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The nature of magnetic ordering in $TbNi_2B_2C$

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Abstract

The nature of the magnetic ordering in $TbNi_2B_2C$ has been investigated using neutron diffraction techniques on powdered polycrystalline samples. The results show that the Tb moments order below 15.5 K into an incommensurate magnetic structure. The magnetic order consists of a longitudinal modulation of the Tb moments with a wave vector of (0.556 0 0) at 1.5 K along the $\boldsymbol{a}^*$-direction. On increasing the temperature from 1.5 K, the modulation wave vector decreases, goes through a minimum at ≈ 5 K, and then increases up to T_N. The experimental data also indicate the development of a small ferromagnetic component in $TbNi_2B_2C$ along with the antiferromagnetic ordering at 15.5 K.

Keywords: Magnetic order; $TbNi_2B_2C$

1. Introduction

The nature of magnetic ordering in RNi_2B_2C compounds, with R = magnetic rare-earth ion (Tb–Tm), have been studied very extensively [1–8] due to their interesting magnetic properties at low temperatures. In addition, the compounds with R = Tm, Er, Ho and Dy show magnetic ordering of the rare-earth moments which coexists with superconductivity. Neutron diffraction measurements have confirmed the nature of the magnetic ordering in the Er [6,7], Ho [3–5], Dy [9] and Tm [10] compounds. $DyNi_2B_2C$ below T_N and $HoNi_2B_2C$ below 5 K show a simple commensurate antiferromagnetic (AFM) ordering. In $HoNi_2B_2C$, two incommensurate modulations of the magnetic order occur, one with a wave vector along $\boldsymbol{c}^*$ between 5–8 K and another along $\boldsymbol{a}^*$ between 5–6.5 K. The magnetic ordering in the Er compound is incommensurate with a modulation along $\boldsymbol{a}^*$ whereas the magnitude of the magnetic moment is modulated sinusoidally along the (1 1 0) direction in the case of $TmNi_2B_2C$.

$TbNi_2B_2C$ is not superconducting above 300 mK, but shows interesting magnetic properties [11]. The compound shows two magnetic transitions; one at 15.5 K (T_N) and another at 5 K. Neutron diffraction measurements on single crystals of $TbNi_2B_2C$ [12] confirm the ordering of Tb moments below 15 K and suggest the development of a small ferromagnetic component below 8 K as the reason for the magnetic transition at 5 K. However, the anomaly at 15 K seen in the data [12] is not explained. In this paper, we report the magnetic structure of $TbNi_2B_2C$ obtained from neutron diffraction experiments on powder samples. The compound shows magnetic ordering of the Tb moments below 15.5 K with an incommensurate magnetic structure and a quasi-sinusoidal longitudinal modulation of the moments along $\boldsymbol{a}^*$, which agrees well with the results in Ref. [12]. However, we find that the temperature variation of the magnitude of the wave vector goes through a minimum at ≈ 5 K, where the second magnetic transition takes place. We also observe the development of a ferromagnetic component below 15.5 K (T_N). These results are further confirmed by a recent single crystal experiment [13]. We find no evidence of an

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additional ferromagnetic component developing below 8 K in our experiments.

2. Experimental details

The samples were prepared by standard arc-melting method and subsequent annealing. The isotope ^{11}B was used to prepare these samples to avoid the large absorption of neutrons by the naturally occurring ^{10}B. Neutron diffraction experiments were carried out using the D1B multi-detector at the Institut Laue Langevin in Grenoble, using an incident wavelength of 2.524 Å in the temperature range of 1.5–24 K.

3. Results and discussion

At temperatures above 15.5 K, only nuclear reflections were observed, as shown in Fig. 1(a). The lattice parameters, estimated after indexing all the nuclear peaks using the condition, $h + k + l =$ even, are $a/b = 3.566 \pm 0.11$ Å and $c = 10.505 \pm 0.026$ Å at 24 K. Any contribution from the impurity phases was estimated to be less than 5%. As the temperature is lowered below 15.5 K, additional diffraction peaks appear. These magnetic peaks, as shown in Fig. 1(b), can be indexed by considering a modulation of the magnetic moments along $\boldsymbol{a}^*$ with a wave vector value of 0.556 at 1.5 K. The peak at $2\theta = 33.8$ (*) could not be indexed, and may result from a magnetically ordered impurity phase. The observation of third- and fifth-order satellites implies that the longitudinal modulation is not a simple sinusoid. Since the intensities of the fifth-order satellites fall off very sharply as 2θ increases, these peaks were not included in the model to calculate the magnetic intensities. The magnetic moment of Tb^{3+} is estimated from the first-order satellites to be 9.5 ± 0.1 μ_B at 1.5 K. The

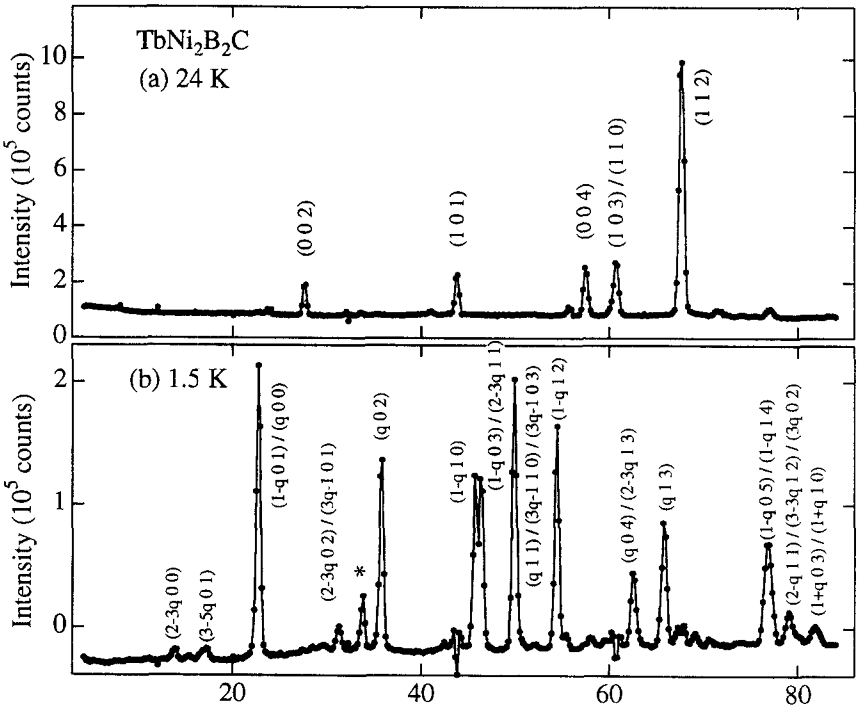

Fig. 1. Diffraction pattern for $TbNi_2B_2C$ for (a) nuclear peaks at 24 K and (b) magnetic peaks at 1.5 K.

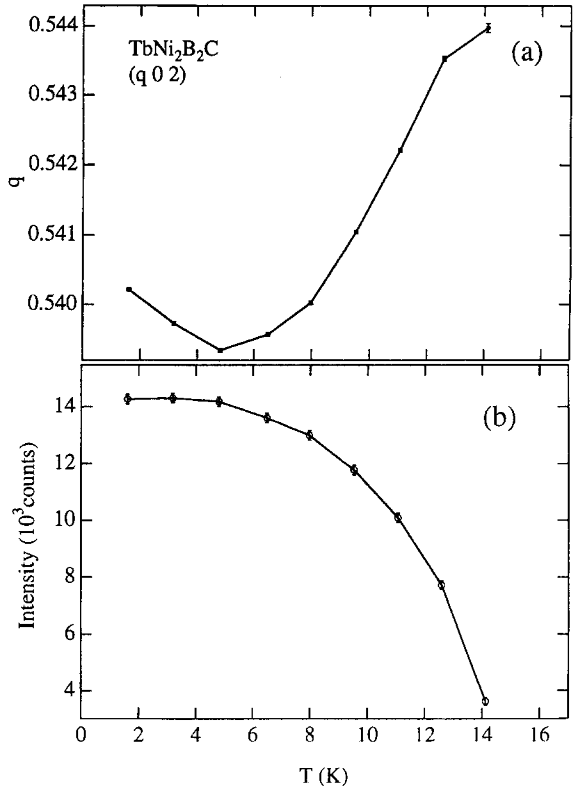

Fig. 2. Temperature variation of the magnitude of the wave vector q and the integrated intensity for the (q0 2) magnetic peak.

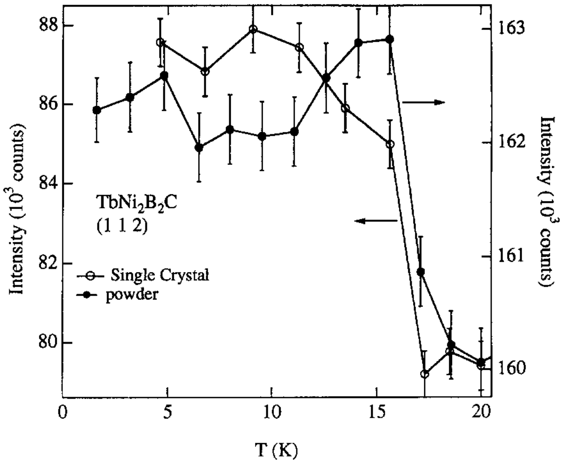

Fig. 3. Temperature variation of the (1 1 2) nuclear peak for $TbNi_2B_2C$ powder and a single crystal.

moment value calculated from the third-order satellites is 2.1 ± 0.1 μ_B, which is smaller than one-third of the magnetic moment from the first-order satellites. This implies that the longitudinal spin wave is not completely squared. The moment direction is close to the a-axis, at an angle of $\pm 3°$.

Fig. 2 shows the temperature variation of the integrated intensity and q values for the (q 0 2) peak. As the temperature increases from 1.5 K, q decreases initially, goes through a minimum and then increases up to T_N. Even though the origin of such a variation of the q values is not clear, the minimum in the wave vector value coincides well with the temperature range where the second magnetic transition takes place. In Fig. 3, the intensity variation of the (1 1 2) nuclear peak is shown as a function of the temperature. There is a clear increase in the intensity of this nuclear peak below 15.5 K, indicating the development of a ferromagnetic component along with the AFM ordering of the Tb moments. We have observed an additional peak in our specific heat data [11], along with the peak corresponding to the magnetic ordering at 15.5 K in $TbNi_2B_2C$ single crystal. It is likely that this peak arises from the ferromagnetic component developing at 15.5 K, as seen in the neutron diffraction results. A similar increase in the intensity of the (1 1 2) nuclear peak is observed in our recent neutron diffraction measurement on a single crystal of $TbNi_2B_2C$ [13] and is shown in Fig. 3. Now evidence for an additional ferromagnetic component below 8 K, as observed in Ref. [12], is seen in our experimental data.

The nature of magnetic ordering in $TbNi_2B_2C$ is different compared to that observed in other members of this family. Even though the magnetic structure resembles that of $ErNi_2B_2C$, the variation of the magnitude of the incommensurate wave vector with temperature and the appearance of the ferromagnetic component along with the AFM ordering are unique to this compound. A detailed analysis of the single-crystal data is currently being carried out and will be published elsewhere [13].

References

[1] H. Eisaki et al., Phys. Rev. B 50 (1994) 647.
[2] P.C. Canfield et al., Physica C 230 (1994) 397.
[3] C.V. Tomy et al., Physica B 213 & 214 (1995) 139.
[4] T.E. Grigereit et al., Phys. Rev. Lett. 73 (1994) 2756.
[5] A.I. Goldman et al., Phys. Rev. B 50 (1994) 9668.
[6] S.K. Sinha et al., Phys. Rev. B 51 (1995) 681.
[7] J. Zarestky et al., Phys. Rev. B 51 (1995) 678.
[8] C.V. Tomy et al., Phys. Rev. B 52 (1995) 9186.
[9] P. Dervenagas et al., Physica B 212 (1995) 1.
[10] L.J. Chang et al., Phys. Rev. B 13 (1996) 9031.
[11] C.V. Tomy et al., Phys. Rev. B 53 (1996) 307.
[12] P. Dervenagas et al., Phys. Rev. B 53 (1996) 1.
[13] C.V. Tomy et al., unpublished.