Experimental report

29/01/2024

Proposal: **DIR-294** **Council:** 4/2023

Title: Determining the microscopic originof magnetic phases in Ba0.4Sr1.6Mg2Fe12O22

Research area: Physics

This proposal is a new proposal

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Samples: Ba0.4Sr1.6Mg2Fe12O22

Instrument	Requested days	Allocated days	From	To
D23	3	0		
D10	3	3	02/11/2023	05/11/2023
ORIENTEXPRESS	1	1	02/11/2023	03/11/2023

Abstract:

Hexaferrites have great potential as spintronic devices for applications such as low energy dissipation magnetic random-access memory because of their observed magnetoelectric behavior. Giant magnetoelectric coefficients have been reported for the Y-type hexaferrite single crystalline Ba2-xSrxMg2Fe12O22 with x=1.6 (BSMFO), which undergoes several phase transitions upon increase of an applied magnetic field. On removing the field, the magnetization can be reversed by application of electric field. We ask for time to investigate a new magnetic phase that has been observed in this material, using polarized neutrons to examine the chirality of this phase.

Experimental Report
Instrument: D10
Experiment Number: 3-15-294

Title: Determining the microscopic origin of magnetic phases in $Ba_{0.4}Sr_{1.6}Mg_2Fe_{12}O_{22}$

Experiment Date: 02/11/2023 – 05/11/2023

Experimental Team: Oskar Stepančić, Lingjia Shen (online), Annika Stellhorn (unable to attend), Elizabeth Blackburn (Lund University)

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Introduction

Hexaferrites have great potential as spintronic devices for applications such as low energy dissipation magnetic random-access memory because of their observed magnetoelectric behaviour. Giant magnetoelectric coefficients have been reported for the Y-type hexaferrite single crystalline $Ba_{2-x}Sr_xMg_2Fe_{12}O_{22}$ with x=1.6 (BSMFO), which undergoes several phase transitions upon increase of an applied magnetic field. On removing the field, the magnetization can be reversed by application of electric field.

The hexaferrite materials are well-known multiferroics [1]. Investigations into the multiferroic properties of hexaferrites started from the direct magnetoelectric (ME) effect, namely, the induction of ferroelectricity by magnetic field [3]. The converse ME effect was discovered shortly afterwards [4]. One of the most intricate signatures of the converse ME effect in hexaferrites is magnetization reversal. While such reversal behaviour tends to be ubiquitous in hexaferrites [2, 4-5], the microscopic origin is still under debate. One of the leading scenarios is the spin current model, which is based on a noncollinear spin structure in the ME state [6]. BSMFO is a Y-type hexaferrite that displays this type of behaviour. In Figure 1a, the magnetization in BSMFO (x = 1.6) is shown being switching while cycling through different electric fields [2]. Within these materials, the Fe ions are arranged in blocks along the c axis (~43 Å) that may order separately, leading to a rich set of magnetic structures (see Figure 2), which have been explored by neutron diffraction (Fig. 1b, from Ref. [2]).

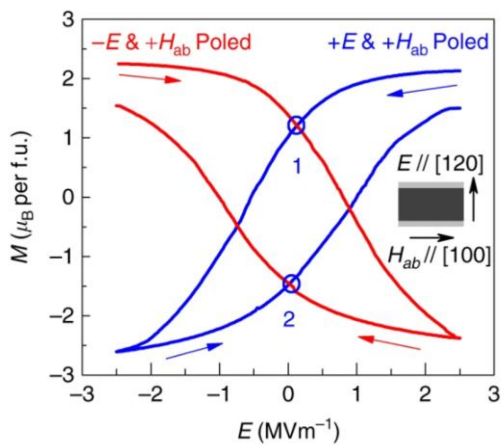


Figure 1: Electric field control of magnetization in BSFMO (x = 1.6) at 10 K [2]. The magnetic / electric field poling protocol is discussed in the Results section.

Sample Details and Instrumental Configurations

A single crystalline BSMFO (x = 1.6) with dimensions around 2*2*1 mm^3 was used; it was synthesized by Kun Zhai [2]. This material is reported to be hexagonal, with lattice parameters a = b = 5.841 Å and c = 43.256 Å at room temperature. The experiment was performed on the four-circle diffractometer D10. The sample was first aligned in the $H0L$ plane on OrientExpress and glued on the dedicated pin and inserted into the Blue Charlie cryomagnet for the measurement. The b* axis was parallel to the neutron beam. We used pyrolytic graphite monochromator and filter with wavelength = 2.36 Å. Measurements of structural Bragg peaks were taken at base temperature of 5 K and magnetic Bragg peaks were collected at 5 K and 5 T. A 2D detector was used.

<u>Results</u>

After the alignment and cooling procedure we found that there is an off-set of 0.167 in the cn motor which created a systematic error in the data – not all Bragg peaks were properly centered at the detector. The magnetic field and base temperature were kept constant at 5 K and 0 T for the structural Bragg peaks and for magnetic Bragg peaks the magnetic field was set to 5 T for the total duration of the experiment.

Structural Bragg reflections

First set was of 356 reflections from P1 space group. The literature [2] says that the space group of the BSMFO is R-3m, we found that is not true. So we gathered reflections from P1 space group to collect both allowed and not allowed reflections in R-3m. Our suspicions were confirmed; we found many forbidden structural reflections.

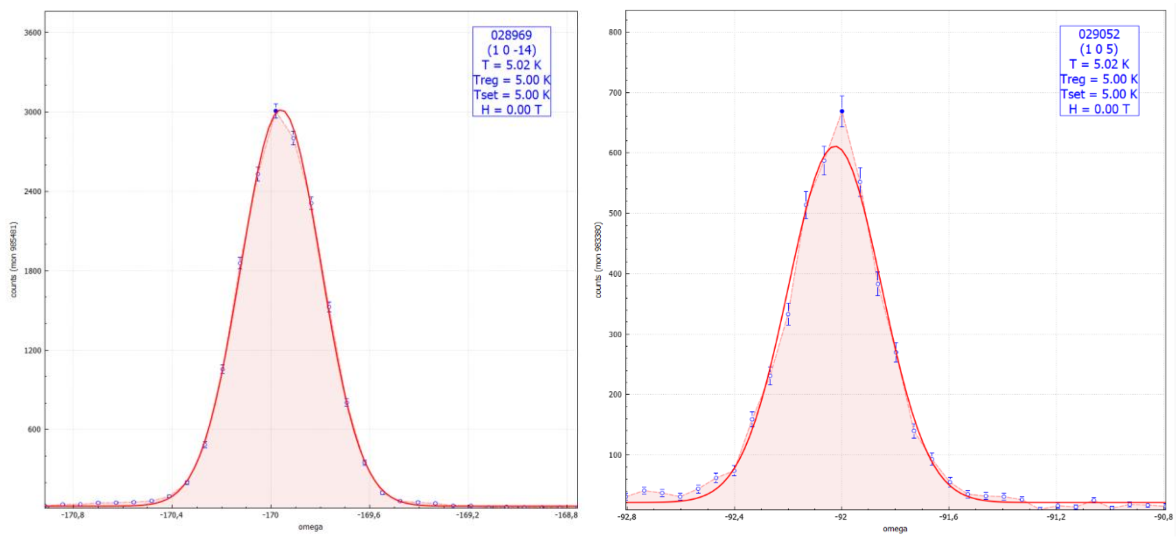
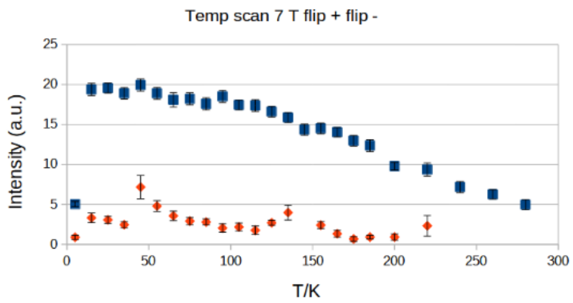


Figure 3. (left) Structural Bragg peak (1 0 -14) from R-3m space group and (right) Bragg peak (1 0 5) forbidden in R-3m space group.

Magnetic reflections

The total number of 46 of magnetic reflections was collected for determining the magnetic propagation vector. The magnetic Bragg peaks were indexed as $\mathbf{k}_3$ peaks where $\mathbf{k}_3$ = (0 0 1.67) or (0 0 1.33).



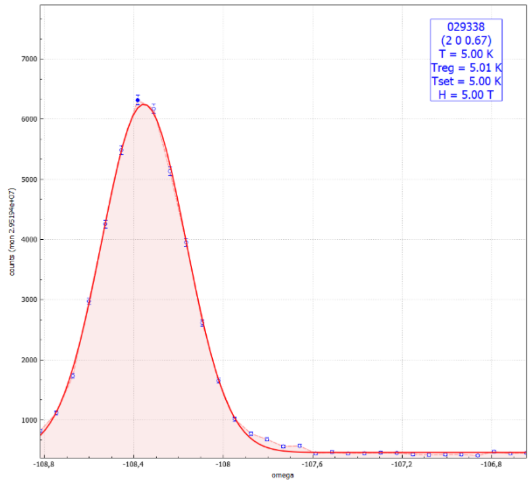


Figure 2: (left) Temperature dependence of the $\mathbf{k}_3$ phase at applied magnetic field of 7 T from D33 data [9]. The blue points are with Flipper + and the red points are Flipper – in the half-polarized setup. (right) Magnetic Bragg peak at (2 0 0.67).

Summary

Our experiment has shown that there is an additional magnetic phase $\mathbf{k}_3$ with wavevector (0 0 1.67). Correction for the motor error has been proposed but has not yet been implemented.

Literature

[1] Kimura, Annu. Rev. Condens. Matter Phys., **3:93–110** (2010)
[2] Zhai *et al.*, Nat. Commun. **8, 519** (2017)
[3] Kitagawa *et al.*, Nature **9, 797** (2010)
[4] Chun *et al.*, Phys. Rev. Lett. **108, 177201** (2012)
[5] Kocsis *et al.*, Nat. Commun. **10, 1247** (2019)
[6] Katsura *et al.*, Phys. Rev. Lett. **95, 057205** (2005)