The highly diluted antiferromagnet $Mn_{0.35}Zn_{0.65}F_2$ has been investigated by neutron scattering for $H > 0$. A low-temperature ($T < 11$ K), low-field ($H < 1T$) pseudophase transition boundary separates a partially antiferromagnetically ordered phase from the paramagnetic one. For $1 < H < 7$ T at low temperatures, a region of antiferromagnetic order is field induced but is not enclosed within a transition boundary.

Diluted uniaxial antiferromagnets (AF) in applied fields are ideal random-field Ising model (RFIM) systems. $Mn_{0.35}Zn_{0.65}F_2$ is a three dimensional ($d = 3$) system with a magnetic concentration $x$ close to the percolation threshold, $x_p = 0.25$. Its behavior may be contrasted with $Fe_xZn_{1-x}F_2$, which differs magnetically from $Mn_xZn_{1-x}F_2$ only in the nature and strength of the anisotropy, which is dipolar in the latter and is dominated by a much larger single-ion anisotropy in the former. Samples of $Fe_xZn_{1-x}F_2$ have been investigated with $x = 0.25, 0.27$ and $0.31$. The first two do not order even with $H = 0$ and show spin-glass-like behavior at all $H$. The $x = 0.31$ sample shows AF long-range order (LRO) at low $H$ and spin-glass-like behavior at higher fields. In $Mn_xZn_{1-x}F_2$, ac susceptibility measurements indicate a spin-glass-like clustering at low temperatures for samples with $0.2 < x < 0.35$. We present evidence suggesting that frozen spin-glass-like clusters also affect the stability of the AF long-range order in $Mn_{0.35}Zn_{0.65}F_2$. 
The neutron scattering experiments were performed at the Oak Ridge National Laboratory High Flux Isotope Reactor using a two-axis configuration with a monochromated 14.7 meV beam. Further experimental details have been previously reported \[17\]. For simplicity, the transverse line shapes used in fits of the data for $H > 0$ are of the mean-field RFIM form \[1\]

$$S(q) = \frac{A}{q^2 + \kappa^2} + \frac{B}{(q^2 + \kappa^2)^2},$$

where $\kappa$ is the inverse correlation length for fluctuations. We do not fit data in the Bragg scattering region $|q| < 0.008$ reciprocal lattice units (rlu).

Figure 1 shows AF (100) transverse scans obtained by heating with $H > 0$ after cooling in zero field (ZFC) and the fits to Eq. 1 for $H = 0.35$ T. A striking feature of these scans is the relatively small change in the line shape with temperature when compared with the $H = 0$ scans reported previously \[17\], particularly for $T > T_c(H)$, where $T_c(H)$ is a transition-like temperature. The fits to the data are essentially identical whether $B$ is fixed to zero or allowed to vary, indicating that the squared-Lorentzian term in Eq. 1 is unimportant. The results for $\kappa$, which reflect the unusual line shape behavior, are shown in Fig. 2. The values for $H = 0.35$ T drop well below the values for $H = 0$ which are concentration-gradient limited, indicating that Eq. 1 does not describe the line shapes very well for $H > 0$. The clear minimum in $\kappa$ vs. $T$ and Bragg scattering intensities vs. $T$ (not shown) do indicate that the system is trying to undergo a transition, but it is questionable that one successfully occurs. For $H = 0.75$ T, when $B$ is fixed to zero, the values of $\kappa$ are artificially much smaller than the instrumental resolution. The results when $B$ is allowed to vary are those shown in Fig. 2. The minimum in $\kappa$ vs. $T$ is extremely shallow although a transition-like region is indicated by a peak in the scattering at $|q| = 0.008$ rlu vs. $T$ as well as the rapid decline in the Bragg scattering intensity. Either a transition does not actually take place or very few spins are involved. From temperatures at which the maxima in the off-Bragg scattering at $|q| = 0.008$ rlu and the maxima in the temperature derivative of the Bragg scattering with respect to temperature occur, the AF pseudophase boundary is determined. The boundary is shown by the points with horizontal error bars in the inset of Fig. 3. The points with vertical error bars indicate the magnetic
field at which an intensity change is observed in the Bragg scattering and at which the peak of the off-Bragg scattering occurs as the field is changed while $T$ is kept constant. The transition region again appears quite broad. An example of this at $T = 5K$ is shown in Fig. 3 which also indicates substantial hysteresis when comparing ZFC data and data obtained upon cooling in the field (FC) for both $q = 0$ and $|q| = 0.008$ rlu and is consistent with earlier magnetization measurements [16].

For $2 < H < 7$ T a region of AF LRO is indicated by the $q = 0$ intensities in Fig. 4. The order is most intense at $H \approx 5$ T. There is no peak in the off-Bragg ($|q| = 0.008$ rlu) scattering for $T > 5$ K, as exemplified for $H = 5$ T in the inset of Fig. 4. This indicates that there is no phase transition boundary associated with this AF order and that the AF order is most likely field induced. Within a cluster the sublattice with an excess of spins will preferentially order along the field direction. The other sublattice will then order in the opposite direction as a result of the exchange interaction. At fields above 5 T, the AF order weakens. This contrasts the behavior observed [18] in $Mn_{0.5}Zn_{0.5}F_2$, where a spin-flop phase with a clear transition boundary occurs above the AF one.

Previous magnetization measurements were made of the pseudotransition boundary [14]. The inset in Fig. 3 shows the peak positions of $d(MT)/dT$ for $H < 0.5T$ as the starred data points. The widths of these peaks are very large. For example, the half width at half maximum at $H = 0.35T$ is more than 1 K. These widths are much larger compared to measurements at larger $x$ [18,19]. Note that the positions do not coincide with the boundary determined with neutrons and even the curvature is different. For the neutron boundary, $T - T_c(H) \sim H^{2/\phi}$ with $\phi = 1.4$ as in RFIM systems further from $x_p$ [1]. In contrast, the magnetization data are fit with $\phi = 3.4$ [16], the typical spin-glass exponent. Above $H = 0.5$ T, it was not possible to reliably determine a peak position. These results reinforce the scenario in which the boundaries do not represent a true transition to AF LRO, but rather an AF transition that is strongly interfered with by spin-glass-like frozen clusters. The transition at $T = 11$ K for $H = 0$, in contrast, seems much more normal, though spin-glass-like behavior is evident [17] below $T = 7$ K. Slow relaxation seems evident in both the neutron scattering and magnetization for $H > 0$, probably a result of clustering induced by the alignment of domains by the field. At low $H$, hysteresis is observed well above $T_c(H)$ and clustering is indicated by a
strong deviation from Curie-Weiss behavior below $T = 22$ K [6]. The small anisotropy in the $MnxZn_{1-x}F_2$ system allows the field to align clusters more easily [5] than in $Fe_xZn_{1-x}F_2$ and this effect certainly must account for the differences between these two systems.

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FIG. 1. The logarithm of the ZFC scattering intensity vs. $q$ for various temperatures above and below $T_c(H)$ for $H = 0.35$ T.
FIG. 2. The results for $\kappa$ vs. $T$ for $H = 0, 0.35$ and 0.75 T using Eq. 1.
FIG. 3. The scattering intensity vs. $H$ at $q = 0$ and $|q| = 0.008$ rlu for field increasing (triangles) and field decreasing (squares) after zero-field cooling to $T = 5$ K. The inset shows the pseudophase boundary determined from neutron scattering (squares) and magnetization (stars) measurements.
FIG. 4. The scattering intensity vs. $T$ at $H = 3$, 5 and 7 T at $q = 0$ rlu upon heating after ZFC (open symbols) and upon FC (filled symbols). The inset shows the scattering intensity vs. $T$ for $H = 5$ T at $|q| = 0.008$ rlu after ZFC (open symbols) and upon FC (filled symbols).