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RANDOM EXCHANGE ISING MODEL DYNAMICS: Fe$_{0.46}$Zn$_{0.54}$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 Fe$_{0.46}$Zn$_{0.54}$F$_2$ and for FeF$_2$ at $H = 0$. The data are adequately described for $q = 0$ by $\Gamma = \Gamma_0 t^{\gamma_\text{v}}$. $\Gamma_0$ is decreased 100 fold upon dilution. For both systems $\gamma = \gamma_\text{v}/\nu$ in agreement with the conventional theory.

The static critical 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 $\kappa$, the staggered susceptibility $\chi_s$, the specific heat $C_m$, and the staggered magnetization $m_s$ obtained in the Ising-like antiferromagnetic system Fe$_x$Zn$_{1-x}$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 ($\tau$) dependent spin correlation function $S(q, \kappa, \tau)$ in the Ising antiferromagnet Fe$_{0.46}$Zn$_{0.54}$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 Fe$_x$Zn$_{1-x}$F$_2$ with very high crystalline quality can be grown. The particular crystal of Fe$_{0.46}$Zn$_{0.54}$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 Fe$_x$Zn$_{1-x}$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 $6 \text{Å}$. The resolution was 0.008 $\text{Å}^{-1}$ and 0.027 $\text{Å}^{-1}$ in the transverse and longitudinal directions, respectively. Inelastic measurements were resolution corrected by integrating over $q$ using the scaling functions $\Omega(z)$ described and justified below. The point closest to $T_N$ was used solely for further refinement, assuming that $\Gamma$ approaches zero as $t$ does.

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

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

(1)

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

$$\Gamma(q = 0, t) = \Gamma_0 t^{\gamma_\text{v}}$$

(2)

for $t > 0$ with $z = 1.7 \pm 0.2$ for Fe$_{0.46}$Zn$_{0.54}$F$_2$. With $z = 1.7$ the amplitude $\Gamma_0 \approx 12 \text{µeV}$. 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 $\chi_s$ and $\kappa$, respectively. Calculations [6] yield the value $z = 2.3$ to $O(\varepsilon^{1/2})$ 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.
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 $\Gamma$ 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 Fe$_{0.46}$Zn$_{0.54}$F$_2$.

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

$$\Gamma(q, t = 0) = \Gamma(0, 0) q^{-6}$$

(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 $\Gamma(q, \kappa) = \kappa^x \Omega(x)$ where $x = q/\kappa$.
For FeF$_2$ we find satisfactory agreement with the form
suggested by Hutchings, et al. [3] $\Omega(x) = 5.7 + 2.8 x^2$,
with $\kappa$ and $\Gamma$ in units of Å$^{-1}$ and meV, respectively.
For Fe$_{0.46}$Zn$_{0.54}$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 $\Gamma$ 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
Fe$_{0.46}$Zn$_{0.54}$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 compari-
son, 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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