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# Random crystal field effect on the kinetic spin-3/2 Blume–Capel model under a time-dependent oscillating field

A.G. El Hachimi [a,*], O. Dakir [a], S. Sidi Ahmed [a], H. Zaari [a], M. El Yadari [b], A. Benyoussef [c], A. El Kenz [a]

[a] *Laboratoire de Magnétisme et de Physique des Hautes Energies, associé au CNRST (URAC 12), Département de Physique, B.P. 1014, Faculté des Sciences, Université Mohammed V-Agdal, Rabat 10000, Morocco*

[b] *Department of Science, Moulay Ismael University, Faculté Polydisciplinaire, B.P.: 509 Boutalamine, 52000 Errachidia, Morocco*

[c] *Hassan II Academy of Science and Technology, Rabat, Morocco*

## HIGHLIGHTS

- Random crystal-field on the kinetic spin-3/2 Blume–Capel model is studied.
- New dynamical mixed phases appear $F_{3/2}+F_{1/2}$, $F_{3/2}+F_1$ and $F_1+F_{1/2}$.
- The system exhibits isolated end points, multicritical and dynamical tricritical phenomenon.

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## ABSTRACT

The effect of random crystal-field on the stationary states of the kinetic spin-3/2 Blume–Capel model is investigated within the framework of the mean-field approach. The Glauber-type stochastic dynamics is used to describe the time evolution of the system which is subject to a time-dependent oscillating external magnetic field. In addition to the well-known phase transitions and the appearance of the partly ferromagnetic phase characterized by the magnetization $m = 1$ in equilibrium case, a new dynamical regions between the ferromagnetic phases $F_{1/2}$, $F_1$ and $F_{3/2}$ are found where $F_{3/2}+F_{1/2}$, $F_{3/2}+F_1$, $F_1+F_{1/2}$ phases coexist for a weak value of the reduced magnetic field ($h$). Whereas for higher value of $h$ both solutions ordered $F$ and disordered $P$ phases coexist. Hence we present six types topologies of phase diagrams which exhibit dynamical first-order, second-order transition lines, dynamical tricritical and isolated critical end points. Furthermore, the dynamical thermal behavior magnetizations, susceptibilities and phase space trajectories are given and discussed.



## 1. Introduction

The Blume–Capel model, was first introduced by Blume [1] and independently by Capel [2]. In this model the Hamiltonian of the Ising system contains crystal field interaction in addition to the bilinear exchanged interaction. It plays a fundamental role in the multicritical phenomena associated with various physical systems, such as multicomponent fluids [3–5], ternary alloys [6], and magnetic systems [7].

* Corresponding author.
*E-mail address:* ag.elhachimi@gmail.com (A.G. El Hachimi).

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The spin-3/2 Ising model Hamiltonian with arbitrary bilinear ($J$) and biquadratic ($K$) nearest-neighbor interactions, has been introduced earlier [8] to give a qualitative description of phase transitions observed in the compound $DyVO_4$ within the mean field approximation (MFA).

Later on, the spin-3/2 Ising model contains a crystal field interaction or single ion anisotropy in addition to the exchange interactions $J$ and $K$, also known as the spin-3/2 Blume–Emery–Griffiths model was used in a study of tricritical properties of a ternary fluid mixture and compared with the experimental observations on the systems of ethanol–water–carbon dioxide [9].

Besides, the ferromagnetic spin-3/2 Blume–Capel, model has been studied within the effective field theory [10–12], the mean field approximation [13], the two spin cluster approximation in the cluster expansion method [14], conventional finite size scaling, conformal invariance, Monte Carlo simulations [15] and Ornstein–Zernike approximation [16]. While the antiferromagnetic spin-3/2 BC model has been studied within the MFA [17], the transfer matrix, finite size scaling calculations and Monte Carlo simulations [18]. Moreover, the effect of random crystal-field effect on the spin-3/2 Blume–Capel model on the square lattice has been investigated by the mean field method [19]. The model has also been studied within the cluster variation method [20].

Moreover, the dynamic phase transition is widely extended to more complex systems such as the Heisenberg-spin systems [21,22] X–Y model [23]. The high-spin Ising models have also been studied, such as the kinetic spin-1 Blume–Capel model [24], the kinetic spin 1/2 in the semi-infinite Ising model [25], the kinetic Blume–Capel model under an anisotropic coupled field interaction [26] and the kinetic of a mixed spin 1/2 and spin 1 Ising model [27]. The hysteresis for a two-dimensional spin-neighbor kinetic nearest-Ising ferromagnet in an oscillating field using Monte Carlo simulation is also studied [28,29].

In this work, the Adams Moulton predictor corrector numerical method is used to solve the mean field equation of motion obtained from the master equation. The time dependence of dynamical magnetization and the effect of random crystal field on this behavior are investigated. Moreover, a variety of phase diagrams are presented and commented.

The outline of this paper is as follows: In Section 2, we present the BC model with a random crystal field and we give the mean field dynamic equation of motion. In Section 3, we discuss the dynamical phase diagrams. The magnetizations and phase space trajectories are presented in Section 4. Finally, in Section 5 we give our conclusions.

### *1.1. The model and derivation of mean-field dynamical equation of motion*

The Hamiltonian of the spin-3/2 Blume–Capel model with a random crystal field in the presence of a time-dependent oscillating external magnetic field is given by:

$$\boldsymbol{H} = -J\sum_{\langle i,j\rangle} S_iS_j - \sum_i \Delta_i\,(S_i)^2 - H\left(\sum_i S_i\right) \tag{1}$$

where the spin $S_i$ located at the site $i$ takes the values $\pm 3/2$ and $\pm 1/2$. In the first term $J$ ($J > 0$) indicates the ferromagnetic exchange interaction between the spins at sites $i$ and $j$. $\langle i, j\rangle$ denotes the summation over all pairs of nearest neighbors. The second term represents a random crystal field interaction which is distributed according to the law:

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

with $\alpha \geq 0$. The last term, is a time dependent external oscillating magnetic field $H$ taken as:

$$H(t) = H_0 \sin(\omega t) \tag{3}$$

where $H_0$ and $\omega = 2\pi\upsilon$ are the amplitude and the angular frequency of the oscillating magnetic field, respectively. The system is in contact with an isothermal heat bath at absolute temperature.

The system evolves according to a Glauber-type stochastic dynamics at rate of $\frac{1}{\tau}$ transitions per unit time. Let as define $P\left(S_1, S_2, \ldots, S_N;\ t\right)$ the probability that the system has the $S$-spin configuration at time $t$. Then, we calculate $W_i\left(S_i \to S_i'\right)$ the probabilities per unit time that the $i$th $S$ spin changes from $S_i$ to $S_i'$. The time derivative of $P\left(S_1, S_2, \ldots;\ t\right)$ as:

$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{d}\xi}P\left(S_1, S_2, \ldots, S_N;\ t\right) = &-\sum_i\left[\sum_{S_i\neq S_i'} W_i\left(S_i' \to S_i\right)\right]P\left(S_1, S_2, \ldots, S_i, \ldots, S_N;\ t\right)\\ &+\sum_i\left[\sum_{S_i\neq S_i'} W_i\left(S_i \to S_i'\right)P\left(S_1, S_2, \ldots, S_i, \ldots, S_N;\ t\right)\right].\end{aligned} \tag{4}$$

Each spin $S$ can flip with probability per unit time given by the Boltzmann factor [30,31]. Furthermore, the sum of the probabilities is normalized to one, by multiplying both sides of Eq. (4) by $S_k$ and integrating over the probability distribution