ESRF	**Experiment title:** X-ray resonant scattering of the magnetoelectric properties of TbMnO3	**Experiment number**: 28-01-741
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Report:

The $RMnO_3$ series of compounds have attracted a considerable amount of attention, due to their giant magnetoelectric effects. In $TbMnO_3$, for example, the electric polarization can be switched by applied magnetic fields. Determining the microscopic mechanisms of the magnetoelectric coupling in these materials is of fundamental importance to understanding their fascinating physical properties. This goal maybe achieved utilizing a microscopic electron polarisation specific probe such as resonant x-ray scattering RXS.

In $TbMnO_3$ the Mn^{3+} magnetic moments first order below T_{N1}=41 K. From neutron diffraction data, it has been reported that in this phase the moments are polarized along the b direction with a modulation wavevector Q_{Mn}=(0 qMn 1), q=0.27 r.l.u. Below T_{N2}=28 K the magnetic structure becomes non-colinear and, at exactly the same temperature, ferroelectric. Indeed, by comparing the magnetic structures above and below T_{N2}, a model was proposed whereby the ferroelectric transition is driven by a loss of inversion symmetry at the Mn sites as the magnetic structure changes from collinear to non-collinear. On further cooling below T_{N3}=7 K, the Tb moments order but, unusually, with a distinct wavevector of (0 q_{Tb} 0) with q=0.42 r.l.u.

Our recent RXS experiments at XMaS have discovered two new order parameters, which occur at Q_{Mn2}=(0 k±q_{Mn} 0) with k even and Q_{Mn3}=(0 k±q_{Mn} 0) with k odd. Although these new *incommensurate* wavevectors are similar to the principal Mn *magnetic* wavevector Q_{Mn}, the observed RXS response cannot simply be reconciled with the deduced magnetic structure of $TbMnO_3$. Firstly, the RXS at Q_{Mn2} and Q_{Mn3} show a strong azimuthal dependence (see Fig. 1.) that is inconsistent with the report that the magnetic moments are oriented along b. We have additionally investigated the magnetic structure of our sample at ID20 using non-resonant x-ray magnetic scattering NRXMS. This work finds no evidence for NRXMS at either the Q_{Mn2} or Q_{Mn3} positions and confirms that the NRXMS signal observed at Q_{Mn}=(0 qMn 1) originates from an ordered magnetic moment along b axis (see Fig. 1). Secondly, the temperature dependence of Q_{Mn2} and Q_{Mn3} are dramatically different. The Q_{Mn2} RXS occurs below T_{N1}=41K, while the QMn_3 RXS is only present below T_{N2}=28K, where the material is also ferroelectric. Moreover, the RXS Q_{Mn3} has a finite $\sigma\rightarrow\sigma$ polarisation, which is forbidden for simple E1 RXMS. Finally, we also note that the Q_{Mn2} RXS is observed at the Mn K-edge and at the Tb L_3 edge, while the Q_{Mn3} RXS is only observed at the Tb L_3 edge. The fact that we observe RXS at the Mn-like incommensurate wavevectors also at the Tb L-edges is also very interesting. Presumably this effect arises from some kind of polarization and hybridization of the Tb 5*d* electrons from the Mn 3*d/4p* states and is possibly related to magnetoelectric coupling in $TbMnO_3$.

Possible explanations may include an interference (E1-E1) between magnetic and anisotropic tensor scattering (ATS) as has been recently found in GdB4, or alternatively a E1-E2 interference term associated with polar and magnetoelectric order parameters. From our preliminary analysis, we find that a magnetic torroidial moment (anapole) is consistent with the azimuth symmetry and scattered polarisation of the RXS observed at Q_{Mn2}. A detailed account of these experiments will be submitted to Physical Review B in the near furure.

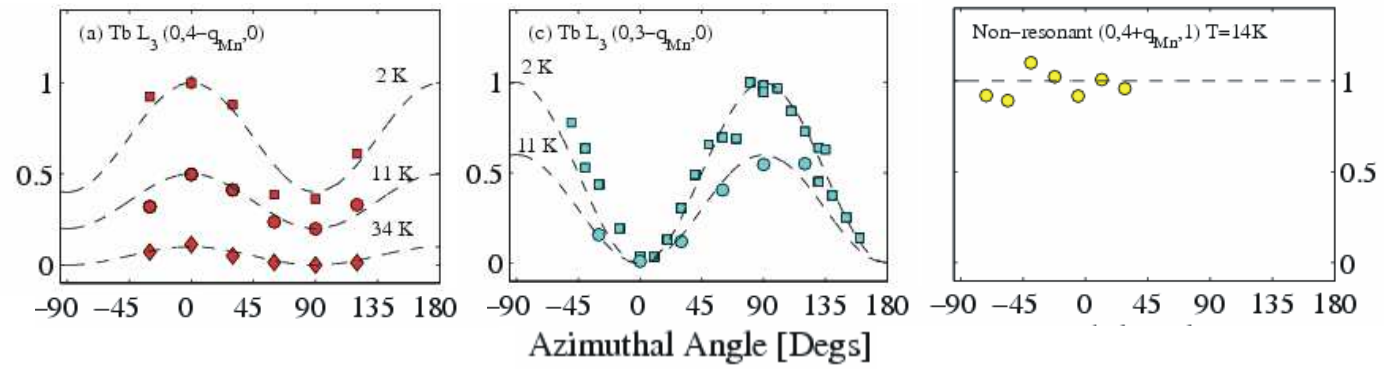

Figure 1. Summary of the azimuthal dependence of the RXS observed at Q_{Mn2}=(0 4-q_{Mn} 0) [red points] and Q_{Mn2}=(0 3+q_{Mn} 0) [blue points]. Since the nominal magnetic moment is orientated parallel to Q_{Mn2} and Q_{Mn3} (i.e. along the b axis no azimuth dependence about these wavevectors is expected if their order parameters were simply magnetic in origin. This is demonstrated for the non-resonant scattering observed at Q_{Mn}=Q_{Mn2}=(0 k±q_{Mn} 1) [yellow points] for which only a weak azimuth dependence is observed, as expected based on the known magnetic structure.