Journal of Magnetism and Magnetic Materials 329 (2013) 125–128

Contents lists available at SciVerse ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Review

Bimodal random crystal field distribution effects on the ferrimagnetic mixed spin-$\frac{1}{2}$ and spin-$\frac{3}{2}$ Blume–Capel model

Ali Yigit [a,]*, Erhan Albayrak [b]

[a] Çankırı Karatekin University, Department of Physics, 18100 Çankırı, Turkey
[b] Erciyes University, Department of Physics, 38039 Kayseri, Turkey

ARTICLE INFO

Article history:
Received 26 May 2012
Received in revised form
18 September 2012
Available online 16 October 2012

Keywords:
Mixed spin model
Random crystal field
Effective-field theory
Compensation temperature

ABSTRACT

The effects of bimodal random crystal field on the phase diagrams and magnetization curves of ferrimagnetic mixed spin-1/2 and spin-3/2 Blume–Capel model are examined by using the effective field theory with correlations for honeycomb lattice. The phase diagrams are obtained on the $(\Delta, kT/|J|)$, (Δ, T_{comp}) and $(p, kT/|J|)$ planes for given values of p and Δ, respectively. The model exhibits only the second-order phase transitions as in the Blume–Capel model with constant crystal fields. In addition, it was found that the model presents one or two compensation temperatures for appropriate values of random crystal field for given probability in contrast to constant crystal field case. Therefore, it is shown that the random crystal field considerably affects the thermal variations of net and sublattice magnetizations.

1. Introduction

In the last two decades, the mixed spin Ising models have been studied extensively. The mixed-spin Ising models in comparison to the systems with one type of spins present less translational symmetry and may exhibit a new type of critical temperature called as the compensation temperature (T_{comp}) at which the total magnetization vanishes below the critical temperatures [1]. Its existence provides interesting possibilities in technological applications such as in the thermomagnetic recording and magneto-optical readout applications [2]. Furthermore, they have also been proposed as possible models to describe a certain type of molecular-based magnetic materials that are studied experimentally [3].

On the other hand, the inclusion of a crystal field (CF) into the model considerably affects its critical behavior. If it is strong enough, the energy difference between the split levels is large. In this case, it is energetically more favorable to put as many electrons into the lower energy level before one starts to fill the higher energy level. Filling all the orbitals in the lower level means that they have to be paired up (within each orbital) with opposite spins. The effect of pairing electrons with opposite spins makes no addition to the total spin which results in a lower-spin state. Thus its competition with the bilinear interaction parameter leads to first-order phase transitions. One usually considers a CF which is constant throughout the lattice. There are only a few works about the spin-1/2 and spin-3/2 Blume–Capel (BC) model with constant CF in the literature: The phase diagrams and magnetization curves of the model were investigated by using the effective field theory (EFT) with correlations [4], the critical properties of the model was examined in terms of recursion relations on the Bethe lattice [5], the transverse Ising model was studied within framework EFT with correlations on the honeycomb lattice [6] and on the square lattice [7,8] and the kinetic behaviors of the model were investigated within mean field approach (MFA) [9]. Lately, the random crystal field (RCF) with some probability distribution instead of a constant one, i.e. $p=1$, become popular to investigate as well. The RCF effects are considered, since the CF may be altered with some internal or external effects such as the lattice distortions, impurities, defects, etc. The impurities and defects are known to play important roles in the existence of first-order phase transitions [10], therefore, the mixed spin-1/2 and spin-3/2 BC model with RCF is going to be studied in here. It should be mentioned that there are only two works with the mixed spin-1/2 and spin-3/2 model with RCF. The first one analyzes the model in terms of recursion relations on the Bethe lattice [11] and the other one approaches to the problem within the MFA [12]. The latter uses a different RCF distribution then the one that we consider in here and from [11].

Therefore, the aim of the present work is to investigate the RCF effects by using the EFT with correlations on the phase diagrams and magnetization curves of the ferrimagnetic mixed spin-$\frac{1}{2}$ and spin-$\frac{3}{2}$ BC model. The rest of this work is set up as follows: The next section is devoted to the explanation and formulation of the model and the last section includes our illustrations and findings in addition to a brief summary and conclusions.

* Corresponding author.
E-mail address: ayigit80@karatekin.edu.tr (A. Yigit).

0304-8853/$ - see front matter Crown Copyright © 2012 Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jmmm.2012.10.011

2. Formulation

The Hamiltonian of the mixed spin-1/2 and spin-3/2 BC model is given as

$$\mathcal{H} = -J\sum_{\langle i,j\rangle} S_i\sigma_j - \sum_j D_j\sigma_j^2, \tag{1}$$

where each S_i located at site i represents a spin-$\frac{1}{2}$ which takes the discrete values $\pm\frac{1}{2}$ and each σ_j located at site j represents a spin-$\frac{3}{2}$ which takes the discrete values $\pm\frac{3}{2}$, $\pm\frac{1}{2}$. The first sum runs over all pairs of nearest-neighbor (NN) sites, J is the bilinear interaction parameter between the NN spin pairs and which is taken $J<0$ for the ferrimagnetic case and D_j is the site dependent CF. The latter is distributed in a bimodal fashion according to

$$P(\Delta_j) = p\delta(\Delta_j - \mathit{\Delta}) + (1-p)\delta(\Delta_j), \tag{2}$$

where $\Delta_j = D_j/|J|$. This random distribution of the CF either turns on or turns off the CF randomly for given probabilities p and $1-p$, respectively, on the sites of lattice.

The sublattice magnetizations of mixed spin-1/2 and spin-3/2 BC model is obtained in here in terms of the EFT with correlations which is widely used in the study of the Ising models. It was first introduced by Honmura and Kaneyoshi [13] and Kaneyoshi et al. [14]. In this work, the magnetizations of spin S_i and spin σ_j for honeycomb lattice are obtained within the framework of EFT with correlations and with the usage of the general but approximate van der Waerden identity [15]. Therefore, the magnetizations of the sublattices are given as,

$$M_a = \langle S_i\rangle = \left[\cosh(J\eta\nabla) + \frac{M_b}{\eta}\sinh(J\eta\nabla)\right]^3 f_A(x)|_{x=0} \tag{3}$$

and

$$M_b = \langle\sigma_j\rangle = \left[\cosh(\tfrac{1}{2}J\nabla) + 2M_a\sinh(\tfrac{1}{2}J\nabla)\right]^3 f_B(x)|_{x=0}. \tag{4}$$

In addition a parameter q is defined as

$$q = \eta^2 = \langle (S_i)^2\rangle = \left[\cosh(\tfrac{1}{2}J\nabla) + 2M_a\sinh(\tfrac{1}{2}J\nabla)\right]^3 G(x)|_{x=0}, \tag{5}$$

where $\nabla = \partial/\partial x$ is the differential operator and the functions $f_A(x)$ for spin-1/2 and, $f_B(x)$ and $G(x)$ for spin-3/2 are found as

$$f_A(x) = \frac{1}{2}\tanh\left(\frac{\beta}{2}x\right), \tag{6}$$

$$f_B(x) = \frac{3\sinh(\frac{3}{2}\beta x) + \sinh(\frac{1}{2}\beta x)\exp(-2\beta\Delta_i)}{2\cosh(\frac{3}{2}\beta x) + 2\cosh(\frac{1}{2}\beta x)\exp(-2\beta\Delta_i)}, \tag{7}$$

$$G(x) = \frac{9\cosh(\frac{3}{2}\beta x) + \cosh(\frac{1}{2}\beta x)\exp(-2\beta\Delta_i)}{4\cosh(\frac{3}{2}\beta x) + 4\cosh(\frac{1}{2}\beta x)\exp(-2\beta\Delta_i)}, \tag{8}$$

where $\beta = 1/k_BT$, k_B is the Boltzmann constant, and T is the absolute temperature.

We should note that after expanding the right-hand sides of Eqs. (3)–(5), they are solved numerically within an iteration scheme. The readers can find all the details of the calculations in [6,16].

Lastly, the compensation temperatures T_{comp} is the temperature at which total magnetization vanishes and then given by

$$M_{Total} = \frac{(M_a + M_b)}{2}. \tag{9}$$

In the next section, the topologically distinct phase diagrams and our findings are presented which are obtained by studying the thermal variations of magnetizations for given values of our model parameters.

3. The thermal variations, phase diagrams and conclusions

In this section, we present the thermal variations of magnetizations, i.e. M_a, M_b and M_t, therefore, the phase diagrams of the model. The latter are obtained on the three possible planes for the honeycomb lattice, i.e., on the $(\mathit{\Delta}, kT/|J|)$, $(\mathit{\Delta}, T_{comp})$ planes for given values of probability p between 0 and 1 and on the $(p, kT/|J|)$ plane for given values of $\mathit{\Delta}$. The solid lines are the second-order phase transition lines which separate the ferromagnetic (F) regions from the paramagnetic (P) ones.

In Fig. 1, we illustrate the temperature changes of $M_a = M_{1/2}$ and $M_b = M_{3/2}$. It is obtained for various values of $\mathit{\Delta}$ when $p=0.5$. At the second-order phase transition temperatures, these magnetization curves combine at temperatures labeled with T_c for each $\mathit{\Delta}$. It is clear from the figure that, the ground-state (GS) values of $M_{3/2}$ are the usual ones, i.e., 1/2 for $\mathit{\Delta} = -1.0$ and -3.0 and 3/2 for $\mathit{\Delta} = 0.0$ and 3.0, in addition to the unusual one, i.e. 1 for $\mathit{\Delta} = -0.75$ (see also Fig. 2 of [4]). Especially, at the critical value $\mathit{\Delta} = -0.75$, $M_{3/2} = 1$, which indicates that in the GS the spin configuration of σ_j in the system consist of the mixed phase; the σ_j are randomly in the $\sigma_j = \pm 3/2$ or $\sigma_j = \pm 1/2$ state with equal probability. It is also obvious that the $\mathit{\Delta}$ drives the spins to the lower spin values for some values of p as it becomes increasingly negative.

An important explanation is now in order: If one uses the EFT with van der Waerden identity such as in Ref. [17] which actually leads to MFA [18] since it neglects all the correlations between the spins and in which case one cannot observe the GS with 1 [19] (call it as I. Approximation). But when one introduces the generalized van der Waerden identity such as in [6,16] (call it as II. Approximation) then the correlations are somewhat introduced into the model which leads to GS value of 1 as in this work.

The model displays one or two compensation temperatures, $T_{comp} < T_c$, as shown in Fig. 2. Only one $T_{comp} = 0.447$ is seen when $p=0.9$ and $\mathit{\Delta} = -2.5$. But the model displays two T_{comp}'s which are found at $T_{comp1} = 0.493$ and $T_{comp2} = 0.79$ for $p=0.4$ and $\mathit{\Delta} = -1.53$. We have only found the compensation temperatures when the sublattice magnetizations have the same GS's that is in this case is 1/2. Our obtained Fig. 2 are compatible with Fig. 6(b) and (c) of [20]. We also note the compensation temperature is not observed in the constant CF case [4] in opposition to our RCF work.

The first phase diagrams of the model is given on the $(\mathit{\Delta}, kT/J)$ plane for given p values with the intervals of 0.1 as illustrated in Fig. 3. The $p=0$ case has the same effect as $\mathit{\Delta} = 0.0$, since the

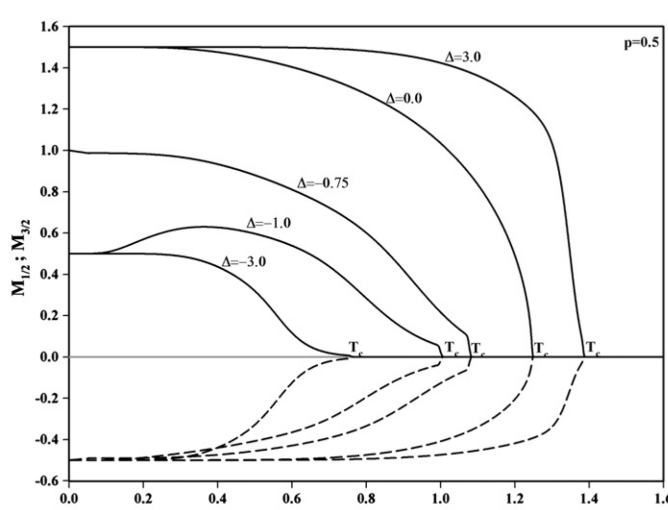

Fig. 1. The thermal variations of sublattice magnetizations for the mixed spin-1/2 and spin-3/2 BC model with $p=0.5$ and $\mathit{\Delta} = 3.0$, 0.0, -0.75, -1.0 and -3.0 for the honeycomb lattice.