Phase Diagram of the Random-Field Ising System
Fe(0.60)Zn(0.40)F(2) at Intense Fields

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Phase Diagram of the Random-Field Ising System Fe_{0.60}Zn_{0.40}F_2 at Intense Fields

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The critical and irreversibility phase boundaries of the d = 3 diluted uniaxial antiferromagnet Fe_{0.60}Zn_{0.40}F_2 have been determined under strong external magnetic fields by means of magnetization measurements. Our data reveal that the random-field-induced glassy phase, previously observed in the upper part of the (H,T) phase diagram for highly diluted samples (x ≈ 0.3), is extended to higher values of x.

Keywords: Magnetic phase diagrams, Random fields, Spin glass - behavior

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Most of the experimental work in the diluted antiferromagnetic (DAF) compound Fe$_x$Zn$_{1-x}$F$_2$, in the context of the random-field Ising model (RFIM) problem [1], has been performed under relatively low external magnetic fields (H) applied parallel to the easy axis. In this regime, antiferromagnetic (AF) long-range order (LRO) is the zero temperature ground state and the transition from AF to paramagnetic takes place at a critical temperature $T_c(H)$. The position of $T_c(H)$ obeys the following scaling law: $T_N - T_c(H) \approx H^{2\phi}$, with $\phi \approx 1.42$ being the crossover exponent from the universal random-exchange Ising model (REIM) to RFIM, and $T_N$ the Néel temperature. AF LRO was also shown to be stable for $T < T_c(H)$ in all measured samples of Fe$_x$Zn$_{1-x}$F$_2$ with $x > 0.3$ (providing the sample been zero-field cooled (ZFC) to the low-T phase before the application of H). However, the nature of the phase transition at $T_c(H)$ is still a subject of considerable controversy [2]. Random fields of larger magnitudes introduce important modifications in the critical and irreversible behavior of DAFs. In particular, the lack of stability of LRO [3] and a separate glassy phase induced by strong random fields [4] were theoretically predicted for certain regions of the phase
Indeed, a random-field-induced spin-glass-like behavior was experimentally observed [5] to appear in the upper part of the (H,T) phase diagram of the highly diluted compound Fe$_{0.31}$Zn$_{0.69}$F$_2$. To extend the study to the entire phase diagram of Fe$_x$Zn$_{1-x}$F$_2$ for higher x, intense magnetic fields were required due to the large values of the exchange (H$_E$) and anisotropic (H$_A$) fields in this system.

In this paper we map the critical and irreversibility phase boundaries of Fe$_{0.60}$Zn$_{0.40}$F$_2$ from magnetization measurements performed in a wide magnetic field range (0 < H < 18 T), applied parallel to its easy magnetization direction. Measurements were made using a vibrating sample magnetometer adapted to a 20 Tesla superconducting magnet at the National High Magnetic Field Laboratory, Los Alamos Facility. Our results indicate that $T_c(H)$ data follows the REIM-RFIM crossover scaling, with $\phi \approx 1.4$ for $H < 5$T, in agreement with earlier results for all measured samples of Fe$_x$Zn$_{1-x}$F$_2$ with $x > 0.3$. For higher H, however, strong random fields nucleate a glassy behavior in the upper part of the (H,T) phase diagram. A new (lower) irreversibility boundary appears, separating regions of the phase diagram where dynamics is governed by the AF ground state from regions where AF configuration is unstable. No evidence of a spin-flop (SF) phase could be found in the temperature (T) and magnetic field (H) ranges investigated.

Fig. 1 shows the positive H part of M versus H cycles in Fe$_{0.6}$Zn$_{0.4}$F$_2$, for several values of T. In these measurements, the sample has been first zero-field cooled (ZFC) from $T = 80$ K (paramagnetic phase) to the temperature where field-increasing (FI)
and field-decreasing (FD) cycling takes place. An excess of magnetization ($\Delta M = M_{FD} - M_{FI}$) appears in the FD procedure for all $T < T_N$. Defining the upper and lower equilibrium boundaries in the ($H,T$) phase diagram as $H_{eq}^u(T)$ and $H_{eq}^l(T)$ respectively, we have observed that hysteresis occurs only within the interval $H_{eq}^u < H < H_{eq}^l$. The Inset in Fig. 1 shows $dM/dH$ versus $H$ for some values of $T$, both for FI and FD procedures. For low $H$, $M_{FI}$ is stable for all $T < T_c(H)$, supporting the AF configuration as the lowest energy state of the weak RFIM problem. In this regime, ZFC-FI peaks in $dM_{FI}/dH$ are signatures of phase transitions occurring along the critical boundary $T_c(H)$. The positions of these $dM_{FI}/dH$ peaks in the ($H,T$) phase diagram coincides quite well with the ones of the costumary $dM_{FI}/dT$ peaks [6], which appear at low $H$ when the sample is heated in presence of a fixed $H$ (FH) from the AF phase (see Fig. 2). For values of $H$ exceeding a $T$-dependent limit (not shown in this work), $M_{FI}$ increases with time and the AF configuration is unstable [6]. In the latter, strong random-field regime even if cooperative phenomena occur along $T_c(H)$, a fraction of the spins does not participate in it. (NOT CLEAR!!!)

Our results are summarized in the phase diagram of Fig. 2. The departure of the critical boundary $T_c(H)$ from the REIM-RFIM crossover scaling, with $\phi \approx 1.4$, occurs for $H > 5T$ (see inset). For low $H$, the upper equilibrium boundary, $H_{eq}^u(T)$ was previously defined as $T_{eq}(H)$, the temperature above which different field cycling procedures give the same results in all measurements made in the same time scale. For $H < 5T$, $T_{eq}(H)$ follows a REIM-RFIM crossover scaling similar to the one given for
\[ T_c(H), \text{i.e., } T_N - bH^2 - T_{eq}(H) = C_{eq}H^{2\phi}, \text{ with } \phi \approx 1.4. \] This is in agreement with earlier results [1] for \( T_{eq}(H) \) data in samples of \( \text{Fe}_x\text{Zn}_{1-x}\text{F}_2 \) with \( x=0.73, 0.40, 0.31 \). At \( H = 0 \), the extrapolation of \( T_c(H) \) and \( H_{eq}^{-}\) lines join at the Néel temperature \( T_N = 46.8 \text{ K} \).

For higher values of \( H \), the \( H_{eq}^{-}\)(T) data change from concave (\( \phi \approx 1.4 \)) to a convex shape (\( \phi > 2 \)), marking the onset of the glassy phase in the upper part of the phase diagram. The lower irreversibility line \( H_{eq}^{+}(T) \) has not been determined in previous works due to the requirement of intense magnetic fields. For \( H < H_{eq}^{+}(T) \), \( \Delta M = 0 \) and the magnetization of the antiferromagnetic configuration is recovered in the FD procedure. The difference \( \Delta H_{eq} = H_{eq}^{+} - H_{eq}^{+} \) decreases with increasing \( T \), approaching a singular region [6] in the \((H,T)\) phase diagram.

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Figure Captions

Fig. 1 - M vs. H curves of \( \text{Fe}_{0.60}\text{Zn}_{0.40}\text{F}_2 \) for several \( T \) after ZFC from the paramagnetic phase. Field increasing, FI, (decreasing, FD, ) procedures are shown by
up (down) arrows. Inset shows $\frac{dM}{dH}$ vs. $H$ for some values of $T$ where FI (FD) data are represented by full (open) symbols.

Fig. 2 - Critical and irreversibility phase boundaries in Fe$_{0.60}$Zn$_{0.40}$F$_2$. Full symbols, with horizontal (vertical) error bars, represent $T_c(H)$ originating in the position of ZFC $\frac{dM_{FH}}{dT}$ ($\frac{dM_{FI}}{dH}$) peaks. The irreversibility boundaries are represented by open symbols. The inset shows $T_c(H)$ data in a $H^{2/3}$ vs $T$ plot.

REFERENCES


Fig. 2