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Monte Carlo study of the random magnetic field effect on the phase diagrams of a spin-1 cylindrical nanowire

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In this work, the phase diagrams and the tricritical behavior of a cylindrical nanowire, consisting of a ferromagnetic core of spin-1 atoms surrounded by a ferromagnetic shell of spin-1 atoms with ferromagnetic or antiferromagnetic interfacial coupling are studied in the presence of a random magnetic field. Based on Metropolis algorithm, Monte Carlo simulation has been used to investigate the effects of the exchange coupling of the shell, the interfacial coupling, and the random magnetic field on the critical behavior of the nanowire. Depending on the values of the system parameters, different types of phase diagrams were found. A variety of multicritical points such as tricritical point, isolated critical point, and triple point are obtained. In addition, the compensation temperature can be appear in the ferrimagnetic system case.

1. Introduction

Magnetic properties of the nanostructures such as nanowires [1,2], nanotubes [3], nanofilms [4], nanorods [4,5], and nanoparticles [6] have been one of the most interesting topics of many investigations due to their small size, and for their potential applications in many fields. In particular, Nanowires can be applied in ultra-high-density magnetic recording media [7,8], magnetic resonance imaging [9], ferrofluids [10], catalysis [11], medical applications [12], permanent magnets [13]. Experimentally, magnetic nanowire such as Zno [14], Mn doped Zno [15] and Fe_xPd_{1-x} [16] can be synthesized by several experimental techniques. Also, nanowire arrays [17–19] are fabricated by various coating methods and they have many applications in technology. Theoretically, magnetic behavior of nanowires have been studied by several methods, including the mean field theory [20], effective field theory [21], Green function formalism [22], Beth Perils approximation [23] and Monte Carlo simulation (MCS) [24]. Recently, Feraoun et al. [25] have investigated the magnetic properties of a mixed spin (1, 3/2) ferrimagnetic nanowire on a hexagonal lattice using Monte Carlo simulation. The results present rich critical behavior, which includes the first- and second-order phase transitions, the tricritical and critical end point. In Refs. [26–28], the magnetic properties of a hexagonal nanowire, cubic nanowire and multisublattice cubic nanowire with mixed spin (1, 3/2) have been examined by the EFT. Two compensation points can exist for certain values of the system parameters. In recent work, Jiang et al. [29] have investigated the compensation behavior, and the magnetic properties of a ferrimagnetic nanotube, which includes ferromagnetic spin $-3/2$ inner shell and spin -1 outer layer with a ferrimagnetic inter-layer coupling. Two compensation points have been found for certain values of the system parameters. Kantar et al. [30] have proposed a ternary Ising spin (1/2, 1, 3/2) model to investigate the thermal and the magnetic properties of magnetic nanoparticles with core–shell structure by using effective field theory with correlations. They have found that the system exhibits a tricritical point, reentrant and five different type (Q, P, R, S and W) of compensation behaviors that strongly depend on interaction parameters.

On the other hand, the random field Ising model (RFIM) has been studied extensively both theoretically and experimentally [31–36], because it helps to simulate many interesting but complicated problems. It can be used to describe such processes as the phase separation of a two component fluid mixture in porous material or gelatin and solution of hydrogen in metallic alloys [37]. Certain experiments on the liquid vapor transition in aerogel [38] reveal a coexistence curve similar to the pure Ising model but slow dynamics that are suggestive of random-field effects. Since the

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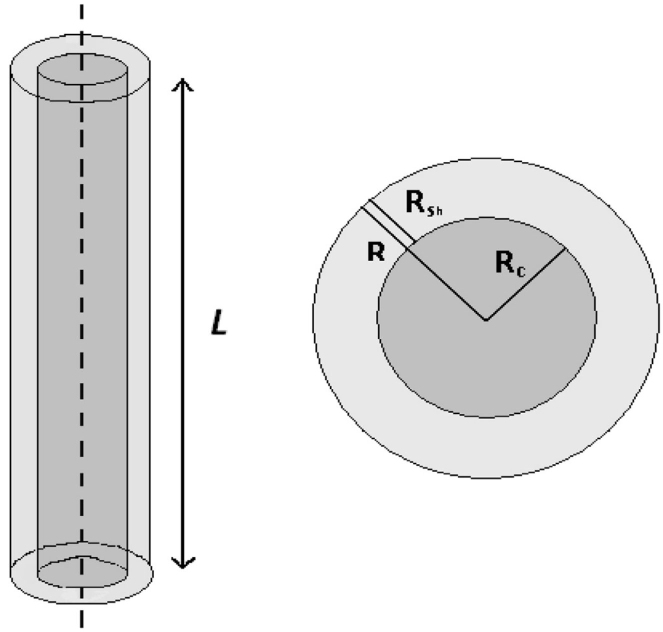

Fig. 1. Schematic representation of a nanowire with cylindrical shape of length L and radius R.

aerogel creates a random network that attracts the fluid, the RFIM should be an appropriate model [39] for this system. However, the RFIM has been treated by using various techniques, such as mean field theory [40–42], effective-field theory [43–45], Monte Carlo simulations [46–48], renormalization-group calculations [49–51], finite cluster approximation [52,53] and Bethe Peirls approximation [54]. Some studies show that we can find in these systems a very rich critical behavior and many interesting phenomena (the existence of a reentrant behavior and tricritical points). Using the effective field theory based on a probability distribution method, Magoussi et al. [55,56], have investigated the influence of the trimodal random magnetic field on the magnetic properties and the hysteresis behaviors of a spin-1 Ising nanotube. They have observed that the system presents tricritical point and reentrant or double reentrant phenomenon. Akinci [57,58] has studied the effect of the continuous or the discrete random magnetic field distributions on the phase diagrams and ground state magnetizations of an Ising nanowire by using the effective field theory with correlations. Some interesting results have been found such as disappearance of the reentrant behavior and first order transitions which appear in the case of discrete distributions. Zaim et al. [59,60], have examined the effects of the random magnetic field on the magnetic behaviors of a hexagonal nanowire and nanoparticle with core/shell morphology by using effective field theory. A number of characteristic behaviors have been found, such as the existence of double or triple hysteresis loops for appropriate values of the system parameters.

Despite these studies, as far as we know, the influence of the bimodal random magnetic field on the magnetic properties and the phase diagrams of a spin-1 cylindrical nanowire with core–shell structure have not been studied. Therefore, in this work, we study the phase diagrams and the tricritical behavior of a spin-1 cylindrical nanowire with core–shell structure in the presence of a random magnetic field by using Monte Carlo simulation based on Metropolis algorithm.

The organization of this paper is as follows: In Section 2, we give the Formalism and Monte Carlo simulation. In Section 3, we present the results and discussions, while Section 4 is devoted to a brief conclusion.

2. Model and Monte Carlo simulation

We consider a ferromagnetic core/shell Ising nanowire with cylindrical shape of length L and radius R, located on a simple cubic (SC) lattice with the distances between network nodes are equals to unity ($a = 1$). Two regions are distinguished inside the nanowire: a ferromagnetic core with radius R_c and a ferromagnetic shell of thickness $R_{sh} = R - R_c$. The sites of the nanowire are occupied by spin-1 atoms. The Hamiltonian describing our system can be written as:

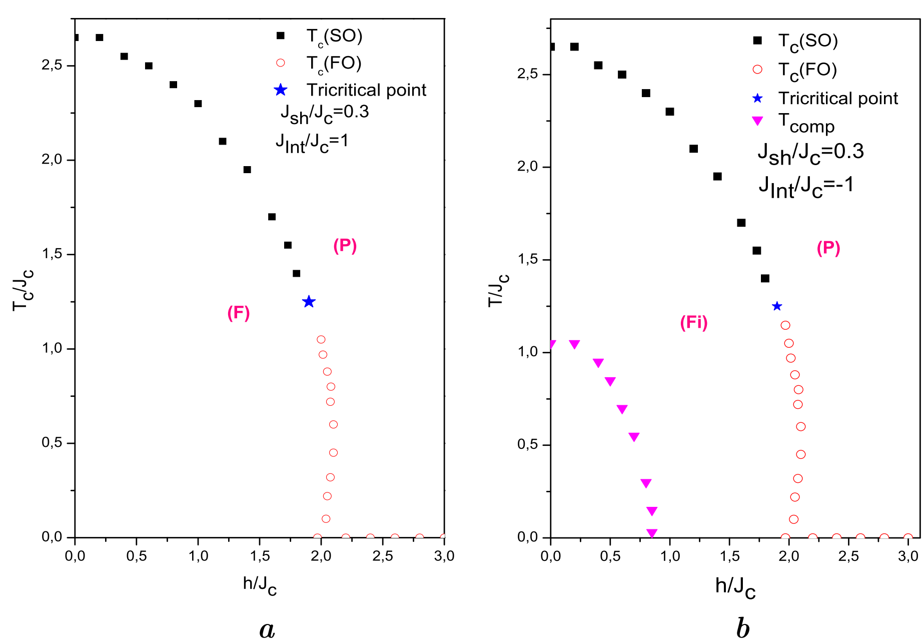

Fig. 2. The phase diagram in the (T_c/J_c,h/J_c) plane for $J_{sh}/J_c = 0.3$ and $J_{Int}/J_c = -1$.