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ACTIVATED DYNAMIC SCALING IN Cd$_{1-x}$Mn$_x$Te: IS IT A SPIN GLASS?
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Abstract. - The linear ac susceptibility $\chi'(\omega, T)$ in Cd$_{1-x}$Mn$_x$Te has been measured in the temperature region of the putative spin glass transition for $x = 0.4$ and $x = 0.65$. $\Delta\chi' = [\chi'(0, T) - \chi'(\omega, T)] / \chi'(0, T)$ is found to obey activated dynamic scaling. The possibility of a dynamically inhibited transition to a type III-like AF state is explored.

The fcc antiferromagnet (AF) is fully frustrated and with the randomness of dilution, as in Cd$_{1-x}$Mn$_x$Te, might exhibit a spin glass state. Typical SG behavior such as frequency dependence of $T_f(\omega)$ [1], hysteresis [2], etc. have been seen in this system. However, since such effects occur in diverse systems, the observation of dynamic scaling with characteristic critical exponents would be more meaningful evidence of a continuous phase transition from a paramagnetic to a SG state.

The relative $\chi'(\omega, T)$ in Cd$_{1-x}$Mn$_x$Te was measured by Faraday rotation (Figs. 1 et 2). The nonlinear response was $< 10^{-3}$. Experimental details are reported elsewhere [3].

We chose to scale the quantity [4]

$$\Delta\chi' = \left[\chi_0(T) - \chi'(\omega, T)\right] / \chi_0(T).$$

The equilibrium $\chi_0(T) = \chi'(\omega = 0, T)$ for $x = 0.4$ can be directly observed in the data above $T = 13.3$ K. At lower $T$, $\chi_0(T)$ was extrapolated by fitting the quadratic and cubic corrections to the Curie-Weiss law. The reliability of the extrapolation (used only between 12 K and 13.3 K) was verified by the predictive accuracy of fits extrapolated down to 13.3 K from data between 15 to 18 K, and the uncertainty is of the order of our experimental error. Within conventional scaling, $\Delta\chi'$ scales as $\Delta\chi'(\omega, T) \sim \epsilon^\delta \Gamma (\omega \epsilon^{-z\nu})$ where $\epsilon = (T - T_c) / T_c$. When the data of figure 1 are fit with this form, excellent scaling plots are obtained for $z\nu = 12 - 15$, $\beta = 0.6 - 0.7$ and $T_c = 12.05 - 12.2$ [3]. However if only the data above 10 Hz were included, satisfactory fits could also be obtained with $z\nu \sim 10$ and higher $T_c$, thus emphasizing the importance of a large dynamic range to constrain the parameters.

The uncharacteristically large value of $z\nu$ suggests thermally activated critical dynamics which is not generally expected to occur at a SG transition [5]. Activated dynamic scaling reflects free energy barriers, $\Delta F$, for relaxation processes which scale as $\Delta F \sim \xi^\phi$ with $\tau \approx \tau_0 e^{\Delta F/kT}$ or $\ln \left(\tau / \tau_0\right) \sim \xi^\phi \sim \epsilon^{-\nu\phi}$ [6]. $\Delta\chi'(\omega, T)$ now scales as

$$\Delta\chi' \sim \epsilon^Q G \left(-e^Q \ln \omega \tau_0\right),$$

with $Q = \theta \nu, P = \beta$. The data for $x = 0.4$ and $x = 0.65$ were scaled according to (2) and shown in figure 3. The 40% data scaled well with $T_c = 12.1 \pm 0.2$ K, $\tau_0 = 10^{-12 \pm 1}$ S, $P = Q = 0.65 \pm 0.1$. The smaller dynamic range for the 65% sample gave larger error bounds but similar $\tau_0, P, Q$, with $T_c = 28.4 \pm 0.4$ K. Note that $T_c = 12.1$ is significantly below $T_i \approx 12.8$ for $\nu = 0.1$ Hz (see Fig. 1). This highlights the unreliability of so called “dc” measurements of $T_c$ as true equilibrium can only be attained at inaccessible long times, as implied by figure 1 in [7]. Apparent irreversibility in the magnetization may appear above $T_c$.
due to the slow dynamics, so this criterion may also mislead one to overestimate $T_c$ and hence underestimate $\xi$. The suggestion of activated critical dynamics (or unexpected large $\xi$; see [8]) observed here, the failure to observe the expected divergence in the non-linear susceptibility [9], and the neutron scattering observation for $0.35 \leq x \leq 0.7$ [10] of a significant AF correlation length, $\xi_{AF}$, in Cd$_{1-x}$Mn$_x$Te all suggest something other than the usual SG transition. The type III AF structure seen [10] corresponds to ordered domains associated with unit cell doubling along one of the three [100] axes. Effects of dilution here are akin to random fields [11] which govern the transition and lead to activated dynamics. For $x = 0.65$, it was found that $\xi_{AF}$ increased rapidly down to $T \sim 30$ K (peak in $\chi'$ in Fig. 2) and then saturated at a value of at least 65 Å. This may be due to the very slow dynamics near $T_\text{i}(\omega)$ which inhibits the development of long range order [12]. A considerably smaller $\xi_{AF}$ is seen [10] at lower $x$ which seems to argue against incipient long range order at lower $x$. However, the similar activated dynamics (Fig. 3) for $x = 0.4$ and $x = 0.65$ suggest a common mechanism rooted in the AF structure. Daniel Fisher [13] has also pointed out that neutron scattering only measures a spin coherence length, $\xi_{AF}$, but type III tetragonality may persist in a given direction over a greater distance with phase slippage between spins in a shorter distance, $\xi_{AF}$.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig3.png}
\caption{Activated dynamic scaling of $\Delta' (\omega, T)$ corresponding to equation (2) in text. Reduced temperature $\varepsilon$ for 0.008 to 0.2. Symbols (e, o, x, +, v, s, e) denote frequencies from $0.975 \times 10^9$ to $0.975 \times 10^{-1}$ Hz in decade steps.}
\end{figure}

The current explanation of critical activated dynamics requires that a zero temperature fixed point governs the critical behavior [6]. If dilution, $x$, were the only relevant variable then the phase diagram in the $x, T$ plane could not possibly have a multicritical point separating AF and SG phase, and a higher dimensional phase diagram would be required to allow both AF and SG phases [14]. At present, we also cannot rigorously exclude the possibility of cross-over behavior at lower values of $x$ in which short range AF order is embedded in a different ordered phase, perhaps a SG phase.

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