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RANDOM EXCHANGE ISING MODEL DYNAMICS: $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$

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Abstract. – Spin-echo neutron scattering techniques were used to investigate the dynamic critical behavior for $T > T_N$ of the random exchange Ising antiferromagnet $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$ and for FeF_2 at $H = 0$. The data are adequately described for $q = 0$ by $\Gamma = \Gamma_0 t^{\nu z}$. Γ_0 is decreased 100 fold upon dilution. For both systems $z \approx \gamma/\nu$ in agreement with the conventional theory.

The static criticals behavior of the random exchange Ising model (REIM) has been well characterized in pure and dilute $d = 3$ antiferromagnets [1]. It has been established, in agreement with theory, that upon dilution a new universality class, distinct from that of the pure $d = 3$ Ising one, describes the critical behavior. All of the universal static critical parameters for the inverse correlation length κ , the staggered susceptibility χ_s , the specific heat C_m , and the staggered magnetization m_s obtained in the Ising-like antiferromagnetic system $\text{Fe}_x\text{Zn}_{1-x}\text{F}_2$ agree well with theory for both the pure and dilute cases.

Attention has turned to the characterization of the dynamic behavior of the REIM. We have used the neutron spin-echo inelastic scattering technique [2] to investigate the critical dynamic behavior of the time (τ) dependent spin correlation function $S(q, \kappa, \tau)$ in the Ising antiferromagnet $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$ which is, for $H = 0$, an ideal system for the study of the REIM. For comparison, we also present measurements on nearly pure FeF_2 ($x \approx 0.005$) which extend the study of $d = 3$ Ising dynamics to longer time scales than previously studied [3].

FeF_2 is very anisotropic and shows Ising exponents and amplitude ratios throughout the critical region $|t| < 5 \times 10^{-2}$, where $t = (T - T_N)/T_N$ [4]. Magnetically dilute mixtures of $\text{Fe}_x\text{Zn}_{1-x}\text{F}_2$ with very high crystalline quality can be grown. The particular crystal of $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$ used in this experiment is described elsewhere [1, 5]. It has the particular advantage of being extremely homogeneous ($\delta x \approx 0.0002$). The concentration $x = 0.46$ is small enough to ensure that REIM behavior is easily observed throughout the critical region $|t| < 0.1$ but is well above the percolation limit $x = 0.24$. The c -axis was vertically oriented. The sample temperature was controlled to better than 0.01 K. T_N was located to within approximately 0.03 K by the observed peak in the quasielastic scattering intensity at the (100) magnetic Bragg point ($q = 0$).

For comparison, we have also performed similar measurements on a nearly pure $\text{Fe}_x\text{Zn}_{1-x}\text{F}_2$ crystal

with $x \approx 0.005$. With such a small concentration of impurities we expect [1] crossover to random exchange only for extremely small $|t|$. Hence, for this experiment, the pure $d = 3$ Ising model is well represented by this crystal and we henceforth refer to it as FeF_2 . The crystal is 1 cm in diameter and 1.1 cm in length with the c -axis along the cylindrical axis. T_N was located to within 0.02 K.

The neutron spin-echo inelastic scattering measurements were obtained using the IN11 spectrometer at the Institute Laue-Langevin. All data were taken near (100) with an incident wavelength of 6 Å. The resolution was 0.008 Å^{-1} and 0.027 Å^{-1} in the transverse and longitudinal directions, respectively. Inelastic measurements were resolution corrected by integrating over q using the scaling functions $\Omega(x)$ described and justified below. The point closest to T_N was used solely for further refinement, assuming that Γ approaches zero as t does.

In both the dilute and pure systems we found the dynamical behavior to be adequately described by

$$S(q, \kappa, \tau) \propto \exp(-\Gamma(q, \kappa)\tau). \quad (1)$$

Using this form, the data shown in figure 1 are adequately described by the power law behavior

$$\Gamma(q = 0, t) = \Gamma_0 t^{\nu z} \quad (2)$$

for $t > 0$ with $z = 1.7 \pm 0.2$ for $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$. With $z = 1.7$ the amplitude $\Gamma_0 \approx 12 \mu\text{eV}$. The exponent value agrees with the conventional theory result $z = \gamma/\nu = 1.9 \pm 0.1$, using the measured [1] exponents $\gamma = 1.31 \pm 0.03$ and $\nu = 0.69 \pm 0.01$ for χ_s and κ , respectively. Calculations [6] yield the value $z = 2.3$ to $O(\epsilon^{1/2})$ which is not compatible with the measured one.

For FeF_2 the exponent $z = 2.1 \pm 0.1$ agrees well with the conventional theory result $z = \gamma/\nu = 1.95 \pm 0.07$, using the measured exponents $\gamma = 1.25 \pm 0.02$ and $\nu = 0.64 \pm 0.01$ [4]. We cannot resolve the subtle difference between the conventional theory and renormalization

Fig. 1. $-\log \Gamma(q=0, t)$ vs. $\log t$, where $t = (T - T_N)/T_N$ for $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$ and FeF_2 .

theory predictions [7] for z . With $z = 2.1$, we obtain $\Gamma_0 \approx 1.6$ meV. The amplitude is very sensitive to the exponent chosen and the actual values of Γ are in good agreement with Hutchings, *et al.* [3]. Although z in the dilute crystal is close to that of pure FeF_2 , the amplitude of the correlated decay is 100 fold smaller for $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$.

Although we have not investigated the q dependence to any appreciable accuracy, we can conclude that the data are consistent with the scaling behavior

$$\Gamma(q, t=0) = \Gamma(0, 0) q^z \quad (3)$$

with $z = 1.7$ for the dilute crystal and $z = 2.1$ for the pure one.

We also briefly investigated the scaling function $\Omega(x)$ given by $\Gamma(q, \kappa) = \kappa^z \Omega(x)$ where $x = q/\kappa$. For FeF_2 we find satisfactory agreement with the form suggested by Hutchings, *et al.* [3] $\Omega(x) = 5.7 + 2.8x^2$, with κ and Γ in units of $\text{\AA}^{-1}$ and meV, respectively. For $\text{Fe}_x\text{Zn}_{1-x}\text{F}_2$ we find $\Omega(x) \approx 0.05(1 + x^2)$. This demonstrates the selfconsistency in having used these forms originally to perform the q resolution corrections.

We have seen that the most dramatic effect of the dilution of the magnetic lattice is the decrease of the amplitudes for Γ by two orders of magnitude. Other-

wise, the REIM dynamical behavior is not unlike that observed in the pure FeF_2 Ising system.

We also briefly investigated the case of an applied field which induces random field critical behavior in $\text{Fe}_{0.46}\text{Zn}_{0.54}\text{F}_2$ at small $|t|$. One might expect a very large effect from the application of the field since the effects of extreme critical slowing down are observed, for example, in ac susceptibility experiments [8] and quasielastic neutron scattering experiments [9] near T_C . We find dramatic changes with the application of even a relatively small field. For $|t|$ as large as 0.05 and H as small as 0.1 T, the behavior is observed to be much less inelastic than for $H = 0$. For comparison, the specific heat of this crystal shows crossover to random field behavior for $|t|$ as large as 0.05 only in applied fields of $H = 5$ T or greater [10].

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