Dipolar Interaction in a One-Dimensional Ising Ring

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ABSTRACT

As synthesis of low-dimensional magnetic systems become possible, the need for theoretical understanding of their behavior arises. In this work, the authors explore a one-dimensional magnetic structure with the spins having dipolar interaction.

The effects of a long-range interaction in a one-dimensional (1D) magnetic ring is studied. This ring consists of N equally spaced spins i. The spin interaction is described by a modified Ising model and the system's total energy E is given by

$$E = -J\sum_{i\neq j} s_i s_j + G\sum_{i\neq j}\frac{s_i s_j}{r_{ij}^3} \qquad (1)$$

where $i = \pm 1$ and r_{ij} is the distance between spins i and j. The first sum is the exchange interaction restricted to nearest-neighbor pairs in the original Ising model (Yeomans, 1997). The second sum represents the dipolar interaction over all pairs of moments within the ring. The energy is measured in units of the exchange constant J. In this study we set $J = 1.0$. Here G is the strength of dipolar interaction in units of J.

We investigate the behavior of the ring as the dipolar strength G is varied for $N = 10$ spins. We employ the Metropolis algorithm (Gould & Tobochnik, 1996) to obtain the equilibrium state of the system of spins. This procedure realizes the importance sampling which restricts the sampling space only to statistically feasible configurations. Figure 1 shows the plot of the average magnetization ($\langle M\rangle$) as a function of temperature (T).

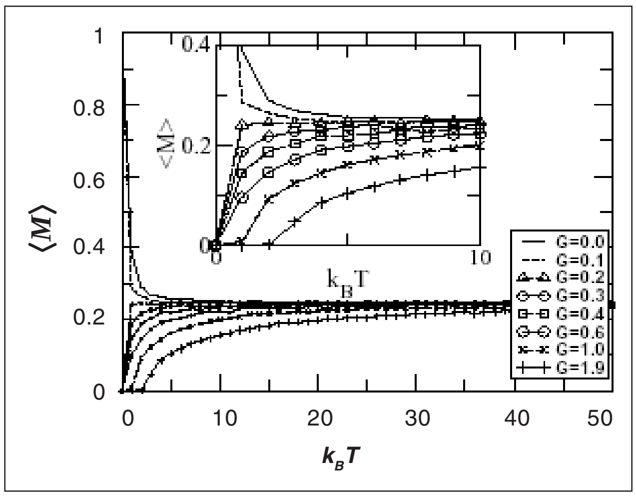

Fig. 1. Behavior of the magnetization with temperature for different values of G. The temperature is given in energy units (k_BT), where k_B is the Boltzmann constant.

$\langle M\rangle$ is obtained by summing all the spins and dividing the result by the total number of spins.

At low temperatures, the behavior of the average magnetization as a function of T is shown to depend on the strength of the dipolar interaction (G). Ferromagnetic states occur in the ground state ($T = 0$) for a small value of G. On the other hand,

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antiferromagnetic states are favored when G is large even at a finite temperature. The magnetization saturates at high T. Also, an effective lowering of the total energy is achieved when smaller values of G approach zero and when large values of G are increased further.

Similar effects are observed for rings having a larger number of spins. Increasing the number of spins in a ring decreases the value of the transition point in G.

Our findings, which show the dependence of the ground state with the dipolar strength, are in contrast to results in higher dimensions, where dipolar interactions favor ferromagnetic alignment of spins (Tang & Sun, 2002). Indeed, the state of a magnetic system is dictated by its dimension and spin interaction.

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