Vol 15 No 4, April 2006
1009-1963/2006/15(04)/0842-03
Chinese Physics
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and IOP Publishing Ltd

The study of magnetization of the spin system in the ground state*

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(Received 7 December 2005; revised manuscript received 17 December 2005)

Within the framework of the effective-field theory with self-spin correlations and the differential operator technique, the ground state magnetizations of the biaxial crystal field spin system on the honeycomb lattices have been studied. The influences of the biaxial crystal field on the magnetization in the ground state have been investigated in detail.

Keywords: ground state, biaxial crystal field spin system, magnetization
PACC: 7510D, 7510H, 7550G

1. Introduction

In magnetic materials with localized magnetization, the crystal-field anisotropy plays a role in determining the magnetic behaviour of the system. The effects of the uniaxial and biaxial crystal-field anisotropy on the magnetic properties of spin systems have been an important theoretical problem for many magnetic materials. The finite temperature behaviours of a spin system with biaxial crystal field on the honeycomb and square lattice have been studied in our previous works[1,2] and others.[3–5] The ground state properties of a spin-S Ising model with the biaxial crystal-field have been only recently examined within an effective mapping to the transverse Ising model.[6] The effect of uniaxial and biaxial crystal-field on magnetic properties of a mixed spin-1/2 and spin-1 Ising model on the honeycomb lattice at finite and zero temperature has been discussed[7]. The nonlinear magnetization dynamics of the classical ferromagnet with biaxial anisotropies in an external magnetic field has been investigated.[8] However, as far as we know, there has not been an investigation of magnetic properties concerning the honeycomb lattice high spin systems with the biaxial crystal-field in the ground state. In this paper, we consider the ferromagnetic spin-3/2 and spin-2 Ising model in biaxial crystal-field on honeycomb lattice within the framework of the effective-field theory (EFT) with correlations. The outline of this paper is as follows. In the next section we shall introduce briefly the basic framework of the EFT theory with correlations and give the formulation for the systems. In Section 3, numerical results for the magnetization in the ground state will be presented in detail. Finally, we shall give the summary in Section 4.

2. Formulations

The Hamiltonian of the model and the magnetization for the system is given by:[1,2,9]

$$H = -J\sum_{\langle i,j\rangle} S_i^z S_j^z - D_x \sum_i (S_i^x)^2 - D_y \sum_i (S_i^y)^2, \tag{1}$$

$$\begin{aligned} M =& \langle S_i^z\rangle = \langle \exp(E_i\nabla)\rangle F(x)\,|_{x=0} \\ =& \left[\cosh(J\eta\nabla) + \frac{M}{\eta}\sinh(J\eta\nabla)\right]^3 F(x)|_{x=0}, \end{aligned} \tag{2}$$

$$\begin{aligned} \eta^2 =& \langle (S_i^z)^2\rangle = \langle \exp(E_i\nabla)\rangle G(x)\,|_{x=0} \\ =& \left[\cosh(J\eta\nabla) + \frac{M}{\eta}\sinh(J\eta\nabla)\right]^3 G(x)|_{x=0}, \end{aligned} \tag{3}$$

where S_i^x and S_i^y are the components of quantum spin operator at site i. The first summation is carried out only over nearest-neighbour pairs. D_x and D_y are biaxial crystal-field. $\nabla = \partial/\partial x$ is differential operator. $F(x)$ and $G(x)$ can only be described as:

*Project supported by the Natural Science Foundation of Liaoning province (Grant No 20041021) and the Scientific Research Foundation of the Educational Department of Liaoning province (Grant No 2004C006).
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for the spin-3/2 case:

$$F(x) = \frac{1}{\sum_{n=1}^{4} \exp(\beta\lambda_n)} \times \left\{ \sum_{n=1}^{4} \langle\varphi_n|S_i^z|\varphi_n\rangle \exp(\beta\lambda_n) \right\}, \quad (4)$$

$$G(x) = \frac{1}{\sum_{n=1}^{4} \exp(\beta\lambda_n)} \times \left\{ \sum_{n=1}^{4} \langle\varphi_n|(S_i^z)^2|\varphi_n\rangle \exp(\beta\lambda_n) \right\}, \quad (5)$$

for the spin-2 case:

$$F(x) = \frac{1}{\sum_{n=1}^{5} \exp(\beta\lambda_n)} \times \left\{ \sum_{n=1}^{5} \langle\varphi_n|S_i^z|\varphi_n\rangle \exp(\beta\lambda_n) \right\}, \quad (6)$$

$$G(x) = \frac{1}{\sum_{n=1}^{5} \exp(\beta\lambda_n)} \times \left\{ \sum_{n=1}^{5} \langle\varphi_n|(S_i^z)^2|\varphi_n\rangle \exp(\beta\lambda_n) \right\}, \quad (7)$$

where $\beta = 1/k_{\mathrm{B}}T$, k_{B} is the Boltzmann constant and T is the absolute temperature.

3. Numerical results and discussions

In this section, we shall study the ground-state behaviour of the system for the honeycomb lattice by taking into account the zero-temperature limit T=0K, $\beta \to \infty$. In the figures of this paper, the crystal-field are selected as D_x/J=0, –0.5, –1.0 respectively. The crystal-field D_y/J dependence of magnetization in the ground state is plotted in Fig.1 for the spin-3/2. From the figure we can see that when D_y/J increases for negative value, magnetization increases from $M \neq 0$, passes through a maximum, and disappears at a positive value of D_y/J. The values of D_y/J corresponding to $M = 0$ are D_y/J =3.207, 3.029, and 2.819 respectively. In the Fig.2 the crystal-field D_y/J dependence of magnetization in the ground state is given for the spin-2. The curves of the magnetization are quite different from those in Fig.1. It can be seen that when D_y/J increases for negative value, magnetization increases from M=0 ($M \neq 0$ in Fig.1), passes through a maximum, and disappears again at a positive value of D_y/J. The values of D_y/J corresponding to $M = 0$ are D_y/J =–13.65, 2.656; –12.55, 2.390; –11.41, 2.435 respectively. It is also found that magnetization in the ground state is not symmetric with D_y/J. This interesting result is the quantum effect produced by the biaxial transverse crystal-field.

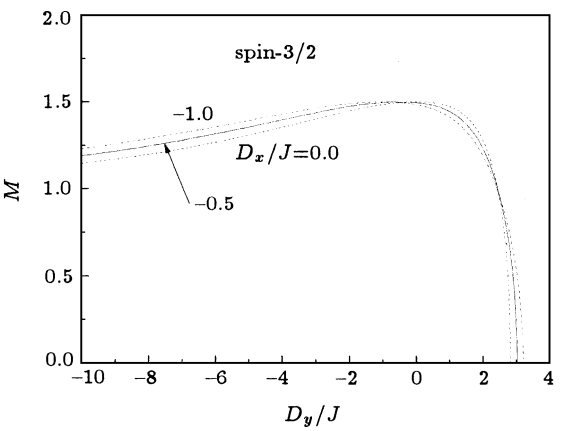


Fig.1. The biaxial crystal field D_y/J dependence of the magnetization for the spin-3/2 system in the ground state. The numbers accompanying each line are the values of the biaxial crystal field D_x/J.

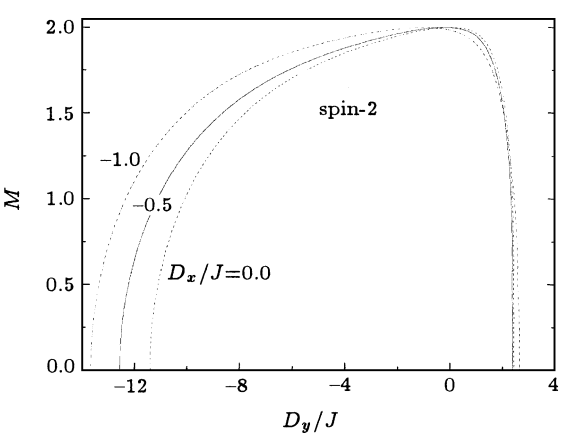


Fig.2. The biaxial crystal field D_y/J dependence of the magnetization for the spin-2 system in the ground state. The numbers accompanying each line are the values of the biaxial crystal field D_x/J.

4. Conclusions

We have studied the magnetization in the ground state of spin-3/2 and spin-2 Ising systems with the biaxial crystal-field. Within the framework of the EFT based on the differential technique, the effects of the biaxial crystal-field on the honeycomb lattice system have discussed in detail. It is found that the magnetization in the ground state is not symmetric with D_y/J. This interesting result is the quantum effect produced by the biaxial transverse crystal-field.

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