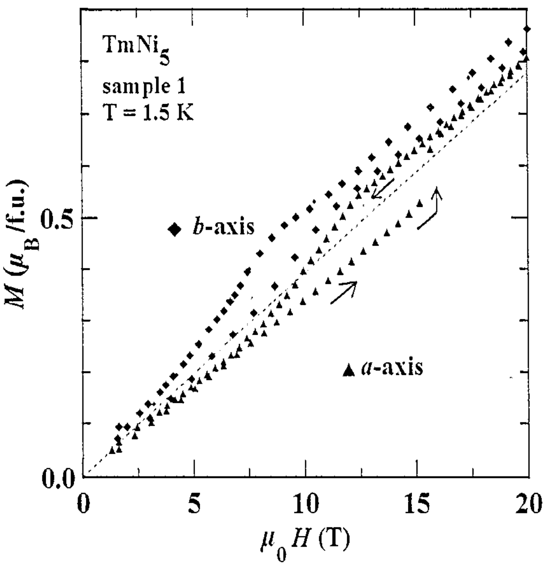

Fig. 2. Blow-up of Fig. 1. Magnetization curves of $TmNi_5$ along a-axis and b-axis at $T = 1.5$ K. The solid symbols give data in linearly increasing and decreasing field (increasing and decreasing field indicated by arrows). The dashed line shows the calculated magnetization.

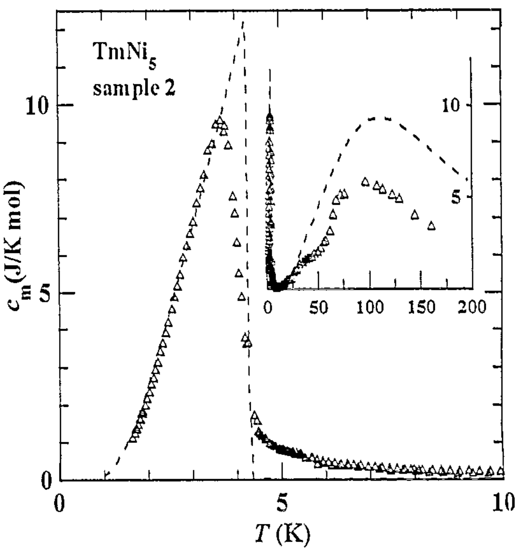

Fig. 3. Magnetic specific heat of $TmNi_5$ versus temperature. As it has been experimentally determined as the difference of the molar specific heats of $TmNi_5$ and $LaNi_5$ (Δ), and as it has been calculated (dashed line, see text for the model used).

Acknowledgement: This work has been partly supported by the European Commission within its BRITE/EURAM R&D Programme, BREU-0068 BIREM.

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