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Tricritical behavior in the diluted transverse spin-1 Ising model with a longitudinal crystal field

K. Htoutou[a], A. Oubelkacem[a], A. Ainane[a], M. Saber[a,b,*]

[a]Physics Department, Faculty of Sciences, University of Moulay Ismail, B.P. 4010 Meknes, Morocco
[b]Max-Planck Institut für Physik Complexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany

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Abstract

The transverse spin-1 Ising model with a longitudinal crystal field exhibits a tricritical behavior. Within the effective field theory with a probability distribution technique that accounts for the self-spin correlations, we have studied the influence of site dilution on this behavior and have calculated the temperature-transverse field-longitudinal crystal field-concentration phase diagrams and determined, in particular, the influence of the concentration of magnetic atoms c on the tricritical behavior. We have found that the tricritical point appears for large values of the concentration c of magnetic atoms and disappears with the increase in dilution (small values of c). Results for square lattice are calculated numerically and some interesting results are obtained. In certain ranges of values of the strength of the longitudinal crystal field D/J when it becomes sufficiently negative, we found re-entrant phenomenon, which disappears with increase in the value of the strength of the transverse field.

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1. Introduction

Over recent years, there has been considerable interest in the theoretical study of the transverse spin-1 Ising model with a longitudinal crystal field. In the case of absence of the transverse field, the magnetic properties of the system have been studied by many approximate methods [1–11] and have successfully been used to describe cooperative physical systems, such as ternary alloys, multicomponent fluids as well as various magnetic problems, such as surface magnetism, thin films and multilayers, which are now current topics of magnetism [12–14]. Many authors have examined the critical properties of the system. These are of interest because a number of

*Corresponding author.
E-mail addresses: m-saber@caramail.com, saber@fsmek.ac.ma (M. Saber).

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interesting phenomena have been found in these quantities and can be attributed to the transverse field or to the longitudinal crystal field, such as tricritical phenomena. Recently, it has been shown that the transverse spin-1 Ising model with a longitudinal crystal field shows a tricritical behavior, i.e., there exists a point at which the phase transition changes from the second order to the first order when the transverse field Ω and the single ion anisotropy D (or the longitudinal crystal field) take the critical values Ω_t and D_t. Within the effective field theory based on the operator differential technique, Jiang et al. [5] have studied the pure transverse spin-1 Ising model with a longitudinal crystal field and have discussed the existence of a tricritical point when the value of D becomes sufficiently negative in the transverse field for the honeycomb lattice. It is found that the tricritical point exists for $1.235 < -D/J \leqslant 1.427$ and for $\Omega < 0.934$. For the square lattice [11], we have found that the tricritical point exists for $1.568 < -D/J \leqslant 1.8892$, when $\Omega/J < 1.447$.

On the other hand, many authors have examined the critical phenomena of the diluted spin-S Ising model with spin of magnitude $S = \frac{1}{2}, 1$ and the mixed spin Ising model in the presence of a longitudinal crystal field or a transverse field by various methods, such as the effective field theory [15–22], the finite cluster approach based on a single-site cluster approximation and some interesting results were obtained. Generally speaking, the magnetic properties of the diluted magnetic systems may be obviously different from those of the corresponding pure systems. It has been known that a lot of new physical phenomena can appear in these diluted magnetic systems. Recently, the phase transition of the bond-diluted spin-1 transverse Ising model with longitudinal crystal field interaction has been examined for the honeycomb lattice [26], and some interesting results are obtained.

The purpose of this work is to investigate the phase diagrams of the diluted spin-1 transverse Ising model with a longitudinal crystal field using the numerical diagonalization method within the framework of the effective field theory based on a probability distribution technique that accounts for the single site kinematic relations [22,23] on a square lattice ($N = 4$). In this paper, we investigate the study of the dependence of the critical temperature versus concentration of magnetic atoms c, the strength of the transverse field and the strength of the longitudinal crystal field. We discuss also the tricritical behavior of the system. Besides, we have found that our system exhibits the reentrant phenomenon depending on the values of the strength of the crystal and transverse fields. Our results such as tricritical behavior and reentrant phase transition behavior are in agreement with those obtained in [26]. In Section 2, we outline the formalism and derive the equations that determine the critical and tricritical temperatures. The numerical results are discussed in Section 3. Section 4 is devoted to a brief conclusion.

2. Model and formalism

We consider a diluted transverse spin-1 Ising model with a longitudinal crystal field on a square lattice. The Hamiltonian of the system is given by

$$H = -\sum_{\langle ij\rangle} J_{ij} c_i c_j S_{iz} S_{jz} - \Omega \sum_i c_i S_{ix} - D \sum_i c_i S_{iz}^2, \tag{1}$$

where S_{iz} and S_{ix} denote, respectively, the z and x components of a quantum spin $\overrightarrow{S}_i$ of magnitude $S = 1$ at site i, $J_{ij} = J$ is the strength of the constant coupling between the spins at nearest-neighbor sites i and j, Ω is the applied transverse field, D is the longitudinal crystal field and c_i is the occupation number on the lattice site i, $c_i = 1$ if the lattice site is occupied by a magnetic atom and zero otherwise.

In the single-site cluster theory, attention is focused on a cluster comprising just a single selected spin labelled 0, and the neighboring spins with which it directly interacts. To this end, the Hamiltonian is split into two parts, $H = H_0 + H'$, where H_0 is that part of the Hamiltonian containing the spin 0, namely

$$\beta H_0 = -\beta c_0 S_{0z} \sum_{j=1}^{N} c_j S_{jz} - \beta\sqrt{2} c_0 \Omega S_{0x} - \beta c_0 D S_{0z}^2. \tag{2}$$