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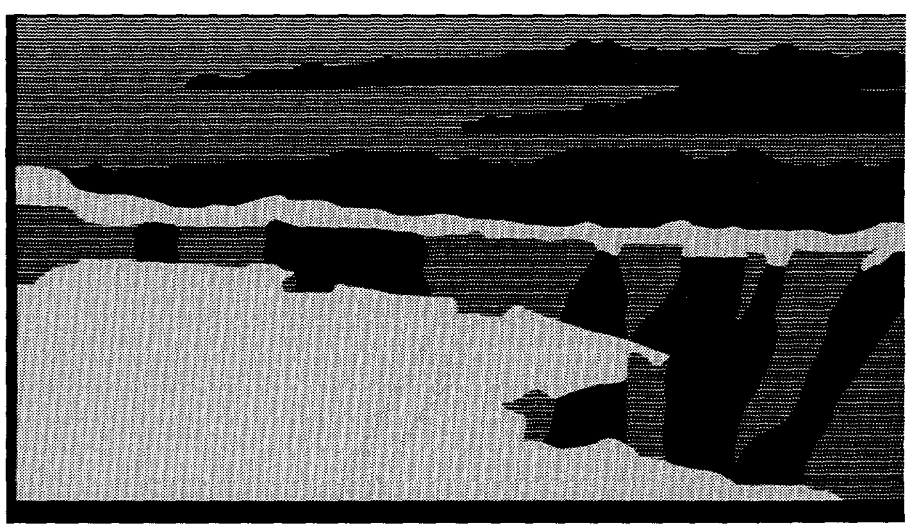

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Phase Diagram of the Random-Field Ising System $Fe_{0.60}Zn_{0.40}F_2$ at Intense Fields

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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 ($x \cong 0.3$), 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 $Fe_xZn_{1-x}F_2$, 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 $\phi \cong 1.42$ 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 $Fe_xZn_{1-x}F_2$ 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 diagram. 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 $Fe_xZn_{1-x}F_2$ 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 $\phi \cong 1.4$ for $H < 5T$, in agreement with earlier results for all measured samples of $Fe_xZn_{1-x}F_2$ 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 $T \cong 80$ 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_{FH}/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 $\phi \cong 1.4$, 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

$T_c(H)$, i.e., $T_N - bH^2 - T_{eq}(H) = C_{eq}H^{2/\phi}$, with $\phi \cong 1.4$. This is in agreement with earlier results [1] for $T_{eq}(H)$ data in samples of $Fe_xZn_{1-x}F_2$ with x=0.73, 0.40, 0.31. At H = 0, the extrapolation of $T_c(H)$ and H_{eq}^u lines join at the Néel temperature $T_N \cong 46.8$ K. For higher values of H, the $H_{eq}^u(T)$ data change from concave ($\phi \cong 1.4$) to a convex shape (ϕ>2), marking the onset of the glassy phase in the upper part of the phase diagram. The lower irreversibility line $H_{eq}^l(T)$ has not been determined in previous works due to the requirement of intense magnetic fields. For $H < H_{eq}^l(T)$, $\Delta M = 0$ and the magnetization of the antiferromagnetic configuration is recovered in the FD procedure. The difference $\Delta H_{eq} = H_{eq}^u - H_{eq}^l$ 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 $Fe_{0.60}Zn_{0.40}F_2$ for several T after ZFC from the paramagnetic phase. Field increasing, FI, (decreasing, FD,) procedures are shown by

up (down) arrows. Inset shows 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 dM_{FH}/dT (dM_{FI}/dH) peaks. The irreversibility boundaries are represented by open symbols. The inset shows $T_c(H)$ data in a $H^{2/\phi}$ vs T plot.

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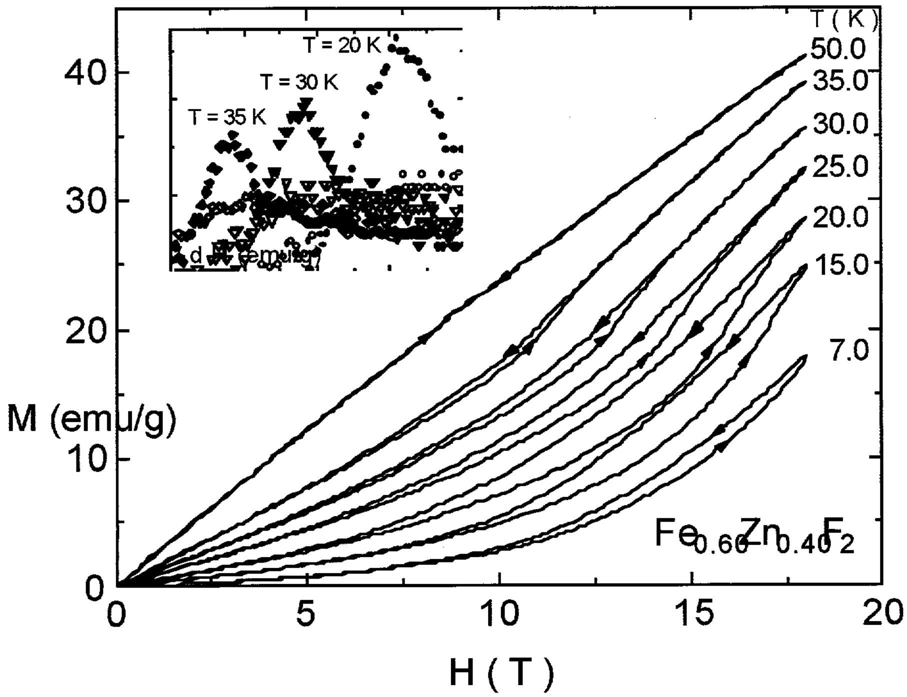

T = 20 K
T = 30 K
T = 35 K
T (K)
50.0
35.0
30.0
25.0
20.0
15.0
7.0
40
30
20
10
0
M (emu/g)
$Fe_{0.60}Zn_{0.40}F_2$
0
5
10
15
20
H (T)

Fig. 1

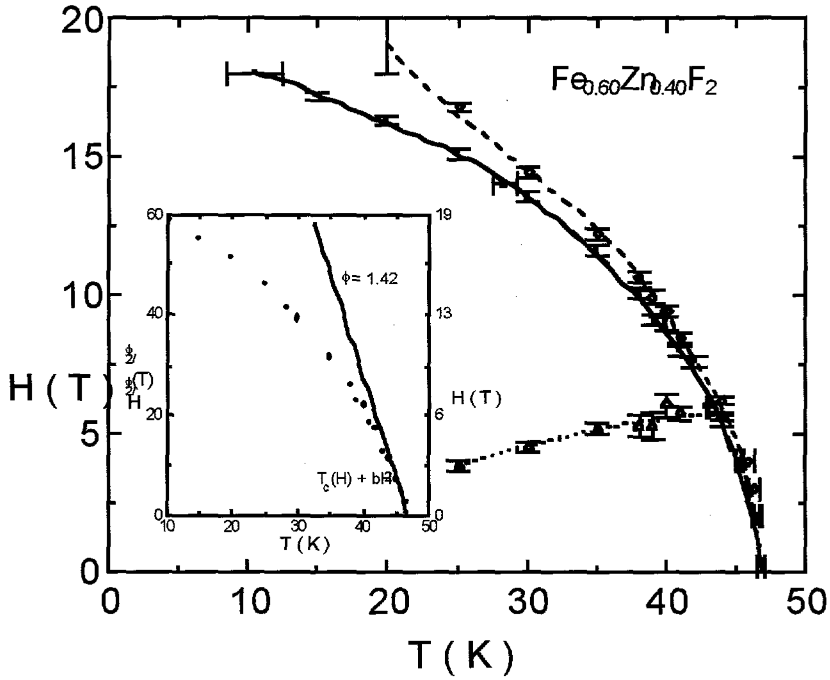

Fig. 2