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The multi-compensation temperatures for the four-sublattice Heisenberg ferrimagnetic system

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HIGHLIGHTS

- We study magnetizations of four-sublattice Heisenberg ferrimagnetic system on square lattice.
- Green's function technique is employed.
- There are the first-order phase transitions from ferrimagnetic to ferrimagnetic or ferromagnetic states.
- System exhibits one-, two- and three-compensation temperatures.
- Frustrated spin is observed.

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ABSTRACT

The various types of magnetizations of a four-sublattice mixed-spin Heisenberg ferrimagnetic system are investigated with the help of the double-time temperature-dependent Green's function technique. One obtains the first-order phase transitions from ferrimagnetic states to ferrimagnetic or ferromagnetic states with respect to the choice of parameters in Hamiltonian. The system exhibits one-, two- and three-compensation temperatures where the sublattice magnetizations compensate each other at one- or more-points. We have managed to obtain three different spin configurations at the absolute temperature. Moreover, we observed a so-called frustrated spin.

1. Introduction

The ferrimagnets have very complex magnetic structures, so the theoretical studies of these substances are very difficult. One of the most interesting properties of ferrimagnets is that they exhibit the compensation temperature. This phenomenon observes that the sublattice magnetizations compensate each other at one- or more-points. Theoretically, for the two-sublattice system, using different models, one-, two- and three-compensation temperatures have been obtained [1–6]. Experimentally, there are many substances exhibiting one-compensation temperature [5–10]. On the other hand, one observed experimentally two-compensation temperatures in the series $(Ni^{II}_{0.22}Mn^{II}_{0.6}Fe^{II}_{0.18})_{1.5}\ [Cr^{III}(CN)_6].7.6H_2O$ with the four sublattices [11] and in the series $K^{I}_{0.18}\ (Co^{II}_{0.39}Mn^{II}_{0.61})_{1.41}\ [Cr^{III}(CN)_6].9H_2O$ with the three sublattices [12].

The double-time temperature-dependent Green's function technique seems to be helpful to discuss a multi-sublattice model within the whole temperature range. The Green's function technique is used to obtain, for the first time, the parallel and perpendicular susceptibilities for an antiferromagnetic crystal with a four-sublattice [13]. In the four-sublattice ferrimagnetic systems, the retarded Green's function has been used by Qui and Zhang within the framework of the linear

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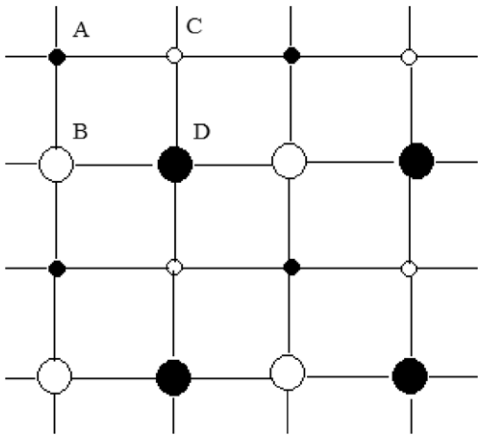

Fig. 1. The schematic representation of four sublattices on the square lattice.

spin-wave approximation [14,15]. Moreover, the Hamiltonian for a four-sublattice Heisenberg ferrimagnet or ferromagnet with different exchange constants was established by Zhang [16].

In our previous work, we have studied the spin configurations of rectangular lattice which has four sublattices [17]. We present application of the Green's function technique to the four-sublattice (A, B, C, D) Heisenberg ferrimagnetic system with single-ion anisotropies. To be consistent with the structure of $(Ni^{II}_{0.22}Mn^{II}_{0.6}Fe^{II}_{0.18})_{1.5}$ $[Cr^{III}(CN)_6].7.6H_2O$ compounds, we consider $S_A = 3/2$ (for sublattice A), $S_B = 2$ (for sublattice B), $S_C = 1$ (for sublattice C) and $S_D = 5/2$ (for sublattice D). We obtain the various types of magnetization curves. Some of them have been already classified according to Néel classification [18], but some are not classified. Depending on the choice of parameters in Hamiltonian, we obtain the first-order phase transition from ferrimagnetic states to ferrimagnetic or ferromagnetic states. We found one-, two- and three-compensation temperatures. Moreover, there are three different spin configurations at the absolute temperature and we observe a so-called frustrated spin. Although exchange interaction is a negative value, the system becomes ferromagnetic order. The outline of this paper is as follows. In Section 2, we present the formalism of the Green's function method and establish the self-consistent equations. In Section 3, the numerical results are discussed for the magnetization curves. Finally, Section 4 contributes to conclusions.

2. Green's function formalism and model

The four sublattices are denoted by A, B, C and D, as shown in Fig. 1. The lattice is a square lattice and the distance between the atoms is taken as l. All sublattices are also square lattices.

We shall apply Green's function theory to the mixed spin-3/2, spin-2, spin-1 and spin-5/2 Heisenberg ferrimagnetic system, including the single-ion anisotropies for all sublattices. We deal with the following Hamiltonian:

$$\begin{aligned} H = & -\sum_{\langle ij\rangle} J_{ij} S_i \cdot S_j - \sum_{\langle ik\rangle} J_{ik} S_i \cdot S_k - \sum_{\langle im\rangle} J_{im} S_i \cdot S_m - \sum_{\langle jk\rangle} J_{jk} S_j \cdot S_k - \sum_{\langle jm\rangle} J_{jm} S_j \cdot S_m \\ & - \sum_{\langle km\rangle} J_{km} S_k \cdot S_m - \sum_{\langle ii'\rangle} J_{ii'} S_i \cdot S_{i'} - \sum_{\langle jj'\rangle} J_{jj'} S_j \cdot S_{j'} - \sum_{\langle kk'\rangle} J_{kk'} S_k \cdot S_{k'} - \sum_{\langle mm'\rangle} J_{mm'} S_m \cdot S_{m'} \\ & - D_A \sum_i (S_i^z)^2 - D_B \sum_j (S_j^z)^2 - D_C \sum_k (S_k^z)^2 - D_D \sum_m (S_m^z)^2 \end{aligned} \tag{1}$$

where the subscripts i, j, k and m label lattice sites for sublattices A, B, C and D respectively, and the corresponding spin operators are $\mathbf{S}_i$, $\mathbf{S}_j$, $\mathbf{S}_k$ and $\mathbf{S}_m$. $J_{ij} = J_1, J_{ik} = J_2, J_{im} = J_3, J_{jk} = J_4, J_{jm} = J_5, J_{km} = J_6$ are the exchange constants between the nearest-neighboring sites and $J_{ii'} = J_7, J_{jj'} = J_8, J_{kk'} = J_9$ and $J_{mm'} = J_{10}$ are the exchange constants between the second nearest neighboring sites for the sublattices A, B, C and D. Moreover, D_A, D_B, D_C and D_D are the single-ion anisotropy parameters of corresponding sublattices.

To derive the required equations of motion, we chose Green's functions as follows:

$$\mathbf{G}(t) = \begin{pmatrix} \langle\langle S_i^+(t); B_l(0)\rangle\rangle \\ \langle\langle S_j^+(t); B_l(0)\rangle\rangle \\ \langle\langle S_k^+(t); B_l(0)\rangle\rangle \\ \langle\langle S_m^+(t); B_l(0)\rangle\rangle \end{pmatrix} \tag{2}$$

where $B_l = e^{aS_l^z} S_l^-$, a is Callen's parameter [19].