Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Journal of Magnetism and Magnetic Materials 272–276 (2004) 701–702
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Hysteresis jumps in magnetic systems with random anisotropy

R. García Calderón[a], J.C. Gómez Sal[a], J.R. Iglesias[b,c,*]

[a] Departamento CITIMAC, Facultad de Ciencias, Universidad de Cantabria, Avda. Los Castros s/n, Santander 39005, Spain
[b] Laboratoire de Physique des Solides, Université Paris-Sud, Bâtiment 510, Orsay 91405, France
[c] Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre 91501 – 970, Brazil

Abstract

Monte Carlo simulations on three-dimensional lattices have been performed considering a simple model of a ferromagnetic spin system in an external magnetic field and with a random local anisotropy. For some particular values of the ratio between the anisotropy strength and the exchange constant, we obtain hysteresis cycles exhibiting sharp jumps that disappear when increasing temperature, in agreement with experimental results for some cerium compounds.

PACS: 71.27.+a; 75.60.Ej; 61.46.+w

Keywords: Cerium compounds; Random anisotropy; Hysteresis cycles; Hysteresis jumps

The existence of intrinsic magnetic inhomogeneities as magnetic clusters has been evidenced in many interesting new magnetic materials as manganites [1] or strongly correlated Ce compounds [2,3]. The description of the system as a Griffith's phase [4] of magnetic clusters embedded in a nonmagnetic matrix is an attractive model for these inhomogeneities. In the case of Ce or rare earth systems, strong local anisotropy is also expected. This situation is clearly reminiscent of the fine particle case with competing anisotropies. The evidence of hysteresis cycles with sharp discontinuities at very low temperatures (85 mK) in some compounds of the $CeNi_{1-x}Cu_x$ series [5], motivated us to simulate such a situation, with a model that, in our opinion, could be extended to other magnetic systems with similar phenomenology.

To describe the interacting magnetic clusters, we have modeled the system with a simple three-dimensional Ising-like spin Hamiltonian, written as

$$H = -\frac{J}{2N}\sum_{i,\delta} s_i s_{i+\delta} - K\sum_i s_i \cos\phi_i - h\sum_i s_i (1),$$

where the first term represents a ferromagnetic interaction between the clusters, the second one corresponds to a random local field of strength K and oriented with an angle ϕ_i on each cluster and the third one to the applied magnetic field, h. Similar models have been previously studied by other authors, with random anisotropy [6] or dipolar interaction [7].

In the numerical calculation, we assign to each cluster a spin $s_i = \pm\frac{1}{2}$ in order to represent just two directions of local magnetization. A more realistic model should also consider that the magnitude of the spin is site dependent, but for the moment we consider an average value. Also, the simulation is performed on a cubic spin lattice with $30 \times 30 \times 30$ spins and periodic boundary conditions. The system has been studied considering a finite number of anisotropy directions in the crystal. This could be justified considering a cubic or orthorhombic structure in contrast with some hysteresis models for single particles in which the anisotropy direction is oriented randomly [6]. In this simulation, we considered 3, 5 and 7 possible anisotropy orientations. For some particular values of the ratio between the anisotropy strength (K) and the exchange constant (J), we obtain hysteresis cycles that exhibit sharp jumps. Fig. 1 shows the cycles obtained for $K/J = 2.5$, $T/J = 0.01$ and several values of the anisotropy angle. It is clear that the number of jumps increases when the number of

*Corresponding author. Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre 91501 – 970, Brazil. Tel.: +55-51-3316-6466; fax: +55-51-3316-7286.
E-mail address: iglesias@if.ufrgs.br (J.R. Iglesias).

0304-8853/$ - see front matter
doi:10.1016/j.jmmm.2003.11.255

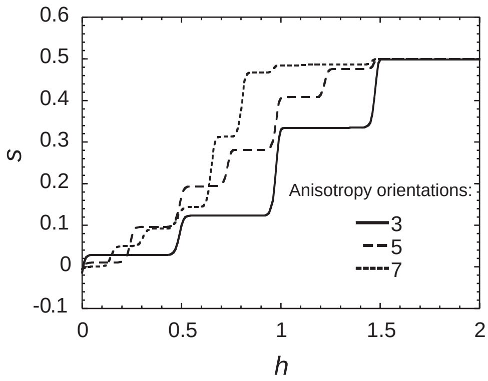

Fig. 1. Variation of the number of jumps in the mean value of the spin per site (s) for a cubic 3D spin lattice $30 \times 30 \times 30$ with $K/J = 2.5$, $T/J = 0.01$ and different number of possible anisotropy orientations (only the first magnetization curve is shown).

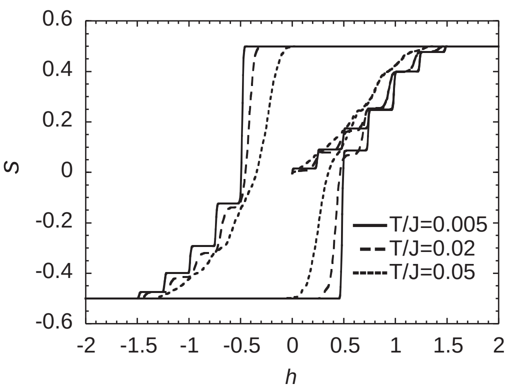

Fig. 2. Hysteresis loops for a cubic 3D spin lattice $30 \times 30 \times 30$ with $K/J = 2.5$, 5 possible anisotropy orientations and different values of the temperature ($T/J = 0.005$, 0.02, 0.05).

possible orientations of the anisotropy is larger, and also that the number of intermediate ''plateaux'' is proportional to the number of possible orientations.

Moreover, an increase of the temperature softens the jumps of the hysteresis curve (Fig. 2), that disappear for higher temperatures, as has been experimentally observed in the above-mentioned Ce system [5].

When the spin assigned to each site i changes to a higher value, an increase of the number of jumps in the field dependence of the spin per site (s) is observed. The appearance of these jumps depends not only on the value of the spin considered, but also on the value of the coefficient K/J. The results obtained for values of the spin $S = 1, \frac{3}{2}$ are shown in Fig. 3.

So, this simple model has proven itself to be able of describing in a qualitative way the appearance of sharp jumps in the hysteresis loops and its dependence with temperature, anisotropy and spin magnitude. This could

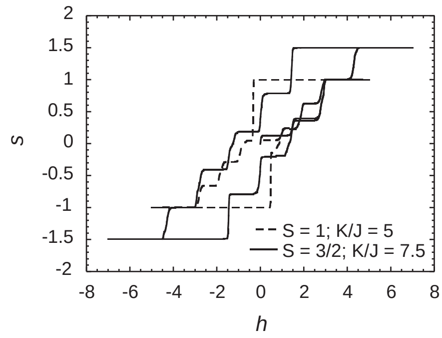

Fig. 3. Hysteresis loops obtained for $T/J = 0.05$ and three anisotropy orientations for two different spin magnitudes.

be useful in the study of magnetic systems as the strongly correlated Ce compounds in which this kind of effects have been observed. The number of jumps seems to be in strong correlation with the value of the spin and of the possible orientations of the random field. Actually, the low temperature behavior of Kondo lattice Ce compounds with strong anisotropy may be described by our model. And the spin $\frac{1}{2}$ case should be particularly well adapted if the ground state is a doublet. Although the general trends of the experimental results are well described by the present results (symmetric hysteresis loops and evanescence of the jumps with increasing temperature), at this stage it is difficult to carry out a direct comparison with the experimental results. Future work will be centered in extensive determination of low temperature magnetization data for several Ce compounds, and in the determination of the appropriate parameters of the model to fit the experimental results.

We thank N. Marcano for communication of her results prior to publication. J.R.I. thanks University of Cantabria for the kind hospitality during the realization of this work.

References

[1] J.M. de Teresa, C. Ritter, M.R. Ibarra, P.A. Algarabel, J.L. García Muñoz, J. Blasco, J. García, C. Marquina, Phys. Rev. B 56 (1997) 3317.

[2] S. Süllow, M.B. Maple, D. Tomuta, G.J. Nieuwenhuys, A.A. Menovsky, J.A. Mydosh, R. Chau, J. Magn. Magn. Mater. 226–230 (2001) 35.

[3] J.C. Gómez Sal, J.I. Espeso, J. Rodríguez Fernández, N. Marcano, J.A. Blanco, J. Magn. Magn. Mater. 242–245 (2002) 125.

[4] A.H. Castro Neto, G. Castilla, B.A. Jones, Phys. Rev. Lett. 81 (1998) 3531.

[5] N. Marcano, private communication.

[6] D.A. Dimitrov, G.M. Wysin, Phys. Rev. B 50 (1994) 3077.

[7] A. Magni, Phys. Rev. B 59 (1999) 985.