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ISING CRITICAL BEHAVIOR IN SPIN GLASSES: Fe$_{0.25}$Zn$_{0.75}$F$_2$

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Abstract. — We present a scaling analysis of the nonlinear susceptibility data above the freezing temperature in the spin glass system Fe$_{0.25}$Zn$_{0.75}$F$_2$. The critical exponents obtained are in excellent agreement with those found in metallic systems and are also compatible with theoretical predictions for short range Ising spin glasses.

The randomly diluted highly anisotropic antiferromagnet Fe$_{x}$Zn$_{1-x}$F$_2$ with $x \leq 0.3$ has recently been shown [1] to display many features of a three dimensional, short-ranged, Ising spin glass (SG) system. By contrast, at higher concentrations of magnetic ions, ($x > 0.4$) and in presence of a uniform field parallel to the uniaxial direction, this compound is recognized as a truly ideal physical realization of a random field Ising model (RFIM) system [2]. It thus seems that a system is available which can be used to study the similarities and contrasts [1] between two important classes of random magnetic systems.

In this paper, we report a scaling analysis of the nonlinear susceptibility data above the freezing temperature for a Fe$_{0.25}$Zn$_{0.75}$F$_2$ sample with $x = 0.25$. The magnetization ($M$) measurements were carried out with a vibrating sample magnetometer in magnetic field ($H$) up to 65 kOe. The temperature was measured with a carbon glass thermometer and controlled within 1 mK in the range $4.2 < T < 60$ K. Below an onset of irreversibility temperature $T_i(H)$, $M$ is shown to display history dependent behavior similar [1] to that found in usual SGs. The temperature dependence of $M$ measured after zero-field cooling (ZFC) and field-cooling (FC) procedures is presented in the inset of figure 1, for an arbitrary value of the applied field. The main figure shows a plot of the $T_i(H)$ data that can be fitted by $t(H) = -AH^{2/\phi}$, where $t = [T_i(H) - T_i(0)] / T_i(0)$ and $\phi$ is a crossover exponent. The measurement yield $T_i(0) = 11.2 \pm 0.2$ K and $\phi = 3.4 \pm 0.2$. This value of $\phi$ is compatible, in low fields, with the $H^{2/\phi}$ dependence of the de Almeida-Thouless (A-T) mean field instability curve, shown by the dashed line in figure 1. On analysing the critical behavior of spin glasses, the experimental quantity of interest is the reduced nonlinear susceptibility $\chi_{NL} \equiv (\chi_0 H - M) / \chi_0 H$, which is assumed proportional to the order parameter of the phase transition. The $\chi_{NL}$ data was obtained from the $M$ vs. $H$ curves in the temperature range $T_i < T < 2T_i$, by subtracting the linear component $\chi_0 \equiv (dM/dH)_{H \to \infty}$, which is determined by the initial slope of these curves and has a sharp maximum at the freezing temperature $T_i = 10.0 \pm 0.2$ K. The divergence of the quantity $\chi_{NL} / H^{2/\phi}$ as $H \to 0$ and $T \to T_i$ can be clearly observed in the data (see Fig. 2) consistent with the existence of an equilibrium continuous phase transition in this system. We used the scaling form

$$\chi_{NL} = H^{2/\phi} f_{\phi} \left( t / H^{2/\phi} \right),$$

where $t = (T - T_i) / T_i$, $\delta$ and $\phi$ are scaling exponents, and $f_{\phi}(x)$ is a scaling function which approaches a constant as $x \to 0$ and approaches $x^{-\gamma}$ as $x \to \infty$. The exponent $\delta$ was determined by the initial slope of a log-log plot of $\chi_{NL}$ versus $H$ at $t = 0$ (see inset of Fig. 3), where $\chi_{NL} \sim H^{2/\phi}$. We obtain $\delta = 3.2 \pm 0.2$ for fields up to $\sim 20$ kOe, where the data collapse in a straight line. This establishes the range of fields for which the scaling of the Ising critical behavior is valid. The data for low-fields are not shown in the figure due to poor resolution, since in this system nonlinearities in the magnetization are appreciable only for fields above $\sim 5$ kOe. For $H \gtrsim 20$ kOe we find deviations towards

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higher values of $\delta$, indicating a crossover to a different critical behavior. The exponent $\phi$ is the same [3] as for the A-T transition line of figure 1. Scaling was tested for 20 different temperatures between $T_I$ and $2T_I$ and $H$ up to 20 kOe (shaded region in Fig. 1). The best fit is obtained using $T_I = 10.0$ K, $\phi = 3.4$ and $\delta = 3.0$, for which the data collapse on a curve, shown in figure 3, indicating that the system satisfies scaling in the critical region above $T_I$: as $x \to 0$, $f_+(x)$ saturates at a value consistently given by $\ln (x^{NL} / H^{2/3})$ at $t = 0$, whereas for $x \to \infty$ the asymptotic limit of $f_+(x)$ is obtained for “small” values of $H$ such that the relation $(x^{NL} / H^2) \sim t^{-\gamma}$ defines the exponent $\gamma$. The value determined in this manner, $\gamma = 2.3 \pm 0.3$, agrees with the value obtained independently from the scaling relation $\gamma = \phi (\delta - 1) / \delta$. From the above analysis we obtain for $Fe_{0.25}Zn_{0.75}F_2$: $\delta = 3.2 \pm 0.2^*$, $\gamma = 2.3 \pm 0.3^*$; $\beta = 1.0 \pm 0.2$; $\phi = 3.4 \pm 0.2^*$; $\alpha = -2.4 \pm 0.5$; $\eta = 0.4 \pm 0.1$ and $\nu = 1.4 \pm 0.2$. The asterisk indicates the exponents experimentally determined. The other ones are found using scaling relations such to minimize the error bars. These exponents are then compared with those of metallic (Ising) AgMn [4, 5] and theoretical predictions from Monte Carlo studies [6, 7] and high-temperature series expansions [8, 9] of short-range Ising SG model systems. The consistency among the experimental values is impressive, as is the agreement with theory for $\nu$, $\phi$, $\alpha$ and $\gamma$. However, theoretical estimates [7, 8] for $\eta$ predict a small negative value (yielding lower values for $\beta$ and higher values for $\delta$) in disagreement with experiment. The results of this work and the companion paper on the dynamic scaling experimentally confirm the universality of Ising critical behaviour in spin glasses, regardless of their insulating or metallic natures.

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