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DYNAMIC SCALING IN THE ISING SPIN GLASS Fe$_{0.25}$Zn$_{0.75}$F$_2$

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Abstract. - The ac parallel susceptibility $\chi'(\omega, T)$ was measured in Fe$_{x}$Zn$_{1-x}$F$_2$ with $x = 0.25$ and 0.10. $\chi'(\omega, T)$ exhibits all features of a canonical spin glass: it has a peak in $T$ which reduces in amplitude and shifts to higher $T$ as $\omega$ increases; as $H_0$ increases the peak is reduced but does not shift in $T$. A dynamic scaling analysis for the 0.25 sample yields $\beta \approx 1$ and $\nu \approx 7.5$, exponents appropriate for an Ising spin glass.

It has been shown recently [1, 2] that the randomly diluted antiferromagnet Fe$_{x}$Zn$_{1-x}$F$_2$ with $x < 0.3$ is a short range Ising spin glass. This is a most interesting finding because it is known that this system with $x < 0.4$ under an external uniform fields $H_0$ is an excellent realization of a random-field Ising model (RFIM) system [3]. Since spin glasses and random field systems have quite different grounds states, nonequilibrium and critical behaviour, it is remarkable that the same system can display the properties of both types of random magnets. The previous studies of the spin glass phase of Fe$_{x}$Zn$_{1-x}$F$_2$ were based on measurements of the dc magnetization. Here we present ac susceptibility $\chi'(\omega)$ studies which confirm its spin glass nature.

We have measured the temperature ($T$) dependences of the real $\chi'(\omega)$ and imaginary $\chi''(\omega)$ parts of the susceptibility parallel to the $c$-axis of Fe$_{x}$Zn$_{1-x}$F$_2$ using the standard ac inductance method. The data were taken mostly in $H_0 = 0$ at several frequencies $\omega / 2\pi$ between 17 Hz and 6970 Hz with a driving field of $\approx 1$ Oe RMS. Only at 155 Hz, where the signal to noise ratio of the bridge is maximum, we took data at several values of $H_0$ applied parallel to the ac field.

Figure 1 shows the overall behavior of $\chi'(T)$ for the $x = 0.25$ sample at several frequencies in zero field. Similar results were obtained for the $x = 0.10$ sample. Similarly to other canonical spin glasses [4], $\chi'(T)$ has a cusp at $T_c(\omega)$ which shifts to higher temperatures, broadens and reduces in amplitude as $\omega$ increases. Note that this is in marked contrast to the behaviour of $\chi'(T, \omega)$ in the RFIM phase ($x = 0.46$) which shows no shift in the cusp temperature with varying frequency [5]. The inset in figure 1 shows the field dependence of $\chi'(T)$ at 155 Hz. The smearing of the cusp with increasing field with no shift in the peak temperature is also a standard feature of a spin glass. Here again there is a sharp contrast to the behaviour observed [5] in the RFIM phase of Fe$_{x}$Zn$_{1-x}$F$_2$ which is characterized by a strong field dependence of the peak temperature. Note also that the field values necessary to produce the smearing of the cusp in $\chi'(T)$ are quite large compared to those in metallic spin glasses [4], which is consistent with the earlier dc data [1].

The frequency and temperature dependences of the susceptibility are governed by the dynamics of the spin correlation functions [6, 7]. In spin glasses dynamic scaling has been observed above the transition temperature in several measurable quantities, such as [8].

$$\Delta \chi'(\omega, T) = \left[ \chi_0(T) - \chi'(\omega, T) \right] / \chi_0(T).$$  \text{(1)}

Since we cannot measure the equilibrium $\chi_0(T) = \chi'(0, T)$, following reference [8] we represent it by a

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function obtained from a fit of the Curie-Weiss law with quadratic and cubic corrections to the 17 Hz data from 12 K to 20 K. Assuming conventional critical slowing down when the spin glass transition is approached from above, the temperature dependence of the relaxation times is described by

\[ \tau \sim T_0 (T / T_c - 1)^{-z \nu} \]  

(2)

where \( T_c = T(0) \), \( z \) is the dynamic exponent, \( \nu \) is the correlation length exponent, and \( T_0 \) is a microscopic relaxation time. When \( T \to T_c \) and \( \omega \to 0 \), \( \Delta \chi' \) assumes the scaling form [8, 10]

\[ \Delta \chi'(\omega, T) \sim (T / T_c - 1)^\beta F[(\omega / T_c)^{-z \nu}] \]  

(3)

where \( \beta \) is the order parameter exponent and \( F \) a characteristic scaling function. Scaling of the data was tested for several values of \( T_c \), \( \beta \) and \( z \nu \). Large deviations from scaling occur for \( \beta \) outside the range 1.0 \pm 0.2. However, good scaling is obtained in a large range of combined values of \( T_c \) and \( z \nu \), larger \( z \nu \) requiring lower \( T_c \). Certainly data over several decades of \( \omega \) would allow a precise determination of \( T_c \) and \( z \nu \) from \( \chi' (\omega) \) alone. Since our ac bridge does not provide good data outside the range reported here, we have determined \( z \nu \) by requiring \( T_c \) to be consistent with the dc magnetization data. This is done by calculating \( T_c(\omega) \) from the experimentally determined scaling function and requiring that for \( \omega \sim 10^{-2} \) s\(^{-1}\) (the time scale of the "dc" measurements) \( T_c = 10.0 \pm 0.2 \) K [1, 2]. With this constraint on the range of \( T_c \), the best scaling (shown in Fig. 2) is obtained with \( T_c = 9.95 \) K, \( \beta = 1.0 \) and \( z \nu = 7.5 \). The values of \( \beta \) and \( z \nu \) are close to those measured in other spin glasses. Moreover \( z \nu \) is in good agreement with the values predicted by Monte Carlo simulations of a short range Ising spin glass [6] and by recent renormalization group calculations [11], being very different from \( z \nu \approx 14 \) obtained in the RFIM phase of Fe\(_2\)Zn\(_{1-x}\)F\(_2\) [5].

Finally we mention that \( \chi' (\omega) \) for the \( x = 0.1 \) sample was found to exhibit a paramagnetic like upturn at temperatures below 4.2 K. A similar but weaker behavior was also found at lower temperatures in the \( x = 0.25 \) sample and we recently learned of similar results in Fe\(_{0.22}\)Zn\(_{0.78}\)F\(_2\) [12]. This behavior has also been observed in other "good" short range spin glasses and is attributed to loose spins or small spin clusters [13]. Assuming that at \( T = 1.6 \) K 40 % of the value of \( \chi' (155 \) Hz) = 4.2 \times 10^{-4} \) emu/g measured in the \( x = 0.25 \) sample is due to loose spins, we obtain a Curie constant for the paramagnetic sub-system \( C = 2.7 \times 10^{-4} \) K emu/g. This corresponds to a number of loose spins of only 10^{-3} of the total Fe\(_{2+}\) ions, resulting in a contribution less than 8 % of the measured \( \chi' \) at temperatures above the spin glass \( T_c \).

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