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Magnetization jumps in the $\pm J$ spin glass model

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We investigate the hysteresis curve of a 2D Random Bond Ising Model (RBIM) with anti- (AF) and ferromagnetic (F) couplings at concentration of 50% each. The hysteresis curves show magnetization jumps (first order transitions) at well defined magnetic fields indicating topological blocking effects caused by frustration domains in the system.

Keywords: Ising model; magnetic systems; hysteresis

Se investigan curvas de hysteresis en el modelo de Ising en 2D con enlaces aleatorios $\pm J$ en concentracion de 50%. Las curvas de hystéresis muestran saltos en la magnetización (transiciones de primer orden) a campos bien definidos. Este fenómeno es una consecuencia de bloqueo topolólogico de dominios en el sistema, debida a la frustración de los dominios del sistema.

Descriptores: Modelo de Ising; sistemas magnéticos; hystéresis

PACS: 75.50.Pa; 75.40.Mg; 75.60.-d

1. Introduction

Recently [1, 2], is was found that the isothermal hysteresis loops M *versus* H of some site-diluted antiferromagnetic samples show a series of well defined jumps, for temperatures below the Néel temperature ($T_N \approx 10K$). Magnetization jumps are associated with the so called Barkhausen effect [3, 4], *i.e.* the noise generated when a domain wall jumps erratically from one pinned configuration to the next. The abrupt and stochastic response of the magnetization to the external field arises from the intrincate character of interactions, magnetoelastic properties and defects in the system. A detailed study of this behavior appears to be very difficult. The investigation of these athermal avalanches have become an interesting subject in the physics of disordered system. A simple way to study this effect is to introduce some disorder on simple models. Sethna and coworkers [5] considered a random-field Ising model (RFIM) at zero temperature to study the magnetization as a function of external magnetic field. The obtained hysteresis loops evidence the possibility of having return-point memory. They also show that changing the amount of disorder, the hysteresis cicle changes from a percolating avalanche to a situation where all avalanches are small. The phase transition takes place at a critical value of disorder for which the avalanches have no characteristic length scale. Alternatively, the magnetic field dependence of a random bond Ising model (RBIM) at zero temperature was investigated by Vives and Planes [6]. They introduce disorder by changing the width of the Gaussian probability distributions for the spin-spin interactions J_{ij}. It induces smearing of the first-order ferromagnetic reversal process, similarly as obtained in the RFIM case. A critical amount of disorder causes the disappearance of infinite avalanches at the reversal transition, which then becomes of second order. Again, at the critical disorder, avalanches on all lengh scales were obtained. Contrary to the RFIM case, no return-point memory properties are observed.

In this paper, another scenario of first-order phase transition, under another kind of disorder, is presented. The $\pm J$ Ising model (RBIM) with equal concentration of bonds, has been studied. The disorder is introduced distributing randomly these bonds through the lattice.

2. Model

We performed Montecarlo simulations [7] for the RBIM in external magnetic field H on a 6×6 square lattice with periodic boundary conditions. The Hamiltonian of this system is:

$$\mathcal{H} = \sum_{i,j} J_{ij} S_i S_j - B \sum_i S_i .$$

The first sum extends over all pairs of nearest neighbors, $S_i = \pm 1$ represents the third component of the spins at sites i and j respectively. Half of the exchange interactions J_{ij}, randomly chosen (concentration $p = 0.5$), take the value $-J$

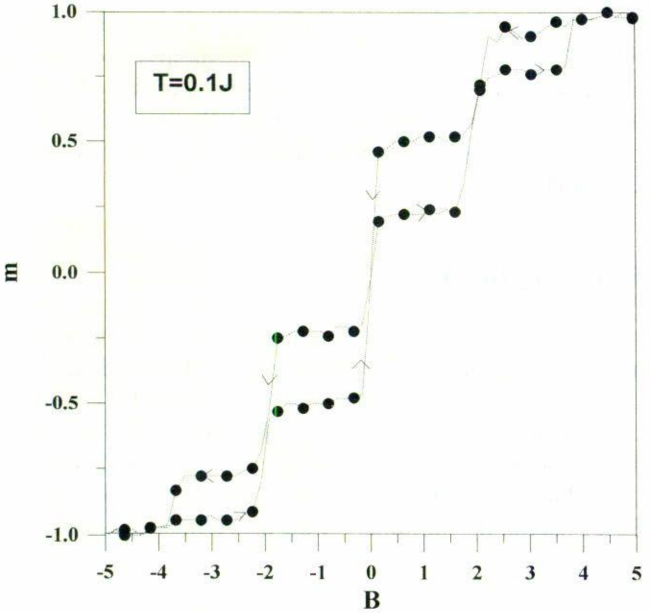

FIGURE 1. Field cooled, isothermal hysteresis loop for one sample of a 6×6 lattice in the $\pm J$ RBIM, at $T = 0.1\,J$. The arrows show the history followed by the external magnetic field B.

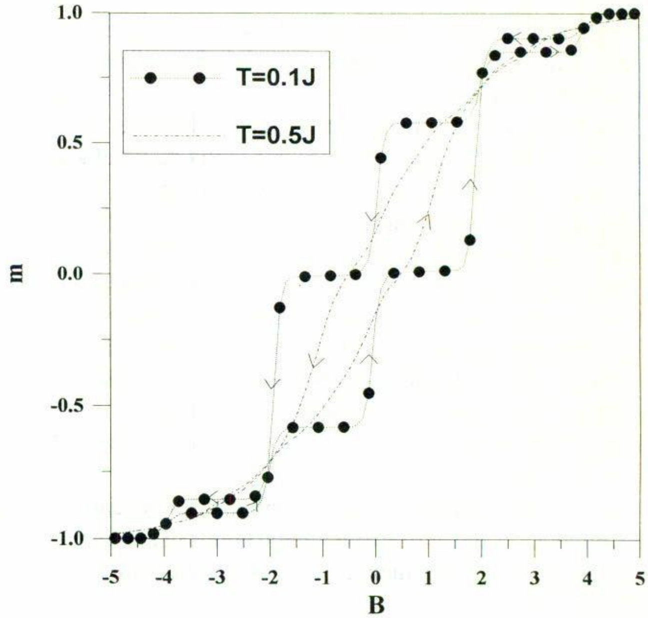

FIGURE 2. Field cooled, isothermal hysteresis loops of the $6{\times}6$ lattice for the $\pm J$ RBIM. The reduced magnetization m is the average value over 500 samples. The dotted line represent the results at $T = 0.1\,J$ (low temperature) and the dashed-dotted line despicts the results for $T = 0.5\,J$ (high temperature). The arrows show the history followed by the magnetic field B.

(ferromagnetic coupling), while the other half take the value $+J$ (antiferromagnetic coupling). B represents the external magnetic field measured in units of J for dimensionless spins. Ensemble averages were calculated using 500 samples of randomly distributed bonds. The ground state properties of this model in absence of external field has been extensively studied in the literature [8]. This model represents the Edwards Anderson model of a spin glass [9]. It is known that in a square lattice and when $p > p_c$, this system undergoes a spin glass transition at $T = 0$ K. The critical value is around $p_c \approx 0.15$, and it is associated with the percolation of nonfrustrated "plaquettes" [10]. In three-dimensional $\pm J$ lattices it is accepted that they behave as spin-glasses under $T = 1.175$ in units of J [11]. However, in two dimensions there is still some controversy whether or not this transition happens at finite temperature [12]. Therefore, it is important to establish whether or not there is hysteresis for these objects and which are its main properties.

3. Results

Montecarlo simulations using 360 000 steps for each system, were used to calculate the magnetization of the system. Results for the reduced magnetization m defined as:

$$m = \frac{1}{N} \sum_{i=1}^{N} S_i,$$

as a function of the external magnetic field are illustrated in the following figures.

The magnetization m as a function of external magnetic field at $T = 0.1\,J$, considering one particular configuration of bonds (a sample) of the 500 samples in a $N = 6 \times 6$ square lattice is shown in Fig. 1. Here we see clearly jumps in the magnetization at fields $B = 0$, $B = \pm 2\,J$ and $B = \pm 4\,J$, and also hysteresis.

In Fig. 2 we show the results of the average magnetization m of the system as a function of external field B. The m value was calculated as the ensemble average over the 500 samples. For $T = 0.1\,J$ (dotted line and filled circles) we see magnetization jumps at the same fields as in Fig. 1 ($B = 0$, $2\,J$ and $4\,J$). For a higher temperature case, $T = 0.5\,J$, (dashed-dotted line) the system presents a smooth hysteresis curve where the jumps have dissapeared. The jumps at low temperature for the ensemble average are the fingerprint of the first order transition.

4. Discussion and conclusions

Discontinuities in $\pm J$ Ising lattices has been already observed by Vogel and Cartes [13]. They studied the same system, as presented above, under an uniform static magnetic field and calculated energy, magnetization and correlation at zero temperature. All magnitudes present discontinuities, evidencing of topological pinning in different lattices. The jumps at $B = 0$, $B = 2\,J$ and $B = 4\,J$ appear to be a general property of the $\pm J$ Ising model. From a simple point of view, the local fields at a particular site can take only the values $-4\,J$, $-2\,J$, 0, $2\,J$, and $4\,J$ for any random distribution of bonds (any of the 500 samples). Consequently, we expect, at these field values, macroscopic spin avalanches (magnetization jumps), irrespective of the lattice size, in order to reach the true ground state for a given magnetic field, at zero temperature.

Currently we are investigating the lattice-size dependence of this jumps, as well as the magnetization values at those field. We can argue that a triangular lattice, with 6 nearest neighbors, will show magnetization jumps at $B = 0, \pm 2\,J, \pm 4\,J$ and $\pm 6\,J$, as a consequence of the possible exchange fields on the sites. Our result can be compared to that of Vives and Planes [6], in the sense that we are using a bimodal distribution of bonds, instead of a Gaussian distribution in a ferromagnetic model. Further calculations are necessary to establish if our model shows the return–point memory [5]; this was not the case for the systems studied by Vives and Planes.

We conclude that the $\pm J$ RBIM with equal concentration of ferromagnetic and antiferromagnetic bonds in a square lattice presents, as a consequence of topological pinning, magnetization jumps (first order transitions) at low temperatures at fields $B = 0, \pm 2\,J$, and $B = \pm 4\,J$. The jumps arise when the external field equals one of the possible exchange fields on each site.This result is independent of lattice size. Preliminary results show also that the reduced magnetization is size independent [14]

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