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Ground states of the frustrated Blume–Emery–Griffiths model in a field

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ABSTRACT

Ground-state properties of the Blume–Emery–Griffiths model with antiferromagnetic nearest-neighbor interactions on a triangular lattice are investigated in the presence of an external magnetic field. In particular, we explore the model's parameter space and identify regions with different degenerate ground states that may give rise to different magnetic phases also at finite temperatures. We demonstrate the presence of such phases by Monte Carlo simulations of magnetization processes for selected values of parameters.

1. Introduction

A frustrated triangular lattice Ising antiferromagnet (TLIA) with spin 1/2 is long known to display no long-range ordering down to zero temperature [1], albeit the ground state is critical with the power-law decaying spin-correlation function [2]. Nevertheless, a long-range order can occur in the ground state if the spin is larger than some critical value, estimated as 11/2 [3–5]. Generally, the lack of order in frustrated spin systems is due to large ground-state degeneracy. However, this can be lifted by various perturbations, such as an external magnetic field [6–9] or selective dilution [10,11], which can result in long-range ordering even in TLIA with spin 1/2. In the Ising models with spin larger than 1/2, a single-ion anisotropy and higher-order (e.g., biquadratic) exchange interactions may play a crucial role in their critical properties (see, e.g., [12–14]). The model that incorporates the above mentioned effects is known as Blume–Emery–Griffiths (BEG) model [14] and has a long history of investigation [14–23]. In the case of the BEG model with antiferromagnetic interactions, it is interesting to study its behavior in an external magnetic field. A recent study by using exact recursion relations on the Bethe lattice [24] produced some interesting results, such as the reentrant phenomenon with the consecutive phase transitions from disorder to order and back to disorder as the field was increased. However, as already observed for example in the simple TLIA model with spin 1/2, a frustrated antiferromagnet in the presence of an external field behaves quite differently than its nonfrustrated counterpart [6–9]. A frustrated Blume–Capel model on a triangular lattice, which is special case of our BEG model with zero biquadratic exchange interactions and zero magnetic field, has been investigated by position-space renormalization group methods [25] and has been shown to display finite-temperature long-range ordering within a certain range of the single-ion anisotropy strength, accompanied with a multicritical behavior. In order to understand finite-temperature behavior of the frustrated spin systems, which is often unexpected and intricate, it is important to understand their ground-state properties.

In the present Letter we consider the geometrically frustrated antiferromagnetic BEG model on a triangular lattice in the presence an external magnetic field. As a result of the frustration, the ground state of such a system is highly degenerate. On the other hand, the model features a number of different perturbations that can lift this degeneracy in different ways and thus we can expect much richer variety of magnetic structures in a broad parameter space than for a nonfrustrated case.

2. Model and methods

We consider the spin-1 Ising model on a triangular lattice described by the Hamiltonian

$$\mathcal{H} = -J_1 \sum_{\langle i,j\rangle} S_i S_j - J_2 \sum_{\langle i,j\rangle} S_i^2 S_j^2 - D \sum_i S_i^2 - h \sum_i S_i, \qquad (1)$$

where $S_i = \pm 1, 0$ is a spin on the ith lattice site, $\langle i, j\rangle$ denotes the sum over nearest neighbors, $J_1 < 0$ is an antiferromagnetic bilinear

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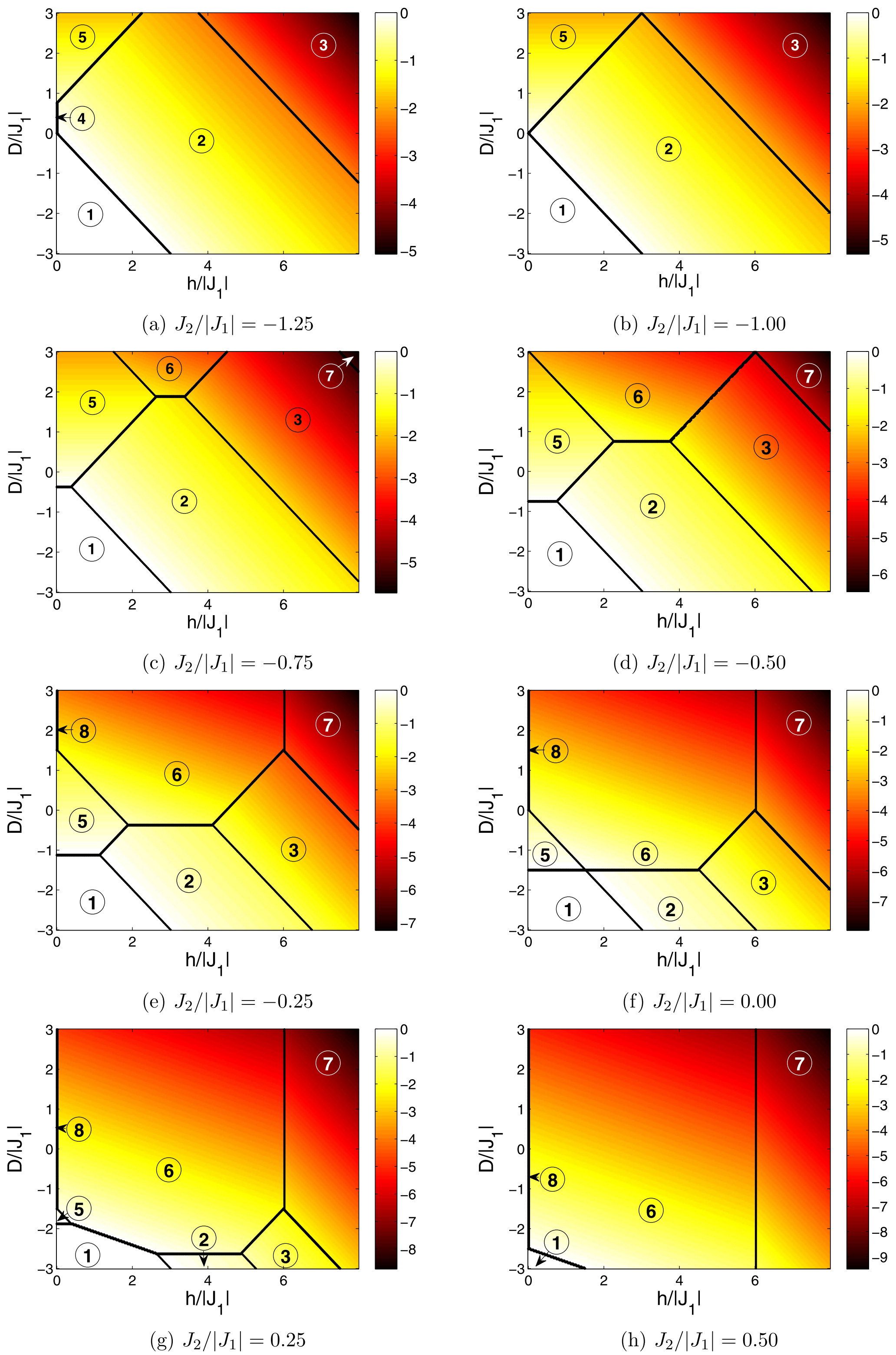

(a) $J_2/|J_1| = -1.25$ (b) $J_2/|J_1| = -1.00$

(c) $J_2/|J_1| = -0.75$ (d) $J_2/|J_1| = -0.50$

(e) $J_2/|J_1| = -0.25$ (f) $J_2/|J_1| = 0.00$

(g) $J_2/|J_1| = 0.25$ (h) $J_2/|J_1| = 0.50$

Fig. 1. (Color online.) Surfaces of the ground-state energy f_{GS} in the $D/|J_1| - h/|J_1|$ parameter plane for various values of the biquadratic exchange parameter $J_2/|J_1|$. The lines mark the borders between different phases, presented in Table 1.

exchange interaction parameter, J_2 is a biquadratic exchange interaction parameter, D is a single-ion anisotropy parameter, and h is an external magnetic field.

Considering the presence of only nearest-neighbor interactions, it is sufficient to focus on an elementary triangular plaquette formed by the neighboring spins. Then, a reduced zero-temperature energy per spin can be expressed as

$$e/|J_1| = \sum_{\langle k,l\rangle} S_k S_l - J_2/|J_1| \sum_{\langle k,l\rangle} S_k^2 S_l^2 - D/(3|J_1|) \sum_k S_k^2 - h/(3|J_1|) \sum_k S_k, \tag{2}$$

where the summation $\langle k,l\rangle$ runs over the nearest neighbors S_k and S_l $(k,l = 1,2,3)$ on the plaquette. Ground-state (GS) spin