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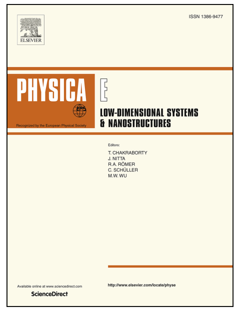

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Magnetic and magnetocaloric properties of the exactly solvable mixed-spin Ising model on a decorated triangular lattice in a magnetic field

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Abstract

The ground state, zero-temperature magnetization process, critical behaviour and isothermal entropy change of the mixed-spin Ising model on a decorated triangular lattice in a magnetic field are exactly studied after performing the generalized decoration-iteration mapping transformation. It is shown that both the inverse and conventional magnetocaloric effect can be found near the absolute zero temperature. The former phenomenon can be found in a vicinity of the discontinuous phase transitions and their crossing, while the latter one occurs in some paramagnetic phases due to a spin frustration to be present at zero magnetic field. The inverse magnetocaloric effect can also be detected slightly above continuous phase transitions following the power-law dependence $|-\Delta\mathcal{S}_{iso}^{min}| \propto h^n$, where n is depends basically on the ground-state spin ordering.

Keywords: Ising model, Magnetization process, Spin frustration, Magnetocaloric effect, Exact results

1. Introduction

Exactly solvable mixed-spin Ising models on two-dimensional (2D) lattices belong to attractive issues of the statistical mechanics, because they provide a convincing evidence for many controversial results predicted in the phase transition theory. More specifically, these systems represent useful testing ground for a rigorous theoretical investigation of the spin frustration [1–14], reentrant phenomenon [1–4, 12–17], compensation behaviour [2, 16–20], change of the usual critical points to the multi-critical ones [14, 15, 20–22], as well as striking spontaneous 'quasi one-dimensional' spin order at the absolute zero temperature [23, 24]. Moreover, quantum effects can also be exactly examined by imposing the transverse magnetic field or the biaxial single-ion anisotropy on some spins of the 2D lattices [17–19, 25–27].

On the other hand, a rigorous investigation of the magnetic-field effect on magnetic properties of the 2D Ising models still remains an open topic due to the lack of closed-form exact solution for the partition function at finite magnetic fields. At present, there are known just a few mixed-spin Ising models which allow an exact study of the magnetic-field effect in 2D, namely, the spin-1/2 Ising model on a kagomé lattice [5–7], the spin-1/2 Fisher super-exchange model on a decorated square lattice [8, 9] and its another extensions [10–13]. All these models involve the action of the longitudinal magnetic field on two-thirds of all the lattice sites. This assumption allows one to obtain exact solutions for the models by using the concept of generalized algebraic transformations [28–31]. In fact, the generalized decoration-iteration and star-triangle transformations establish a rigorous mapping correspondence between the aforementioned models and the spin-1/2 Ising lattices with known exact analytical solutions [29, 32, 33], which gives the opportunity to gain a comprehensive picture on the critical behaviour as well as thermodynamics of these systems. Moreover, it has been demonstrated in our recent works [13] and [34] that the Fisher super-exchange model and its another variants represent excellent tools for a rigorous theoretical investigation of the magnetocaloric effect (MCE) in a proximity of the continuous (second-order) phase transitions. Thanks to its exact solvability, important MCE quantities such as the isothermal entropy change and the adiabatic temperature change may be straightforwardly calculated.

Besides the academic interest, the 2D mixed-spin Ising models, which do not assume the magnetic-field effect on all particles, are also valuable for elucidation of an unusual magnetic behaviour of several real compounds. This specific requirement can be observed, e.g. in the ferrimagnet $SrCr_8Ga_4O_{19}$, which consists of kagomé slabs with magnetic spins residing just at one-third of all lattice sites [35], or various high-T_c antiferromagnetic cuprates including CuO_2 planes in their crystal structures, such as $Ba_2YCu_3O_{9-\delta}$ [36], $Pr_{1-x}LaCe_xCuO_{4+\delta}$ [37], $La_{2-x}M_xCuO_{4-\delta}$ (M=Ba, Sr) [38].

Taking into account the aforementioned facts, we propose in this paper a novel mixed-spin Ising model on a decorated triangular lattice in a longitudinal magnetic field for which the closed-form exact solution can be derived. The proposed model is somewhat reminiscent of the generalized Fisher super-exchange model on a square lattice [8–13], but its main novelty lies in definition on a non-bipartite triangular lattice, which provides a possible playground for a new type of spin frustration. Besides the ground-state analysis, our attention is focused on the study of the zero-temperature magnetization process, critical behaviour and magnetocaloric properties of the system.

The organization of the paper is as follows. Section 2 con-