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CCNE

COMPETITION BETWEEN SPIN-GLASS AND ANTIFERROMAGNETISM: A CLUSTER APPROACH

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INTRODUCTION

Disorder in spin systems is a permanent source of challenging problems. The spin glass (SG) state is one of the most interesting examples showing that disorder can provide a new physics. The SG state appears when disorder is combined with competition between ferromagnetic (FE) and antiferromagnetic (AF) interactions, which leads the magnetic moments to a conflict situation. This avoids any conventional long-range order, but rises a richness of physical properties.

Among the current problems in disordered spin systems, an interesting one occurs when there are clusters of spins instead of canonical spins. Recently, the competition between AF or FE orders and cluster SG (CSG) behavior has motivated several experimental studies.

Recently, Yamamoto has proposed the so called correlated cluster mean-field (CCMF) theory to improve the mean-field approximation for the canonical spin systems. This theory divides the original spin lattice in clusters in such a way that the resulting system of clusters follows the original lattice symmetry. The presence of clusters in the CCMF approach is, in fact, an artefact to incorporate spin correlations.

In this work, we consider a cluster spin model with short-range antiferromagnetic interactions (J_0) and long-range disordered couplings (J) between clusters. The disordered interactions are treated with an usual mean-field approach. The antiferromagnetic interactions are evaluated by adapting the correlated cluster mean field theory.

MODEL AND METHOD

We consider AF short-range interactions (J_0) and long-range van-Hemmen disordered couplings (J) between clusters in a square lattice that is divided into clusters with n_s sites. The resulting one-cluster model can then be written as,

$$H_{eff}^{AF} = -\sum_{(i,j)\in\nu} J_0\sigma_i^p\sigma_j^{p'} - \sum_p \sum_{i\in\nu,p}(J(\xi+\eta)q + h_{p,i}^{eff})\sigma_i^p$$

where the effective field is

$$n_s=4 \qquad h_{p,i}^{eff} = J_0(m_p^{\sigma_i^p\sigma_j^{p'}} + m_p^{\sigma_i^p\sigma_k^{p'}})$$

$$n_s>4 \qquad \begin{cases} h_{p,i}^{eff} = J_0(m_p^{\sigma_i^p\sigma_j^{p'}} + m_p^{\sigma_i^p\sigma_k^{p'}}), & \text{if } i \text{ is on the corner;} \\ h_{p,i}^{eff} = J_0 m_p^{\sigma_k^{p'}\sigma_i^p\sigma_j^{p'}}, & \text{if } i \text{ is not on the corner;} \end{cases}$$

The average value from the spin in the neighbor site k' determine the mean field, i.e.

$$m_A^{ss'} = \langle Tr\sigma_{3'}^B \exp(-\beta H_{eff}^{'AF})/Tr\exp(-\beta H_{eff}^{'AF})\rangle_{\xi\eta} = -m_B^{\bar{s}\bar{s}'}.$$

The order parameters q and staggered magnetization $m_s = |m_p - m_{p'}|/2$ describe the phases SG and AF, respectively:

$$q = \frac{1}{n_s}\int_{-\infty}^{\infty}\frac{dx e^{-x^2/2}}{\sqrt{2\pi}}\frac{Tr\frac{\sqrt{2}x}{2}S_\nu e^{-\beta H_{eff}}}{Tre^{-\beta H_{eff}}}$$

and

$$m_p = \langle Tr\sum_i \sigma_i^p \exp(-\beta H_{eff}^{AF})/Tr\exp(-\beta H_{eff}^{AF})\rangle_{\xi\eta}.$$

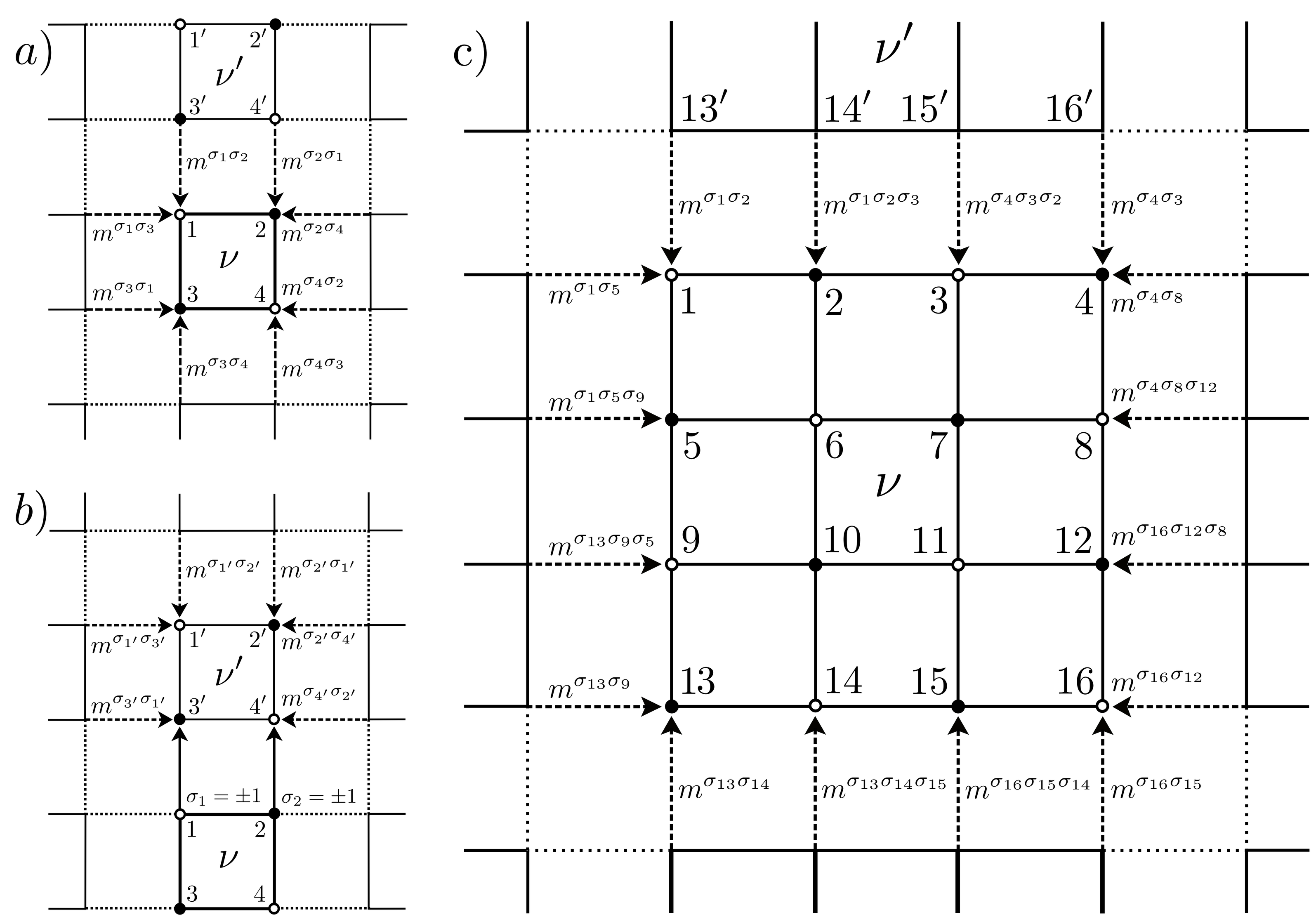

Figure 1 - Schematic representation for a square lattice divided into clusters. The mean-fields are pointed by arrows that represent for: n_s=4 (a) the interactions between the cluster ν with its neighbors and (b) the interactions on ν' used to evaluate the $m^{ss'}$; and n_s=16 (c) the interactions between the cluster ν with its neighbors. For the AF case it is considered two sublattices that are represented by solid and open circles.

RESULTS

We present the results for the competition between CSG and AF. The Figure 2 present (a) the phase diagram and (b) the susceptibility behavior obtained for n_s=4. In the Figure 3 the phase diagrams for several cluster sizes are presented.

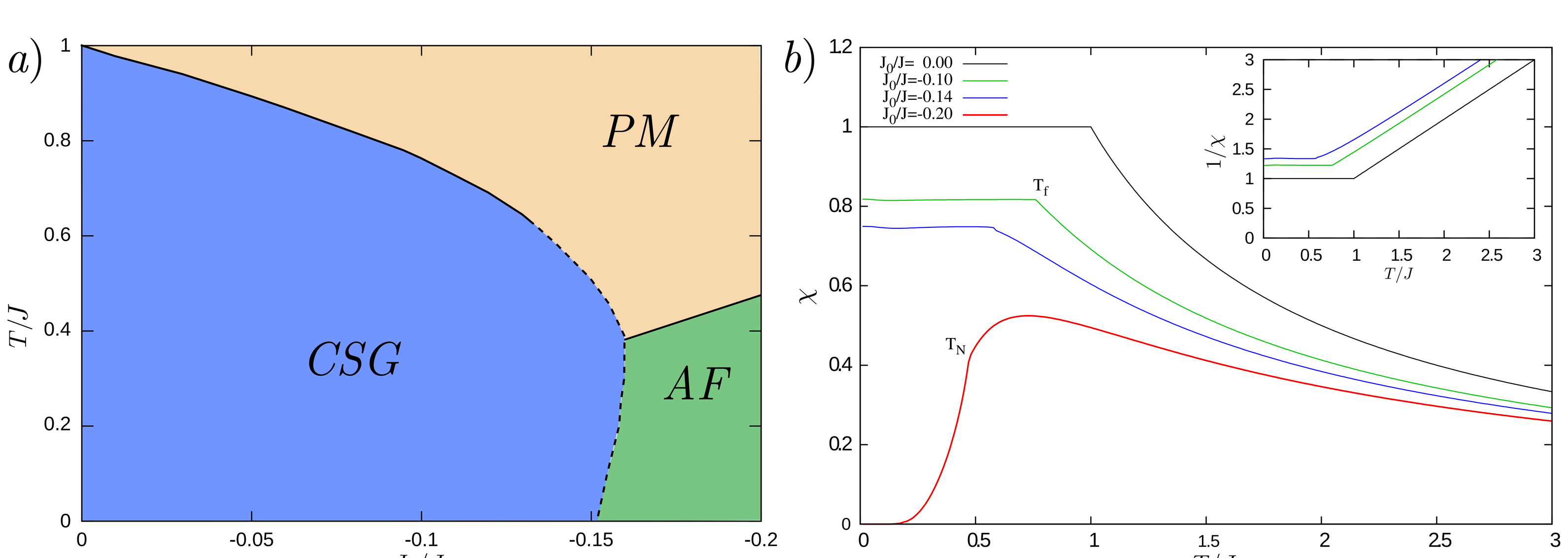

Figure 2 - Results for n_s=4: (a) the phase diagram show that the T_f decreases when the antiferromagnetic interaction (J_0) increases; (b) the magnetic susceptibility is independent of T below the T_f and present a typical Ising AF behavior for high enough values of J_0. The inset in (b) present the inverse of χ.

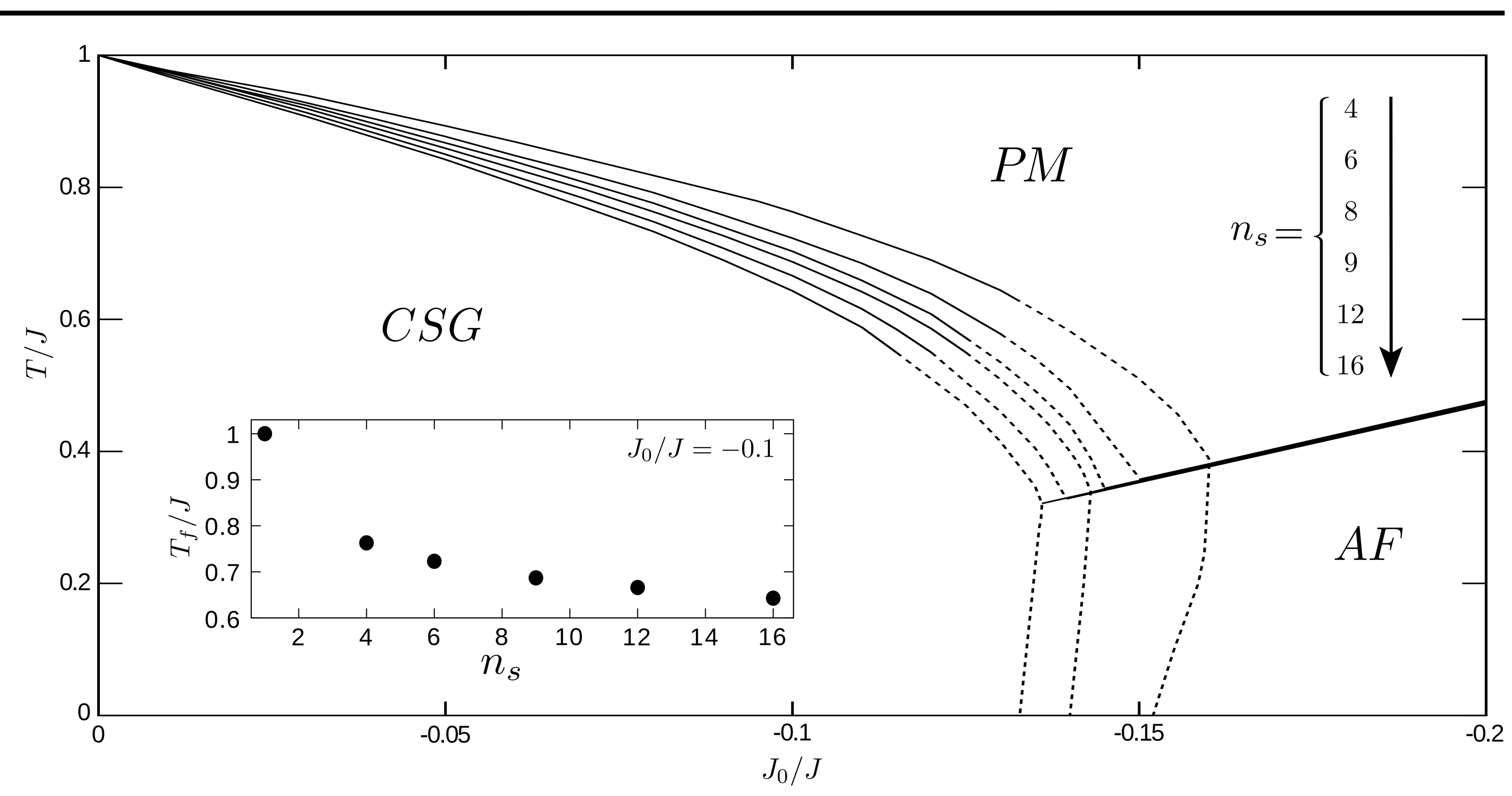

Figure 3 - Phase diagrams T/J versus J_0/J for antiferromagnetic interactions and several cluster size. The inset exhibits the behavior of T_f when n_s increases for a constant J_0/J=-0.1. The increase in n_s reduces the CSG region.

CONCLUSIONS

The results presented in Figures 2 show that the CSG phase is decreased by increasing the AF coupling strength. This reduction is attributed to the decreasing of the total magnetic moment of clusters due to the presence of short-range AF interactions. These interactions affect the disordered intercluster coupling at the same time that can favor the AF order.

Figure 3 shows that the increase in n_s also reduces the CSG region. However, different from J_0, the cluster size can increase the number of spins that couple antiferromagnetically inside the clusters. This situation can energetically favor cluster configurations with a high number of AF spin couplings and low cluster magnetic moment. As a consequence, the disordered intercluster interactions are weakened and the CSG phase occurs only at lower temperatures (see the inset of Fig. 3). It means that the increase of n_s intensifies the effects of J_0 on the CSG phase.

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