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Thermal Expansion and Magnetostriction of the Ising Antiferromagnet TbNi_2Ge_2

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Abstract. We have measured the linear thermal expansion and magnetostriction of the Ising antiferromagnet TbNi_2Ge_2 along its c -axis from room temperature to 2 K and in magnetic fields to 14 T. We find a magnetic phase diagram that agrees with earlier work and estimate aspects of its uniaxial pressure dependence. We also find a new high field feature near 10 T which may signal the onset of an additional field-induced phase.

Keywords: Thermal Expansion, Magnetostriction, Antiferromagnetism.
65.40.De, 75.50.Ee, 75.80.+

INTRODUCTION

The ternary rare-earth intermetallic compound TbNi_2Ge_2 crystallizes in a body-centered tetragonal ThCr_2Si_2 structure and exhibits Ising-like antiferromagnetism with phase transitions into incommensurate and commensurate states at $T_N = 16.7$ K and $T_t = 9.6$ K respectively; six additional metamagnetic phases have been observed in applied fields at 2 K. The magnetic properties of TbNi_2Ge_2 are driven by indirect exchange interactions (presumably of the RKKY variety) between the magnetic rare-earth ions via the conduction electrons. TbNi_2Ge_2 has been studied by Bud'ko *et al.* as part of a more general inquiry into the magnetic behavior of rare-earth- Ni_2Ge_2 compounds [1]; references to earlier work may also be found in Ref. [1].

We have measured the linear thermal expansion and magnetostriction along the c -axis of TbNi_2Ge_2 (the axis along which the spins align) using a capacitive dilatometer constructed of OFHC copper and designed to operate in a Physical Property Measurement System available from Quantum Design Inc. A detailed description of the dilatometer will appear elsewhere [2].

RESULTS AND DISCUSSION

The linear thermal expansion of TbNi_2Ge_2 along its c -axis ($\alpha = d\ln(L)/dT$ where L is the length of the

sample, 0.85 mm here) is shown in Fig. 1. Features associated with the phase transitions at T_N and T_t are clearly visible. The broad maximum near 30 K is due to crystal field effects.

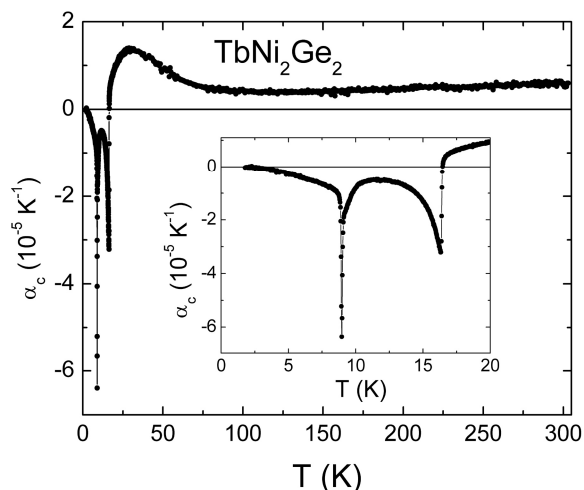


FIGURE 1. Linear thermal expansion of TbNi_2Ge_2 along its c -axis. The inset shows an expanded view of the low temperature phase transitions.

We first focus on the feature at T_N , the shape of which suggests that it is due to a 2nd order phase transition. Combining the jump in thermal expansion ($\Delta\alpha = 2.9 \times 10^{-5} \text{ K}^{-1}$) with the jump in molar specific heat from Ref. [1] ($\Delta C_p = -15 \text{ J/mol K}$), we can use the Ehrenfest relation

$$\frac{dT_N}{dP_c} = V_M T_N \frac{\Delta\alpha_c}{\Delta C_p}, \quad (1)$$

where P_c is the uniaxial pressure along the c-axis and V_M is the molar volume, to estimate the uniaxial pressure dependence of T_N to be -0.16 K/kbar.

The sharp feature at T_t suggests that this phase transition is 1st order, a suggestion that is supported by the presence of magnetic hysteresis across this phase boundary in higher magnetic fields [1]. However, the feature observed in C_p at this temperature is relatively broad and therefore at odds with this suggestion. Should this be a 1st order transition, a Clausius-Clapyeron equation would apply:

$$\frac{dT_t}{dP_c} \approx V_M \frac{\Delta(\Delta L/L)}{\Delta S}, \quad (2)$$

where $\Delta(\Delta L/L)$ is the jump in the expansivity $\Delta L/L = L(T)-L(0)/L(0)$ at the phase transition ($\Delta L/L$ is determined by integrating $\alpha(T)/T$ across the transition), and ΔS is the jump in molar entropy at the phase transition (determined by integrating $C_p(T)/T$ across the transition). Integrating our data shows that $\Delta(\Delta L/L)$ is clearly finite at T_t , but integrating the specific heat data suggests that ΔS is very close to zero. If this transition is 1st order, Eqn. (1) suggests that the uniaxial pressure dependence of T_t might be very large.

The magnetostriction of TbNi_2Ge_2 at 2 K, measured along its c-axis with magnetic fields applied parallel to the c-axis, is shown in Fig. 2 where $\Delta L/L = L(H)-L(0)/L(0)$. Magnetic hysteresis is observed in low fields along with a series of metamagnetic phase transitions consistent with the measurements of Bud'ko *et al.* [1] up to about 6 T.

We observe an abrupt change in the slope of $\Delta L/L$ near 10 T at 2 K (marked by an arrow in Fig. 2, the derivative of the data with respect to magnetic field in the vicinity of 10 T is shown in the inset of Fig. 2). We suspect that this feature may signal a new field-induced phase transition although there is no corresponding signal of such a transition in high field magnetization measurements [1]. The feature was quite reproducible in our measurements and increased in field as the temperature increased (reaching 12.8 T at 30 K; the feature was not observed at 50 K up to our maximum field of 14 T). This temperature dependence suggests that the feature may be due to a spin-flop-like transition, though one would expect to see an associated metamagnetic-like feature in the field

dependent magnetization, a feature that is not observed [1]. Understanding the origin and nature of this feature will require further study.

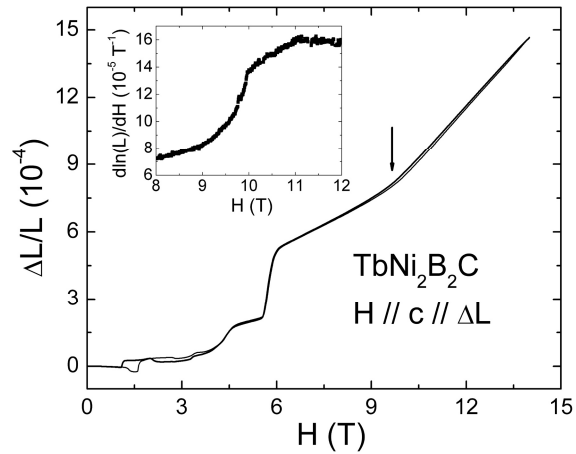


FIGURE 2. Magnetostriction of TbNi_2Ge_2 at 2 K, measured along its c-axis in magnetic fields applied parallel to the c-axis. The arrow denotes the position of a new feature. The inset shows a derivative of the data with respect to magnetic field in the vicinity of the feature.

CONCLUSIONS

We have measured the thermal expansion and magnetostriction of TbNi_2Ge_2 along its c-axis from room temperature to 2 K and in magnetic fields to 14 T. Our results on the magnetic phase diagram agree with earlier results except for the observation of what may be a new field-induced phase above 10 T at low temperature. Application of thermodynamic relations to our results allowed us to estimate the affect of uniaxial pressure on the magnetic phase transitions in zero field.

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