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The Study of the Three-Dimensional Spin-3/2 Ising Model on a Cellular Automaton

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Abstract. The spin-3/2 Ising model on the simple cubic lattice with nearest-neighbour ferromagnetic bilinear interaction ($J>0$) is simulated on a cellular automaton by using the cooling algorithm improved from the Creutz cellular automaton. The phase diagrams of the model are constructed in the (D/J, kT/J) and (K/J, kT/J) plane. Comparison of the results are made with those of other methods. The temperature dependence of the order parameters and associated fluctuations are calculated at various of the model parameters and the static critical exponents are estimated within the framework of the finite-size scaling. The results are compatible with the universal Ising critical behavior except for $D/J=-3$ and $K/J=-2.3$.

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Key words: Spin-3/2 Ising model, Creutz cellular automaton, phase diagram, critical exponents, simple cubic lattice.

1 Introduction

The Hamiltonian of the spin-3/2 Ising model with bilinear (J) and biquadratic (K) interactions and a single-spin anisotropy parameter (D), also known as the spin-3/2 Blume-Emery-Griffiths (BEG) model, is

$$H_I=-J\sum_{<ij>}S_iS_j-K\sum_{<ij>}S_i^2S_j^2+D\sum_i S_i^2, \tag{1.1}$$

where the spin variables S_i located at site i on a discrete lattice can take the values $\pm 3/2$, $\pm 1/2$ and the first two summations run over all nearest-neighboring pairs.

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In recent years, much attention has been directed to the spin-3/2 Ising systems [1] which was initially introduced to give a qualitative description of phase transition observed in the compound DyVO4 and also to study tricritical properties in ternary mixtures [2].

There has been a number of theoretical studies to obtain the phase diagrams and critical and multicritical behavior of the model. All these studies were done by different methods, such as mean field approximation (MFA) [1–4], renormalization group (RG) methods [5,6], the effective-field theory (EFT) [7–9], cluster variation method (CVM) [10–12] and Monte Carlo (MC) simulation [3,13]. Most of these studies have considered some portion of the phase diagram of the model. Within the MFA and MC calculations [3], only the phase diagrams of the isotropic spin-3/2 BEG model and the spin-3/2 BC model which includes only J and K interactions were obtained. These models were also studied by using the EFT [8] and CVM [10]. Recently, the phase diagrams of the spin-3/2 BEG model in the $(D/J, kT/J)$ plane for several values of K/J and in the $(K/J, kT/J)$ plane for several values of D/J have been presented [6,11,12]. In spite of these studies, further studies using alternative methods are desirable to obtain the new phase diagrams and the critical behavior of the model. However, as far as we know, there is no extensive analysis within the framework of the finite-size scaling theory to determine the static critical exponents of the spin-3/2 BEG model in three dimensions.

In this paper, the critical behavior of the three-dimensional spin-3/2 BEG model has been studied by using an improved algorithm from the Creutz Cellular Automaton (CCA). Our interest is focused to obtain the phase diagrams in the $(D/J, kT/J)$ and $(K/J, kT/J)$ planes and estimate the static critical exponents on three dimensional lattice within the framework of finite-size scaling theory. The CCA algorithm is a microcanonical algorithm interpolating between the canonical Monte Carlo and molecular dynamics techniques on a cellular automaton, and it was first introduced by Creutz [14]. In the previous papers [14–21], the CCA algorithm and improved algorithms from CCA were used to study the critical behavior of the different Ising model Hamiltonians in two and three dimensions. It was shown that they have successfully produced the critical behavior of the models. The remainder of this paper is organized as follows: The details of the model are explained in Section 2, the results are discussed in Section 3 and a conclusion is given in Section 4.

2 Model

Three variables are associated with each site of the lattice. The value of each sites is determined from its value and those of its nearest-neighbors at the previous time step. The updating rule, which defines a cellular automaton, is as follows: Of the three variables on each site, the first one is Ising spin S_i. The Ising spin energy for the model is given by Eq. (1.1). The second variable is for momentum variable conjugate to the spin (the demon). The kinetic energy associated with the demon is $H_k = nJ$, where n is an integer,