MAGNETIC BEHAVIOR OF A MIXED ISING FERRIMAGNETIC MODEL IN AN OSCILLATING MAGNETIC FIELD.

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Ferrimagnetic ordering seems to play a crucial role in the stable, crystalline, room temperature magnets that are currently being synthesized in the search for materials with technological applications.

Compensation Temperature

Compensation temperatures are very important for magneto-optical recording. It is desirable that the magnetic field required for recording change greatly in a narrow temperature range. Experimentally it has been observed that the coercive field increases near the compensation temperature favoring the creation of small, magnetic domains.
Experimental results

Temperature dependences of coercivity and magnetization of TbFe and GdFe alloys
The 1/2 - 1 Mixed Ising Model

\( \sigma = \pm 1/2 \)

\( S = \pm 1, 0. \)

\[
H = -J_1 \sum_{\langle nn \rangle} \sigma_i S_j - J_2 \sum_{\langle nnn \rangle} \sigma_i \sigma_k + \\
D \sum_j S_j^2 - h(t) \left( \sum_i \sigma_i + \sum_j S_j \right)
\]

The \( J \)'s are exchange interaction parameters, \( D \) is the crystal field and \( h(t) \) is the oscillating magnetic field,

\[ h(t) = h_0 \cos(\omega t), \ T = 2\pi/\omega \]

\( J_1 = -1 \) (the coupling between nearest neighbors is antiferromagnetic)
The Monte Carlo simulation

Monte Carlo techniques were applied to simulate the Hamiltonian on square lattices of 40x40 with periodic boundary conditions. Configurations were generated by randomly sweeping through the lattice and flipping the spins one at a time according to a heat bath algorithm. We calculate the sublattice magnetizations per site at the time $t$,

$$M_1(t) = \frac{2}{L^2} \sum_j S_j(t), \quad M_2(t) = \frac{2}{L^2} \sum_i \sigma_i(t)$$

$$M(t) = \frac{1}{2}(M_1(t) + M_2(t)).$$
The compensation temperature, $T_{\text{comp}}$ is defined such that

$$|M_1(T_{\text{comp}})| = |M_2(T_{\text{comp}})|,$$

$$\text{sign}[M_1(T_{\text{comp}})] = -\text{sign}[M_2(T_{\text{comp}})]$$

To characterize the time behavior we calculate the following integrals of the magnetization,

$$Q = \frac{2\pi}{\omega} \int M(t) dt$$

Dynamical Order Parameter
RESULTS

The coercive field $H_c$ is defined as the minimum value of the external field needed to annul the magnetization $M(t)$. Depends on the temperature.

![Hysteresis loop](image)

Figure 1: Hysteresis loop
Figure 2: Coercive field $H_c$ (*) and Magnetization $M$ (Diamond) vs Temperature

a) $h_0 = 0.1$    b) $h_0 = 0.5$
Figure 3: Coercive field $H_c$ (⋆) and Magnetization $M$ (○) vs Temperature
a) $h_0 = 0.8$ 

b) $h_0 = 2.1$
Figure 4: Coercive field vs Temperature ($\omega = \pi/100$)

The coercive field increases at the compensation point and for small values of $h_0$ is undefined in the vicinities of $T_{comp}$ ($T > T_{comp}$)
Notice that as the temperature increases the loop does not pass through $M=0$, then we can not define a coercive field.

Figure 5: Hysteresis loop- $M(t)$ vs $T$ ($h_0 = 0.5$)
As the $T$ increases there is a dynamical phase transition. The system goes from a paramagnetic region, $Q \approx 0$, to a ferromagnetic region, $Q \neq 0$. The region where the magnetic field is undefined is well into the ferromagnetic region.
Figure 7: Coercive field vs Temperature for different lattice sizes (L)
\[(\omega = \pi/100 \ h_0 = 0.5 \ J_2 = 6 \ D = -1.9)\]

For \(L < 20\) the finite size effects are more evident.
Experimental results

There are 3 well defined regions that depend on the inversion magnetization mechanism.

Figure 8: Coercive field vs Particle diameter
The single-domain and the multi-domain regions are observed. The paramagnetic region is not observed in most of the cases (may be only for $T=0.1$).
Dependence with the frequency of the field ($\omega$)

Figure 10: $H_c$ vs T

($\omega = 2\pi/NMCSS, \omega_1 = \pi/10, \omega_2 = \pi/500$)
Figure 11: $Q$ vs $T$

($\omega = 2\pi/NMCSS$, $\omega_1 = \pi/10$, $\omega_2 = \pi/500$)
Figure 12: $H_c$ vs $\omega^{-1}$ ($\omega = 2\pi/NMCSS$)
Conclusions

We study a mixed Ising ferrimagnetic field in an oscillating external field
\[ h = h_0 \cos \omega t. \]

The model has compensation temperature for small magnetic fields \( h_0 \).

The coercive field increases at the compensation temperatures (consistent with experimental results).

The coercive field is undefined in a range of temperatures \( T > T_{\text{comp}} \), this seems to be related to a dynamical phase transition from a paramagnetic region to a ferromagnetic region.
The maximum value of the coercive field is given by the magnitude of the external field, $h_0$.

As the size of the system increases the peak of the coercive field becomes sharper with the temperature.

The size dependence behavior of the coercive field of our system is in good qualitative agreement with experimental results in magnetic films and nanomagnets.

It seems that for low temperature the coercive field is proportional to the frequency and at high temperatures is inversely proportional to it.