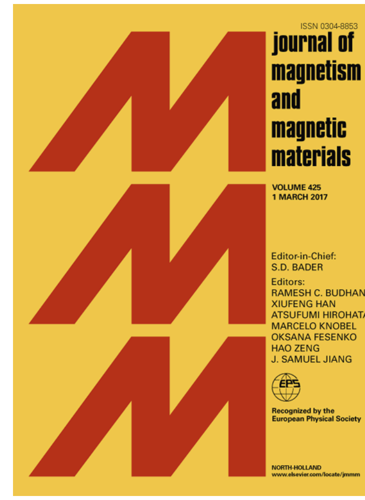

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Field-induced cluster spin glass and inverse symmetry breaking enhanced by frustration

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Abstract

We consider a cluster disordered model to study the interplay between short- and long-range interactions in geometrically frustrated spin systems under an external magnetic field (h). In our approach, the intercluster long-range disorder (J) is analytically treated to get an effective cluster model that is computed exactly. The clusters follow a checkerboard lattice with first-neighbor (J_1) and second-neighbor (J_2) interactions. We find a reentrant transition from the cluster spin-glass (CSG) state to a paramagnetic (PM) phase as the temperature decreases for a certain range of h. This inverse symmetry breaking (ISB) appears as a consequence of both quenched disorder with frustration and h, that introduce a CSG state with higher entropy than the polarized PM phase. The competitive scenario introduced by antiferromagnetic (AF) short-range interactions increases the CSG state entropy, leading to continuous ISB transitions and enhancing the ISB regions, mainly in the geometrically frustrated case ($J_1 = J_2$). Remarkably, when strong AF intracluster couplings are present, field-induced CSG phases can be found. These CSG regions are strongly related to the magnetization plateaus observed in this cluster disordered system. In fact, it is found that each field-induced magnetization jump brings a CSG region. We notice that geometrical frustration, as well as cluster size, play an important role in the magnetization plateaus and, therefore, are also relevant in the field-induced glassy states. Our findings suggest that competing interactions support ISB and field-induced CSG phases in disordered cluster systems under an external magnetic field.

1. Introduction

Disordered systems with competing interactions can exhibit interesting reentrant behaviors [1]. In particular, the reentrant phases can be paramagnetic (PM) or, when there are disorder and frustration, spin glass (SG). It should be noticed that the transition in which an ordered state is cooled down into a reentrant PM phase can also be classified as inverse symmetry breaking (ISB), where an entropic inversion takes place with the ordered phase presenting more entropy than the disordered one, the PM phase [2, 3, 4]. Besides the temperature, another tunable parameter that can induce reentrant behaviors is the magnetic field. For instance, a field-induced SG behavior has been an interesting class of reentrance. Considering that the SG phase appears when quenched disorder interactions lead to frustration [5], even an increase in the freezing temperature (T_f) induced by an external field, which tends to suppress frustration effects, would be quite unexpected for SG systems. Nevertheless, the field induced SG reentrant behavior can be observed in some disordered systems [6, 7, 8, 9]. Therefore, an attracting question is how the interplay among thermal fluctuations, magnetic field and competing interactions can be a route for reentrances in disordered magnets.

Frustration has been often pointed as a driven force of reentrances. In particular, a number of works have shown that frustration introduced by disorder can be relevant to the ISB occurrence [2, 3, 10, 11, 12, 13]. However, there are few approaches accounting for field-induced rentrances in SG systems. For example, in the spin-1 version of the disordered van Hemmen (vH) model, a field-induced SG phase can be observed for a large enough crystal field anisotropy [14]. Besides, a disordered classical m-vector model with uniaxial anisotropy shows a reentrance (i.e., a PM-SG-PM sequence of transitions) in the Gabay-Toulouse line when the external field increases at a fixed temperature [15]. It means that the $T_f(h)$ can exhibit a maximum for a finite external field h when single-ion anisotropy is considered. It should be noticed that these theoretical works rely on crystal field anisotropies to support the field-induced SG reentrant behavior. In other words, the search for alternative mechanisms able to drive field-induced glassiness is still open. For instance, frustration coming from the lattice topology, the geometric frustration (GF), can bring novel issues for the reentrant behavior. In this scenario, disorder-free models with frustrated interactions between Ising spins have exhibited ISB under an external field [16, 17, 18, 19]. In particular, the J_1-J_2 Ising model in the square lattice [18, 19] exhibits both, ISB and field-induced transitions. A natural question that arises is how the coexistence of these two sources of frustration, disorder and GF, can affect the reentrances in systems under a magnetic field.

Recently, cluster frameworks have been considered to study GF effects on magnetic systems [20, 21, 22, 23, 24]. This formalism provides an alternative to introduce short-range interactions, allowing to consider some topological features (i.e., the cluster geometry) in a mean-field approach. In fact, the clusters are used in order to consider the competition between short- and long-range interactions in a disordered model. In

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