NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2019-2020

Understanding the multiferroic properties of the spinel compound $GeFe_2O_4$

General Scope: The term **"multiferroics"** refers to a remarkable class of solid materials where both ferromagnetism (*i.e.* an alignment of magnetic dipoles) and ferroelectricity (*i.e.* an alignment of electric dipoles) coexist and are intertwined (Fig.1 (a)). In these materials, the cross-coupling effect, the so-called magnetoelectric (ME) coupling (between spin and charge degrees of freedom), is a playground for many applications. This ME effect can lead to the control of the polarization **P** (magnetization **M**) by applying a magnetic **H** (electric **E**) field and is a key feature for future information technologies[1]. The quest for novel multiferroic materials exhibiting spectacular ME coupling is one of the most exciting challenges in the field and drives a considerable amount of research from chemists and physicists alike[2]. This was recently re-motivated by the discovery of type II multiferroics, where ferroelectricity is induced by complex magnetic orders and a strong ME coupling is detected[3]. We are interested in the study of the multiferroic properties of the spinel $GeFe_2O_4$. This system presents a complex non-colinear magnetic order[4] and signatures of ME couplings and multiferroicity have been detected (Fig.1 (b)).

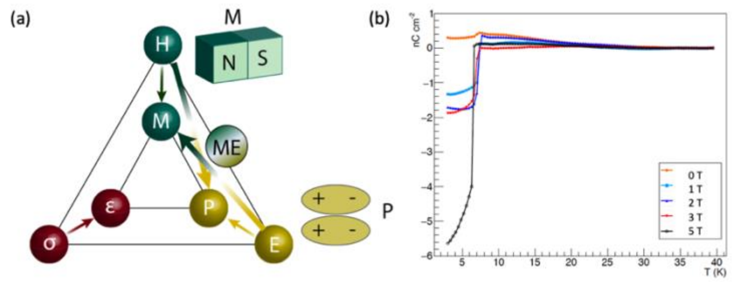

***Figure 1:** (a) The three ferroic orders and their interplay in multiferroic materials. The polarization **P**, magnetization **M**, and strain ε is usually controlled by applying an electric field **E**, magnetic field **H**, and stress σ respectively. In magnetoelectric (ME) multiferroics, the cross-coupling effect induces a control of **P** (**M**) by applying a magnetic **H** (electric **E**) field. (b) Electric polarization measured at low temperature and under magnetic field in $GeFe_2O_4$.*

Research topic and facilities available: The purpose of this internship will be to explore the multiferroic properties of $GeFe_2O_4$. Macroscopic characterizations (magnetization and electrical measurements under magnetic field and at low temperatures) will be performed at the laboratory to complete the data set we already have. These measurements will be supplemented by diffraction at the laboratory and at large-scale facilities when necessary (synchrotron and/or neutron sources). The main objective will be to understand the microscopic mechanisms behind the multiferroic properties of $GeFe_2O_4$. Symmetry analysis and/or simulations will be also considered.

Possible collaboration and networking: The student will be in direct collaboration with the researchers of the "Materials, Radiation and Structure" as well as the "Magnetism and Superconducting" teams of the Néel Institute. This work may also involve interactions with theoreticians and technical staff of the laboratory.

Possible extension as a PhD: This internship could be extended into a PhD with the possibility of opening the research project to the study of dynamical ME effects.

Required skills: The student should have a background in condensed matter physics with a strong interest for experimental physics addressing fundamental questions.

Starting date: January or early February 2020.

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[1] M. Fiebig, J. Phys. D **38**, R123 (2005).
[2] Y. Tokura, *et al.*, Rep. Prog. Phys. **77**, 076501 (2014).
[3] S.-W. Cheong and M. Mostovoy, Nature Mater. **6**, 13 (2007).
[4] G. Perversi et al., *Commun. Phys.* **1**, 69 (2018).