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Neutron scattering study of spin waves in $TbFeO_3$

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Abstract

Iron sublattice spin waves have been studied in $TbFeO_3$ by inelastic neutron scattering on the PRISMA spectrometer at ISIS. Magnon dispersion curves were measured along [1 0 0] and [0 0 1] directions up to energies 80 meV and the results fitted to a model taking into account near-neigbour (J_1) and next-nearest-neigbour (J_2) isotropic Heisenberg interactions. The exchange parameters $J_1 = -28.7(0.3)$ K and $J_2 = -1.4(0.5)$ K obtained for $TbFeO_3$ agree with those found earlier for another orthoferrite $TmFeO_3$.

Keywords: Spin waves; Antiferromagnetism; Pulsed neutrons; Perovskite

Rare-earth orthoferrites are of interest due to their peculiar magnetic properties, such as weak ferro/antiferromagnetism, spin reorientation (SR) transitions, etc. [1,2]. A spin-dynamics of $TbFeO_3$ has been studied using the time-of-flight neutron inelastic spectrometer PRISMA at ISIS and the results are presented here.

Orthoferrites crystalize in the orthorhombically distorted perovskite structure with four formula units per unit cell. The spins of four Fe ions in $TbFeO_3$ order at $T_N = 681$ K and are arranged in the (G_x A_y F_z) configuration. (Vector components G_x, A_y, F_z are standard linear combinations of the spins $F = S1 + S2 + S3 + S4$, $A = S1 - S2 - S3 + S4$, $G = S1 - S2 + S3 - S4$ [2].). At 8 K a reorientation of the Fe spins occurs, with the magnetic symmetry described as the (F_x C_y G_z) mode. In both cases the G mode describes the main antiferromagnetic component, while F and A represent the weak ferro- and antiferromagnetic components ($F/G, A/G = 10^{-2}$), respectively. Finally, below 3.1 K magnetic ordering of Tb takes place.

A sample of $TbFeO_3$ of volume 1.2 cm^3 with $a = 5.326$, $b = 5.602$, $c = 7.635$. A was oriented with an [0 1 0] axis vertical so that the a^*–c^* plane could be surveyed. Pyrolytic graphite (0 0 2 reflection) analysers were used and 90 min collimators installed before and after the analysers. The measurements were performed in the region of q-/ω space around the (-3 0 3) reflection in the [0 0 ξ] and [ξ 0 0] directions. Since no significant difference was found between the spectra measured at 13 K and at 4.2 K, the measurements were carried out at 4.2 K (below the SR transition).

One of the spectra measured in the vicinity of the (-3 0 3) reflection is presented in Fig. 1. It appears that apart from the peaks due to the spin waves (SW) of Fe-sublattice extra peaks exist originating from crystal fields transitions of Tb paramagnetic ions. As seen from Fig. 2, where the magnon dispersion curves measured in two symmetry directions are shown, the paramagnetic scattering from Tb

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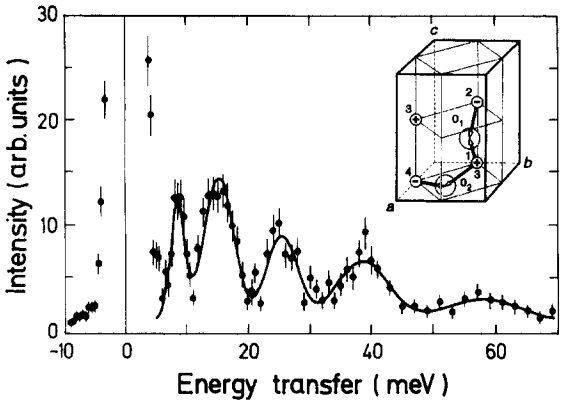

Fig. 1. Neutron inelastic scattering from $TbFeO_3$ at 4.2 K.

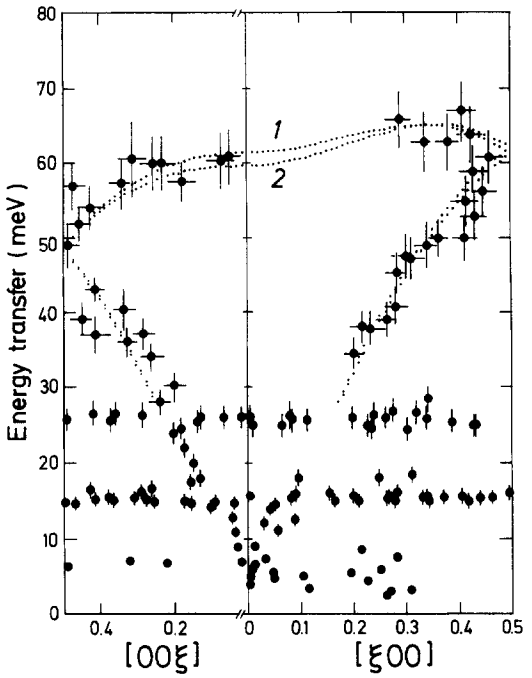

Fig. 2. SW spectra of $TbFeO_3$. Dotted curves show the results of best fitting: (1) $J_1 = -25.2(0.3)$ K, $J_2 = 0$ K; (2) $J_1 = -28.7(0.3)$ $J_2 = -1.4(0.5)$ K.

due to crystal field transitions gives two flat branches at 15 meV and at 26 meV, which makes it rather difficult to measure the Fe acoustic mode below 30 meV. At the same time the upper part of the SW acoustic mode and the optic mode are well separated from the paramagnetic scattering. Since the high-energy transfer peaks can be attributed unambiguosly they were essentially used to refine the exchange parameters.

According to crystal structure results [3] the strongly coupled Fe^{3+}-ions in orthoferrites are separated from each other by large intervening diamagnetic anions O_2^-. Therefore, the magnetic interaction is mainly due to the indirect exchange via O_2^- ions. Since the nearest-neighbour (nn) interaction (Fe atoms 1–2 and 1–4) involves one oxygen ion (see inset in Fig. 1), it should be considerably stronger than the next-nearest-neighbour one (nnn) involving at least two O_2^- ions. In reality, the nn exchange parameters J_{12} and J_{14} are distinct because the bond lengths for two nearest neighbours differ slightly, but since the difference is rather small (less than 2%), the same exchange parameter can be used for both interactions ($J_{12} = J_{14} = J_1$). A similar assumption ($J_{11} = J_{13} = J_2$) can be applied to the nnn exchange in spite of a slightly bigger difference in the bonds lengths (6%).

The dotted curve in Fig. 2 shows the best least-square fit to the data for the model taking into account only nn exchange. This model gives $J_1 = -25.2(0.3)$ K, $J_2 = 0$ K. Including the nnn exchange improves the fit insignificantly giving $J_1 = -28.7(0.3)$ $J_2 = -1.4(0.5)$ K. These values of isotropic exchange parameters are in a good agreement with those deduced from the value of T_N using mean field theory and with the values obtained by neutron scattering for another orthoferrite $TmFeO_3$ ($J_1 = -24.5$ K, $J_2 = 0$ K and $J_1 = -29.1$ K, $J_2 = -1.88$ K under similar assumptions, respectively [4]). Unfortunetly, the presence of strong paramagnetic scattering from Tb and the constraints of the PRISMA analysers configuration [5] at that time did not allow us to study the low energy part of the magnetic excitation spectra properly, so further low-energy transfer measurements are needed to study the SR phenomena and anisotropy in $TbFeO_3$.

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