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Magnetic properties of single crystal $TbNi_2B_2C$

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Abstract

Magnetic and transport properties of single crystals of $TbNi_2B_2C$ have been investigated by AC susceptibility, DC magnetisation and resistance measurements. The AC susceptibility and low field DC susceptibility data contain peaks corresponding to two magnetic transitions, one due to the magnetic ordering of Tb moments at 15 K and another at lower temperature ($T = 5.1$ K) due to a spin reorientation. As the applied magnetic field is increased, the low temperature transition is suppressed. The electrical resistance measurements show a sharp decrease in the resistance at 15 K but contain no observable features corresponding to the lower transition. Our resistance measurements show that $TbNi_2B_2C$ does not become superconducting above 300 mK.

1. Introduction

Superconductivity and magnetism in RNi_2B_2C (R = rare earth) compounds have recently been the subject of detailed investigations [1–14]. Even though this phase forms for most of the R ions, superconductivity is observed only for R = Y, Lu, Tm, Er, Ho and Dy [2, 12, 13]. The compounds with magnetic R ions show an ordering of the magnetic moments which coexists with superconductivity. The compounds with R = Tm, Er and Ho order magnetically in the superconducting state [2–11]. In contrast, the Dy compound becomes superconducting ($T_c = 6.5$ K) after first ordering magnetically ($T_N = 10.5$ K) [12, 13]. Our investigations [12] have shown that the phase purity plays an important role in the observation of the superconductivity in the Dy compound. The fact that the T_c decreases slowly from 10.5 K for Tm to 6.5 K for Dy suggests that the Tb compound may also be expected to exhibit superconductivity at finite temperatures. This has prompted us to search for a superconducting phase in $TbNi_2B_2C$. Our resistance measurements down to 300 mK show no evidence of superconductivity in this compound for various carbon compositions ranging from 0.8 to 1.2 nor in stoichiometric single crystals. Here we report detailed measurements of the magnetisation and resistance behaviour of $TbNi_2B_2C$ single crystals. $TbNi_2B_2C$ orders magnetically at around 15 K [2]. The AC susceptibility and low field DC magnetisation measurements show transitions corresponding to the ordering of the Tb moments ($T_N = 15$ K) and a spin reorientation at lower temperatures ($T_N = 5.1$ K). As the applied field is increased, the nature of the low temperature ordering changes; the peak vanishes for fields $\geqslant 5$ kOe. The resistance measurements show a change in the slope at T_N. However, no features are observed at the low temperature transition. The compound does not show superconductivity down to 300 mK.

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2. Experimental details

Polycrystalline samples of $TbNi_2B_2C$ were prepared by a standard arc-melting method. Single crystals were grown using Ni_2B as flux [12]. The crystals were characterised by X-ray Laue photographs and AC susceptibility

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measurements. The AC susceptibility was measured using a mutual inductance method. The DC magnetic susceptibility was measured using a SQUID (Quantum Design). The resistance measurements were performed using a four probe DC method in an ILL orange cryostat (for temperatures in 1.5–300 K) and in a Heliox cryostat (Oxford Instruments, UK) for temperatures between 300 mK and 1.6 K.

3. Results and discussion

Fig. 1 shows the AC susceptibility of a $TbNi_2B_2C$ single crystal for a magnetic field of 3 Oe applied perpendicular to the *c*-axis. The peak at 15 K corresponds to the AFM ordering of the Tb moments. This is confirmed via neutron diffraction measurements [16]. This peak is followed by another much more prominent maximum at lower temperatures (5.1 K). The susceptibility is much weaker when the field is applied along the *c*-direction of the crystal, as shown in the inset of Fig. 1. No peak is observed at 5.1 K although there is a shoulder in the data and a sharp increase in susceptibility at lower temperatures. It is quite possible that the low temperature features seen in the data are caused by a spin reorientation of the Tb moments, which lie mainly in the *a–b* plane. The DC susceptibility measurements for various applied DC fields are shown in Fig. 2. The 20 Oe magnetisation curve resembles the AC susceptibility data. It is quite evident that as the field is increased the nature of the low temperature ordering changes, and that the spontaneous spin reorientation seen in low fields is suppressed for fields > 5 kOe.

The variation of resistance with temperature for a single crystal of $TbNi_2B_2C$ is shown in Fig. 3. The resistance shows metallic behaviour down to the magnetic ordering temperature, where a sharp decrease in resistance occurs. No features are present in the data which can be associated with the low temperature spin reorientation. The resistivity tends towards a residual resistance saturation behaviour, as shown in the inset of Fig. 3. The resistance measurements were extended down to 300 mK to check for the presence of a superconducting phase. From these measurements, there are no indications of a superconducting phase in $TbNi_2B_2C$ down to 300 mK.

In RNi_2B_2C compounds, the interaction between the magnetic moment of the R ion and the conduction electrons are not strong enough to produce pair breaking effects and the destruction of superconductivity. This is evident from the coexistence of superconductivity and magnetic order in RNi_2B_2C compounds with R = Tm, Er, Ho and Dy. If the same type of interactions are assumed to be present for this whole family of

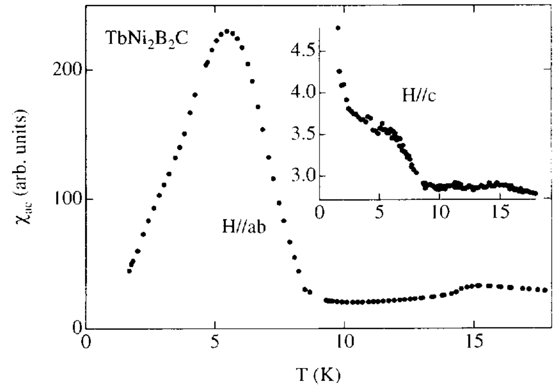

Fig. 1. The temperature variation of AC susceptibility for a $TbNi_2B_2C$ single crystal, H_{ac} = 3 Oe, applied perpendicular to the *c*-axis. The inset shows the AC susceptibility of the same crystal for the field along the *c*-direction.

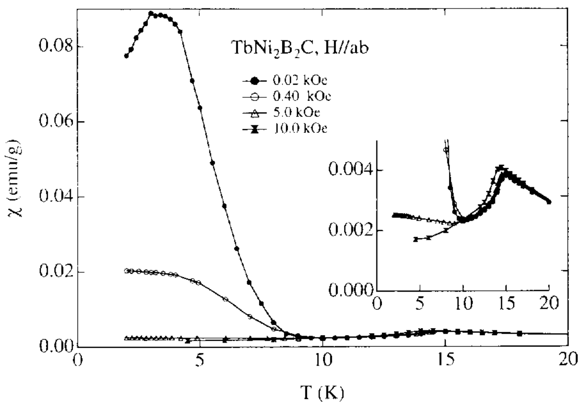

Fig. 2. DC magnetic susceptibility as a function of temperature for various DC fields applied perpendicular to the *c*-axis of a $TbNi_2B_2C$ single crystal. The inset shows the expanded scale for the same curves.

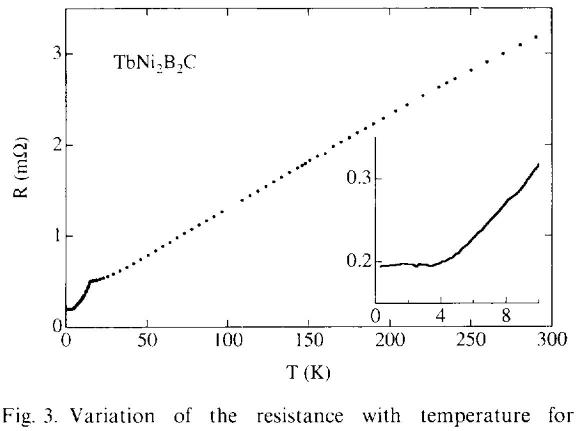

Fig. 3. Variation of the resistance with temperature for a $TbNi_2B_2C$ single crystal. The inset shows the extended measurements down to 300 mK.

compounds, then by the de Gennes' scaling, a T_c of 1 K or higher can be expected for the Tb compound. However, the fact that all other phase forming RNi_2B_2C compounds do not show superconductivity, including the non-magnetic La compound, suggests the R ions do play a role in the onset of superconductivity, and that there may be other reasons for the gradual reduction of T_c from Tm to Dy and higher T_c's for Y and Lu. It is possible that the size of the ion also has an effect on the superconductivity in these compounds. This may be one of the reasons for the abrupt disappearance of superconductivity below Dy. It is also possible that the interactions between the Tb moments in the magnetically ordered state are not the same as the other magnetic R ions. The low temperature peak in the magnetisation of the Tb compound strengthens this argument. Further investigations on the magnetic properties of this compound are in progress.

In conclusion, we have shown that $TbNi_2B_2C$ does not show superconductivity down to 300 mK. The magnetisation measurements show two peaks corresponding to the ordering of the Tb moments ($T_N = 15$ K) and a spin reorientation at lower temperatures ($T_N = 5.1$ K). As the applied field is increased, the nature of the low temperature ordering changes; the spin reorientation peak vanishes for fields $\geqslant 5$ kOe.

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