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Phase transitions of Ising mixed spin 1 and 3/2 with random crystal field distribution

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HIGHLIGHTS

- The Ising mixed spin-1 and spin-3/2, in the presence of the random crystal field, is studied.
- The mean field approach based on the Bogoliubov inequality for the Gibbs free energy is used.
- Five topologies of the phase diagrams have been presented and discussed.

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ABSTRACT

The thermal and magnetic properties of the mixed spin-1 and spin-3/2 in the presence of the random crystal field are studied within the mean field approach based on the Bogoliubov inequality for the Gibbs free energy. The model exhibits first, second order transitions, a tricritical point, triple point and an isolated critical end point. It is found that the system displays simple and double compensation temperatures, five topologies of the phase diagrams. A re-entrant phenomenon is also discussed and the thermal dependences of total magnetization according to extended Neel classification have been also given.

1. Introduction

During the last decades great effort has been devoted to study a molecular based magnetic material [1–3], where different kind of spin can be regarded as two different interpenetrating sublattices. In these materials, ferromagnetic ordering is of fundamental relevance.

In order to get insight on thermal and magnetic behaviours of this system, many studies deal with mixed-spin Ising models which have less translation symmetry than their single spin counterpart. In recent years more interest has been paid to mixed-spin Ising model with a crystal field which has an impact on the critical behaviours of the system, and the system can lead to the first order transition because of its competition with the bilinear interaction parameter. In many cases, the crystal field acts as constant through the system, as it has been investigated by variety of techniques, such as exact solutions [4–7], mean field approximation (MFA) [8], effective field theory, [9,10], finite cluster approximation [11] and Migdal, Kadanoff renormalization [12,13]. On the other hand, in the presence of the random crystal field (RCF), the

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system can exhibit a very interesting magnetization phenomena, as isolated critical end points at very low temperature and the existence of the compensation points which have an important application in the information storage [14–17]. More particularly in the thermo-magnetic recording [18]. The effect of the RCF has been discussed using different models: Spin-1 Ising model [19–22], Spin-2 Blume–Capel model [23], decorated ferromagnetic Ising model [24] and mixed system [25].

In the following paper, we use the MFA based on the Bogoliubov inequality for the Gibbs free energy [26–29] to study the influence of random crystal field on the phase diagrams, magnetizations and compensation temperatures of the mixed spin-1 and spin-3/2 Ising system with antiferromagnetic interaction $\mathcal{J}$ between pairs of nearest-neighbour spin $S^a = 1$ and $S^b = 3/2$.

The layout of this work is as follows: In the next section, we introduce the model and we present the mean field theory method. In Section 3, we present the ground state phase diagram. In Section 4, we discuss the main numerical results about the phase diagrams. The thermal magnetic behaviour, compensation temperatures dependence of random crystal field, re-entrant phenomenon of the system and the extended Néel classification are given in Section 5. In the last section, we give our summary and conclusion.

2. Model and method

The MFA method is used to study the magnetic behaviour of the complex spin systems, such as the ferrimagnetic mixed spin models [30–34]. The model of our interest consists of two sublattices **A** and **B** which are arranged alternately. The sublattice **A** is occupied by spins S^a assumed to take the values $0, \pm 1$, while the sublattice **B** is occupied by the spins S^b which take four values $\pm 3/2$ and $\pm 1/2$. The exchange interaction between S^a and S^b is assumed to be antiferromagnetic. The Hamiltonian of the system is given by:

$$H = J \sum_{\langle ij \rangle} S_i^a S_j^b + \sum_i \Delta_i \left[(S_i^a)^2 + (S_i^b)^2 \right] \tag{1}$$

where the first summation is carried out only over nearest pairs of spins. The coupling parameter J is assumed positive in order to favour the antiferromagnetic exchange interaction and Δ_i is a random crystal field distributed according to the probability distribution [19,24,25]:

$$\mathcal{P}(\Delta_j) = \frac{1}{2} \left\{ \delta\left(\Delta_i - \Delta(1+\alpha)\right) + \delta\left(\Delta_i - \Delta(1-\alpha)\right) \right\} \tag{2}$$

where α is a positive constant.

The variational principle based on the Gibbs–Bogoliubov inequality for the free energy per site is described by

$$F \leq \Phi = F_0 + \langle H - H_0 \rangle_0 \tag{3}$$

$$F_0 = -T \ln(Z_0) \tag{4}$$

where F is the true free energy of the model described by the Hamiltonian (1), F_0 is the average free energy of the trial Hamiltonian H_0 and $\langle \cdots \rangle_0$ denotes a thermal average over the ensemble defined by H_0 which is defined by

$$H_0 = h_a \sum_{i=1}^{N} S_i^b + h_b \sum_{i=1}^{N} S_i^b + \sum_i \Delta_i \left[(S_i^a)^2 + (S_i^b)^2 \right] \tag{5}$$

where h_a and h_b are the variational parameters related to the molecular fields acting on two different sublattices associated with the order parameters m_a and m_b given respectively by:

$$h_a = J \sum_{j=1}^{z} \langle S_j^b \rangle = Jzm_b \tag{6}$$

$$h_b = J \sum_{j=1}^{z} \langle S_j^a \rangle = Jzm_a \tag{7}$$

where z is a coordinate number.

The partition function generated by the above Hamiltonian H_0 is given by:

$$Z_0 = Tr(\mathrm{e}^{-\beta H_0}) \tag{8}$$

$$Z_0 = \{1 + 2\mathrm{e}^{\beta \Delta_i} \cosh(\beta\, h_a)\}^N \left[2\left(\mathrm{e}^{\left(-\frac{9}{4}\beta\Delta_i\right)}\right) \cosh\left(\frac{3}{2}\beta\, h_b\right) + 2\left(\mathrm{e}^{\left(-\frac{1}{4}\beta\Delta_i\right)}\right) \cosh\left(\frac{1}{2}\beta\, h_b\right) \right]^N \tag{9}$$

where T is the absolute temperature and $\beta = 1/k_\beta T$, the Boltzmann's constant k_β has been set to unity.