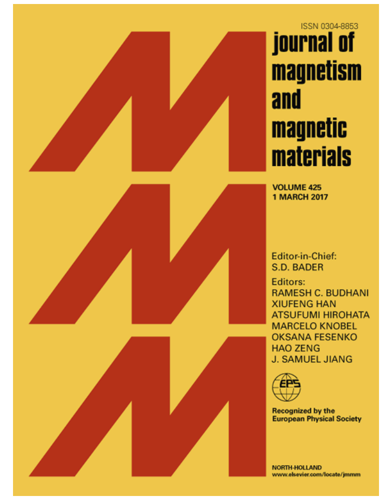

"Metamagnetoelectric" effect in multiferroics

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"Metamagnetoelectric" effect in multiferroics☆

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Abstract

We present a theoretical calculation of magnetoelectric properties in a quasi-two dimensional spin chain externally controlled by a static electric field in *y*-direction and magnetic field in *z*-direction. Given the diversity of properties in functional materials and their applications in physics, the multiferroic model is investigated. By using the Fermi-Dirac statistics of quantum gases and the Landau theory, we assess the effects of the Dzyaloshinskii-Moriya interaction and the electric polarization on the magnetoelectric coupling that induces at low temperature the "metamagnetoelectric" effet, and likewise affects the ferroelectricity induced through symmetry mechanisms and magnetic properties of the multiferroic system. In fact, the variation of the induced polarisation due to spin arrangement through the Dzyaloshinskii-Moriya interaction gives rise to a multistep interdependant metamagnetic and metaelectric transitions which are settled up by the corresponding Dzyaloshinskii-Moriya parameter and the system then exhibits a spin gap that results from an electric and a magnetic demagnetization field range. This metamagnetoelectric effect observed in these multiferoic materials model is seem to be highly tunable via the external electric and magnetic fields and thus can be crucial in the design of new mechanisms for the processing and storage of data and other spintronic applications.

Keywords: Multiferroic, magnetoelectric coupling, metaelectric transition, metamagnetic transition, metamagnetoelectric transition.
2010 MSC: 00-01, 99-00

1. Introduction

Multifunctional materials are of profound interest in current material sciences research. Particular focus remains on the understanding of the mechanisms at the base of the coupling between several ferroic orders in these materials. The possibility of controlling one ferroic order using the other ferroic order is of particular interest for future applications in the design of novel devices such as actuators, transducers and storage devices [1, 2, 3, 4, 5]. Usually, ferroelectricity and magnetism are concomitantly present in a class of Mott insulators known as multiferroics materials [6, 7, 8]. The theoretical investigation on multiferroic materials with magnetoelectric (ME) coupling has been carried out using spin 1/2 chains [9, 10, 11, 12, 13, 14, 15], and a microscopic model for the electric ordering based on a spin-current mechanism has been introduced [16]. Some existing phenomenological models of this electric ordering have attributed the ferroelectricity to certain types of magnetic order which can lower the symmetry of the system to one of the polar groups [17, 18, 19]. Experimental results in $Ba_{0.5}Sr_{1.5}Zn_2Fe_{12}O_{22}$ [20], $Ni_3V_2O_8$ [18], and $TbMnO_3$ [17] show that helical magnetic structures are the most likely candidates to host ferroelectricity. In fact, a spin chain with ferromagnetic exchange interactions between neighbouring spins having uniform ground state with all spins parallel, is frustrated when an antiferromagnetic next-nearest-neighbour interaction is considered [21]. A net electric polarisation is found under spiral and conical spin structures and is well described by the spin-current model [16, 22, 23], $\mathbf{P}_i \sim e_{ij} \times (S_i \times S_j)$, where e_{ij} is the propagation direction of the spin spiral and S_i and S_j are the moments on neighbouring spins.

Recently, an experimental study of multiferroic $BiFeO_3$ suggested that the Dzyaloshinskii-Moriya (DM) interaction and the Single Ion Anisotropy (SIA) are additional terms to be considered in the frustrated spin Hamiltonian for theoretical investigations [24, 25, 26, 27, 28]. In the classical isotropic model without transverse magnetic field the frustration leads to a helical spin arrangement with a pitch angle $\phi = \arccos(1/4a)$ with $a = |J'/J| > 1/4$ (J and J' being respectively the nearest and the next nearest exchange couplings). Many attempts on similar models had been made using numerical simulation and experiments showing the spin waves behaviour or the interplay of several interactions being present [28, 29, 30, 31, 32].

It is well-known from spin interactions in multiferroic system that, with magnetoelectric coupling, the magnetic order and ferroelectric polarisation are closely related. By taking advantage of this coupling between magnetism and ferroelectricity, electric-field control of magnetism or the reverse becomes essential. Considering the model constructed around a helical frustrated spin system with nearest neighbor interac-

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